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Observations From a Field Study of the Performance of Polymer-Modified Bitumen Roofing

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ABSTRACT

The use of modified-bitumen membranes for low-sloped roofing in the United States has increased greatly over the last decade. In spite of this growth, voluntary consensus standards to aid in the proper selection and use of these membrane materials are not available. Moreover, few reports describing performance in service have been prepared. The two primary modifiers currently used to produce modified bitumens are: atactic polypropylene (APP) and styrene-butadiene-styrene (SBS) block copolymer.

This report presents the results of a field study of polymer-modified bitumen roofing. Observations on in-service performance are beneficial for identifying field problems that require study to attain solutions. Fifty-three roofs, ranging in age from 24 to 131 months and located in Washington/Baltimore, Jacksonville, Florida, and Dallas, Texas, were inspected. The types of membrane modifiers were almost equally distributed between APP and SBS polymers. Re-roofing predominated the type of construction and was divided somewhat evenly between tear-off and re-covering.

The overall performance of these relatively young roofs was considered to be satisfactory. About 70 percent of the roofs were considered visually to be in fine condition. Still, about a quarter of the roofs showed some defects that contributed to a lowered performance ranking. The key defects observed with some membranes were surface cracking of both APP and SBS sheets, loss of granules (particularly in ponded water), slippage of SBS sheets, and unsealed or relatively extensive repairing of the laps of an APP system. Although limited, the field experiences provide evidence that performance-related standards are needed to evaluate the membrane materials' ability to resist such defects and to minimize future problems.

Key words: building technology; field study; low-sloped roofing; membranes; performance; polymer-modified bitumens; roofs; standards development

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1. INTRODUCTION

1.1 Background

Polymer-modified bituminous roofing membranes were introduced to the U.S. market during the "single-ply" revolution of the mid-to-late 1970s [1]. The membrane material consists of a factory-fabricated reinforced sheet, composed basically of asphalt, reinforcement, and various polymeric modifiers [2]. Polymer modification of the asphalt is intended to extend its useful temperature range by lowering the brittle point and raising the softening point [3]. Recent estimates from the National Roofing Contractors Association (NRCA) indicate that modified bitumens[1] accounted for about 20 percent of U.S. commercial roofing installed in 1991, with a slightly higher percentage used for re-roofing than new roofing applications [4]. Although they were often used as "single-plies" when first introduced, modified bitumen membranes are normally not now used in that fashion but usually include one or more additional plies.

The two primary modifiers currently used to produce modified bitumens are: atactic polypropylene (APP) and styrene-butadiene-styrene (SBS) block copolymer. Other modifiers may be used in the future as the industry continues to develop [5]. In general, the APP modifier has constituted about 25 to 30 percent of the bitumen blend; whereas the SBS modifier has comprised about 8 to 14 percent of the blend [6]. The modified bitumen displays elastomeric properties if the modifier is an elastomer (i.e., SBS), and plastic properties if the modifier is a plastomer (i.e., APP) [3]. As a consequence, the elastomer-modified bitumens are usually more flexible and have greater elasticity at low temperatures; whereas the plastomer-modified bitumens are stiffer and have greater resistance to high temperatures.

The two major reinforcing mats used in fabricating the sheets are polyester and fibrous glass [3]. These reinforcements may be incorporated alone or together. As a consequence, the available membrane materials exhibit a wide variety of load-elongation properties ranging from high-strength/low-elongation to low-strength/high-elongation. From a performance point of view, the types of component materials used to fabricate the sheet products are not of concern as long as the finished membranes provide the long-term performance expected by the user [7].

Over the 20 years that modified bitumens have been available, their performance has been generally satisfactory, although not without problems [8-10]. For example, the members of the CIB/RILEM

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[1]Polymer-modified bituminous membrane materials are frequently referred to as "modified bitumens," a term often used in this report.

Committee[2] on Elastomeric, Thermoplastic, and Modified Bituminous Roofing have described performance as generally being good to excellent [8]. They indicated that problems experienced included some rupturing, blistering, shrinkage, and seam separation.

In the United States, in spite of more than a decade of use, few reports are available on the performance of modified bitumens in service. An understanding of performance in service is important. As emphasized by the participants at the 1987 U.S. Roundtable on Roofing Research, it provides a basis for identifying problems and selecting those that are significant and require study [11]. Lessons learned from past performance provide future guidance to take advantage of system strengths and to overcome weaknesses and avoid errors. Additionally, information on field performance is beneficial to the standardization process by helping to identify key performance characteristics that should be addressed in specifying requirements incorporated in consensus standards. In the United States, ASTM standards have not been developed to assist in the selection and use of modified bitumens. A report [12] from the National Institute of Standards and Technology (NIST) suggested criteria to be used in the interim while consensus standards were developed. However, no recommendations were made on important performance criteria such as weather resistance and seam performance because sufficient data were not available to provide the basis for these criteria.

1.2 Past Observations on North American Field Performance

Although relatively few reports have been published concerning in-service performance of modified bitumens in North America, some may be cited that provide examples of performance concerns that have arisen. In 1987, Baxter [9] reviewed his experiences and indicated that performance was acceptable and promising, but described field problems including rupturing (splitting), slippage, blistering, separations at membrane flashing junctures, lap separation, and membrane material delamination. In 1989, Dupuis [10] wrote a similar paper, although limited in scope to a discussion of concerns associated with the application of the membrane materials. He reported that the main concerns were associated with the proper heating of asphalt during the application of the sheets or the fabrication of the laps between sheets. More recently in 1991, Booth et al. [13] characterized the performance of the systems in Canada, indicating that it has been generally satisfactory. Major performance problems included slippage, splitting, and wrinkling of the membrane material after installation.

The reports cited above [9,10,13] provide some qualitative examples of in-service performance deficiencies experienced by modified bitumens. These examples may be complemented by the reports from

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[2]CIB is a French acronym for Conseil International du Batiment pour la Recherche, l'Etude, et la Documentation; RILEM is a French acronym for Reunion Internationale des Laboratoire d'Essais et des Recherches sur les Materiaux et les Construction.

the National Roofing Contractors Association's (NRCA) Project Pinpoint [14], which provides survey information from roofing contractors on the trends with respect to roofing materials and systems and the incidence of problems associated with their use.

Cullen's summary [15] of the 1989 Project Pinpoint data included a listing of the five most common problems reported for modified bitumens. These were:

Problem	Percent of Problems Reported
Seam Defects	36
Shrinkage	11
Blistering	10
Embrittlement	8
Wind Related	2

As is evident, the experiences of the authors quoted above were consistent with, but not identical to, the Project Pinpoint findings. For example, Booth et al. [13] did not discuss the performance of seams in Canada, although it tops the list of deficiencies in the Project Pinpoint survey. Similarly, Project Pinpoint does not include slippage as a deficiency, whereas both the Baxter [9] and Booth et al. [13] papers include it as a main concern. Clearly, benefits are to be gained in complementing survey information on in-service performance with firsthand reports from the research community.

1.3 Objective and Scope of the Study

The objective of this study was to obtain and analyze information on the in-service performance of polymer-modified low-sloped roofing systems. Visits were made to selected roofs to observe firsthand their condition, and to discuss performance with individuals associated with their installation and maintenance such as roofing contractors, consultants, material manufacturers, and building owner representatives. Sampling of the inspected roofs was beyond the scope of the study and, consequently, no laboratory testing was performed.

Industry organizations[3] including ARMA, MRCA, NRCA, and RCI assisted in many aspects of the study such as arranging visits to the roofs and discussing the conduct of roof inspections. RCI also contributed by requesting members to submit information on observations recorded for roofs they personally inspected during the time period NIST staff was making field visits. A limited number of summary reports were sent to NIST, and comments are given in the text of the present report in instances where the information complemented that obtained by NIST staff during the field visits. Additionally, at this time, the NRCA and MRCA are

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[3]The acronyms are Asphalt Roofing Manufacturers Association (ARMA), Midwest Roofing Contractors Association (MRCA), National Roofing Contractors Association (NRCA), and Roof Consultants Institute (RCI).

also conducting a field study on the performance of modified bitumen roofing, and a report is planned for 1993. Their findings should complement those of the present study.

2. THE FIELD INSPECTIONS

2.1 The Roofs Inspected

Table 1 presents a summary of the roof inspections. The information summarized was generally provided by the individual(s) who accompanied NIST research staff on the roofs. Fifty-three (53) roof inspections were performed in the Washington/Baltimore, Jacksonville, FL, and Dallas, TX areas. A "roof" was considered as a section (e.g. wing, level, area) of the building's top surface that had a distinct waterproofing system. The roofs were selected, in many cases, on the basis of opportunity; i.e., some one was willing to show NIST staff the roof. Concerns regarding the performance of a specific roof often motivated its inclusion in the study. The inspections were performed by walking over the roofs during which notes were recorded and photos were taken. This provided an opportunity to inspect the visible characteristics of

Table 1. Summary of the roof inspections

Inspection Parameter	Descriptor
1. Number of Roofs:	53 including 27 with APP membranes and 26 with SBS membranes
2. Age of the Roofs:	24 to 131 months
3. Size of the Roofs:	commercial buildings ranged from 93 to 8360 m^2 (1,000 to 90,000 ft^2); the one residential building was about 56 m^2 (600 ft^2)
4. Building Types:	apartment, dormitory, manufacturing plant, hospital, hotel, office, row house residence, shop, shopping center, swimming pool, temple, warehouse
5. Inspection Location:	Washington, DC/Baltimore, MD (26 roofs) Jacksonville, FL (16 roofs) Dallas, TX (11 roofs)
6. Type of Construction:	new (4 roofs) re-roof with tear-off (27 roofs) re-roof without tear-off (20 roofs) unknown (2 roofs)
7. Type of Insulation:	fiberglass, cellular glass, perlite, polyisocyanurate, polyisocyanurate covered with perlite, woodfiber; 35 roofs reportedly had no insulation applied as part of the low-sloped roof system
8. Type of Deck:	cementitious-fiber, concrete, lightweight insulating concrete on concrete, metal (steel), wood
9. Manufacturers:	7 for APP membranes 6 for SBS membranes

the exposed membrane system, but precluded obtaining information regarding the condition of the hidden interior portions of the roofing. Discussions with those familiar with the roofs' histories afforded background information, to the extent available, on general performance elements such as leaks and repairs.

The inspections encompassed a variety of buildings (Table 1). With the exception of a swimming pool, none of the buildings was considered to have extraordinary interior temperature and humidity conditions, although sections of some buildings included kitchens, bathrooms, or similar rooms.

The type of modified bitumen was equally split between APP and SBS. Re-roofing predominated the type of construction, although this was divided somewhat evenly between tear-off and re-covering (i.e., without tear-off). In the latter case, all re-covered membranes were the conventional built-up bituminous type. The ages of the roofs varied from 24 to 131 months. Fig. 1 is a frequency plot (in 5-month increments) of the roof ages. All roofs were considered relatively young, which reflected the fact that modified bitumen roofing in the United States was quite limited a decade ago. As evident in Fig. 1, about 40 percent of the roofs were less than five years old, which is quite young for a roof.

The variety of insulations and decks of the roofs inspected were representative of those commonly used in low-sloped roof constructions. Two-thirds of the roofs did not contain insulation as part of the low-sloped roofing system, and the membranes were placed directly on the deck. These roofs had either a wood-frame deck construction (generally with insulation in cavities below the deck), or decks consisting of concrete or lightweight concrete fills over concrete or metal.

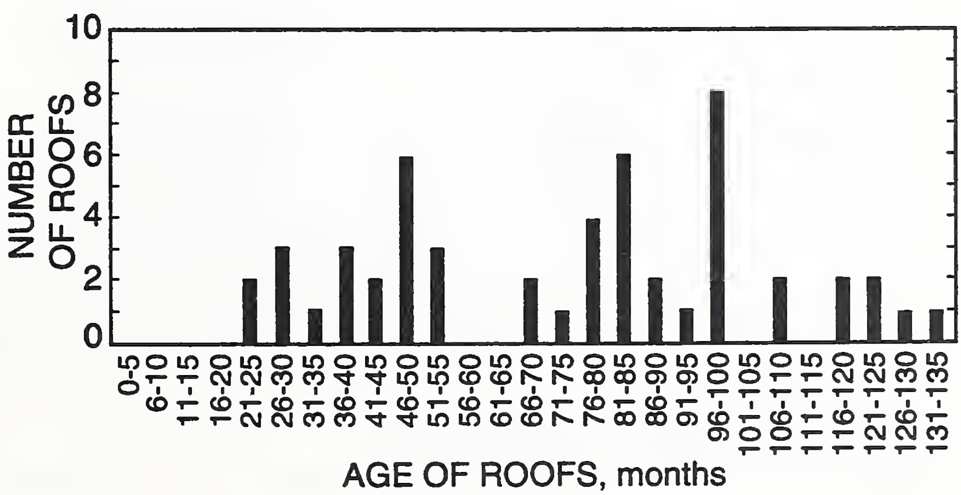

Figure 1. Number and age of the roofs inspected

2.2 Membrane Characteristics

Table 2 provides a summary of the membrane characteristics along with the type of roof construction. Sixteen (16) distinct membrane types (combinations of membrane material, base ply, and surfacing) were inspected. If the type of roof construction is also considered, then the total is 22, which is almost half the number of roofs in the study. As a consequence, it is not feasible to make broad generalizations on the performance of a specific membrane system vis-a-vis any other, as the data base for any one system is small. Note also that other factors which may influence system performance such as age, insulation, deck, and slope are not considered in tabulating the number of membrane systems in Table 2.

In the case of APP membranes, the predominant system observed was the application of the membrane material without a base ply and surfacing in re-roofing without tear-off projects. This observation was consistent with the early industry practice of

Table 2. Membrane characteristics and roof constructions[a]

Membrane Material	Type of Base Ply	Type of Surfacing	Type of Construction[b]	No. of Roofs
APP	none	none	new	2
	none	none	re-roof wo tear-off	10
	none	aluminized coating	re-roof w tear-off	2
	none	white synthetic	re-roof wo tear-off	1
	none	insulation/gravel[c]	new	1
	organic	aluminized coating	re-roof wo tear-off	3
	organic	asphalt emulsion	re-roof w tear-off	1
	organic	asphalt emulsion	re-roof wo tear-off	1
	fiberglass	none	re-roof w tear-off	2
	fiberglass	none	re-roof wo tear-off	1
	fiberglass	aluminized coating	re-roof w tear-off	2
	fiberglass	aluminized coating	re-roof wo tear-off	1
SBS[d] (hot)	organic	granules	re-roof w tear-off	1
	fiberglass	granules	re-roof w tear-off	2
	fiberglass	granules	re-roof wo tear-off	2
	mod. bitumen	granules	new	1
	mod. bitumen	granules	re-roof w tear-off	5
	org/mod-bit[e]	granules	re-roof w tear-off	3
	fg/mod-bit[e]	granules	re-roof w tear-off	6
SBS (torch)	none	granules	re-roof w tear-off	1
	mod. bitumen	foil	re-roof w tear-off	2
SBS (cold)	none	granules	re-roof wo tear-off	1

[a]The number of roofs totals less than 53 because the membrane characteristics were not always fully known.
[b]The symbols are as follows: w = with and wo = without.
[c]This was a protected membrane installation.
[d]The SBS membrane materials inspected had been applied with hot asphalt, a torch or a cold mastic.
[e]These membranes included 2 additional plies: the first (base) was either an organic (org) or fiberglass (fg) felt; the second was a modified-bitumen ply.

using modified bitumens for re-covery applications [6]. In contrast, the predominant SBS system was application of a granule-surfaced membrane material in conjunction with a modified-bitumen base sheet in re-roofing with tear-off constructions.

2.3 General Performance of the Roofs

The overall general performance of the roofs inspected may be gauged through a comparison of the relative performance of the individual roofs. To this purpose, a numerical, yet subjective, ranking system was devised for assigning a performance rating to each roof inspected. The ratings assigned ranged from 1 to 4, with 4 being the top ranking. The basis of the numerical ratings were as follows:

Rating	Basis
4	No problems observed; or if observed, they were considered to be minor and easily repairable (or already repaired), or not directly attributable to the modified bitumen membrane system.
3	Some problems were observed, but were not considered to be cause for great concern regarding the functionality of the roof; (such observations led to questions regarding the reasons for the problems, and the need to address solutions through development of appropriate standards and criteria).
2	Relatively serious problems (often having been already repaired) were observed; they were cause for concern regarding their effect on the long-term functionality of the roof; nevertheless, the roof was functional when inspected.
1	Relatively serious problems were observed and the roof was severely leaking at the time of the inspection.

Note that the ratings consider the overall condition of the roof and not just that of the modified bitumen. Limitations of the rating system are that it is subjective and based only on the observations made of the visible portions of the roof system. Consequently, any deficiencies hidden in the system, perhaps due to leaks that had been repaired, or due to moisture entrapped in a re-cover installation, were undetected and not considered in the rankings.

A summary of the ratings assigned to the roofs is:

Rating	Number of Roofs	Percent of Roofs
4	13	25
3	24	45
2	13	25
1	2	4
(not rated)	1	2

Considering the limitations mentioned above, the overall performance of these relatively young roofs was considered to be satisfactory. This was not unexpected and consistent with previous comments on performance by members of the CIB/RILEM Committees and others cited previously [9,10,13]. About 70 percent of the roofs were classified as being visually in fine condition (ratings 4 & 3 combined). Fig. 2 shows a field view of a typical roof that was performing satisfactorily.

Figure 2. Example of a roof that was providing satisfactory performance

One quarter of the roofs displayed problems of relatively serious concern. However, the significance of this finding needs careful interpretation. As indicated in the introduction, a benefit of any field survey is to identify important problems whose understanding and solutions may need to be the subject of study. In the present case, a bias may have been introduced as NIST staff was taken to some roofs that were known to have experienced problems.

Of the 13 roofs assigned a 2-rating, six had APP membrane systems and seven had SBS membrane systems. The problems observed are discussed later in the report. The majority of the ratings were based on deficiencies associated with membrane performance:

Modifier	No. Roofs	Nature of the Problem(s)
APP	4	- considerable lap repairs
	1	- extensive surface cracking; ponding
	1	- much patching of membrane in highly ponded areas of the roof
SBS	2	- slippage (a system problem)
	2	- degranulation; surface cracking in ponds
	1	- considerable blistering; surface cracking on some sheets
	1	- surface degranulation
	1	- surface cracking

The two roofs classified with a 1-rating had APP membrane systems. Both were leaking and plans had reportedly been discussed for replacing the systems. In one case, many sections of seams had considerable repair and some were found to be open during the inspection. In the second case, the problem was independent of the membrane material and a major system of the system was needed. The problem centered on a cementitious track for a high-rise window washer was leaking and allowing water to penetrate under the modified bitumen membrane.

3. OBSERVATIONS REGARDING FACTORS AFFECTING PERFORMANCE

The observations regarding the performance of the roofs were categorized for discussion as follows:

- o general condition of the roofs,
- o general condition of the membranes,
- o condition of the membrane surface,
- o condition of the membrane laps, and
- o condition of perimeter and penetration flashings.

3.1 General Condition of the Roofs

The vast majority of the roofs were reportedly watertight at the time of the inspections, albeit many (about 30%) had experienced minor leaks at some point in their brief lifetimes. Sources of leaks included both membranes and flashings, but the leaks were not always directly attributable to the use of a modified-bitumen membrane. As is often the case with low-sloped roofing, the roof included details that would be difficult to make watertight no matter the type of membrane installed. Fig. 3 shows a junction of two roof sections near a penetration. Reportedly, this area of the roof was constantly leaking. The incidence of leaks served as a reminder that, in addition to good materials, the other principles of sound roofing practice, i.e., good design, good installation, and good maintenance, apply equally to modified-bitumen roofing. Although a leak may be readily repaired, the consequential damages (e.g., deterioration of components or loss of thermal efficiency) of water penetrating the roof can be high.

Figure 3. Junction of two roof sections that was difficult to keep from leaking

3.1.1 Ponding. For the majority of the roofs, sufficient slope was present and the roofs generally drained well. Nevertheless, typical of low-sloped roofing, slope was not always adequate over all sections of the roof. Over 50 percent of the roofs were noted as having some degree of ponding. Generally the extent was minor, as evidence by limited areas of standing water or dirt accumulated on the surface where water had collected and evaporated. Fig. 4 shows a small roof section near a gutter-edge that had insufficient slope.

Five roofs were categorized as being extensively ponded (Fig. 5). In these cases, the modified bitumen had been applied in a re-roofing application, where opportunity was available to install slope or drains. Good roofing practice dictates that water be drained from the roof as experience has shown that ponding water can be detrimental to roof membranes [16]. Moreover, when roofs adequately drain, the consequences of unexpected leaks damaging the building and its contents may be minimized.

The many observations of ponding raised questions regarding the membrane material's ability to resist ponded water. European experience with modified-bitumens has indicated that water has not, in general, affected the performance characteristics of the modified bitumens, provided that the reinforcement is sufficiently impregnated and coated [12]. Individual products have experienced loss of low-temperature flexibility, bitumen adhesion to reinforcement, and granule imbedment. In the present study, some SBS granule-surfaced roofs had undergone extensive granule loss and cracking in ponded areas, particularly where dirt and other debris had accumulated, although the membranes were functional in those locations (Fig. 6). The surface deterioration in these ponds has at times been referred to as "mud cracking." On some roofs, the observations recorded gave hints that the environment of the pond may contribute to the granule loss. For example, it was observed on one roof that granule loss had noticeably occurred where effluent from an air-conditioner ran across the membrane surface and ponded.

Not in all cases was ponding observably deleterious. Some ponded surfaces both with and without granules did not display any visible surface deficiencies. Fig. 7 shows an eight-year old APP roof that had considerable dirt and debris accumulated in a ponded area. A small section of this membrane surface cleared of debris was seen to be free of cracks, crazing, or other outward signs of deterioration. A lesson from these observations is that, if some modified bitumens can accommodate ponding over the long-term without deterioration of performance properties whereas others cannot, then criteria for differentiating the two need to be available.

Figure 4. Limited ponding along a roof edge that lacked sufficient slope

Figure 5. Example of a roof that had extensive ponding

Figure 6. Ponded roof area that experienced significant granule loss

Figure 7. Significant accumulation of dirt and debris in a ponded area

3.1.2 Lack of Maintenance and Abuse. Historically, lack of routine maintenance and abuse of low-sloped roof systems have plagued their performance. It was not surprising to find evidence that modified bitumens are no exception. Many items for maintenance and repair were observed including the deficiencies noted elsewhere in this report. Fig. 8 shows a clogged drain, which was a signal seen too often that the roof under inspection had been neglected.

Examples of abuse included rocks, glass bottles and other objects thrown on the roofs, foot-traffic damage (loss of granules) by individuals not authorized to be on the roofs and, in one case, a bullet hole. Such observations provided sufficient evidence that modified-bitumen roofing are no exception to standard practice that periodic maintenance inspections and repair (where warranted) are a necessity, and that unauthorized use of the roof is to be avoided.

Figure 8. A drain clogged with leaf debris

3.2 General Condition of the Membranes

3.2.1 Blisters. The observations regarding blistering were positive. With one exception, this phenomenon, which has long been among the serious defects for built-up bituminous roofing (BUR), was not found to be a significant deficiency in the roofs inspected. Nine membranes, representing a cross-section of both APP modifieds with and without a base ply and SBS modifieds with a base ply, contained minor blistering (three or four blisters of relatively small size). Because cutting of the membranes was beyond the scope of the project, the location of the blisters (e.g., between plies or at the interface of the membrane and substrate) was not known. One roof with an SBS membrane applied over a lightweight concrete fill was seriously blistered to the extent that considerable patching had been performed. The unrepaired blisters had the shape of long, narrow ridges (Fig. 9), and one was found during the inspection to have short split (about 75 mm or 3 in.) on the top of the ridge. The observations that blistering can occur in modified bitumens serve as a reminder that, as with BUR membranes, care must be exercised to minimize incorporation of voids in the asphalt layers, and to assure that moisture is not entrapped in the system [9,17].

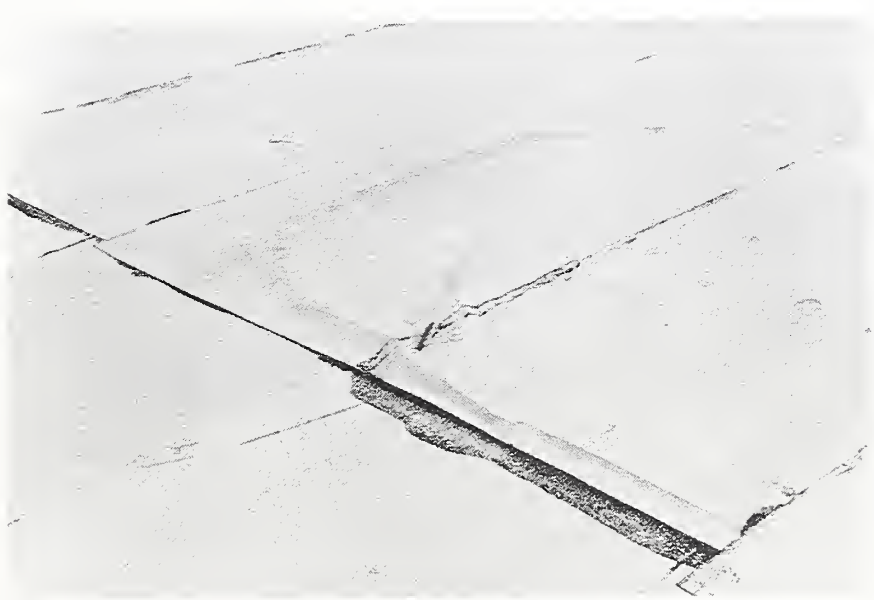

Figure 9. Ridge-like blisters in an SBS membrane

3.2.2 Slippage. Slippage, whereby one or more plies of a bituminous membrane slide down a slope often exposing a base ply or substrate, was observed on seven roofs. All roofs had SBS membranes with base plies installed using conventional roofing asphalt, and were located in the warm climates of Dallas and Jacksonville. The membrane ply sheets were applied parallel to the slope, which was about 40 mm/m (1/2 in./ft) for the roofs in question. The extent of the problem was, in some cases, limited to small highly sloped sections of a roof (Fig. 10); whereas, in other cases, it occurred over large sections of the field of the roof (Fig. 11). In no case had slippage occurred to the extent that the roofs were reported to be leaking through the membrane.

One of the roofs with membrane slippage also had sections of the SBS base flashings which had slipped from vertical walls. These areas had no mechanical attachment of the base flashing to the wall, and were presumably leaking as the slippage resulted in openings in the waterproofing.

The National Institute of Standards and Technology[4] (NIST) studied the factors contributing to slippage of bituminous membranes over 20 years ago, and made recommendations to minimize the risk [18]. Baxter [9] has indicated that slippage of modified bitumens is primarily associated with SBS membranes in warm climates (as was found in this study), and that it can generally be controlled if the proper installation precautions are taken. These include use of asphalt having a suitably high viscosity, strapping of the membrane during application (i.e. application of the ply sheets parallel to the slope), and appropriate mechanical attachment of the membrane to the substrate when the deck has slopes about 40 mm/m (1/2 in./ft.) or more. An example of the effectiveness of strapping was apparently seen in the study. One wing of a building experiencing considerable slippage over many sections of the roof had the membrane installed in "strap fashion." Slippage had not occurred on this wing.

Baxter [9] also raised a question as to whether possible incompatibility between the conventional roofing asphalt and the polymer-modified asphalt contributes to the risk of slippage, for example, by creating an oily exudate at the interface of the two. He cited, as evidence, cases where normal precautions to select asphalts having the proper softening point (or viscosity) to prevent slippage on relatively low slopes were unexpectedly non-successful, and slippage occurred. The question of incompatibility has not been studied to date, and should be.

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[4]formerly the National Bureau of Standards (NBS) when the cited report was written.

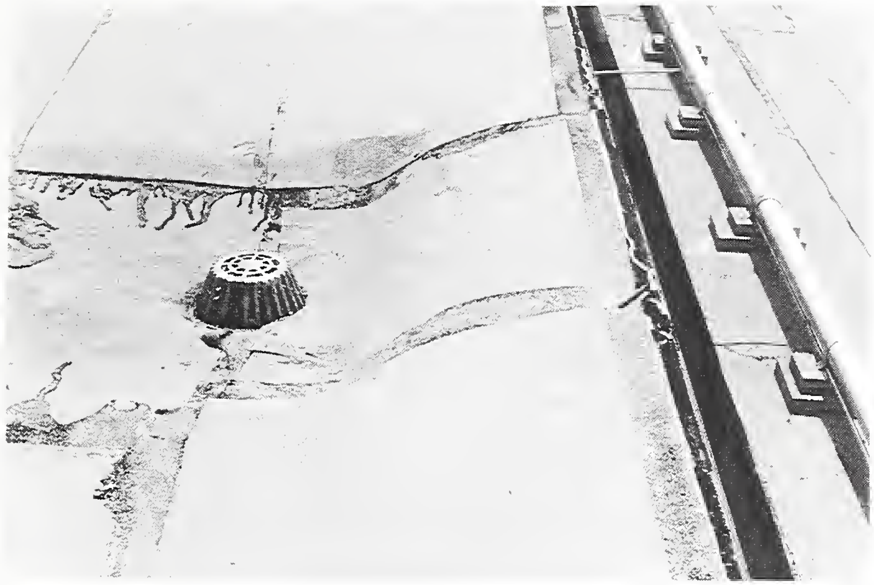

Figure 10. Slippage of the membrane on the slope of a drain slump; note the membrane wrinkling

Figure 11. Slippage of an SBS membrane in the field of the roof

3.2.3 Punctures. Puncturing of the membranes inspected was almost non-existent. Only one of the 53 roofs was found to have a puncture of unknown cause (Fig. 12). The majority of the roofs had some equipment such as ventilators and air-conditioners, which necessitated some degree of foot traffic. The finding that the roofs were virtually puncture-free was consistent with past experiences in the United States. Puncturing of modified bitumens has not been singled out as a major problem in any reports describing field performance [8-10,13,14].

Two of the complementary reports described puncture-related defects in APP systems whereby mechanical fasteners backed out of metal decks and penetrated through the membranes. This problem has not been unique to modified-bitumen roofing but has generally occurred in any systems incorporating fasteners, and may be minimized by using properly designed and installed fastener systems [19].

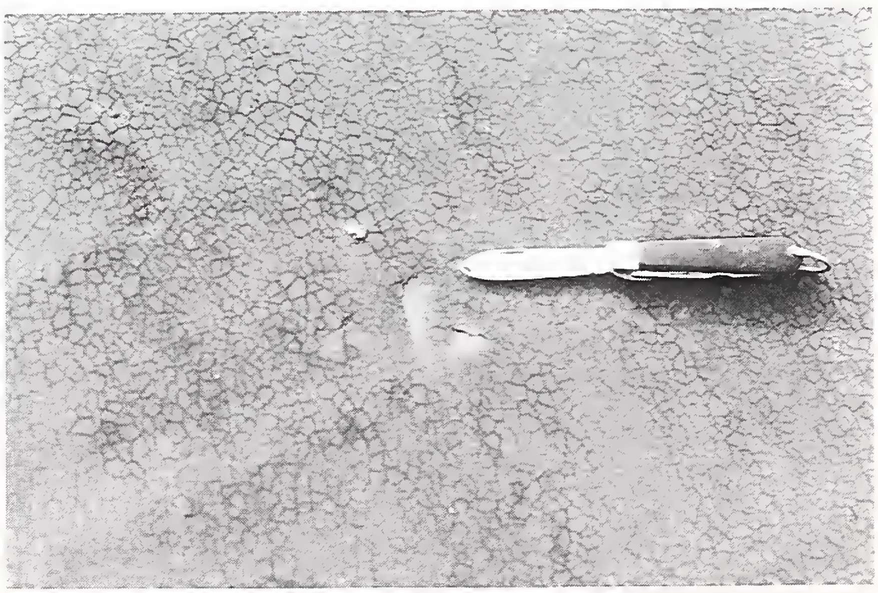

Figure 12. Puncture of an APP membrane; its cause was not established

3.2.4 Shrinkage. In contrast to puncture, shrinkage of modified-bitumen membrane materials in service has been subject of concern; for example, it is the second most-reported problem for modified bitumens in NRCA Project Pinpoint surveys [15]. In the present study, none of the roofs inspected exhibited evidence of shrinkage. One complementary report on shrinkage was provided by RCI.

The contrast between the field observations on shrinkage obtained in the present study and the findings of Project Pinpoint surveys [15] might perhaps be explained on the basis of limited number of roofs inspected. It is imaginable that 53 roofs were not a sufficiently large database to capture examples of the problem. The Project Pinpoint findings should not be ignored. A suggestion is that efforts continue to describe more fully examples of shrinkage and its effect on long-term performance.

3.2.5 Other Membrane Conditions. In planning the field inspections, it was of interest to have firsthand experience on deficiencies such as splitting, delamination of the bitumen binder from the reinforcement, and wind damage. Some occurrence of these types of problems have been reported [9,13,15] for modified-bitumen systems. No observations of such conditions were recorded for the limited number of roofs inspected.

3.3 Condition of the Membrane Surfaces

Observations on the condition of the membrane surfaces was an important consideration in the study as they are directly subjected to the many stresses of the rooftop environment including weather and mechanical action such as foot traffic. APP membranes are installed either unsurfaced (i.e., modified asphalt exposed directly to the weather) or with protective surfacings such as a field-applied coating or factory-applied granules. SBS membranes always have a protective surfacing that usually consists of factory-applied granules, while some products have a factory-applied foil facing or are field coated.

3.3.1 APP Membranes. The majority of the APP roofs were unsurfaced (Table 2). Many of these appeared to be in satisfactory condition (Fig. 13) without any visible signs of cracking or other major surface defects. The oldest age of these roofs was about 11 years. In some cases a superficial surface craze was noticeable on some sheets, and one membrane surface had a few pockmarks. In the case of a specific membrane product that had a fiber glass reinforcement close to its top surface, some glass fibers were exposed (fiberglass bloom) due to erosion of the membrane material surface. The bloom imparted a silvery-gray sheen to the surfaces. No evidence was obtained that the bloom was detrimental to the functionality of the roofs, as it appeared to be limited to the surface. The oldest of the roofs with fiberglass bloom was 11 years.

Two roofs were observed where extensive cracking of the membrane was apparent (Fig. 14). These roofs were about 8 years old when inspected, although their ages when the cracking initiated were not

Figure 13. An example of an unsurfaced APP membrane showing a surface in satisfactory condition

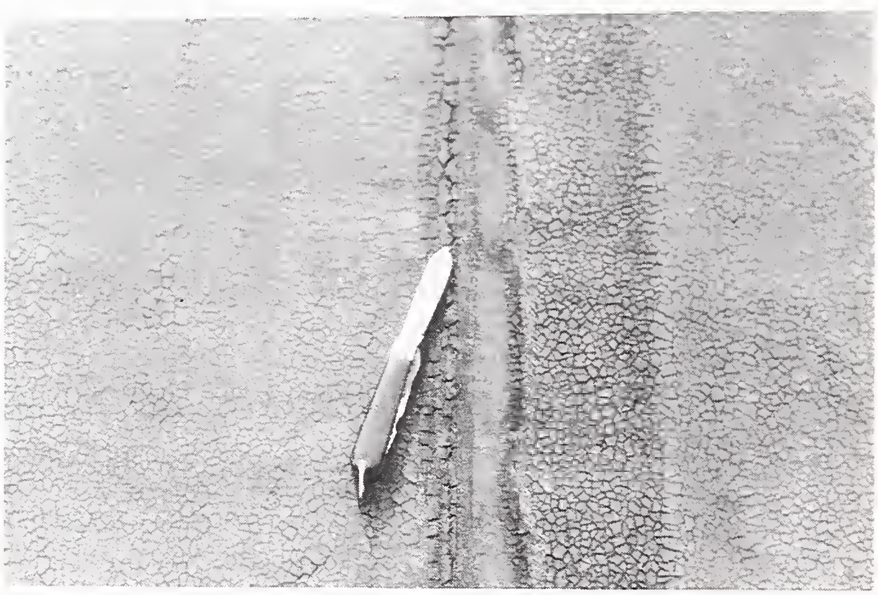

Figure 14. An example of an unsurfaced APP membrane whose surface was extensively cracked

known. The cracking resembled "alligatoring" that occurs with conventional roofing asphalts as they weather. The cracks extended into the membrane material, but the depth was not determined as samples for analysis were not obtained. Neither roof was reportedly leaking through the membrane. In one case, an aluminized coating had been applied as a possible protective measure against further deterioration. The coating was only 6-months old when the roof was observed, and some cracking of the coating had occurred in locations corresponding to the cracks in the modified-bitumen surface. In a related observation, the surface of an exposed APP membrane was found to be generally in acceptable condition with the exception of two sheets that contained surface cracking similar to that just described.

The observations on cracking raised questions regarding the resistance of unsurfaced membrane materials to environmental conditions such as UV radiation and heat, and to what extent the resistance is dependent on production factors such as formulation, asphalt-modifier compatibility, and quality control of the production process. For example, in the case just described, why did two sheets deteriorate when the bulk of the exposed membrane surface was visibly in acceptable condition? Criteria to judge whether unsurfaced APP membranes will perform acceptably over the long-term without surface deterioration are not available and should be developed for inclusion in standards. A recent paper by Hendricks [20], which examined factors affecting surface cracking, could serve as a starting point for developing the criteria.

Another observation noted for the unsurfaced APP membranes was the presence of a thin layer of an oily exudate on some areas of the roofs (Fig. 15). The exudates were not considered to be a cause of concern with regard to membrane performance. However, their

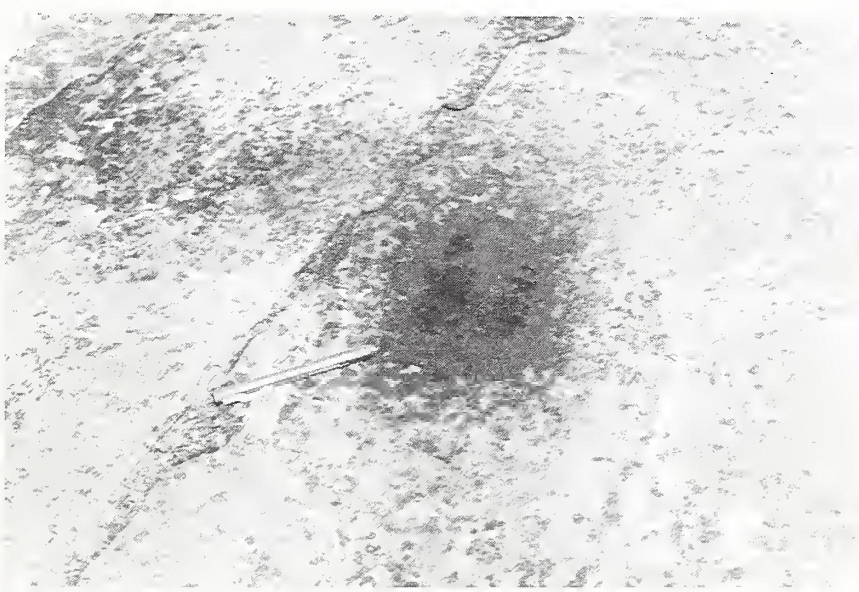

Figure 15. Section of an APP unsurfaced membrane having an oily exudate

presence can adversely affect adhesion of coatings applied directly to the surface of weathered membranes [21]. Coating of unsurfaced new and aged APP membranes is a current issue in the U.S. industry [22].

Eight of the APP membranes were coated with aluminized coatings with ages ranging from 6 to 120 months. Fig. 16 illustrates an aluminized coating that was 96 months old. In all cases, the coatings were considered acceptable without any alarming signs of flaking or peeling, even in areas of ponding. Normal weathering often resulted in uneven exposure of the modified-bitumen surfaces, as indicated by some sections of roofs showing the black of the membrane. For the roofs in question, the 120-month old coating was the most extensively weathered and in need of re-coating. The limited observations that the coatings inspected during the study exhibited no flaking in ponded areas of the roof were positive and in contrast with some past experiences of the authors where aluminized coatings in ponds had flaked.

Other types of coatings on APP membranes were asphalt emulsions (2 roofs) and a white synthetic (1 roof). One of the asphalt emulsion coatings was in satisfactory condition after 39 months exposure; whereas the other was seen to have agglomerated on the roof surface (Fig. 17) during coating application. In the latter case, the 2-year old APP membrane was primed with solvent-based primer before application of the coating. Apparently the emulsion coating was incompatible with the primed membrane surface and, consequently, did not wet the surface when applied. As to the white synthetic, it had severely flaked from the membrane, particularly in ponded areas.

A disconcerting aspect regarding the examinations of coated membranes was that information on important variables such as the properties of the coating, number of layers applied, method of application, and membrane surface treatment was often not available. Such information can expand and strengthen the technical bases on which recommendations for the selection and use of coatings for modified bitumens are made. For example, the Roof Coating Manufacturers Association (RCMA) has provided guidance on methods for preparing modified bitumens to receive surface coatings [20]. The limited observations from the study showed examples of very successful coating of APP membranes. Opportunity to contribute to continuing development of the technology is missed if the information on the factors influencing performance is not available.

Figure 16. An 96-month old aluminized coating; the darker sections are due more to dirt collection in ponds than coating erosion

Figure 17. An asphalt emulsion coating that apparently agglomerated on the roof surface

3.3.2 SBS Membranes. The majority of the SBS modified-bitumen membranes contained granule surfacings (Table 2), which was not unexpected since it is general industry practice for providing surface protection to these systems. Other than extensive granule loss in areas of ponds (Section 3.1.1), the majority of the surfaces of these SBS membranes exposed normally to weather was seen to be in acceptable condition (Fig. 18). As previous stated, instances of abuse due to unauthorized foot traffic resulted in excessive granule loss (Fig. 19).

Some examples of less-than-satisfactory surface performance of non-ponded, non-abused roof sections were seen, as evidenced by granule loss and cracking. In a notable case, granule-erosion had been so extensive that considerable surface restoration had been performed by overlaying additional sheets of the membrane material. Although the membrane surface was protected by the repair, the color of the granules on the overlayment sheets was not always quite the same as that of the original material. The roof was readily visible from its surroundings and, reportedly, the building owner was not pleased with the aesthetic appearance of the somewhat mottled repaired roof. In a couple other instances, the surfaces of the membrane sheets did not appear to be as well covered with granules as generally observed for the majority of the granule-surfaced roofs. This was evidenced by a slightly "blacker" appearance of the surface where asphalt was somewhat visible through the granules. Whether these conditions developed over time or were present from the time of roof installation was not ascertained. It would be of value to re-inspect these roofs at some time in the future to observe whether their surface appearances are changing.

In addition to granule loss, cracking of granule surfaces, as shown in Fig. 20, was observed on a couple of roofs. When present, such cracking was generally limited to a few sheets. Also, the inspections included two roofs where a few sheets of the membrane material developed small blisters (or bubbles) in the granule surfacings (Fig. 21). These blisters resembled those that develop at times in the granule surfaces of asphalt shingles. At one location, the defect had been extensive enough that sheets with blisters had been overlaid with additional membrane material.

The isolated instances of granule loss, cracking, and blisters raised questions as to their causes and steps that may be taken to minimize the risk of future occurrences. The availability of criteria to evaluate the ability of products to resist such defects would help assure that only SBS membrane materials having acceptable surface protection are installed.

Figure 18. A typical granule-surfaced SBS roof

Figure 19. Granule loss of an SBS membrane at a high school; students often climbed on the roof

Figure 20. Cracking of a granule-surfaced SBS membrane material including the base flashing

Figure 21. Small blisters in the granule-surfacing of an SBS sheet

Aluminum foil was the surfacing on two of the SBS membranes. Both were observed to be in satisfactory condition without any signs of foil delamination. The age of the older roof was 9 years. In this case, the building was located along a railroad track, and a considerable number of stones had been thrown onto the roof (Fig. 22). Punctures were observed in the foil, but no signs of excessive weathering of the small areas of exposed modified-asphalt were detectable.

Other surface-condition features noted for SBS membranes during the study included: slight (almost non-perceptible) rippling in some surfaces; seemingly insignificant, yet discernible, scratch marks in granule surfacings, and scattered minor staining of the surfaces of a couple roofs. These observations were classified as curiosities and did not raise concerns regarding membrane functionality.

3.4 Condition of Laps in the Membranes

As indicated in the introduction, the number one problem reported for modified bitumens in NRCA Project Pinpoint surveys has been defective lap performance [15]. Consequently, considerable attention was paid to laps during the inspections and many discussions were held on the subject with those accompanying NIST researchers to the roofs.

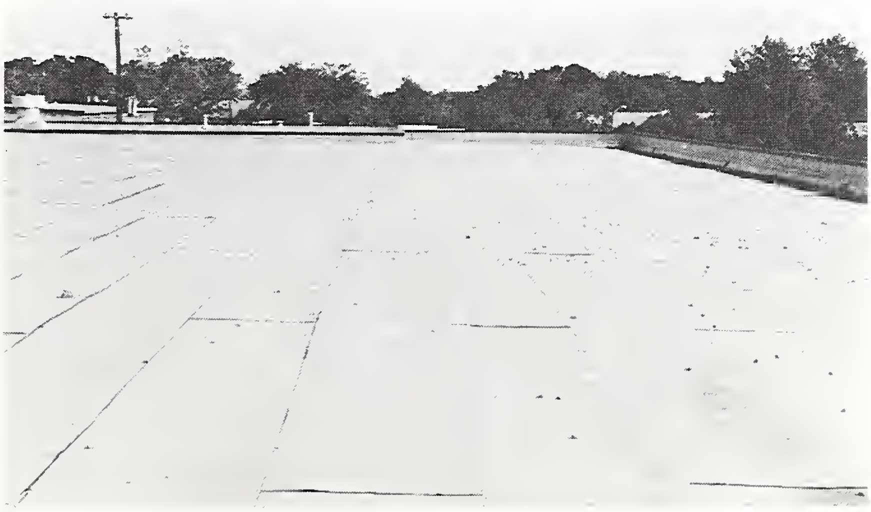

Figure 22. A foil-surfaced SBS membrane in acceptable condition although thrown rocks produced some small punctures in the foil

With the exception of one membrane product, observations concerning the performance of the laps of both the APP and SBS roofs inspected were favorable. For the roofs in general, the laps appeared to be intact and tight, and signs of potential trouble areas such as excessive wrinkling or buckling were not found. Fig. 23 illustrates laps typical of those observed with many of the SBS membranes. Many sections of laps were probed with the tip of a blunt blade. The technique was rough, but the laps generally resisted the probe. As a complement to the NIST observations, it is noted that four complementary reports from RCI included incidents of lap openings. All were described as being minor problems.

No evidence of delaminations of the end laps between SBS sheets were observed, but one of complementary reports that commented on lap deficiencies included an instance of minor end-lap disbonding of an SBS system. End laps of SBS membranes have experienced delamination problems in service associated with difficulties in bonding the top sheet to the granule surface of the second sheet comprising the lap [9]. Edge laps of SBS membranes have not raised the same concern as one longitudinal edge of the granule-surfaced sheets normally has a selvage area (without granules) for bonding.

Figure 23. Laps of a SBS membrane illustrative of many observed; the end and sides laps were tight

It was also observed that many of the roofs had laps without "bleed-out." This is an industry term applied to the relatively narrow ribbon of asphalt that flows away from the lap during its fabrication (Fig. 24). It is taken by some, but not all, practitioners as an indication that adequate heat and/or asphalt was applied during membrane construction. However, caution must be exercised in interpreting the significance of bleed-out, because its presence does not necessarily indicate that proper fusion of the lap sheets has occurred. On the basis of the field observations, no evidence was obtained that the laps without bleed-out were performing differently than those with bleed-out.

The exception to the generally positive findings on lap performance involved membranes constructed from a torch-applied APP product that had been, but is no longer, available from a particular manufacturer. Twelve of the 53 roofs included in the study had such membranes. For 5 of these 12 roofs, the visual evidence was that the laps were in satisfactory condition without signs of disbond or lap repair. The ages of these roofs ranged from 54 to 96 months. In contrast, six of these membranes, with ages ranging from 74 to 131 months when inspected, showed indications of serious lap problems at some point during their service. One of these roofs was found to have sections (a few millimeters to a half of meter in length) of laps that were unbonded (Fig. 25), and a number of patches had been made. Note in Fig. 25 that no unusual signs of distress such as pulling or rippling of the membrane were apparent where the blade is inserted in the section of open lap. Five of the other roofs had laps with a considerable number of patches, as exemplified in Fig. 26. Generally the patches were located randomly across the membrane. However, the relatively large roof depicted in Fig. 26 had the patches concentrated in relatively small areas, while other sections were patch-free.

Figure 24. Example of asphalt bleed-out at the edge of a lap of a coated APP membrane

Figure 25. An opening in a lap of an APP membrane

Figure 26. Example of an APP membrane with repair patches made to the laps

In the case of half of the repaired roofs, the ages of the membranes when seam patches were first applied were reported to be about 24 to 36 months; for the others, the ages of initial patching were unknown. But even when the ages were not known, those accompanying NIST staff were quite positive that the roofs in question were leak-free when installed. Although scant, these few details on age indicate that time was a factor influencing the performance of these laps. However, little other information was gleaned from these individuals regarding factors affecting the lap performance.

As a final note on the laps of this APP membrane system, one 10-year old roof was reported by the contractor who installed it to have developed a few lap leaks when the membrane was about 2 years old. The open sections of lap were sealed with a mastic cement, and the roof reportedly provided satisfactory service since the repairs were made.

A final observation to note on laps involved an SBS roof that was under replacement at the time of its inspection. Only a portion of the original SBS membrane remained for examination. An inspector overseeing the installation of the replacement roof indicated that unsealed laps were among the defects that lead to the decision to re-roof. However, none of the examined laps of the remaining portion of SBS membrane were found to be open.

3.5 Condition of Flashings

The flashings at penetrations and perimeters were generally in good condition. Poor flashing performance was never found to be a major problem on any roof. In most cases, the modified-bitumen membrane material was used as the base flashing. As an example, Fig. 27 shows a curb-mounted ventilator with a base flashing fabricated from the APP membrane material. One granule-surfaced SBS membrane system often had foil-faced base flashings.

In spite of the acceptable performance, isolated instances of flashing defects were observed during the inspections, and those accompanying NIST researchers reported instances where leaks through flashings had been repaired. Some of the observed defects were mentioned earlier in the report; for example, base flashing that slipped (Section 3.2.2) and a granule-surfaced material with cracks (Fig. 20). Fig. 28 shows a small split in the perimeter flashing at a joint in the edge metal. Although not observed firsthand in the study, complementary information on field performance provided an instance where a foil-faced flashing had exhibited delamination of the facer from the modified-bitumen sheet. The examples and reports of isolated flashing defects are evidence that, as with all low-sloped roofing, flashings of modified-bitumen roofs need to be properly designed and installed and, once in place, their routine maintenance should not be neglected.

Figure 27. Flashing of a ventilator penetration of an APP membrane

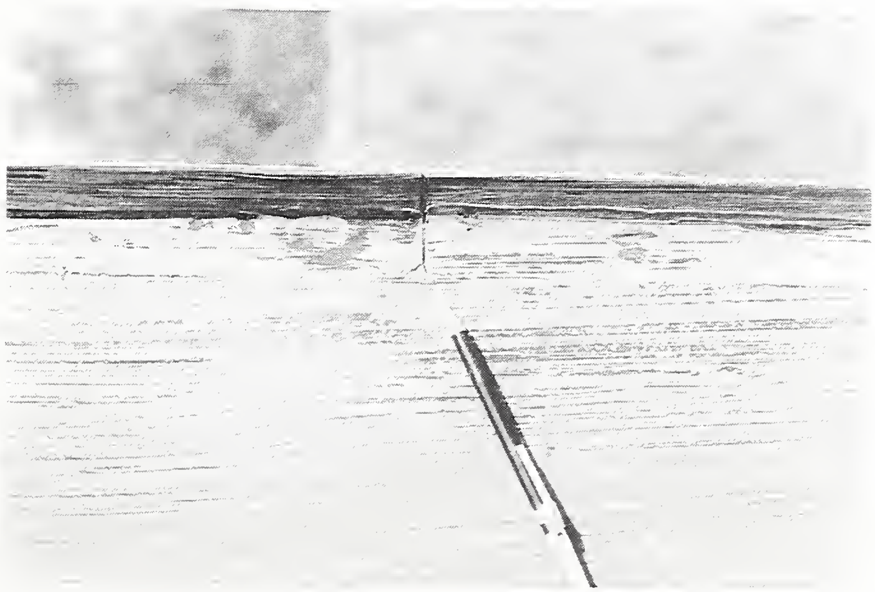

Figure 28. Small split in perimeter flashing at a joint in the edge metal

4. SUMMARY AND RECOMMENDATIONS

The use of modified-bitumen membranes for low-sloped roofing in the United States has increased greatly over the last decade, and presently accounts for about 20 percent of the membrane systems installed. In spite of the growth, voluntary consensus standards are not available. Few reports that describe their performance in service have been prepared. Although performance has generally been satisfactory, it has not been problem-free. Observations on in-service performance are beneficial for identifying significant problems that require study to attain solutions. In turn, the results of the studies help to provide the technical bases on which the needed standards are developed.

This report describes a field study of polymer-modified bitumen roofing. Fifty-three roofs, ranging in age from 24 to 131 months and located in Washington/Baltimore, Jacksonville, Florida, and Dallas, Texas, were inspected to observe firsthand their performance. The types of membrane modifiers were almost equally distributed between APP and SBS polymers. Re-roofing predominated the type of construction and was divided somewhat evenly between tear-off and re-covering. Strictly speaking, because of the limited size of the database, the observations in the survey should apply only to the roofs inspected. Nevertheless, their broad interpretation has significance for standards development.

The results of the survey were positive and, considering the relatively young ages of the roofs, their overall performance was considered to be satisfactory. About 70 percent of the roofs were rated as being visually in fine condition. Still, about a quarter of the roofs showed some defects that contributed to lowered performance. Such defects were attributed to both the total roof system or the membrane material. Key examples in the former category were inferior design including inadequate drainage, lack of maintenance, and abuse of the roofing. These deficiencies are not unique to modified-bitumen roofing, but are unfortunately too often associated with low-sloped roofing. The key defects observed with some membrane materials were surface cracking of both APP and SBS sheets, loss of granules (particularly in ponded water), slippage of SBS sheets, and unsealed or relatively extensive repairing of the laps of an APP system from a particular manufacturer.

Although these observations were limited, the experiences gained in the field provide evidence that evaluative criteria and requirements in standards are needed to minimize future problems. Such criteria should address factors associated with proper modification and quality control in the production of modified bitumens. This is considered important, as the evidence is that some modified materials were capable of withstanding the effects of weather without developing deficiencies such as surface cracking, granule loss, or lap delamination; whereas others have developed such problems. Or, in some specific instances, the vast portion of the roof area appeared to be acceptable condition, but a few sheets out of the number installed exhibited problems.

Thus, based on the field results, two key areas are suggested for study:

- o the development of criteria for assessing the effects of the weather environment on performance. The criteria would be intended to minimize defects associated with the surface. The criteria could also address the question of membrane material shrinkage.

- o the development of criteria for assessing the compatibility of modified asphalt comprising membrane sheets and conventional asphalts used to install them. The criteria would be intended to evaluate the role of incompatibility on slippage and thereby minimize its future occurrence in practice.

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6. REFERENCES

[1] Rossiter, Walter J., Jr., "Single-Ply Roofing -- A Decade of Change," ASTM Standardization News, Vol. 1, No. 9 (September 1985), pp. 2-5.

[2] Johnson, Ray, "History and Development of Modified Bitumen," Proceedings, 8th NBS/NRCA Conference on Roofing Technology, National Roofing Contractors Association, Rosemont, IL (1987), pp. 81-84.

[3] Meynard, Jean-Yves, "Modified Bitumens: What to Look For," in "The Single-Ply Roofing Membrane," National Roofing Contractors Association, Rosemont, IL (198), pp. 14-16.

[4] LaValley, Alison L., "How was 1991? Roofing Market Slides to $16.02 Billion," Professional Roofing, National Roofing Contractors Association, Rosemont, IL (February 1992), pp. 4-7.

[5] Saracino, P. and Becker, W., "The Introduction to an Advance All Purpose Asphalt Modified Roofing Membrane," Proceedings, VIII International Congress of the International Waterproofing Association, Brussels (1992), pp. 585-597.

[6] Dupuis, R.M., "Test Results and Trends for EPDMs and Modified Bitumens," 1986 Handbook of Commercial Roofing Systems, HBJ Publications, Cleveland, OH (1986), pp. 11-12.

[7] Rossiter, Walter J., Jr., Frohnsdorff, Geoffrey J.C., Masters, Larry W., and Martin, Jonathan W., "A Performance Approach to the Development of Criteria for Low-Sloped Roof Membranes," National Institute of Standards and Technology, NISTIR 4638 (July 1991), 36 pages.

[8] "Elastomeric, Thermoplastic, and Modified Bitumen Roofing," A Technical Report of CIB W.8 and RILEM 75-SLR Joint Committee, Materials and Structures, Vol. 19, No. 112 (July/August 1986), pp. 2-0.

[9] Baxter, Richard P., "Field Performance of Polymer-Modified Bituminous Roofing Membranes," Proceedings, 8th NBS/NRCA Conference on Roofing Technology, National Roofing Contractors Association, Rosemont, IL (1987), pp. 85-90.

[10] Dupuis, René M., "Concerns in the Application of Modified Bitumen," Proceedings, 9th NIST/NRCA Conference on Roofing Technology, National Roofing Contractors Association, Rosemont, IL (1989), pp. 7-77.

[11] "Roofing Research: the Challenge and the Opportunity," Summary of the Roundtable Seminar, National Roofing Contractors Association, Rosemont, IL (December 1987), 18 pages.

[12] Rossiter, Walter J., Jr. and Seiler, James F., Jr., "Interim Criteria for Polymer-Modified Bituminous Roofing Membrane Materials," National Institute of Standards and Technology (U.S.), Building Science Series 167 (February 1989), 50 pages.

[13] Booth R.J., Minialoff, J.M., and Murphy, M., "Field Experiences Versus Standards and Design," Proceedings, Third International Symposium on Roofing Technology, Montreal, Canada, National Roofing Contractors Association, Rosemont, IL (1991), pp. 51-55.

[14] Cullen, William C., "Project Pinpoint Analysis: Trends and Problems in Low-Slope Roofing 198-1989," National Roofing Contractors Association, Rosemont, IL (1989), 27 pages.

[15] Cullen, William C., "Project Pinpoint's Database Continues to Grow," Professional Roofing (April 1990), pp. 28-1.

[16] "Handbook of Accepted Roofing Knowledge (HARK)," National Roofing Contractors Association, Rosemont, IL (1989), p. 7.

[17] Rossiter, Walter J., Jr., and Mathey, Robert G., "Risk of Blistering of Built-Up Roofing Membranes Applied to Polyurethane Foam Insulation," in "Thermal Insulation: Materials and Systems, "ASTM STP 922, Powell, F.J. and Matthews, S.L., Eds., American Society for Testing and Materials, Philadelphia, PA (1987), pp. 41-448.

[18] Cramp, A.P., Cullen, W.C., and Tryon, M., "Slippage of Built-Up Roof Membranes: Causes and Prevention," NBS Report 10 950 (November 1972), 90 pages.

[19] "Current Roofing Fastener Technology," National Roofing Contractors Association, Rosemont, IL (November 1989), 22 pages.

[20] Hendricks, N.A. and Woonink, R., "Field and Laboratory Investigations of the Crazing Phenomena of APP Modified Bitumen Sheetings," Proceedings, VIII International Congress of the International Waterproofing Association, Brussels (1992), pp. 179-195.

[21] "Methods for Preparation of Modified Bitumen Membranes for the Application of Surface Coatings," Roof Coatings Manufacturers Association, Rockville, MD (25 June 1991), 4 pages.

[22] Carlson, James, "Coating of Modified Bitumen Membranes, " Proceedings, Proceedings, 10th NIST/NRCA Conference on Roofing Technology, National Roofing Contractors Association, Rosemont, IL (1992), paper in review.