

AD/A-000 908

STUDIES OF DETERIORATION OF COATINGS
FOR COLLAPSIBLE FUEL TANKS. PART II

T. W. Chalmers

Goodyear Tire and Rubber Company

Prepared for:

Army Mobility Equipment Research and
Development Center

October 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER DAAK 02-74-C-0011	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER <i>ADIA-000905</i>	
4. TITLE (and Subtitle) Studies of Deterioration of Coatings for Collapsible Fuel Tanks - Part II		5. TYPE OF REPORT & PERIOD COVERED Final report March 1974 - October 1974	
		6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) T. W. Chalmers		8. CONTRACT OR GRANT NUMBER(s) DAAK 02-74-C-0011	
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Goodyear Tire & Rubber Co. Akron, Ohio 44316		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1G762708AH67/FA	
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Mobility Equipment Research and Development Center STSFB-GFO Ft Belvoir, Virginia 22060		12. REPORT DATE October 1974	
		13. NUMBER OF PAGES	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED	
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES Elastomers, volume change, tensile strength, ultimate elongation, diesel fuel, combat gasoline, fuel tanks, deterioration.			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes the accomplishments of the second phase of a program to determine the causes for the deterioration of flexible fuel tank coatings. The first phase program revealed that only the combat gasoline soak test, exposure to combat gasoline in combination with ultraviolet radiation and high humidity, and exposure to diesel fuel in combination with ultraviolet radiation and high humidity showed sufficient deterioration of the coatings for further evaluation.			

In all three of the exposure tests, the effect of not changing the fuel periodically caused more severe degradation of the coating materials than when the fuels were changed at each two-week period. The probable cause of the increased deterioration of the coatings in combat gasoline was the change in composition of the test fluid caused by volatilization of the lower boiling fractions. The probable cause of the increased deterioration of the coatings in diesel fuel was the change in pH of the fuel due to exposure to ultraviolet radiation and moisture.

All three of the exposure conditions caused accelerated deterioration of the coating materials. Based on the results of this program, approximately three months exposure will be required to draw definite conclusions concerning the deterioration of a coating material.

Destroy this report when no longer needed.

Do not return to originator.

The findings in this report are not to be construed
as an official Department of the Army position,
unless so designated by other authorized documents.

PREFACE

This report was prepared by The Goodyear Tire and Rubber Company in compliance with the terms of Contract No. DAAK02-74-C-0011. The study was performed as part of Project/Task No. 1G762708AH67/FA for the Development of Bulk Fuel Storage Facilities. This work was the second phase of a two part program administered under the direction of the U. S. Army Mobility Equipment Research and Development Center, R&D Procurement Office, with Mr Philip Mitton of the Fuels Handling Equipment Division, Mechanical Technology Department acting as the Contracting Officer's Technical Representative (COTR).

TABLE OF CONTENTS

	<u>Page</u>
Section 1 - Introduction	6
Section 2 - Experimental Procedures and Discussion	8
1. General	8
2. Preparation of Specimen	9
3. Exposure to Combat Gasoline	10
4. Exposure to Ultraviolet Radiation in Combination with Fuels and High Humidity	10
Section 3 - Test Results	12
1. General	12
2. Effect of Exposure to Combat Gasoline	12
3. Exposure to Combat Gasoline, Ultraviolet Radiation and High Humidity	12
4. Exposure to Diesel Fuel, Ultraviolet Radiation and High Humidity	12
5. pH of Test Fluids	13
Section 4 - Discussion of Results	14
1. General	14
2. Exposure to Combat Gasoline	16
3. Exposure to Combat Gasoline, Ultraviolet Radiation, and High Humidity	17
4. Exposure to Diesel Fuel, Ultraviolet Radiation and High Humidity	17
Section 5 - Conclusions	19
Section 6 - Recommendations	20

LIST OF TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
1	Test Compounds	8
2	Exposure to Combat Gasoline at 158°F - Tested Saturated	21
3	Exposure to Combat Gasoline at 158°F - Tested Dry	22
4	Exposure to Combat Gasoline Combined with Ultraviolet and High Humidity at 145°F	23
5	Exposure to Diesel Fuel Combined with Ultraviolet and High Humidity at 145°F	24
6	pH Change of Fuels in Ultraviolet Chambers	25
7	pH of Combat Gasoline in Reactor Pots	25

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	Environmental Test Chamber	26
2	Effect of Exposure to Combat Gasoline at 158°F on Polyester Urethane Tested Saturated	27
3	Effect of Exposure to Combat Gasoline at 158°F on Polyether Urethane Tested Saturated	28
4	Effect of Exposure to Combat Gasoline at 158°F on Nitrile/Vinyl Blend Tested Saturated	29
5	Effect of Exposure to Combat Gasoline at 158°F on Epichlorohydrin Copolymer Tested Saturated	30
6	Effect of Exposure to Combat Gasoline at 158°F on Caprolactone Ester Polyurethane Tested Saturated	31
7	Effect of Exposure to Combat Gasoline at 158°F on Polyester Urethane Tested After Drying	32
8	Effect of Exposure to Combat Gasoline at 158°F on Polyether Urethane Tested After Drying	33
9	Effect of Exposure to Combat Gasoline at 158°F on Nitrile/Vinyl Blend Tested After Drying	34
10	Effect of Exposure to Combat Gasoline at 158°F on Epichlorohydrin Copolymer Tested After Drying	35
11	Effect of Exposure to Combat Gasoline at 158°F on Caprolactone Ester Urethane Tested After Drying	36

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
12	Effect of Combat Gasoline Combined with Ultraviolet Radiation and High Humidity at 145°F on Polyester Urethane	37
13	Effect of Combat Gasoline Combined with Ultraviolet Radiation and High Humidity at 145°F on Polyether Urethane	38
14	Effect of Combat Gasoline Combined with Ultraviolet Radiation and High Humidity at 145°F on Nitrile/Vinyl Blend	39
15	Effect of Combat Gasoline Combined with Ultraviolet Radiation and High Humidity at 145°F on Epichlorohydrin Copolymer	40
16	Effect of Combat Gasoline Combined with Ultraviolet Radiation and High Humidity at 145°F on Caprolactone Ester Urethane	41
17	Effect of Diesel Fuel Combined with Ultraviolet Radiation and High Humidity at 145°F on Polyester Urethane	42
18	Effect of Diesel Fuel Combined with Ultraviolet Radiation and High Humidity at 145°F on Polyether Urethane	43
19	Effect of Diesel Fuel Combined with Ultraviolet Radiation and High Humidity at 145°F on Nitrile/Vinyl Blend	44
20	Effect of Diesel Fuel Combined with Ultraviolet Radiation and High Humidity at 145°F on Epichlorohydrin Copolymer	45
21	Effect of Diesel Fuel Combined with Ultraviolet Radiation and High Humidity at 145°F on Caprolactone Ester Urethane	46
22	pH Change of Test Fluids in Test Chambers	47

SECTION I

INTRODUCTION

In tropic and desert service, fuel tank exterior coatings are deteriorated severely by exposure to sunlight. This deterioration is especially severe if the coating is exposed to fuel leakage as well as diffusion through the tank wall. The extent of deterioration is greater than that experienced by fuel immersion alone or sunlight exposure alone. Tank coatings have suffered serious deterioration in tropical conditions within twelve to fourteen months. A minimum service life of two years in the tropics is desired.

A program, which began 15 July 1973, was conducted by The Goodyear Tire & Rubber Company to determine the cause of the excessive deterioration of tank coatings due to the combined exposure to sunlight, rain, stress and fuels. To accomplish this, special test chambers were constructed to expose safely the coating materials to fuels in combination with ultraviolet radiation, humidity, and elevated temperature. This work was outlined in the report titled "Studies of Deterioration of Coatings for Collapsible Fuel Cells" dated March 1974.

During that program, five different types of flexible fuel tank coatings were exposed to ultraviolet radiation, two different fuels, ultraviolet radiation in combination with fuels and high humidity, ozone, and ozone in combination with fuels and high humidity. The results of that program showed that the exposure to ultraviolet radiation in combination with fuels and high humidity was the most severe test. This test caused excessive deterioration of all coating materials tested at 84 days when combat gasoline was used as the fuel. At 28 days exposure, none of the materials were degraded excessively. These tests also showed that the combat gasoline caused more severe deterioration than diesel fuel. It is known that, in field installations of these fuels in flexible pillow tanks, the diesel fuel causes a more severe deteriorating effect than combat gasoline.

During the initial program, it was shown that the pH of the diesel fuel was reduced considerably by exposure to

ultraviolet radiation for a 14-day period. The fuel was changed after each 14-day exposure period. It was felt that the diesel fuel would have become considerably more acid if it had not been changed periodically.

The work described in this report is the second phase of the initial program which fills in the missing data between the 28-day exposure and 84-day exposure periods. The fuels were not changed periodically. It was suspected that the diesel fuel would become considerably more acid and that this could have a more deteriorating effect on the test materials.

SECTION 2
EXPERIMENTAL PROCEDURES AND DISCUSSION

1. General

Since this program is a continuation of the first phase, the same elastomer types were used. These were chosen because they are now being used for fuel tank applications or are being considered for such use. The five types are listed below in Table I.

Table I
Test Compounds

Compound No.	Compound Type
1	Polyester polyurethane
2	Polyether polyurethane
3	Nitrile Rubber - polyvinyl chloride blend
4	Epichlorohydrin - ethylene oxide copolymer
5	Caprolactone polyurethane

The polyurethanes were prepared from three polyol types - an ester, an ether and an aliphatic caprolactone ester. The choice was made for the following reasons: the ester was expected to show fuel resistance and good hydrolytic stability, the ether for its exceptional hydrolysis resistance and the caprolactone ester for its improved hydrolysis resistance, although it might show less fuel resistance.

The nitrile-vinyl blended material is a Goodyear production compound containing plasticizers for aiding in processing and low temperature flexibility. The

epichlorohydrin copolymer compound was made from Herculor-C and contained a minimum amount of processing aids. All of the elastomer compounds contained some black pigment.

The fuels used to evaluate the selected coating compounds were combat gasoline (conforming to Specification MIL-G-3056) and Diesel DF-2 fuel. The DF-2 fuel was certified as conforming to Specification VV-F-800, except the requirement for determining a Cetane Number Motor Rating was waived with concurrence of the project COTR.

During the initial program, a number of deterioration tests were performed on the selected materials. That program revealed that only three of the tests showed sufficient degradation to be considered for further evaluation. For this reason only the combat gasoline exposure test, the exposure to combat gasoline in combination with ultraviolet radiation and high humidity, and the exposure to diesel fuel in combination with ultraviolet radiation and high humidity were considered in this second phase.

It was determined that a low pH causes a very definite deteriorating effect in combination with ultraviolet radiation and moisture. Couple this with the fact that the ultraviolet radiation and moisture cause a reduction in the pH of the diesel fuel, and it was expected that if the diesel fuel is not changed periodically during the program, the deteriorating effect of the diesel fuel would be more severe. For this reason, the fuels were not changed periodically during the second phase program. Only that amount of fuel necessary to maintain the fuel quantity was added.

2. Preparation of Specimens

The sheet elastomer stocks used for this program were either cast or compression molded depending upon the type of material. The gauge of each specimen was held to 0.030 inches, as closely as possible.

Specimens measuring 1" x 6" were cut from the sheets. These strips were stapled to a rigid substrate.

After exposure to the environmental conditions, the 1" x 6" strips were removed from the substrate and allowed to dry in a circulated air oven for 48 hours at 140°F + 5°F. If the specimen was to be tested while saturated with fuel, it was placed in a container of test fluid. In all cases dumbbells were cut from the strip in the condition in which they were to be tested. All stress-strain data are based on the cross-section of the material as tested and not on the original cross-section.

3. Exposure to Combat Gasoline

Each of the five coating materials was exposed separately to combat gasoline at 158°F + 3°F in glass reactor pots. Due to the volatility of the combat gasoline, it was necessary to use a reflux condenser on the reactor pot. The fuel was not changed during the entire exposure period. Additional fuel was added only as evaporation took place.

The specimens were exposed for periods of 42 days, 56 days, and 70 days. At the end of each exposure period, four specimens of each material were removed. Two of these specimens were placed in a container of the test fluid and allowed to cool to room temperature, and the stress-strain relations were determined while saturated with the fuel. The remaining specimens were dried for 48 hours at 140°F + 5°F, and the stress-strain relations were determined after drying. These data show both the plasticizing effect of the fuel on the swollen materials and any permanent chemical degradation caused by the fuel immersion.

4. Exposure to Ultraviolet Radiation in Combination with Fuels and High Humidity

For these conditions, a specially designed chamber was used. This is the same chamber that was used during the first phase. The apparatus is shown in Figure 1 and is designed to show the effects of ultraviolet radiation, elevated temperature, high humidity and fuel. The basic chamber (a) was made from a cut-off 55 gallon drum. The fuel was gravity fed from a twenty gallon fuel tank (b) through a copper manifold (c) having twenty outlet nozzles with individual

needle valves for flow control. The aluminum sample holder (d) was made in the shape of a frustum of a cone and had twenty sample clamps corresponding to the twenty nozzles. The aluminum catch-pan (e) was connected to a twenty gallon collecting tank outside the test chamber. The outlet from the catch-pan was arranged so that there would always be some fuel in the pan to maintain a saturated fuel vapor in the chamber. The bottom of the chamber contained water to create a high humidity within the chamber.

A GCT-1-30 heating tape (f), rated at 1650 watts, was wrapped around the chamber. The temperature was controlled by a Pak-Tronics No. 1214 Mini-Temp controller (g) which was attached to a Pak-Tronics No. 1102 temperature probe (h). The entire chamber was insulated with fiberglass insulation (i). This arrangement gave a temperature control of the chamber which fell within the desired range.

The ultraviolet radiation source was a General Electric RS-HUV high ultraviolet lamp (j). A 2 mm thick quartz lens, specifically designed to transmit the entire UV output from the RS-HUV lamp, was purchased from the American Ultra-Violet Company and was used to transmit the radiation into the chamber. These lamps were replaced with new lamps after the 42-day exposure period.

During the 70-day exposure period, the chambers were monitored once each working day. At this time the fuel was transferred from the catch tank to the supply tank and the nozzles were checked to insure constant dripping. The fuels were not replaced as was done during the previous program. New fuel was added to maintain the minimum amount necessary to insure a constant flow from the nozzles.

All five (5) Compound Types were exposed together in the chamber. After each exposure period, a sample of fuel was taken to determine the change in pH.

SECTION 3
TEST RESULTS

1. General

All samples were visually inspected after being removed from each exposure test. All appeared to be rubbery, with no evidence of surface cracking or crazing. It was observed that the surfaces of these specimens which were exposed to gasoline appeared to dry rapidly as the specimens were removed from the gasoline. The surfaces of specimens exposed to diesel fuel remained wet with the fuel.

2. Effect of Exposure to Combat Gasoline

Table 2 gives the results of specimens tested while saturated with fuel along with the results of specimens tested similarly in the previous program. These data are shown graphically in Figures 2, 3, 4, 5, and 6. Table 3 gives the results of specimens tested after drying along with the results of specimens tested similarly in the previous program. These data are shown graphically in Figures 7, 8, 9, 10, and 11. The data in the graphs show both the ultimate tensile and the tensile modulus at 100% elongation.

3. Exposure to Combat Gasoline, Ultraviolet Radiation and High Humidity

The results of the effects of exposure to ultraviolet radiation and combat gasoline are presented in Table 4. The table also includes data from similar tests performed in the first phase program. These data are illustrated graphically in Figures 12, 13, 14, 15 and 16. The graphs show both the ultimate tensile and the modulus at 100% elongation.

4. Exposure to Diesel Fuel, Ultraviolet Radiation and High Humidity

The results of the exposure to diesel fuel in combination with ultraviolet radiation and high

humidity are presented in Table 5. This table also includes data from a similar test performed during the first phase program. These data are presented graphically in Figures 17, 18, 19, 20, and 21. The graphs show both the ultimate tensile strength and the modulus at 100% elongation.

5. pH of Test Fluids

Throughout the test program samples were taken of the test fluids from the test chamber at each exposure period. These samples were used to determine the pH of the fuel.

To determine the change in pH, the samples were added to equal quantities of distilled water and agitated for one hour. The pH of the water was then determined using a standard pH meter.

The results of these tests are shown in Table 6. The table also includes the 14-day period which was obtained in the first phase program. These data are shown graphically in Figure 22.

In addition, samples were taken from each of the reactor pots of combat gasoline containing the various coating materials after 50 days and 70 days exposure. The pH of each of these samples was determined. These data are also shown in Table 7.

SECTION 4
DISCUSSION OF RESULTS

1. General

Observation of the graphed data shows that, for most of the coating materials, a fairly smooth curve can be used to represent the data. The one exception to this is the data obtained for the polyester polyurethane coating. Figures 2, 7, 12, and 17 indicate that materials used for this type coating in the second phase program are not the same as those used in the first phase. This is confirmed by the control data for the two phases. The control data are as follows:

	<u>Phase 1</u>	<u>Phase 2</u>
Ultimate Tensile (psi)	7700	5800
100% Modulus (psi)	2850	4050
Ultimate Elongation (%)	300	210

The second phase elastomer was stiffer and is shown to have better resistance to the effects of both gasoline and diesel fuel.

Although it was intended to duplicate the polyester polyurethane elastomer of the first phase, it was not evident until the original physical properties were obtained after 45 days that this was not the case. At this time, it would have been too late in the program to prepare other specimens and retest.

As soon as it was realized that a different elastomer was being used, an analysis of the materials and procedures was made. The procedures were exactly the same for this elastomer in both phases; however, some discrepancies did appear in the materials used. New polyester polyurethane controls were prepared resulting in elastomers which gave essentially the same physical properties as the second phase controls. However, it should be pointed out that the new controls were made from the same ingredients as the second phase controls. Due to the time lag between

initiation of the two phases, the polyester polyol and the diisocyanate used to make this elastomer were not available for the second phase.

The polyester polyol used to prepare the prepolymer in the second phase was from a different batch of the same polyol from the same supplier. The hydroxyl number of the two batches were slightly different. There is some indication that a slight error may have been made in determining the hydroxyl number which would cause a different stoichiometric balance resulting in an elastomer of different physical properties.

The diisocyanate used in the first phase could not be obtained from the same source. This was due to a shortage in materials causing the manufacturer to discontinue production of this material. As a result the diisocyanate was obtained from an alternate source. Although these diisocyanates were supposedly the equivalent, diisocyanates from different sources made by dissimilar procedures may give different ratios of isomers. These differences may produce elastomers having different physical properties as well as chemical and age resistance.

As stated previously, the original physical test data were obtained after the elastomers were allowed to post cure at ambient conditions for 45 days. This was done to follow the same procedure as that used in the first phase. The data presented in the Tables show that, in many cases, the tensile strength increases for the first few test periods. This phenomena is characteristic of this type of polyurethane elastomer. It does not indicate a lack of sufficient chemical reaction, commonly called curing. The elastomers are prepared with a slight excess of diisocyanate. This reacts further when subjected to temperatures and humidity above ambient room conditions giving a higher tensile strength although only slightly affecting the modulus.

2. Exposure to Combat Gasoline

Observation of Figures 2 through 11, clearly shows the effect of not changing the fuel throughout the exposure periods. In almost every case, the 84-day exposure period data do not fit on the curve through the other data. The 84 day data were obtained in the first phase program in which the fuel was changed periodically.

At the test temperature, the combat gasoline tended to boil when fresh fuel was added. After a short time, the boiling would cease. This indicated that the low boiling fractions were rapidly removed from the fluid. Additional losses occurred but at a slower rate. This was indicated by the fact that additional combat gasoline had to be added to the system at frequent intervals to maintain the desired level in the reactor pot.

It is suspected that the composition of the fluid changed considerably over the 70-day exposure period. The final composition of the test fluid was probably very high in the higher boiling fractions. It was perhaps much higher in aromatic content than the original combat gasoline. An increased aromatic content alone might be sufficient to cause the differences observed in these tests.

It is believed that the tests in combat gasoline may be too severe since combat gasoline has not caused a great deal of deterioration problems. During the laboratory study, the specimens were constantly saturated with fuel on the exposed surface. They were also constantly in saturated vapor. In field installations the fuel could only reach the exposed surface by permeation, leakage, or spills. Due to the high volatility of the combat gasoline, it is quickly evaporated from the surface of a pillow tank. Couple this fact with the fact that the composition of the fuel is changed in the laboratory test by the volatilization of lower boiling fractions, and it can be seen that this test may be quite severe.

If the polyester urethane is not considered, the remaining materials could be rated on the basis of

their stress-strain relations after exposure in the following order:

<u>Rating</u>	<u>Coating Material</u>
1	Nitrile/Vinyl Blend
2	Polyether Polyurethane
3	Epichlorohydrin Copolymer
4	Caprolactone Ester Urethane

3. Exposure to Combat Gasoline, Ultraviolet Radiation, and High Humidity

Observation of Figures 12 through 16 do not show as clear an effect of not changing the gasoline as is shown in gasoline soak alone. Perhaps one reason for this is the fact that some of the specimens were so severely degraded after the 84-day exposure period that no data were obtained in the first phase at this period.

During the first phase program, this test was rated as the most severe. However, if the 84-day data are not considered, the soaking test in combat gasoline alone appears to be more severe than this test if the fuel is not changed periodically. The only coating material which showed this exposure to be more severe through 70 days was the epichlorohydrin copolymer.

If the polyester urethane is not considered, the remaining materials could be rated on the basis of their stress-strain relations after exposure in the following order:

<u>Rating</u>	<u>Coating Material</u>
1	Polyether Polyurethane
2	Nitrile/Vinyl Blend
3	Caprolactone Ester Urethane
4	Epichlorohydrin Copolymer

4. Exposure to Diesel Fuel, Ultraviolet Radiation, and High Humidity

Observation of Figures 17 through 21 clearly shows the effect of not changing the diesel fuel during the

exposure period. However, it is believed that the differences are due to the change in pH of the fuel during the exposure periods rather than a loss of volatile fractions. During the 70-day exposure period, very little diesel fuel had to be added to the system to replace volatilized fuel.

Figure 22 shows that the pH of the diesel fuel was lowered from 7.2 to 3.8 during the 70-day exposure period. It is known that an acid pH can cause accelerated degradation of some of the coating materials in the presence of ultraviolet radiation and moisture. It is suspected that this change in pH of the fuel is the major cause of the more severe degradation in the second phase program.

This test does appear to cause a definite accelerated deterioration of the coating materials; however, it appears that at least three months exposure would be required to draw definite conclusion concerning the deterioration of coating materials.

Since the most probable cause of the accelerated deterioration of the coating is the change of pH of the fuel due to ultraviolet radiation and moisture, it might be possible to further accelerate this degradation by starting the exposure tests with a fuel having a pH adjusted to perhaps 2 or 3. If the major effect of the ultraviolet radiation and moisture is on changing the pH of the fuel and not directly on the coating material, it might be possible to obtain greatly accelerated deterioration of coating materials by using an elevated temperature soak test with the pH of the diesel fuel adjusted to a pH of 2 or 3.

If the polyester polyurethane is not considered, the remaining materials could be rated on the basis of their stress-strain relations after exposure in the following order:

<u>Rating</u>	<u>Coating Material</u>
1	Polyether Polyurethane
2	Nitrile-Vinyl blend
3	Caprolactone Ester Polyurethane
4	Epichlorohydrin Copolymer

SECTION 5

CONCLUSIONS

1. In all three of the exposure tests in this program the effect of not changing the fuel periodically caused a more severe degradation than when the fuels were changed at each two-week period.
2. The probable cause of the increased degradation of the coatings in combat gasoline is the change in composition of the fluid due to volatilization of lower boiling fractions.
3. The probable cause of the increased degradation of the coatings in diesel fuel is the change in pH of the fuel due to exposure to ultraviolet radiation and moisture.
4. All three tests could be used as accelerated deterioration tests; however, it appears that at least three months exposure would be required to draw definite conclusions concerning the deterioration of coatings.
5. It is suspected that both of the exposure tests in combat gasoline are too severe.
6. The test in diesel fuel is probably realistic. It is suspected that further acceleration of this test could be accomplished by adjusting the initial pH of the fuel downward.

SECTION 6
RECOMMENDATIONS

1. A program be initiated to determine if further acceleration of the deterioration of the coating materials can be obtained by adjusting the initial pH of the diesel fuel to 2 or 3 in both the diesel fuel soak test and the diesel fuel test combining ultraviolet radiation and high humidity.
2. Select coating materials, which have actual field experience data available, and subject them to these exposure conditions. These data could then be compared with the field experience data to determine the validity of using these tests as accelerated aging tests.

Table 2
Exposure to Combat Gasoline at 158°F - Tested Saturated

Program Phase	I	II	I	I	I	I	II	I	II	II	II	I
Exposure Time (days)	0	0	7	14	28	42	56	70	84			
	Ultimate Tensile (psi)											
Polyester Urethane	7700	5800	4000	2400	3150	5850	5350	3850	1050			
Polyether Urethane	5600	5400	3350	2550	2600	2350	1150	470	2000			
Nitrile-vinyl	2100	2150	1600	1700	1650	1800	1650	1100	1650			
Epichlorohydrin Copolymer	1850	1900	1400	1400	1400	1300	950	540	650			
Caprolactone Ester	5000	5300	4100	2350	2400	2200	380	120	260			
	100% Modulus (psi)											
Polyester Urethane	2850	4050	890	530	940	1500	1850	1750	950			
Polyether Urethane	1650	1550	990	780	930	770	580	-	610			
Nitrile-vinyl	460	455	290	250	360	350	410	360	360			
Epichlorohydrin Copolymer	700	517	730	560	830	390	350	230	-			
Caprolactone Ester	1110	1110	550	670	570	580	-	-	-			
	Ultimate Elongation (%)											
Polyester Urethane	300	210	340	420	320	260	270	260	130			
Polyether Urethane	300	330	330	340	290	490	320	90	450			
Nitrile-vinyl	470	500	420	500	390	430	380	330	340			
Epichlorohydrin Copolymer	300	320	170	210	150	260	220	260	80			
Caprolactone Ester	350	360	480	380	470	470	80	15	50			

TABLE 3
Exposure to Combat Gasoline at 158°F - Tested Dry

Program Phase	I		II		I		I		I		II		II		I	
	0	0	0	0	7	14	28	42	56	70	84					
Exposure Time (days)	Ultimate Tensile (psi)															
	Polyester Urethane															
	Polyether Urethane															
	Nitrile-vinyl															
	Epichlorohydrin Copolymer															
Caprolactone Ester																
100% Modulus (psi)																
Polyester Urethane																
Polyether Urethane																
Nitrile-vinyl																
Epichlorohydrin Copolymer																
Caprolactone Ester																
Ultimate Elongation (%)																
Polyester Urethane																
Polyether Urethane																
Nitrile-vinyl																
Epichlorohydrin Copolymer																
Caprolactone Ester																

TABLE 4
Exposure to Combat Gasoline Combined with Ultraviolet and High Humidity at 145°F

Program Phase	I	II	I	I	II	II	I	II	II	I
Exposure Time (days)	0	0	14	28	28	56	70	84		
	Ultimate Tensile (psi)									
Polyester Urethane	7700	5800	6050	5600	5900	5300	5650	-		
Polyether Urethane	5600	5400	6200	4400	5350	2900	2850	2250		
Nitrile-vinyl	2100	2150	2200	2100	2300	2250	2250	2350		
Epichlorohydrin Copolymer	1850	1900	1850	1100	640	560	210	1100		
Caprolactone Ester	5000	5300	6550	5450	4900	2300	1200	-		
	100% Modulus (psi)									
Polyester Urethane	2850	4050	1800	2050	3150	3700	3400	-		
Polyether Urethane	1650	1550	1650	1450	1550	1400	1300	1700		
Nitrile-vinyl	460	455	1100	1350	1500	1750	2000	-		
Epichlorohydrin Copolymer	700	517	860	690	310	280	-	-		
Caprolactone Ester	1100	1110	1050	1150	1250	1150	1000	-		
	Ultimate Elongation (%)									
Polyester Urethane	300	210	310	320	230	190	240	-		
Polyether Urethane	300	330	340	370	390	390	430	180		
Nitrile-vinyl	470	500	320	250	250	190	150	20		
Epichlorohydrin Copolymer	300	320	220	170	320	230	80	20		
Caprolactone Ester	350	360	440	390	400	360	210	-		

TABLE 5
Exposure to Diesel Fuel Combined with Ultraviolet and High Humidity at 145°F

Program Phase	I	II	I	I	II	I	II	II	I	II	I
Exposure Time (days)	0	0	14	28	28	42	56	70	84		
	Ultimate Tensile (psi)										
Polyester Urethane	7700	5800	6200	6250	6600	6000	6150	5750	3650		
Polyether Urethane	5600	5400	5650	5800	5530	4100	4300	3000	3650		
Nitrile-vinyl	2100	2150	2200	2200	2250	1950	1800	1550	2000		
Epichlorohydrin Copolymer	1850	1900	1700	1300	1350	630	290	60	430		
Caprolactone Ester	5000	5300	7700	6000	5050	2950	2750	1600	4000		
	100% Modulus (psi)										
Polyester Urethane	2850	4050	2000	2250	4350	4050	4200	3900	1100		
Polyether Urethane	1650	1550	1600	1650	1500	1400	1400	1300	1550		
Nitrile-vinyl	460	455	960	1050	1020	1100	1100	900	1050		
Epichlorohydrin Copolymer	700	517	670	530	380	290	160	-	220		
Caprolactone Ester	1110	1110	1110	1050	1150	1050	1050	930	1060		
	Ultimate Elongation (%)										
Polyester Urethane	300	210	300	280	210	210	210	220	370		
Polyether Urethane	300	330	320	340	400	460	450	420	310		
Nitrile-vinyl	470	500	350	310	300	240	210	230	240		
Epichlorohydrin Copolymer	300	320	260	250	330	250	220	20	270		
Caprolactone Ester	350	360	390	400	460	430	400	330	390		

TABLE 6

pH Change of Fuels in Ultraviolet Chambers

<u>Days Exposure</u>	<u>pH of Fuel</u>	
	<u>Diesel Fuel</u>	<u>Combat Gasoline</u>
0	7.2	7.0
14	5.9	6.9
28	5.2	6.8
42	4.9	6.7
56	4.3	6.6
70	3.8	6.6

TABLE 7

pH of Combat Gasoline in Reactor Pots

<u>Exposure Days</u>	<u>Coating Material</u>				
	<u>Polyester Urethane</u>	<u>Polyether Urethane</u>	<u>Nitrile/vinyl Blend</u>	<u>Epichlorohydrin Copolymer</u>	<u>Caprolactone Ester</u>
50	6.9	6.7	6.7	6.1	7.0
70	6.8	6.9	6.8	6.4	6.9

FIGURE 1
ENVIRONMENTAL TEST CHAMBER

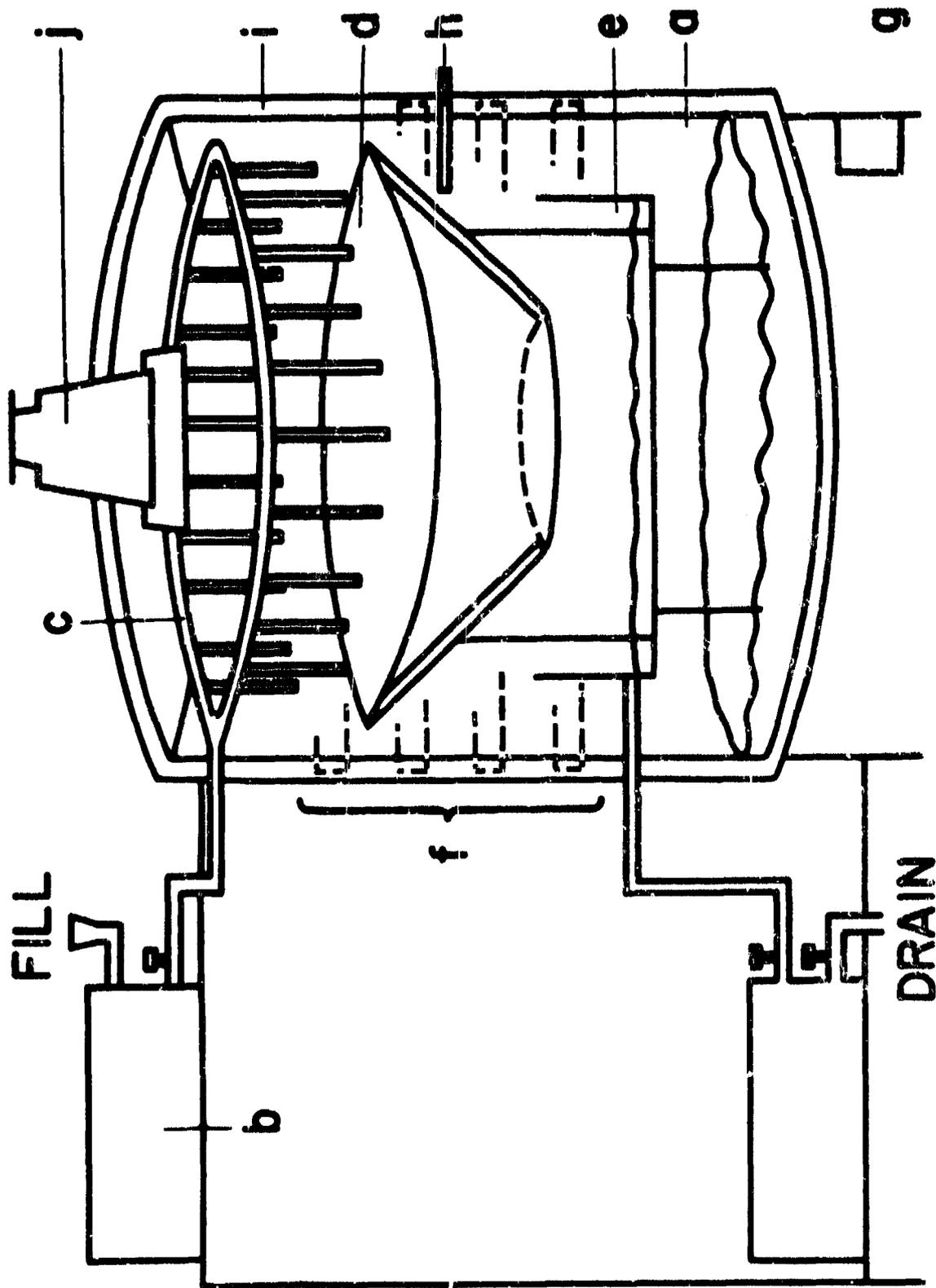


Figure 2

Effect of Exposure to
Combat Gasoline at 158°F
on Polyester Urethane
Tested Saturated

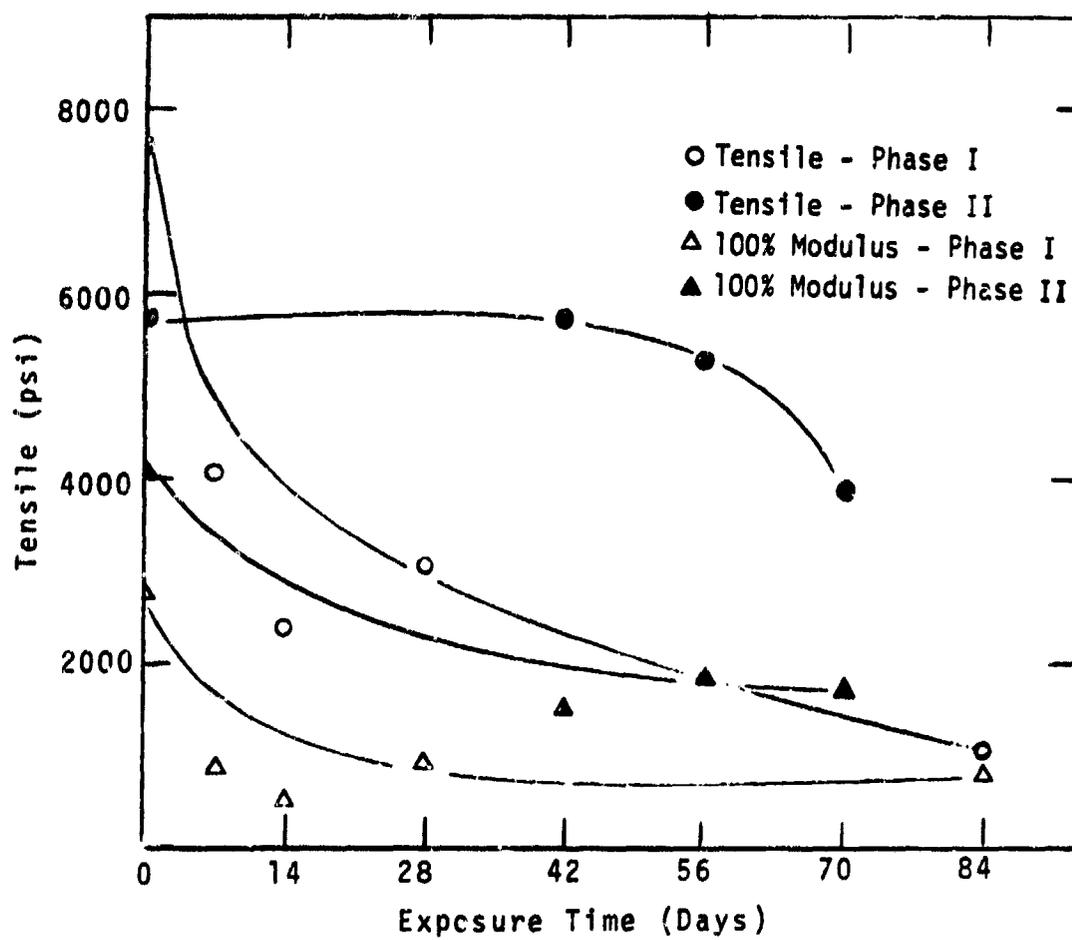


Figure 3
Effect of Exposure to
Combat Gasoline at 158°F
on Polyether Urethane
Tested Saturated

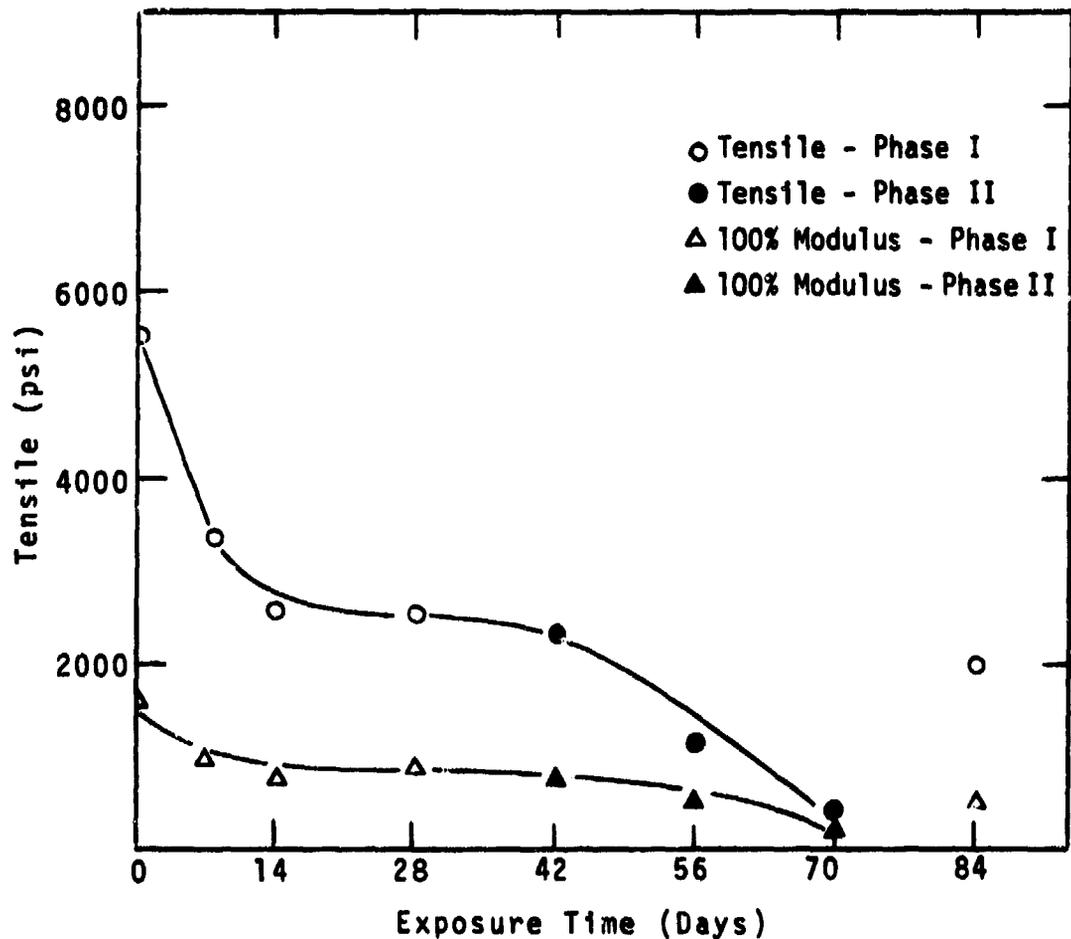


Figure 4

Effect of Exposure to
Combat Gasoline at 158°F
on Nitrile/Vinyl Blend
Tested Saturated

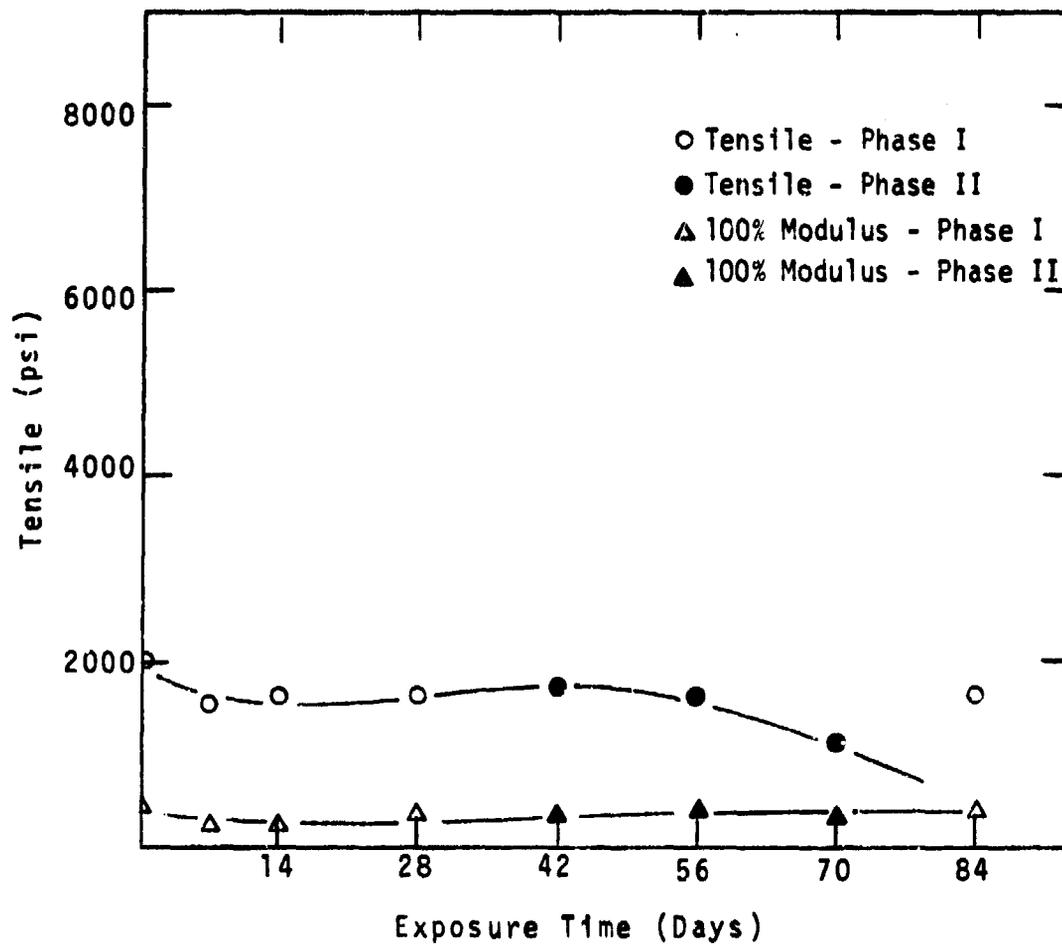


Figure 5
Effect of Exposure to
Combat Gasoline at 158°F
on Epichlorohydrin Copolymer
Tested Saturated

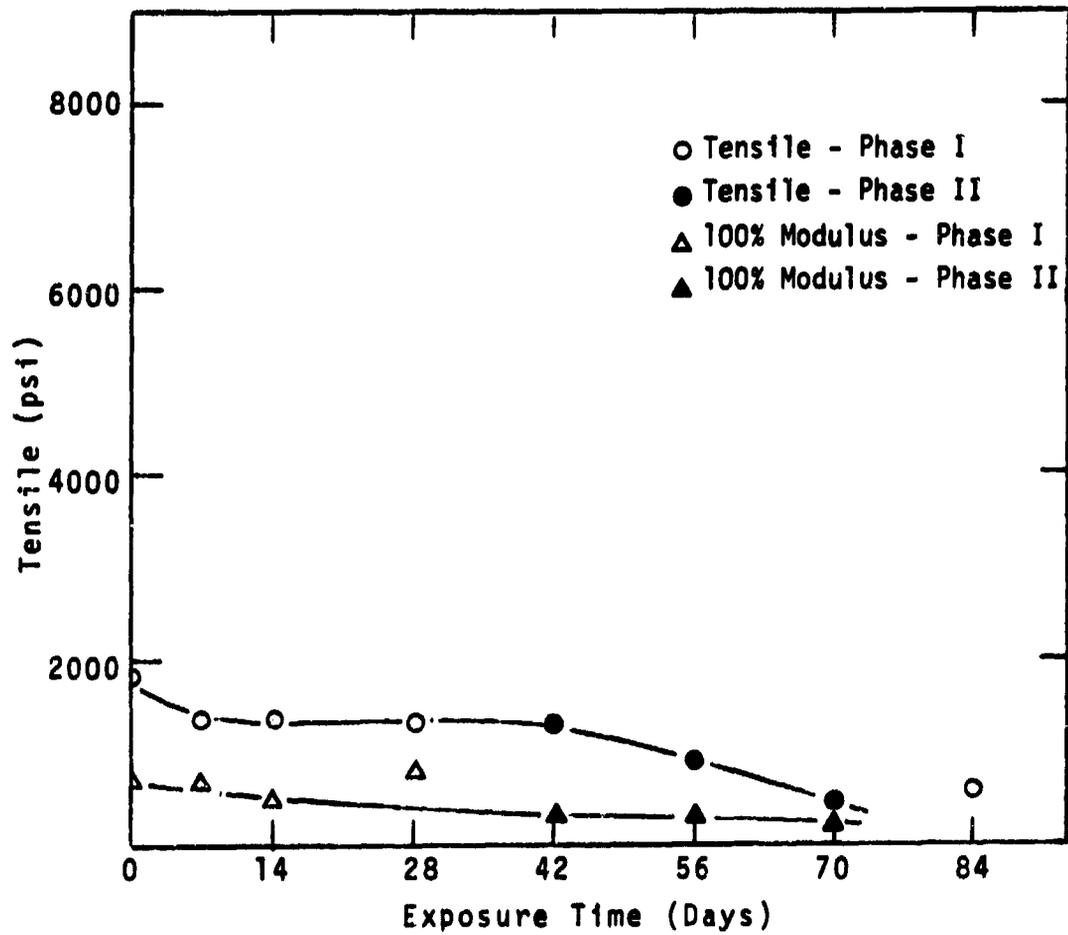


Figure 6

Effect of Exposure to
Combat Gasoline at 158°F
on Caprolactone Ester Polyurethane
Tested Saturated

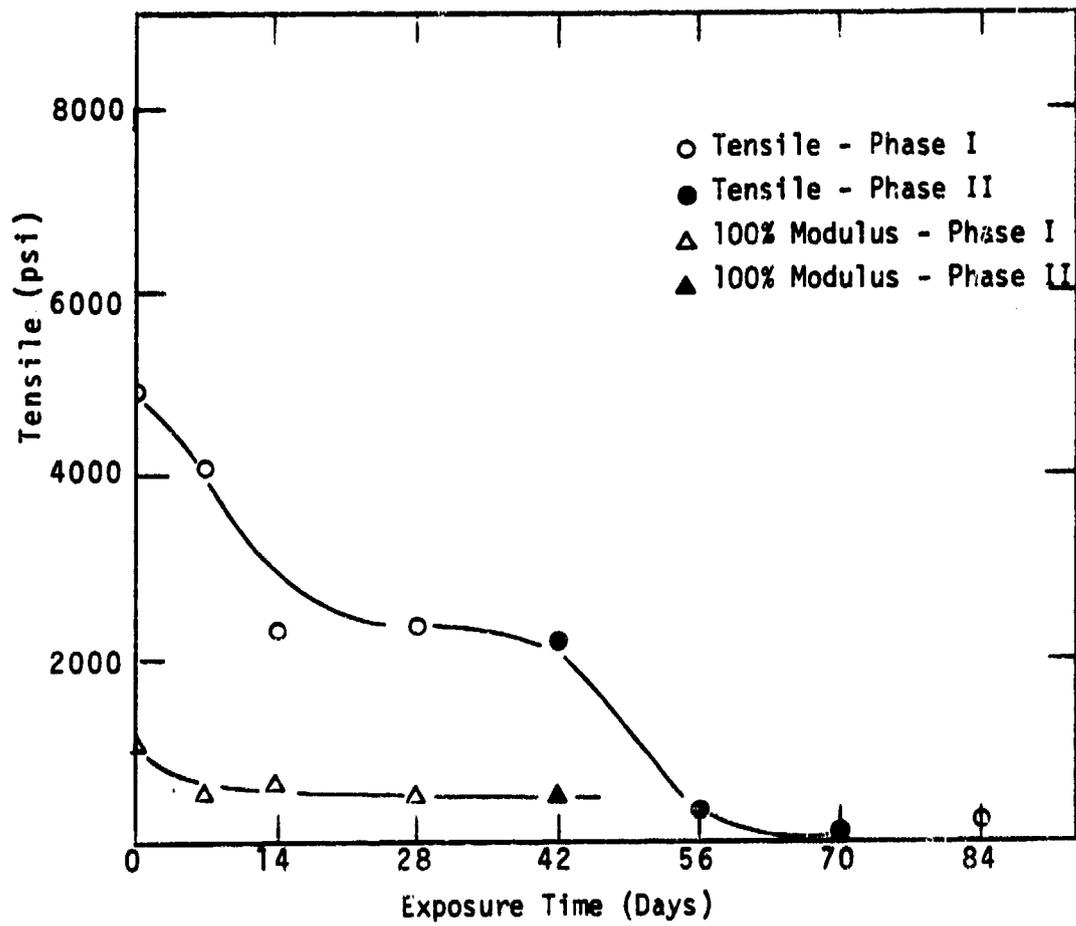


Figure 7

Effect of Exposure to
Combat Gasoline at 158°F
on Polyester Urethane
Tested After Drying

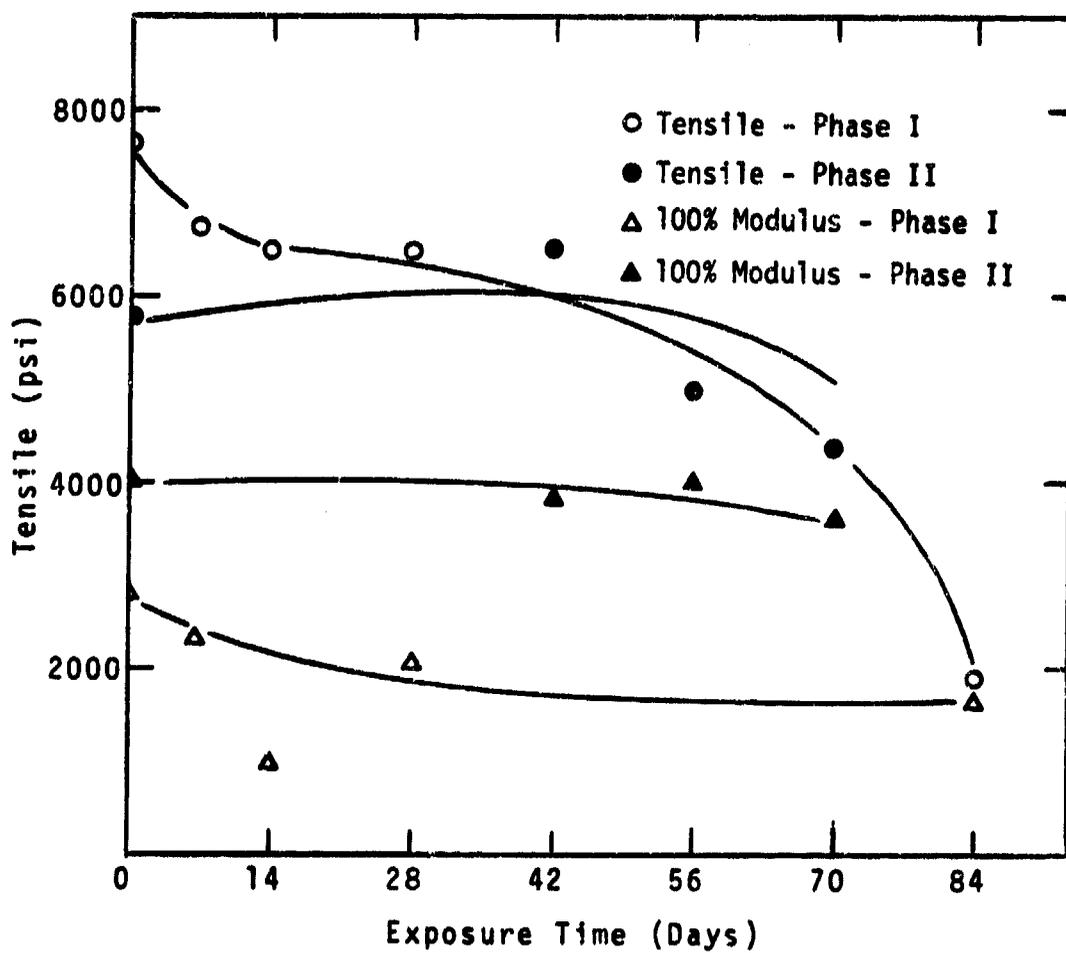


Figure 8

Effect of Exposure to
Combat Gasoline at 158°F
on Polyether Urethane
Tested After Drying

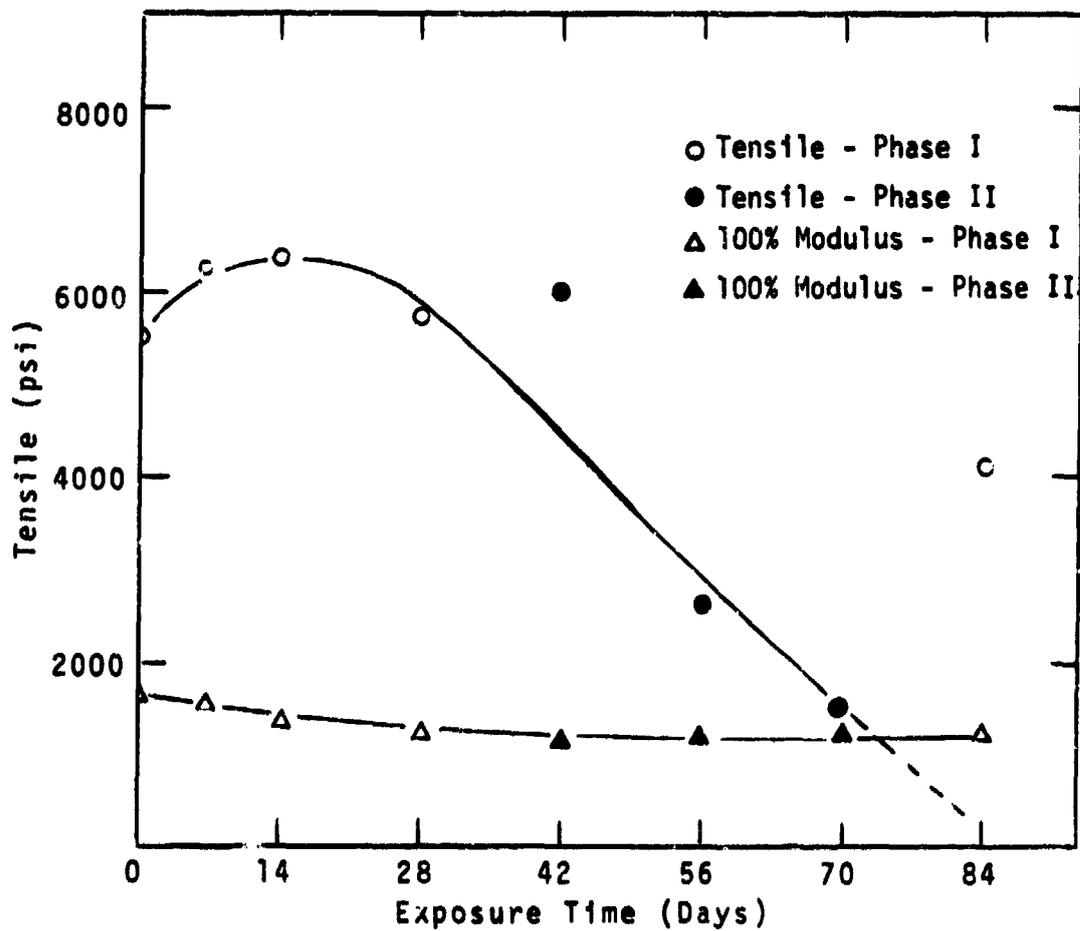


Figure 9

Effect of Exposure to
Combat Gasoline at 158°F
on Nitrile/Vinyl Blend
Tested After Drying

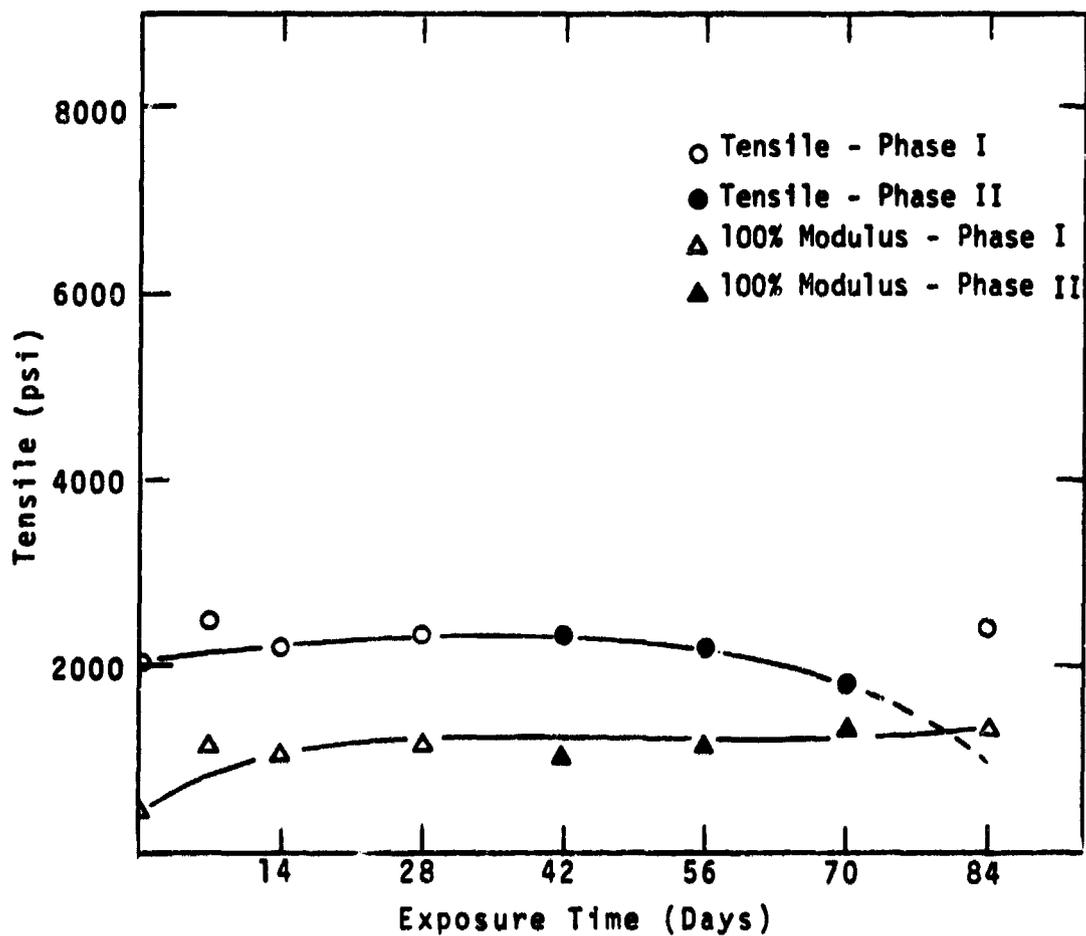


Figure 10

Effect of Exposure to
Combat Gasoline at 158°F
on Epichlorohydrin Copolymer
Tested After Drying

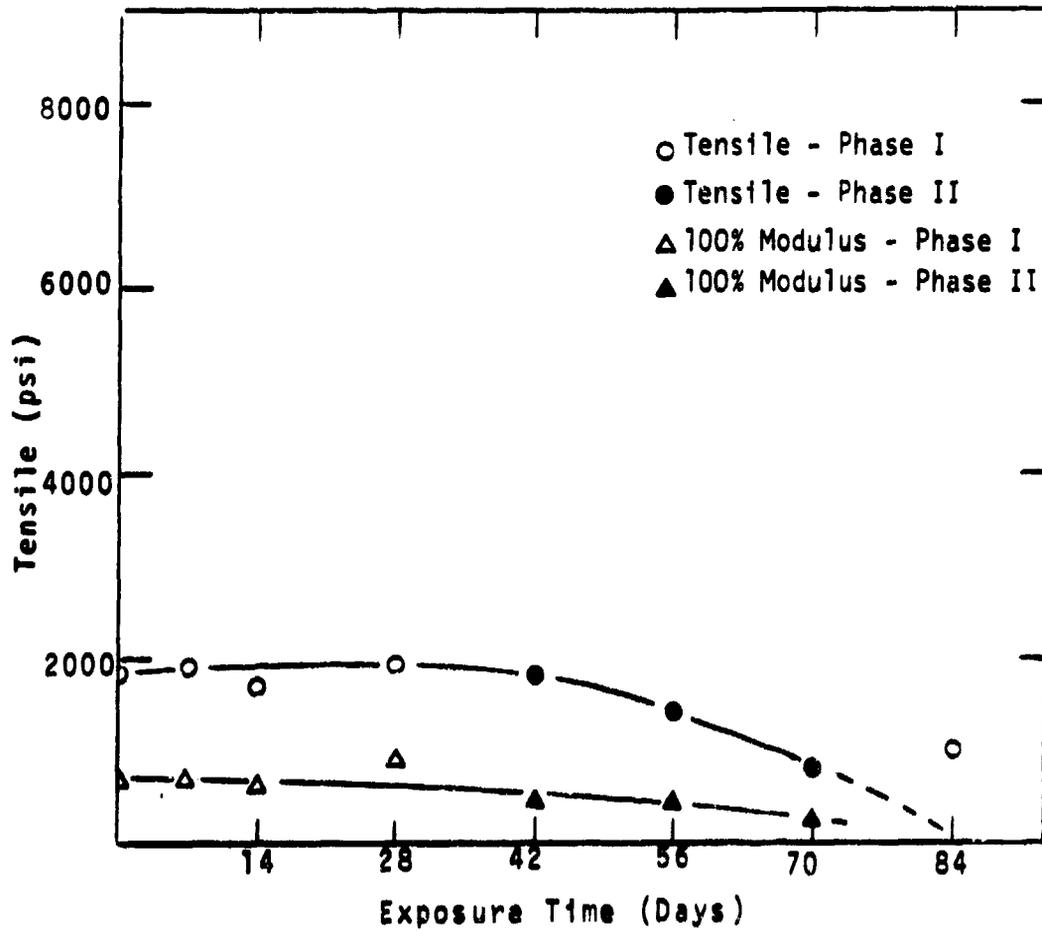


Figure 11
Effect of Exposure to
Combat Gasoline at 158°F
on Caprolactone Ester Urethane
Tested After Drying

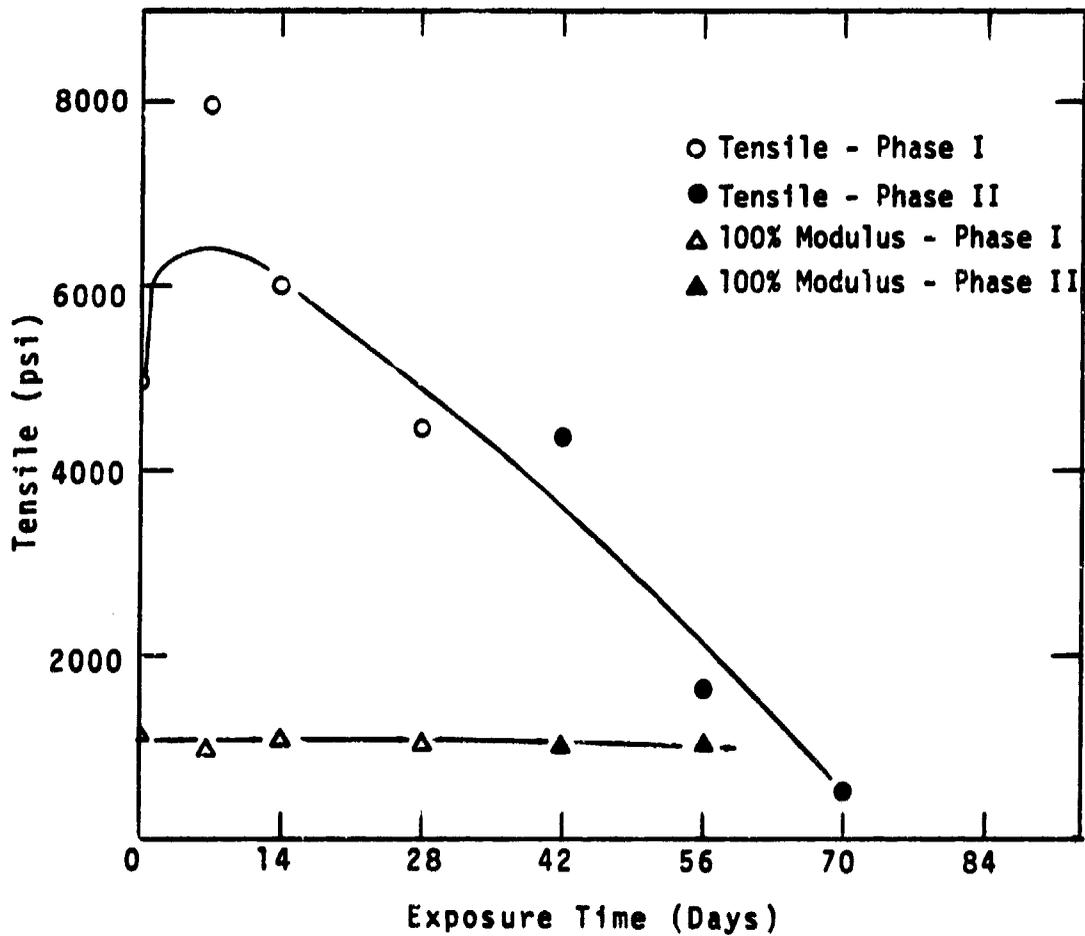


Figure 12

Effect of Combat Gasoline
Combined with Ultraviolet Radiation
and High Humidity at 145°F
on Polyester Urethane

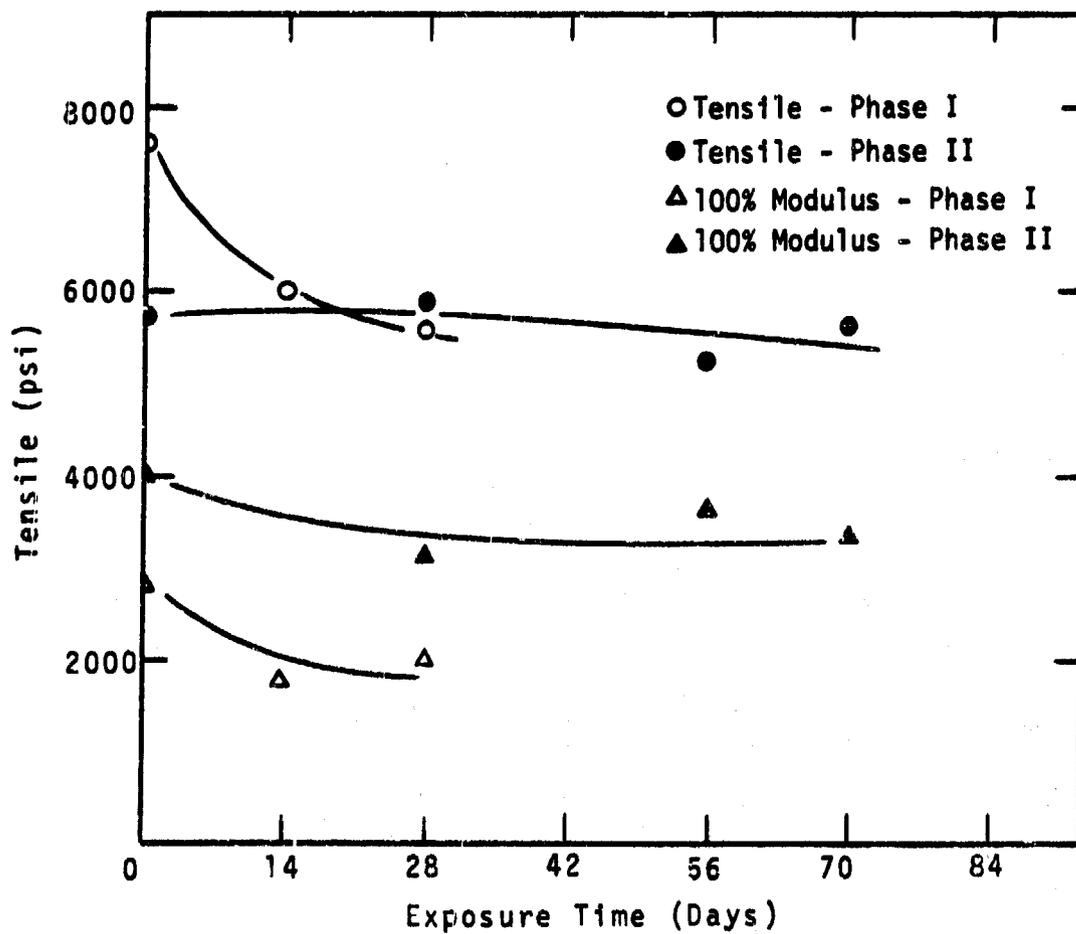


Figure 13

Effect of Combat Gasoline
Combined with Ultraviolet Radiation
and High Humidity at 145°F
on Polyether Urethane

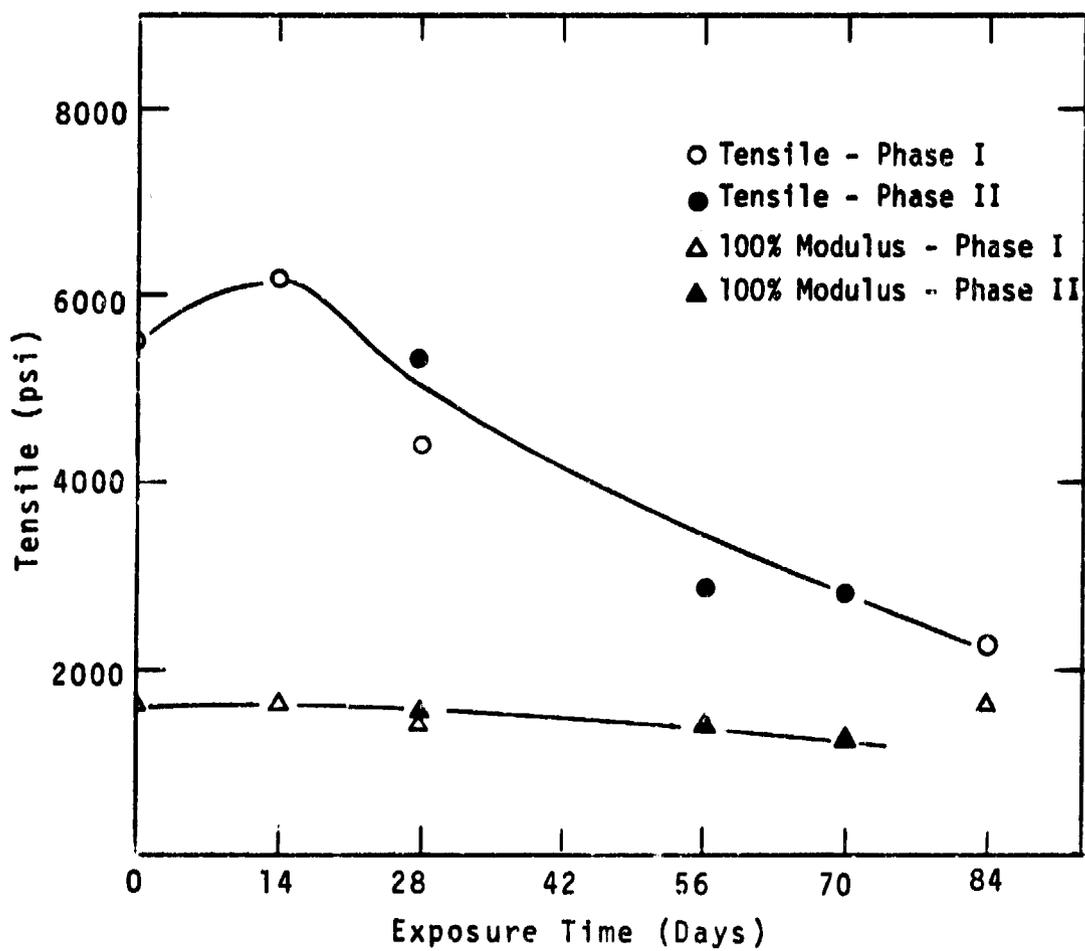


Figure 14

Effect of Combat Gasoline
Combined with Ultraviolet Radiation
and High Humidity at 145°F
on Nitrile/Vinyl Blend

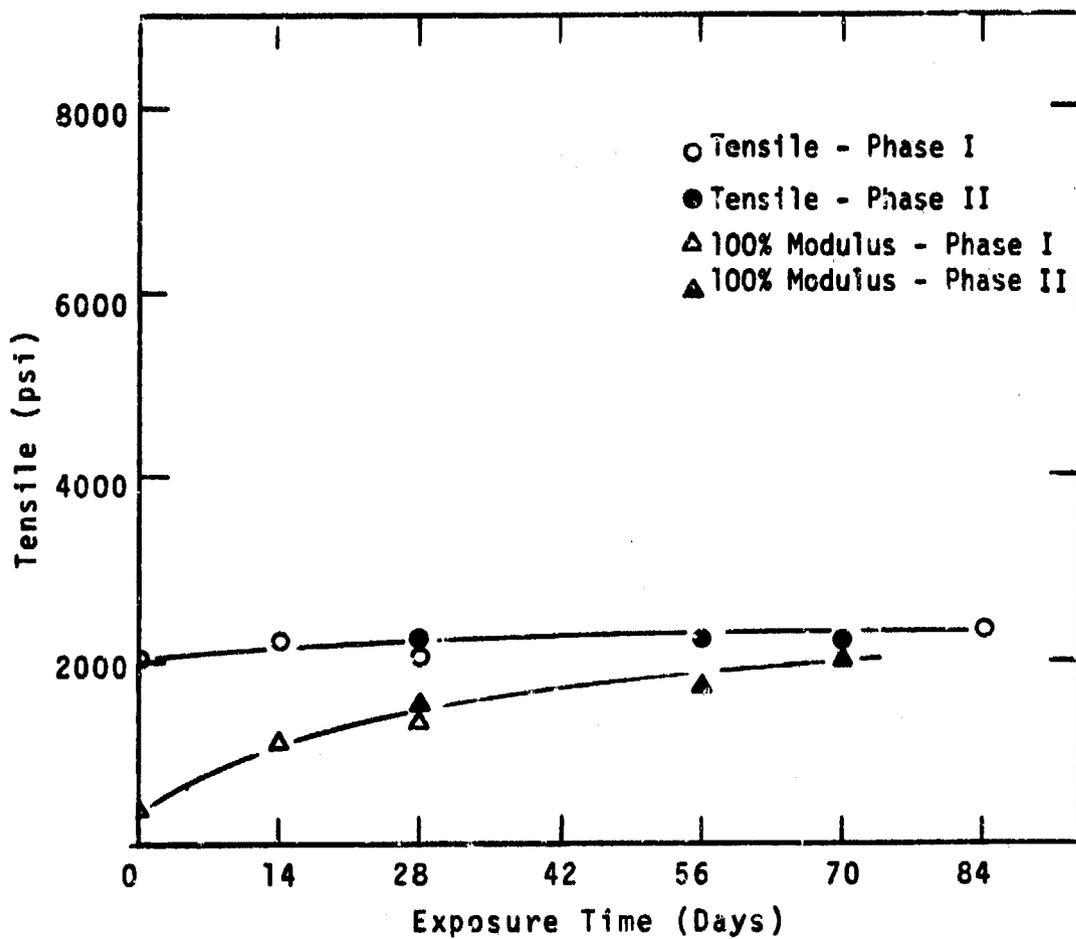


Figure 15

Effect of Combat Gasoline
Combined with Ultraviolet Radiation
and High Humidity at 145°F
on Epichlorohydrin Copolymer

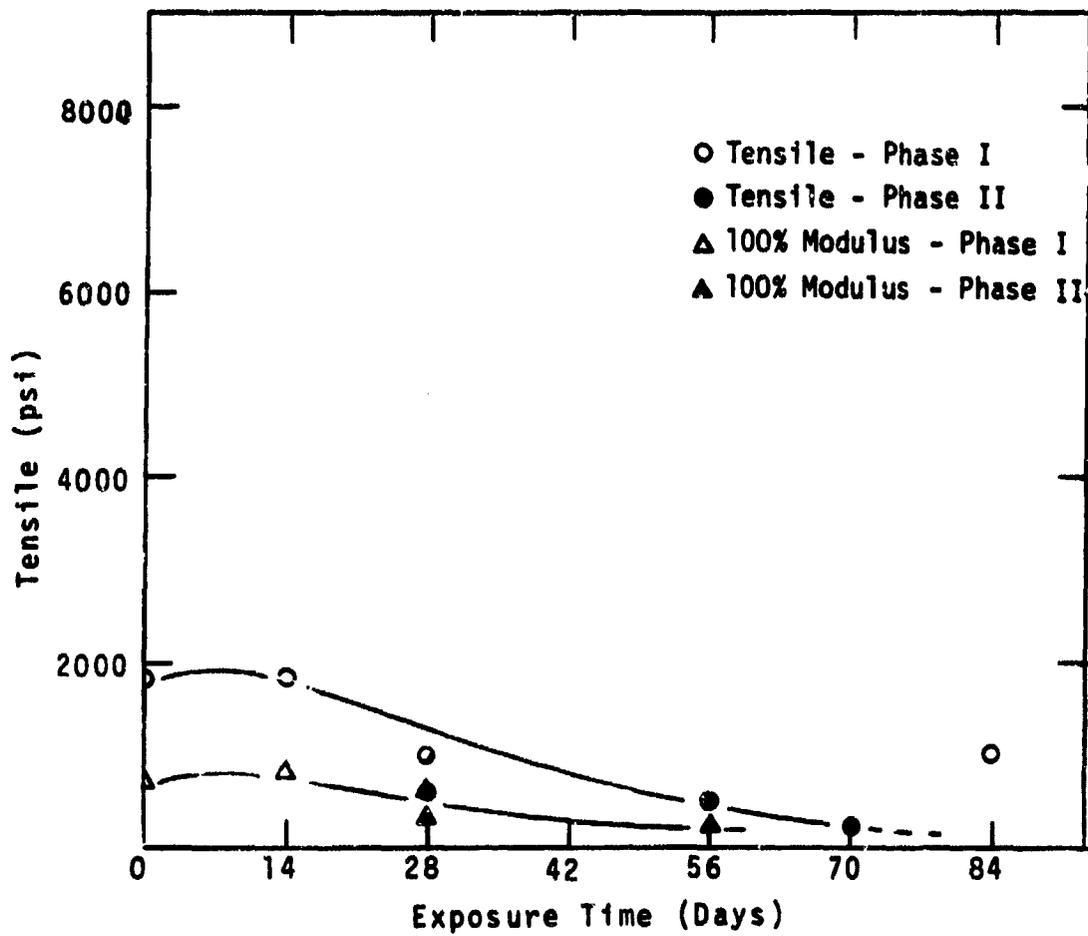


Figure 16

Effect of Combat Gasoline
Combined with Ultraviolet Radiation
and High Humidity at 145°F
on Caprolactone Ester Urethane

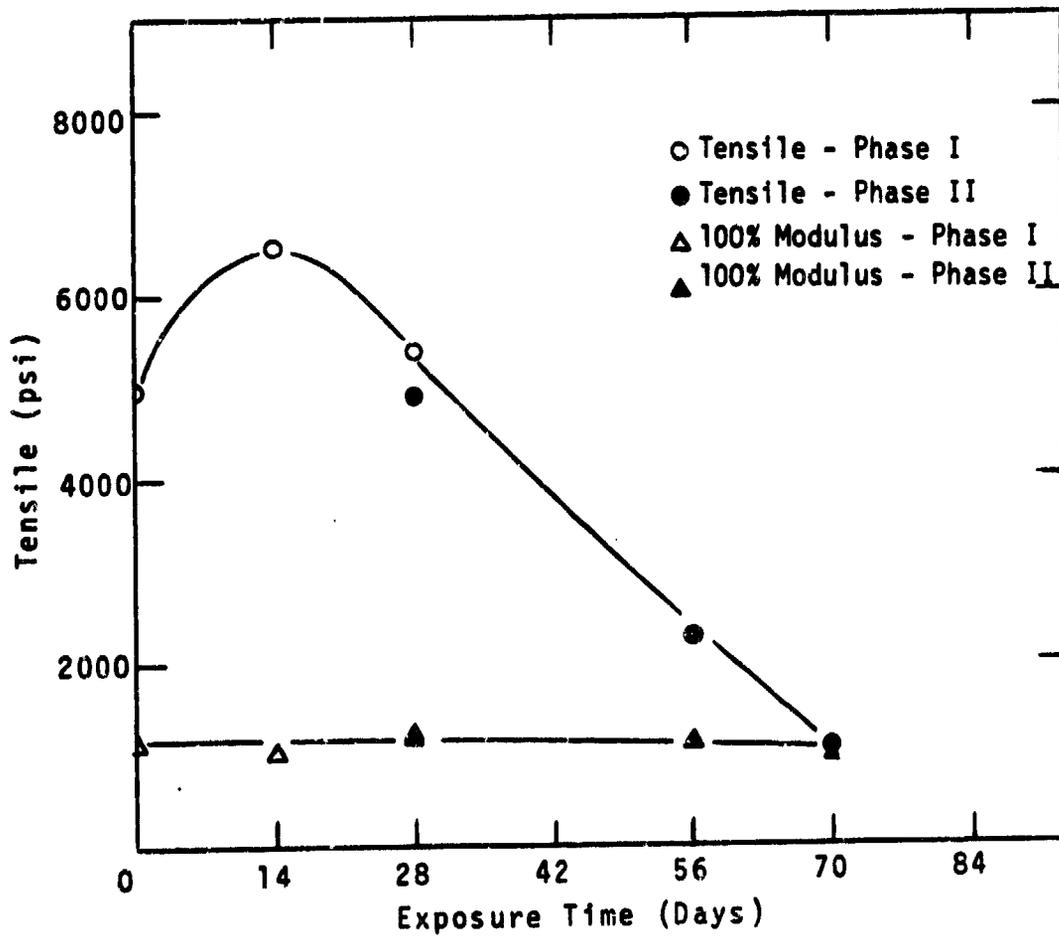


Figure 17

Effect of Diesel Fuel
Combined with Ultraviolet Radiation
and High Humidity at 145°F
on Polyester Urethane

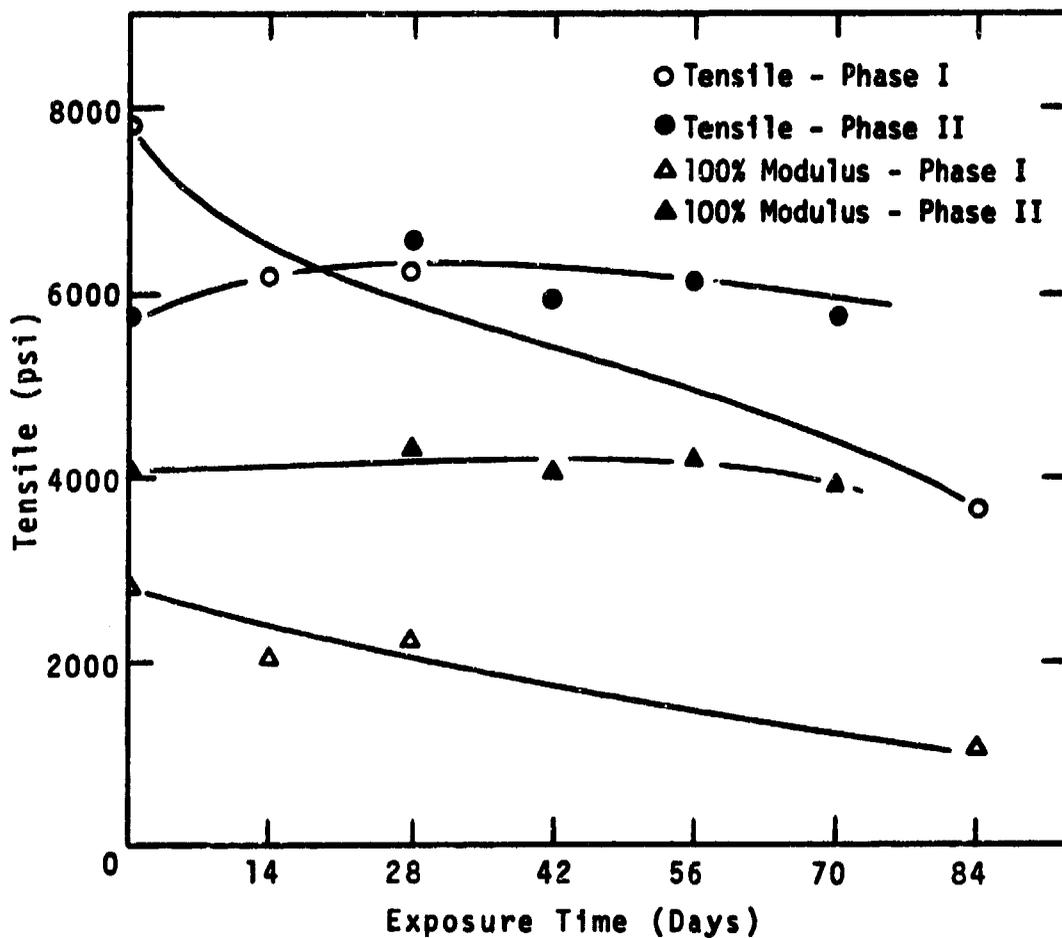


Figure 18

Effect of Diesel Fuel
Combined with Ultraviolet Radiation
and High Humidity at 145°F
on Polyether Urethane

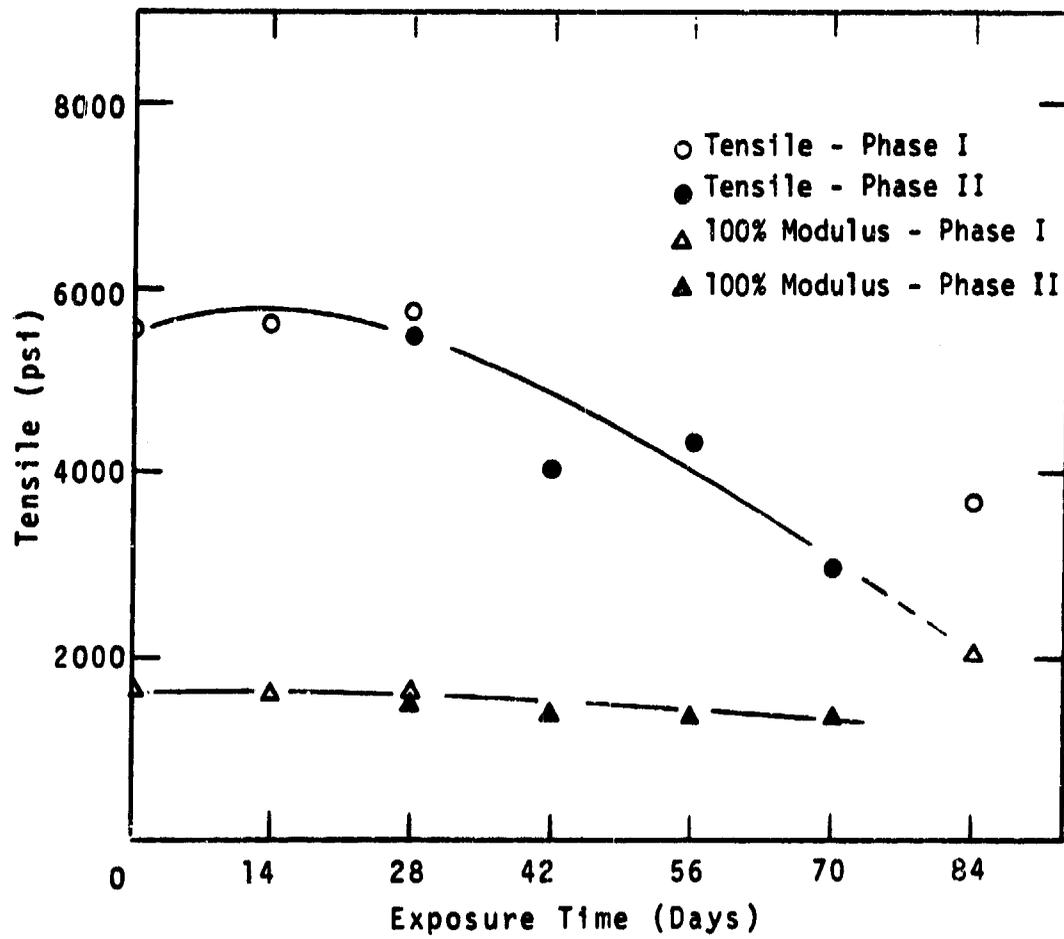


Figure 19

Effect of Diesel Fuel
Combined with Ultraviolet Radiation
and High Humidity at 145°F
on Nitrile/Vinyl Blend

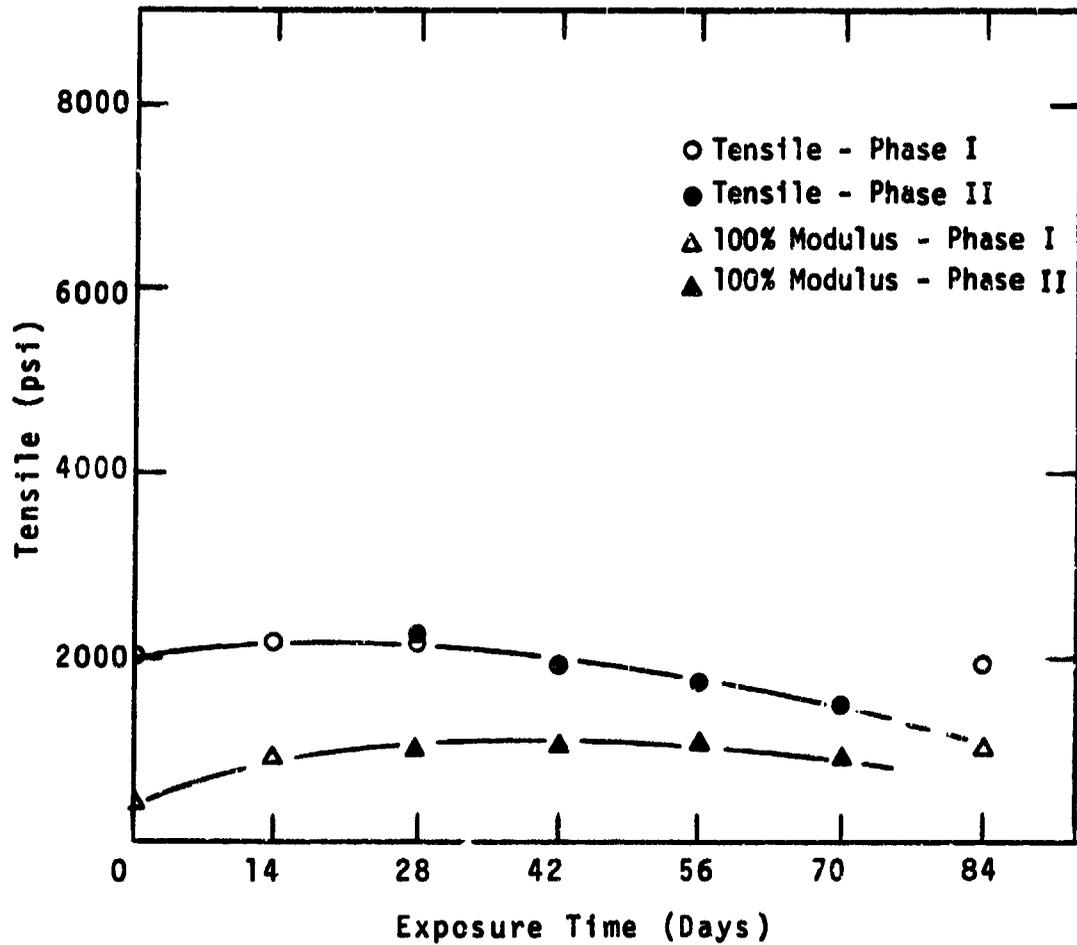


Figure 20

Effect of Diesel Fuel
Combined with Ultraviolet Radiation
and High Humidity at 145°F
on Epichlorohydrin Copolymer

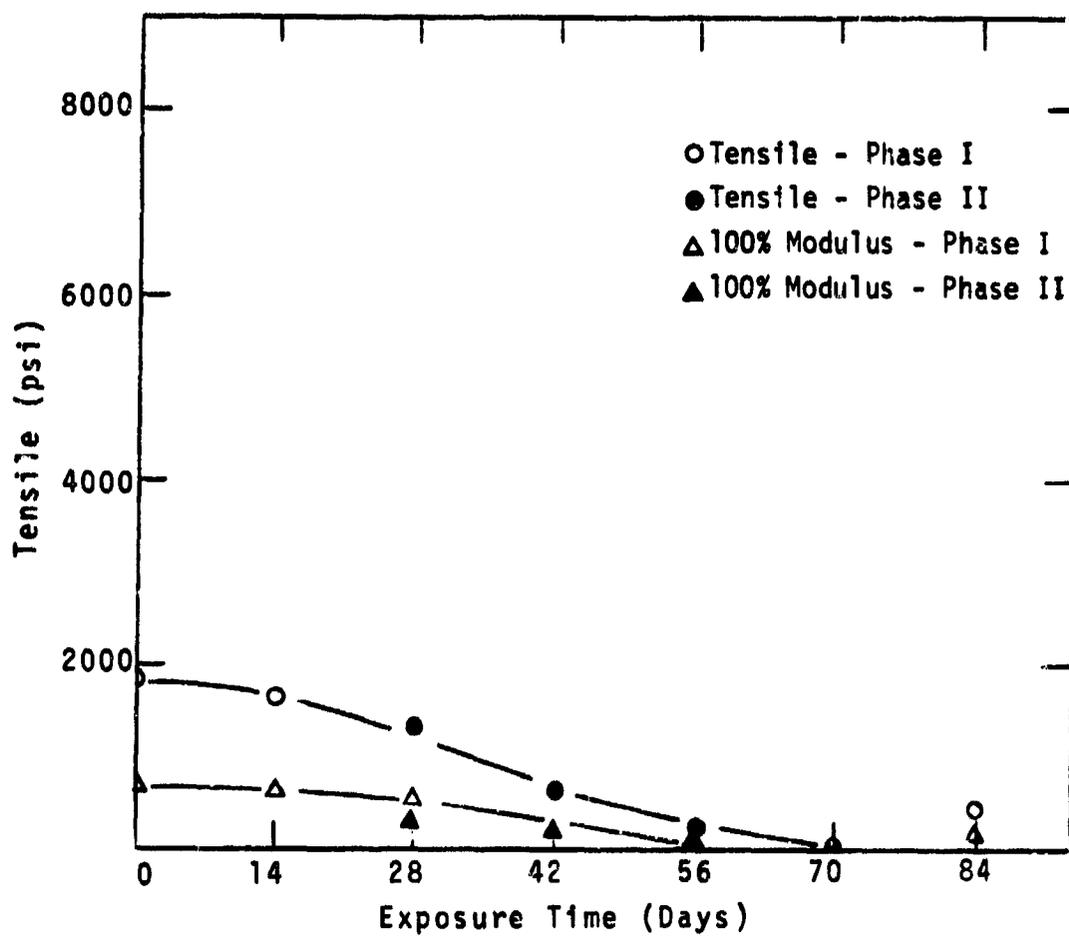


Figure 21

Effect of Diesel Fuel
Combined with Ultraviolet Radiation
and High Humidity at 145°F
on Caprolactone Ester Urethane

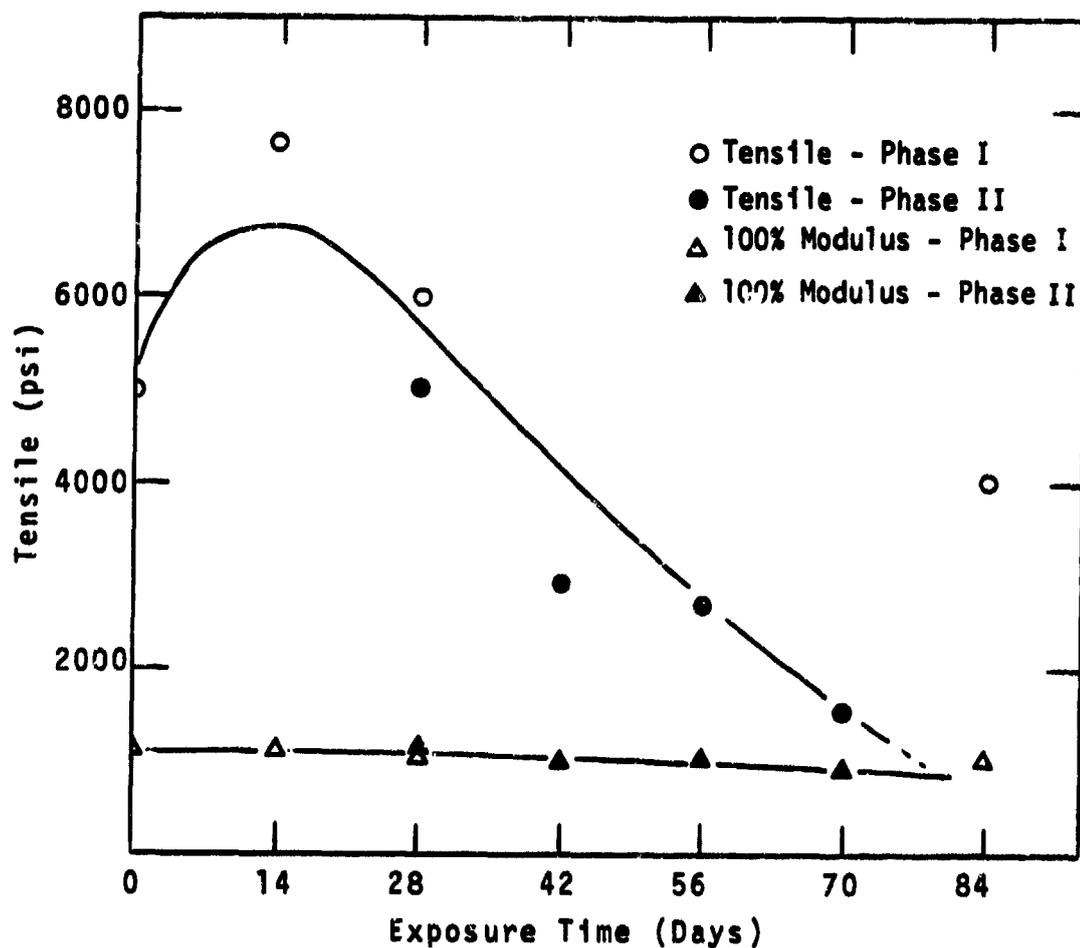


Figure 22

pH Change of Test Fluids
in Test Chambers

