WEATHERING TESTS FOR EPDM RUBBER SHEETS FOR USE IN ROOFING APPLICATIONS

BRIAN D. GISH and THOMAS L. JABLONOWSKI

Representing the Rubber Manufacturers Association
Washington, D.C.

The long-term performance of EPDM rubber sheets for use in roofing applications depends on the membranes' resistance to ozone cracking; embrittlement or softening from heat aging; water absorption; low-temperature brittleness; solar ultraviolet (UV) radiation and other factors, such as acid rain and industrial fallout. There has been general consensus about what test methods and physical properties are necessary for high-quality EPDM rubber sheets in the domestic market. The only exception to this is a test requirement for UV resistance. Test methods and requirements for EPDM (excluding UV resistance) are specified by the ANSI/RMA IPR-1 and IPR-2 American National Standards.[1]

The Rubber Manufacturers Association (RMA) Roofing Council[2] agreed to provide the time and funding to study the UV weathering resistance of EPDM by establishing a Weathering Test Program in February 1984. The RMA Roofing Technical Committee[3] was charged with the responsibility of establishing and monitoring the program with the following objectives:

- To establish a correlation between indoor and outdoor weathering tests
- To develop a recommendation for a proposed weathering test to be specified in industry standards, based on results obtained
- To relate the results of indoor and outdoor weathering tests with known experience of a reference material.

This paper reports on the RMA Weathering Test Program from the specific testing details to the results obtained from the study. The paper establishes recommendations for weathering tests for *black* EPDM rubber sheets for industry standards. The results of the weathering test program for black EPDM were conclusive and the objectives of the test program were met. Correlation was established for black EPDM rubber sheets between laboratory weathering tests and outdoor Florida weathering.

The weathering of *white* rubber sheets is being investigated further by the RMA Roofing Technical Committee. The Weathering Test Program results for white EPDM were not as conclusive as for black, and additional program work is planned.

THE WEATHERING TEST PROGRAM

Sample selection for exposure and testing

The members of the Roofing Technical Committee who market EPDM sheets were asked to submit *unidentified* samples of commercially available, non-fabric reinforced membrane. From all of the submitted sheets, one black and one white EPDM membrane were randomly chosen for testing and are henceforth referred to only as *black* and *white.*

Another black EPDM sheet, used as a control, was made from a known formulation with a 20-year history of proven weather performance.[4] In the referenced study, this control-based formulation was exposed to Florida 45° south outdoor exposure under no strain for 20 years starting in 1961, with physical properties determined every five years. The sample made from this control formulation is henceforth referred to only as *control.*

Sample preparation

The *white, black,* and *control* samples were cut into specimens for weathering exposure. The specimen size was approximately 2 inches by 8 inches or 2 inches by 12 inches, depending on the weather exposure apparatus. The lengthwise direction of the specimen was parallel to the machine-processing direction of the sample. Either 2-inch or 4-inch-wide "benchmarks" were placed on each specimen to allow precise measurement of the 50 percent elongation (strain) under which half the specimens were to be exposed.

The specimens for outdoor weathering were mounted on kiln-dried white oak boards, while the specimens for laboratory weathering were mounted on exterior-grade plywood covered with aluminum foil. The specimens were divided into two groups: one group was mounted under no strain (0 percent elongation), and the other group was mounted with 50 percent strain (50 percent elongation).

Weather exposure test conditions

The mounted specimens were exposed to four types of weather/UV exposure:

Xenon-arc weathering apparatus (ASTM G26) XENON

Filter type:	Borosilicate inner and outer
Exposure:	0.35W/m² @340 nm
Cycle:	690 minutes light; 30 minutes light and water spray
Black panel temp:	80±3°C
Relative humidity:	50±5%
Spray water:	Deionized
Spray nozzle:	F-80
Specimen rotation:	Every 250 hours
Exposure time:	500, 1000, 1500, 2000, 2500, 3000, 3500, 4000 hours

Fluorescent UV—condensation apparatus (ASTM G53) UV-COND

Lamp type:	Fluorescent UVB-313 (UVB-B)
Test cycle:	20 hours UV at 80°C 4 hours condensation at 50°C
Exposure time:	500, 1,000, 1500, 2000, 2500, 3000, 3500, 4000 hours

South Florida direct inland weathering FLORIDA 45 S

Location:	12 miles southwest of Homestead, Fla.
Sample positioning:	45°south
Exposure time:	3, 6, 9, 12, 18, 24 months with corresponding total irradiance of 1534, 4290, 4980, 6276, 9429, and 12505 MJ/m^2

Concentrated natural sunlight (ASTM D 4141) CONC SUN

Location:	New River, Ariz.
Equipment:	Fresnel reflecting concentrator with 10 mirrors, equitorial mount that follows the sun
Spray water:	Night-time only
Exposure time:	19, 44, 61, 93, 132 days with corresponding total irradiance of 4000, 8000, 12000, 16273, and 20000 MJ/m^2

Note: 1 MJ/m^2 is equivalent to 23.8 Langleys of solar radiation or 88 BTU/ft^2 of energy.

Specimen inspection and testing

The specimens were inspected after each exposure period for general appearance, chalking, cracking, and crazing. Tensile strength and ultimate elongation were measured using ASTM Test Method D412. The tear resistance was measured using ASTM Test Method D624, but is not discussed because the values did not decrease with weather exposure, until severe deterioration occurred with the white specimens.

PHYSICAL PROPERTY TEST RESULTS

The results of the tensile strength and ultimate elongation testing are shown in the Tables. The approach selected to evaluate the physical property changes after weathering is the *percent retained fractional strain energy* (PRFSE). The fractional strain energy is a measure of the aged tensile strength and elongation compared to the original tensile strength and elongation.

$$PRFSE = \frac{(\text{Tensile strength x ultimate elongation})_{\text{aged}}}{(\text{Tensile strength x ultimate elongation})_{\text{original}}} \times 100$$

As an example, note that the control specimen exposed to Florida 45° south weathering under no strain (Table 3) had an original tensile strength of 1625 psi and an elongation of 450 percent. After an exposure period of 24 months, the tensile strength was 1780 psi with an elongation of 370 percent. The PRFSE for the control under the above stated exposure condition is 90.

$$PRFSE = \frac{(1780X370)}{(1625X450)} (\times\ 100 = 90)$$

The values for the PRFSE are plotted for the control in Figures 1, 4, and 7; for the black in Figures 2 and 5; and for the white in Figures 3 and 6. The control formulation that was exposed for 20 years in Florida is shown in Figure 7.

VISUAL INSPECTION OF THE SPECIMENS

The specimens were inspected under no magnification after each exposure period. The black and control specimens did not show any indication of surface deterioration by either cracking, crazing, or chalking while examined unstrained; however, very slight cracking was seen on the control exposed under 50 percent strain, after 3500 hours Xenon-arc exposure. The white specimens began to chalk early in the program with crazing becoming more pronounced as the exposure periods increased. The Xenon-arc and Florida 45° south exposures produced the greatest amount of surface deterioration in the white specimens (chalking and crazing), with the Fluorescent UV-Condensation producing chalking and crazing to a lesser extent. Concentrated Natural Sunlight produced chalking but no crazing on the white specimens.

DISCUSSION AND CONCLUSIONS

Single-ply polymer-based sheets, including the rubbers and thermoplastics, must be properly formulated to withstand the degradative effects of weathering, particularly from UV radiation. Resistance to UV deterioration is not an intrinsic property of the polymers used in the roof sheet; the polymer must be protected by the judicious selection of UV-absorptive compounding ingredients. It is most important to select the proper weathering tests to identify any deficiencies that the sheet may have to long-term weather resistance.

It is possible to note some general conclusions or trends that are evident from the exposure data:

- After extended aging, the EPDM sheet tensile strength and elongation (and, therefore, its fractional strain energy) is reduced. As shown in Figure 7, the control EPDM's retained fractional strain energy after 20 years of Florida 45° south exposure was reduced to 25 percent, but its tensile strength (1350 psi) and elongation (200 percent) indicate the potential for additional years of useful service life.
- Relatively short weather exposure can actually increase the membrane's retained fractional strain energy, perhaps by increasing the membrane's state of cure.
- Florida 45° south exposure is more severe than Concentrated Natural Sunlight for either equivalent total solar radiation or the UV portion of the total radiation. Concentrated Natural Sunlight has the advantage, though, for accelerated UV testing because the specimen is exposed to more radiation per unit of time. It required more than 18 months (548 days) of Florida 45° south exposure to equal the 462 MJ/m^2 of UV radiation that the specimens received after 132 days of Concentrated Natural Sunlight exposure (Table 1).
- The specimens exposed to Florida 45° south weathering under 50 percent strain had lower retained fractional strain energy than those exposed to Florida 45° south under no strain. The differential between 50 percent strain and no strain is less pronounced for the other weathering tests.
- Xenon-arc and Fluorescent UV-Condensation caused essentially comparable reductions in retained fractional strain energy.
- Surface deterioration after weathering of the white specimens was much greater that that of the black and control specimens (Fig. 8). Crazing and chalking occurred during Florida 45° south, Xenon-arc, and Fluorescent UV-Condensation on the white specimens. The 80° C black body temperature used in the Xenon-arc and the 80° C chamber temperature used in the Fluorescent UV-Condensation test is higher than rooftop temperatures for white membranes, and this may be too severe a test to evaluate long-term weathering characteristics.

- The black and control specimens had very similar PRFSE curves for outdoor and laboratory weathering. The prediction can be made that the black specimen would have similar aging characteristics as the control specimen on the 20-year Florida exposure.
- Comparing the PRFSE curves for the control for the 20-year Florida exposure (Fig. 7) with those of the Fluorescent UV-Condensation and Xenon-arc shows the 4000-hour PRFSE values to be comparable to the 15-year mark of the Florida exposure.

RECOMMENDATIONS

The correlation of real-time weathering to short-term accelerated weather testing has been and will continue to be a topic for study and debate; however, the technology and equipment does exist to determine the general weather resistance of EPDM rubber sheets.

The RMA Roofing Technical Committee recommends the following weathering test(s) for black EPDM sheets to be used in industry standards:

Xenon-arc weathering apparatus (ASTM G26)

Filter type:	Borosilicate inner and outer
Exposure:	0.35 W/m^2 @340 nm
Cycle:	690 minutes light; 30 minutes light plus water spray
Black panel temp:	80±3°C
Relative humidity:	50±5%
Spray water:	Deionized
Spray nozzle:	F-80
Specimen rotation:	Every 250 hours
Exposure time:	4000 hours

or

Fluorescent UV-condensation apparatus (ASTM G53)

Lamp type:	Fluorescent UVB-313 (UVB-B)
Test cycle:	20 hours UV at 80°C 4 hours condensation at 50°C
Exposure time:	4000 hours

After exposure, remove specimen and inspect under 7X magnification, while specimen is under 10 percent strain (10 percent elongation). Also die out ASTM D412 tensile specimens and determine tensile strength and ultimate elongation. Compare original tensile strength and elongation with the aged tensile strength and elongation, and calculate the percent retained fractional strain energy (PRFSE):

$$\text{PRFSE} = \frac{(\text{Tensile strength x ultimate elongation})\ \text{aged}}{(\text{Tensile strength x ultimate elongation})\ \text{original}} \times 100$$

Pass/fail criteria

Visual inspection shall show no cracks or crazing.

The PRFSE shall be a minimum of 30, and the aged ultimate elongation shall be a minimum of 200 percent.

REFERENCES

[1] The RMA Roofing Council. ANSI/RMA IPR-1 Minimum Requirements for Non-reinforced Black EPDM Rubber Sheets for Use in Roofing Applications and IPR-2 Minimum Requirements for Fabric-reinforced Black EPDM Rubber Sheets for Use in Roofing Applications, by RMA, Washington, D.C. (August 1985)

[2] RMA Roofing Council Member Companies:
Carlisle SynTec Systems, Division of Carlisle Corp.
Colonial Rubber Works, Inc.
Firestone Building Products Co.
Gates Engineering Co., Inc.
Goodyear Tire & Rubber Co., The
J.P. Stevens & Co., Inc.
Uniroyal Plastics Co., Inc.

[3] RMA Roofing Technical Committee Participants:
Ashland Chemical Co.
Carlisle SynTec Systems, Division of Carlisle Corp.
Colonial Rubber Works, Inc.
DiversiTech General, Inc. Subsidiary of GenCorp.
E.I. DuPont de Nemours & Co.
Firestone Building Products Co.
Gates Engineering Co., Inc.
Goodyear Canada, Inc.
Goodyear Tire & Rubber Co., The
J.P. Stevens & Co., Inc.
Lord Corp.
Manville Service Corp.
Polysar, Inc.
Protective Coatings, Inc.
Reeves Brothers, Inc.
SYEnergy Methods, Inc.
Uniroyal Chemical Co., Inc.
Uniroyal Plastics Co., Inc.

[4] E.I. DuPont de Nemours & Co. "Weather Resistance of Black Compounds Based on Nordel Hydrocarbon Rubber," by M.A. Shoenbeck, Wilmington, Del. (January 1982).

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DEFINITIONS

Several terms used in this paper have definitions that may be different from common usage. These words are defined as follows:

Chalking: the formation of a powdery residue on the surface of a rubber resulting from surface degradation (ASTM D1566).

Crack (atmospheric): fissures, originating in the surface of a rubber vulcanizate resulting from weathering (ASTM D1566).

Crazing: network of apparent fine cracks on or beneath the surface of materials (ASTM E284, partial).

Fissure: a surface split or crack (ASTM D1566).

Ozone cracks: fissures originating in the surface of a rubber vulcanizate under strain, resulting from exposure to an ozone-containing environment. Note—These cracks are perpendicular to the direction of strain (ASTM D1566).

Sample: the portion or unit(s) selected to represent the lot (ASTM D1566).

Specimen: a piece of material appropriately shaped and prepared so that it is ready to use for a test (ASTM D1566).

Strain: the unit change, due to force, in the size or shape of a body referred to its original size or shape (ASTM D1566).

Ultimate elongation: the elongation at the time of rupture (ASTM D1566).

Vulcanizate: the product of vulcanization; a crosslinked rubber (ASTM D1566).

Water absorption: the amount of water absorbed by a material under specified test conditions (ASTM D1566).

Weathering: surface deterioration of a rubber article during outdoor exposure (ASTM D1566).

Aging test	Exposure time	Irradiation total	(MJ/m^2) UV only	No strain			50% Strain		
				Elongation (%)	Tensile (PSI)	PRFSE	Elongation (%)	Tensile (PSI)	PRFSE
Unaged				520	1855	100	520	1855	100
Florida 45S	3M	1534	73	560	1735	101	435	2045	92
	6M	4290	144	510	1810	96	435	2080	94
	9M	4980	219	480	1800	90	410	2080	88
	12M	6276	282	480	1840	92	395	2050	84
	18M	9429	419	425	1845	81	330	1990	68
	24M	12505	562	430	1860	83	310	1960	63
CONC SUN	19D	4000	110	550	1780	101	460	2040	97
	44D	8000	242	500	1720	89	425	2000	88
	61D	12000	394	480	1800	90	400	2180	90
	93D	16273	451	460	1850	88	395	1960	80
	132D	20000	462	435	1800	81	390	2140	87
UV-COND	500H	53*	52*	385	1765	70	380	2115	83
	1000H	106	103	420	1850	81	395	2155	88
	1500H	159	155	390	1750	71	370	2165	83
	2000H	213	206	360	1960	73	320	2095	70
	2500H	266	258	320	1720	57	330	2110	72
	3000H	319	310	290	1670	50	270	2040	57
	3500H	372	361	290	1620	49	280	1980	57
	4000H	425	413	250	1480	38	230	1820	43
XENON	500H	711*	72*	435	1800	81	370	2200	84
	1000H	1422	144	395	1840	75	340	2210	78
	1500H	2133	216	385	1900	76	330	2250	77
	2000H	2844	288	345	1800	64	290	2120	64
	2500H	3555	360	385	1760	70	310	2180	70
	3000H	4266	432	305	1680	53	275	1890	54
	3500H	4977	504	280	1460	42	245	1890	48
	4000H	5688	576	325	1460	49	255	1950	52

*Total and UV irradiance are calculated, not measured.

Table 1 *Physical properties after weathering tests—black specimens*

Aging test	Exposure time	Irradiation total	(MJ/m^2) UV only	No strain			50% Strain		
				Elongation (%)	Tensile (PSI)	PRFSE	Elongation (%)	Tensile (PSI)	PRFSE
Unaged				500	1745	100	500	1745	100
Florida 45 S	3M	1534	73	515	1780	105	415	2065	98
	6M	4290	144	520	1780	106	410	2125	100
	9M	4980	219	520	1550	92	400	2030	93
	12M	6276	282	530	1420	86	400	1780	82
	18M	9429	419	490	1330	75	375	1710	73
	24M	12505	562	490	1330	75	340	1610	63
CONC SUN	19D	4000	110	520	1680	100	460	1970	104
	44D	8000	242	520	1680	100	450	1870	96
	61D	12000	394	490	1550	87	410	1900	90
	93D	16273	451	515	1740	103	410	1860	87
	132D	20000	462	480	1550	85	365	1840	77
UV-COND	500H	53*	52*	500	1620	93	495	1840	104
	1000H	106	103	440	1480	75	435	1510	75
	1500H	159	155	465	1565	83	470	1580	85
	2000H	213	206	490	1510	85	450	1490	77
	2500H	266	258	460	1350	71	485	1530	85
	3000H	319	310	310	840	30	290[1,2]	1130[1,2]	38
	3500H	372	361	320[2]	860[2]	32	205[1,2]	700[1,2]	16
	4000H	425	413	140[2]	540[2]	9	80[1]	380[1]	3
XENON	500H	711*	72*	505	1600	93	455	1840	96
	1000H	1422	144	530	1510	92	400	1780	82
	1500H	2133	216	480	1360	75	365	1820	76
	2000H	2844	288	500	1340	77	395	1690	77
	2500H	3555	360	520	1360	81	400	1720	79
	3000H	4266	432	510	1120	65	160[1]	190[1]	3
	3500H	4977	504	120	250	3	490[1]	440[1]	25
	4000H	5688	576	430	520	25	—[1]	—[1]	—

[1]Sample broke during exposure [2]Value uncertain due to wide spread in test results
*Total and UV irradiance are calculated, not measured.

***Table 2** Physical properties after weathering tests—white specimens*

Aging test	Exposure time	Irradiation total	(MJ/m²) UV only	No strain Elongation (%)	No strain Tensile (PSI)	No strain PRFSE	50% Strain Elongation (%)	50% Strain Tensile (PSI)	50% Strain PRFSE
Unaged				450	1625	100	450	1625	100
Florida 45S	3M	1534	73	405	1660	92	370	1925	97
	6M	4290	144	405	1685	93	325	1890	84
	9M	4980	219	400	1760	96	300	1870	77
	12M	6276	282	430	1730	102	295	1900	77
	18M	9429	419	375	1790	92	235	1870	60
	24M	12505	562	370	1780	90	210	1690	49
CONC SUN	19D	4000	110	450	1730	106	410	1910	107
	44D	8000	242	450	1740	107	315	1830	79
	61D	12000	394	425	1780	103	305	2040	85
	93D	16273	451	420	1860	107	295	1940	78
	132D	20000	462	390	1770	95	325	1960	87
UV-COND	500H	53*	52*	400	1680	92	400	1950	107
	1000H	106	103	370	1680	85	325	1860	83
	1500H	159	155	370	1700	86	350	1910	91
	2000H	213	206	320	1715	75	300	1920	79
	2500H	266	258	310	1680	71	300	1970	81
	3000H	319	310	220	1520	46	165	1820	41
	3500H	372	361	210	1430	41	180	1800	44
	4000H	425	413	190	1390	36	170	1760	41
XENON	500H	711*	72*	375	1690	87	350	2165	104
	1000H	1422	144	340	1630	76	305	2210	92
	1500H	2133	216	315	1640	71	300	2140	88
	2000H	2844	288	335	1720	79	210	2080	60
	2500H	3555	360	305	1580	66	270	2090	77
	3000H	4266	432	220	1460	44	165	1540	35
	3500H	4977	504	185	1330	34	160	1500	33
	4000H	5688	576	180	1360	33	170	1540	36

*Total and UV irradiance are calculated, not measured.

Table 3 *Physical properties after weathering tests—control specimens*

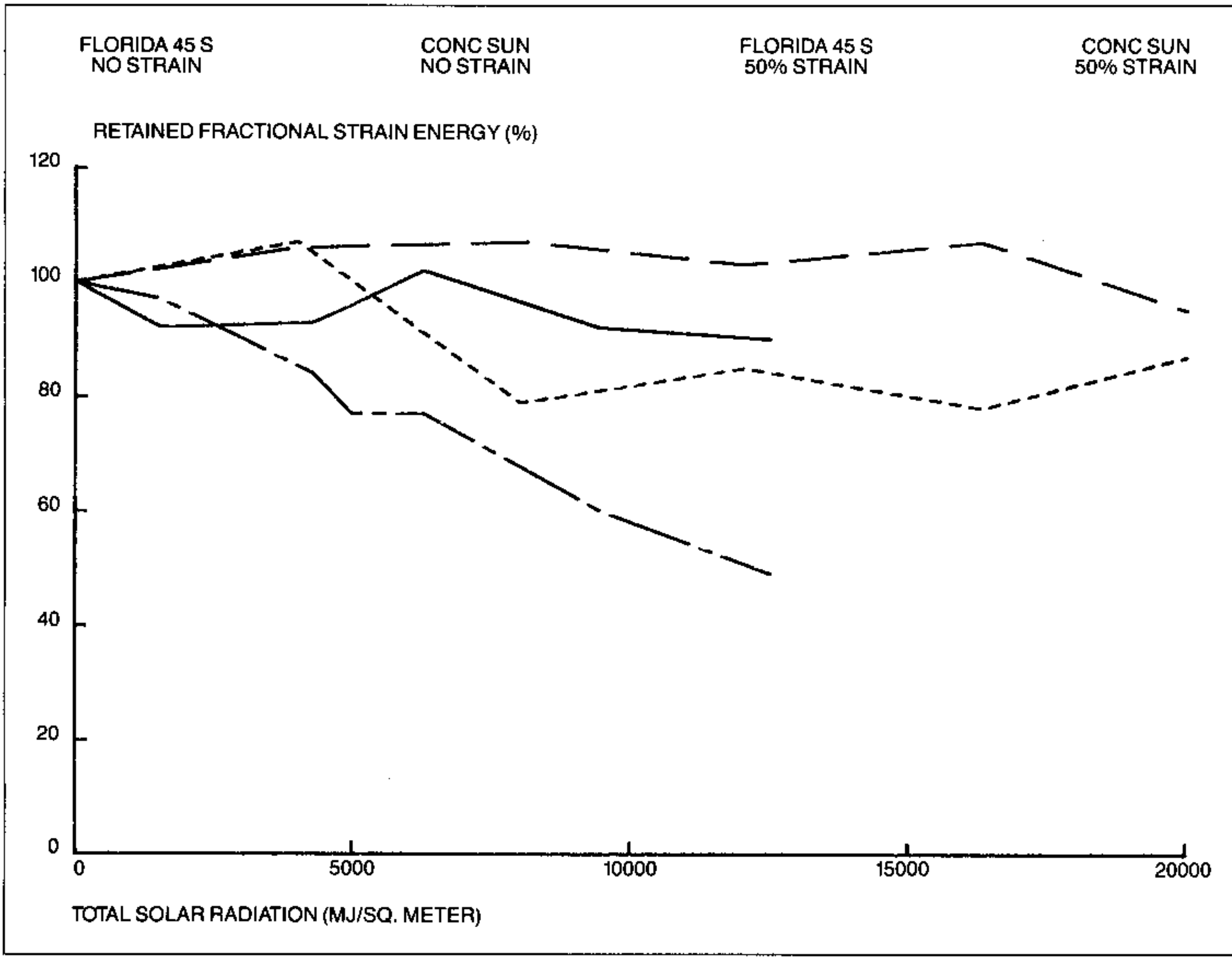

Figure 1 Control exposed to outdoor weathering

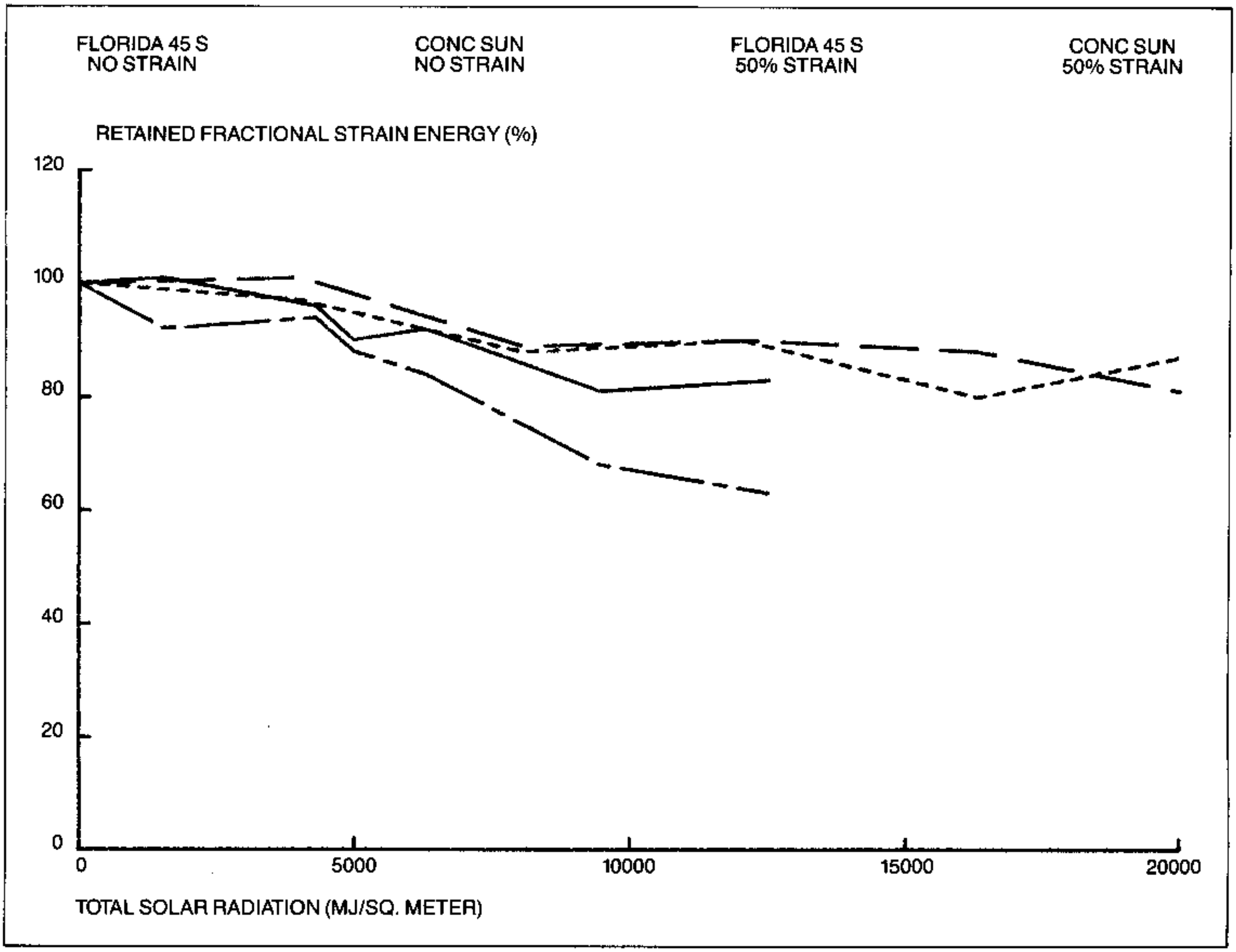

Figure 2 *Black exposed to outdoor weathering*

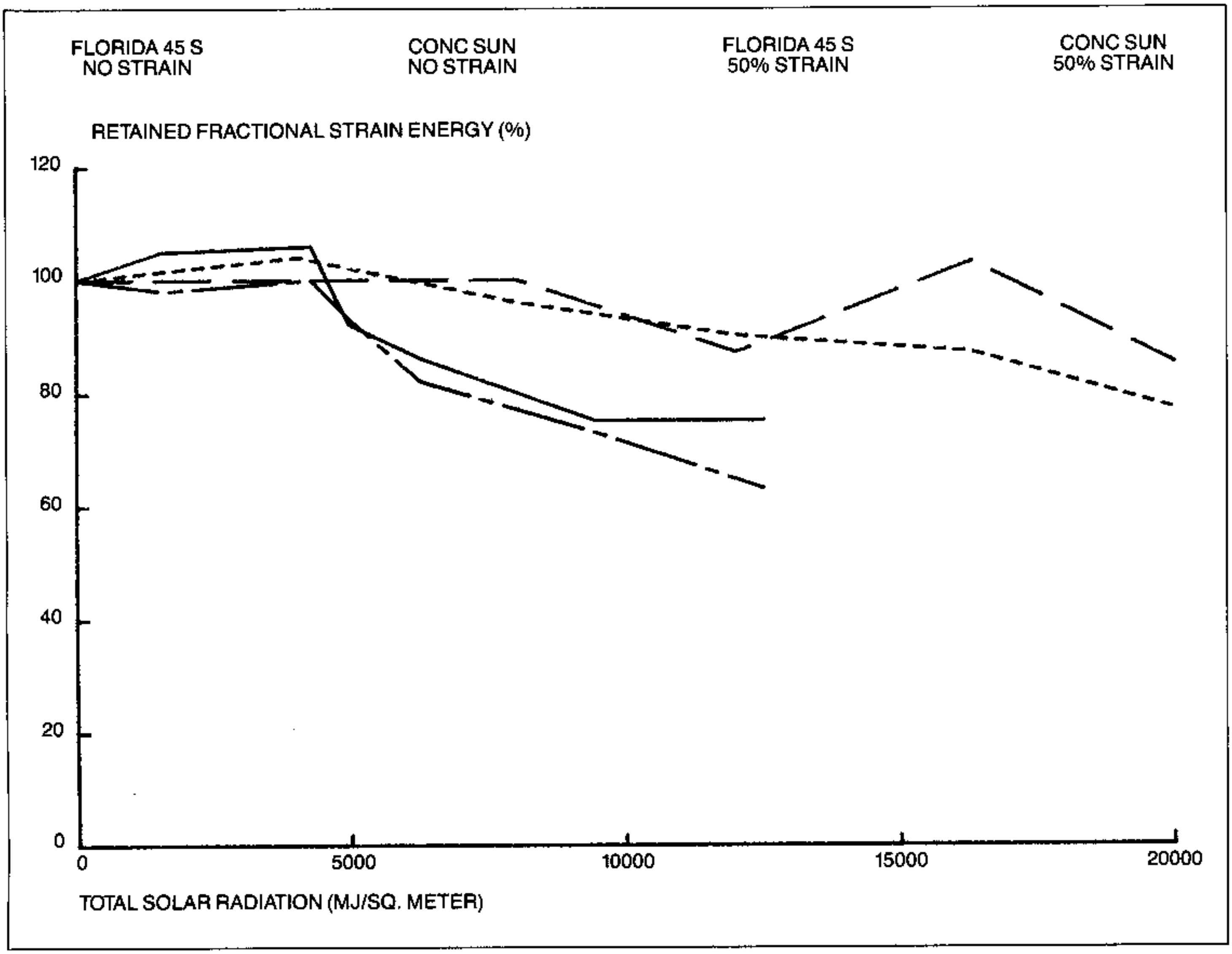

Figure 3 *White exposed to outdoor weathering*

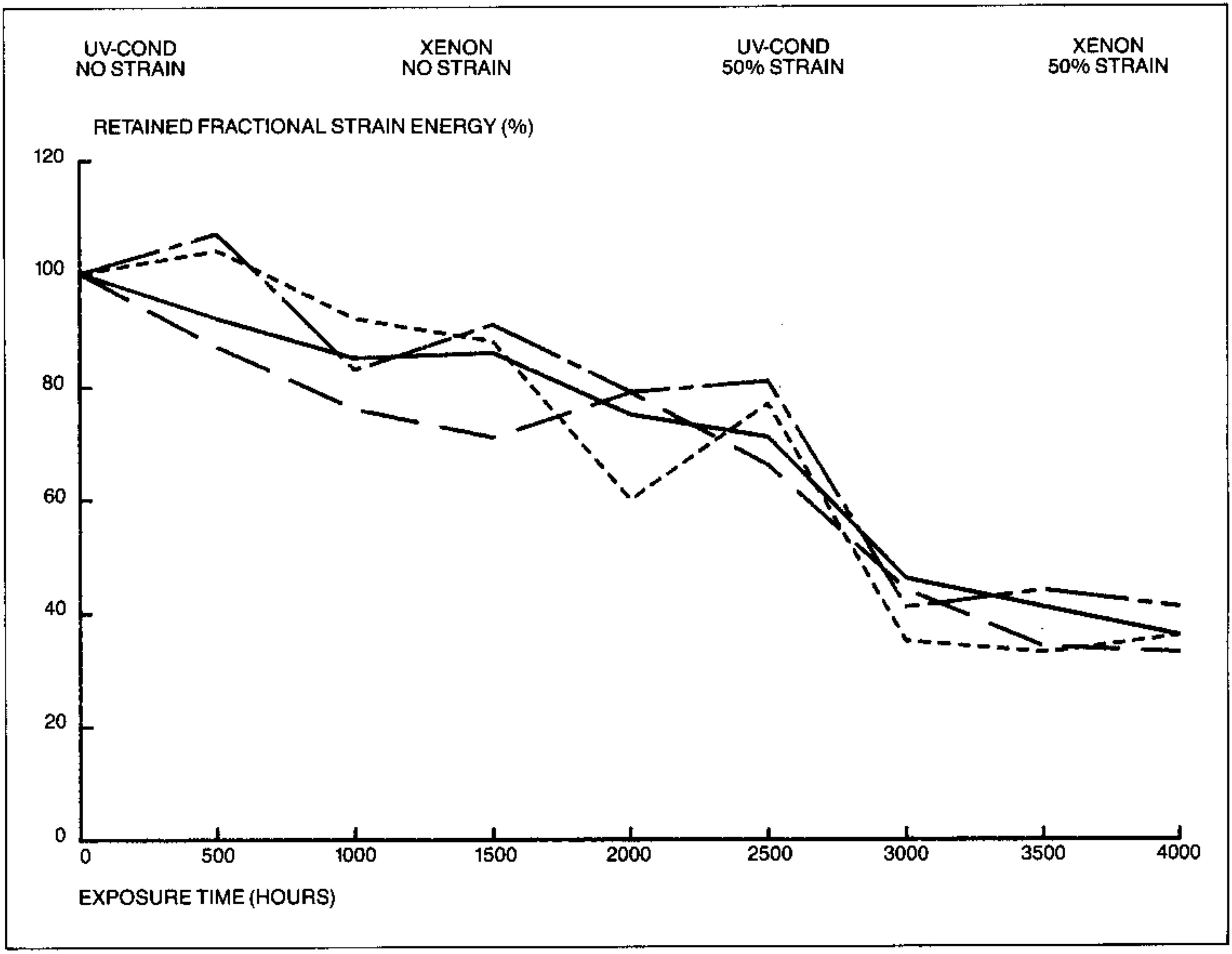

Figure 4 *Control exposed to laboratory weathering*

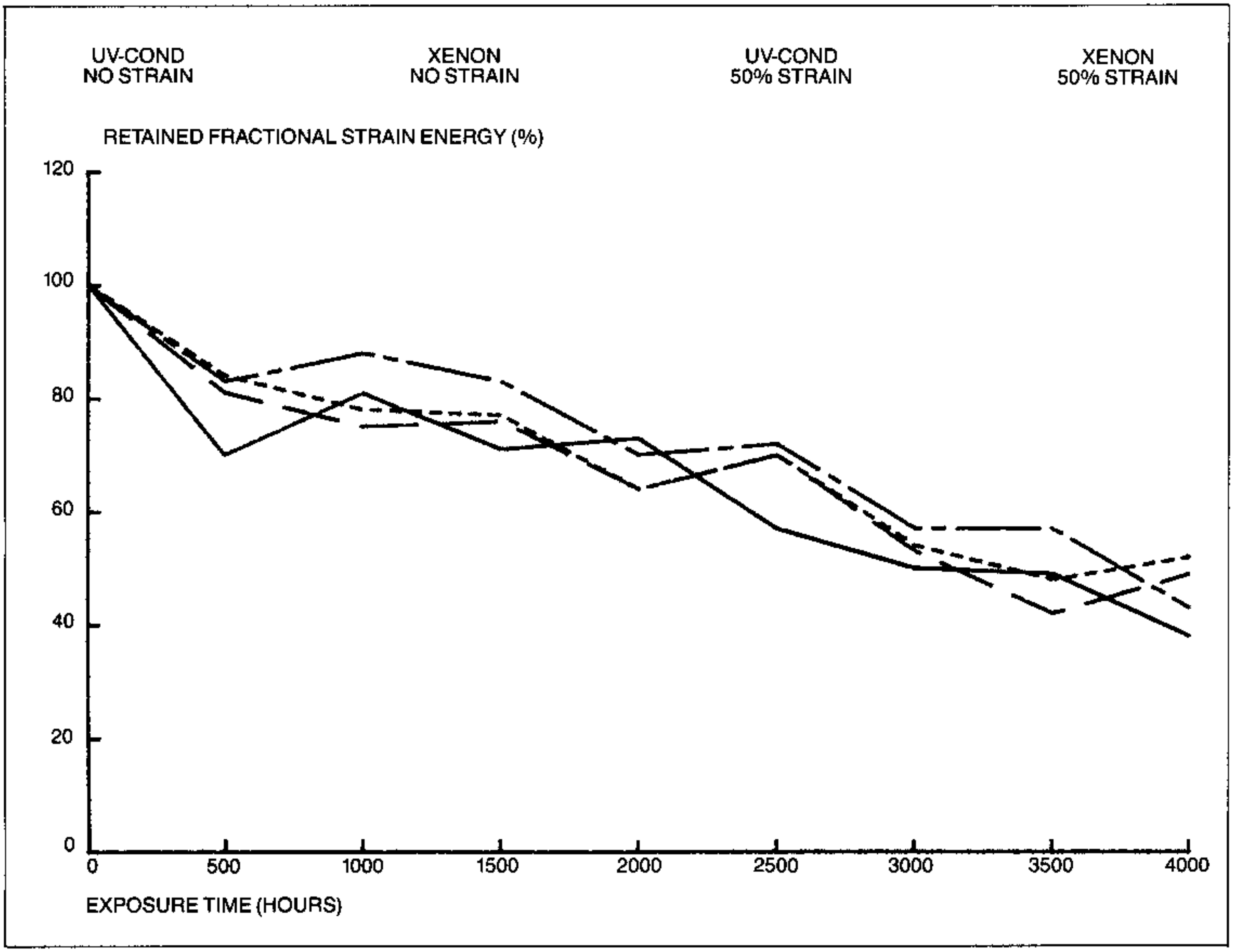

Figure 5 *Black exposed to laboratory weathering*

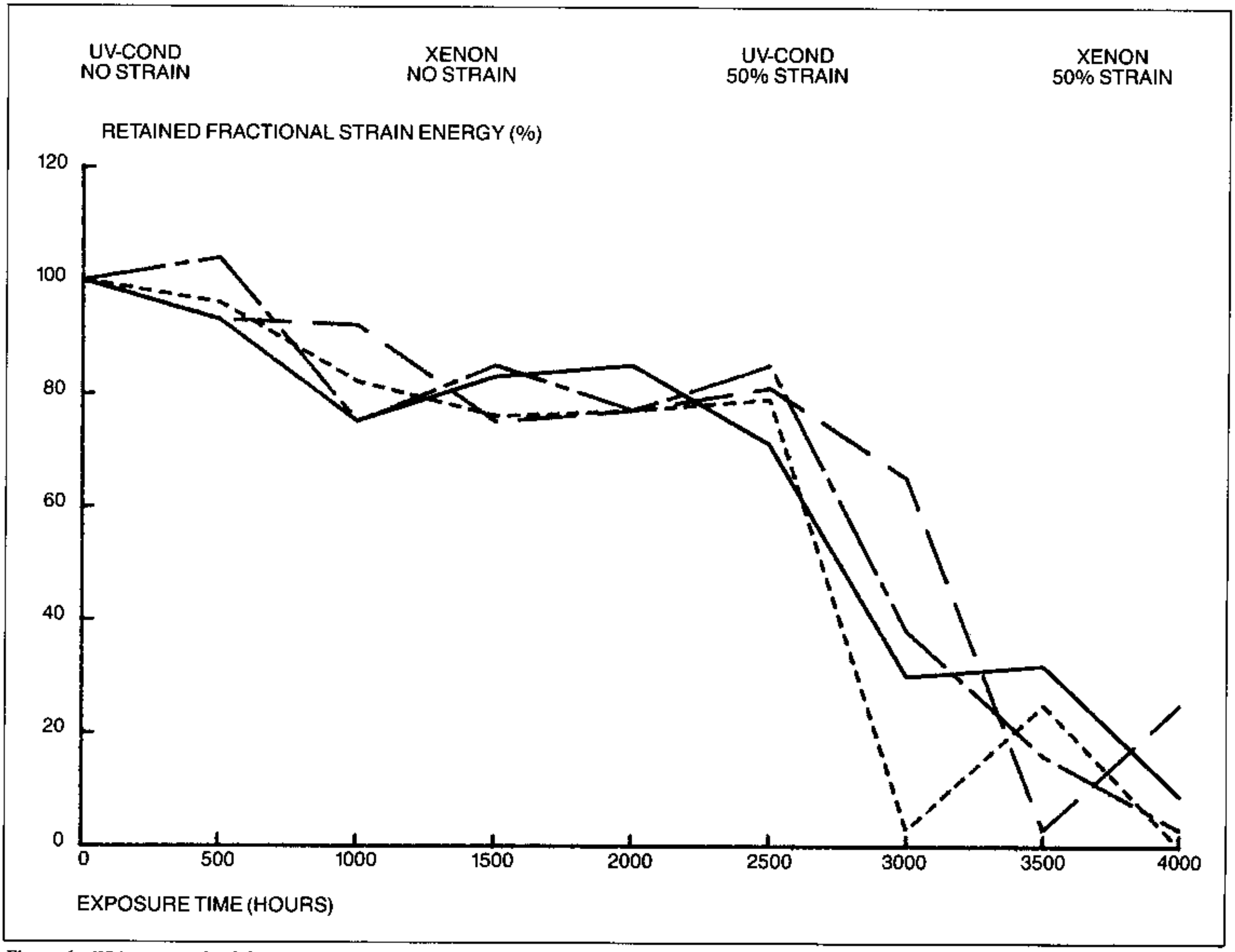

Figure 6 *White exposed to laboratory weathering*

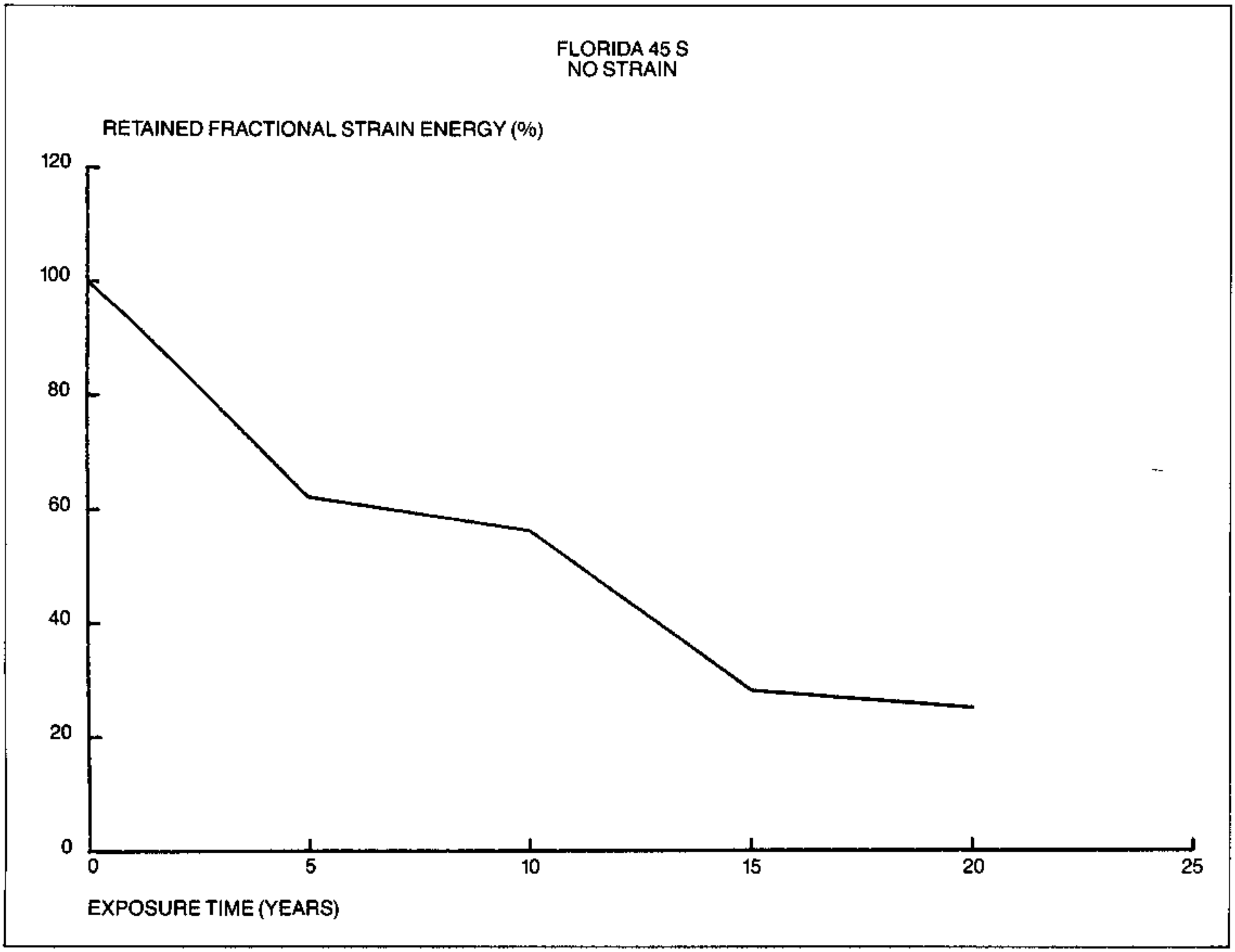

Figure 7 *Control exposed for 20 years in Florida*

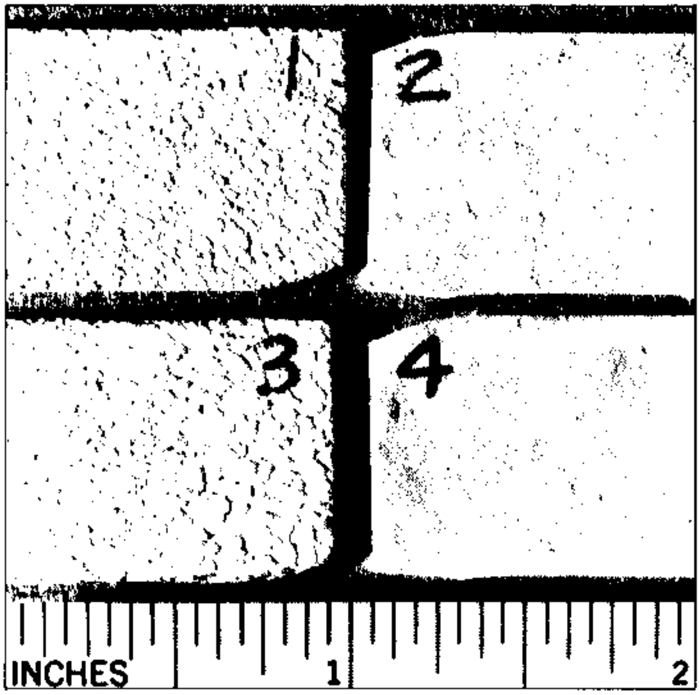

Figure 8 White specimens after exposure to weathering tests. Magnification is about 2×.
(1) 2 years in Florida 45 south outdoor
(2) 4000 hours in fluorescent UV-condensation
(3) 4000 hours in xenon-arc
(4) 132 days in concentrated natural sunlight

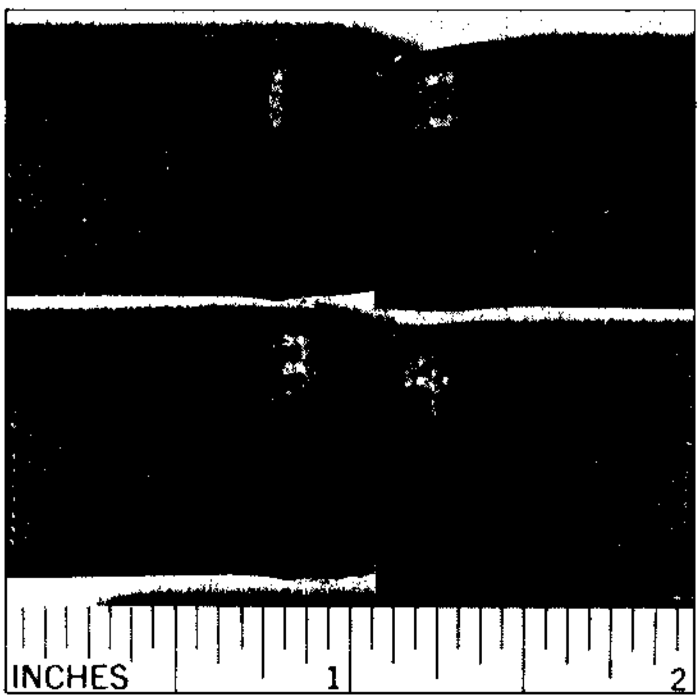

Figure 9 Black specimens after exposure to weathering tests. Magnification is about 2×.
(1) 2 years in Florida 45 south outdoor
(2) 4000 hours in fluorescent UV-condensation
(3) 4000 hours in xenon-arc
(4) 132 days in concentrated natural sunlight

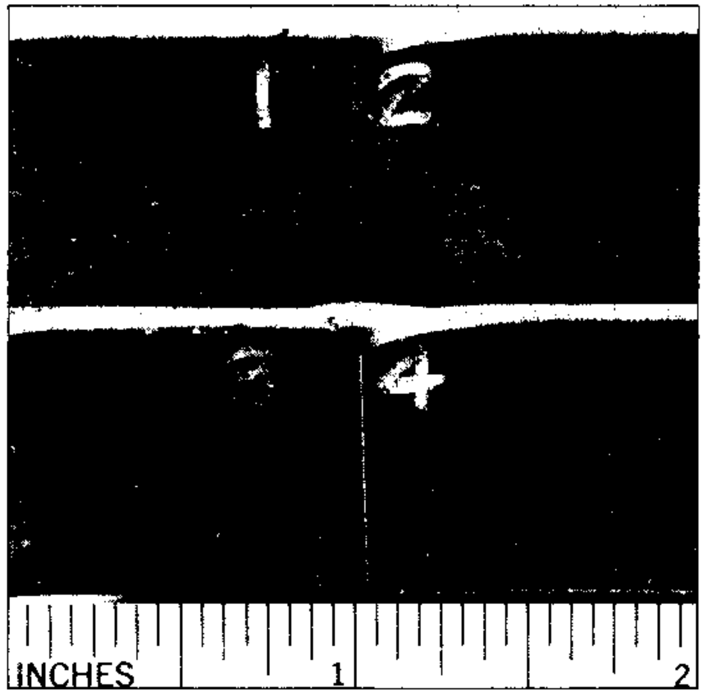

Figure 10 Control specimens after exposure to weathering tests. Magnification is about 2×.
(1) 2 years in Florida 45 south outdoor
(2) 4000 hours in fluorescent UV-condensation
(3) 4000 hours in xenon-arc
(4) 132 days in concentrated natural sunlight

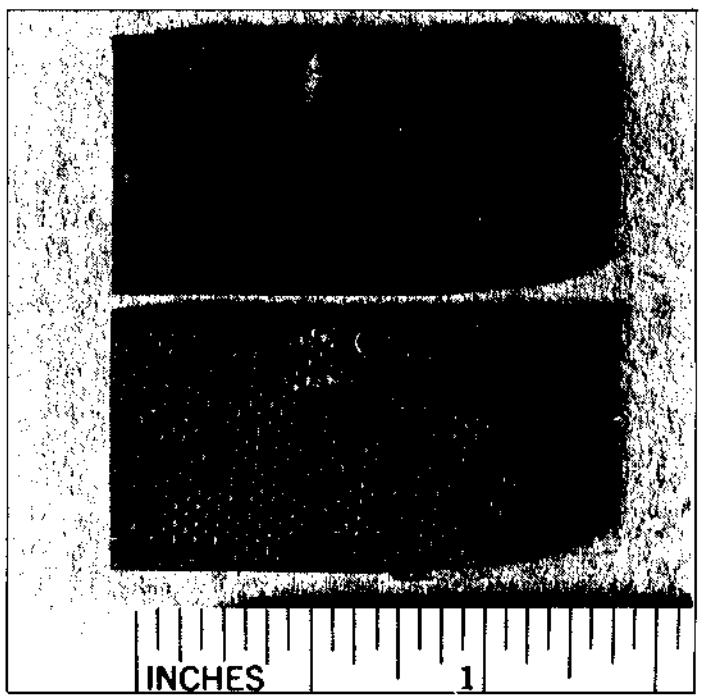

Figure 11 Control specimen (1) and black specimen (2) before aging. Magnification is about 2×.

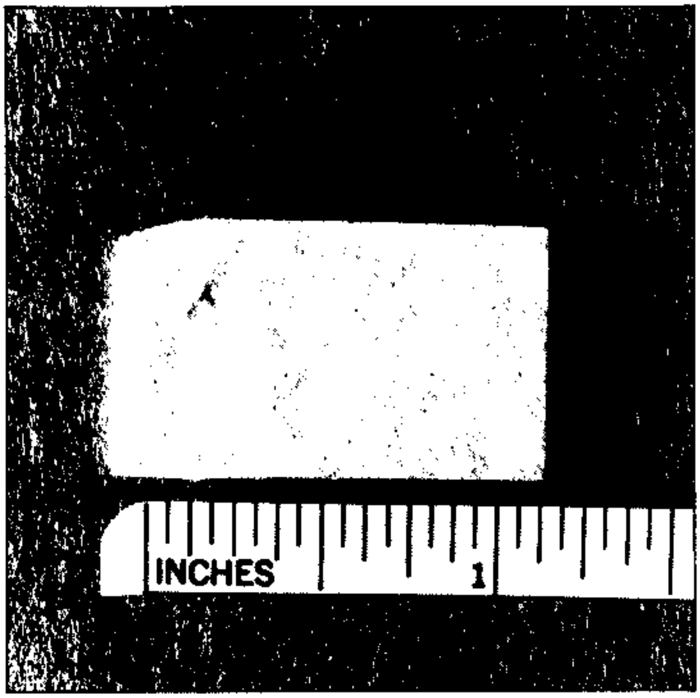

Figure 12 *White specimen before aging. Magnification is about 2×.*