FIELD PERFORMANCE RESEARCH OF APP MODIFIED BITUMEN ROOF MEMBRANES AND COATINGS

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A multi-faceted field research program utilizing seven different APP modified bitumen membranes and three types of liquid-applied reflective coatings began in 1991. This long-term project is intended to evaluate:

- The performance of the various membranes and coatings, including comparison of the weathering effects on coated and uncoated membranes;
- Comparative performance of coating application soon after membrane installation, versus coating application after the membrane has been allowed to weather (pre-weathering);
- Thermal performance offered by coatings; and
- Aspects of recoating.

This paper includes: 1) Information on the physical and thermal performance of the membranes and coatings through November 1992; 2) recommendations regarding membrane preparation prior to coating; 3) recommendations on coating; and 4) recommendations for improvements to the Roof Coatings Manufacturers Association (RCMA)/Asphalt Roofing Manufacturers Association (ARMA) guide for membrane preparation prior to coating.

KEYWORDS

APP, coating preparation, energy conservation, exudate, modified bitumen, pre-weathering, reflectivity, roof performance, thermal performance, weathering.

INTRODUCTION

In the literature, there has been limited reporting on the comparative field performance of coated versus uncoated APP polymer modified bitumen roof membranes. Because of the need for a greater understanding of the various aspects related to coated and uncoated APP membranes (including membrane longevity and thermal efficiency), the National Roofing Contractors Association (NRCA) and Oak Ridge National Laboratory (ORNL) collaborated on a full-scale research project in the Chicago, Ill. area. The project is referred to as the "APP Weathering Farm." The test roof and fluid-applied coatings were installed during the spring and summer of 1991.

The APP Weathering Farm is scheduled as a long-term project, (10+ years), to research the comparative weathering performance of seven APP modified bitumen membranes and three types of reflective roof coatings. Besides comparing the performance of the seven membranes to one another, comparison is being made of the performance of coated versus uncoated portions of each membrane. The work also includes an evaluation of coating soon after membrane installation versus coating the membrane after it has weathered (which is referred to as pre-weathering). In addition, the roof was instrumented to obtain data on thermal performance offered by commonly applied reflective coatings. And, in the future, aspects of recoating will be evaluated (e.g., special membrane preparation).

This paper includes: a roof system description, a description of membrane preparation and coating application, observations of changes to the membranes and coatings, the thermal performance of the coated membranes (including estimated coating cost payback time periods), conclusions and recommendations.

INDUSTRY PROBLEMS

APP modified bitumen roofing has been used throughout the majority of the different climatic regions of the U.S. In some regions, this material has been used for more than a decade. The majority of these roofs have been left uncoated. Many roofs have exhibited limited signs of weathering (see Figure 1). However, numerous roofs have exhibited premature degradation (e.g., surface cracking) (see Figure 2).[1,2]

Those membranes that have prematurely degraded, as well as those that have not, may have achieved a longer service life if they had been coated relatively soon after membrane installation. Besides acting as a protective sacrificial surfacing (which may wear away over time, while protecting the underlying membrane), if the coating is also reflective, it can reduce solar radiation. Reduced solar radiation results in lower membrane temperatures, which should thereby retard heat aging and extend the membrane's service life.

In the U.S., in the early years of APP modified bitumen roofing, the membranes were typically left exposed. However, currently, most manufacturers of APP modified bitumen materials offer longer warranties if their membranes are coated after installation, or they require coating to obtain a manufacturer's warranty.[3]

A primary aspect of this research is to evaluate the surface degradation (due to weathering) of several differently formulated and reinforced membranes, and to compare the service life of the exposed membranes to those of their counterparts, which were coated. The evaluation thus far has been by visual observation. In the future, laboratory analysis may also be utilized.

The other industry issue that this research is evaluating is the question of the optimum time to coat a new APP modified bitumen membrane. Some people advocate letting the membrane weather for approximately 30 to 90 days prior to coating (referred to as pre-weathering). Others advocate coating within a few days of membrane application. The issue regarding the optimum time to coat is primarily related to exudate, which can affect coating adhesion.[4]

According to the Roof Coatings Manufacturers Association (RCMA) and the Asphalt Roofing Manufacturers Association (ARMA), exudate is an oily constituent of the sheet's asphalt/polymer blend. The exudate that has migrated to the surface of the membrane (exudation) can inhibit adhesion of a coating to that surface.[5] Over time, this surface exudation is broken down by oxidization and becomes water-soluble. Precipitation can then rinse the exudate from the surface of the membrane.[4]

The postulate behind coating soon after membrane application is that the coating will inhibit exudation. The postulate behind pre-weathering is that if a membrane is going to exude, the exudate will have time to migrate to the surface and oxidize, and be carried off of the roof by precipitation or membrane preparation prior to coating application. In 1991, RCMA and ARMA recommended coating soon after membrane application.[4] However, no research in the open literature documents the performance of coatings over newly-applied modified bitumen membranes versus pre-weathered membranes.

ROOF SYSTEM DESCRIPTION

The APP Weathering Farm roof is installed on the office portion of a two-story building. The roof's structural assembly consists of galvanized steel roof decking over steel joists. The deck slopes approximately 1/4:12.

The roof system consists of:

- One 2.2 inch (56mm) layer of phenolic foam roof insulation, mechanically fastened to the deck;
- ¾ inch (19mm) perlite coverboard, adhered to the phenolic foam in continuous moppings of hot asphalt (ASTM D 312, Type III);
- One ply of No. 28 glass-fiber reinforced base sheet, set in continuous moppings of hot asphalt (ASTM D 312, Type III);
- One ply of smooth-surfaced APP modified bitumen, torch-applied to the base sheet; and
- Coatings, as described later and shown in Figures 3 and 4.

Based on the insulation manufacturer's published in-service R-value, the total R-value of the roof assembly, including air films, is approximately 24.

APP Modified Bitumen

Seven different manufacturers supplied the APP modified bitumen sheets (see Table 1 for physical descriptions). The materials were procured from local distributors. Membrane application observations are presented in Appendix 1.

The APP sheets are installed parallel with the slope of the roof in "strapped" fashion. The roof area is divided into segments so that each type of membrane is coated with each type of coating (see Figure 4). Approximately 25 percent of the roof surface was left exposed, as a control, to facilitate weathering and thermal comparison with the coated areas. The remaining 75 percent of the roof area was apportioned for each of the three types of coatings.

To compare the performance of coatings applied to recently installed membranes versus coatings applied to pre-weathered membranes, each of the areas designated to receive coatings was divided in half. On one half, the coating was applied soon after the membranes were installed (shown as Phase 1 in Figure 4). On the other half of each of the three areas to be coated, the membranes were allowed to pre-weather an additional 35 to 42 days prior to coating application (shown as Phase 2 in Figure 4).

Coatings

Four coating manufacturers supplied three different types of reflective coatings. The four coatings were designated as "A," "B," "C" and "D." Coatings "A" and "D" were shipped by the manufacturers, and coatings "B" and "C" were obtained from local distributors. *(Note: Limitations imposed by the size of the roof precluded the use of products from additional manufacturers.)*

Latex: Two white latex (acrylic) coatings were utilized (coatings "A" and "B"). The coatings were from different manufacturers. They were not required to meet an industry standard, as no standards were known to exist at that time. *(Note: An ASTM standard is under development. RCMA issued a standard for latex coatings in 1991.)*

Aluminum-pigmented asphalt: According to the manufacturer's product literature, this coating was manufactured to comply with ASTM D 2824, Type III (fibrated, containing no asbestos fiber).[6] This product was designated as coating "C."

Reflective asphalt emulsion: This coating incorporated a titanium dioxide pigment for reflectivity. ASTM D 1227[7] is for asphalt emulsions, but it does not include reflective (titanium pigmented [sometimes referred to as albino], or aluminum-pigmented) emulsions. This product was designated as coating "D."

SURFACE PREPARATION

Parting agent(s) (e.g., sand, mica, talc, plastic films, etc.) are applied on the surfaces of the sheets in the factory to keep the material from sticking together in the roll. However, some parting agents can inhibit coating adhesion, unless the membrane is adequately prepared prior to coating application. Also, dust, airborne fallout and other contaminates (including surface exudate) can hamper coating adhesion.

Prior to application of the coatings, the membrane surfaces were evaluated and prepared for coating in accordance with a guide document developed by RCMA and ARMA[5] In accordance with the RCMA/ARMA guide, a "white cloth test" was performed to ascertain the surface cleanliness of each of the seven membranes (see Figure 5).

Preparation of Newly Applied Membranes (Phase 1)

The seven membranes had been in place from three to 13 days at the time Phase 1 preparation began (see Appendix 1). All seven membranes failed to pass the white cloth test. Accordingly, the membrane areas scheduled to receive the Phase 1 coatings were prepared for coating in the following manner:

> The membrane surfaces were rinsed with water from a garden hose. After a portion of the surface was squeegeed (to facilitate drying) and allowed to dry;

the white cloth test was again performed. Once again, all seven membranes failed to pass the test. The membranes were then wetted and scrubbed with a relatively stiff bristled push broom (24 inch [600mm] wide). After scrubbing, rinsing and being allowed to dry, all seven membranes passed the white cloth test. However, except for products #6 and #7, some loose residual parting agent could still be detected with the bare hand.

(Note: The intent in cleaning the membranes was not to provide an exceptionally or overly-clean surface. Rather, the intent was to follow the cleanliness guidelines set forth in the RCMA/ARMA document.)

Preparation of Pre-weathered Membranes (Phase 2)

Areas assigned to pre-weather prior to coating application weathered for an additional 35 to 42 days beyond Phase 1 application (which was around the middle of the 30-90 day period associated with pre-weathering of APP membranes). These areas had not been scrubbed or disturbed (other than wetting) during preparation of the areas coated in Phase 1. All seven pre-weathered membranes failed to pass the white cloth test.

Since the RCMA/ARMA guide document references "water blast" as one option for cleaning, the membrane surfaces were washed with water from a "power washer" (see Figure 6). The washer did not have a gauge, but it is believed that it delivered approximately 600 to 800 psi (4.1 to 5.5 MPa). After squeegeeing small areas and allowing them to dry, the white cloth test was performed. Even after pressure washing, all seven membranes still failed the white cloth test. Therefore, a garden hose was used to wet the areas and they were scrubbed with a 24 inch (600mm) stiff bristle push broom (see Figure 7). After scrubbing, rinsing and being allowed to dry, all seven membranes passed the white cloth test. However, several footprints were on the membranes, as a result of walking through dirty water during preparation work.

Product #3 exhibited variable adhesion of the sand parting agent. In some areas, the sand was readily removed by brushing, but in other areas it remained bonded. The sand in some areas was moderately adhered (not loose, but not well-bonded).

Because of accumulations of dust from airborne fallout, more extensive preparation was necessary (i.e., more brushing work), compared to the preparation that was performed to the Phase 1 areas that were coated soon after membrane application.

COATING APPLICATION

After the membrane surfaces were cleaned and dried, the coatings were mixed with a ½ inch (13mm) drill motor and steel paddle mixer. Then the coatings were applied in accordance with the coating manufacturers' requirements, at typical rates used in the roofing industry.

Latex: Coatings "A" and "B" were applied in two applications, at approximately ¾ gallon per 100 square feet (0.3 liters per m^2). The well-mixed latex was poured onto the membrane, then rolled with 18 inch (460 mm) wide, medium nap rollers. Shortly after the first coat dried tack-free, the second application was rolled at 90 degrees to the first.

(Note: At coating "B," for the sake of a weathering comparison, an area approximately 100 square feet (9.3 m^2) in size, on both non and pre-weathered sections, was coated with a total of 1½ gallons per 100 square feet (0.6 liters per m^2) in one application. At this area, because the coating was applied at a greater thickness, and because of the hot membrane surface, vapor was observed rising from the roof surface as the coating was applied. Also at this area, the coating coagulated quickly and tended to lift or peel if back-rolled.)

Aluminum-pigmented asphalt (coating "C"): This well-mixed coating was poured onto the membrane, then rolled on in one application with 18 inch (460mm) wide, medium nap rollers at approximately 1½ gallons per 100 square feet (0.6 liters per m^2).

Reflective asphalt emulsion (coating "D"): This coating was applied in one application at approximately three gallons per 100 square feet (1.2 liters per m^2). The well-mixed emulsion was poured onto the membrane, then spread with a 36 inch (920mm) wide push broom.

Roof membrane and flashing application was completed on May 8, 1991, and Phase 1 coatings were applied on May 9, 1991. Phase 2, coating "D" and the first ¾ gallon per 100 square feet (0.6 liters per m^2) of coating "B" were applied on June 13, 1991. However, a shortage of manpower on the 13th, then poor weather on the following days, postponed application of coatings "A," "C" and the finishing ¾ gallon per 100 square feet of coating "B" until June 20, 1991.

To limit the possibility of dust and other airborne fallout impairing the bond between the first and second applications of coating "B," the manufacturer was contacted and the method of surface preparation was discussed. It was agreed to rinse, then lightly agitate the surface with a soft bristled broom, rinse clean and allow to dry, prior to coating. This preparation work was executed, and coatings "A," "C," and the remainder of "B" were applied on June 20, 1991. For both Phases 1 and 2, there was no precipitation during the coatings' cure time.

Weather conditions and ambient temperatures recorded during coating applications were as follows:

- Phase 1: Sunny with some scattered clouds. Maximum temperature for the day was 76°F. The ambient air temperature at 9:00 a.m. was 68°F; at noon—74°F; and at 3:00 p.m.—75°F. At noon, the relative humidity was 48 percent.
- Phase 2: On June 13, 1991, it was sunny with some haze in the afternoon. The maximum temperature for the day was 89°F. The ambient air temperature at 9:00 a.m. was 79°F; at noon—86°F; and at 3:00 p.m.—86°F. At noon, the relative humidity was 53 percent.
- On June 20, 1991, it was foggy during the early morning hours, but this burned-off by mid-morning to a clear, sunny afternoon. The maximum temperature for the day was 94°F. The ambient air temperature at 9:00 a.m. was 84°F; at noon— 90°F; and at 3:00 p.m.—90°F. At noon, the relative humidity was 52 percent.

POST-APPLICATION OBSERVATIONS

Following application of the Phase 1 coatings, 11 post-application observations were made over a 17-month period (through November 1992). Detailed observations are presented in Appendix 2. A summary of the salient observations follow.

Latex "A": After approximately 10 months of weathering, extensive coating cracking occurred over APP membrane products #3, #4 and #5. Approximately one month later, smaller cracks were observed over product #6. After 17 months, coating "A" was severely cracked. *A significant premature failure (i.e., peeling) of this coating appears eminent (see Figure 8).*

Latex "B": The small area that received all of the coating in one application had experienced significant peeling by November 1992 (approximately 18 months after coating application). See Figures 9 and 10. The peeling initiated at a small bird bath, which previously held exudate residue that had migrated up through the coating after coating application. Two areas approximately 6 inches (150mm) in diameter had also begun to peel. These two areas received the coating in two applications.

Aluminum-pigmented asphalt "C": Coating cracking that appeared to be related to mechanical forces (rather than weathering) occurred on Phase 1 at products #1, #6 and #7. These stretch cracks at #1 and #6 were noticed the day after the coatings were applied. Stretch cracks at #7 were observed about a month after coating application. The cracks at #1 and #6 increased in width during the first month after application. Since June 1991, the cracks at #1, #6 and #7 have changed very little. The largest crack is approximately ¼ inch (6mm) wide (see Figure 11).

Coating "C" also has some minor cracking and peeling that appears to be related to weathering. This was observed at Phase 2, products #3, #4 and #5. It was also observed at Phase 1, products #4 and #5. At one of the areas on Phase 1, product #5, the cracking and peeling occurs at a small bird bath, which previously held exudate residue (this occurred after the coating application). See Figures 12 and 13.

Coating "C" has several areas of minor erosion at both Phases 1 and 2 (see Figure 14).

Erosion is explained in the "Discussion" section of this paper.

Reflective emulsion "D": After 17 months exposure at Phase 2, product #7 (at a small bird bath), the coating has pronounced checking (very closely spaced surface cracking) that is associated with weather-induced deterioration (referred to as "weather-checking"). This area previously held exudate residue (this occurred after coating application).

Coating "D" has a few areas of minor erosion at both Phases 1 and 2 (see Figure 15).

Throughout the field of Coating "D," at 8x magnification, the coating surface is weather-checked.

Exposed membranes: Weather-checking was observed on product #1 about four months after application. By November 1992 (approximately 19 months after membrane application), via visual observation, the depth of the checking had increased (see Figure 16).

Product #2: Small linear cracks developed by November 1992. One large star-shaped crack was also observed (see Figure 17).

Product #3 had minor weather-checking by November 1992.

By November 1992, Product #4 developed small craters (hemispherical surface cavities), with two or three cracks typically extending from them (see Figure 18).

Product #5: Weather-checking was observed about five months after application. By November 1992, cracking had developed (see Figure 19).

Products #6 and #7: At 8x magnification, no signs of weather-checking or cracking were observed in November 1992.

Exudation: In June 1991 (approximately six weeks after membrane application), exudation was observed in the field of all seven exposed membranes (see Figure 20).

Exudation was observed at isolated areas on coating "B" (Phase 1) at products #1, #2 and #5 in July 1991 (approximately 10 weeks after Phase 1 coating application). At the same time, it was also observed at isolated areas on coating "C" (Phases 1 and 2) at all seven products. Isolated areas were also observed on coating "D" (Phase 1) at product #1, and on Phase 2 at product #7.

At small isolated areas, exudation may have caused or influenced coating peeling at coatings "B" and "C," and checking at coating "D" (see Figures 12 and 13).

By August 1991 (approximately 14 weeks after Phase 1 coating application), at the coated areas, small bird baths that previously held exudate residue now appeared to be free of the residue.

During the May 1992 observations (approximately one year after membrane application), it appeared that exudate had migrated down-slope from the latex-coated areas, onto the aluminum-pigmented coating. This occurred at products #1 through #7. The portion of product #1 that did not have a latex coating upslope from the aluminum-pigmented coating did not exhibit signs of exudate migration. Minor exudation was also observed on the exposed portion of product #1.

Appearance: The appearance of the coatings and exposed membranes changed notably during the first several months of exposure. After approximately 17 months of exposure, the latex coatings have several light brown, dirty areas where dust has accumulated at small depressions.

THERMAL PERFORMANCE

The first report on this project presented the initial thermal performance data and analysis, and also provided a detailed description of the project's instrumentation.[8] Thermocouple locations are shown on Figure 4. The following is a brief update on the thermal performance of the project, including estimated coating cost payback time periods.

After approximately 17 months of weathering, the latex coating is providing the greatest solar radiation reflection, thereby only allowing the membrane to warm about 20°F (11°C) more than the ambient temperature on sunny days. Through November 1992, the maximum membrane temperature recorded under the latex coating was 124°F (51°C).

The aluminum-pigmented asphalt and reflective emulsion coatings provide comparable moderation of roof membrane temperatures, despite their slightly different solar reflectivity measurements (as described below). During the first few months of weathering (August through September 1991), the emulsion provided cooler maximum membrane temperatures (138°F or 59°C) than the aluminum-pigmented coating (143°F or 62°C). However, as time has progressed, the reflective emulsion and the aluminum-pigmented coated membranes' thermal performance is similar. As shown in Figure 22, the emulsion and the aluminum-pigmented coated membranes warmed to about 60°F (33°C) above ambient.

On sunny days, the uncoated membrane's (product #4) temperature is frequently 70°F (39°C) or greater above the ambient air temperature. The highest recorded exposed membrane temperature for the first 18 months of data collection was 169°F (76°C) on June 13, 1992. *(Note: The maximum temperature recorded on this day was only 91°F (33°C), not overly hot.)*

The maximum temperature recorded thus far is substantially below that recorded in other research projects. A temperature of 192°F (89°C) has been recorded at ORNL on a black, smooth surface (glaze coated) built-up membrane.[9]

To gain additional thermal comparison data, a thermocouple was also installed in an adjacent ballasted EPDM roof system over the shop area of the building. (This roof system is described in Reference 8. The increased mass and light-grayish colored aggregate ballast reduced the EPDM membrane temperature by about 40°F (22°C), compared to the exposed APP membrane. Table 2 shows an example of the comparative thermal performance of the instrumented exposed, coated and ballasted roof areas for a typical sunny day in June 1992.

Shortly after Phase 1 application, each of the coatings' solar reflectances were measured at Tennessee Technological University (TTU) using a solar reflectometer. Samples of the APP membrane coated with each of the coatings were measured and found to have the following solar reflectances (see Table 3): Latex "B" measured 0.61; the aluminum-pigmented coating "C" was 0.48; the emulsion "D" was 0.28; and the exposed membrane (product #4) was 0.07. A thermocouple was not placed at coating "A," hence there was no reflectivity measurement.

After approximately 1½ years of weathering, test cuts of the uncoated and coated APP membranes were taken for measurement with the solar reflectometer at TTU. They were found to have values that had changed slightly with weathering exposure. The solar reflectance values measured as follows: Latex "B" was 0.56; the aluminum-pigmented asphalt "C" was 0.42; the asphalt emulsion "D" was 0.34; and the uncoated membrane (product #4) was 0.13. As expected, the light colored surfaces darkened as they weathered and aged, and the darker surface lightened in color (see Table 3). This research project will continue to collect solar reflectometer measurements over the upcoming years to monitor changes in reflectivity.

Cured coatings may be of different shades and have varying degrees of solar reflectivity. Product formulation (e.g., percentage of pigment, etc.), extent of mixing, shelf life, application method and other factors may affect the finished "brightness" and resultant reflectivity of the installed and cured coatings. And over time, these various factors may influence a coating's change in solar reflectivity.

To assess the initial cost of coatings versus energy savings, theoretical estimated "simple paybacks" for an office building in Chicago, Orlando and Phoenix are presented in Table 4, utilizing data from this project (based upon an ORNL guide[10]). These figures are somewhat different than those presented in Reference 8. This is due to the use of solar reflectometer measurements after 1½ years versus those that were measured on recently applied coatings.

These estimated figures are based on assumptions for cost of material and labor to apply the coating (which can vary greatly for a variety of reasons), and energy cost and consumption. A constant value was utilized for solar reflectivity (over the life span of the roof) based upon solar reflectometer measurements after 1½ years. The figures do not consider coating life, nor the costs associated with recoating (if necessary). *The figures do not account for potential extended membrane service life and the associated cost savings; nor do they account for the reduced size and expense of HVAC equipment.*

From Table 4, it is important to note that as the thermal resistance (total R-value) of the insulation is lowered, the estimated simple paybacks are reduced dramatically (particularly in hot climates). Thus, the less insulation, the sooner the payback from the initial investment in reflective coating.

DISCUSSION

- Due to the roof size and geometry, it was necessary to lay out the coatings in a cross-slope direction. Accordingly, water runs from coating "A" to "B" to "C" to "D" to the exposed membranes, and then off of the roof. It does not appear that drainage from one area to another has influenced coating performance. However, ideally, a research project of this nature would arrange the layout of the coatings to avoid this variable.

  Drainage from one area to another made the assessment of post-coating application exudation difficult. It was sometimes unclear where the exudation originated. For example, at some of the pools of exudate residue, it appeared the residue had migrated downslope from another coated area. At other pools of residue, it appeared that exudate had migrated through the coating at that area, but this was not confirmed.

- Minor loss of the aluminum-pigmented asphalt and the reflective emulsion (coatings "C" and "D") has been experienced (Figures 14 and 15). Based upon visual observation at 8x magnification, it appears that this was due to erosion. Erosion is defined as the gradual loss of coating over time, due to weathering. Erosion is the desired cause of coating loss, compared to an undesirable premature loss due to cracking, peeling or flaking.

  At the APP Weathering Farm, there are several minor eroded areas at coatings "C" and "D." These first areas of erosion are believed to be associated with a relatively thin layer of coating.

CONCLUSIONS

1. By utilizing coatings on APP modified bitumen membranes, it is likely that the membrane service life will be extended (particularly on those membranes that are prone to premature deterioration by weathering).

However, the amount of increased service life that coatings may provide is currently unknown.

2. At several locations on one roll of product #5, the reinforcement became exposed because the roll stuck together during unrolling (see Figure 22). It is likely that such a condition would not be observed by the applicator. By coating the membrane, future problems may be postponed or avoided. Had the membrane not been coated, premature degradation and eventual leakage may have eventually developed due to the partially exposed reinforcement.

3. The RCMA/ARMA guide's[5] criteria for membrane surface cleanliness may be overly conservative. The cleanliness evaluation prior to the Phase 1 application failed on all seven membranes, even though they had only been in place for a short time. Even after hosing with water, all seven membranes still failed the cleanliness test.

   Throughout the country, many APP modified bitumen membranes have been successfully coated without any on-site surface preparation.[2] While some minimal level of cleanliness is undoubtedly required for good performance of each type of coating, if the cleanliness criteria in the guide is too conservative and if it is strictly followed, building owners may be spending excessively on membrane preparation.

4. The physical performance of the coatings that were applied soon after membrane completion compared to the performance of coatings applied to pre-weathered membranes is essentially the same after approximately 17 months of exposure. Since the pre-weathered membrane preparation was more time-consuming (due to the accumulation of dust and other airborne fallout) the RCMA/ARMA recommendation to coat soon after application versus after pre-weathering[4] does have some merit relative to preparation effort.

5. Exudation was experienced with all seven products. It was visually more pronounced at the exposed membranes, compared to the coated membranes. Exudation appears to have migrated through the latex, and quite possibly, through the aluminum-pigmented coatings.

   After approximately 17 months of exposure, the exudation appears to have had no significant impact on the performance of the exposed membranes or coatings. However, at small isolated bird bath areas, exudation may have caused or influenced the deterioration of all three types of coatings.

   High heat on hot summer days during the first summer's exposure appeared to greatly influence exudation. During the second summer, only a minor amount of exudation was observed early in the summer.

6. Latex coating "A" will likely experience a significant premature peeling failure. The problem appears to be related to the coating material.

7. Coatings "B," "C" and "D" have exhibited signs of deterioration by weathering, but in general they are performing reasonably well.

8. Exposed products #1 through #5 have exhibited signs of deterioration by weathering, but in general they are performing reasonably well. Exposed product #2 developed a large star-shaped crack that may present premature problems. Exposed products #6 and #7 have not exhibited signs of degradation by weathering.

9. The development of small, random bare spots in the coating due to erosion should be expected. Regardless of coating application method, some variation in coating thickness will occur. Loss of coating due to erosion will naturally occur at those areas with the least coating thickness. This will eventually result in a non-uniform loss of coating over the roof area.

   For those coatings that are suitable for two applications, two applications (as was done for the latex coatings) should minimize the rapid development of small, random bare spots. However, except for the latex coatings, the additional cost may not be justified.

10. The latex manufacturer's recommendation to apply the coating in two applications appears to be valid. In the experimental area where coating "B" was applied in one application, coating peeling was experienced. Also, the "hiding" (coverage) capacity of the coating is greater when applied in two applications.

11. Reflective coatings reduce maximum membrane temperatures. Some coatings provide a significant reduction of peak temperatures. Reduction in membrane temperatures may also result in increased membrane service life (due to reduced heat aging), though the magnitude of the increased life (if any) will not be quantifiable for several more years.

    The ultimate decay (reduction) of the solar reflectivity of the coatings, and hence, their long-term influence on membrane temperatures, is unknown. Some decay in reflectivity did occur during the first year. Also, local climatic influences (including air quality), roof slope and perhaps the coating's material properties may influence reflectivity decay on specific roofs.

12. Reflective coatings can reduce energy consumption and reduce the required size of HVAC equipment. The reduction in energy consumption may be dramatic in hot climates.

RECOMMENDATIONS

1. It is recommended that ASTM D 1227 be revised to include criteria for reflective coatings (for both titanium dioxide and aluminum-pigmented), or a new standard be developed for these products.

2. It is recommended that when ASTM standards are developed for APP modified bitumen sheets, they include criteria and test methods for cracking. The test method presented in Reference 12 may be applicable.

3. To enhance smooth surface membrane performance, it is recommended that designers specify a coating for APP modified bitumen membranes. In most regions of the U.S., a reflective coating will decrease a building's energy consumption. Accordingly, where appropriate,[10] a reflective coating is recommended.

4. It is recommended that coatings be applied as soon as

practical after membrane application to minimize the amount of membrane preparation work that is required. However, this research project thus far indicates that coating soon after membrane application versus pre-weathering does not appear to make a significant difference in coating performance.

APP modified bitumen sheets may experience significant post-application exudation and cause coating problems.[13] However, it is believed that this is likely to primarily occur with poorly formulated sheets.

5. It is recommended that the RCMA/ARMA preparation guide[5] be consulted prior to coating APP modified bitumen membranes. However, it is recommended that reasonable judgment be employed. Otherwise, time and effort could easily be wasted. For example, performing the white cloth test on "clean" membranes, can easily result in smudge marks on the cloth. This condition should be judged "acceptable," since the intent of cleaning is not to get the membrane so clean that the cloth does not pick up anything. Rather, the intent is to get the membrane suitably clean—which will require on-the-roof judgment by experienced people.
6. Although the RCMA/ARMA preparation guide is a relatively good document, a number of improvements are recommended:
   - Section 3.3 indicates that the membrane is to be "freed" of loose parting agents and foreign matter. In a strict sense, this provision is essentially impossible to meet. It should be revised to reflect the intent, which is to get the membrane reasonably clean, but not totally free of parting agents or foreign matter.
   - Section 4.1.2 states that the parting agent must be permanently adhered or completely removed. It is essentially impossible for the contractor to ascertain in the field whether or not a parting agent is "permanently" adhered. Within reason, the contractor can determine if the agent is reasonably well adhered at the time the membrane is being prepared.
   - Section 4.2 indicates that remedial work should be performed to eliminate ponds prior to coating. While ponding can (but not always[2]) adversely affect coating performance, the ponding issue should not be linked to preparation of the membrane. Elimination of ponding is a design issue, rather than an applicator issue, which the guide addresses. Furthermore, if ponding exists, application of a coating may be beneficial (in terms of membrane performance), even though coating life may be compromised.
   - Section 5.2.1.1 should give further guidance on performing the white cloth test. It is recommended that the forefinger be covered with the cloth, and then a swipe with moderate pressure be made over the membrane. The length of the swipe is recommended to be approximately 4 inches (100mm).
   - Section 5.2.3 indicates that the embedment of embedded mineral matter can be revealed by lightly brooming with a stiff broom. The authors found this to be a poor indicator. It is recommended that rubbing with a forefinger be utilized in lieu of a broom to evaluate the bond of mineral matter.
   - Section 5.2.5 discusses the use of a tape test to assess the membrane surface. The authors found this to be a poor indicator. The tape picked up loose material, but did a poor job in picking up poorly-bonded material. It is recommended that this test not be relied upon as an indicator of suitable roof surface conditions.
   - Section 5.2.6 discusses the use of test patches to assess long-term adhesion and compatibility of the membrane/coating. Although this research project did not evaluate test patches, the authors believe a short-term test patch may give misleading results. Unless the patch is allowed to weather for a substantial period of time, or unless it is artificially aged, it is recommended that a test patch not be relied upon.
   - While the document gives surface evaluation test methods, it does not give acceptance criteria. Admittedly, such criteria is difficult to establish. In the absence of criteria, it is recommended that the building owner's representative, the manufacturers of the membrane and coating, and the contractor agree on the method and adequacy of the surface preparation (on a small representative area of the roof, prior to preparing and coating the entire roof area).

     If post-application coating problems develop, the adequacy of the preparation may be questioned. Accordingly, in addition to obtaining agreement on the adequacy of the preparation, it is recommended that the contractor document the preparation work as it progresses.
   - The document does not adequately address what steps are to be taken if un-oxidized exudation is present.
   - The document does not adequately address the assessment and preparation of membranes that have previously been coated (and now may be in need of recoating). Nor does it appear to adequately address uncoated membranes that have been in service for a few years and that are now being considered for coating.
7. There is a range of application rates for the various types of coatings.[11] It is recommended that criteria be established to allow rational selection of the rate for a given type of coating in a given climatic region for a given job.
8. It is recommended that rolls be produced with well-defined side-lap laying lines (printed in a color that contrasts with the background color of the roll), and that the line dimension matches the manufacturers' printed requirements for side-laps.
9. It is recommended that roll-bands be of a material that quickly vaporizes upon heating or are readily removable, so as to avoid possible leaks at end laps.

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Numerous acknowledgements are in order for the cooperation that went into assembling this in-situ project. First, acknowledgements to all participating manufacturers that contributed materials: Dibiten U.S.A.; Firestone Building Products Co.; GAF Building Materials Corp.; Nord Bitumi U.S. Inc.; Owens-Corning Corp.; Performance Roof Systems, Inc.; U.S. Intec Inc.; Field's Corp.; Karnak Corp.; and Monsey Products Co. *(Note: Latex coating manufacturer "A" requested not be named).*

Acknowledgments to Hans Rosenow Roofing Co. for contributions of its new office roof space, labor and miscellaneous materials, and to the Oak Ridge National Laboratory, for its data analysis and contribution of the data logger and associated equipment (part of this work was sponsored by the Office of Building Technologies, U.S. Department of Energy, under Contract No. DE-ACO5-840R21400.) A fond thank you to Rene Dupuis for his suggestion to study weathering of coated and uncoated APP modified bitumen membranes.

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[12] Hendriks, N.A., "Field and Laboratory Investigations of the Crazing Phenomena of APP Modified Bitumen Sheetings," Proceedings of VIII International Roofing and Waterproofing Congress, pp. 177, 1992.

[13] LaTona, R.W., Consultant's Rap Session, 1993 NRCA Convention, San Antonio, Texas, (cassette recording).

APPENDICES

Appendix 1
Membrane Application Observations

Available from NRCA upon request.

Appendix 2
Detailed Post-Application Observations

Available from NRCA upon request.

	APP Modified Bitumen Product Number						
	1	2	3	4	5	6	7
Thickness* (avg. 5 measurements)	168 mils (4.27mm)	168 mils (4.27mm)	153 mils (3.89mm)	155 mils (3.94mm)	176 mils (4.47mm)	153 mils (3.89mm)	146 mils (3.71mm)
Thickness range:	162-173 mils	162-171 mils	148-158 mils	148-164 mils	171-181 mils	143-166 mils	143-152 mils
Reinforcement							
Polyester:	X	X	X	X	X		
Glass fiber:							
Polyester and glass fiber:						X	X
Top Side Surfacing	Talc & mica	Talc	Sand	Talc	Talc	Talc	Sand
Bottom Side Surfacing	Poly film	Thin poly film	Poly film	Poly film	Poly film	Talc	Light sand
Reinforcement Location Upper ⅓						Glass near top	Glass near top
Near middle of sheet	X	X	X	X	X	Glass & poly	Glass & poly
Side Lap Laying Line (distant from edge of sheet)	4 1/16"-4 3/16" (103-106mm)	3 15/16"-4 1/16" (100-103mm)	3¾"-3⅞" (95-98mm)	3" (76mm)	3 3/16"-3¼" (81-83mm)	2⅞"-3 1/16" (73-79mm)	2⅞"-3⅛" (73-79mm)
Date of Manufacture	03/07/91	05/19/90	Unknown	03/06/91	05/09/90	12/19/90	Unknown
*Per ASTM D 5147-91.							

***Table 1** Physical description of APP modified bitumen products.*

Ambient	Latex	Aluminum-Pigmented Asphalt	Reflective Emulsion	Exposed (Uncoated) Membrane	Ballasted EPDM
91°F (33°C)	124°F (51°C)	152°F (67°C)	152°F (67°C)	169°F (76°C)	134°F (57°C)

Table 2 Peak temperature comparison example, June 13, 1992.

Age of coating at time of measurement	Solar Reflectivity				
	Latex "B"	Aluminum-Pigmented	Reflective Emulsion	Exposed Membrane	
Recently Applied	0.61	0.48	0.28	0.07	
After Weathering 1½ Years	0.56	0.42	0.34	0.13	

Table 3 Solar reflectometer measurements.

City and Coating	R-Value of 16	R-Value of 10	R-Value of 5
Chicago	**Years**	**Years**	**Years**
Latex	14-28	9-18	6-11
Aluminum	16-32	10-20	6-13
Emulsion	18-41	12-26	7-16
Orlando			
Latex	9-18	6-11	4-7
Aluminum	10-21	7-13	4-8
Emulsion	12-27	7-17	5-10
Phoenix			
Latex	7-15	5-9	3-6
Aluminum	9-17	5-11	3-7
Emulsion	10-20	6-14	4-9
Note: See text for assumptions and notes regarding these estimates.			

Table 4 R-value of roof assembly and theoretical estimated payback using reflectance data from 1½year-old exposed coatings.

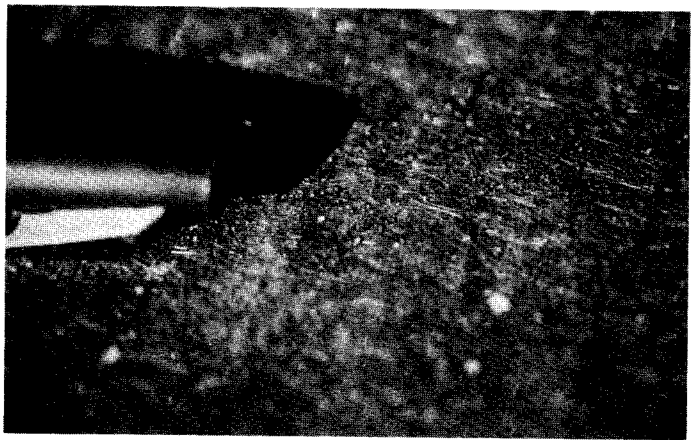

Figure 1 Twelve-year-old APP modified bitumen membrane near New Orleans shows very little weathering effect. A few grains of sand and dirt are on the membrane, and some reinforcement fibers can be seen on the surface. An ink pen shows the scale.

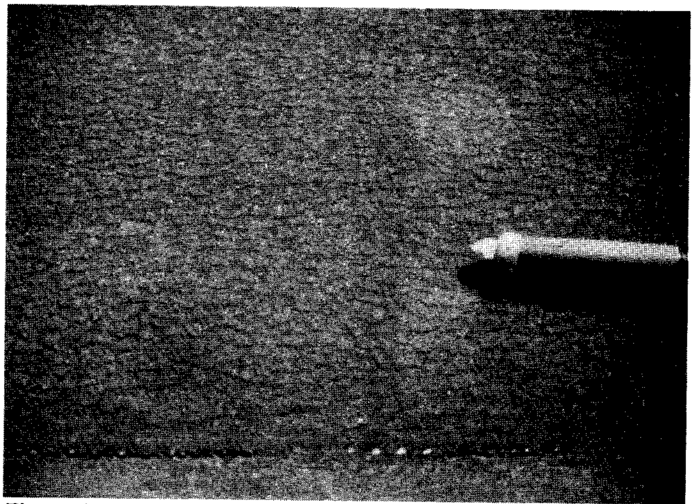

Figure 2 Surface cracking on six-year-old APP modified bitumen membrane near Chicago. A lumber keel shows the scale.

Figure 3 General view of the APP Weathering Farm roof. From left-to-right: Latex coatings "A" and "B," aluminum-pigmented asphalt coating "C," reflective emulsion coating "D" and the exposed membranes. Some shading variation is noticeable between the Phases 1 and 2 coatings. This was taken the day following the completion of Phase 2 coating application, which was approximately six weeks after the application of the Phase 1 coatings.

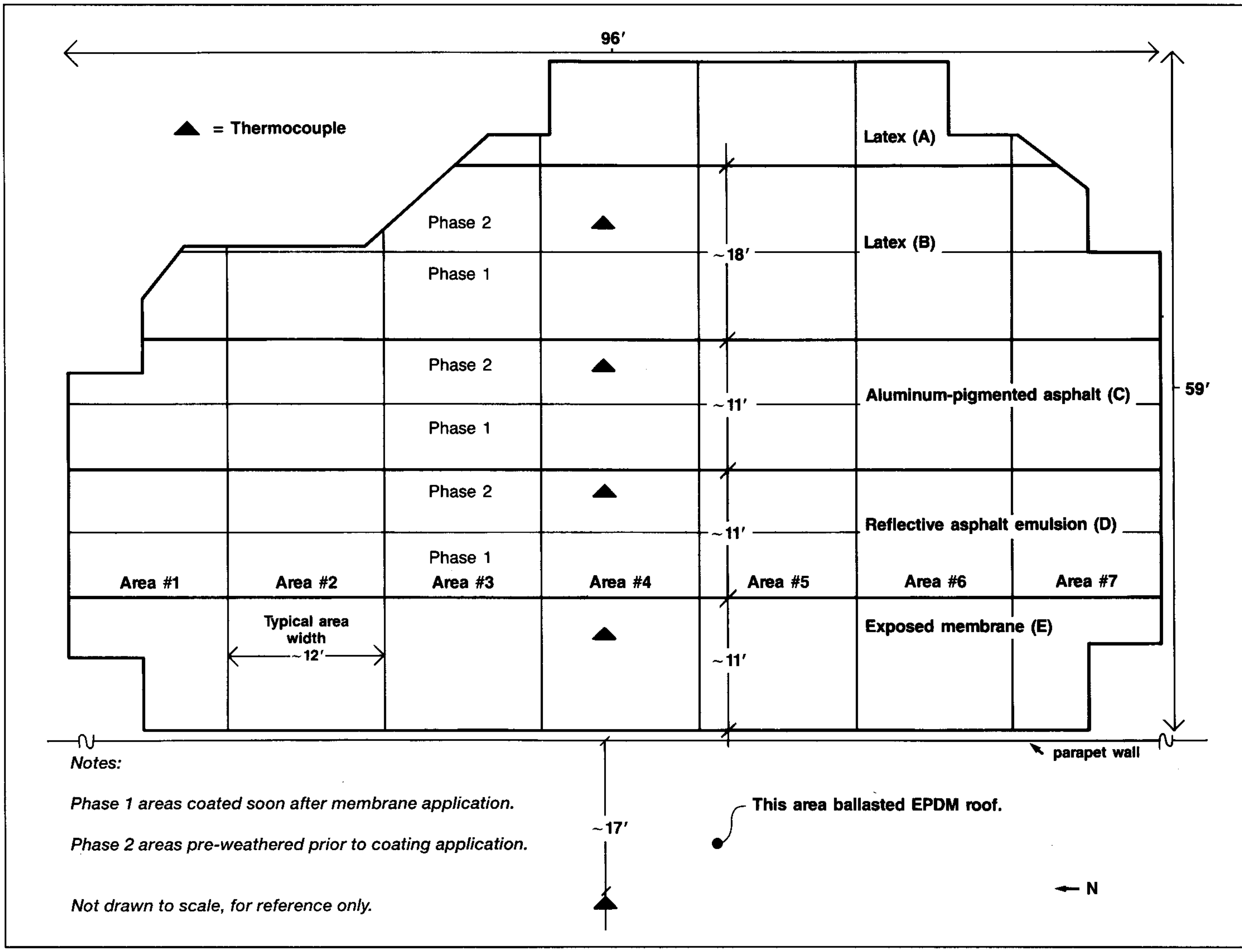

Figure 4 Plan view of the APP Weathering Farm showing exposed and coated membrane layout, and thermocouple locations.

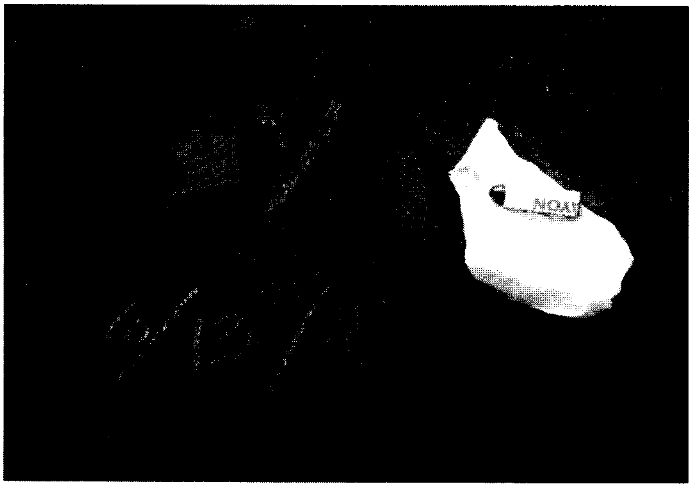

Figure 5 "White cloth" test performed on APP product #7. The forefinger was covered with the cloth, then a swipe with moderate pressure was made over the membrane. The swipe was approximately 4 inches long.

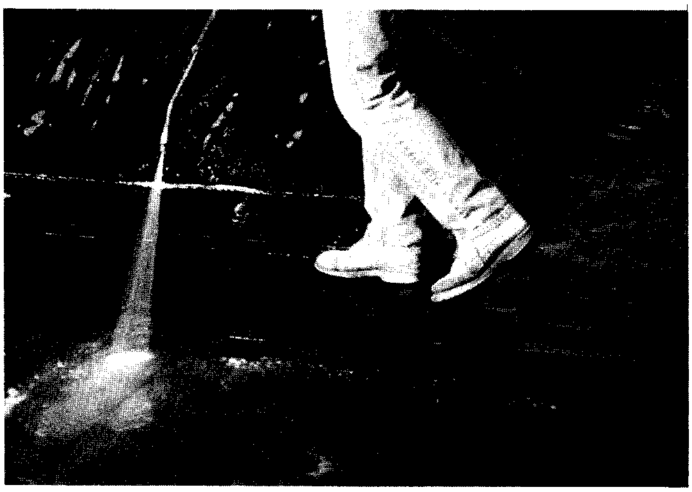

Figure 6 Phase 2 cleaning with a power washer. This was found to be ineffective with the apparatus used on this project (see Figure 7).

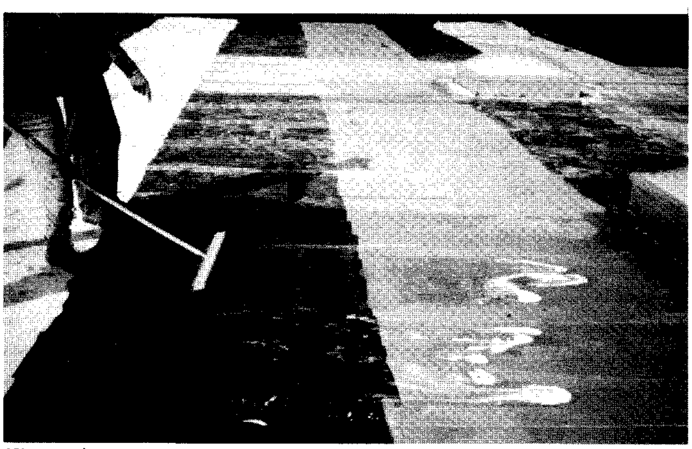

Figure 7 This area was rinsed with the power washer, but it failed to pass the white cloth test. A push broom was then used to scrub the membrane. Note the amount of dirt on the coating to the right, which the power washer did not remove from the exposed membrane.

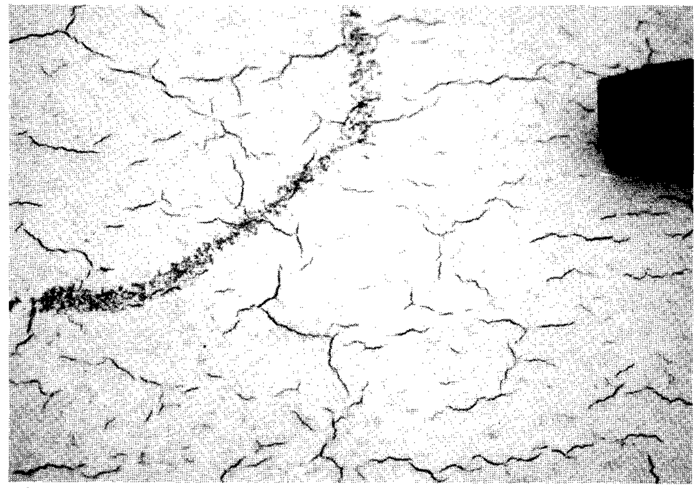

Figure 8 Severe cracking of latex "A" over APP product #3 (Nov. 24, 1992, after approximately 17 months of coating exposure). The problem appears to be related to the coating material. An ink pen shows the scale.

Figure 9 Isolated peeling of latex "B" over APP product #1 (Nov. 24, 1992). This is the area where the coating was applied in one application. The affected area was approximately 4 feet x 4 feet (1,200mm x 1,200mm). See Figure 10.

Figure 10 Close-up view of the most severe peeling (shown in Figure 9). An ink pen shows the scale.

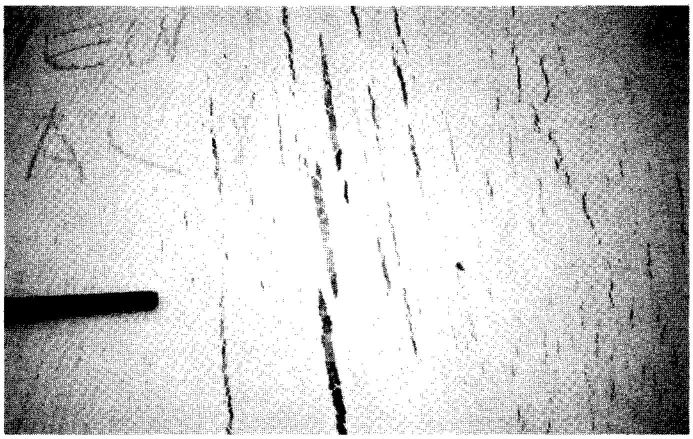

Figure 11 Stretch-cracks in the Phase 1 aluminum-pigmented asphalt coating "C" over APP product #1 (Sept. 27, 1991, approximately 20 weeks after the coating application). The largest crack is approximately ¼ inch (6mm) wide.

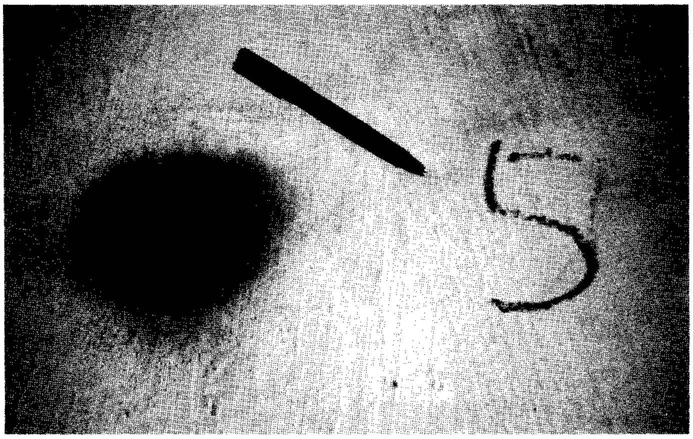

Figure 12 Exudation in a small bird bath at the Phase 1 aluminum-pigmented asphalt coating "C" over APP product #5, approximately six weeks after the coating application. The exudation developed after the coating application. See Figure 13.

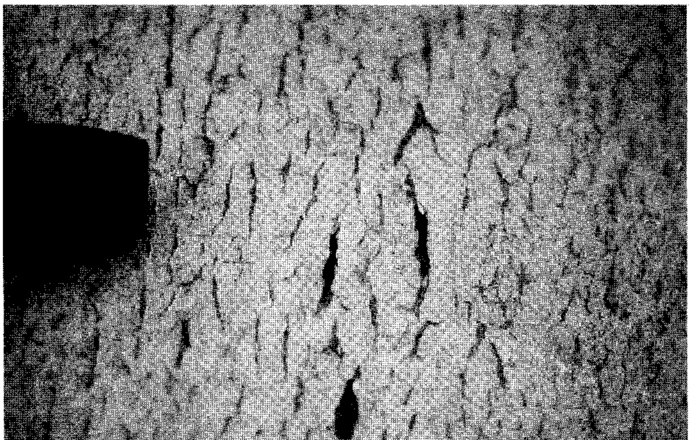

Figure 13 Close-up view of Figure 12 taken on Nov. 24, 1992 (approximately 18 months after the coating application). The coating has cracked and has begun to peel in the area that previously held exudate residue.

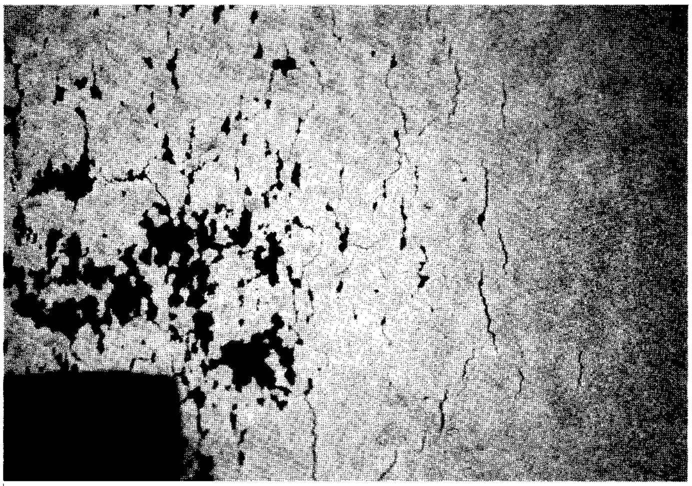

Figure 14 Close-up view of an area of minor erosion of the aluminum-pigmented asphalt coating "C" taken on Nov. 24, 1992. The width of the eroded area was ½ inch to 2 inches (13mm to 50mm) and the length was approximately 24 inches (600mm).

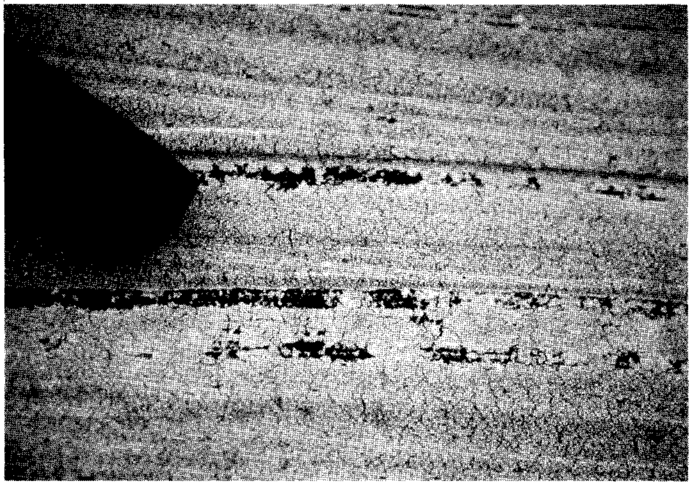

Figure 15 Close-up view of an area of minor erosion of the reflective emulsion coating "D" taken on Nov. 24, 1992. The dark horizontal lines are brush marks. Apparently, the broom-applied coating was relatively thin in the bristle-marked locations.

Figure 16 Weather-checking at exposed (uncoated) APP product #2 (Nov. 24, 1992, approximately 19 months after the membrane application).

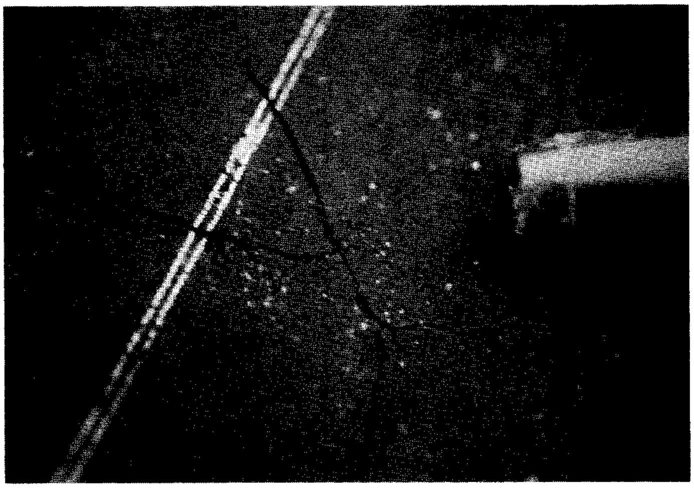

Figure 17 *A large, relatively deep star-shaped crack at exposed APP product #2, (Nov. 24, 1992).*

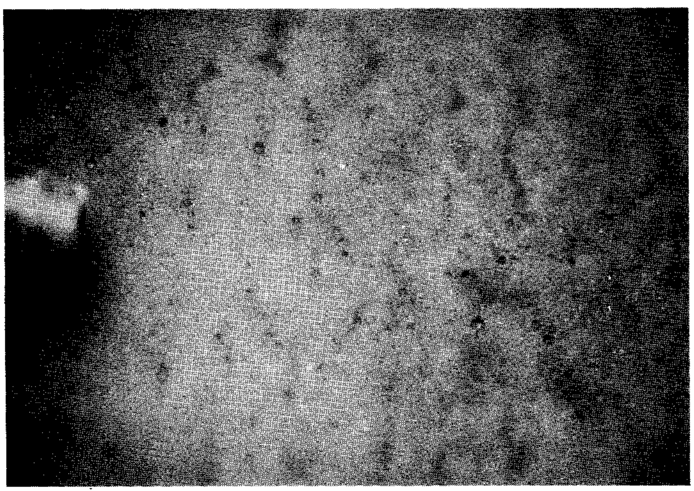

Figure 18 *Small craters at the exposed APP product #4 (Nov. 24, 1992). Two or three small cracks typically extended from the craters.*

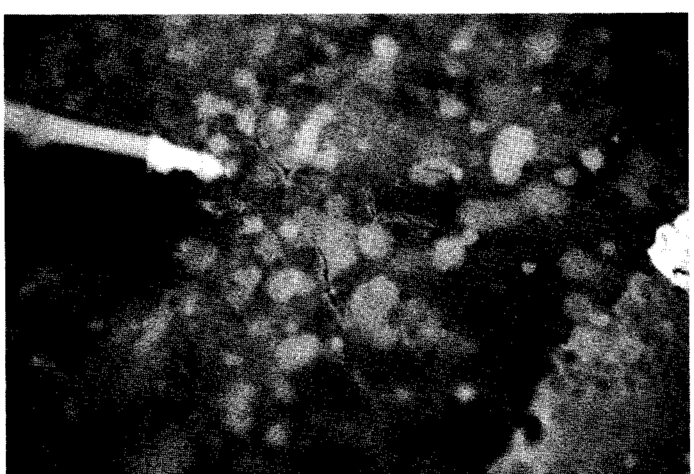

Figure 19 *Cracking at the exposed APP product #5 (Nov. 24, 1992).*

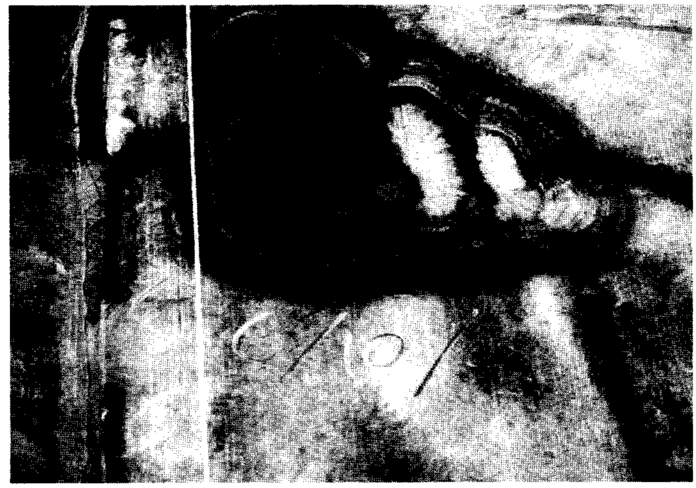

Figure 20 *Pool of exudation on an exposed membrane (June 10, 1991, approximately six weeks after membrane application). Similar conditions were observed on all seven exposed APP products.*

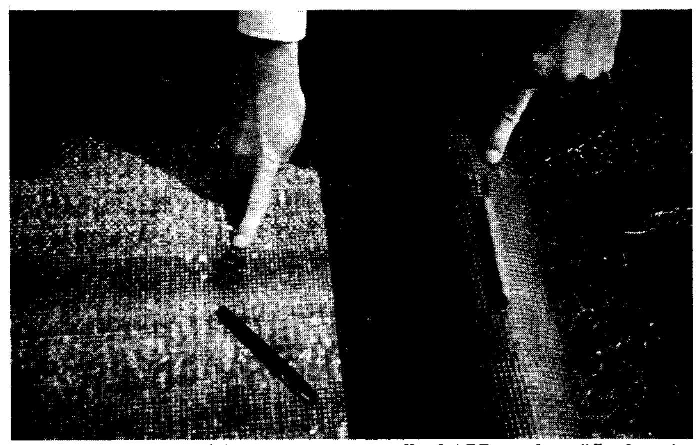

Figure 21 *At several locations on one roll of APP product #5, the reinforcement became exposed because the roll stuck together during unrolling.*

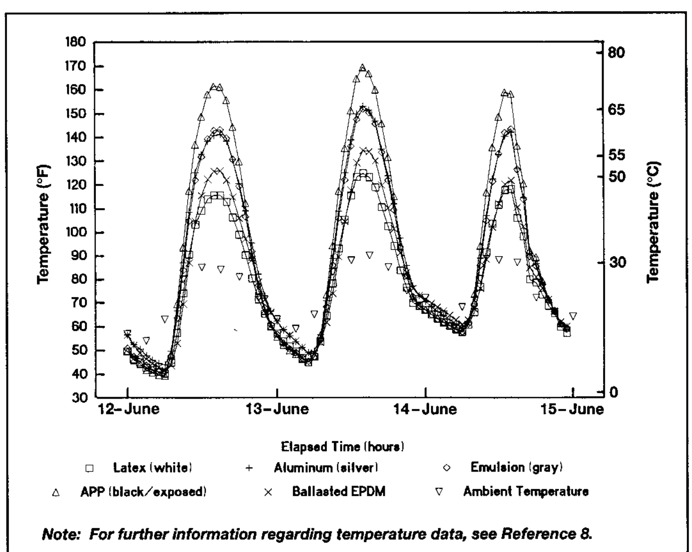

Figure 22 *Hourly membrane temperatures for June 12-14, 1992.*