PHYSICAL PROPERTIES OF BUR MEMBRANES TESTED AT LOW RATES OF LOADING

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INTRODUCTION

It is well known among roofing researchers that the mechanical properties of roofing membranes obtained from standard test procedures depend greatly on the rate of loading. Published performance criteria values of membrane properties are for the most part based on ASTM D 2523-70. ASTM D 2523-70 is the recommended guide for determining the load-strain properties of roofing membranes and their components at various temperatures. Furthermore, ASTM states in this standard that "this recommended practice is designed to aid those who are interested in the engineering properties of roofing membranes". This standard continues and states, "the data obtained will not predict the service life of a membrane under given conditions. It will provide a basis for study of the mechanical properties of the membrane. Note that if different strain rates are used, data may not be strictly comparable."

Unfortunately, the values obtained from using the ASTM standard do not really aid those interested in the engineering properties; they merely constitute a vast amount of comparative data. The values obtained by following the ASTM standard are actually misleading when an attempt is made to predict the behavior of a roof membrane during its service life. As noted previously, the ASTM specification does, however, include a cautionary note advising the reader that different strain rates may produce data which may not be "strictly comparable."

The work presented in this paper explores two basic topics with regard to the physical properties of roofing membranes. First, it documents the effects of rates of loading on strength and modulus values. Second, it establishes the strength and modulus values at a reasonable loading rate, to aid in the understanding of the physical properties of built-up roofing membranes as manifested in field practice.

The authors believe that the data presented in the following sections give a practical basis for understanding the field behavior of a roofing membrane.

SPECIMENS

The ultimate strength and modulus of elasticity were to be determined for various rates of loading using specimens with a uniform width of 1" with a clear distance of 10" between the end blocks. Each end of the specimen was embedded in an epoxy material, which provided an easy means of transferring the tensile loads generated by the tension tester.

Both 2-ply and 4-ply built-up roof membranes, prepared in accordance with recommended field practice, were tested in this program. The 2-ply samples were constructed with a 43-lb. coated base sheet as the base ply and a 30-lb. coated sheet as the top ply. Steep asphalt was used for the interply mopping as well as a mop coat on top of the built-up roof membrane for all test specimens. The 4-ply built-up roof membranes were constructed with a 43-lb. coated base sheet as the base ply, with three more plies of No. 15 saturated felts with perforations. All felts were organic.

All specimens were tested in the cross (transverse) direction of the felts under room conditions, unless otherwise specified.

STRENGTH AND MODULUS AT VARIOUS RATES OF LOADING

To determine the effects of the slower loading rates on the physical properties of the built-up roof membranes, loading rates of 0.100, 0.014, 0.002 and 0.0002 inches per minute were used to determine the ultimate strength and the modulus of elasticity. Note that for a 10" sample, the loading rate of 0.100 inches per minute is equivalent to the one percent per minute as recommended by ASTM. The four rates represent four orders of magnitude, with the ASTM recommended rate as the fastest rate of loading. One should bear in mind that in considering uniform strain over a roof, the rate of strain is in the order of 5 x 10^{-6} inch/inch/minute or for a 10" sample, 50 x 10^{-6} inch/minute. One of the purposes was to determine the order of magnitude between the results obtained from different rates of loading.

Both 2-ply and 4-ply built-up test specimens (a minimum of five per lot) were tested at each of the four loading rates. The typical scattering characteristics within each lot are shown in Table 1 and Table 2, which list the individual results of each sample tested at 0.0002 and 0.002 inches per minute for strength and modulus respectively. Table 3 tabulates average values for ultimate strength and modulus of elasticity for various loading rates as a result of this experimental program. As shown in Table 3, the difference between the results from a loading rate of 0.100 and 0.014 inches per minute is quite pronounced as compared to the difference between the results of the three slower rates of loading.

STRENGTH AND MODULUS AT LOADING RATE OF 0.014 INCHES PER MINUTE

The difficulty involved in the selection of a proper loading rate for the determination of strength and modulus values for built-up roof membranes is a practical problem. If uniform strain is to occur on a roof, the magnitude of the strain rate would be in the order of 5 x 10^{-6} inch/inch/minute.

While it is impossible to predict the exact rate of movement due to temperature on a given roof, it is possible to determine the order of magnitude of the rate of movement. For a maximum temperature variation of 50°F over a three-hour period (cold shower on a hot summer day), for a roof with an average coefficient of 20 x 10^{-6} inch/inch/°F, and 200 ft. between expansion joints, the movement in the roofing membrane due to temperature change can be represented by approximately 0.014 inches per minute. Note, too, that the **exact rate** of loading used in the determination of strength and modulus is not as significant as the **order of magnitude of the rate** of loading and that the results for both strength and modulus obtained at this rate of loading would be an **upper bound** result.

A series of tests was conducted to determine the strength and modulus of both 2-ply and 4-ply built-up roof membranes at the above loading rate of 0.014 inches per minute, at temperatures ranging from - 30°F to 120°F. The results are shown in Table 4 and Table 5 for the 2-ply and 4-ply built-up roof membranes respectively. As the data indicates, both the strength and modulus values generally increase at lower temperature.

CONCLUSIONS

In summary, here are our conclusions:

1. Average ultimate strengths **on a per ply basis** of both 2-ply and 4-ply membranes at room temperatures are not significantly different.
2. Typical ultimate strains of both 2-ply and 4-ply membranes at room temperature are similar.
3. Ultimate strengths and modulus of elasticity of both 2-ply and 4-ply membranes at room temperatures are much lower at the slower loading rates similar to those experienced in the field than the results obtained from a loading rate of 0.1 inches per minute.
4. Ultimate transverse strains in a 2-ply membrane are **less** at lower temperatures.
5. Ultimate transverse strains in a 4-ply membrane are **greater** at lower temperatures.
6. A slower rate of loading generally produces lower results, with the difference in magnitude between values obtained from 0.1 inches per minute and 0.014 inches per minute larger than the difference between the three slower loading rates.

TABLE 1

"SLOW RATE" OF LOADING TESTS. ULTIMATE STRENGTH OF MEMBRANES AT ROOM TEMPERATURE - TRANSVERSE DIRECTION

MEMBRANE TYPE	2-PLY				4-PLY			
RATE OF LOADING (IN/MIN)	0.0002		0.002		0.0002		0.002	
UNITS OF REPORTED VALUES	PSI	LBS/IN	PSI	LBS/IN	PSI	LBS/IN	PSI	LBS/IN
SAMPLE 1	66.2	17.8	82.2	22.1	95.9	37.6	105.1	41.2
SAMPLE 2	63.9	17.2	78.8	21.2	97.7	38.3	124.7	48.9
SAMPLE 3	64.3	17.3	79.2	21.3	98.5	38.6	110.0	43.1
SAMPLE 4	62.8	16.9	81.8	22.0	89.8	35.2	116.1	45.5
SAMPLE 5	70.3	18.9	85.9	23.1	91.1	37.5	121.9	47.8
AVERAGE	65.5	17.6	81.6	21.9	94.6	37.1	115.6	45.3
AVERAGE/PLY		8.8		11.0		9.3		11.3

TABLE 2

"SLOW RATE" OF LOADING TESTS. MODULUS OF ELASTICITY OF MEMBRANES AT ROOM TEMPERATURE - TRANSVERSE DIRECTION

MEMBRANE TYPE	2-PLY				4-PLY			
RATE OF LOADING (IN/MIN)	0.0002		0.002		0.0002		0.002	
UNITS OF REPORTED VALUES	PSI	LBS/IN	PSI	LBS/IN	PSI	LBS/IN	PSI	LBS/IN
SAMPLE 1	5,227	1,406	4,822	1,297	7,870	3,085	8,207	3,217
SAMPLE 2	4,041	1,087	6,201	1,668	7,847	3,076	9,069	3,555
SAMPLE 3	4,401	1,184	6,383	1,717	7,594	2,977	8,577	3,362
SAMPLE 4	4,394	1,182	5,985	1,610	8,605	3,373	8,722	3,419
SAMPLE 5	5,089	1,369	5,810	1,563	6,852	2,686	8,431	3,305
AVERAGE	4,630	1,250	5,840	1,570	7,750	3,040	8,600	3,370
TYP. ULT. STRAIN	1.7%		1.9%		1.6%		1.4%	

TABLE 3

ULTIMATE STRENGTH AND MODULUS OF ELASTICITY OF MEMBRANES FOR VARIOUS RATES OF LOADING AT ROOM TEMPERATURE - TRANSVERSE DIRECTION

RATE OF LOADING (IN/MIN)	2-PLY				4-PLY			
	ULTIMATE STRENGTH		MODULUS OF ELASTICITY		ULTIMATE STRENGTH		MODULUS OF ELASTICITY	
	LBS/IN	PSI	LBS/IN	PSI	LBS/IN	PSI	LBS/IN	PSI
0.0002	17.6	65.5	1,250	4,630	37.1	94.6	3,040	7,750
0.0020	21.9	81.6	1,570	5,840	45.3	116.0	3,370	8,600
0.0140	22.0	100.0	1,550	7,040	41.3	132.0	3,320	10,610
0.1000	37.9	141.0	3,750	13,930	77.2	197.0	7,100	18,120

TABLE 4

AVERAGE STRENGTH AND MODULUS OF 2-PLY BUR MEMBRANES (LOADING RATE, 0.014 IN/MIN)

TEMPERATURE (°F)	LONGITUDINAL		TRANSVERSE		TYPICAL ULTIMATE STRAIN	
	ULTIMATE STRESS PSI	MOD. OF ELASTICITY PSI	ULTIMATE STRESS PSI	MOD. OF ELASTICITY PSI	LONGITUDINAL	TRANSVERSE
-30	756 (166)*	72,630 (15,980)	459 (101)	123,000 (27,060)	1.4%	0.9%
0	788 (173)	77,730 (17,100)	381 (84)	59,070 (13,000)	1.3%	1.5%
30	533 (117)	35,475 (7,805)	252 (55)	21,700 (4,774)	2.4%	1.5%
60	317 (70)	29,245 (6,434)	132 (29)	10,010 (2,202)	2.5%	2.9%
90	185 (41)	15,905 (3,499)	68 (15)	4,075 (897)	1.9%	2.9%
120	110 (24)	7,565 (1,664)	47 (10)	3,049 (671)	1.3%	3.0%

* LOWER FIGURES IN PARENTHESES ARE RESULTANT VALUES IN LBS/IN

TABLE 5

AVERAGE STRENGTH AND MODULUS OF 4-PLY BUR MEMBRANES (LOADING RATE, 0.014 IN/MIN) - TRANSVERSE DIRECTION

TEMPERATURE (°F)	ULTIMATE STRESS - PSI	MODULUS OF ELASTICITY - PSI	TYPICAL ULTIMATE STRAIN
0	791 (247)*	56,490 (17,650)	2.6%
30	341 (107)	20,490 (6,403)	2.4%
75	132 (41.3)	10,610 (3,316)	2.4%
120	70.8 (22.1)	5,653 (1,767)	1.4%

* LOWER FIGURES IN PARENTHESES ARE RESULTANT VALUES IN LBS/IN