AN ANALYSIS OF LOAD-STRAIN PROPERTIES OF SBS MODIFIED BITUMEN ROOFING MEMBRANES

RANDY JOLITZ, HELENE HARDY PIERCE, SARA DANIEL and DOROTHEA DONOHO
TAMKO Roofing Products, Inc.
Joplin, Missouri

The objectives of this research were:

- To determine the load-elongation behavior of several different types of styrene butadiene styrene (SBS) modified bitumen roofing membranes.
- To determine the differences in the load-elongation behavior of SBS modified bitumen roofing membranes relative to the type of reinforcement in the SBS sheet(s).
- To characterize the load-elongation behavior of SBS modified bitumen roofing membranes relative to the number of base ply(s) in the roofing membrane.

The results of this testing program give an indication of the relative load-elongation performance of roofing membranes which differ from each other in both the type of reinforcements(s) and the number of plies used in those membranes tested that combine built-up ply sheets and SBS modified bitumen cap sheets. From our results, the type of reinforcement in the SBS cap sheet has a much greater effect on the load-elongation behavior in SBS modified bitumen roofing membranes than the number or type of base plies. The load-elongation performance of SBS modified bitumen sheets reinforced with polyester when tested as a roofing system is much greater than the performance of SBS modified bitumen roofing membranes utilizing only fiberglass reinforcement.

KEYWORDS

Fiberglass, load-elongation, modified bitumen roofing membrane, polyester, styrene-butadiene-styrene (SBS).

INTRODUCTION

SBS modified bitumen roofing membranes have been used successfully in the United States for more than 18 years. Efforts under way at the American Society of Testing and Materials (ASTM) have been focused on developing test methods and product standards for this class of product. These product standards will assist the roofing user in delineating from one product to another when specifying or using SBS modified bitumen sheets. These standards will not, however, assist with the delineation between different SBS modified bitumen roofing membrane specifications.

These roofing membranes are typically composed of one or more base plies, which may or may not be polymer modified, and then an SBS cap sheet. There are a number of variables that affect the configuration and performance of the finished roofing membrane, including, but not limited to: type of base ply, number of total plies, type of reinforcement of SBS sheet(s), level of polymer modification, and quality of the SBS polymer modified bitumen. As these roofing membranes have gained greater acceptance and consequentially have seen more use, the roofing industry has been overwhelmed with variations from one SBS modified bitumen roofing membrane to another. Review of the current NRCA *Roofing Materials Guide*[1] shows 30 different SBS modified bitumen sheet suppliers with a total of 256 different SBS modified products and more than 600 different roofing membrane specifications.

SBS modified bitumen roofing membranes utilize much of the same installation technology found in traditional built-up roofing membranes, including a redundancy of plies typically installed in hot asphalt and base plies that often are the same type of ply sheets used in a built-up roof. Due to these similarities, as SBS modified bitumen roofing membranes gained in popularity, efforts were undertaken to define these products in terms of their performance relative to the performance characteristics of a built-up roof. In particular, different users have defined SBS sheet materials in terms of the performance property of tensile strength already associated with bituminous membrane roofs.

In 1974, Mathey and Cullen[2] presented 20 performance attributes of bituminous membrane roofing and then offered criteria for several of these attributes. Included in their recommendations was the performance criterion of 35 kN/m (200 lbf/in.) of tensile strength when tested at -17.8°C (0°F) in the weakest direction. This criterion was determined based on the tensile strength performance of roof membranes in service at that time. Since 1974, correctly or incorrectly, this 35 kN/m (200 lbf/in.) of tensile strength has become the benchmark of built-up roofing performance criteria; however, when applied to modified bitumen roofing membranes, this criterion does not take into consideration the contribution that elongation makes to performance.

The ASTM test methods standard D 5147[3] includes the test methods for determining the tensile strength at maximum load, the percent elongation at maximum load, the tensile strength at specimen break, the percent elongation at specimen break, and the strain energy at both maximum load and at specimen break of these sheet materials. Likewise, the proposed ASTM product specifications all include load-elongation criterion for each product type. Dupuis[4] has described the different load-elongation behaviors of several different types of polymer modified sheet materials and the relative performance differences between these materials and the traditional built-up roofing membrane.

Rossiter[5] analyzed the load-elongation properties of several bituminous roofing membranes and proposed strain energy as an alternative criterion to tensile strength. Rossiter's work focused on bituminous built-up membranes, including membranes fabricated from reinforcements such as polyester and an SBS modified bitumen sheet material. As a reference, a four-ply, fiberglass reinforced built-up roofing membrane will exhibit greater than 35 kN/m (200 lbf/in.) of tensile strength with an accompanying elongation of 1 to 3 percent when tested at -17.8°C (0°F).

Dupuis[4] concludes that "the overall performance is difficult to establish if we only study individual material characteristics," yet, as the number of configurations of SBS roofing membranes has grown, little has been done to quantify the load-elongation characteristics of these membranes. And if the load-elongation curve is directly related to the "toughness" of the membrane, as suggested by Rossiter,[5] then this information relative to different membrane configurations is important when assessing one membrane configuration with another. For these reasons, testing was initiated to determine the load-elongation characteristics of an assortment of SBS modified bitumen roofing membranes.

SYSTEM CONFIGURATIONS AND CONSTRUCTION

The different types of roofing membranes available utilizing one or more SBS modified bitumen sheet materials is quite numerous, as noted. For this reason, the authors selected 10 roofing membranes for the testing program that were considered to be representative of the more frequently installed configurations. Table 1 defines the products used in the different membranes, and Table 2 summarizes the 10 roofing membranes tested in this program. As noted in the tables, products from four different manufacturers were utilized, and each of the membranes constructed was made with material from a single manufacturer. This was done to verify the relative performance characteristics of the different general types or classes of products and to blind the data from any particular manufacturer.

The roofing membranes tested were all constructed in the same manner. The decks were constructed using 1.2 m x 2.4 m (4 ft. x 8 ft.) plywood. A 12.7-mm (½ in.) wood fiber insulation was mechanically fastened to the plywood deck and the roofing membranes were mopped to the wood fiber insulation with ASTM D 312,[6] Type III asphalt. The mopping grade asphalt was heated to a temperature of 246°C (475°F), which yielded an application temperature of approximately 232°C (450°F). After each membrane was mopped, it was identified, stored and cooled without sustaining any damage.

After a minimum of 48 hours at ambient temperature, each membrane was separated from the insulation and cut into strips. Subsequently, the strips were cut into the "dog bone" shapes used in ASTM D 2523[7] with a die and pneumatic press to ensure that all the specimens would be the same size.

Product Designation	Product Description
BP1 (3 manufacturers)	Ply sheet, ASTM D2178.[8] Type IV
BP2 (2 manufacturers)	SBS modified base sheet, 90 mils thick, fiberglass reinforced
BP3 (1 manufacturer)	SBS modified base sheet, 160 mils thick, 180 g/sq.m polyester reinforcement
CS1 (3 manufacturers)	BS modified cap sheet, 160 mils thick, 180 g/sq.m polyester reinforcement
CS2 (1 manufacturer)	BS modified cap sheet, 160 mils thick, 250 g/sq.m polyester reinforcement
CS1 (2 manufacturers)	BS modified cap sheet, 130 mils thick, polyester reinforcement

Table 1.

LOAD-ELONGATION TESTS

The specimens were tested in accordance with ASTM D 2523[7] except as modified by paragraphs 6.1.2.3 and 6.1.2.4 of ASTM D 5147[3] using an Instron model 5500R with 38.1-mm x 50.8-mm (1½-in. x 2-in.) serrated pneumatic jaws. The Instron used for the testing utilizes series 9 software and all tensile, elongation, and strain energy values were calculated using Instron Enhanced Report software.

All specimens were conditioned a minimum of 24 hours at the test temperature. The temperatures were determined using a calibrated thermocouple and the temperature was maintained by using an environmental chamber. The tests were conducted with a cross head speed of 50.8 mm (2 in./min.) for the 22.8°C (73°F) test temperature and a cross head speed of 2.03 mm/min. (0.08 in./min.) for the -17.8°C (0°F) test temperature.

The load-elongation tests were performed in both the machine direction (md) and the cross-machine direction (xmd). Three specimens were tested in each direction for each of the roofing membranes tested. Table 3 summarizes the results of the load-elongation tests. The average curve stress-strain diagrams for each of the roofing membranes tested at -17.8°C (0°F), in both the machine and cross-machine direction are shown in Figures 1-20.

Manufacturer	System Designation	System Description
A	A-1BP1-1CS1	One ply of BP1, one ply of CS1
B	B-1BP1-1CS1	One ply of BP1, one ply of CS1
C	C-1BP1-1CS1	One ply of BP1, one ply of CS1
B	B-3BP1-1CS1	Three plies of BP1, one ply of CS1
C	C-3BP1-1CS1	Three plies of BP1, one ply of CS1
A	A-3BP1-1CS2	Three plies of BP1, one ply of CS2
A	A-1BP2-1Bp1-1CS2	One ply of BP2, one ply of BP1, one ply of CS2
A	A-3BP3-1CS2	One ply of BP3, one ply of CS2
D	D-1BP2-1CS3	One ply of BP2, one ply of CS3
A	A-3BP1-1CS3	Three plies of BP1, one ply of CS3

Table 2.

DISCUSSION

Analysis of the data yields several observations:

- The roofing membranes utilizing polyester reinforcements in the cap sheet, and in the case of A-1BP3-1CS2, which used a polyester reinforcement in the base ply also, generally exhibited strengths equal to the roofing membranes with only fiberglass reinforcement in the base plies and cap sheet. The machine direction tensile strength of all membranes utilizing polyester cap sheet exceeded the machine direction tensile strength of D-1BP2-1CS3 and many of the cross-machine direction strengths of the membranes using a CS1 or a CS2 cap sheet were higher or similar to the cross-machine direction strength of D-1BP2-1CS3.
- The strain energy, in both directions, of all SBS modified

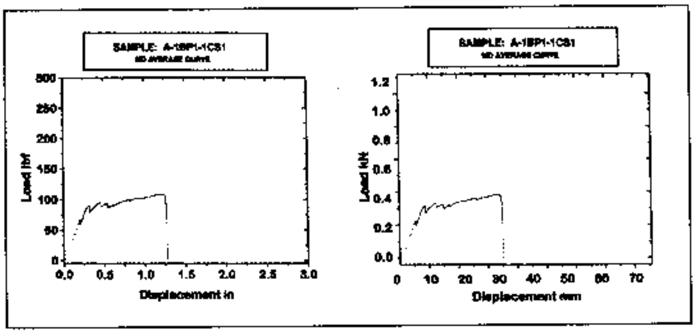

Figure 1.

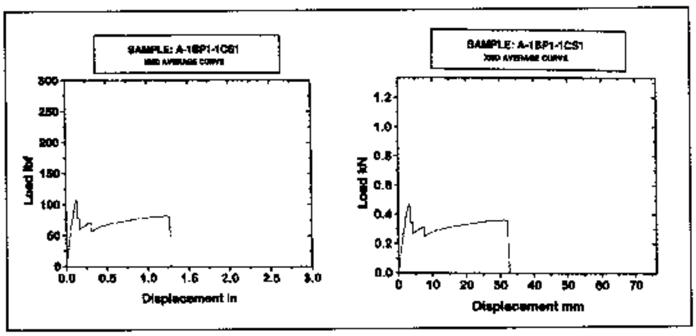

Figure 2.

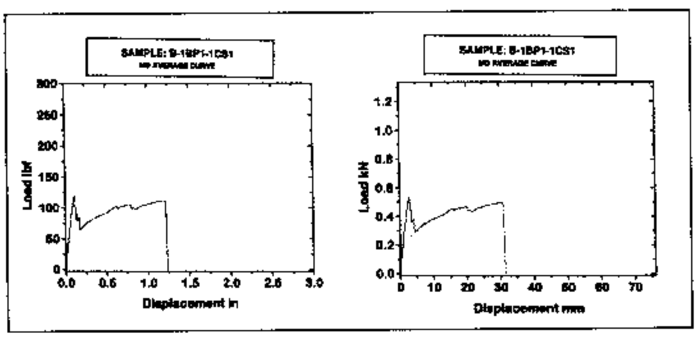

Figure 3.

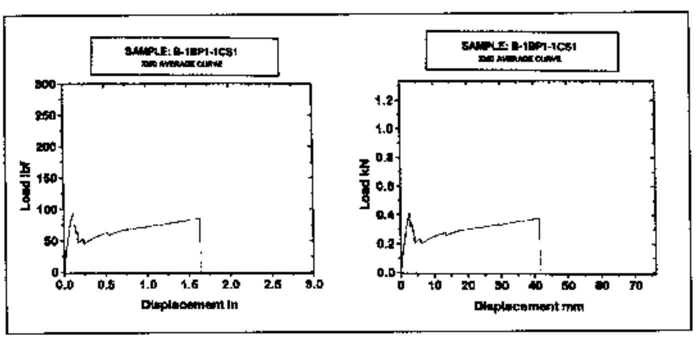

Figure 4.

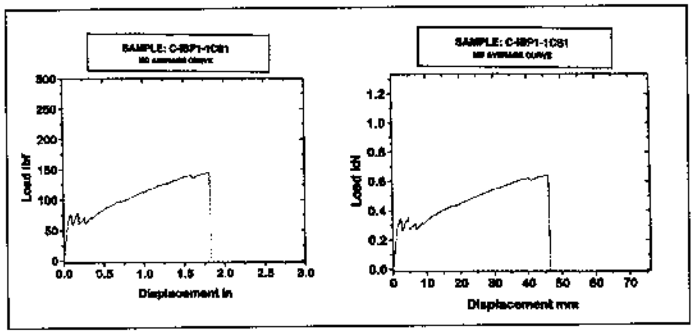

Figure 5.

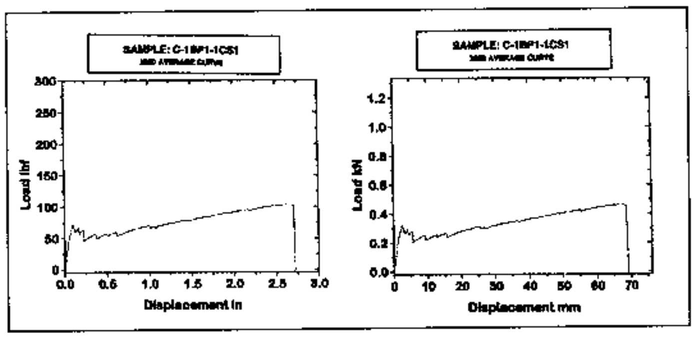

Figure 6.

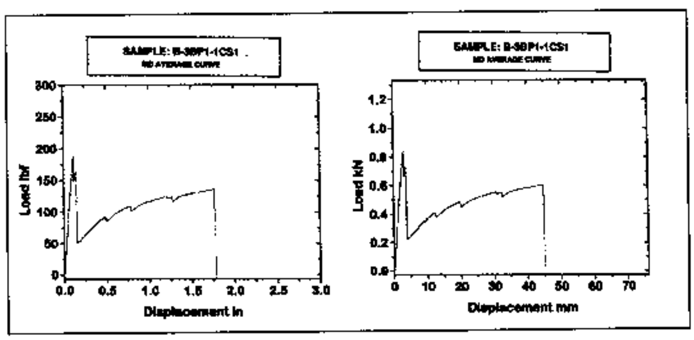

Figure 7.

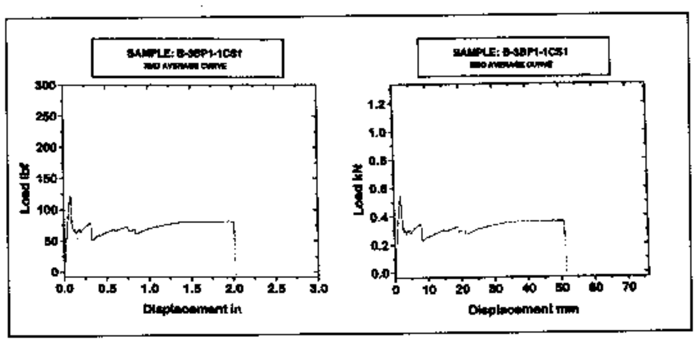

Figure 8.

bitumen membranes tested exceeded the strain energy of traditional built-up roofing which is typically in the 13.3-22.2 N-m/m (3-5 lbf-in./in.) range, depending upon the test temperature.

- As one would expect, all of the roofing membranes exhibited higher strength at the -17.8°C (0°F) test temperature than at the 23°C (73.4°F) test temperature. Additionally, all of the membranes except for those made with product produced by Manufacturer B exhibited higher elongation at the 23°C (73.4°F) test temperature than at the -17.8°C (0°F) test temperature.
- The differences between the tested roofing membranes utilizing a polyester reinforcement in the cap sheet are more dependent upon the specific modified cap sheet than the number of base plies as exhibited by the similarities between the B-1BP1-1CS1 and B-3BP1-1CS1 and the

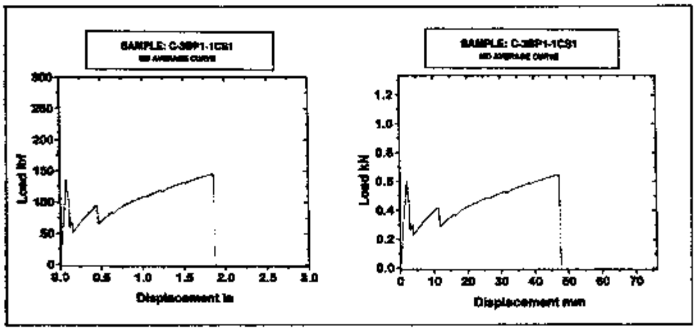

Figure 9.

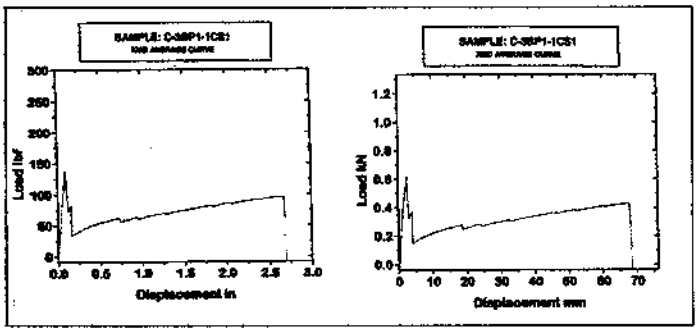

Figure 10.

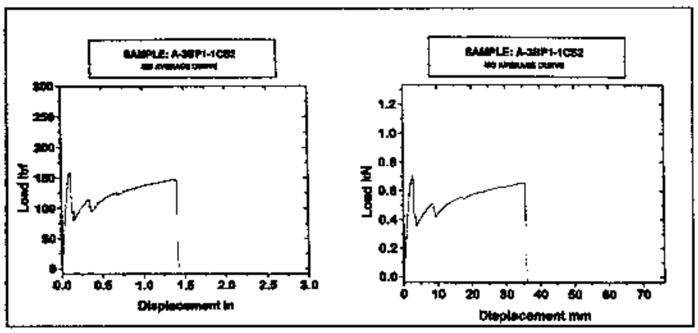

Figure 11.

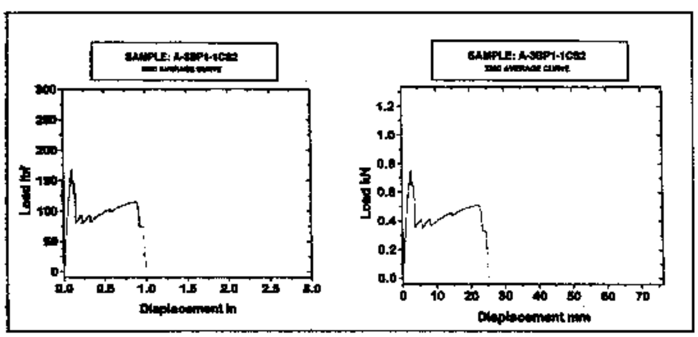

Figure 12.

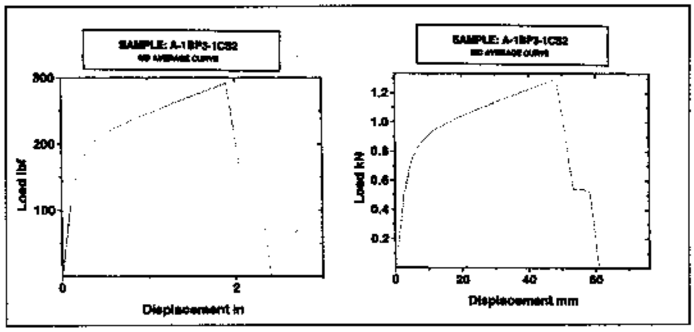

Figure 13.

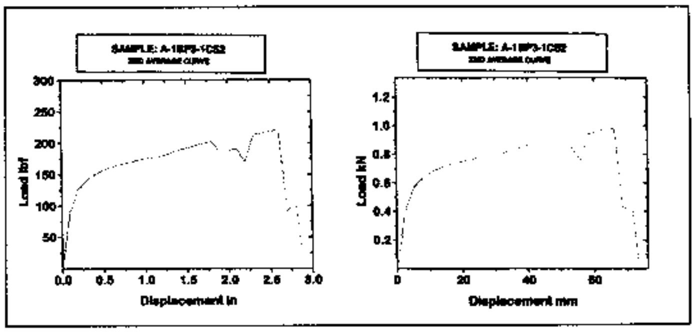

Figure 14.

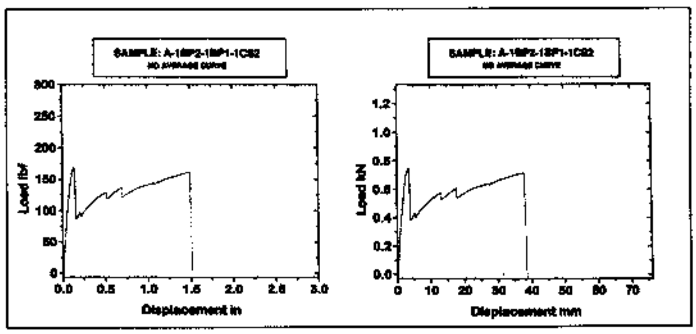

Figure 15.

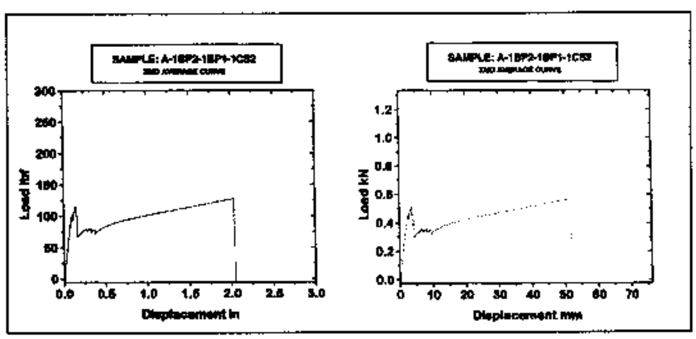

Figure 16.

differences between B-3BP1-1CS1 and A-3BP1-1CS2. Of these membranes, the two with three ply sheets below the modified cap sheet exhibited similar elongation results in both directions and at both test temperatures; however, the tensile strength and the strain energy appear to be more specific to the manufacturer and not the specific composite of the membrane. This is further exemplified by the slightly higher strain energy of B-1BP1-1CS1 when compared with B-3BP1-1CS1. This result was not expected; however, it could be due to slight damage to the polyester cap sheet when the three ply sheets ruptured in B-3BP1-1CS1; it could be due to the variation in the independent layers used to construct the membranes; or it could be that the variation in the data shows no significant difference in the strain energy of these two membranes. This apparent anomaly requires further testing to determine its cause.

- Currently, there is not a standard test method for testing roofing membranes in which all of the data can be compared equally, i.e., at the same rate of jaw separation regardless of the ultimate elongation of the material or the test temperature. The two standards that are applicable for modified bitumen membranes and sheet materials, ASTM D 2523[7] and ASTM D 5147,[5] respectively, use different sample sizes and strain rates, which indicates that the data cannot be compared.
- When comparing the testing performance of the the same "type" of membrane from different manufacturers, one needs to remember that the individual components used are manufactured to each manufacturer's respective specification(s) and that one should not expect a membrane from one manufacturer to perform the same as a like membrane from another manufacturer.

SUMMARY AND CONCLUSIONS

The load-elongation curves generated by this testing exhibit the expected results for each of the types of membranes tested; the membranes with a fiberglass reinforced cap sheet, D-1BP2-1CS3 and A-3BP1-1CS3, exhibit strength with low elongation and the remaining membranes, those which utilize a polyester reinforced cap sheet, exhibit strength from the fiberglass ply sheets and elongation and strength from the polyester reinforced material.

The results of this testing indicate that there is no significant difference in the strain energy properties of an SBS modified bitumen roofing membrane utilizing one ply sheet under the SBS cap sheet and an SBS modified bitumen roofing membrane utilizing three ply sheets under the SBS cap sheet. Further, there is not a linear relationship between the number of ply sheets and the tensile strength of the membrane; more precisely, for each ply sheet meeting ASTM D 2178, Type IV, the tensile strength does not appear to increase by 195.7 N (44 lbf). In layman's terms, additional plies should be chosen for the benefit of redundancy in waterproofing plies or a performance attribute other than an increase in the amount of energy or "work" it would take to split the membrane.

Load-elongation testing also characterizes the differences between the types of reinforcement in the SBS sheet material. The membranes utilizing a polyester reinforced cap sheet exhibited similar strengths as the membranes utilizing a fiberglass reinforced cap sheet; however, the strain energy of the membranes tested was on a magnitude of order of 5 to 10 times greater for the membranes utilizing a polyester reinforced cap sheet.

This paper has presented preliminary work done on a limited number of SBS modified bitumen roofing systems. It is hoped that discussion of the data presented will lead to fur-

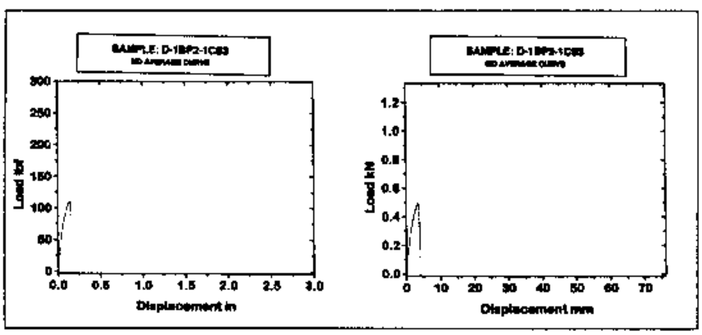

Figure 17.

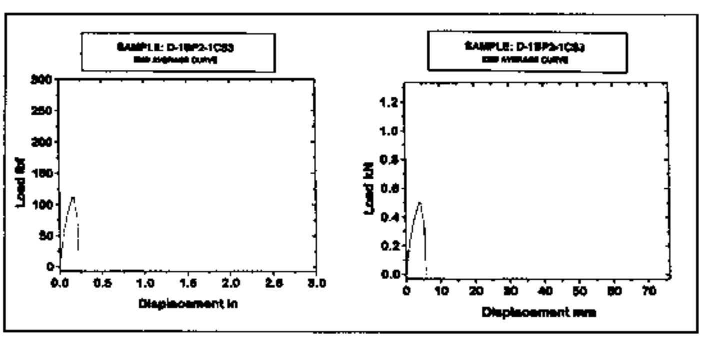

Figure 18.

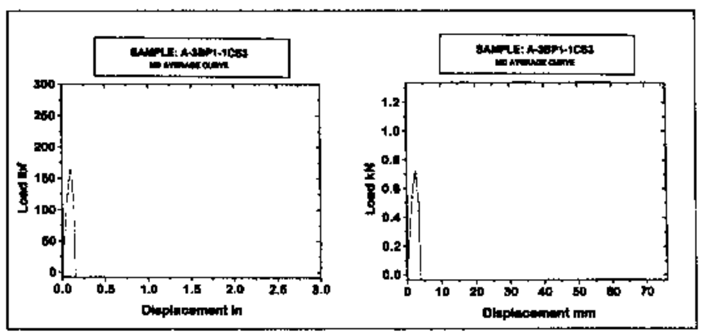

Figure 19.

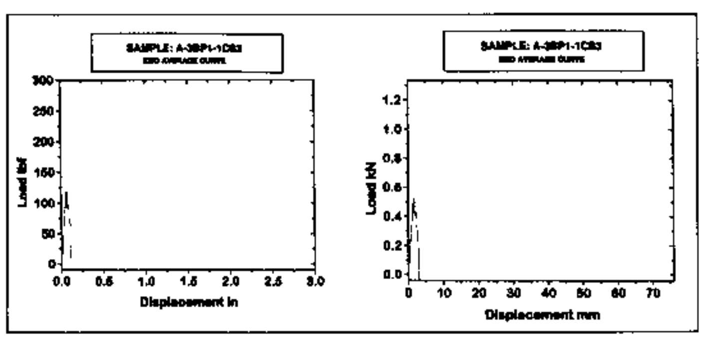

Figure 20.

ther investigation of different types of roofing membranes, including built-up roofing.

REFERENCES

1. *Commercial Low-Slope Roofing Materials Guide*, 1996 Edition, National Roofing Contractors Association, Rosemont, Illinois, 1996.
2. Mathey, Robert G. and William C. Cullen. "Preliminary Performance Criteria for Bituminous Membrane Roofing," 12 pages, National Bureau of Standards (U.S.), Building Science Series 55, November 1974.
3. ASTM D 5147, "Standard Test Methods for Sampling and Testing Modified Bituminous Sheet Materials," *Annual Book of ASTM Standards*, Vol. 04.04, ASTM, Philadelphia, Pennsylvania, 1996.
4. Dupuis, Rene M. "Applying 'strain energy' to Test Modified Bitumens," *RSI* magazine, August 1987, 32-38.
5. Rossiter, Walter J., Jr. and Dale P. Bentz. "Strain Energy of Bituminous Built-Up Membranes: An Alternative to the Tensile Strength Criterion," 41 pages, National Bureau of Standards (U.S.), NBSIR 86-3418, September 1986.
6. ASTM D 312, "Standard Specification for Asphalt Used in Roofing," *Annual Book of ASTM Standards*, Vol. 04.04,. ASTM, Philadelphia, Pennsylvania, 1996.
7. ASTM D 2523, "Standard Practice for Testing Load-Strain Properties of Roofing Membranes," *Annual Book of ASTM Standards*, Vol. 04.04, ASTM, Philadelphia, Pennsylvania, 1996.
8. ASTM D 2178, "Standard Specification for Asphalt Glass Felt Used in Roofing and Waterproofing," *Annual Book of ASTM Standards*, Vol. 04.04, ASTM, Philadelphia, Pennsylvania, 1996.

System Designation	Temperature, F (C)	Direction	Displace @ Max.Load, in. (mm)	Elongation @ Max.Load (%)	Load @ Max.Load lbf (N)	Maximum Displacement, in. (mm)	Maximum) Elongation (%)	Strain Energy, lbf-in/in (N-m/m)
A-1BP1-1CS1	73.4 (23.0)	md	2.08 (52.8)	42	95.4 (424.3)	2.15 (54.6)	43	57.8 (257.1)
	0 (-1.78)	md	1.51 (38.4)	30	115.8 (515.1)	1.55 (39.4)	31	48.5 (215.7)
	73.4 (23.0)	xmd	0.77 (19.6)	15	78.3 (348.3)	2.09 (53.1)	42	35.2 (156.6)
	0 (-17.8)	xmd	0.13 (3.3)	3	109.6 (487.5)	1.64 (41.7)	33	41.1 (182.8)
B-1BP1-1CS1	73.4 (23.0)	md	1.73 (43.9)	35	96.7 (430.1)	1.94 (49.3)	39	47.8 (212.6)
	0 (-1.78)	md	1.94 (49.3)	39	149.5 (665.0)	1.99 (50.5)	40	71.7 (318.9)
	73.4 (23.0)	xmd	2.36 (59.9)	47	56.9 (253.1)	2.81 (71.4)	56	43.4 (193.0)
	0 (-1.78)	xmd	2.75 (69.9)	55	104.8 (466.2)	2.83 (71.9)	57	73.0 (324.7)
C-1BP1-1CS1	73.4 (23.0)	md	1.28 (32.5)	26	92.3 (410.6)	1.78 (45.2)	36	41.1 (182.8)
	0 (-1.78)	md	0.73 (18.5)	15	132 (587.1)	1.64 (41.7)	33	54.6 (242.9)
	73.4 (23.0)	xmd	0.18 (4.6)	4	67.4 (299.8)	2.07 (52.6)	41	21.2 (94.3)
	0 (-1.78)	xmd	0.14 (3.6)	3	101 (449.2)	1.77 (45.0)	35	40.8 (181.5)
B-3BP1-1CS1	73.4 (23.0)	md	0.12 (3.0)	2	111.7 (496.8)	1.88 (47.8)	38	47.2 (209.9)
	0 (-1.78)	md	0.74 (18.8)	15	156.2 (694.8)	1.95 (49.5)	39	68.4 (304.2)
	73.4 (23.0)	xmd	0.16 (4.1)	3	99.4 (442.1)	3.5 (88.9)	70	61.3 (272.7)
	0 (-1.78)	xmd	0.12 (3.0)	2	160 (712.1)	2.8 (71.1)	56	68.3 (303.8)
C-3BP1-1CS1	73.4 (23.0)	md	0.72 (18.3)	14	99.2 (441.2)	1.81 (46.0)	36	42.5 (189.0)
	0 (-1.78)	md	0.14 (3.6)	3	208.2 (926.1)	1.89 (48.0)	38	69.1 (307.4)
	73.4 (23.0)	xmd	0.17 (4.3)	3	101 (449.2)	2.13 (54.1)	43	28.9 (128.5)
	0 (-1.78)	xmd	0.08 (2.0)	2	126.4 (562.2)	2.11 (53.6)	42	51.7 (230.0)
A-3BP1-1CS2	73.4 (23.0)	md	1.52 (38.6)	30	140.1 (623.2)	1.96 (49.8)	39	73.8 (328.3)
	0 (-1.78)	md	1.2 (30.5)	24	182.2 (810.4)	1.71 (43.4)	34	73.4 (326.5)
	73.4 (23.0)	xmd	0.17 (4.3)	3	108.3 (481.7)	1.67(42.4)	33	40.3 (179.3)
	0 (-1.78)	xmd	0.12 (3.0)	2	224.9 (1000.4)	1.82 (46.2)	36	68.1 (302.9)
A-1BP2-1BP1	73.4 (23.0)	md	2.12 (53.8)	42	121.7 (541.3)	2.21 (56.1)	44	77.5 (344.7)
	0 (-1.78)	md	0.64 (16.3)	13	179.1 (796.6)	1.58 (40.1)	32	69.2 (307.8)
	73.4 (23.0)	xmd	1.85 (47.0)	37	96.5 (429.2)	2.56 (65.0)	51	70.5 (313.6)
	0 (-1.78)	xmd	1.46 (37.1)	29	147.5 (656.1)	2.19 (55.6)	44	74.5 (331.4)
A-1BP3-1CS2	73.4 (23.0)	md	2.4 (61.0)	48	203.8 (906.5)	2.71 (68.8)	54	132.6 (589.8)
	0 (-1.78)	md	1.9 (48.3)	38	292.32 (1300.2)	2.4 (61.0)	48	167.1 (743.3)
	73.4 (23.0)	xmd	3 (76.2)	60	156.6 (696.6)	3.3 (83.8)	66	124.1 (552.0)
	0 (-1.78)	xmd	2.6 (66.0)	52	220.1 (979.0)	2.92 (74.2)	58	157.7 (701.4)
D-1BP2-1CS3	73.4 (23.0)	md	0.26 (6.6)	5	32.5 (144.6)	2.1 (53.3)	42	12.9 (57.4)
	0 (-1.78)	md	0.17 (4.3)	3	117.7 (523.5)	0.19 (4.8)	4	5.2 (23.1)
	73.4 (23.0)	xmd	0.21 (5.3)	4	47.8 (212.6)	2.11 (53.6)	42	14.6 (64.9)
	0 (-1.78)	xmd	0.18 (4.6)	4	117.8 (524.0)	0.49 (12.4)	10	6.4 (28.5)
A-3BP1-1CS3	73.4 (23.0)	md	0.2 (5.1)	4	127.4 (566.7)	0.94 (23.9)	19	5.8 (25.8)
	0 (-1.78)	md	0.12 (3.0)	2	186.2 (828.2)	0.16 (4.1)	3	5.2 (23.1)
	73.4 (23.0)	xmd	0.15 (3.8)	3	97.2 (432.3)	0.74 (18.8)	15	4.9 (21.8)
	0 (-1.78)	xmd	0.09 (2.3)	2	140.7 (625.8)	0.17 (4.3)	3	3.0 (13.3)

Table 3.