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INVESTIGATIONS OF MOISTURE PROBLEMS IN BUILT - UP BITUMINOUS ROOFS

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COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION

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I. INTRODUCTION

Problems associated with built-up bituminous roofs in Australia were first investigated by the Division of Building Research about ten years ago. These roofing membranes were not giving reliable service and a survey of roofs throughout the country revealed three main reasons for this. Specifications to define the correct materials to use were not in existence; no details were available of how to design the membrane to form an integral waterproofing system over the whole building, including movement joints, parapets and protrusions; and finally, the need to protect the waterproofing membrane with a weathering surface maintained in good order was not appreciated.

Work commenced at the Division by constructing experimental membranes at sites in the vicinity of Melbourne and closely observing their performance. Considerable knowledge was obtained from these investigations and formed the basis of a general study which was prepared to give design data to assist the architect and builder (Ballantyne and Martin 1960). Laboratory examinations of roofing fabrics and bitumens* supplemented the work and as a result the Division was in a position to assist in the drawing up of specifications for bituminous roofing felts by the Standards Association of Australia (1959, 1960). In these specifications both composition and performance tests were included, and in connection with development of the performance tests the deterioration of bituminous membranes that have no additional surface protection has been studied more closely. Such membranes are used in light low cost construction to roof dwellings, schools, libraries, and the like, where the flat roof allows complex plans to be easily roofed or where a flat roof is required as an architectural feature. The most common faults with these roofs are associated with moisture ingress. This paper summarizes recent work on bituminous roofing fabrics carried out at the Division and other basic data which contribute to an understanding of how the moisture problems develop and how they may be minimized without resorting to higher cost massive surface protection.

* The term bitumen is used in a general sense embracing coal tar pitches, petroleum or asphaltic bitumens and naturally occurring asphalts.

II. THE FAULTS

Within 12 months of exposure a membrane that consists of alternate layers of waterproofing bitumen and stabilizing bituminized fabric with only a coating of bitumen as a surfacing is likely to develop small bubbles in the coating, as shown in Figure 1. These may remain the same size for many years, or they may burst and leave holes through the coating. The membrane itself may also develop much larger bubbles commonly known as blisters; a particularly bad case of which is illustrated in Figure 2. After about 5 years without maintenance the top layer of fabric may shrink and distort or become extremely weak and rupture. This type of deterioration is illustrated in Figure 3.

One of the most important factors is the composition of the bituminized fabric. Both saturated and coated fabrics are used for constructing built-up roofs in Australia. The former are those produced by impregnating a raw fabric with a low softening point bitumen and squeezing out the excess so that the material retains a dry hairy surface. A coating of a high softening point bitumen applied to the saturated fabric converts it to a coated fabric, which is dusted to prevent sticking when the product is made up into rolls. The raw fabrics used are cellulosic felt, asbestos felt, woven hessian, or glass fibre random tissue, the latter differing from the others in that the fabric is saturated and coated with the harder bitumen in one operation.

III. SOME BASIC STUDIES

(a) Water absorption

The layer of bitumen providing the surface coating is usually 0.01 to 0.04 in. thick, and with one surface in contact with water will slowly absorb moisture at a continuously decreasing rate. The study of this process is difficult because absorption apparently ceases after about 100 days at normal temperature, when solution of the bitumen by water and volatilization of the bitumen (particularly coal tar pitches) counters the increase in weight due to water absorption. Under these circumstances various bitumens have been compared by the weight of water absorbed during an initial specific period per unit of exposed surface area. It has been found that numerous factors such as the type and hardness of the bitumen and the presence of salts and

fillers influence the rate of water absorption, but the effects are not important in relation to the observed faults since in all cases the rate of water absorption is extremely slow (of the order of 0.0001 lb/sq.ft./day maximum initial rate).

The absorption of water into bituminized fabrics has more important effects, particularly in the saturated cellulosic felts which absorb water about 500 times faster than the bitumens. The absorbed water causes an increase in the thickness of the organic fibres, and since the fibres are orientated more in the machine direction (length of roll) than in the cross direction, most swelling of the fabric takes place in the cross direction. Another factor inherent in raw felt manufacture adds to this effect. Part of the shrinkage in the raw felt while it is passing over the drying rollers is prevented by the tension that is applied in the machine direction. When the felt is subsequently rewetted this prestrained condition counterbalances some of the swelling in this direction so that again most of the movement takes place in the cross direction. The saturating bitumen does not prevent water absorption and subsequent swelling because the bitumen enters only 75 per cent. of the volume of voids in cellulosic felts and only 55 per cent. in asbestos felts (Brown 1960). The asbestos felts contain about 15 per cent. of organic fibres in order to give good felt formation and consequently these fibres will also swell when in contact with water, but the overall swelling of asbestos felts is much less. Glass fibre random tissue relies upon organic adhesives to provide inter-fibre bonding and moisture may slowly displace the adhesives from the raw tissue. However, bitumen impregnation of the very open tissue eliminates practically all voids and only a negligible amount of moisture is absorbed by glass fibre roofing material.

On drying out the cellulosic fibres shrink, but this does not take place uniformly and redried felts are thicker and permanently shrunk, particularly in the cross direction. The amount of permanent shrinkage varies with different felts and has been compared by subjecting them to four cycles of immersion in water and oven drying and measuring the change in the cross direction dimension from the initial wet to the final dry condition (Martin 1959). Some shrinkages of bitumen-saturated fabrics in this test are:

Cellulosic felt, poor quality	2.5 per cent.
Cellulosic felt, good quality	1.5 "
Hessian	1.5 "
Asbestos felt	0.2 "
Glass tissue (coated)	Nil

It has also been noted that the moisture absorbed by the bitumen-saturated felts releases inter-fibre bonds and considerably reduces the tensile strength. On drying out some bonds do not reform, and in this way the tensile strength of roofing felts

deteriorates as a result of outdoor exposure (Martin 1961). A comparison of this behaviour for various bituminous saturated felts has been made by measuring the tensile strength of some fabrics after cycles of immersion in water at 77° F for 8 hr and oven drying at 130-140° F for 16 hr. Results obtained on 1 in. wide strips by testing at 1 in. per min. over a 3-in. gauge length are given in Table 1.

TABLE 1
TENSILE STRENGTHS OF SATURATED FELTS

Material		Mean Tensile Strength (lb)			
Fabric Type	Bitumen Saturant	Dry			Wet
		No Treatment	5 Cycles	15 Cycles	$\frac{1}{2}$ Cycle
Glass	Blown asphaltic	23	26	27.5	24
Asbestos	Residual asphaltic	24	20	17.5	12
Cellulosic	Residual asphaltic	26	22	20	9
Cellulosic (English)	Coal tar	45	37	22.5	12
Hessian	Residual asphaltic	9.2	9.5	9.0	6.5

These results indicate a marked superiority of glass fibre fabrics, but this applies only when moisture has penetrated to the fabric fibres themselves. When commercially available coated felts are examined it is found that considerable moisture is absorbed, the water absorption varying between different samples of roofing but often being one-fifth of the amount absorbed by the saturated felts. The moisture is stored in the saturated felt portion of the fabric, and the high water absorptions are due either to a lack of integrity of the coatings or to a high rate of diffusion through the coatings.

(b) Moisture permeability

Moisture transfer through intact bitumen coatings is a well understood process which may be described by mathematical formulae involving the concept of a moisture permeability constant (Martin 1958). However, these formulae apply only to what is known as the steady state condition, which takes of the order of 10 days to become established across 0.02 in. thick layers of roofing grade bitumens kept at a constant room temperature and a particular relative humidity. Bitumens of

similar hardness have similar moisture permeability constants, which are extremely low. A blown asphaltic bitumen will increase in permeance about five times over the temperature range 40° to 140°F, and although coal tar pitches and residual asphaltic bitumens would increase more than this the effect is not very important when the low orders of permeance are considered.

Bituminous coatings to roofing felts usually contain inorganic fillers which have been found to reduce the permeance of intact coatings, more moisture being stored in a filled coating but less penetrating it. The permeance of commercial coated felts should be similar to that of an intact bitumen coating of similar thickness to the coating on the felt. However, it is found that the coated felts are many times more permeable than this, as is shown by the results given in Table 2.

TABLE 2

TYPICAL RESULTS FOR MOISTURE PERMEANCE

Sample	Thickness (in.)	Permeance (perms)*			
		40°F	70°F	100°F	120°F
Asbestos felt Saturated	0.026	4.0	4.0	4.6	4.0
Cellulosic felt. Saturated	0.046	10.7	12.1	10.2	10.5
Asbestos felt Coated	0.063	0.27	0.12	0.14	0.11
Cellulosic felt. Coated	0.067	0.23	0.15	0.15	0.17
Glass Fibre Roofing	0.05	0.06	0.04	0.07	0.08
Laboratory made Coating	0.020	0.003	0.005	0.009	0.014

* 1 perm is 1 gr of water transferred through 1 sq.ft. of material in 1 hr under a vapour pressure gradient equal to a head of 1 in. of mercury.

The coated felts behave similarly to the saturated felts in that they are little influenced by temperature except for an increase of permeance at the lowest temperature. It is concluded from these results that coatings to commercially available felts contain microcracks which become larger at lower temperatures as a result of thermal contraction of the coating (the cubical coefficient of thermal expansion for bitumen is about $3 \times 10^{-4}/^{\circ}\text{F}$, which is ten times greater than for most metals). Migration of water through the holes is obviously more important than diffusion of moisture through the intact coating.

If three or more layers of coated felt (or saturated fabric) are completely bonded together with layers of bitumen to form a membrane, the transfer of moisture through the membrane takes years to reach the steady state. Attempts to measure the permeance of these membranes have been unsuccessful, but it has been established that with liquid water on one side and an atmosphere of low relative humidity on the other no moisture transfer takes place during the first 50 days. With regard to the problems under discussion the membranes as a whole may be considered impermeable. Some moisture will enter the exposed surface of a newly constructed roofing membrane and may penetrate into the top layer of reinforcing fabric, but moisture will not pass through the membrane, unless it has ruptured.

(c) Pressures developed by confined water vapour and air

Built-up bituminous membranes may contain air trapped in two ways: firstly, the roofing fabric may contain voids, and secondly, voids will occur where imperfect adhesion occurs between the bonding bitumen and the deck or the roofing fabric. It is of interest to note how little moisture is required to saturate air voids under temperatures comparable to those existing in roof membranes, viz:

0.00041 lb/ft ³	at 40 ^o F
0.00158 lb/ft ³	at 80 ^o F
0.00492 lb/ft ³	at 120 ^o F
and 0.0129 lb/ft ³	at 150 ^o F

Considerable increases of pressure will develop within these voids if they are restricted to a constant volume and simultaneously heated. Table 3 shows the pressure increases due to heating a confined void initially in equilibrium with external air pressure at 70 F.

TABLE 3

PRESSURE INCREASES IN VOIDS

Content of Voids	Pressure Increase for Temperature Reached (lb/sq.in.)		
	110°F	130°F	150°F
1. Dry air	1.1	1.6	2.2
2. Air and water vapour (saturated at 70°F)	1.1	1.6	2.2
3. Air, water vapour, and liquid water	2.0	3.4	5.5

The presence of sufficient water to maintain the relative humidity of the void at 100 per cent. over the temperature range involved causes the maximum pressures to be developed. A roof reaches much higher temperatures than the surrounding air and it has been shown that daily temperature cycles of 70 F to 150 F may occur many times during exposures in Australia, unless precautions are taken to reduce membrane temperatures by applying reflective surfacings (Ballantyne and Spencer 1957).

Interesting findings have been made concerning the voids in the roofing felts. Fresh samples of coated cellulosic and asbestos felts direct from the manufacturers have been found to contain about 1.3 and 0.6 per cent. of moisture respectively (Brown 1960). This moisture is derived from the inherent hygroscopicity of the raw felt, and this property has been investigated. The moisture content of typical raw felts has been found to depend upon the relative humidity and temperature of the air surrounding the felt, as shown in Figure 4. It is important to note that the moisture content decreases with increase of temperature, indicating that moisture held by the felt at ordinary temperatures becomes free at higher temperatures. The moisture content left in coated felts after processing is 8.8 per cent. of the content of raw cellulosic felt and 2.8 per cent. of the raw asbestos felt. According to the results in Figure 4 this means a relative humidity in the voids of the coated felts of a little more than 50 per cent. at 70 F, but more than enough free moisture to saturate the voids at temperatures exceeding 100 F. It follows that the maximum pressures develop in these voids when the coated felts are exposed to solar radiation.

(d) Thermoplasticity of bitumens

Each of the faults to be discussed involves a deformation which overcomes the viscous resistance of either the bonding or coating bitumen. This resistance to deformation or viscosity depends upon the grade or hardness of the bitumen and varies most markedly with temperature, as shown in Table 4.

TABLE 4
VISCOSITIES OF BITUMENS

Type	Softening point (°F)	Hardness (penetration at 77°F) (0.01 cm)	Viscosity (poise) at		
			32°F	77°F	150°F
Blown asphaltic	215	15	1×10^9	1×10^8	1×10^6
Blown asphaltic	185	30	2×10^8	2×10^7	1×10^5
Residual asphaltic	145	25	1×10^9	2×10^7	1×10^4
Residual asphaltic	135	45	5×10^8	5×10^6	5×10^3
Coal tar pitch	135	15	8×10^9	2×10^7	4×10^3

The bitumens approach similar viscosities at very low temperatures but at normal and higher temperatures the coal tar pitches and residual asphaltic decrease in viscosity much more than the blown asphaltic bitumens.

IV. FAULT MECHANISMS

(a) Small bubbles

The small bubbles are most commonly found on bitumen coatings over cellulosic or asbestos base felts, but rarely over glass fibre roofing fabrics, which absorb a negligible amount of moisture. The base of the deformation is at the interface between the coating

and the saturated fabric, and it is believed that the deformation is due to the expansion of the moisture-saturated air voids in the saturated felt portion. As previously discussed, rain water may also penetrate microcracks in factory-applied coatings and enter the felt. This usually takes place at comparatively low temperatures, the moisture migrates within the felt while the pressure in the voids remains approximately in equilibrium with external air pressure. When the sun heats the coated felts temperatures of more than 100 F are reached in a few hours, and the pressure in voids that do not gain relief by venting through microholes increases (as in case 3, Table 3). Simultaneously the coating softens (as shown in Table 4) and eventually deformation may take place at higher temperatures. Upon cooling, the viscosity of the coating increases and offers more resistance to any suction that develops as the vapour pressure of the void decreases, so that any deformation is likely to be permanent. Cycles of heating and cooling may thus cause the deformation to increase until the increase in volume of the voids sufficiently compensates for the increase of pressure, or until the coating bursts. Another factor is that the coating progressively hardens as a result of weathering and this retards progressive growth of the bubble.

(b) Shrinkage and puckering

Shrinkage and puckering of the top layers of roofing fabrics are now easily explained as being the dimensional movement induced in the fabric by cycles of wetting and drying. After prolonged exposure, holes in the surface coating become more numerous as the pustules break and cracks develop in the age-hardened coatings. Water absorption by the fabric and also drying out become more rapid and the moisture content of the fabric follows cycles of wet and dry weather. The usual conditions of cool wet and warm dry weather mean that the swelling of the fabric tends to be restrained by the more viscous bitumen but the shrinkage is permitted by the less viscous bitumen; the net result is shrinkage which eventually distorts and puckers the fabric. The shrinkage of saturated fabrics by this mechanism may be as much as 20 per cent (Martin 1959), which is about ten times that of the saturated fabrics loose laid (not bonded with bitumen).

(c) Blistering

The mechanism of blistering is similar to that of bubble formation except that the voids are due to imperfect adhesion of the bonding bitumen to the deck or to the bituminized fabric. The presence of moisture in the void usually results from the use of inherently wet materials (e.g. concrete decks) or it may be from rain which fell during construction. Concrete provides a particular hazard because the surface may look dry even though little of the free water has been removed. This is because the drying out depends upon two processes,

the diffusion of moisture from the interior to the surface and the evaporation of the moisture from the surface, and of these the first process is very much slower than the second. Attempts to bond bitumen to a damp surface give areas of no adhesion and provide air voids saturated with water vapour. Water may also slowly displace the bonding bitumen from an adhering surface and enlarge the void. Moisture has been observed to gain access at a faulty membrane turn up and to migrate in a channel between layers of fabric to an area of poor adhesion, where a large blister has formed. Poor adhesion may also be caused by misses in the bonding bitumen or areas where the bonding bitumen has not wetted the surface. The talc or mica dusting on coated felts makes it more difficult to wet the fabric with the bonding bitumen.

V. HOW TO REDUCE THE INCIDENCE OF FAULTS

It is now possible to suggest ways to improve the performance of roof membranes without using costly massive surface-protecting layers.

Surface coating bubbles will be minimized if a fabric which absorbs a negligible amount of moisture (glass fibre based roofing) is used as the top layer of the membrane. If other fabrics (coated felts, saturated asbestos felt or saturated hessian) are used the resistance to deformation of the final surface coating should be as high as possible. This can be achieved by applying a hard grade of bitumen in the form of a paint to the top layer of fabric after it has been laid. Finally, the peak temperatures of the membrane should be reduced as much as possible to minimize any build up of pressure. This means that the membrane must have a finishing coat of light coloured paint which has a low film strength and will not damage the underlying bitumen. Aluminium leafing paints with bitumen vehicle and some FVA emulsions have been found suitable but are not particularly durable themselves. However, this is not a disadvantage since the need to repaint after about 2 years provides an excellent opportunity to inspect the condition of the membrane and to repair any minor faults. At this stage a more durable higher film strength paint can be applied (e.g. a varnish-based aluminium leafing paint). After this, further treatment will be necessary at only 5 to 10-year intervals.

The same procedures will reduce shrinkage and puckering; a top layer of glass fibre fabric because it shows no moisture movement, an in-situ applied surface coating of hard bitumen kept in good condition to reduce the rate of moisture ingress, and a reflective surface treatment to lower peak temperatures and minimize the changes in viscosity of the bitumen bonding the fabric.

The ways of improving blistering are not as straightforward because much depends upon the circumstances under which roofing operations are carried out, and on the workmanship. Blistering can be reduced by excluding the voids and by applying a reflective surfacing to the membrane. Concerning the practical problem of excluding voids during construction of the membrane the most troublesome enemy is moisture. Bituminous roofing should be constructed only during dry weather and the surfaces concerned should be as dry as possible. In inherently damp decks the simplest way to overcome sub-membrane blistering is to lay the membrane loose with sufficient fixing to resist wind suctions. Any pressure build-up is then distributed over a large area of deck and some relief may be obtained by providing vents from the deck to outside air, either at skirtings or by means of small stacks in the centre of the roof. If rain wets bituminized felts during laying operations the only way to minimize intermembrane blistering is to discontinue work until the surfaces are dry. Sometimes roofing must continue during suspect weather and if this is likely it is advisable to use the fabrics that absorb the least amount of moisture.

Other factors that militate against good adhesion are the presence of loose dust on the surfaces to be bonded, the use of bitumen that is too cool and consequently too viscous to wet the surface properly, and attempts to bond to surfaces that are not flat with fabrics that do not have good pliability. Although proper attention to workmanship may overcome these difficulties the situation can be simplified by using fabrics that are not heavily dusted and which have good pliability characteristics. It should be noted that this latter requirement infers the use of the thinnest fabrics (Ballantyne and Martin 1958). The appropriate temperature for application of the bitumen can be predicted (Martin 1960) and should always be used; finally membrane details should be designed to be as simple as possible.

V. REFERENCES

- Ballantyne, E.R., and Martin, K.G. (1958).- Pliability testing of bituminous coated roofing felts. C.S.I.R.O. Aust.Div.Build.Res. Rep. 02.1-6.
- Ballantyne, E.R., and Martin, K.G. (1960).- Bituminous roofs. C.S.I.R.O. Aust. Div. Build. Res. Build. Study No. 1.
- Ballantyne, E.R., and Spencer, J.W. (1957).- Temperatures of bituminous roof membranes. Bull. Amer. Soc. Test. Mat. 1957 (223):69.

Brown, N.G. (1960).-- The analysis of bituminous felts. C.S.I.R.O. Aust. Div. Build. Res. Rep. 02.4-8.

Martin, K.G. (1958).-- The addition of inorganic fillers to bituminous coatings for roofing. 2. Moisture permeability of bituminous coatings and roofing felts. C.S.I.R.O. Aust. Div. Build. Res. Rep. 02.5-6.

Martin, K.G. (1959).-- Changes in bituminous roofing felts associated with changes in moisture content. C.S.I.R.O. Aust. Div. Build. Res. Tech. Pap. No.8.

Martin, K.G. (1960).-- Bitumens for built up roofs. 1. Specification tests. C.S.I.R.O. Aust. Div. Build. Res. Rep. 02.5-8.

Martin, K.G. (1961).-- Deterioration of bituminous roofing fabrics. C.S.I.R.O. Aust. Div. Build. Res. Tech. Pap. No. 11.

Standards Association of Australia (1959).-- Specifications for Bituminous Felt Roofings:

A.S. No. 98 Type 1(a) saturated organic fibre felts; A.S. No. 99 Type 1(c) coated organic fibre felts.

Standards Association of Australia (1960).-- Specifications for Bituminous Felt Roofings:

A.S. No. 120 Type 2(a) saturated asbestos fibre felts; A.S. No. 121 Type 2(b) coated asbestos fibre felts.

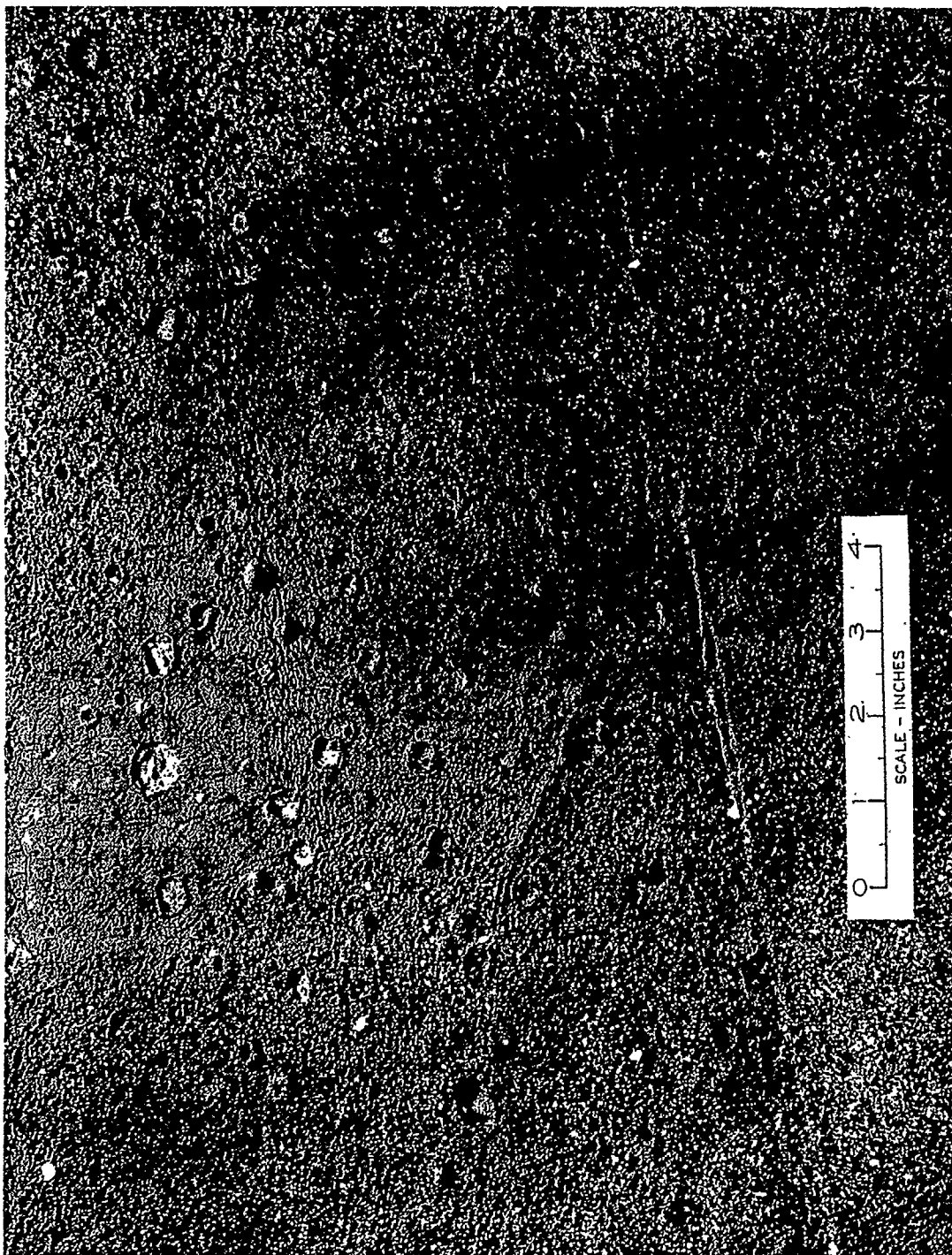


FIG. 1 - SURFACE BUBBLES ON AN AGED BITUMEN COATING

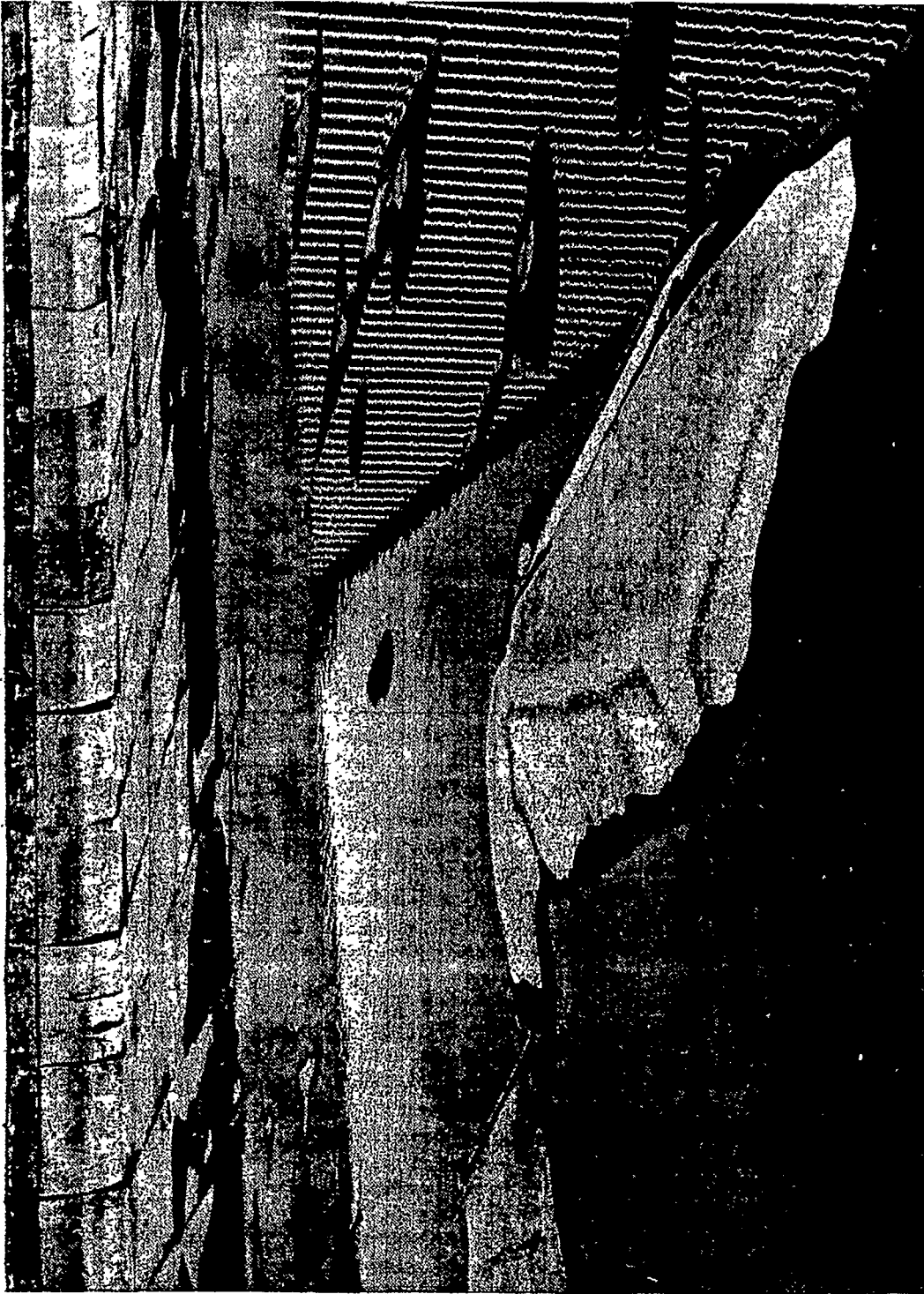
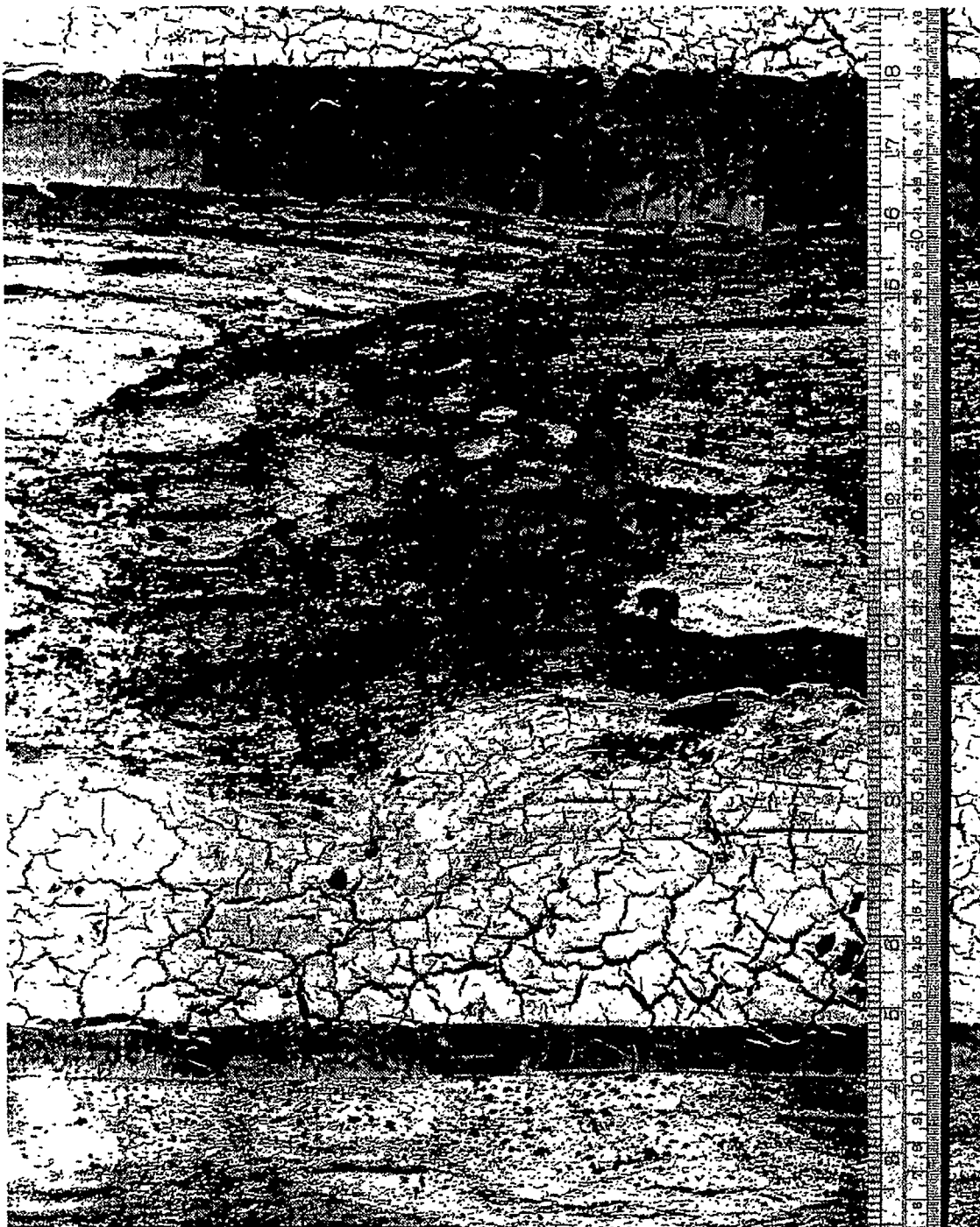


FIG. 2 - BAD BLISTERING IN A FLAT ROOF MEMBRANE



**FIG. 3 - CROSS DIRECTION SHRINKAGE AND DETERIORATION OF
CELLULOSIC BASED ROOFING FELT**

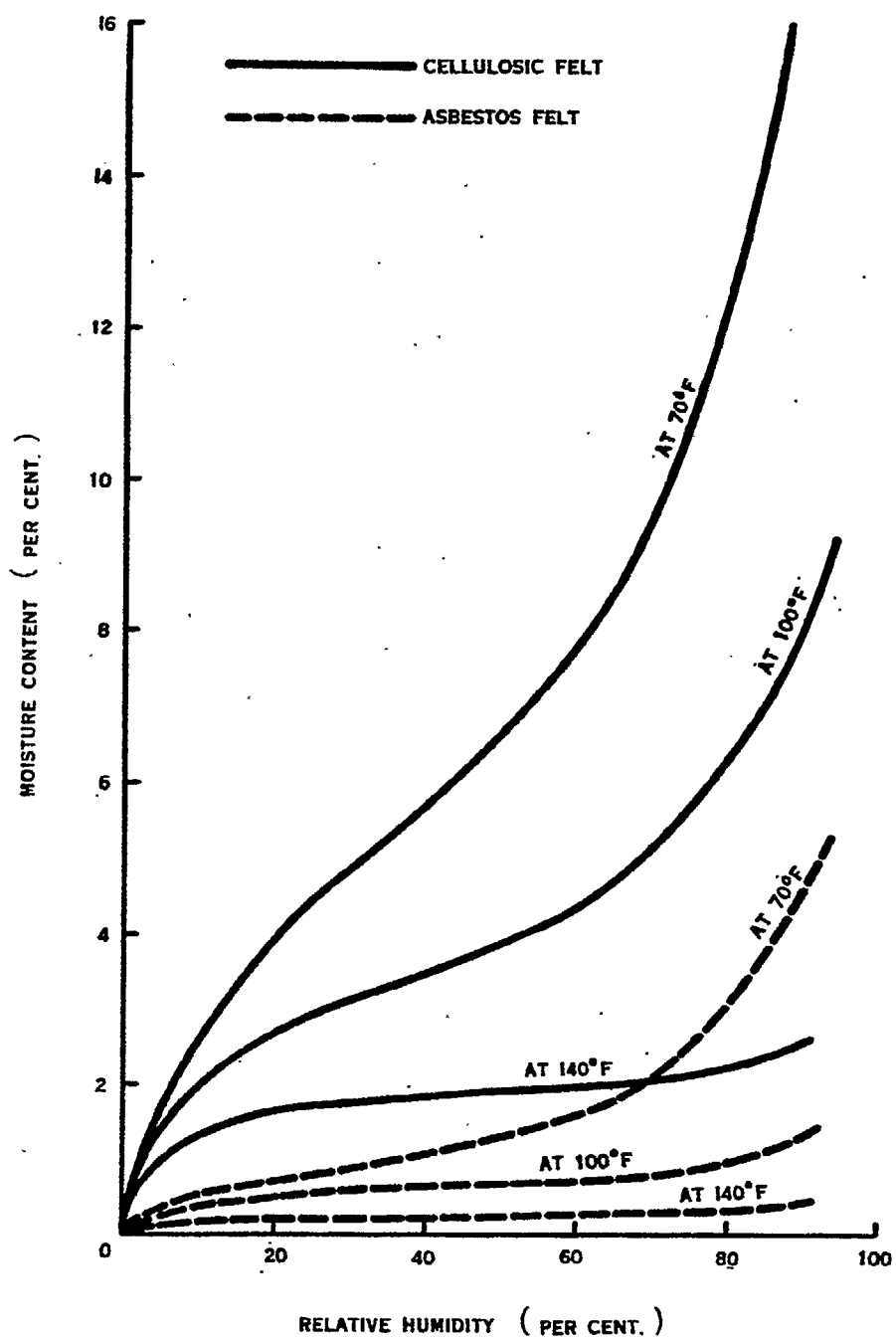


FIG.4 - THE HYGROSCOPICITY OF RAW ROOFING FELTS
(MOISTURE ADSORPTION ISOTHERMS)