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CABLE JACKET AGING STUDY: COMPARISON OF POLYETHER AND POLYESTER URETHANE MATERIALS

Lowell H. Jones

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CABLE JACKET AGING STUDY:
COMPARISON OF POLYETHER AND POLYESTER URETHANE MATERIALS

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Abstract

Accelerated aging experiments for up to 310 days duration were carried out on three polyester and three polyether urethane materials. The aging environments selected were (1) oven aging up to 100°C, (2) water immersion up to 70°C, (3) various combinations of relative humidity and temperature up to 100% R.H. and 50°C, and (4) 0.48% (by volume) NO₂ in air. The sample properties followed included (1) physical dimensions, (2) hardness, (3) weight, (4) ultimate elongation, (5) ultimate tensile strength, (6) 300% tensile modulus, and (7) adhesive bond strengths.

Dimensional and hardness measurements were not sensitive to sample degradation. Weight changes and the three tensile properties were more useful in following the degradation process. The results indicated that the polyesters are superior in both elevated temperature and NO₂ service; the polyethers are superior in water immersion and humid environments. Deterioration of the adhesive bond strength in the polyesters was more severe under humidity cycling.

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Table of Contents

	<u>Page</u>
I. INTRODUCTION	5
II. EXPERIMENTAL	6
Samples	6
Sample Preparation	6
Aging Procedures	7
Post Aging Procedures	8
III. RESULTS	9
Mechanical and Physical Changes	9
Adhesive Bonding	12
IV. CONCLUSIONS	13
V. REFERENCES	14
VI. DATA TABLES 1 THRU 9	15-37
VII. FIGURES 1 THRU 9	38-46

I. Introduction

Polyester and polyether based urethane materials are presently being used or being considered as cable jacketing materials in weapons applications. Polyester materials are known to degrade under elevated humidity conditions.^{1,3-6} At the request of R. S. Nelson, Division 2154, a program was initiated to compare the stability of the two types of materials under accelerated environmental conditions. The environments were chosen to simulate conditions to which the jacket materials might be exposed during either pre-weapon storage at a production facility or inside a finished weapon during its lifetime. These environments were then accelerated in an attempt to produce degradation within the one year time limit of the aging program. The environments included elevated temperatures, humidity, water immersion, and NO₂ gas. The upper temperature of 100°C was chosen because of indications in the literature that slightly higher temperatures produce rapid degradation.¹ The humidity tests were chosen as possible conditions which might occur during pre-weapon storage. The water immersion study was included as another method of accelerating the possible deteriorating effects of water on the materials. Since the oxides of nitrogen are often found as decomposition products of the high explosives present in weapons,² the effects of NO₂ gas on the materials were studied. Physical and mechanical properties were used to follow the aging process with time in the various environments. This report summarizes the results of this study.

The literature contains a number of references to studies on humidity and thermal aging of polyester and polyether urethanes.^{1,3-8} The majority of these studies were completed within 30 days. Changes in various physical and mechanical properties were used to monitor the aging process.

Some data also exists on the reaction of polyurethanes with NO₂ environments.^{9,10} In these reports very thin films of unfilled linear urethane polymers were exposed to NO₂ gas for up to one day periods at various temperatures and pressures. The results indicated that the urethane linkages are irreversibly severed. The present study concentrated on comparisons of filled commercial materials under thermal, humidity, water immersion and NO₂ environments. Periods of time up to one year were selected to allow lower and more realistic thermal stress levels to be utilized. Bond strength aging comparisons were also made.

II. Experimental

Samples

A cross section of commercially available polyester and polyether urethane materials for use as cable jackets was obtained from various manufacturers. Table I, which lists the materials used in this study, gives the manufacturer's designation, material type, thickness and material form. The Fair M polyester is presently used for cable jacket applications in weapons. The other formulations were evaluated as possible replacement jacket materials.

Sample Preparation

The unaged sheet and tube materials were cut into samples 3/4 inch wide by 1-1/2 inch long. Some of the 58092 polyester material was cut down to 0.025-0.035 inch thick samples to test the effect of thickness on the degradation rate. The physical properties of hardness, sample length, sample thickness, and weight were measured before aging. On each sample, the hardness and physical dimensions were obtained at three locations and the average number recorded. Hardness was measured with a Shore A

durometer to within one unit using a 1/2 inch thickness of unaged material as backing. Sufficient quantities of aged material were not available for use as backing materials as specified in the ASTM hardness testing procedure. The physical dimensions of length and thickness were measured to within 0.002 inches using a Helios Vernier caliper for length measurements and a Starrett dial indicator gauge for thickness measurements. The samples were weighed on a Mettler H-18 balance to approximately one milligram uncertainty.

Aging Procedures

Since a limited number of samples were available for aging, only one sample was aged for each time and environmental condition. At least three virgin samples of each material were used to establish the unaged parameters. The conditions selected for long term aging were:

- (1) thermal aging^{*}, 50°C, 70°C, and 100°C
- (2) water immersion at 25°C, 50°C, and 70°C
- (3) relative humidity (R. H.)
 - a. 100% at 23°C and 50°C
 - b. 50% at 50°C

The thermal aging studies were conducted in air circulating ovens set to the appropriate temperature. The water immersion studies used sealed glass jars containing distilled water placed in ovens at the desired temperature. The humidity studies used chambers of one cubic foot volume placed in ovens at temperature. The 50% relative humidity was obtained by using a super saturated salt solution of reagent grade sodium dichromate ($\text{NaCr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$) in distilled water inside the chamber. In all

^{*}The relative humidity at elevated temperature inside the ovens on the basis of ambient laboratory conditions of 23°C and 30% are approximately (1) 50°C - 7% R.H. (2) 70°C - 3% R.H. (3) 100°C - 1% R.H.

cases the oven controllers maintained the desired temperature to within $\pm 1^\circ\text{C}$.

For the NO_2 aging experiments, air containing 0.48% NO_2 by volume was flowed at 10 cc/minute through a 500 cc glass and stainless steel vessel containing the samples at 23°C . The gas was supplied by Airco Industrial Gas Company in aluminum cylinders.

Post Aging Procedures

After aging for various times samples were removed from the environments. It was observed that some samples exposed to water immersion and 100% R.H. changed appearance from their original amber color to opaque white. The original amber color returned after one week time under laboratory conditions of 23°C and 30% R.H. The color changes proceeded from the outside surfaces toward the center indicating water was diffusing out of the sample. In an attempt to follow these changes, hardness measurements were made on these samples as a function of time after extraction from the aging environment. Figure 1 shows typical data after removal from a 70°C water immersion environment. Since color and hardness essentially stopped changing after one week in laboratory air, all aged samples were allowed to equilibrate to laboratory conditions for a minimum of one week prior to testing. Hardness dimensions and sample weight were measured using the same methods as those used before aging. All samples were cut into "dog bone" shaped microtensile specimens for tensile testing with a die made according to ASTM D 1708 standards.¹¹

Before tensile testing each sample's cross section was estimated for use in obtaining ultimate tensile strength and 300% modulus information. Since the samples were too short to allow the use of an extensometer, the

elongation data was monitored by following the clamp separation; initial clamp separation was approximately $3/4$ ". The samples were strained at $5"/\text{minute}$ using an Instron model 1130 tensile machine. The three mechanical properties of ultimate elongation, ultimate tensile strength and 300% modulus were calculated from data taken from the resulting stress strain curves.

The adhesive bond strengths were determined in a tensile adhesion test. The unaged specimens, cut to $3/4$ inch by $3/4$ inch size, were bonded with Conap EN-7 two part urethane adhesive to vapor degreased and dry sandblasted aluminum tensile adhesive plugs. The adhesive was cured for 16 hours at 200°F . Half of the adhesive bonded specimens were aged for ten cycles (1 cycle/2 days) at 93% relative humidity with the temperature cycled between 20°C and 65°C as per Sandia Laboratories specification SC-4451(M) dated August 1967. The samples were allowed to equilibrate to laboratory conditions for about two weeks and then tensile tested on an Instron machine at a cross head speed of $.05$ inches/minute.

III. Results

Mechanical and Physical Changes

Table 2 compares some of our unaged results with corresponding data from the manufacturer's literature. Because of the large values of ultimate elongation we had some difficulty keeping the samples from slipping through the sample grips. The majority of the samples failed adjacent to the grips rather than in the gauge length. These factors made the absolute values of the ultimate properties somewhat less reliable than hoped for. However, on a relative basis the results should be useful since all of our experiments were carried out under nearly identical

conditions. From repeated runs at identical conditions, we estimated our uncertainty to be $\pm 20\%$.

Tables 3 through 8 present the most useful data generated by this study. The data for various times in each environment is shown as a percentage change in the measured value of a property relative to the unaged value of that property. As can be seen from the tables, the two mechanical properties of ultimate tensile strength, and 300% modulus were the sensitive parameters for monitoring the aging process. The ultimate elongation measurements were less sensitive to early aging changes because the large tensile elongations caused excessive sample grip slippage. Under certain environments, the sample weight changes correlated well with the mechanical property changes. Those samples which experienced the most rapid degradation of mechanical properties tended to change weight most rapidly. Typically, samples exposed to thermal aging, water immersion, and relative humidity lost weight while samples exposed to the NO_2 environment gained weight. All of the samples experienced weight changes of less than 3% except one NO_2 sample whose weight changed 7%.

As can be seen in the tables, hardness changes were not sensitive indicators of the aging process especially in the early stages. Since the changes in thickness and length caused by aging were small compared to the uncertainties in the measurements, this data is not presented in the tables.

Some of the significant changes of sample properties under various accelerated aging conditions are shown in Figures 2 through 9. For simplicity, these figures all represent smoothed data; the actual data can be obtained from the tables. For mechanical property changes, the 300% modulus is shown; the other mechanical properties of ultimate elongation, ultimate tensile strength showed similar trends.

Figure 2 compares the thermal oxidative degradation of 58300 polyether with 58092 polyester. At 100°C the polyether degraded badly after 310 days but the polyester did not show any noticeable degradation. Both materials darkened considerably during the thermal exposure. At the lower temperatures of 50 and 70°C, all of the materials showed less than 20% change in mechanical properties during the 310 days test.

Figure 3 compares the water immersion degradation of polyester versus polyether materials. The polyester materials failed completely in less than 50 days at 70°C and less than 310 days at 50°C. The loss of mechanical properties at 70°C for the two thicknesses of 58092 were the same within experimental error. None of the polyether materials were adversely affected by this environment.

Figure 4 compares the degradation of polyester and polyether urethanes for various relative humidities and temperatures. Although these environments badly degraded the polyester materials, the polyether materials were unaffected. Even though the 9341 polyester data is not shown on this figure, it closely followed the 58092 curves.

Figures 5 and 6 show the degradation of polyether and polyester materials respectively after exposure to 0.48% NO₂ for up to 20 days. For 58092, the degradation is faster for thinner samples indicating that the diffusion of NO₂ into the samples is the rate determining step in the degradation process. Since this same trend (more rapid degradation for thinner samples) seems to hold for the various polyether materials (Figure 5) and for the polyester materials (Figure 6), it seems likely that NO₂ diffusion into the samples is the rate determining step in all these materials. The effects of diffusion make it more difficult to predict the results of lower concentrations of NO₂ for longer periods of time.

Figure 7 depicts the 0.48% NO₂ exposure weight gain comparison between polyether and polyesters. The polyethers gained weight more rapidly than the polyesters. The thinner samples within each group gained weight most rapidly. The degradation rates (Figures 5 and 6) generally correlate to these weight changes.

Figure 8 is a summary of the effects of all the environments used in this study on 58300 polyether material. The two exposures which degrade this material are thermal aging at 100°C and 0.45% NO₂ aging. The other polyether materials degraded in a similar fashion.

Figure 9 shows the effects of all the exposures used in this study on 58092 polyester. The presence of liquid water or elevated relative humidity creates an extremely degrading environment toward this material. The other polyesters behaved in a similar manner. The NO₂ will also degrade this material given sufficient exposure time.

Adhesive Bonding

The results of the tensile adhesive bonding test using EN-7 as the adhesive are shown in Table 9. The ultimate tensile strength values are the average of 5 samples. The decrease in the adhesive bond strength of the EN-7 alone after humidity cycling indicates that the adhesive is susceptible to moisture attack. The adhesive bond strength between the two thicker polyether materials and the aluminum tensile plugs increased under humidity cycling probably from post curing of the adhesive. The adhesive bond strength for the similar thickness polyesters remained the same or decreased under similar conditions. The decrease in adhesive bond strength for the polyester materials seems to indicate that these materials allowed more moisture to permeate to the EN-7 interface than the

polyether materials. Longer humidity cycling would probably decrease the polyester adhesive bond strength further. Since all of the failures occurred at the EN-7 adhesive interfaces, the tests were really a comparison of the adhesive bond strengths of the materials to the adhesive. The data in this paper indicates that the choice of material for a given application will depend on the environment(s) seen by the material.

IV. Conclusions

The conclusions from the present accelerated aging study are as follows:

1. Polyester materials appear to be superior to polyether material in elevated temperature service.
2. Polyether materials are far superior to polyester materials in water immersion and relative humidity environments at elevated temperature.
3. For short time exposures to relatively high NO_2 concentrations, polyester materials appear to be superior to polyether materials although both materials are readily attacked by NO_2 .
4. Under humidity cycling conditions using EN-7 as the adhesive, it appears that the adhesive bond strength of the FAIR M polyester to the aluminum tensile plugs was inferior to those of the other materials.

V. References

1. B. F. Goodrich Chemical Company Bulletin G-56 on Environmental Resistance of Estane ® Polyurethanes.
2. Sandia Laboratories Internal Memorandum, subject: CF 2049 Cable Jacket Deterioration, from G. L. Scholer to D. H. Weingarten, dtd. 5/31/74.
3. F. H. Gahimer and F. W. Nieske, J. Elast. & Plast. 1, 266, October 1969.
4. F. H. Gahimer and F. W. Nieske, Insulation/Circuits, 18, 15, August 1972.
5. F. W. Nieske and F. H. Gahimer, Naval Avionics Facility, NAFT TR-1778 1972.
6. F. W. Nieske and F. H. Gahimer, Naval Avionics Facility, NAFT TR-1967 1973.
7. American Cyanamid Company Bulletin on Cyanaprene ® Polyurethanes, 1974.
8. Mobay Chemical Corporation Bulletin on Texin ® 986A, 1975.
9. H. H. G. Jellinek and T. J. Y. Wang, J. Polym. Sci., Polym. Chem. Ed., 11, 3227 (1973).
10. H. H. G. Jellinek and F. Martin, and H. Wegener, J. Appl. Polym. Sci., 18, 1773 (1974).
11. ASTM Test D1708, Tensile Properties of Plastics by Use of Microtensile Specimens.
12. American Cyanamid Company Preliminary Data Sheet GWS-11/75 on 9300 Polyurethanes.
13. Sandia Laboratories Drawing Number 2170456, Insulation Sleeving, Electrical, Polyurethane.
14. Sandia Laboratories Technical Report, SAND-76-5225, N. J. DeLellis, "Processing and Bonding Characteristics of a Urethane Resin/Silane Primer System," Table IV, 1977.

Table 1
Polyurethane Materials Used in this Study

Manufacturer	Manufacturer's Designation	Material Type	Material Form Supplied	Thickness (Inches)	Size (Inches)
B. F. Goodrich	58300	Polyether	Sheet	0.126-0.127	6 × 3
B. F. Goodrich	58092	Polyester	Sheet	0.129-0.131	6 × 3
Mobay Chemical Co.	986A	Polyether	Sheet	0.065-0.066	6 × 3
American Cyanamid	9341	Polyester	Sheet	0.089-0.090	6 × 3
LaBarge, Inc.	Fair X	Polyether	Tube	0.032-0.040 Wall	$\frac{1}{2}$ Outside Diameter
LaBarge, Inc.	Fair M	Polyester	Tube	0.022-0.027 Wall	$\frac{1}{2}$ Outside Diameter

Table 2
Usaged Properties of Polyurethane Materials

Material	Ultimate Tensile Strength (Pascal)* $\times 10^{-7}$		Ultimate Elongation (Percent)		300% Modulus (Pascal) $\times 10^{-6}$		Instantaneous Hardness (Shore A)	
	Measured	Literature	Measured	Literature	Measured	Literature	Measured	Literature
58300 Polyether	2.48	3.45 ^(a)	830	700 ^(a)	7.78	7.58 ^(a)	86	83 ^(a)
58092 Polyester	3.45	3.58 ^(a)	600	450 ^(a)	17.9	21.3 ^(a)	95	95 ^(a)
986A Polyether	2.48	3.24 ^(b)	650	570 ^(b)	8.96	9.65 ^(b)	89	87 ^(b)
9341 Polyester	4.75	5.24 ^(c)	800	600 ^(c)	13.0	14.5 ^(c)	88	82 ^(c)
Fair X Polyether	2.68	-	810	-	7.92	-	84	-
Fair M Polyester	3.58	3.10 ^(d) Minimum	590	400 ^(d) Minimum	12.7	-	87	-

* 1 Pascal = 1.45×10^{-4} psi

(a) Reference 1
(b) Reference 8
(c) Reference 12
(d) Reference 13

Table 3
58300 Polyether Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
50°C Oven Aged					
2					-1.2
7	15	16	-2	.13	-2.3
20	-9	-3	12	0	0
50	0	13	15	.04	0
124	7	11	15	.25	0
200	10	18	9	-.10	1.2
310	-2	14	23	-.13	0
70°C Oven Aged					
2					-1.2
7	0	6	6	.15	-2.3
20	20	37	14	-.06	-2.3
50	-2	2	14	-.09	-2.3
124	9	13	15	.13	0
200	13	27	15	-.14	-1.2
310	11	30	22	-.12	-2.3

Table 3 (Cont'd)
58300 Polyether Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
100°C Oven Aged					
2					-5.9
7	P u l l e d	O u t	2	.08	-5.9
20	14	9	15	-.13	-5.9
50	22	0	6	-.22	-5.9
124	33	-20	2	-.05	-4.7
200	-57	-73	-16	-.72	-22.
310	-71	-74	*	-2.0	-15.
23°C Water Immersion					
2					0
7	1	0	0	-.32	-2.3
20	-9	-2	10	-.54	-2.3
50	-7	5	17	-.44	-2.3
124	1	4	10	-.83	0
200	0	16	13	-1.16	2.3
310	2	22	14	-1.14	0

* Broke before elongating 300%

Table 3 (Cont'd)
58300 Polyether Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
50°C Water Immersion					
2					-1.2
7	6	6	3	-.62	-3.5
20	-4	3	11	-.76	-2.3
50	-7	0	21	-.78	-3.5
124	20	14	14	-1.12	-4.7
200	31	27	15	-1.20	-4.7
310	22	24	16	-.16	-2.3
70°C Water Immersion					
2					-2.3
7	P u l l e d	O u t	2	-.74	-7.0
20	13	15	15	-.88	-5.9
50	18	9	12	-.86	-5.9
124	31	0	7	-1.39	-1.2
200	25	-4	6	-1.69	0
310	24	-5	10	-1.78	-1.2

Table 3 (Cont'd)
58300 Polyether Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
23°C 100% Relative Humidity (R.H.)					
2					-1.2
7	P u l l e d	O u t	-3	-.38	-3.5
20	-12	-6	18	-.43	-1.2
50	-2	8	15	-.22	-2.3
124	-2	1	10	-.55	-2.3
200	0	10	14	-.86	+2.3
310	-4	11	24	-.82	+2.3
50°C 100% Relative Humidity (R.H.)					
2					0
7	9	13	7	-.57	-2.3
20	-2	7	18	-.72	-2.3
50	-2	4	15	-.58	-3.5
124	13	4	19	-.81	-3.5
200	16	11	17	-1.12	-1.2
310	13	20	27	-1.05	-1.2

Table 3 (Cont'd)
58300 Polyether Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
50°C 50% Relative Humidity (R.H.)					
2	4	6	0		-1.2
7	4	8	3	-.08	-1.2
20	-6	4	15	-.18	-2.3
50	-4	6	17	-.04	-2.3
124	22	20	14	+.13	-1.2
200	16	20	10	-.13	-1.2
310	6	24	27	-.12	-2.3
23°C 0.48% Nitrogen Dioxide (NO ₂)					
1	8	15	8	.28	
3	1	-16	0	.94	
8	10	-26	-14	.87	
20	-80	-87	*	2.5	

* Broke before elongating 300%

Table 4
58092 Polyester Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
50°C Oven Aged (.130" thick)					
2	5	4	0		-1.1
7	6	16	-3	.05	-2.1
20	Recorder Failure			-.02	-1.1
50	-11	5	5	0	-2.1
124	4	-2	-7	.18	1.1
200	10	21	2	-.03	1.1
310	7	15	28	-.04	1.1
70°C Oven Aged (.130" thick)					
2	4	3	-1		-1.1
7	11	12	-2	.10	-1.1
20	-4	-2	12	0	-1.1
50	6	17	8	.01	-2.1
124	13	16	5	.25	1.1
200	19	19	0	.11	2.1
310	11	16	17	.11	3.1

Table 4 (Cont'd)
58092 Polyester Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
100°C Oven Aged (.130" thick)					
2	26	17	0		-2.1
7	17	3	-3	.07	-4.2
20	17	7	3	.08	-3.1
50	17	10	-7	.07	-3.1
124	11	0	-8	.31	0
200	-14	-10	0	.21	0
310	-10	-13	8	.31	0
23°C Water Immersion (.130" thick)					
2	3	6	3		-1.1
7	7	-6	-23	.18	-3.1
20	-7	3	23	.12	0
50	8	25	12	.11	-1.1
124	20	25	-3	-.02	-1.1
200	5	16	12	-.56	2.1
310	0	12	27	-.65	2.1

Table 4 (Cont'd)
58092 Polyester Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
50°C Water Immersion (.130" thick)					
2	14	16	-6		-2.1
7	P u l l e d	O u t	-27	-.33	-2.1
20	0	6	15	-.44	0
50	0	0	10	-.50	-3.1
124	22	-24	-22	-1.14	1.1
200	-17	-66	-42	-1.38	2.1
310	-90	-82	*	-2.31	3.1
70°C Water Immersion (.130" thick)					
2	3	-11	-11		0
5	22	-3	-20	-.39	-2.1
7	6	-19	-23	-.51	-3.1
12	20	8	12	-.90	-1.1
20	11	-20	0	-.68	-1.1
30	0	-44	-28		
50	-79	-80	*	-1.11	-2.1

* Broke before elongating 300%.

Table 4 (Cont'd)
58092 Polyester Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
23°C 100% Relative Humidity (R.H.) (.130" thick)					
2	0	-2	-5		0
7	3	-9	-22	.14	-2.1
20	0	4	12	.14	-1.1
50	0	5	12	.19	-2.1
124	6	6	-3	-.21	3.1
200	0	8	6	-.36	2.1
310	-7	1	12	-.41	4.2
50°C 100% Relative Humidity (R.H.) (.130" thick)					
2	3	-5	-7		-2.1
7	7	-7	-20	-.31	0
20	0	2	11	-.41	1.1
50	4	3	17	-.37	0
124	13	-34	-25	-.87	0
200	-49	-77	*	-.86	2.1
310	-98	-92	*	-.21	-2.1

* Broke before elongating 300%.

Table 4 (Cont'd)
58092 Polyester Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
50°C 50% Relative Humidity (R.H.) (.130" thick)					
2	6	1	-3		-1.1
7	10	4	-10	-.05	-1.1
20	-9	-9	10	-.15	-2.1
50	9	18	3	-.08	-3.1
124	11	3	-12	-.11	2.1
200	15	6	-8	-.27	2.1
310	7	-34	-18	-.22	2.1
70°C Water Immersion (0.030" thick)					
2	17	-3	-10		
4	24	2	-6		
7	29	-6	-17		
14	37	-11	-17		
21	44	-35	-9		
28	9	-60	-20		
38	-8	-81	-41		
49	-84	-88	*		

* Broke before elongating 300%.

Table 4 (Cont'd)
58092 Polyester Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
23°C 0.48% NO ₂ (0.130" thick)					
1	14	40	13	.04	
3	4	21	18	.14	
8	1	3	8	.17	
20	12	14	2	.43	
23°C 0.48% NO ₂ (0.030" thick)					
1	25	-13	-19		
4	-4	-28	-10		
7	3	-20	-7		
11	-3	-39	-19		
14	-2	-56	-36		
18	-9	-63	-41		
22	-2	-74	-56		

Table 5
986A Polyether Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
70°C Oven Aged					
2	4	-2	1		-1.1
7	-12	-2	7	.49	-5.6
20	-14	-18	10	.07	-6.7
50	-4	-19	1	.12	-1.1
124	31	-2	-13	.37	0
200	27	2	-7	.02	-1.1
310	25	2	1	.03	1.1
70°C Water Immersion					
2	6	13	-1		-2.2
7	10	10	1	.04	-2.2
20	8	-10	-5	-.04	-4.5
50	16	-1	-8	-.63	-1.1
124	59	6	-11	-.52	0
200	51	3	-7	-.73	-5.6
310	34	-6	-5	-.49	-2.2

Table 5 (Cont'd)
986A Polyether Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
50°C 100% Relative Humidity (R.H.)					
2	-6	-4	5		0
7	2	9	-1	-.54	-3.4
20	-6	-20	-5	-.67	-3.4
50	14	10	1	-.56	-2.2
124	28	2	-7	-.32	-3.4
200	16	-1	-1	-.62	-6.7
310	-2	19	7	-.49	-5.6
50°C 50% Relative Humidity (R.H.)					
2	-12	-13	5		-1.1
7	6	13	-1	-.05	0
20	-4	-10	2	-.16	-1.1
50	8	11	2	0	0
124	17	8	-2	.28	-2.2
200	17	22	1	.02	-3.4
310	19	31	5	.09	-2.2

Table 5 (Cont'd)
986A Polyester Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
23°C 0.48% NO ₂					
1	10	-15	-13	.48	
3	13	-45	-21	1.39	
8	-6	-66	-31	1.46	
20	-74	-92	*	4.04	

* Broke before elongating 300%.

Table 6
9341 Polyester Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
70°C Oven Aged					
2					2.3
7	0	10	9	.13	-1.2
20	3	0	3	.02	-1.2
50	2	0	8	.09	-1.2
124	-4	0	-5	.33	-1.2
200	6	8	-1	.10	2.3
310	7	11	12	.11	-2.3
23°C Water Immersion					
2	2	.6	1		1.2
7	-8	3	3	-.49	-1.2
20	-5	-2	5	-.77	0
50	8	-8	7	-.89	0
124	-4	-10	2	-1.25	1.1
200	-3	1	3	-1.64	0
310	5	13	11	-1.76	0

Table 6 (Cont'd)
9341 Polyester Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
	50°C Water Immersion				
2	2	2	-2		1.2
7	8	14	0	-.86	-3.4
20	7	-2	-2	-1.1	-3.4
50	8	0	8	-1.4	-1.2
124	13	-56	-23	-1.86	3.4
200	-77	-90	*	-3.3	-1.2
310	Failed, Couldn't Measure			*	10.5
	50°C 100% Relative Humidity (R.H.)				
2	5	11	-2		-3.4
7	3	8	-4	-.62	-2.3
20	7	0	-4	-.79	-1.1
50	2	-5	6	-.67	-3.4
124	-4	-67	-34	-.65	2.3
200	-96	-96	*	-.29	-2.3
310	Failed in Handling				9.3

* Broke before elongating 300%.

Table 6 (Cont'd)
9341 Polyester Aging Data

Time Days	% Change				
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight	Hardness (Instantaneous)
50°C 50% Relative Humidity (R.H.)					
2	0	2	2		-2.3
7	5	8	5	-.13	0
20	2	0	3	-.23	0
50	-2	-6	3	-.11	-1.1
124	8	-5	-8	.06	2.3
200	6	-30	-13	-.13	-1.1
310	-9	-68	-32	-.01	-1.1
23°C 0.48% NO ₂					
1	-14	-22	12	.11	
3	4	3	3	.23	
8	-2	-12	3	.19	
20	-6	-21	0	.64	

Table 7
Fair X Polyether Aging Data

Days	% Change			
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight
100°C Oven Aged				
16	17	3	4	-.62
50	25	-5	0	-.70
100	22	-1	-2	-.82
70°C Water Immersion				
16	14	-4	-9	-.23
50	15	22	30	-.21
100	37	8	-9	-.18
23°C 100% Relative Humidity (R.H.)				
16	14	7	-12	-.08
50	-7	13	31	0
100	-3	18	23	.15
50°C 100% Relative Humidity (R.H.)				
16	13	-2	-13	-.08
50	-12	1	28	-.02
100	0	20	26	-.09
23°C 0.48% NO ₂				
1	8	-33	0	1.1
3	-22	-82	-43	2.4
8	-53	-84	-44	2.6
20	-88	-99	*	6.8

* Broke before elongating 300%.

Table 8
Fair M Polyester Aging Data

Time Days	% Change			
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight
100°C Oven Aged				
21	-7	-38	-15	.01
49	32	-7	-10	.14
101	-4	-21	10	.17
70°C Water Immersion				
3	21	23	8	-.27
7	36	12	-11	-.34
14	32	24	8	-.41
21	64	2	-30	-.39
31	44	-45	-49	-.37
49	-94	-90	*	-2.27
23°C 100% Relative Humidity (R.H.)				
21	-2	-8	4	-.06
49	9	-11	-4	-.06
101	6	-4	-2	-.01
50°C 100% Relative Humidity (R.H.)				
21	36	-17	-15	-.04
49	8	-60	-32	.04
101	-94	-93	*	.42

* Broke before elongating 300%.

Table 8 (Cont'd)
Fair M Polyester Aging Data

Time Days	% Change			
	Ultimate Elongation	Ultimate Tensile Strength	300% Modulus	Weight
50°C 50% Relative Humidity (R.H.)				
21	8	-14	-10	.03
49	20	-28	-15	0
101	-14	-58	-26	.22
23°C 0.48% NO ₂				
1	37	-12	-22	.46
3	14	-16	-27	1.10
7	14	-61	-31	1.86
10	7	-74	-69	2.25
14	11	-78	-72	2.65
21	-95	-83	*	3.2

* Broke before elongating 300%.

Table 9

Comparative Bond Strengths of Polyether and Polyester
Materials Bonded with EN-7 to Aluminum Tensile Plugs

Ultimate Tensile Strength (Average)
3/4" x 3/4" Specimens

Material	Pascal x 10 ⁻⁶	As cured + 20 days Humidity Cycling ^(a) Pascal x 10 ⁻⁶
EN-7 Alone ¹⁴	9.1	6.9
Polyethers		
58300	1.77	2.16
986A	2.40	3.08
Fair X	3.54	2.76
Polyesters		
58092	3.49	3.48
9341	2.61	2.17
Fair M	5.57	2.88

1 Pascal = 1.45×10^{-4} psi

(a) Humidity cycling as per SC-4451 (M) document change #1
August 1, 1961, (10 48 hour cycles of 93% R. H. between
20°C and 65°C).

FIGURE 1

Hardness after extraction of
58300 polyether from 70°C water
immersion.

1. Instantaneous Hardness Reading
2. 10 Second Hardness Reading

FIGURE 2

Thermal oxidative aging comparisons
of polyester and polyether materials.

	<u>MATERIALS</u>	<u>TEMPERATURE °C</u>	
1.	58300	100	POLYETHER
2.	58092	100	POLYESTER
3.	All Materials	50 and 70	

FIGURE 3

Water immersion aging comparisons of polyester and polyether materials.

	<u>MATERIALS</u>	<u>TEMPERATURE °C</u>	<u>THICKNESS (Inches)</u>	
1.	FAIR M	70°C	0.025	} POLYESTERS
2.	58092	70°C	0.130	
3.	58092	70°C	0.030	
4.	9341	50°C	0.090	
5.	58092	50°C	0.130	
6.	All Polyethers			

FIGURE 4

Relative humidity aging comparisons
of polyester and polyether materials.

	<u>MATERIALS</u>	<u>TEMPERATURE °C</u>	<u>RELATIVE HUMIDITY %</u>	
1.	FAIR M	50	100	} POLYESTERS
2.	FAIR M	50	50	
3.	58092	50	100	
4.	58092	50	50	
5.	58092	23	100	
6.	Polyethers	23,50	50,100	

FIGURE 5

0.48% NO₂ Aging Comparisons
of Polyether Materials.

	MATERIAL	THICKNESS (INCHES)
1.	FAIR X	0.035
2.	986A	0.065
3.	58300	0.127

FIGURE 6

0.48% NO₂ Aging Comparisons of
Polyester Materials.

	<u>MATERIAL</u>	<u>THICKNESS (INCHES)</u>
1.	FAIR M	0.025
2.	58092	0.030
3.	9341	0.090
4.	58092	0.130

FIGURE 7

Weight Gain Comparisons for 0.48% NO₂
Aging of Polyester and Polyether Materials

	<u>MATERIAL</u>	<u>THICKNESS (INCHES)</u>	
1.	58092	0.130	} Polyesters
2.	9341	0.090	
3.	FAIR M	0.025	
4.	58300	0.127	} Polyethers
5.	986A	0.065	
6.	FAIR X	0.035	

FIGURE 8
Summary of 58300 Polyether
Aging Data

	<u>TEMPERATURE °C</u>	<u>CONDITION</u>
1.	100	
2.	50, 70	
3.	50	Water Immersion
4.	70	Water Immersion
5.	50	50% R.H.
6.	50	100% R.H.
7.	23	0.48% NO ₂

FIGURE 9

Summary of 58092 Polyester
Aging Data

	TEMPERATURE °C	CONDITION	THICKNESS (INCHES)
1.	50, 70, 100		0.130
2.	50	Water Immersion	0.130
3.	70	Water Immersion	0.130
4.	50	50% R.H.	0.130
5.	50	100% R.H.	0.130
6.	23	0.48% NO ₂	0.130
7.	23	0.48% NO ₂	0.030

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