

EPDM ROOF MEMBRANES: LONG TERM PERFORMANCE REVISITED

by

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INTRODUCTION

Ethylene-propylene-diene-terpolymer (EPDM) membranes were introduced into the single-ply roofing market in the mid 1960's. EPDM continues to be the number one roofing membrane of architects, roof consultants and contractors for both new construction and replacement roofing projects.¹ Due to the chemical structure of EPDM, the material is inherently ozone resistant as compared to other rubber materials.² Additionally, the material is intrinsically resistant to most acids and bases (alkali). EPDM is mixed into complex rubber formulations to improve the physical and mechanical properties of the base material. Carbon black is added to provide reinforcement, which serves to enhance the physical and mechanical properties of the formulation, and to improve UV resistance. Processing oils improve processability and the flexibility of the membrane at low temperatures. Curatives are mixed in the formulation to facilitate vulcanization or cross-linking of the rubber. Chemical cross-linking serves to improve the heat and solvent resistance, increase the hardness, tensile strength, modulus and tear strength of the compound. Since EPDM polymers are hydrocarbons, proprietary ingredients can be incorporated into the rubber formulation to impart fire resistance.

The long-term performance of a roofing material is dependent upon its resistance to the combined effects of water, UV radiation, ozone, heat and thermal cycling. Additionally, the design of the roof system and site location can serve to exploit or diminish the impact of the environmental factors. In 1985, Strong and Puse reviewed several EPDM aging

and weathering studies.³ EPDM samples (80 *mils* thick) were aged for 10 years in a tropical environment. The samples were relatively unaffected by the humid conditions. After ten years, a 25% decrease in tensile strength and ultimate elongation was observed. Samples (40 *mils* thick) exposed 10 – 15 years in subtropical Florida conditions displayed a 25 % reduction in tensile strength after 15 years, and a 50 % decrease in ultimate elongation after 10 years. The tensile strength and percent elongation of exposed and ballasted rooftop samples aged seven years were compared at various test temperatures (-20 – 80 °C). The results indicate a relatively small decrease in tensile strength and a greater loss in ultimate elongation over the test temperature range for the exposed sample.

Gish and Lusardi studied the aged properties of 45 *in situ* roof samples cut from various roof systems ranging in age from 5 to 17 years.⁴ In general, an increase in tensile strength, tear resistance, brittleness temperature, Shore A hardness and a reduction in ultimate elongation as compared to unaged samples were observed. No difference was observed in the glass transition temperature or appearance of the aged membrane as compared to the unaged samples. The aged properties of 8 – 9 year old ballasted membranes were comparable to those of exposed (adhered) membranes with the exception of ultimate elongation. Exposed membranes suffered the greatest decrease in ultimate elongation (25 – 40 % reduction for 5 – 12 year samples, 54 % for the 17 year samples). A less pronounced reduction in the ultimate elongation (12 – 40 % for 5 – 10 year samples) was observed for the ballasted membranes. Eighty-seven percent of the samples were observed to exceed the ASTM and MRCA ME-20 specifications for new membranes.^{5,6} All samples were observed to exceed the ASTM and MRCA ME-20 requirements for heat aged membranes.

The purpose of this study is to revisit and extend the Gish/Lusardi study to include performance of aged EPDM membranes, which have been in service for the past 16 – 26 years. Field samples of ballasted and exposed membranes have been collected by two major manufacturers of EPDM roofing membrane and submitted to an independent laboratory for testing. In this paper we report on the findings.

EXPERIMENTAL

Samples of EPDM membrane (approx. 6' x 4.5') were cut from existing (in service) roofs. A one square inch sample was cut from the sample membrane for optical studies. The substrate and adhesive from exposed samples was carefully removed. A total of 33 samples representing 9 states were obtained from commercial roofing systems (not experimental). Roof systems include: fully adhered (22), ballasted (10) and non-penetrating mechanically fastened (1).

The samples were submitted to Architectural Testing Inc., York, Pa, an independent third party laboratory. The samples were tested in the machine direction according to ASTM D 412 and D624 for tensile strength, ultimate elongation and tear resistance.^{7,8} Median values for all test results are reported.

Optical studies were performed on an American Optical Binocular Stereomicroscope, Model Forty at 10 X magnification.

Optical micrographs were recorded at 190 X magnification utilizing a Zeiss Stemi 2000 stereomicroscope equipped with a COHU High Performance CCD Camera, Model Number 4915-51001/0000. Five discrete measurements were obtained, and the median value is reported.

Photographs were recorded with an Olympus Camedia C-700 Digital Camera.

PHYSICAL PROPERTY TEST RESULTS

Physical property test results are separated into two categories; results for exposed membranes and ballasted membranes. Exposed membranes were obtained from primarily fully adhered roof systems with one non-penetrating mechanically fastened system. The physical property results are presented visually in Appendix A, Figures 1 – 6. Each bar represents a specific roof. Actual values are presented in Tables 1 and 2.

TENSILE STRENGTH

The tensile strength for ballasted membranes ranged from 10.8 – 14.9 MPa (1560 – 2160 psi) (Figure 1) and from 9.4 – 13.5 MPa (1350 – 1950 psi) for exposed membranes (see Figure 2). The ASTM D 4637 minimum requirement for new sheet is 9.0 MPa (1305 psi) and 8.3 MPa (1205 psi) for heat aged samples. MRCA ME-20 requires new membranes to meet a minimum of 6.0 MPa (850 psi), and 5.5 MPa (800 psi) for aged membranes. All samples were observed to meet the minimum ASTM and MRCA specifications for new membrane, and well exceed the requirements for heat-aged samples.

ULTIMATE ELONGATION

The ultimate elongation values observed for ballasted membranes ranged from 290 – 370 % (Figure 3) and from 150 – 320 % (Figure 4) for exposed membranes. The ASTM D 4637 minimum requirement for new sheet is 300% and 200 % for heat-aged samples. MRCA ME-20 requires new membranes to meet a minimum of 250 %, and 200 % for aged membranes. All ballasted samples were found to meet the minimum ASTM and MRCA for new and aged membranes. Most exposed membranes examined did not meet the minimum ASTM (21/23) and MRCA ME-20 (17/23) requirements for new membranes. Twelve samples were observed to exceed the minimum requirements for heat-aged samples.

TEAR RESISTANCE

Tear resistance values for ballasted membranes ranged from 45.8 to 65.0 kN/m (261.7 – 371.2 lbf/in) and from 38.1 to 50.5 kN/m (217.7 – 288.2 lbf/in) for exposed membranes. The ASTM D 4637 minimum requirement for new sheet is 26.3 kN/m (150 lbf/in) and 21.9 kN/m (125 lbf/in) for heat-aged samples. MRCA ME-20 requires a minimum of 21.0 kN/m (120 lbf/in) for new membranes. There is no MRCA ME-20 requirement for aged membrane. All samples were observed to meet the minimum ASTM and MRCA ME-20 requirements for new membranes and all ASTM requirements for heat-aged samples.

Physical Properties of Ballasted Membranes

Sample	Location (State)	Age (years)	Gauge (mils)	Tensile Strength (MPa)	Elongation (%)	Tear Resistance (kN/m)
ASTM D 4637 New (Heat Aged)			<u>40</u> (40)	<u>9.0</u> (8.3)	<u>300</u> (200)	<u>26.3</u> (21.9)
1	GA	18	45	13.7	340	49.2
2	VA	20	45	13.7	330	50.9
3	MI	21	45	12.1	300	45.8
4	IL	21	45	14.0	360	56.1
5	OH	21	45	14.1	360	52.4
6	OH	22	45	13.3	370	62.0
7	MI	23	45	12.9	340	54.9
8	OH	23	45	13.2	360	55.4
9	IA	23	45	14.2	330	65.0
10	OH	23	45	14.9	290	60.4

Table 1 – Physical Properties of Ballasted Membranes.

OPTICAL STUDIES AND MEASUREMENTS

Weathering resistance was assessed by visual inspection according to ASTM D 4637. No crazing (network of fine surface cracks) was observed for ballasted membranes, regardless of age. About one-half (12/23) of the exposed membranes exhibited some degree of crazing, when examined under magnification. Crazing was not observed without the aid of magnification. (See Figure 7)

In order to measure the width of any observed crazing, optical micrographs of the membrane samples were obtained. The results can be found in Table 3. The width of the measured artifacts ranged from 0.00059 to 0.0017 inches.

Physical Properties of Exposed Membranes

Sample	Location (State)	Age (years)	Gauge (mils)	Tensile Strength (MPa)	Elongation (%)	Tear Resistance (kN/m)
ASTM D 4637 New (Heat Aged)			<u>40</u> (40)	<u>9.0</u> (8.3)	<u>300</u> (200)	<u>26.3</u> (21.9)
11	IA	16	60	13.5	270	47.6
12	WI	17	45	9.7	180	48.8
13	FL	17	60	10.1	150	41.6
14	WI	17	45	10.5	230	46.3
15	FL	17	60	11.2	180	38.1
16	MI	17	60	11.4	220	45.0
17	MI	17	60	11.5	320	50.5
18	MI	17	60	11.7	290	45.7
19	MI	17	60	12.9	300	49.0
20	WI	18	60	10.4	190	44.9
21	MI	18	60	11.0	240	44.2
22	OH	18	60	12.4	240	47.4
23	GA	19	45	9.5	150	44.7
24	FL	17	60	11.1	180	42.4
25	WI	19	60	11.4	270	45.4
26	MI	20	60	9.4	160	41.3
27	MI	20	60	10.2	180	40.8
28	MI	20	60	10.9	170	43.2
29	WI	20	60	11.3	190	42.2
30	OH	21	60	10.9	230	48.5
31	OH	22	60	9.7	180	48.5
32	PA	24	60	10.7	290	45.0
33	PA	26	60	12.4	230	46.2

Table 2 – Physical Properties of Exposed Membranes.

Weathering Resistance of Exposed Membranes

Sample	Location (State)	Age (years)	Crazing	Size (inches)
11	IA	16	No	
12	WI	17	No	
13	FL	17	No	
14	WI	17	No	
15	FL	17	No	
16	MI	17	Yes	0.00092
17	MI	17	No	
18	MI	17	No	
19	MI	17	No	
20	WI	18	Yes	0.00092
21	MI	18	Yes	0.00092
22	OH	18	Yes	0.00084
23	GA	19	No	
24	FL	19	No	
25	WI	19	No	
26	MI	20	Yes	0.00076
27	MI	20	Yes	0.00092
28	MI	20	Yes	0.00076
29	WI	20	No	
30	OH	21	Yes	0.00059
31	OH	22	Yes	0.0011
32	PA	24	Yes	0.00092
33	PA	26	Yes	0.0017

Table 3 – Weathering Resistance of Exposed Membranes.

DISCUSSION OF RESULTS

As can be seen by examination of Figure 1, the tensile strength for the ballasted membranes remained relatively constant without regard to the age of the membrane. The ultimate elongation and tear resistance values (Figures 2 and 3 respectively) displayed the same trends, i.e. no significant deterioration of the physical properties has been observed in up to 23 years of service life. These results are comparable to those obtained by Gish and Lusardi in 1991.⁴

The same general trend is observed for tensile strengths (Figure 4) and tear resistance values (Figure 6) for the exposed membranes. However, a significant decrease in the ultimate elongation (Figure 5) was observed. Although no significant decrease in the physical properties of the exposed membrane as compared to the ballasted membrane was observed in the Gish/Lusardi study, the results observed in the current study are

consistent with the accelerated weathering model presented in the Gish/Lusardi paper. As per the model, a decrease in the ultimate elongation is observed after 3000 hours of accelerated weathering, while the tensile strength displays a slight decrease.⁴

It is attractive to attempt to compare the aged results to those obtained for newly manufactured membranes, however such comparisons are difficult for a variety of reasons. The formulations used today are not necessarily comparable to those produced 17 – 25 years ago. The industry has seen the development of new polymerization catalysts used to produce EPDM. These catalysts allow for the design of polymers specifically engineered for the single-ply roofing industry. Additionally, advances in the technology of other ingredients have resulted in the improvement of membrane properties. These advances in polymer and ingredient technology have resulted in subtle changes in the physical properties and processability of the resulting rubber formulations. For these reasons, the best comparison is data gleaned from the Gish/Lusardi study, which reports typical original properties for the fourth quarter of 1983.⁴

The typical membrane properties are displayed in Table 4. The tensile strength and tear resistance of ballasted and exposed membranes in this study are consistent with or slightly higher than the 1983 data. The increase in the tensile strength and tear resistance is likely due to post vulcanization cross-linking at rooftop temperatures. The decrease in ultimate elongation is consistent with the accelerated weathering model discussed above. Additionally, the decrease in ultimate elongation is in agreement with the data reviewed by Strong and Puse as discussed in the introduction to this paper.³

Typical Original Membrane Properties 4th Quarter, 1983.

Property	Membrane Mean	Typical Range
Tensile Strength (MPa)	11.7	11.4 – 12.2
Ultimate Elongation (%)	500	450 – 550
Tear Resistance (kN/m)	40.3	36.8 – 42.0

Table 4 – Typical Original Membrane Properties 4th Quarter, 1983.⁴

CONCLUSIONS

The results obtained in this study confirm the outstanding field aging performance of EPDM membranes. The tensile strength and tear resistance data obtained for both ballasted and exposed roofs exceed the ASTM D 4637 specifications new and heat aged membranes after 17 – 26 years of service life.^{5,6} Although a number of samples cut from exposed roofs displayed ultimate elongations below the ASTM D 4637 specifications for heat aged membrane, it is important to remember these EPDM membranes can still stretch to almost twice their dimensions. Additionally, in all roof systems sampled, the membranes were found to be watertight and functional. The tensile strength and tear resistance of the exposed systems are consistent with respect to age. The decrease in the

ultimate elongation and surface crazing are expected observations after long-term exposure to weathering. For black EPDM, we believe that the reduction in elongation is primarily due to heat aging and the observed crazing results from exposure to the UV portion of solar radiation. The physical properties of the ballasted membranes remain constant with respect to age. The data obtained in this study indicates the membranes will continue to function and remain watertight for years to come.

ACKNOWLEDGMENTS

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APPENDIX A

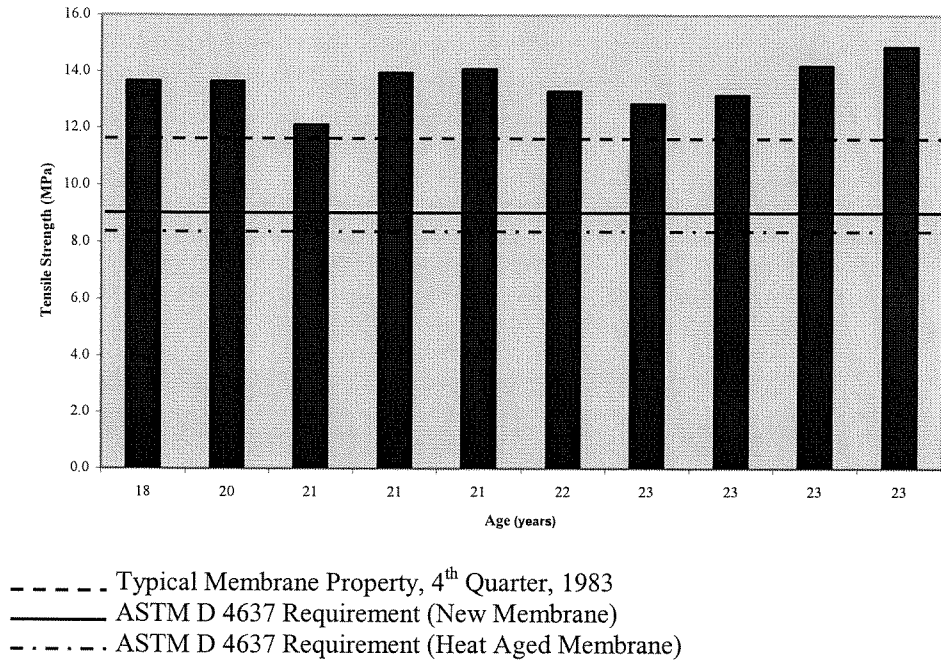


Figure 1 – Tensile Strengths of Ballasted Samples

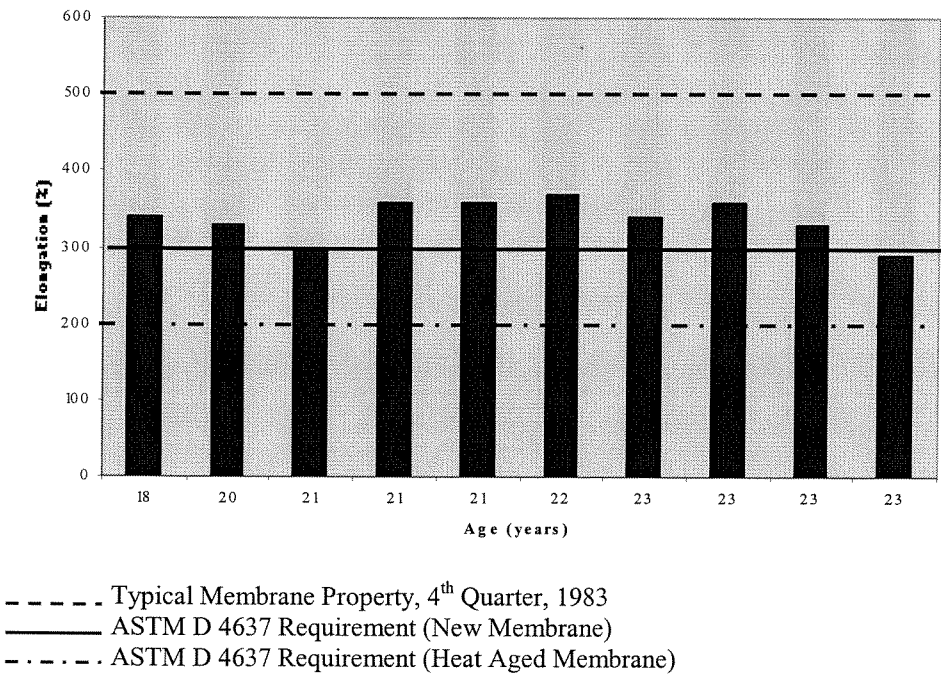
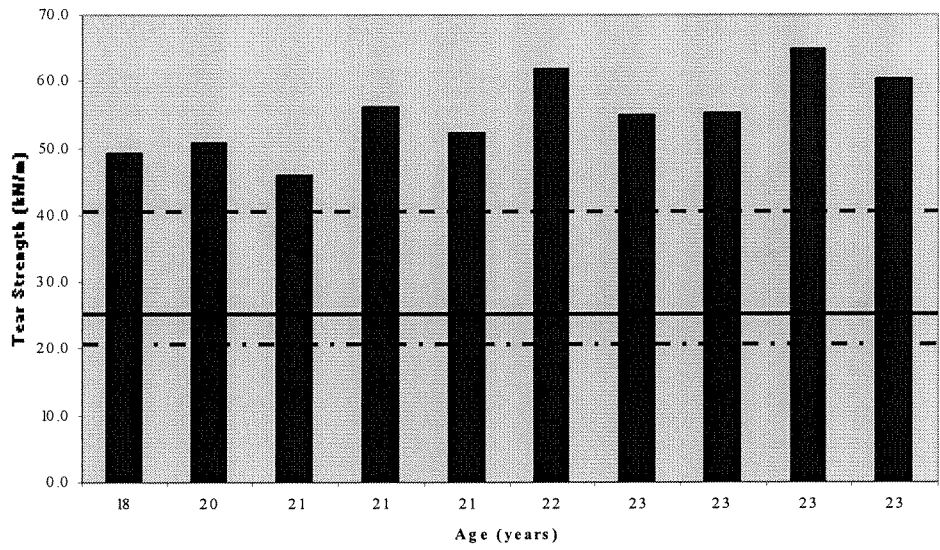
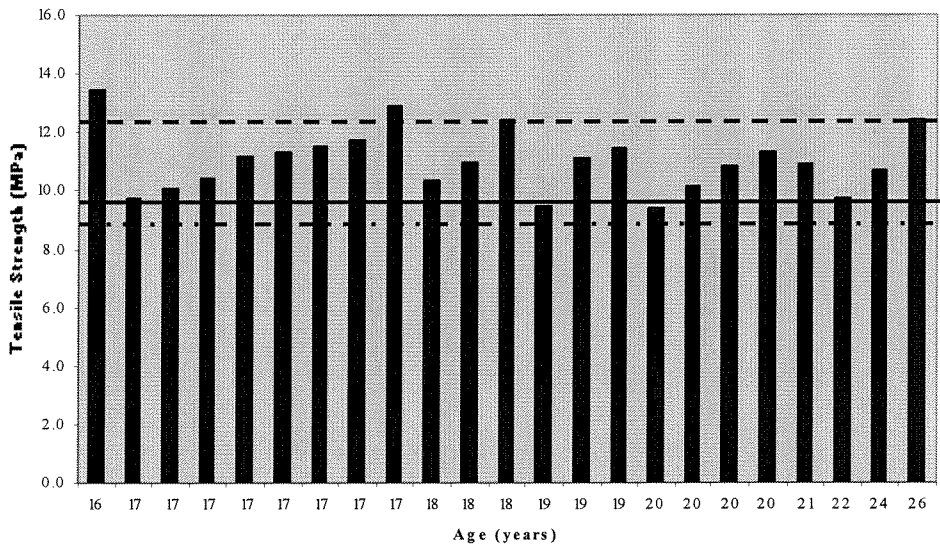


Figure 2 – Ultimate Elongations of Ballasted Samples



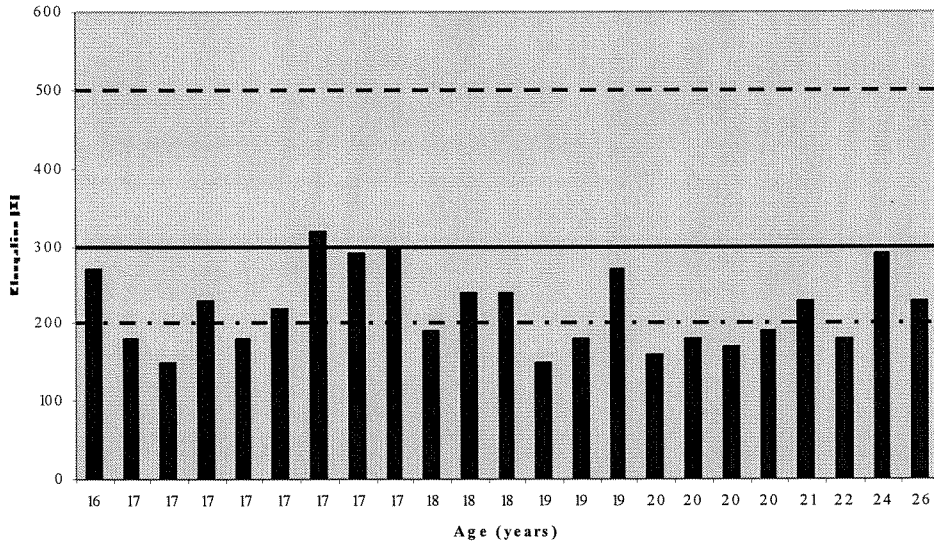
- Typical Membrane Property, 4th Quarter, 1983
- ASTM D 4637 Requirement (New Membrane)
- ASTM D 4637 Requirement (Heat Aged Membrane)

Figure 3 – Tear Resistances of Ballasted Samples



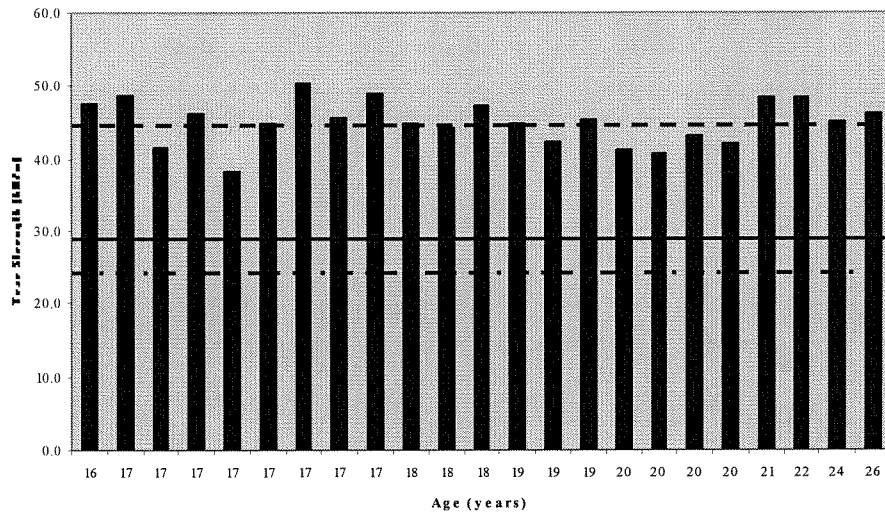
- Typical Membrane Property, 4th Quarter, 1983
- ASTM D 4637 Requirement (New Membrane)
- ASTM D 4637 Requirement (Heat Aged Membrane)

Figure 4 – Tensile Strengths of Exposed Samples



- Typical Membrane Property, 4th Quarter, 1983
- ASTM D 4637 Requirement (New Membrane)
- .-.-.-.- ASTM D 4637 Requirement (Heat Aged Membrane)

Figure 5 – Ultimate Elongations of Exposed Samples



- Typical Membrane Property, 4th Quarter, 1983
- ASTM D 4637 Requirement (New Membrane)
- .-.-.-.- ASTM D 4637 Requirement (Heat Aged Membrane)

Figure 6 – Tear Resistances of Exposed Samples

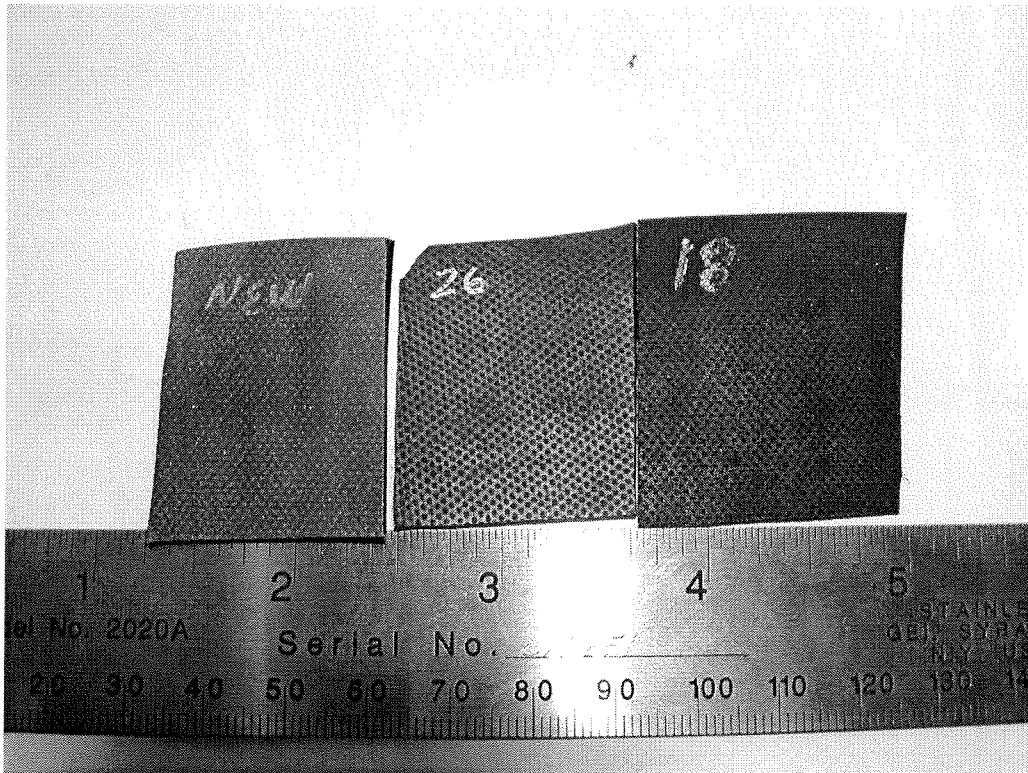


Figure 7 – Surface Photograph of New Membrane, Exposed Membrane (26 years old), and Ballasted Membrane (18 years old).

¹ *Building Design and Construction* and the National Roofing Contractors Association (NRCA) 2002-2003 market surveys, 2003.

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³ Strong, A. G., Puse, J. W., Proc. 2nd Intl. Symposium on Roofing Technology, Chicago, IL, 1985, pp 376 – 381.

⁴ Gish, B. D., Lusardi, K. P., Proc. 3rd Intl. Symposium on Roofing Technology, Montreal, CA, 1991, pp 159-166.

⁵ Annual Book of ASTM Standards, Volume 04.04, American Society for Testing and Materials, Philadelphia, PA., 2003.

⁶ Midwest Roofing Contractors Association, Recommended Performance Criteria for Elastomeric Single-Ply Roof Membrane Systems, Kansas City, MO., 1982.

⁷ Annual Book of ASTM Standards, Volume 09.01, American Society for Testing and Materials, Philadelphia, PA., 2003.

⁸ Annual Book of ASTM Standards, Volume 09.02, American Society for Testing and Materials, Philadelphia, PA., 2003.