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EQUILIBRIUM MOISTURE CONTENT OF ROOFING AND ROOF INSULATION MATERIALS AND THE EFFECT OF MOISTURE ON THE TENSILE STRENGTH OF ROOFING FELTS

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Abstract: Equilibrium moisture content is measured for asphalt impregnated as well as coated organic and asbestos roofing felts, and glass fiber, perlite board, fiberboard, and urethane board insulations, after conditioning in a drying oven, at 40% and 90% relative humidity (RH), and by saturation in water. The liberation of moisture by the application of hot asphalt onto roofing felts is examined quantitatively and qualitatively. Changes in the tensile strength of the felts due to moisture absorption are determined along both principal axes of the felts.

Under optimum field conditions the application of hot asphalt to uncoated organic and asbestos roofing felts conditioned at 40 and 90% RH, can liberate approximately 50% of their absorbed moisture. For organic and asbestos coated felts, hot asphalt can liberate approximately 50% of the absorbed moisture when these felts are conditioned at 90% RH, but if the felts are conditioned at 40% RH, the moisture reduction is approximately 15%.

Our tests show that potentially harmful quantities of moisture can be absorbed by roofing materials merely by storage in a humid environment, and that current moisture content standards are inconsistent and do not provide sufficient protection to the user of these materials.

Key Words: roofing, moisture, strength, felt, asphalt, insulation, temperature, equilibrium moisture content.

1. INTRODUCTION

The harmful effects of moisture trapped within a roofing system are well documented (1, 2, 3). Previous research in the field of roofing technology has proven that moisture reduces the tensile strength of built-up roofing components (1). Many roof investigations have shown that failures can be caused by moisture built into the roofing system. The problem of quantifying the moisture content of roofing materials in terms of the damage that the moisture can produce in the roofing membrane has never been adequately resolved.

We have investigated the possibility that roofing felts, being hygroscopic, might absorb sufficient quantities of moisture, when stored in a humid environment, to seriously reduce their tensile strength. Our research deals with the effect of moisture content on the reaction of the roofing felts to the application of hot asphalt (i.e. extent of foaming), the degree to which hot asphalt liberates the absorbed moisture, and the maximum amount of water that the various roofing felts and insulations can absorb.

We have found that organic and asbestos felts absorb enough moisture under humid storage conditions to produce interply voids in the membrane, that can later develop into blisters in the built-up roof. In addition, the absorbed moisture weakens the felts. Moisture contents of felts stored at 90% RH will generally exceed current ASTM standards for organic and asbestos saturated and coated felts. The ASTM standards themselves do not provide reasonable moisture content limits to prevent moisture damage to built-up membranes. In place of such inadequate and arbitrary moisture limits, we recommend "dry" (i.e., less than 40% RH) storage for roofing felts and insulation boards. Provisions should be made in applicable standards to limit their moisture content, at time of application, to that represented by their equilibrium moisture content (EMC) at 40% RH.

2. MATERIALS

We tested four types of board insulation and four types of asphalt-saturated felts.

Table 1 – Materials Used In Test Program					
MATERIAL TYPE	ASTM SPEC NO.	ASTM SPEC MAX. % MOISTURE	ABBREVIATION	MASS LB/100 SQ. FT.	APPROX. THICKNESS (IN.)
Glass Fiber Board	C 726	10 †	FG		1-5/8
Perlite Board	C 728	1.5†	P		1
Urethane Board	C 591	-	U		1
Fiber Board	C 208	10 †	FB		1/2
#15 Asphalt Organic Felt	D 226	4*	OA	13	
#15 Asphalt Asbestos Felt	D 250	5*	AA	13	
Asphalt Coated Organic Felt	D3158	1**	ACO	29	
Asphalt Coated Asbestos Felt, Type II	D3378	-	ACA	39	

* Loss on heating at 221°F for 5 hours
** by weight, point of manufacture, ASTM D95
† Absorption capacity, ASTM C209, by volume

3. SPECIMEN PREPARATION AND CONDITIONING

Constant humidity atmospheres were maintained in sealed chambers by the use of saturated salt solutions. The solutions used, and the relative humidities developed, are shown in Table 2.

Table 2 – Solutions Used to Maintain Constant Humidity in Test Chambers		
SALT IN SATURATED SOLUTION	°C	RELATIVE HUMIDITY %
Potassium Carbonate	20	40
Zinc Sulphate	20	90

The insulation samples (thicknesses as shown in Table 1) were cut into 2 x 2 inch squares from board stock. Dry weight of the samples was recorded before they were placed in 40% and 90% relative humidity conditioning chambers. Additional samples were submerged in water. A partial vacuum was maintained in the container holding the water and insulation samples, to allow them to obtain water saturation. Five specimens were tested from each type of insulation, under environmental conditions of oven dryness, 40% and 90% RH, and water saturation.

Twelve 6 x 6 inch samples were cut of each of the four types of roofing felts. Three samples of each type of felt were dried in an oven at 105°C (221°F) for 24 hours. Another three samples of each type of felt were submerged in water, under a partial vaccum, for 24 hours. The remaining samples were exposed to either 40% or 90% RH for six and nine weeks respectively, until each sample reached constant weight.

Forty samples of each type of roofing felt were cut into 1 x 6 inch tensile specimens in accordance with the testing procedure of ASTM D146. An equal number of specimens were cut in the machine direction (MD) and across the machine direction (XMD), since the felts have anisotropic properties.

The ten felt specimens (five MD and five XMD) from each of the four sample categories (shown in Table 1) were subjected to the same conditioning environments, as were the 6 x 6 inch felt samples described above.

4. TESTING PROCEDURES

After recording the moisture content[1] of the 6 x 6 inch felt samples, companion samples treated in the same environment were set in a layer of hot asphalt and then surface coated with a poured application of hot asphalt (375° to 425°F). The reaction of the felts was observed and recorded. The moisture content of the felts after the application of hot asphalt was determined according to the procedures of ASTM D95.

Each tensile specimen was strained to failure in a tensile testing machine (Instron). The strain rate was 0.2 in./min. (5 percent/min.), with an initial jaw separation of 4 in.; the temperature of the felt at testing was 20± 2°C.

The moisture contents of the various insulation samples were determined by loss on heating in a 105°C oven.

5. RESULTS AND DISCUSSION

5.1 Equilibrium Moisture Content of Roofing Insulations

The moisture content of insulations, resulting from storage for an extended period at various humidity levels, is shown in Table 3.

Table 3 – Equilibrium Moisture Content (as % of dry weight) of Insulations after Conditioning in Various Constant Humidity Environments.

	CONDITIONING ENVIRONMENT			
Insulation Type	Oven Dry	40% RH	90% RH	Water Saturated
Glass Fiber	≃0	2.0	2.0	690
Perlite	≃0	3.6	3.6	580
Urethane	≃0	2.7	6.3	530
Fiberboard	≃0	*	*	480

*Not Determined

5.2 Equilibrium Moisture Content of Roofing Felts

The moisture content of roofing felts, resulting from storage for an extended period at various humidity levels, is shown in Table 4. The data show that #15 organic felt will absorb twice as much moisture as #15 asbestos felt when water saturated or held in a constant humidity environment. The asphalt coated organic felt absorbs approximately 60% more moisture than the asphalt coated asbestos felt in 40% and 90% RH environments, and absorbs over three times as much moisture when water saturated.

Table 4 – Equilibrium Moisture Content (as % of dry weight) of Roofing Felts after Conditioning in Various Constant Humidity Environments.

	CONDITIONING ENVIRONMENT				
Type of Felt	Oven Dry	40% RH	90% RH	Water Saturated	Allowable under ASTM Specifications (Table 1)
#15 Asphalt Organic Felt	0.4	2.5	5.7	66.6	4
#15 Asphalt Asbestos Felt	0.6	1.1	3.2	32.5	5
Asphalt Coated Organic Felt	0.1	0.8	2.6	11.6	1
Asphalt Coated Asbestos Felt, Type II	0.2	0.5	1.6	3.2	–

The moisture contents of all the felts conditioned at 40% relative humidity were within the current ASTM standards as shown in Table 1.

1 Moisture content of felts determined by ASTM D95, "*Water in Petroleum Products and Bituminous Materials by Distillation,*" 1975.

Foaming, or boiling of moisture out of these felts during the application of hot asphalt (375° to 425°F), became apparent between 1 and 2% moisture content for the #15 organic and asbestos felts, and at 0.5% moisture content for the asphalt coated organic and asbestos felts. These moisture levels for the onset of foaming apply only when the felt is installed under conditions similar to the test conditions described above (i.e. the felt is still warm from being embedded in the hot asphalt, and the temperature of the applied asphalt is 375 to 425°F). The degree of foaming increases as the moisture content and temperature of the felt and the asphalt temperature increase.

Before the application of hot asphalt, moisture contents of the felts conditioned at 90% relative humidity exceeded the ASTM standards, except for #15 asbestos felts, which remained below the limitation shown in Table 1. Foaming upon the application of hot asphalt was observed over all felts in this category, even when the temperature of the top coating asphalt was 375°F. Roofing felts containing high levels of moisture (i.e. those conditioned at 90% RH) lost approximately 50% of their moisture when asphalt (at 375° to 425°F) was applied (Table 5). In felts with lower initial levels of moisture content (i.e. those conditioned at 40%RH), the percent reduction of moisture by asphalt application was lower.

Table 5 – Percent Reduction of Moisture Content in Roofing Felts due to the Application of Hot Asphalt at 375° to 425°F.

AVERAGE MOISTURE CONTENT OF FELT (AS PERCENT OF DRY WEIGHT)						
	Felt Conditioned at 40% Rel. Humidity			Felt Conditioned at 90% Rel. Humidity		
Type of Felt	Moisture Content Before Mopping	Moisture Content After Mopping	Moisture Reduction due to Mopping	Moisture Content Before Mopping	Moisture Content After Mopping	Moisture Reduction due to Mopping
OA	2.50	1.23	51%	5.73	2.30	60%
AA	1.10	0.70	36%	3.20	1.40	56%
ACO	0.77	0.63	18%	2.60	1.40	46%
ACA	0.50	0.45	10%	1.57	0.73	53%*

*Two samples of asphalt coated asbestos felt, which had been exposed to 90% relative humidity for 9 weeks, delaminated (split within the ply of the felt) when asphalt at 400°F was applied. The one remaining sample of asphalt coated asbestos felt similarly conditioned was subjected to a coating with 375°F asphalt and did not delaminate. (The figures in Table 5 indicate the average of the three tests.)

5.3 Tensile Strength of Conditioned Roofing Felts

Roofing felts suffer a substantial loss in their tensile strength after prolonged exposure to 40 and 90% RH environments, and a drastic loss after water saturation (Table 6).

Table 6 – Ultimate Tensile Strength (lb./in. width) of Roofing Felts after Conditioning in Various Constant Humidity Environments

	CONDITIONING ENVIRONMENT				PERCENTAGE REDUCTION IN TENSILE STRENGTH		
Felt Category	Oven Dry*	40% RH	90% RH	Water Saturated	40% RH	Oven Dry to 90% RH	Saturated
OA-MD	36	34	32	12	6	11	67
OA-XMD	13	†	†	4	†	†	69
AA-MD	35	31	26	5	11	26	86
AA-XMD	17	7	6	3	59	65	88
ACO-MD	50	41	31	17	18	38	66
ACO-XMD	24	24	20	9	0	17	63
ACA-MD	49	38	31	16	22	37	67
ACA-XMD	23	18	12	5	22	48	78

* "Oven Dry" is exposure to 105°C for 24 hours.
† not determined.

6. CONCLUSIONS

The following conclusions are based on the work reported.

- Glass fiber and perlite board insulations, conditioned at 40% RH, reach moisture contents (2.0% and 3.6% respectively) which remain unchanged when the conditioning environment is changed to 90% RH. The moisture content of urethane insulation, however, more than doubles (from 2.7 to 6.3%) when the relative humidity increases from 40 to 90%. The moisture content of water saturated insulation is 690% for glass fiber, 580% for urethane, and 480% for rigid fiberboard.
- The test results do not allow definite conclusions as to the "tolerable" moisture level of the insulations. However, we expect any "excess" moisture in the insulation to be available to influence the roofing membrane. Our experience shows that moisture can seriously damage roofing membranes. In view of our field experience, and pending further research results, it seems prudent to assume that insulation moisture will not damage the system, if the moisture does not exceed the equilibrium moisture content attained by 40% RH storage.
- Storage of organic or asbestos roofing felts in high humidity (i.e. 90% RH) can lead to moisture contents exceeding current ASTM standards, as recorded in Table 1. When felts stored at 90% RH are placed into an asphalt mopping (at 375° to 425°F), and then coated with another hot asphalt coating before they have cooled, a part of the moisture in the felts will vaporize and produce immediate boiling in the asphalt top coating. Felts conditioned at 40% RH attain moisture levels well within current ASTM standards for moisture in felts. Depending on the variables of felt and asphalt temperature, felts stored at 40% RH may or may not produce boiling in the asphalt top coating; our observations during the test show that boiling is much less serious when the moisture in the felts is held at the equilibrium moisture content attained by 40% RH storage. Boiling associated with felts stored at 90% RH is certainly excessive; our experiences with roofs in trouble show that this boiling is destructive to the roofing membrane.
- Both coated and uncoated felts conditioned at 90% RH will lose about 50 to 60% of their moisture content by the application of hot asphalt at 375 to 425°F.
- At 40% RH conditioning, mopping with hot asphalt will release about 30 to 50% of the moisture in uncoated felts, but only about 10 to 20% of moisture in coated felts. This is consistent with our field observations on coated two-ply roofing systems, which generally show evidence of high moisture retention in the coated felts.
- The higher moisture loss upon hot asphalt mopping of coated felts conditioned at 90% RH, relative to those conditioned at 40% RH, can be explained by the ready availability of moisture in the 90% RH felts. Our figures for moisture released by the application of hot asphalt derive from laboratory conditions favorable to such release, since the felts are warm and the mopping temperature is high. Actual field conditions are less favorable, resulting in a lower percentage of moisture removed during asphalt mopping.
- Moisture released from the felt by the application of hot asphalt, as well as the moisture retained by the felt, may be detrimental to the performance of the built-up roof. During construction of the built-up membrane, the applied asphalt layer may be covered by the next ply of felt before the bubbles in the asphalt have had time to break and release their vapor to the air. Therefore, though 50% of the moisture may be liberated from the felt by the application of hot asphalt, it may not be eliminated from the roofing system. The vapor trapped within the interplies of the built-up membrane can cause blistering, and eventual failure of the roofing system. Pinholes in the cooled interply asphalt are evidence of this trapped vapor. We have observed many blistered built-up membranes that also exhibited pinholed interply asphalt.
- Moisture absorbed by felts at 90% RH can seriously reduce their tensile strength. At high levels of moisture content, such as achieved by water saturation of the felt, the reduction in tensile strength is drastic.
- Although asbestos felts absorb less moisture than organic felts in any given environment, their loss in tensile strength (as a percent of their initial tensile strength) is roughly proportional to the loss in organic felts. (The initial, i.e. dry, tensile strength of asbestos felt is lower than that of organic felt.)
- Asphalt coated asbestos felts can delaminate upon contact with hot asphalt after prolonged exposure to high humidity.

In view of the data presented in this paper, current allowable limits in ASTM standards for the moisture content of roofing felts appear too high. For example, #15 asbestos felt conditioned at 90% relative humidity attains a moisture content of 3%, which is below current ASTM standards. However, the tensile strength of this felt is approximately 46% of its initial strength (average of MD and XMD strength) in the dry condition. Furthermore, the moisture in this felt produces extensive foaming in the hot asphalt when it is applied, thus increasing the likelihood of voids and blisters in the roofing membrane.

The moisture limits for ASTM felt standards are inconsistent with the quantities of water absorbed by the various felts. For example, asphalt asbestos felts have a lower water absorption than asphalt organic felts, yet

ASTM standards permit 25% more water in #15 asbestos felts than in #15 organic felts. The ASTM standards with respect to moisture limits in felts are arbitrary, irrational, and have no pertinence to the intended use of the felts in built-up roofing.

Inconsistencies such as using two different methods for determining allowable moisture limits (ex. "D95" for ASTM 3158 and "loss on heating" for ASTM D226 and D250) further diminish the relevance and credibility of the current standards.

Storage of roofing felts in environments with less than 40% RH can prevent excessive moisture absorption. It follows that the moisture content obtained by prolonged exposure to not more than 40% RH is a logical limit for felts specified under ASTM standards, and as actually applied under field conditions.

7. RECOMMENDATIONS

Based on the results of the above research, we make the following recommendations:

- We recommend that insulation should not be installed unless its moisture content is below the equilibrium moisture content at 40% relative humidity. This is consistent with our recommendations for roofing felts.
- Limit the moisture content of roofing felts to the equilibrium moisture content that they attain after prolonged exposure to a 40% relative humidity environment.
- Moisture limitations should apply when the materials are installed, and should be incorporated in ASTM specifications.
- Test all roofing material shipments prior to and after shipment to protect the manufacturer and shipper from claims of shipping wet materials, and consumers from the blistered built-up roof that can result from the use of wet felts or insulation.
- Provide dry (i.e. 40% RH) storage for all roofing materials that can absorb moisture.
- Test all felt and insulation shipments for moisture just prior to installation. Do not use any felts which cause significant "boiling" during field application of hot mopping bitumen.
- Use a consistent method for determining moisture content.

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