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# Building Research Note



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by

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In recent years, waterproof membranes made of many new materials have been developed for flat or nearly flat roofs, and for roofs having unusual contours such as curved shells, hyperbolic paraboloids, etc. Prompting this development has been the need for speedier, easier application and greater economy than that now enjoyed by the roofing industry.

During the last hundred years, the most commonly employed roofing materials in Canada are bitumens, usually applied in multiple ply built-up systems. Some of the new systems still use bitumens either as adhesives or waterproofing agents, but recent chemical technology has introduced many new, thin, high-strength materials which are of a completely different nature, both in composition and final appearance. Many of these new roofing membranes have distinct advantages that could enhance their attractiveness to designers and owners. A few of the more obvious features are their relative ease of application, high reflective characteristics and good resistance to traffic.

For a better understanding of the performance of these systems under Canadian climatic conditions, an outdoor exposure program was undertaken by the Division of Building Research of the National Research Council of Canada. This report describes the roofing systems exposed, the method of their application, and the results of a number of visual examinations taken over a 5-year period. Photographs included at the end of this report show the extent of degradation of some of the materials that were exposed for the full 5 years. Also included, is information regarding the performance over a 2-year period of a roofing system that was applied over the deck of a small, heated, instrument shelter constructed on the outskirts of Ottawa.

## ROOF DECKS

A number of small roofs, each measuring 12 ft by 4 ft were prepared in the laboratory at room temperature, and 3 such roofs, designated here as Nos. 10, 11 and 12, were prepared on site. With the exception of No. 12, all the roofs were joined together, forming one long roof. The materials employed and the method of application are described later.

The decks for these roof systems (except that of No. 12) were constructed from panels of 5/16 in. plywood nailed to a 2 by 2 in. lumber frame. A cant strip 2-in. high was nailed along one length of each panel, so that it overlapped the edge of the adjacent roof section. Slight slopes were provided toward the cant strip, and forward, to ensure water drainage. The completed units were securely installed as a protective roof over stored, structural-steel trusses in a way that permitted free air movement under the roof panels. Numbers 1 to 10 were exposed from May 1964, but No. 11 was not installed until April 28, 1967. All systems were weathered in the Ottawa area.

Roof No. 12 was installed during May 1967, over a small enclosure approximately 10 miles from the Ottawa site. This insulated building measured 14 ft by 10 ft; an inside temperature of approximately 72°F was maintained throughout the colder weather. The roofing system was laid over an insulated wood deck constructed with a slight slope for drainage.

## TYPES OF ROOF-SYSTEMS EXPOSED

Roof No.

1 - A polyisobutylene sheet bonded to a supporting reinforcement made of an elastomer-impregnated, asbestos felt, and topcoated with a white acrylic latex.

2 - An asphalt membrane, reinforced with glass fabric and surfaced with aluminum-metal foil, bonded to a base sheet made from glass or asbestos and saturated with asphalt.

3 - A black butyl sheet membrane composed of a copolymer of isobutylene and isoprene, applied to the substrate with a contact-type adhesive.

4 - A butyl sheet like the previous one (No. 3) in composition, but white in colour.

5 - A thin-film roofing, produced by the application of several liquid neoprene coats, and topcoated with successive layers of hypalon (chlorosulphonated polyethylene).

Roof No.

6 - (a) a two component liquid-applied white rubber, used in conjunction with a silicone primer.

(b) a glass-fabric reinforced silicone sheet, applied with a contact-type adhesive.

7 - A cold-process roofing system, employing roofing felts, cold-applied solvent adhesive, and a cold-applied emulsified asphalt.

8 - A single-ply roofing system, consisting of a white polyvinyl-fluoride film, factory laminated to an asbestos felt which is impregnated with a neoprene latex.

9 - A white, liquid-applied, butyl latex system, in which is embedded a reinforcing, lightweight, glass-fibre mat, topcoated with chlorosulphonated polyethylene (hypalon).

10 - A conventional built-up membrane consisting of plies or layers of 15-pound type saturated roofing felt, bonded together with hot asphalt, and topcoated with an application of gravel.

11 - A single-ply white roofing sheet, made of ethylene propylene terpolymer, and applied with a contact-type adhesive.

12 - A single-ply sheet material, comprised of a white hypalon topcoating over a thin polyurethane foam backing, bonded to the substrate with an adhesive.

## METHOD OF APPLICATION

### Roof No. 1

Liquid polyisobutylene adhesive was used to bond this sheet membrane to the deck, and the same adhesive, with asbestos fibres added, sealed the laps. A third type of polyisobutylene adhesive was used to adhere the flashing, which consisted of a polyisobutylene sheet welded to a glass-fibre fabric. Finally, the system was painted with a topcoat of acrylic latex.

Roof No. 2

The base sheet was nailed at 6-in. intervals to the plywood deck. The asphalt, on the underside of the foil-surfaced bitumen sheet, was then heated almost to melting point with an air-acetylene torch, so that an adequate bond to the base felt could be achieved. (An alternative method of application would have been to use hot mopped asphalt.) The edges were flashed with the same material.

Roof No. 3

The butyl-rubber sheet was cut to dimension, laid along the roof deck surface, and allowed to relax. Half of the sheet was then folded back onto itself along its longer dimension, and a contact type cement was applied to the exposed underside and to the deck with a roller. After the adhesive had become dry to touch, the rubber sheet was unfolded back onto the deck, and a roller was used to smooth the surface of the membrane and ensure a good bond. The remaining half of the membrane was folded back onto the cemented portion and the preceding technique was repeated. A 4-in. overlap was allowed when the second sheet was laid; the same materials were used in applying flashings around the edges.

Roof No. 4

This roof was applied using the same technique as that described in the preceding paragraph.

Roof No. 5

A thinned solution of neoprene was first applied to the plywood deck to act as a primer. After drying, all the joints and flashings of the roof deck were covered with pressure-sensitive cotton tape. These tapes, and adjoining areas of up to 4 in., were coated with the uncut neoprene solution. After a 2-hr drying period, the first neoprene coat was applied with a brush and roller, at a rate of $2\frac{1}{2}$ gal per 100 sq ft, to a wet-film thickness of 8 mils. A cure period of 3 hr was allowed before the second application of neoprene was rolled on to a wet-film thickness of 8 to 10 mils. After drying overnight, the topcoatings of hypalon were applied with a roller at the rate of $1\frac{1}{2}$ gal per 100 sq ft. The first coat was applied to produce a wet film thickness of 8 mils and the final application was rolled on to a wet film thickness of 10 mils.

Roof No. 6

A sheet of glass-fibre reinforced silicone, measuring 3 ft by 3 ft, was stuck to one end of the deck with a contact type of adhesive. This portion of the roof was exposed without further treatment. The remainder of the deck area, including all the edges and the cant strip, were coated with a silicone primer. All joints were sealed with a silicone rubber caulking material. The silicone-rubber roofing mixture was prepared by adding 1 part of curing agent to 40 parts of the base material; it was applied to all areas other than that occupied by the silicone sheet. After an overnight cure, a second mixture was prepared and applied by roller and brush. This second coat was cured and the surface was dusted with fine mica.

Roof No. 7

This was a 3-ply roofing system which consisted of 53-lb saturated and coated felts, and a topcoat of asphalt emulsion.

A number of 14 ft lengths of the saturated and coated felts were cut and laid flat for a period of 18 hr. The first strip of felt was laid lengthwise along the cant strip in such a way that it went over and around the cant strip, and covered a 12-in. width of the deck. It was nailed to the cant strip on 8-in. centres. One qt of cold-process adhesive was applied evenly over this nailed felt, and a second length, with its edge against the cant strip, was laid over the first felt so that it covered a 2-ft width of the deck. Because this felt was too rigid to cover the cant strip, the cant was completed with a glass-fabric and asphalt emulsion. The portion of the felt that was over the plywood was nailed on 12-in. centres, and 2 qt of cold-process cement adhesive was applied over this second felt layer. Subsequent sheets, each 3 ft wide, were applied and nailed as before, so that a 3-ply roof of 53-lb saturated and coated felts was obtained.

Roof No. 8

In this system, a 53-lb saturated and coated base sheet was glued to the deck with an asphalt cold-process cement. The base sheets were lapped 4 in., and nailed to the deck and cant strip on 12-in. centres.

The first polyvinyl fluoride-asbestos sheet was then glued to the base sheet with the same type of cold-process cement that was used previously. A second sheet, coated with adhesive up to within an inch of one edge, was laid so that it overlapped the first sheet by 4 in. along this edge. The seam was covered with pressure-sensitive polyvinyl fluoride tape, and the entire membrane was rolled to ensure firm contact between the surfaces. The roof edges were secured by folding the membrane under the deck and fixing with the pressure-sensitive tape.

Roof No. 9

A base coat of butyl latex was applied to the plywood roof deck to a wet-film thickness of between 10 and 15 mils. While still wet, the reinforcing scrim was laid in and rolled, and a small amount of butyl latex was applied over this glass-fibre mat to wet it. Flashings for the deck edge and the cant strip were fixed in place with glass scrim embedded in butyl latex. A 3-hr drying period was allowed before it was painted with butyl latex to a wet-film thickness of 12 mils. After another 2 hr had elapsed, a second coat was applied to a wet-film thickness of 15 mils. After 72 hours, a third coating of butyl latex was applied, again to a wet-film thickness of 15 mils. Finally, after these coats had cured, half the roof was painted with hypalon to a thickness of 12 mils.

Roof No. 10

Two plies of asphalt-saturated rag felts were first nailed to the deck; no adhesive was used. Hot asphalt was then employed to adhere two additional plies to these nailed felts. The cant strip was covered with rag felt; at three edges of the roof, metal flashing was installed, and rag felt was mopped over this flashing. To complete the system, a top pour coat of asphalt was spread over the entire roof and gravel was spread onto this hot asphalt.

Roof No. 11

The material for this roof was rolled out and cut, so that two equal lengths would cover the deck with a 4-in. overlap; the material was then allowed to relax. Before applying this membrane, the joints of the plywood deck were bridged with a self-adhering, green, fabric tape, and the two lengths of roof material were put into place along the deck centre-line. One-half of one length was carefully rolled onto itself, and the recommended adhesive was rolled and brushed onto the exposed underside of the roof material and the corresponding plywood deck. After the adhesive was considered dry to touch, the material was rolled back into place, and the second half of the membrane was adhered following the same procedure. The second length of material was applied in a similar fashion with a 4-in. overlap over the first sheet; the entire roof was rolled and pressed in place. All edges were adhered with the same cement and in some cases tacked with nails to ensure a complete bond.

### Roof No. 12

This roof was installed on site, over a plywood deck during a sunny, windy day with the temperature at 65°F. Four sheets were cut to $15\frac{1}{2}$-ft lengths, which allowed three lap joints of 2-in. each and enough material at all ends to permit a form-fit around and under the edges. Guide lines were scribed lengthwise on the deck to ensure the correct placement of the material, and a continuous coating of special field adhesive was applied over the deck. While it was still wet, the 4 lengths of sheet roofing were embedded into it. A special lap cement secured the lap-joints, and the field adhesive glued the sheet material to the fascia board. A wood trim was nailed over the roofing material into the fascia board, and the excess roofing was trimmed.

## VISUAL EXAMINATION OF ROOFS

The first 11 experimental roof decks were combined to form a continuous roof which was secured approximately 6 ft off the ground. A wooden platform was constructed along one entire length which allowed shoulder height observation and photographs at periodic intervals.

With one exception, (No. 12), none of the roofs tested enclosed a heated space, and therefore the exposure is not considered to be as severe as that encountered in normal usage. The decks were, however, of a lightweight material which would tend to permit greater deflections than normal. In addition, these roof surfaces were initially subjected to considerable foot traffic from interested visitors.

The following visual observations describe the performance of the first 10 roof systems over a 5-year exposure period. Roofs Nos. 11 and 12, also described here, were installed 3 years later than the previous systems, and consequently their performance results are based on only 2 years of exposure.

### Roof No. 1

After 6 to 8 months exposure, small hairline cracks appeared over the entire surface about 2 in. apart. This random surface cracking was very pronounced after 2 years and there was slight damage along the front edge. After 5 year's exposure, this effect had increased so that the distance between each hairline crack was reduced from $\frac{1}{2}$ in. to $\frac{1}{4}$ in.; this cracking did not, however, appear to affect the polyisobutylene sheet. Some small portions of the topcoat were beginning to peel and the adhesive at the centre overlap had failed for a distance of approximately 10 in. to a width of $\frac{1}{4}$ in. Some blistering along the cant strip, and some slight chalking was observed, but there appeared to be only slight dirt retention.

Roof No. 2

Slight dulling of the aluminum-foil surface had taken place by the end of the first 12 months of exposure. After 2 years, the glass reinforcement at the lap was beginning to show; 3 months later there was a slight loss of bond in two locations on the lap joints, 4 ft apart. The final observation after 5 years of exposure showed some loss of adhesion $\frac{1}{2}$ in. inward on the overlap section covering the cant strip, in addition to 3 large ridges running perpendicular to the length of the deck. There were also 8 ridges 1-in. wide running across the width. Surface dulling was moderate and dirt retention moderately high in an area where water ponding took place.

Roof No. 3

After 10 months, the centre-lap joint began to lift slightly. This loss of bond was more noticeable after 2 years when the lap had lifted approximately 1/8 in. along the length of the lap. By then, there was also a lightening of colour and a small crack at the front of the cant. After 5 years, the loss of bond along the lap joint had increased to a maximum depth of 1 in., chalking was of medium intensity, water staining along the low edge was severe, two nails from the deck had lifted but had not penetrated the butyl sheet, and the overlap at one of the corners of the cant strip had lost its adhesion.

Roof No. 4

After 2 months, slight surface chalking was noticeable. At the end of 4 months, this effect was considered pronounced, and with 2 month's additional exposure, the chalking was washing over the edge of the roofing. After 2 years there was a loss of bond at the centre overlap and defects in the membrane were quite noticeable; chalking continued to be severe with large amounts of wash-off taking place, and a pattern of surface cracks had appeared. After

5 years, adhesive failure had begun along the centre overlap to a depth of approximately $\frac{1}{2}$ in., and surface defects in the form of $\frac{1}{2}$-in. long, oblong craters were spread over the whole surface although not penetrating the butyl sheet. A long crack along the front edge had resulted in the separation of the deck and edge covering. A deep crack had also developed along the top edge of the cant strip.

As noted, it became evident in the early stages of this exposure program that a major problem with the material was its severe chalking characteristics. The manufacturers submitted a second sample that had been chemically modified in an attempt to improve the material's resistance to chalking; in a few months, however, it too had chalked heavily.

Roof No. 5

Some minor cracking had developed in this coating immediately following its application and before exposure, but it had become no worse after 1 year's exposure. After 2 years, the flashing tape split in two places and other small splits appeared on the cant strip, the surface was dirty, chalking had begun and a few of the nail heads under the roof material were showing through. Six months later, the splitting which ran along the long dimension of the deck, had become pronounced and the membrane had opened at an edge (due to splitting) which allowed water to enter the deck. After 5 years, several cracks had developed along the cant strip 1 to 2 in. in length. These cracks allowed water entry, and caused loss of adhesion along the length of the cant strip. Several nails pushed through the membrane with resulting rust stains accentuating the dirt accumulation on the low side. The topcoat had cracked to moderate severity.

Roof No. 6

After 2 months, the sheet-applied system showed high dirt retention and a few small blisters whereas the liquid-applied material did not appear to have changed, but after an additional 6 months exposure, both systems were high in dirt retention. In 12 months time this effect was rated as severe. After 2 years, some loss of adhesion was found at the areas adjacent to the portions that had suffered mechanical ruptures. After 5 years, the sheet-applied portion of this roof showed signs of heavy erosion. The entire roof was very dirty and adhesion was poor near the damaged areas.

Roof No. 7

After 1 year, slight chalking of the surface was noted. After $2\frac{1}{2}$ year's exposure, some damage to the leading edge of the surface had occurred as a result of observers climbing onto the roof. No further changes had occurred at the end of the 5-year period.

Roof No. 8

After 2 months, there was slight shrinkage of the tape at the joint. Except for the above-mentioned effect there was no change after $2\frac{1}{2}$ years of exposure. After 5 years, there was a slight loss of gloss, a few punctures in the topcoat (which appeared to have been the result of mechanical damage) and a moderate loss of adhesion at the edges of the centre tape.

Roof No. 9

After 2 months, that portion not covered with hypalon showed slight dirt retention. After 4 months, this dirt staining on the butyl-latex portion had become quite severe, and the glass scrim on the cant strip had pulled away from the cant. There was also some fracture of the butyl-latex glass-scrim membrane at the edge where it had received wear from traffic. After 2 years, cracks had developed on the cant strip. Three months later, a crack appeared over the joint in the substrate. The uncoated, butyl-latex portion of this test sample appeared quite porous, and a large number of holes were evident. After $2\frac{1}{2}$ years, it was observed that this porous uncoated area was allowing water penetration. After 5 years, water was getting into the deck through the cracked joint, several small crater-like depressions had appeared over most of the hypalon-coated area, and there was severe erosion of the uncoated butyl-latex portion.

Roof No. 10

After 2 months, some gravel blow-off had occurred, and in a few small areas of the roof, asphalt had bubbled through the gravel. After 2 year's exposure, this bubbling effect was no worse than slight. After 5 years, it was noted that there was some bubbling of bitumen along the cant strip and over a sizeable portion of the roof, notably over the joints in the deck.

Roof No. 11

After 2 years of exposure, this roof surface had become covered with black spots, approximately 1/8 in. in diameter, that appeared to be a form of mildew or fungus. There was moderate dirt retention and some dulling of the surface.

Roof No. 12

After two year's exposure, the white surface had become slightly dirty, and the lap joints showed just the slightest loss of adhesion.

DISCUSSION

A total of 12 roofing systems were exposed to outside conditions for 2 or 5 years, 10 of the samples receiving the full 5-year exposure. This program was considered to be of sufficient duration to offer some indication of the service life that can be expected of the materials if installed in the conventional manner, i.e., with the membrane unprotected by insulation. It should be mentioned that many of the samples investigated were experimental, and that some are no longer available at least in the form in which they were exposed.

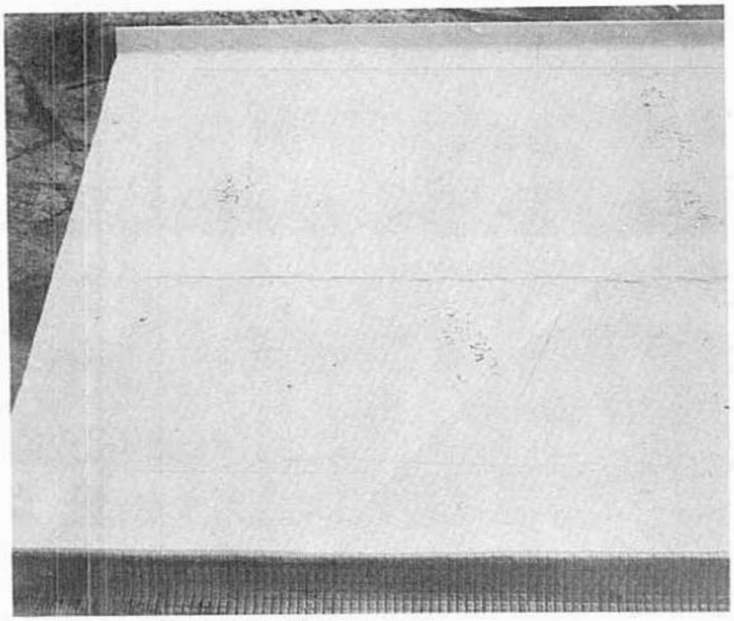
The performance of some of the new roofing systems might suggest that their employment be specified only with great caution. It was noted, however, that the principal failings in many of these systems were the adhesives used at the overlaps and flashings, and the thin liquid-applied top-coatings which underwent relatively rapid failure. While fully cognizant of their failings, one might still employ these materials because of their distinct advantages: the omission of gravel from the membrane surface which simplifies inspection and maintenance of the roof, and the fact that several of these materials are acceptable bases for reflective and decorative coatings. Furthermore, the ease of application of some of the liquid-applied roofing systems make them especially suitable for membranes for irregularly shaped surfaces. Finally, the light weight of these new roof coatings could offer appreciable relief to a building's structural requirements.

Some degredation of the surface of the materials, such as that noted in the white butyl sample, could be tolerated if the wash-off were not allowed to disfigure the building's facade. The polyisobutylene system suffered marked cracking of its reflective, acrylic topcoat, but the sheet material itself appeared to be in excellent condition. If this system, then, were installed in an easily accessible area, periodic recoating would probably ensure satisfactory performance for many years.

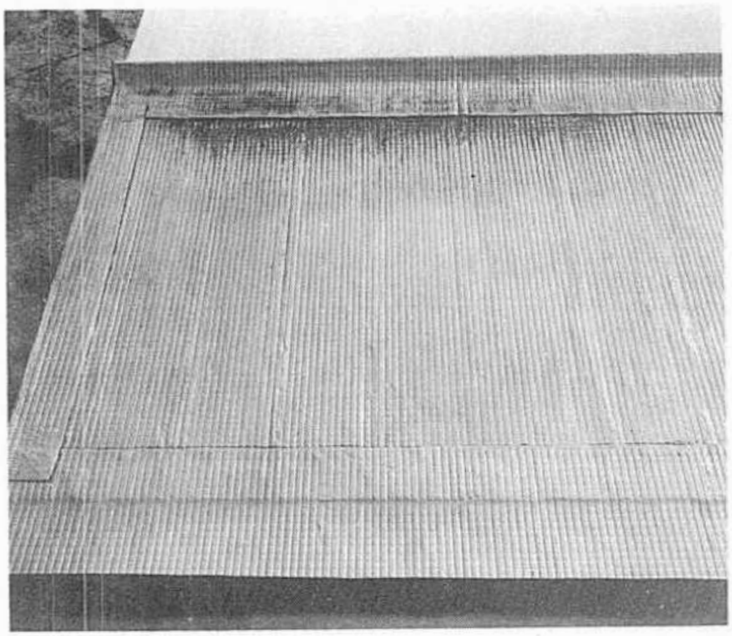
It should also be pointed out that the use of these materials does not eliminate factors such as building movement, trapped moisture, and poor workmanship, which can cause failure in any roof system if they have not been taken into account by the designer.

## CONCLUSION

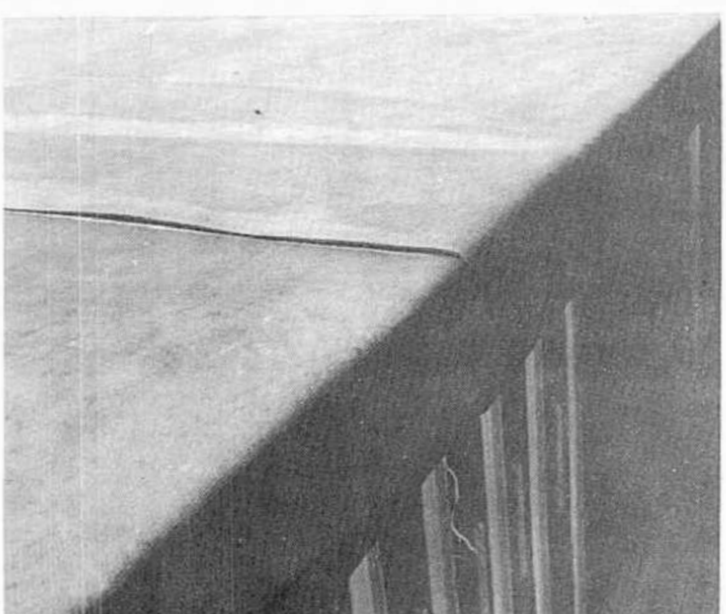
The use of some of these new roofing membranes could be restricted to satisfying certain specific requirements; this exposure program has shown, however, that of the 10 systems exposed for the 5-year period, 4 are performing in a superior manner and might, therefore, receive wide application. These are the foil-surfaced bitumen sheet (No. 2), the cold-process asphalt roofing (No. 7), the polyvinyl fluoride-asbestos sheet (No. 8), and the hot asphalt built-up roof (No. 10). Both of the roof systems that have been exposed for the 2-year period seem to be performing well and as yet there is no evidence to suggest premature failure.



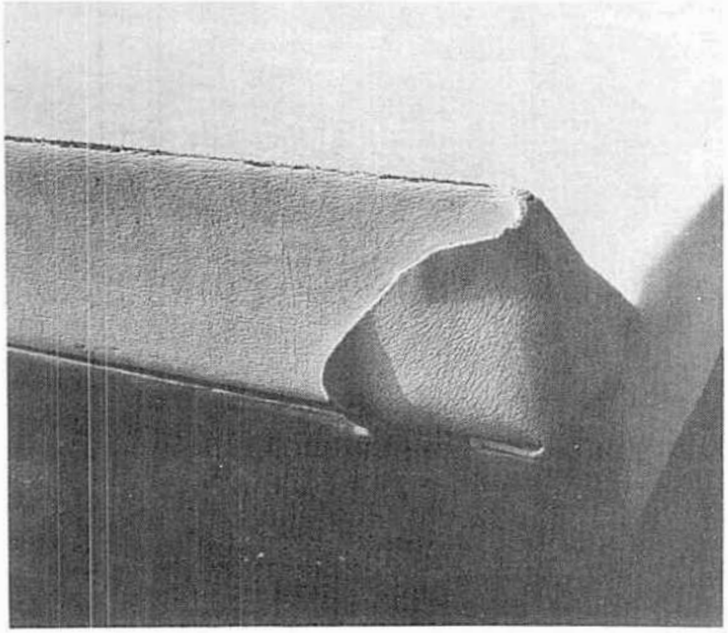
ROOF NO. 1 - 5 years exposure: severe hairline cracking.



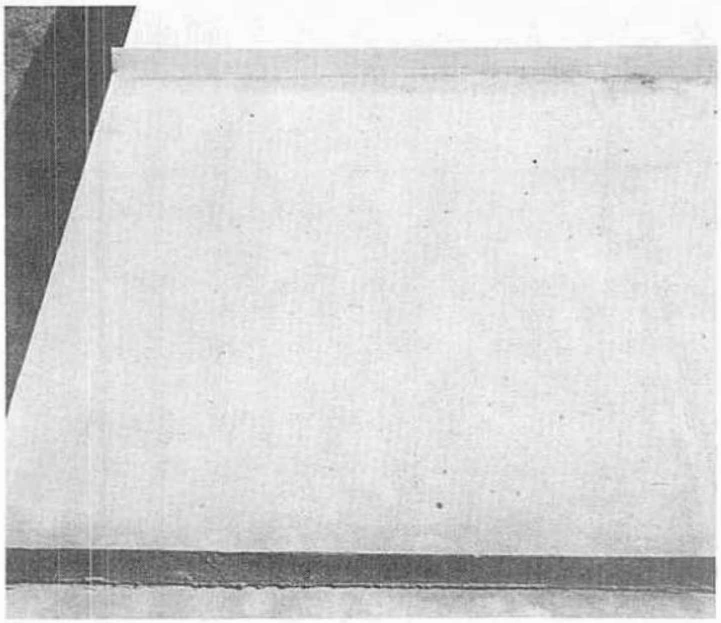
ROOF NO. 2 - 5 years exposure: slight dulling and some ridging.



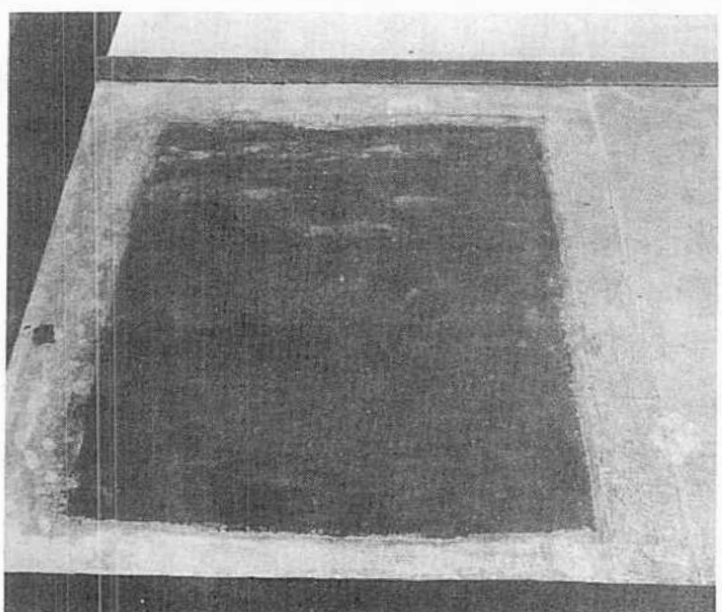
ROOF NO. 3 - 5 years exposure: colour change, chalking and adhesive failure.



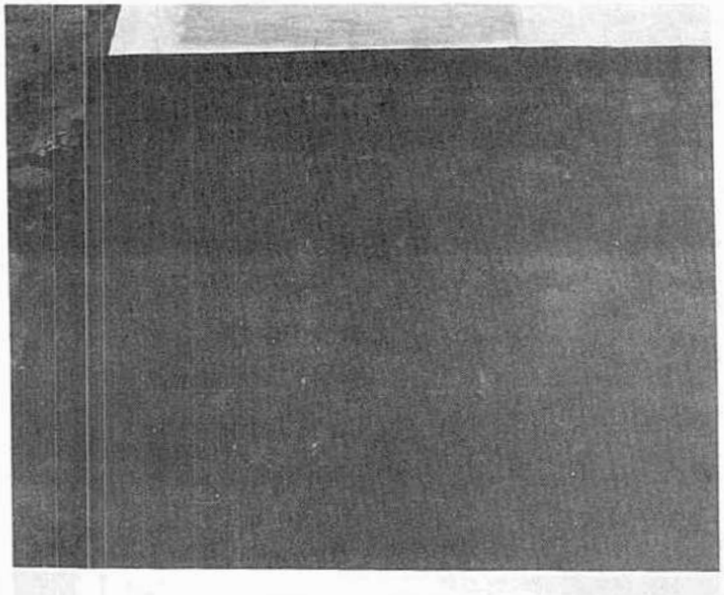
ROOF NO. 4 - 5 years exposure: severe chalking, splitting and checking.



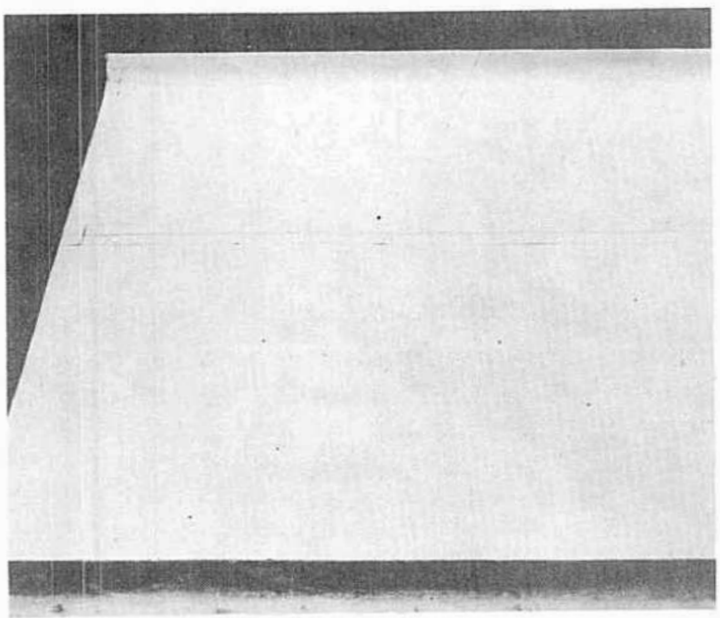
ROOF NO. 5 - 5 years exposure: cracking and splitting.



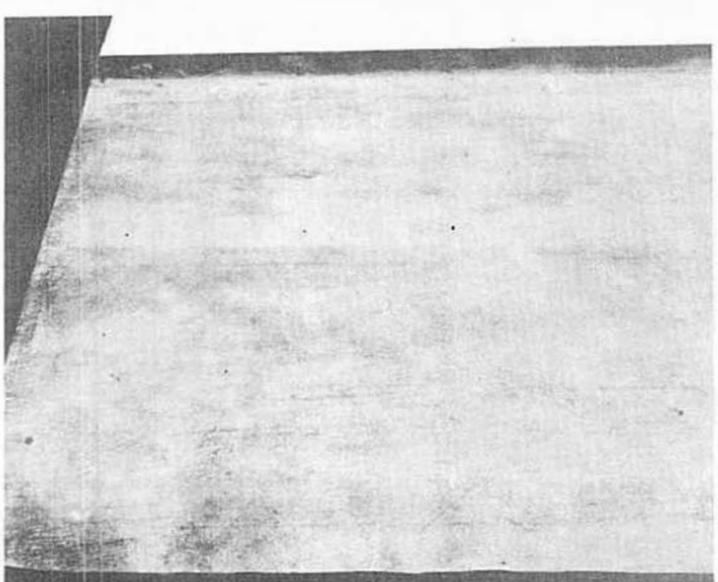
ROOF NO. 6 - 5 years exposure: heavy dirt deposition and surface erosion.



ROOF NO. 7 - 5 years exposure: slight chalking.



ROOF NO. 8 - 5 years exposure: loss of adhesion at taped joint.



ROOF NO. 9 - 5 years exposure: membrane cracked, severe surface erosion, and heavy dirt retention.