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EFFECTS OF MOISTURE AND FREEZE-THAW CYCLES ON THE STRENGTH OF BITUMINOUS BUILT-UP ROOFING MEMBRANES

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ABSTRACT

The water uptake of an asphalt based built-up roofing membrane subjected to immersion and to a thermal-moisture gradient was measured. A 20-year-old coal tar pitch membrane removed from a roof was also exposed to the moisture gradient. The effect of water immersion and subsequent freeze-thaw cycling on the tensile properties of the asphalt membrane was determined.

In preliminary work, an apparatus was developed to produce a large sheet of multi-ply membrane with uniformly thick bonding coats. Improvements were made in preparing dog-bone specimens for tensile testing by reducing edge damage and eliminating slippage at the jaws.

INTRODUCTION

Some 15 to 20% of built-up roofing (BUR) membranes in colder climates fail prematurely: by splitting, ridging, blistering, etc., according to one source. Despite many investigations of these failures, much controversy remains concerning the precise causes.

It has long been recognized that moisture is associated with roofing failures; many researchers have studied the incidence and the source of water in roofs.[2,3,4] The changes caused by moisture and temperature in the dimensions of BUR[5] and felt reinforcing[6] have also been investigated. Despite recommendations on how to minimize problems in BUR construction caused by water,[7,8] failures continue to occur.

Attention is now being focused on studies of the mechanical properties of tensile strength, elongation and modulus of elasticity in the search for ways to prevent failure. It has recently been proposed[9] that some of these and other related properties—e.g. flexural strength—be used to evaluate BUR membranes. Because of the wide range in temperatures to which roofs are exposed, the effect of temperature on tensile properties has also been examined.[10,11] But in all this work, the effect of moisture on the mechanical properties seems to have received little attention.

The work reported here is part of a study to combine the two approaches in an attempt to understand the reasons for BUR failures. In an earlier paper,[12] it was shown that asphalt-saturated organic felt absorbs about 60% water and that strength was reduced to 16% of the original by water immersion and to 80% by just one cycle of wetting and drying. This paper reports the results of similar measurements made on BUR composites. Because concurrent field studies showed that membranes can freeze in winter,[13] the effect of several freeze-thaw cycles is also examined. A new device for preparing reproducible BUR membranes is also described.

CONCLUSIONS

Our research reaffirms the vital importance of positive drainage for conventional BUR systems and for thorough coating of each felt ply in a Protected Membrane Roof, to prevent water from penetrating into an organic felt where it causes a drastic reduction in tensile strength. ASTM asphalt-saturated organic felt membrane specimens (with exposed, unsealed organic felt edges) gained nearly 9% weight after immersion in water for 110 days and lost 81% of its dry tensile strength. The test specimens' behavior indicates what can happen when there is a break in the bitumen coating, which can expose the felt to moisture over long intervals.

Though freeze-thaw cycles do not drastically reduce the strength of an already seriously weakened, water-saturated organic felt membrane, they might be more damaging at intermediate levels of water absorption. (Freeze-thaw cycles cut membrane strength of immersed samples from 19% to 14% of dry strength for one cycle, to 11% for 10 cycles.)

SAMPLE PREPARATION AND APPARATUS

Laboratory Preparation of Bituminous BUR Membrane

The conventional hot press method of preparing built-up roofing membrane, as developed by P. M. Jones,[11] is very useful when a limited number of dog-bone samples in accordance with ASTM D2523 have to be prepared. If many uniform samples are required, a method for producing a relatively large specimen of bituminous BUR membrane was needed. For this purpose, a semi-automatic apparatus was developed to produce a uniform thickness of bonding or flooding asphalt. It has also been used successfully for one-ply monolithic hot-or-cold applied roofing membrane.

The apparatus consists of a 3-ft. by 4-ft. by ½-in. (91.5 cm by 122.0 cm by 1.27 cm) steel plate (Figure 1) with two L-shaped steel bars mounted along the 4-ft. (122.0 cm) edges to serve as rails for the sliding adjustable screed. The plate is heated to 150°F (67°C) by three controlled electric hot plates installed underneath. The screed is a stainless steel blade fitted at each end with two bearings that allow it to roll over the steel plate when it is pushed by the wooden handles. Clearance between the blade and the drawing plate can be adjusted to between 0.005 and 1.000 in. to ± 0.001 in. (0.13 and 25.4 mm ± 0.003 mm). It is also electrically heated with a 500-watt strip heater attached to the other side of the head. Thus asphalt remains hot and fluid and a smooth and uniform surface can be produced during drawing.

In operating this apparatus, silicone-treated aluminum foil or wax release paper is attached to the steel plate with double-sided adhesive tape. The table is heated to 150 ± 5°F (66 ± 3°C) and the asphalt to 325 ± 10°F (163 ± 5°C). Hot asphalt is poured in a zig-zag pattern in front of the screed which is moved forward by another operator (Figure 2). The time to make one drawdown is about 45 seconds. The reinforcing ply is placed on the warm asphalt, the clearance of the blade adjusted and the next coat of asphalt applied in the same manner. The apparatus only needs to be cleaned after the final coat is poured.

Preparation of Specimens for Tensile Test

The "dog-bone" specimen of ASTM Recommended Practice D2523, Testing of Load-strain Properties of Roof Membranes, was modified (Figure 3, top) to allow use of an extensometer for measurement of true elongation at break. The total length of the dog-bone specimens was reduced from 10 to 9-1/4 in. (from 25.4 to 23.5 cm); the width of the pulling region was kept at 1.000 to 1.005 in. (25.4 to 25.5 mm).

Specimens were usually prepared from BUR membrane using the appropriate dies, but this requires the use of a hot press. Edges of the specimen can be damaged by this method and sometimes the specimen is bent during removal from the die. In this study, it was found more effective to use a sharp knife and a template thus eliminating edge damage that might cause variability in results.

Slippage of the dog-bone specimen in the grips of the tensile testing machine due to the asphalt's viscoelastic properties has been a problem. It was overcome by using end clamps made from galvanized sheet bent and drilled as indicated in Figure 3 (middle). Nailing with 13 one-inch (2.54 cm) finishing nails in two rows of 7 and 6 at each end of the specimen provided a firm grip. A pulling attachment to fit the jaws of a tensile test machine is shown in the bottom part of Figure 3.

Tensile Tester

Tensile tests were conducted on the usual type of testing machine, with the following instrument settings:

Crosshead speed:	0.02 in. (0.9 mm) per min
Load range:	20 - 50 kg
Temperature:	23 ± 2°C
Relative humidity:	50 ± 5%

Blister Box

During immersion, unsealed edges of the specimens allow water-free access to the organic felt. Although this may be representative of conditions at a break in the membrane, it does not provide information on the effect of water in contact with the surface of an undamaged membrane. To simulate the latter, specimens were subjected to a thermal-moisture gradient so that moisture would be absorbed through the face of the membrane. A blister box used for testing paints was modified by placing a cold plate on the specimen face opposite the warm side. Temperatures to which roofs might be exposed in the Canadian winter were selected to impose a realistic gradient across the membrane.

The blister box consists of a 2-by-2 by 1-ft. (61.0 by 61.0 by 30.5 cm) stainless steel bath set in a wooden cabinet. The top is covered with 3/4 in. (1.91 cm) thick acrylic plastic with 3-by-3 in. (7.62 by 7.62 cm) openings in which panels can be placed. The temperature of the water bath was thermostatically controlled at 122°F (50°C). To produce freezing temperatures on the other side of the membrane, a coolant composed of 90% n-propanol and

10% glycerol was circulated through a double-jacketed aluminum plate. The liquid was cooled to 5°F (−15°C) in an insulated copper cylinder; the temperature produced at the cold face of the BUR specimens as 18°F (−8°C).

The following types of bituminous material were used in this study:

Asphalt type 1 (new)	CSA Standard A123.7-1973
Coal-tar pitch (new)	CSA Standard A123.7-1973
Coal-tar pitch, top layer of 20-year old roof	obtained by solvent extraction
Coal-tar pitch, bottom layer of 20-year old roof	obtained by solvent extraction
Asphalt-saturated organic felt, 15-lb. type	CSA Standard A123.6-1953
4-ply BUR membrane, 20-year old coal-tar pitch	

EXPERIMENTAL

Water Immersion

Twelve dog-bone specimens from the one sample were placed in distilled water at room temperature 73 ± 2°F (23 ± 1°C) and gently agitated for 110 days. Moisture absorption was determined gravimetrically.

Tensile Tests

Preliminary tensile tests were carried out with a crosshead speed of 0.02 in./min (0.05 cm/min) (1%/min) at 73.5°F (23.0°C) and of 0.0005 in./min (0.00127 cm/min) at 0°F (−18°C) and −25°F (−32°C) to determine whether slippage occurred. Suitably nailed galvanized end clamps eliminated this problem (Figure 4).

Tensile properties of BUR membranes not immersed in water were determined on three dog-bone specimens conditioned at 73.5°F (23°C) and 50% RH for 24 hours prior to being pulled at a rate of 0.02 in./min. (0.05 cm/min.). To determine the effect of water, another 10 specimens were submerged in distilled water at room temperature until weight gain almost ceased. Five of the soaked specimens were damp-dried and then tested similarly to the unexposed specimens. The five remaining moisture-saturated dog-bones were kept overnight in a freezer at −30°F (−34.5°C) and then placed in water at room temperature for 1 hour. Two of the specimens were then tested in the same manner as the other immersed specimens; the remainder were subjected to a total of ten freeze-thaw cycles before testing.

RESULTS AND DISCUSSION

Sample Preparation

With the apparatus developed in this laboratory, it was possible to produce bituminous built-up roofing membranes with plies of closely controlled thickness (Figure 5). For example, the thickness of membranes made with Type 15 asphalt and 4 plies of saturated organic felt, including flood coats, was 0.345 ±.003 in. (0.85±0.01 cm). In other words, the deviation from a total mean thickness in an area 6 ft. sq. (0.56 m^2) was close to 1%, which is extremely good since 40% variation from average thickness is not unusual on actual roofs.

WATER ABSORPTION

Percentage increase in weight of asphalt BUR specimens immersed in water and corresponding tensile properties are listed in Table I together with results from freezing and thawing tests after lengthy immersion. Loads at break values are plotted against moisture absorption in Figure 6.

Membrane strength decreases drastically with water uptake. The strength after immersion was found to be 18.6% of the original strength, which agrees well with the value of 16% for felt alone.[12] Freezing the wet membrane and then thawing it had no effect on water content. It caused only a further small decrease in strength (to 14% of dry strength for one cycle and 11% for 10 cycles). Elongation at break increased by a few per cent, possibly because of water plasticizing the asphalt.

The drastic reduction in strength is probably due to water gaining access to the reinforcing felt exposed at the edges of the unsealed specimens. Hence the results indicate what can occur at cracks in a built-up roof. If felt becomes exposed at a break and subsequently absorbs water, the strength of the top ply will be reduced possibly to the level where stresses in the membrane are strong enough to widen the break and crack the next coat of asphalt. Failure can thus be propagated through the membrane. Felts can also absorb water if exposed to rain or snow through improper storage on the job site or, because of application of insufficient bonding material, during interruptions in the roofing operations.

The amount of water absorbed through the face of membranes exposed to a vapour pressure gradient imposed by a temperature gradient is shown in Table II. The amount absorbed by new asphalt membrane produced in the laboratory was much lower than that absorbed in the immersion test. The coal tar pitch (CTP) membrane removed after 20 years service on a building roof absorbed about nine times as much water as the asphalt membrane. This large difference is probably due to the age of the coal tar roof rather than to the differences between CTP and asphalt. It is suggested that oxidation caused micro-cracks in the flood coats, and thus the felt was partly accessible to moisture.

To test this hypothesis, the coal tar pitch membrane was separated into top and bottom layers and the coal tar pitch from each was extracted with trichlorethylene. Films were prepared from these two layers and from new CTP and subjected to the water vapour permeability test in accordance with ASTM method E96, Procedure B (wet cup). It was found that the permeability of all three coal tar pitches was the same—almost negligible for a film 180 mils thick. Re-forming the pitch into a new film would eliminate any cracks that permitted the membrane to absorb water through the face due to vapour pressure gradient.

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TABLE I

WATER ABSORPTION AND EFFECT ON TENSILE PROPERTIES OF BUR SUBJECTED TO IMMERSION AND FREEZE-THAW

Dog-bone specimens cut from membrane
made with Type 1 Asphalt, edges unsealed

Exposure	Time, days	Weight, Gain, %	Load at Break, kg	Elongation at Break, %
Control kept at 23 ±2°C, 50 ±5% RH	-	-	65.2	4.65
Water Immersion at 23 ±2°C	4	3.44	34.2	3.5
	39	7.26	-	-
	53	7.42	12.3	7.21
	110	8.84	12.1	7.56
110 days Water Immersion and 1 Freeze-thaw Cycle	111	8.69	9.1	7.32
110 days Water Immersion and 10 Freeze-thaw Cycles	120	8.77	7.2	6.71

TABLE II

WATER ABSORPTION IN BUR SUBJECTED TO TEMPERATURE AND MOISTURE GRADIENT

Square specimens, edges sealed

Sample Description	Weight gain % at			
	10 days	48 days	98 days	140 days
New Type I Asphalt Membrane	-	0.14	0.16	0.47
20-Year Old CTP Membrane				
- top facing moisture	0.31	1.83	2.50	4.33
- bottom facing moisture	0.73	1.87	2.87	4.05

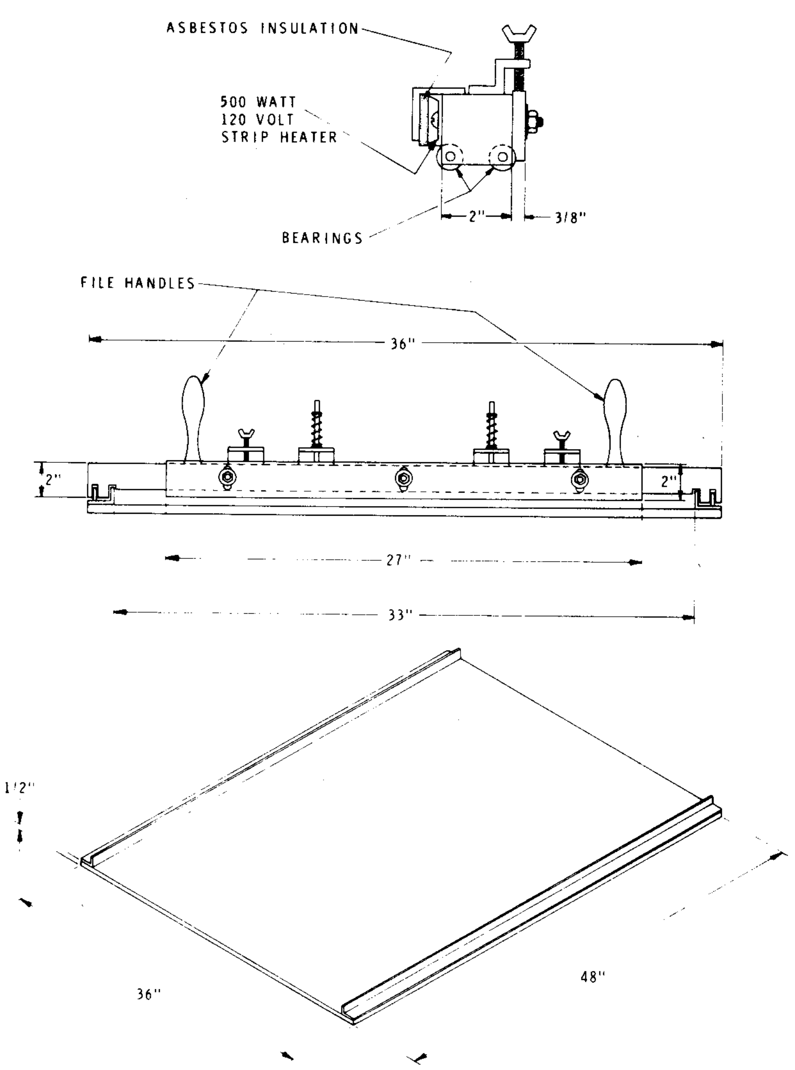

FIGURE 1. APPARATUS FOR LABORATORY PRODUCTION OF UNIFORM BUILT-UP ROOFING MEMBRANE. END VIEW (TOP) AND FRONT VIEW (MIDDLE) OF HEATED, ADJUSTABLE SCREED. BOTTOM: ½" THICK STEEL PLATE WITH NAILS.

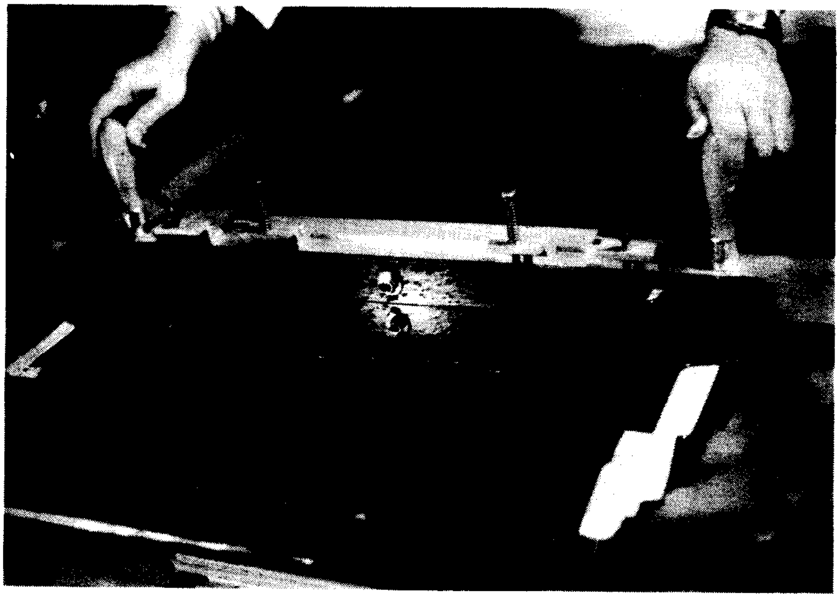

FIGURE 2. LABORATORY PRODUCTION OF UNIFORM BUR MEMBRANE.

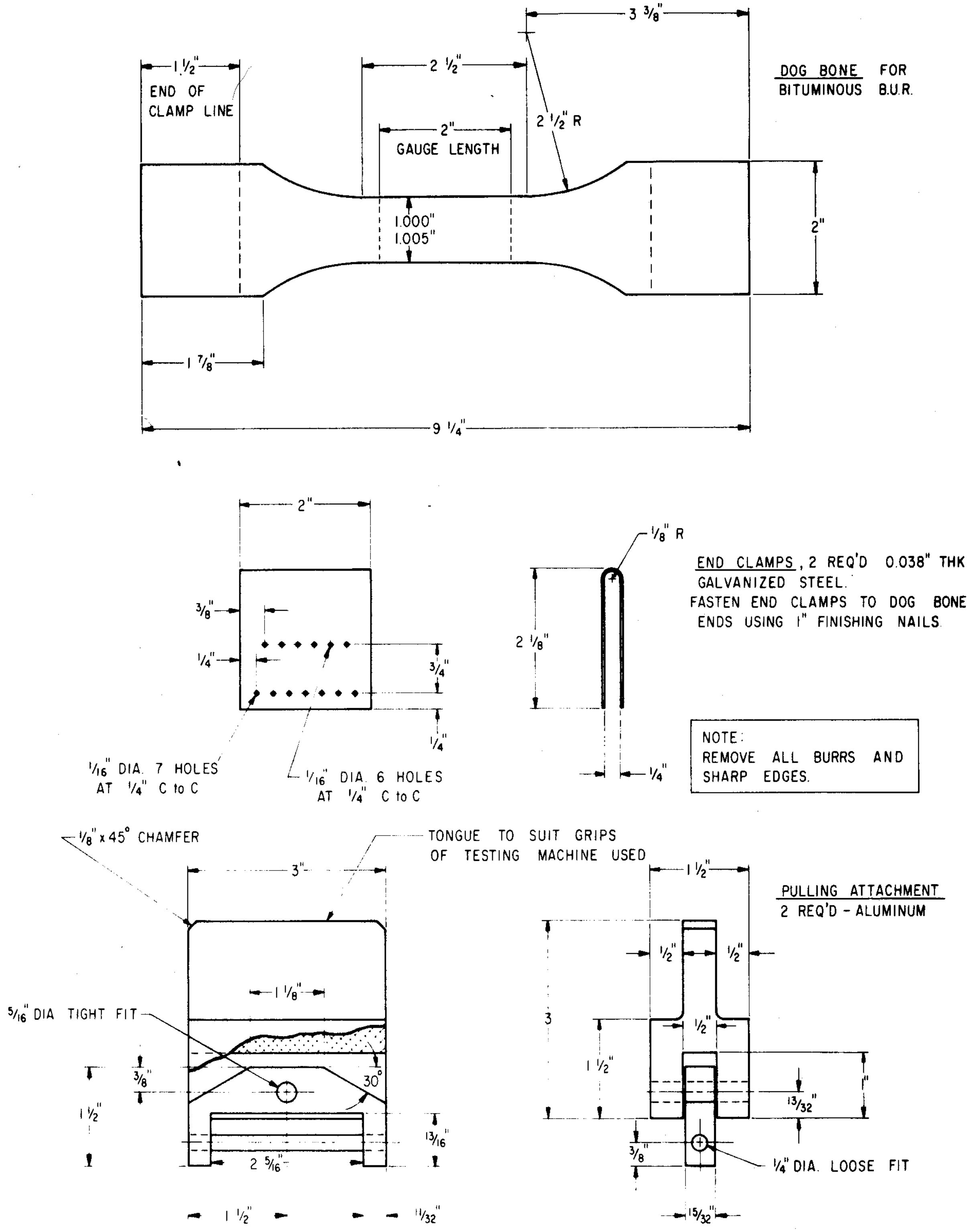

FIGURE 3. TENSILE TEST SPECIMEN FOR BUR MEMBRANE.
TOP: DIMENSION
MIDDLE: METAL END GRIP
BOTTOM: PULLING ATTACHMENT FOR TENSILE MACHINE

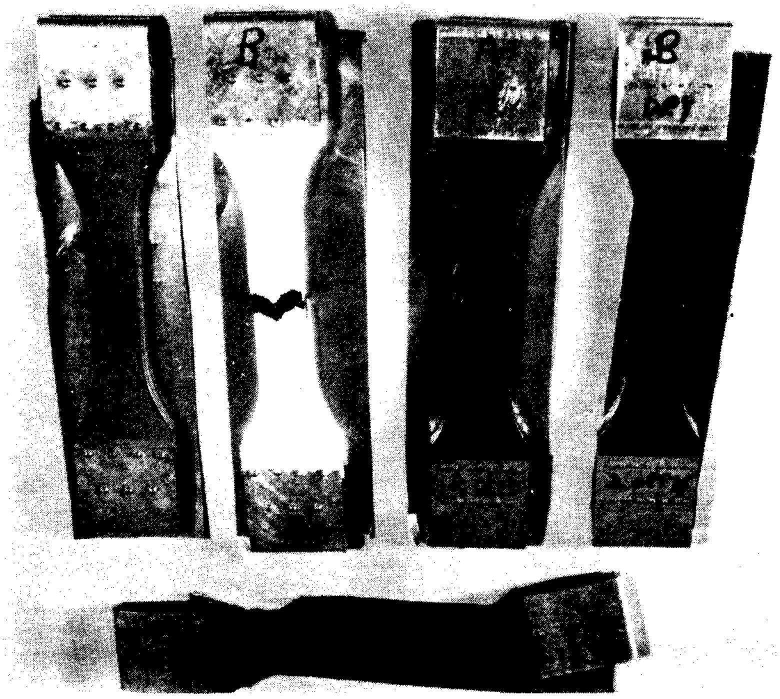

FIGURE 4. DOG-BONE SPECIMENS WITH INADEQUATE AND ADEQUATE NAILING.

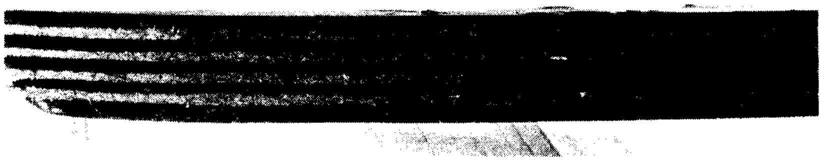

FIGURE 5. CROSS SECTION SHOWING UNIFORMITY OF FOUR-PLY BUR MEMBRANE.

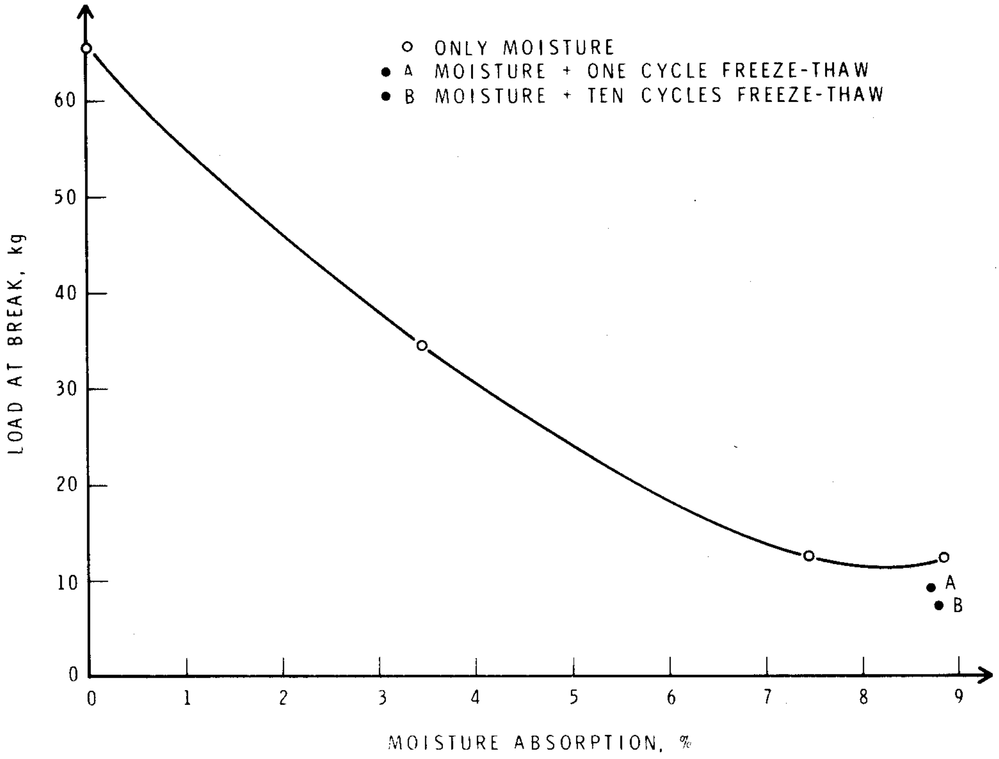

FIGURE 6. MOISTURE CONTENT VS. TENSILE STRENGTH OF BUR MEMBRANE.