AFML-TR-74-266

DEVELOPMENT OF ENGINEERING DATA ON THE MECHANICAL AND PHYSICAL PROPERTIES OF ADVANCED COMPOSITES MATERIALS

IIT RESEARCH INSTITUTE

TECHNICAL REPORT AFML—TR—74—266

FEBRUARY 1975

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AIR FORCE MATERIALS LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT—PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

Marvin Knight

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Project Monitor

FOR THE COMMANDER

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Chief, Materials Engineering Branch
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Data were generated on the effect of various environments on the physical, thermal, and mechanical properties of Thornel 300/Narmco 5208 composites. The laminates were prepared from three-inch wide prepreg tape in accordance with current aerospace specifications.

The environments included steady state humidity conditioning for two exposure periods, cyclic humidity conditioning which

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19. conductivity, density, steady state thermal exposure, thermo-humidity cycling, intralaminar shear, flex tests, Thornel 300 Graphite/Narmco 5208, graphite/epoxy composites, laminate data, laminate fabrication, moisture weight gain.

20. included the effects of thermal shocks and the effect of photo-degradative exposures, and steady and cyclic thermal exposures.

The mechanical properties investigated included tension, compression, in-plane shear, interlaminar shear and flexural static properties, fatigue, creep and stress-rupture resistances.

The strengths of 0° Thornel 300/Narmco 5208 laminates decreased only slightly with increasing temperature. The elastic moduli of the 0° laminates remained relatively constant over the range from room temperature to 350°F. The transverse strength and modulus and the in-plane shear strength decreased with increasing temperature.

Moisture deteriorated the tensile strengths of the 0° and 90° composites by about 20% at the higher temperatures, (350°F) but were not deleterious for the compressive strengths. Slight increases (approximately 10%) were noted for the strengths of $[0/45/135/0/\overline{90}]_s$ laminates and about the same for the moduli.

Steady-state thermal exposure had practically no effect on the strengths or moudli of three orientations studied. The cyclic thermal exposure deteriorated the strength of the $[0/45/135/0/\overline{90}]_s$ laminates the greatest (approximately 35%).

In general no serious effect on the fatigue S-N behavior resulted from either humidity conditioning or cyclic and steady state thermal conditioning. In fact, increases of approximately 10 to 20% were indicated for all cyclic life levels and at all three temperatures where testing was conducted. The same results were indicated for the stress-rupture behavior of Thornel 300/Narmco 5208.

Overall the Thornel 300/Narmco 5208 composite system showed consistent strengths and moduli, over the range of temperatures studied (room temperature to 350°F) and after a wide variety of humidity and thermal conditioning treatments. The system possesses a high resistance to degradation of its mechanical properties after exposure to humidity and thermal conditioning.

ADA014363

FOREWORD

This technical report was prepared by the Mechanics Research Division of the IIT Research Institute, Chicago, Illinois. The authors include K. E. Hofer, Jr. responsible for overall program management and mechanical testing, D. Larsen, responsible for thermo-physical testing, and V. Humphreys responsible for the data analysis. Other supporting staff for this effort include D. Weed, fabrication activities, H. Lane, Static test engineer, L. C. Bennett, fatigue test engineer and Renard Porte, Creep test engineer.

The effort described was conducted in support of Project No. 7381, Material Application, Task No. 738106 for the Systems Support Division during the period of June 1, 1973 through July 31, 1974.

This report was submitted by the authors August, 1974.

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SECTION I

1.0 INTRODUCTION

The objective of this program was to generate data on the effect of various environments on the physical and mechanical properties of Thornel 300 Graphite/Narmco 5208 composites. This system is currently under investigation for a wide variety of aerospace structural components and is commercially available in prepreg tape and broadgoods forms. The laminates and specimens were fabricated at IITRI utilizing autoclave processing techniques.

The environmental conditioning treatments were identical to those employed in a similar program(1)* for three other composites: Avco 5505/Boron; Modmor II Graphite/Narmco 5206; and Hercules 3002M/Courtaulds HMS Graphite and the results of this program together with those of Reference 1 provide critical information on several advanced composite materials. The environments included steady state humidity conditioning for two exposure durations, cyclic humidity conditioning which in turn included the effects of thermal shocks and the effect of photodegradative exposures and steady and cyclic thermal exposures.

The testing program encompassed the following properties:

1. tension
2. compression
3. in-plane shear
4. interlaminar shear
5. flexural tests

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* Numbers in parenthesis refer to the References Section at the end of this report.

6. fatigue
7. creep and stress-rupture
8. thermal expansion
9. thermal conductivity
10. density.

Selected tests were also performed on coated samples.

An outline of the entire program is presented in Tables I through III.

TABLE I

BASE LINE DATA PROGRAM FOR

THORNEL 300 GRAPHITE/NARMCO 5208

Property	Fiber Orient.	Numbers of Specimens RT	260°F	350°F	Total
Tension	0°	5 (3)*	5 (3)	5 (3)	15 (9)
	90°	5 (3)	5 (3)	5 (3)	15 (9)
	0°/90°/± 45°	5 (3)	5 (3)	5 (3)	15 (9)
Compression Sandwich Beam	0°	5 (3)	-	5 (3)	10 (6)
	90°	5 (3)	-	5 (3)	10 (6)
	0°/90°/± 45°	5 (3)	-	5 (3)	10 (6)
Compression Coupon	0°	5 (3)	5 (3)	5 (3)	15 (9)
	90°	5 (3)	5 (3)	5 (3)	15 (9)
	0°/90°/± 45°	5 (3)	5 (3)	5 (3)	15 (9)
In Plane Shear	± 45°	5 (3)	5 (3)	5 (3)	15 (9)
Int. Shear	0°	5	5	5	15
	0°/90°/± 45°	5	5	5	15
Flexure	0°	5	5	5	15
	90°	5	5	5	15
	0°/90°/± 45°	5	5	5	15
Fatigue R = 0.1	0°	10	10	10	30
	90°	10	10	10	30
	0°/90°/± 45°	10	10	10	30
Creep & Stress Rupture	0°	-	10 (10)	10 (10)	20 (20)
	90°	-	10 (10)	10 (10)	20 (20)
	0°/90°/± 45°	-	10 (10)	10 (10)	20 (20)
Thermal Expansion	0°	-	-	3	3
	90°	-	-	3	3
	0°/90°/± 45°	-	-	3	3
Thermal Conductivity	0°	-	-	3	3
	90°	-	-	3	3
	0°/90°/± 45°	-	-	3	3
Density (at RT)	0°	3	-	-	3
	90°	3	-	-	3
	0°/90°/± 45°	3	-	-	3

* Numbers in parenthesis indicate instrumented specimens.

TABLE II

HUMIDITY EXPOSURE DATA PROGRAM FOR
THORNEL 300 GRAPHITE/NARMCO 5208

Property	Humidity Conditioning	0° Orientation			Total	90° Orientation			Total	$[0/45/135/0/\overline{90}]_s$ Orient.			Total	± 45° Orientation			Total	Overall Total
		RT	260°F	350°F		RT	260°F	350°F		RT	260°F	350°F		RT	260°F	350°F		
Tension	Steady/500 Hrs.**	3(3)*	3	3	9(3)	3(3)	3	3	9(3)	3(3)	3	3	9(3)	-	-	-	-	27(9)
	Steady/1000 Hrs.**	3(3)	3(3)	3(3)	9(9)	3(3)	3(3)	3(3)	9(9)	3(3)	3(3)	3(3)	9(9)	-	-	-	-	27(27)
	Thermo-Hum. Cyc.***	3(3)	3	3	9(3)	3(3)	3	3	9(3)	3(3)	3	3	9(3)	-	-	-	-	27(9)
	Acc. Wthrng. ***	3(3)	3(3)	3(3)	9(9)	3(3)	3(3)	3(3)	9(9)	3(3)	3(3)	3(3)	9(9)	-	-	-	-	27(27)
Compression	Steady/500 Hrs.**	3(3)	3	3	9(3)	3(3)	3	3	9(3)	3(3)	3	3	9(3)	-	-	-	-	27(9)
	Steady/1000 Hrs.**	3(3)	3(3)	3(3)	9(9)	3(3)	3(3)	3(3)	9(9)	3(3)	3(3)	3(3)	9(9)	-	-	-	-	27(27)
	Thermo-Hum. Cyc.***	3(3)	3	3	9(3)	3(3)	3	3	9(3)	3(3)	3	3	9(3)	-	-	-	-	27(9)
	Acc. Wthrng. ***	3(3)	3(3)	3(3)	9(9)	3(3)	3(3)	3(3)	9(9)	3(3)	3(3)	3(3)	9(9)	-	-	-	-	27(27)
In Plane Shear	Steady/500 Hrs.**	-	-	-	-	-	-	-	-	-	-	-	-	3(3)	3	3	9(3)	9(3)
	Steady/1000 Hrs.**	-	-	-	-	-	-	-	-	-	-	-	-	3(3)	3(3)	3(3)	9(9)	9(9)
	Thermo-Hum. Cyc.***	-	-	-	-	-	-	-	-	-	-	-	-	3(3)	3	3	9(3)	9(3)
	Acc. Wthrng. ***	-	-	-	-	-	-	-	-	-	-	-	-	3(3)	3(3)	3(3)	9(9)	9(9)
Interlaminar Shear	Steady/500 Hrs.**	3	3	3	9	-	-	-	-	-	-	-	-	-	-	-	-	9
	Steady/1000 Hrs.**	3	3	3	9	-	-	-	-	-	-	-	-	-	-	-	-	9
	Thermo-Hum. Cyc.***	3	3	3	9	-	-	-	-	-	-	-	-	-	-	-	-	9
	Acc. Wthrng. ***	3	3	3	9	-	-	-	-	-	-	-	-	-	-	-	-	9
Fatigue R = 0.1	Steady/500 Hrs.**	5	5	5	15	-	-	-	-	5	5	5	15	-	-	-	-	30
	Steady/1000 Hrs.**	5	5	5	15	-	-	-	-	5	5	5	15	-	-	-	-	30
	Thermo-Hum. Cyc.***	5	5	5	15	-	-	-	-	5	5	5	15	-	-	-	-	30
	Acc. Wthrng. ***	5	5	5	15	-	-	-	-	5	5	5	15	-	-	-	-	30
Creep and Stress Rupture	Steady/500 Hrs.**	-	5(5)	5(5)	10(10)	-	-	-	-	-	5(5)	5(5)	-	-	-	-	-	20(20)
	Steady/1000 Hrs.**	-	5(5)	5(5)	10(10)	-	-	-	-	-	5(5)	5(5)	10(10)	-	-	-	-	20(20)
	Thermo-Hum. Cyc.***	-	5(5)	5(5)	10(10)	-	-	-	-	-	5(5)	5(5)	-	-	-	-	-	20(20)
	Acc. Wthrng. ***	-	5(5)	5(5)	10(10)	-	-	-	-	-	5(5)	5(5)	10(10)	-	-	-	-	20(20)

* Numbers in parenthesis indicate instrumented specimens

** The Steady State Humidity Conditioning Consisted of 98% RH, 120°F for the stated time period see Section 2.2.1

*** Thermo-Humidity and Accelerated Weathering Cycles are defined in Section 2.2.2

TABLE III

THERMAL EXPOSURE DATA PROGRAM FOR
THORNEL 300 GRAPHITE/NARMCO 5208

Property	Thermal Conditioning	0° Orientation RT	260°F	350°F	Total	90° Orientation RT	260°F	350°F	Total	$[0/45/135/0/\overline{90}]_s$ Orient. RT	260°F	350°F	Total	± 45° Orientation RT	260°F	350°F	Total	Overall Total
Tension	Steady 260°F/100 hrs**	3	3	-	6	3	3	-	6	3	3	-	6	-	-	-	-	18
	Steady 260°F/500 hrs**	3(3)*	3(3)	-	6(6)	3(3)	3(3)	-	6(6)	3(3)	3(3)	-	6(6)	-	-	-	-	18(18)
	Steady 350°F/100 hrs***	3	3	3	9	3	3	3	9	3	3	3	9	-	-	-	-	27
	Steady 350°F/500 hrs***	3(3)	-	3(3)	6(6)	3(3)	-	3(3)	6(6)	3(3)	-	3(3)	6(6)	-	-	-	-	18(18)
	Cyclic 260°F/500 Cyc	3	3	-	6	3	3	-	6	3	3	-	6	-	-	-	-	18
	Cyclic 260°F/1000 Cy	3(3)	3(3)	-	6(6)	3(3)	3(3)	-	6(6)	3(3)	3(3)	-	6(6)	-	-	-	-	18(18)
	Cyclic 350°F/500 Cyc	3	3	3	9	3	3	3	9	3	3	3	9	-	-	-	-	27
	Cyclic 350°F/1000 Cy	3(3)	-	3(3)	6(6)	3(3)	-	3(3)	6(6)	3(3)	-	3(3)	6(6)	-	-	-	-	18(18)
Compression	Steady 260°F/100 hrs	3	3	-	6	3	3	-	6	3	3	-	6	-	-	-	-	18
	Steady 260°F/500 hrs	3(3)	3(3)	-	6(6)	3(3)	3(3)	-	6(6)	3(3)	3(3)	-	6(6)	-	-	-	-	18(18)
	Steady 350°F/100 hrs	3	-	3	6	3	-	3	6	3	-	3	6	-	-	-	-	18
	Steady 350°F/500 hrs	3(3)	-	3(3)	6(6)	3(3)	-	3(3)	6(6)	3(3)	-	3(3)	6(6)	-	-	-	-	18(18)
	Cyclic 260°F/500 Cyc	3	3	-	6	3	3	-	6	3	3	-	6	-	-	-	-	18
	Cyclic 260°F/1000 Cy	3(3)	3(3)	-	6(6)	3(3)	3(3)	-	6(6)	3(3)	3(3)	-	6(6)	-	-	-	-	18(18)
	Cyclic 350°F/500 Cyc	3	-	3	6	3	-	3	6	3 -	-	3	6	-	-	-	-	18
	Cyclic 350°F/1000 Cy	3(3)	-	3(3)	6(6)	3(3)	-	3(3)	6(6)	3(3)	-	3(3)	6(6)	-	-	-	-	18(18)
In Plane Shear	Steady 260°F/100 hrs	-	-	-	-	-	-	-	-	-	-	-	-	3	3	-	-	6
	Steady 260°F/500 hrs	-	-	-	-	-	-	-	-	-	-	-	-	3(3)	3(3)	-	-	6(6)
	Steady 350°F/100 hrs	-	-	-	-	-	-	-	-	-	-	-	-	3	3	-	-	6
	Steady 350°F/500 hrs	-	-	-	-	-	-	-	-	-	-	-	-	3(3)	-	3(3)	-	6(6)
	Cyclic 260°F/500 Cyc	-	-	-	-	-	-	-	-	-	-	-	-	3	3	-	-	6
	Cyclic 260°F/1000 Cy	-	-	-	-	-	-	-	-	-	-	-	-	3(3)	3(3)	-	-	6(6)
	Cyclic 350°F/500 Cyc	-	-	-	-	-	-	-	-	-	-	-	-	3	3	-	-	6
	Cyclic 350°F/1000 Cy	-	-	-	-	-	-	-	-	-	-	-	-	3(3)	-	3(3)	-	6(6)

* Numbers in parenthesis indicate instrumented specimens

** For the details of the steady state thermal conditioning, see Section 2.2.3

*** Cyclic thermal conditioning involved thermal changes from 100°F to the stated temperature and back to 100°F at a rate of one cph for the stated number of cycles, see Section 2.2.4.

Continued -

TABLE III - Continued

Property	Thermal Conditioning	0° Orientation RT	260°F	350°F	Total	90° Orientation RT	260°F	350°F	Total	$[0/45/135/0/\overline{90}]_s$ Orient. RT	260°F	350°F	Total	$\pm$ 45° Orientation RT	260°F	350°F	Total	Overall Total
Interlaminar Shear	Steady 260°F/100 hrs**	3*	3	-	6	-	-	-	-	-	-	-	-	-	-	-	-	6
	Steady 260°F/500 hrs**	3	3	-	6	-	-	-	-	-	-	-	-	-	-	-	-	6
	Steady 350°F/100 hrs***	3	3	-	6	-	-	-	-	-	-	-	-	-	-	-	-	6
	Steady 350°F/500 hrs***	3	-	3	6	-	-	-	-	-	-	-	-	-	-	-	-	6
	Cyclic 260°F/500 Cyc	3	3	-	6	-	-	-	-	-	-	-	-	-	-	-	-	6
	Cyclic 260°F/1000 Cy	3	3	-	6	-	-	-	-	-	-	-	-	-	-	-	-	6
	Cyclic 350°F/500 Cyc	3	3	-	6	-	-	-	-	-	-	-	-	-	-	-	-	6
	Cyclic 350°F/1000 Cy	3	-	3	6	-	-	-	-	-	-	-	-	-	-	-	-	6
Fatigue R = 0.1	Steady 260°F/500 hrs	5	5	-	10	-	-	-	-	5	5	-	10	-	-	-	-	20
	Steady 350°F/500 hrs	5	-	5	10	-	-	-	-	5	-	5	10	-	-	-	-	20
	Cyclic 260°F/500 Cyc	5	5	-	10	-	-	-	-	5	5	-	10	-	-	-	-	20
	Cyclic 260°F/1000 Cy	5	5	-	10	-	-	-	-	5	5	-	10	-	-	-	-	20
	Cyclic 350°F/500 Cyc	5	-	5	10	-	-	-	-	5	-	5	10	-	-	-	-	20
	Cyclic 350°F/1000 Cy	5	-	5	10	-	-	-	-	5	-	5	10	-	-	-	-	20
Creep and Stress Rupture	Steady 260°F/500 hrs	-	5(5)	5(5)	10(10)	-	-	-	-	-	5(5)	5(5)	10(10)	-	-	-	-	20(20)
	Steady 350°F/500 hrs	-	5(5)	5(5)	10(10)	-	-	-	-	-	5(5)	5(5)	10(10)	-	-	-	-	20(20)
	Cyclic 260°F/500 Cyc	-	5(5)	5(5)	10(10)	-	-	-	-	-	5(5)	5(5)	10(10)	-	-	-	-	20(20)
	Cyclic 260°F/1000 Cy	-	5(5)	5(5)	10(10)	-	-	-	-	-	5(5)	5(5)	10(10)	-	-	-	-	20(20)
	Cyclic 350°F/500 Cyc	-	5(5)	5(5)	10(10)	-	-	-	-	-	5(5)	5(5)	10(10)	-	-	-	-	20(20)
	Cyclic 350°F/1000 Cy	-	5(5)	5(5)	10(10)	-	-	-	-	-	5(5)	5(5)	10(10)	-	-	-	-	20(20)

* Numbers in parenthesis indicate instrumented specimens

** For the details of the steady state thermal conditioning, see Section 2.2.3

*** Cyclic thermal conditioning involved thermal changes from 100°F to the stated temperature and back to 100°F at a rate of one c.p.h. for the stated number of cycles, see Section 2.2.4

SECTION II

2.0 TECHNICAL DISCUSSION

2.1 Material

A current graphite/epoxy composite material which is being investigated widely for application to aerospace structural components is Thornel 300 Graphite/Narmco 5208. This material is available in a wide variety of forms but is generally utilized in the prepreg tape form.

The specification to which the Thornel 300 Graphite/Narmco 5208 material was ordered was:

General Dynamics specification: FMS 2023, Type III, Form A. "Graphite Fiber High Tensile Strength, Intermediate Modulus, Epoxy or Modified Epoxy Resin Impregnated," dated November 30, 1972 and all amendments.

This specification is used widely throughout the industry and is available directly from General Dynamics Convair Division Fort Worth, Texas.

2.1.1 Material Procurement

Sixty lbs. of material were utilized during this program. The material was ordered in the 3" wide continuous tape form under the trade name Rigidite 5208/Thornel 300 Type III, Form A. Fourteen (14) rolls of batch 53 were delivered to IITRI to meet this order. The resin (solids) content, room temperature and 350°F flexural strengths and moduli and the horizontal shear strengths were determined for the 0° orientation by Whittaker Corporation, Narmco Materials Division. The certification report by Whittaker that this batch conforms to Spec. FMS 2023 is presented in Appendix I. (The rolls 16, 17 and 18 which have a solids content below the minimum were accepted on the basis that the material could be mixed with higher resin content rolls and thus provide an average within the limits of FMS 2023.

2.1.2 Quality Assurance Testing

As a part of IITRI's quality assurance program, 0° and 90° flexural coupons and 0° interlaminar shear coupons were prepared.

The acceptance data for panel No. 7 are shown in Table IV. On the basis of these test results, batch 53 was accepted for this program.

2.1.3 Laminate Fabrication

2.1.3.1 Processing

The fabrication techniques followed at IITRI have been discussed in reference 1. An autoclave provides the pressure and temperature necessary to cure the resin in accordance with the following cure schedule recommended by General Dynamics for fabricating panels:

1. Full vacuum (26" HG) is applied to the bagged green layup.
2. The panel is heated from room temperature to 275°F + 5°, -10°F in 40 ± 8 minutes (corresponding to a 4 to 6 degrees F/minute heat up rate)
3. The layup is held at full vacuum and 275°F + 5°F -10°F for 60 ± 5 minutes.
4. Pressure is then increased to 85 psi ± 5 psi. The vacuum is vented to outside air when the pressure has reached 25 psi.
5. Upon reaching 85 ± 5 psi, the temperature is increased to 355°F + 10°F -5°F in 15 ± 3 minutes.
6. The system is held at 85 psi ± 5 psi and 355°F + 10°F -5°F for 120 ± 5 minutes.
7. The system is then cooled to 140°F maintaining the 85 psi ± 5 psi pressure in not less than 30 minutes.

TABLE IV

QUALITY ASSURANCE TEST DATA ON

BATCH #53 OF THORNEL 300/NARMCO 5208 LAMINATES

PROPERTY	FMS 2023 REQUIREMENTS		PANEL 1, ROLL 1		PANEL 7, ROLL 1		BATCH #53 WHITTAKER Q.A. TEST RESULTS	
	RT	350	RT	350	RT	350	RT	350
0° Flex Strength (ksi)	240	200	250	-	240	180	304	242
0° Flex Modulus (msi)	18	18	-	-	23.1	24.1	21.9	24.8
90° Flex Strength (ksi)	10.0	7.0	10.0	-	10.2	5.1	-	-
Interlaminar Shear (ksi)	13.0	7.0	14.5	-	15.2	8.6	15.5	8.2

8. The panels are postcured subsequently for 240 $\pm$ 5 minutes at 400°F $\pm$ 10°F. The heatup rate for postcuring panels is from RT to 400°F in 64 $\pm$ 10 minutes.

Throughout the postcure, the panels are loosely supported between two layers of 1/2 to 3/4 inch thick aluminum honeycomb core.

The quality assurance panel layups consisted of 15 plies covered with 3 plies of 181 bleeder cloth and 1 ply of 181 vent cloth. Seven quality assurance panels were prepared and the best results were obtained using a top surface caul plate to control the thickness (panel 7). This panel appeared to have less bleed off than many of the previous panels. At the optimum process, fiber volumes of approximately 68% were obtained.

A description of the various panels utilized during this program is shown in Table V.

2.1.3.2 Quality Control Procedures

All Thornel 300Narmco 5208 epoxy laminates prepared for use on this program were nondestructively examined for voids using ultrasonic C-scan procedures. To assist in this effort and N.D.T. test panel, with voids purposefully placed on the inside of the panel was prepared. The panel was an eight ply [0°, 90°, 0°, 0°, 0°, 0°, 90°, 0°] with the flaws between the middle two zero degree plies. The panel measured 6" x 14" and contained 1) a piece of masking tape, 2) a strip of polyethylene film, 3) a strip of teflon vent film and 4) a section of release paper. 120 cloth was added to the laminate in the areas not occupied by the various flaws so as to maintain continuity of thickness over the panel area. This panel was used to establish the gate for the C-scan for acceptance or rejection of all test panels. (See Appendix I)

TABLE V - TEST PANEL DESCRIPTIONS FOR

THORNEL 300 GRAPHITE/NARMCO 5208

ORIENTATION	PLATE GEOMETRY			NO. OF SPECIMENS	
	Length (in)	Width (in)	Thickness (plies/in.)		Plate No.
0°	9.25	10	15/0.081	129	T1301
90°	9.0	19	8/0.042	17	T1302
90°	9.0	19	8/0.042	17	T1303
90°	9.0	19	8/0.040	17	T1304
0°	27.2	13	6/0.032	63	T1305
0°	18.1	12	6/0.032	40	T1306
0°	18.1	12	6/0.033	40	T1307
0°	18.1	12	6/0.032	40	T1308
0°	18.1	12	6/0.031	40	T1309
0°	18.1	12	6/0.031	40	T1310
0°	18.1	12	6/0.030	40	T1311
0°	18.1	12	6/0.032	40	T1312
90°	9	19.8	8/0.041	18	T1313
90°	9	19.8	8/0.039	18	T1314
90°	9	19.8	8/0.041	18	T1315
90°	9	19.8	8/0.041	18	T1316
90°	9	19.8	8/0.042	18	T1317
90°	9	19.8	8/0.042	18	T1318
0°	11	22	6/0.031	10	T1319
90°	11	22	8/0.041	10	T1320
*$[0/45/135/0/\overline{90}]_s$	11	22	9/0.047	10	T1321
± 45°	9	23.1	8/0.042	21	T1322
± 45°	9	23.1	8/0.043	21	T1323
± 45°	9	22	8/0.042	20	T1324
± 45°	9	22	8/0.042	20	T1325
± 45°	9	22	8/0.042	20	T1326

* [0/+45/-45/0/90/0/-45/+45/0]

TABLE V - (Continued)

ORIENTATION	PLATE GEOMETRY			NO. OF SPECIMENS	
	Length (in)	Width (in)	Thickness (plies/in.)		Plate No.
*$[0/45/135/0/\overline{90}]_s$	18.1	12.1	9/0.047	22	T1327
$[0/45/135/0/\overline{90}]_s$	18.1	12.1	9/0.048	22	T1328
$[0/45/135/0/\overline{90}]_s$	18.1	11	9/0.047	20	T1329
$[0/45/135/0/\overline{90}]_s$	18.1	11	9/0.048	20	T1330
$[0/45/135/0/\overline{90}]_s$	18.1	11	9/0.049	20	T1331
$[0/45/135/0/\overline{90}]_s$	18.1	12.1	9/0.050	22	T1332
$[0/45/135/0/\overline{90}]_s$	18.1	12.1	9/0.048	22	T1333
$[0/45/135/0/\overline{90}]_s$	18.1	12.1	9/0.047	22	T1334
$[0/45/135/0/\overline{90}]_s$	18.1	11.0	9/0.049	20	T1335
$[0/45/135/0/\overline{90}]_s$	18.1	11.0	9/0.048	20	T1336
$[0/45/135/0/\overline{90}]_s$	18.1	11.0	9/0.048	20	T1337
$[0/45/135/0/\overline{90}]_s$	18.1	11.0	9/0.047	20	T1338
$[0/45/135/0/\overline{90}]_s$	18.1	11.0	9/0.049	20	T1339
$[0/45/135/0/\overline{90}]_s$	18.1	11.0	9/0.049	20	T1340
$[0/45/135/0/\overline{90}]_s$	18.1	11.0	9/0.049	20	T1341
$[0/45/135/0/\overline{90}]_s$	27.2	11.0	9/0.047	30	T1342
0°	12.0	10.0	12/0.063	99	T1343
90°	11.0	16.0	20/0.106	99	T1344
$[0/45/135/0/\overline{90}]_s$	20.7	11.0	18/0.098	129	T1345
$[0/45/135/0/\overline{90}]_s$	6.6	8.8	9/0.048	66	T1346
0°	8.8	12.3	10/0.053	120	T1347
0°	18.1	12	6/0.031	40	T1348
90°	44	9	8/0.042	40	T1349
$[0/45/135/0/\overline{90}]_s$	37	12	9/0.048	40	T1350

* [0/+45/-45/0/90/0/-45/+45/0]

The N.D.T. test panel described above was then used to set the gate for an ultrasonic C-scan of the test laminates. All of the panels were non-destructively tested. Typical scans are shown in Appendix I for acceptable panels. Appendix I also shows an ultrasonic scan for a reject panel (No. 1333B) which was later refabricated.

2.1.3.3 Physical Properties

Density measurements were made on at least one panel of each set fabricated in the autoclave. Usually a set of three panels were fabricated simultaneously. The densities shown in Table VI were determined using the gravimetric process. The values for the densities of Thornel 300 and of Narmco 5208 resin were obtained from Whittaker Corp. No void contents are shown in this table. This does not mean that the laminates were void free but of low voids.

2.2 Conditioning Treatments

The various conditioning treatments, to which the composite materials were exposed are described in this section. The equipment and procedures followed in the accomplishment of these conditioning treatments are found in Reference 1.

In addition, a comparison base of data was obtained against which the effects of these various conditioning treatments might be measured. The extent of this baseline data program was described in Section I, Table I. The individual baseline data for Thornel 300 Graphite/Narmco 5208 are found in Appendix II.

2.2.1 Steady State Humidity Conditioning

The steady state humidity conditioning of specimens includes 500 and 1000 hr. (3 weeks and 6 weeks) exposure to 98% $\pm$ 2%

TABLE VI

VOLUMETRIC MEASURES OF FIBER AND MATRIX CONTENTS IN THORNEL 300/NARMCO 5208 COMPOSITES

FIBER ORIENTATION	NO. OF PLIES	PLATE NUMBER	DENSITY OF COMPOSITE (gms/cc)	FIBER VOLUME (PERCENT)	RESIN VOLUME (PERCENT)
0°	6	T1301	1.610	70.7	29.2
90°	8	T1302	1.600	68.1	31.9
90°	8	T1313	1.602	69.0	31.0
90°	8	T1318	1.612	71.2	28.8
0°	6	T1322	1.596	67.8	32.2
± 45	8	T1324	1.596	67.8	32.2
$[0/45/135/0/\overline{90}]_s$	9	T1327	1.604	69.6	30.4
$[0/45/135/0/\overline{90}]_s$	9	T1345	1.585	65.6	30.4
90°	8	T1317	1.617	72.2	27.8
90°	8	T1316	1.611	71.8	28.2
± 45	8	T1326	1.598	68.4	31.6
90°	8	T1304	1.610	70.9	29.3
± 45	8	T1325	1.603	69.4	30.6
90°	8	T1303	1.603	69.2	30.8
0°	6	T1323	1.598	68.2	31.8

relative humidity and 120°F (see Table II). This exposure is the same as that recommended by Mil Handbook 17.

The specimens which were subjected to humidity exposure were prepared as follows:

1) All specimens were finish machined and the appropriate room temperature or elevated temperature tabs were bonded prior to initiation of the preconditioning treatment. For elevated temperature tests subject to prior humidity exposure the tab adhesive was Metalbond 329. For room temperature tests subject to prior humidity conditioning the adhesive was FM 1000.

2) All specimens for static and creep tests were instrumented (as required) with electrical resistance foil strain gages. The gages were protected with M-coat resin coating taking care to cover a minimum area.

3) The edges of the samples were not protected since protection could not be guaranteed to be only to the edges and not to the surfaces of specimen.

4) The samples were individually weighed prior to insertion in the chamber.

5) Each sample was arranged in the chamber to permit maximum exposure to the moisture-laden air as it flowed from the inlet orifice to the chamber.

These steps were followed to permit rapid testing of the samples after removal from the chamber. Upon removal from the chamber, the specimens were reweighed, wires were attached to the strain gages and the specimens were tested within 8 hours of removal from the chamber. For certain long term fatigue and creep tests, where the tests were held up for a longer time due to machine unavailability, the samples were sealed in a protective vinyl, moisture proof container. These samples were then reweighed, prior to testing, to determine if moisture loss had occurred.

2.2.2 Cyclic Humidity Conditioning

2.2.2.1 Thermo-Humidity Cycle

Table II listed two cyclic humidity conditioning exposures for resin matrix composites. The first humidity cycle was the Thermo-Humidity cycle selected from a review of previous aerospace practices. The Webber Environmental Chamber was again used for the humidity exposure.

The details of the Thermo-Humidity cycle employed are: (1) The total time period for the cycle was 500 hours. (2) During this period, the specimens were placed in the environmental chamber and exposed to a relative humidity of 95 + 2% at 120° ± 5°F except for one and one half hour each work day of the week when they were taken out and subjected to thermal shock. (3) This shock treatment consisted of exposing the specimens for one hour at -65°F in a cold chamber followed by an exposure of one half hour at 250°F in an oven. (4) During the weekend the specimens remained in the environmental chamber continuously exposed to the humidity conditions mentioned above.

The frost conditions on the specimens after exposure to -65°F were noted but no specimen delamination occurred after removal from the 250°F portion of the cycle (See (1)).

All appropriate specimens were strain gaged in the same manner as the steady-state exposure and were wired after exposure prior to testing. The test specimens were made ready for testing within eight hours after removal from the test chamber as was done for the steady state humidity conditioning exposures.

2.2.2.2 Accelerated Weathering Humidity Cycle

The second humidity cycle was an accelerated weathering cycle. An Atlas Twin ARC Weatherometer, Type D as specified in ASTM G23-69 was employed for these tests. All panels and/or specimens were exposed in the weatherometer to the following operation schedule. The recommended practice for this equipment was as described in ASTM D1499-64 and ASTM G23-69. The apparatus was operated 5 days per week, and each 2-hour cycle of operation was divided into periods, during which the panels and specimens were exposed 102 minutes to light without water and 18 minutes of light with water spray. The test specimens remained undisturbed during the remaining 2 days of the week.

The exposure procedures followed were as follows:

The black panel thermometer unit was placed in the test panel rack and with the light on and the water off, the thermoregulator was set so that the temperature on the thermometer read 145° $\pm$ 5°F., when the thermometer was at the point where the maximum heat was produced as the panel rack revolved around the light.

The water supply was adjusted so that the pressure of the water at the spray nozzle was between 12 and 15 pounds per square inch so that the water struck the specimens in a fine spray in sufficient volume to wet the entire surface of the specimens upon impact.

New carbons and clean filters were installed in the light assembly and the weatherometer was started. At the end of a burning period (daily), the old carbons were removed and the decomposition ash was cleaned from the carbon holders and other parts of the light assembly, and the filters were washed with detergent and water. The position of the test panels and specimens were transposed to provide a uniform distribution of light in a vertical plane over the entire surface of the test specimens. New carbons were installed, the filters were replaced and the weatherometer restarted. These operations were repeated on a daily basis until the test specimens were exposed for a time period of 500 hours including weekend rest periods. (This resulted in a 360 hour active exposure time plus 140 hours of rest periods).

2.2.3 Steady State Thermal Conditioning

For steady state thermal exposure conditioning conventional circulating air ovens were used to obtain exposures at 260°F and 350°F for time periods of 100 and 500 hours. The samples were arranged to get uniform distribution of air circulation over the specimens without localized hot spots.

2.2.4 Cyclic Thermal Conditioning

Thermal cycles from 100°F to 260°F to 100°F and from 100°F to 350°F to 100°F were adopted for cyclic thermal conditioning. Exposure of test samples for both 500 cycles and 1000 cycles was undertaken. A cyclic rate of one cycle per hour was established.

2.3 Test Specimens and Procedures

This section briefly lists the test specimens and procedures utilized for generating the data during this program. A detailed description of the test specimens, specimen fabrication procedures and test equipment is found in Appendix II of Part I of Reference (1).

2.3.1 Tensile, Fatigue and Creep Specimens

The same specimen configuration was utilized for tension, fatigue (R = 0.1) and tensile creep tests. In addition in-plane shear properties were determined using a ± 45° tensile test. The IITRI straight-sided tab ended coupon was utilized for these properties. After environmental conditioning, each static tensile specimen was fitted with three electrical-resistance foil strain gages.

2.3.2 Compression Testing

Two types of specimens were employed for compressive testing. The first was the sandwich beam compression specimen which was utilized only in the generation of baseline data. The second specimen was a coupon specimen commonly known as the Celanese specimen which is an adaptation of the IITRI tensile coupon with longer tabs, reduced gage section and a narrower width. The coupon test fixture was the IITRI compression coupon test fixture.

(All comparative performance results are shown using the coupon test data for the baseline and conditioned curves).

2.3.3 Flexural and Interlaminar Shear Tests

The specimens used for all flexural testing was the fifteen ply, coupon universally used for testing advanced composites. Specimens were loaded in a 3 (0° coupons) or 4-point (90° coupons) bending fixture. Elevated temperature tests were conducted in a Missimer circulating air oven and loads were applied in tension to a flexural test rig.

The maximum interlaminar shear strength of oriented fiber composites was determined on short beam shear specimens. Elevated temperature tests were performed with the assistance of the fixture described above.

2.3.4 In-Plane Shear Properties

The in-plane shear stress-strain curve was determined from a $\pm$ 45° angle ply laminate tested in uniaxial tension supplemented with data from the 0° and 90° tests, and the incrementation of the $\pm$ 45° tensile stress strain curve.

2.3.5 Fatigue Tests

The fatigue tests (R = 0.1) were performed at a cyclic rate of 1800 cpm, employing eccentric weight mechanical dynamic-load applicators.

2.3.6 Creep and Stress Rupture Tests

The creep equipment consisted of 32 tensile stands located on a vibration-free floor. Each stand was provided with a set of tensile grips enclosed in individually controlled ovens. The ovens are capable of achieving specimen temperatures of up to 800°F. A jig was used to align and grip the specimens prior to installation on the creep stands. For the creep stands employed, the load multiplication factor was 10:1.

2.3.7 Thermophysical and Density Properties

Linear thermal expansion was measured by an automatic recording dilatometer similar to that described in ASTM Designation: C337-57. The dilatometer used had an accuracy of more than 99% and a reproducibility within + 2%.

Thermal conductivity measurements were made using the steady state longitudinal heat flow technique. The sample consisted on ten 3/64 x 1/2 x 2-inch laminates sandwiched together to form a 1/2 x 1/2 x 2-inch conductivity specimen. Data are obtained from ambient room temperature to 350°F in air for three specimens in each of three laminate orientations. Densities of the laminates were determined by the gravimetric method.

2.4 Static Properties

2.4.1 Baseline Data

The static baseline data are found summarized in Appendix II including average stress strain curves in tension compression, and shear for 0°, 90° and $[0/45/135/0/\overline{90}]_s$ laminates. The data were obtained from strain gages and were reduced and plotted using computer plotting routines. To average the values of stress and strain obtained from three tests conducted at a given temperature, a program (least squares) to fit a curve to the data was used as a sub-routine to the plotting program.

2.4.2 Effects of Humidity Conditioning

The steady state exposure of the Thornel 300 Graphite/Narmco 5208 composite specimens to 98% relative humidity resulted in moisture pickup by the exposed uncoated samples. Fig. 1 shows the moisture pickup versus time and is an aggregate of moisture pickup for three orientations, three thicknesses (ply thickness), and two widths of sample. Thus, the ratio of surface area to volume of the samples varies over a substantial range and the ratio of exposed fiber ends to surface area also varies.

In plotting these gains for the four different humidity environments account was taken of the various orientations, specimens sizes etc. (see legend on each figure). Thus while the surface area to volume ratio for a nine ply $[0/45/135/0/\overline{90}]_s$ laminate may remain virtually the same as a six ply $[0]_6$ laminate, the exposed fiber ends on the $[0/45/135/0/\overline{90}]_s$ laminate provide more potential entry paths for moisture to enter the specimen.

Groups of specimens of a given type were inserted at various times into the humidity chamber during their appropriate schedules. Therefore several different points appear at the same total exposure time. Each point represents an average of

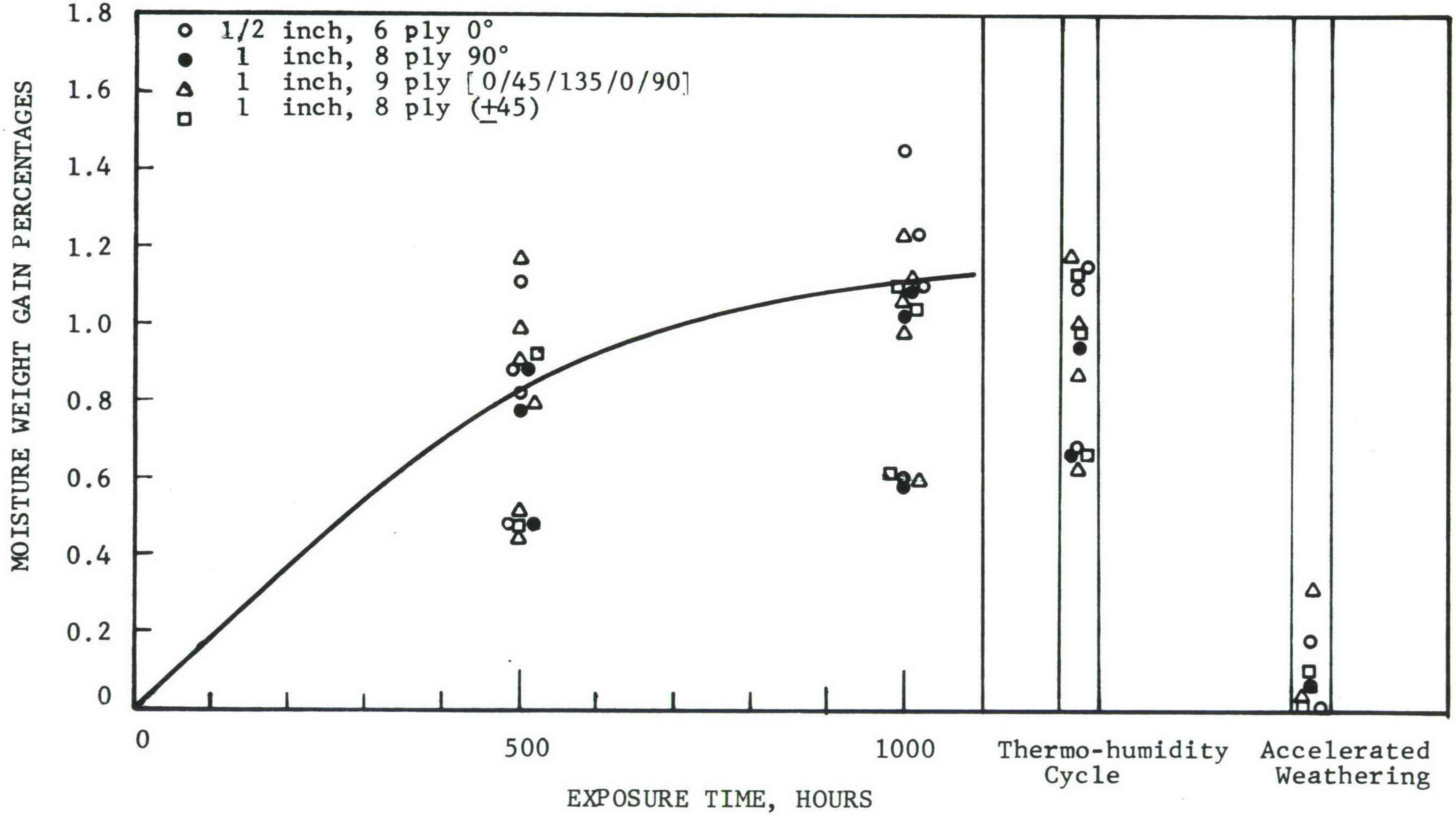

FIG. 1 MOISTURE WEIGHT GAIN PERCENTAGES FOR VARIOUS HUMIDITY CONDITIONING FOR THORNEL 300 GRAPHITE /NARMCO 5208 COMPOSITES

from 10 to 20 specimens of the type indicated. Thus the variability of moisture pickup from group to group can be obtained from Fig. 1 as well.

The results for the Thermo-Humidity Cycle and the accelerated weathering cycles do not show marked differences between specimen orientations. This is in contrast to previous results for other composite materials (see Reference (1)).

In general, the Thermo-Humidity cycle data corresponds to approximately 500 hours of constant humidity exposure and the accelerated weathering data corresponds with approximately 50 to 150 hours of constant humidity exposure.

As described elsewhere (1) this correspondence of the cyclic humidity conditioning to the steady exposure is related to the total exposure time to high humidity conditions.

Figures 2 and 3 show the effects of various steady and cyclic humidity conditioning on the tensile stress-strain behavior of 0° and 90° Thornel 300 Graphite/Narmco 5208 composites.

The effects of the various conditioning treatments on specific properties are seen in Figs. 4 to 9 where strengths and stiffnesses of the three orientations as a function of temperature are plotted. Baseline data is shown as solid lines and data after various conditioning appear as points on the curves at the test temperatures.

Very little decrease in the baseline 0° tensile and compressive strengths of Thornel 300 Graphite/Narmco 5208 is seen in Fig 4. The baseline in-plane shear strength decreases steadily over the range from room temperature to 350°F. Losses in tensile and compressive strengths are shown for the 0° composites after humidity conditioning but up to 40% increase in the in-plane shear strengths were recorded after humidity conditioning (see Fig. 4).

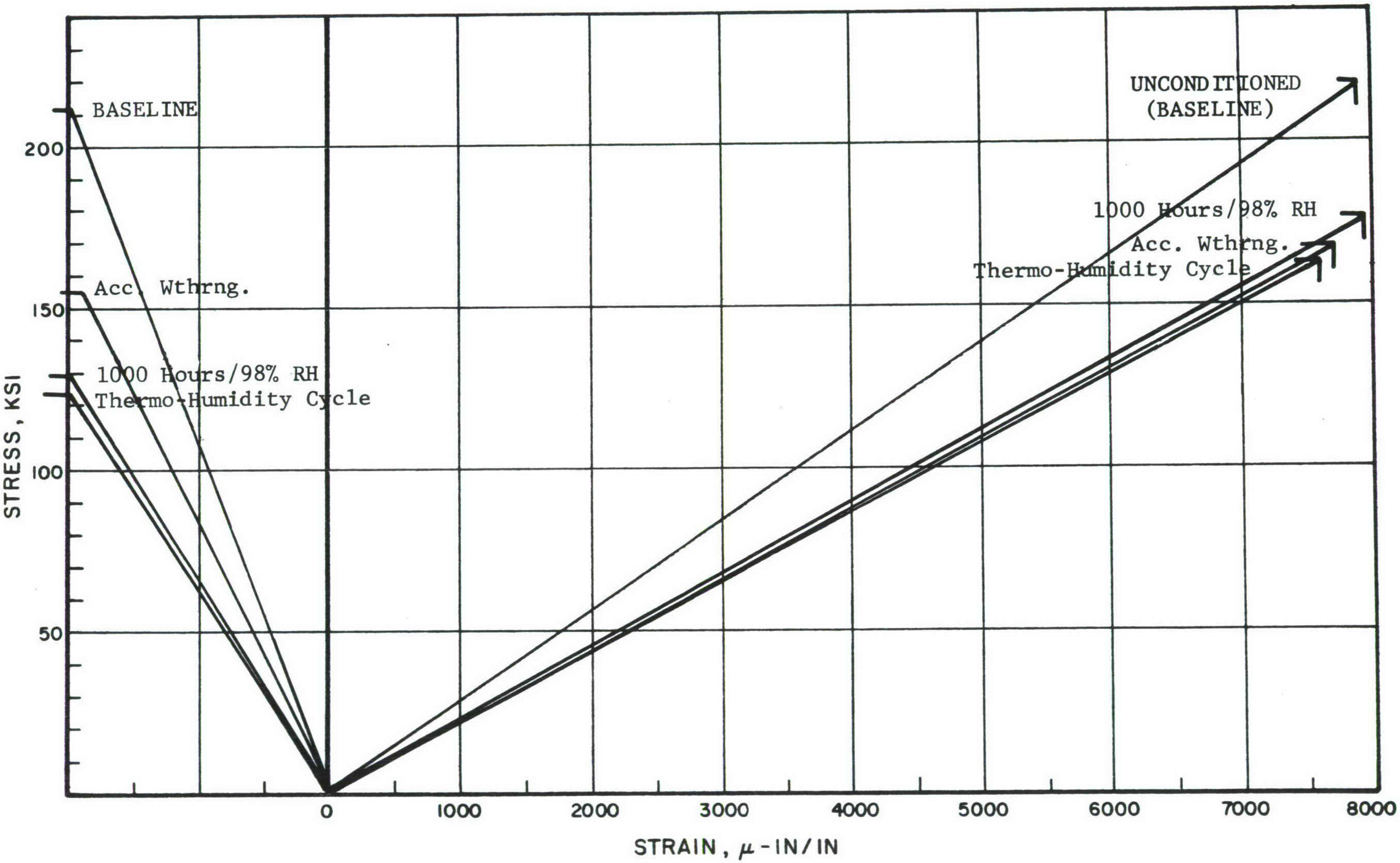

Fig. 2 COMPARATIVE TENSILE BEHAVIOR OF 0° THORNEL 300 GRAPHITE/NARMCO 5208 TESTED AT ROOM TEMPERATURE BEFORE AND AFTER EXPOSURE TO VARIOUS STEADY AND CYCLIC HUMIDITY CONDITIONING

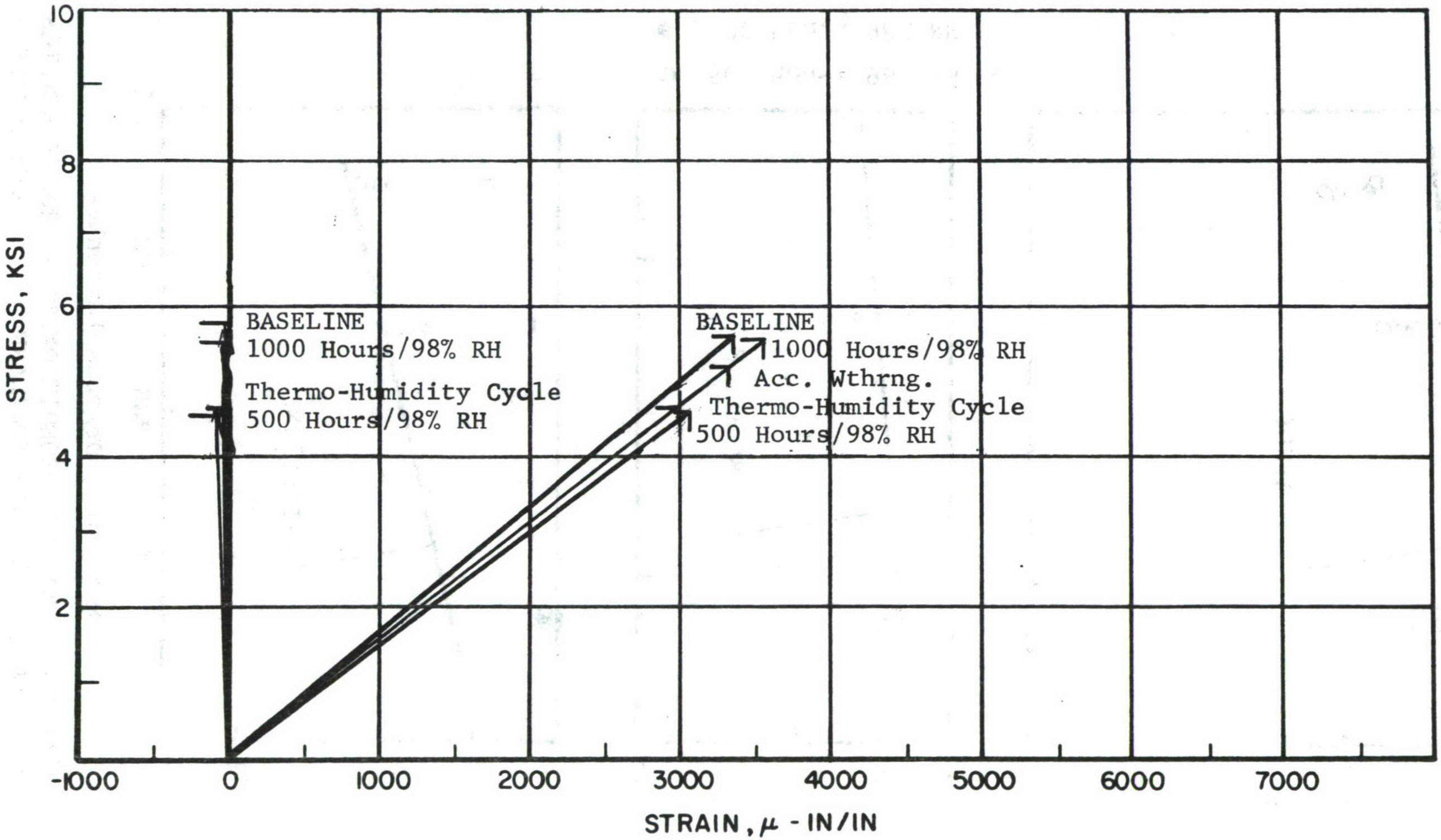

Fig. 3 COMPARATIVE TENSILE BEHAVIOR OF 90° THORNEL 300 GRAPHITE/NARMCO 5208 TESTED AT ROOM TEMPERATURE BEFORE AND AFTER EXPOSURE TO VARIOUS STEADY AND CYCLIC HUMIDITY CONDITIONING

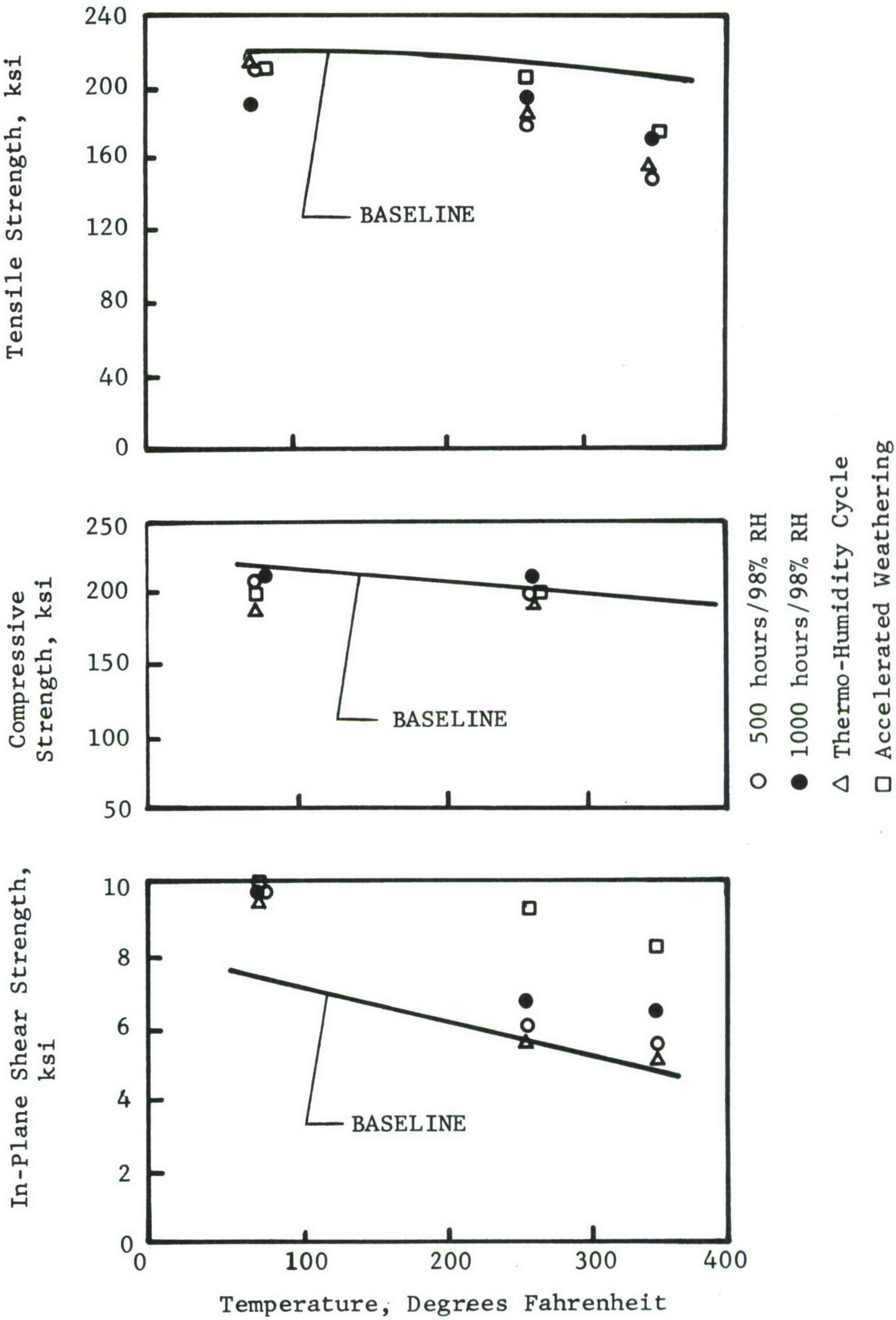

Fig. 4 EFFECT OF HUMIDITY CONDITIONING ON THE STRENGTHS OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 0°

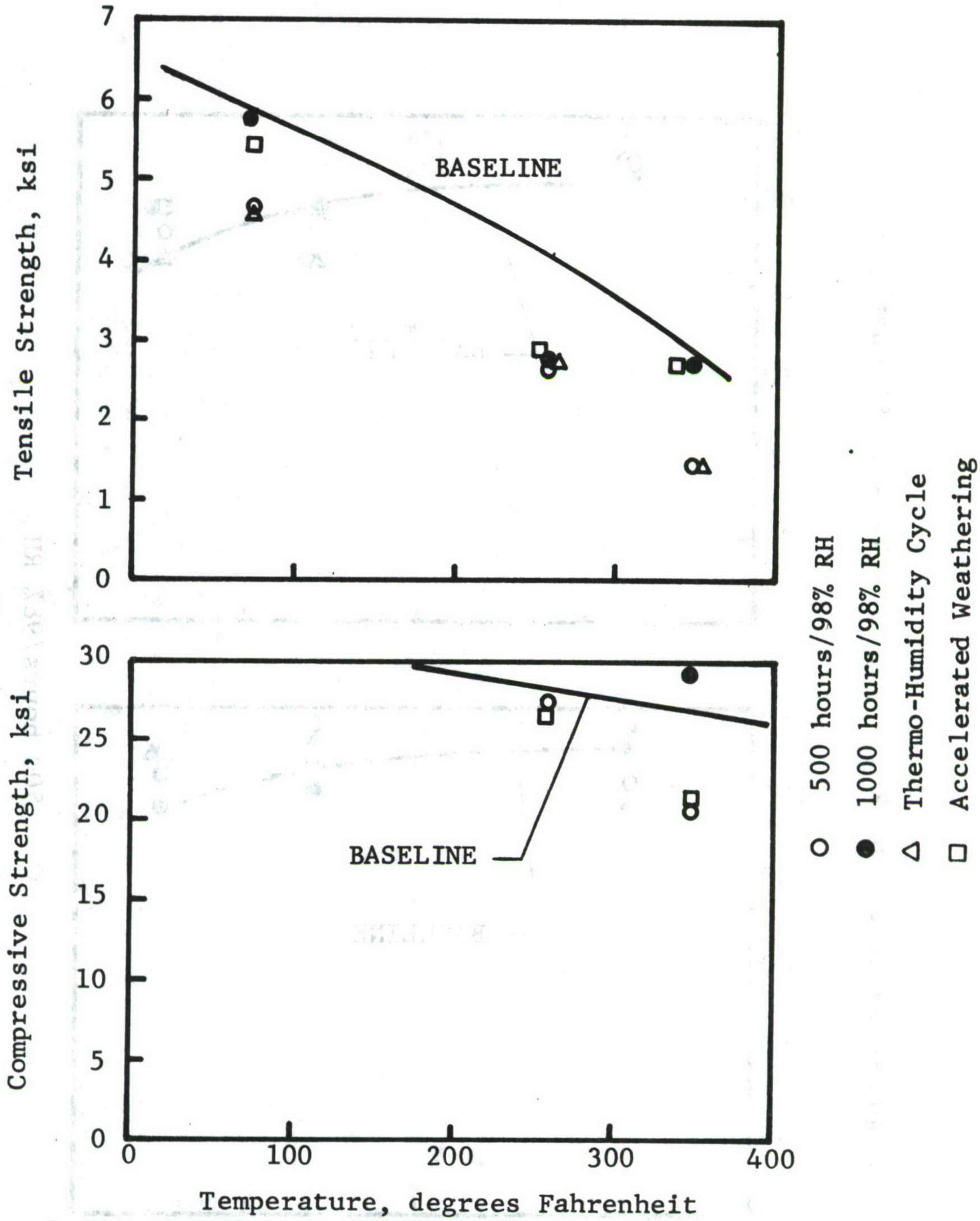

Fig. 5 EFFECT OF HUMIDITY CONDITIONING ON STRENGTHS OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 90°

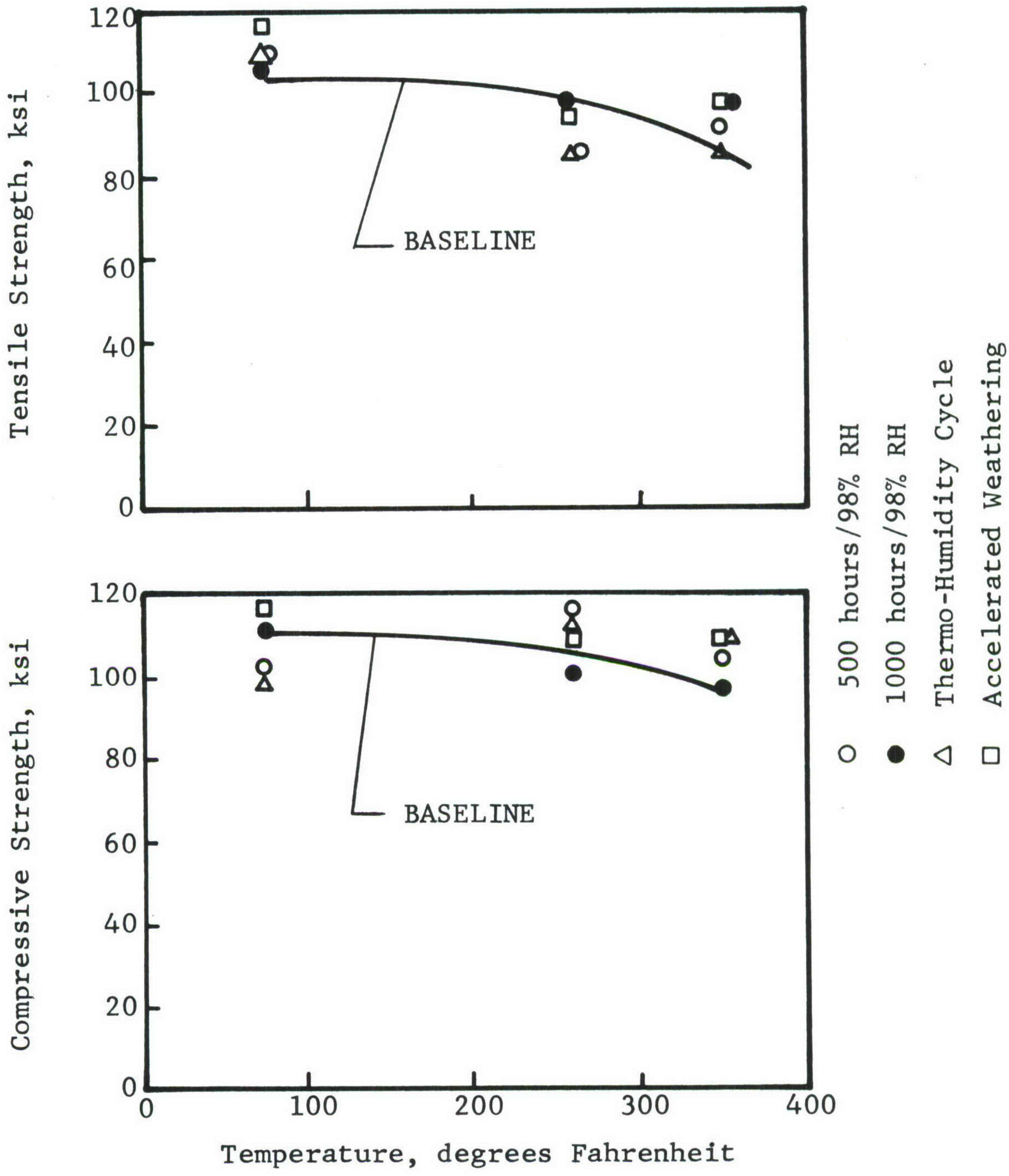

Fig. 6 EFFECT OF HUMIDITY CONDITIONING ON STRENGTHS OF THORNEL 300 GRAPHITE/NARMCO 5208 LAMINATES - $[0/45/135/0/\overline{90}]_s$

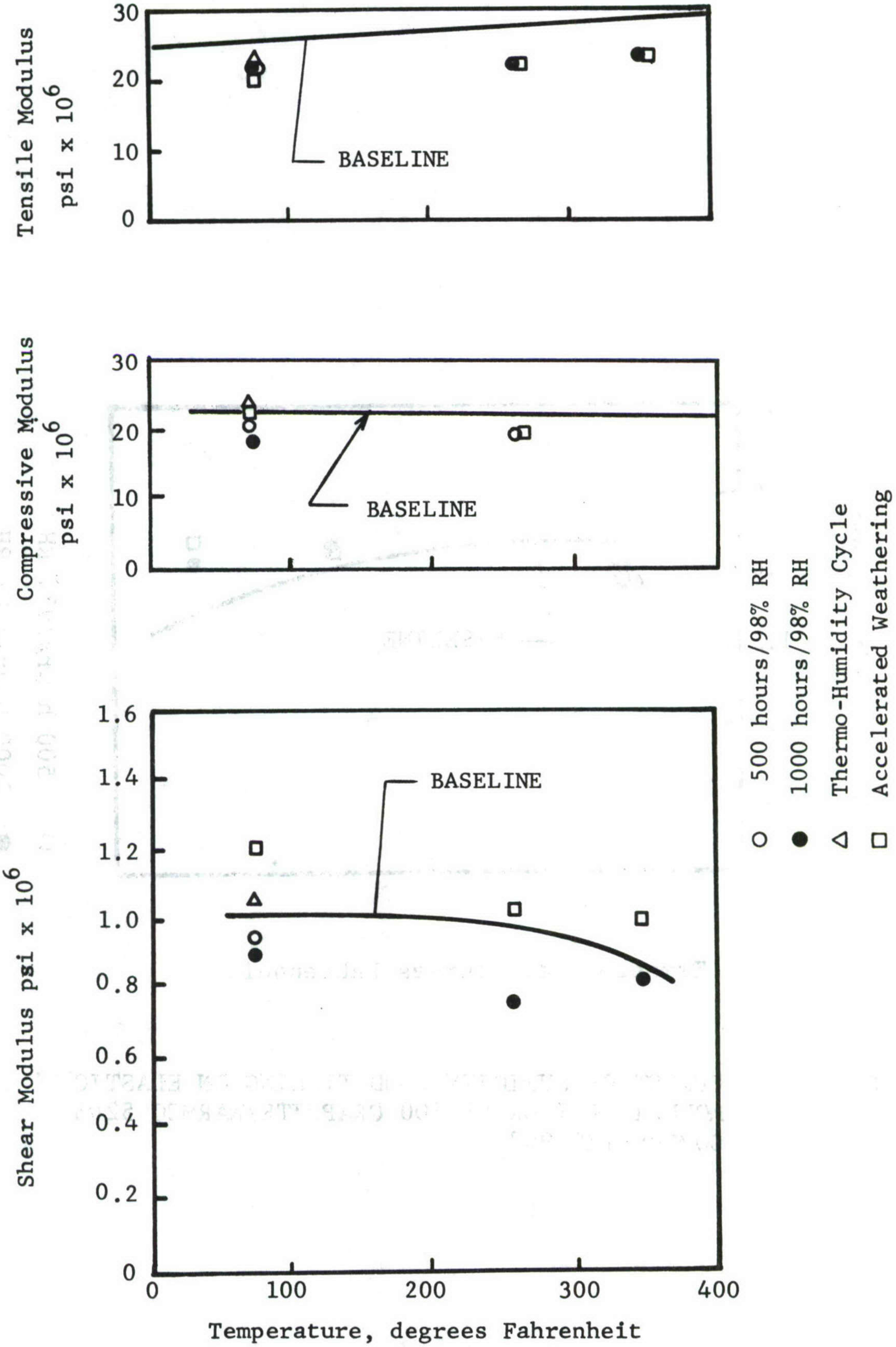

Fig. 7 EFFECT OF HUMIDITY CONDITIONING ON ELASTIC MODULI OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 0°

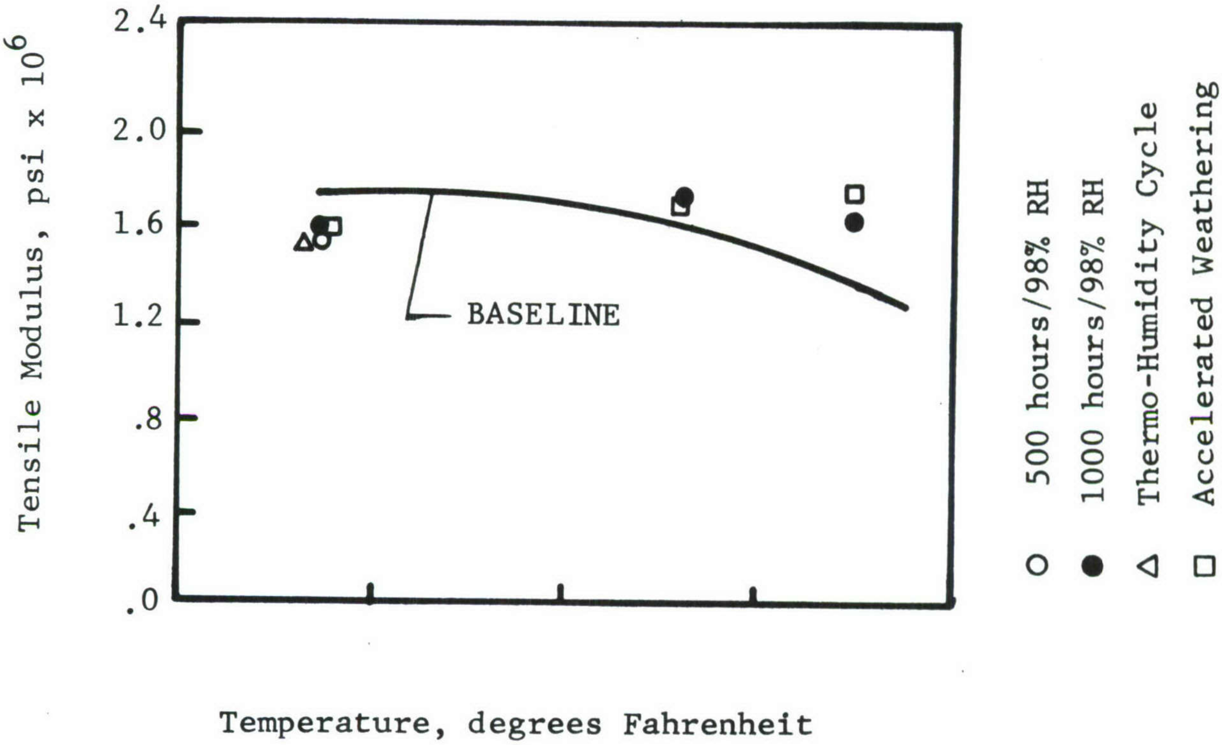

Fig. 8 EFFECT OF HUMIDITY CONDITIONING ON ELASTIC MODULI OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES 90°

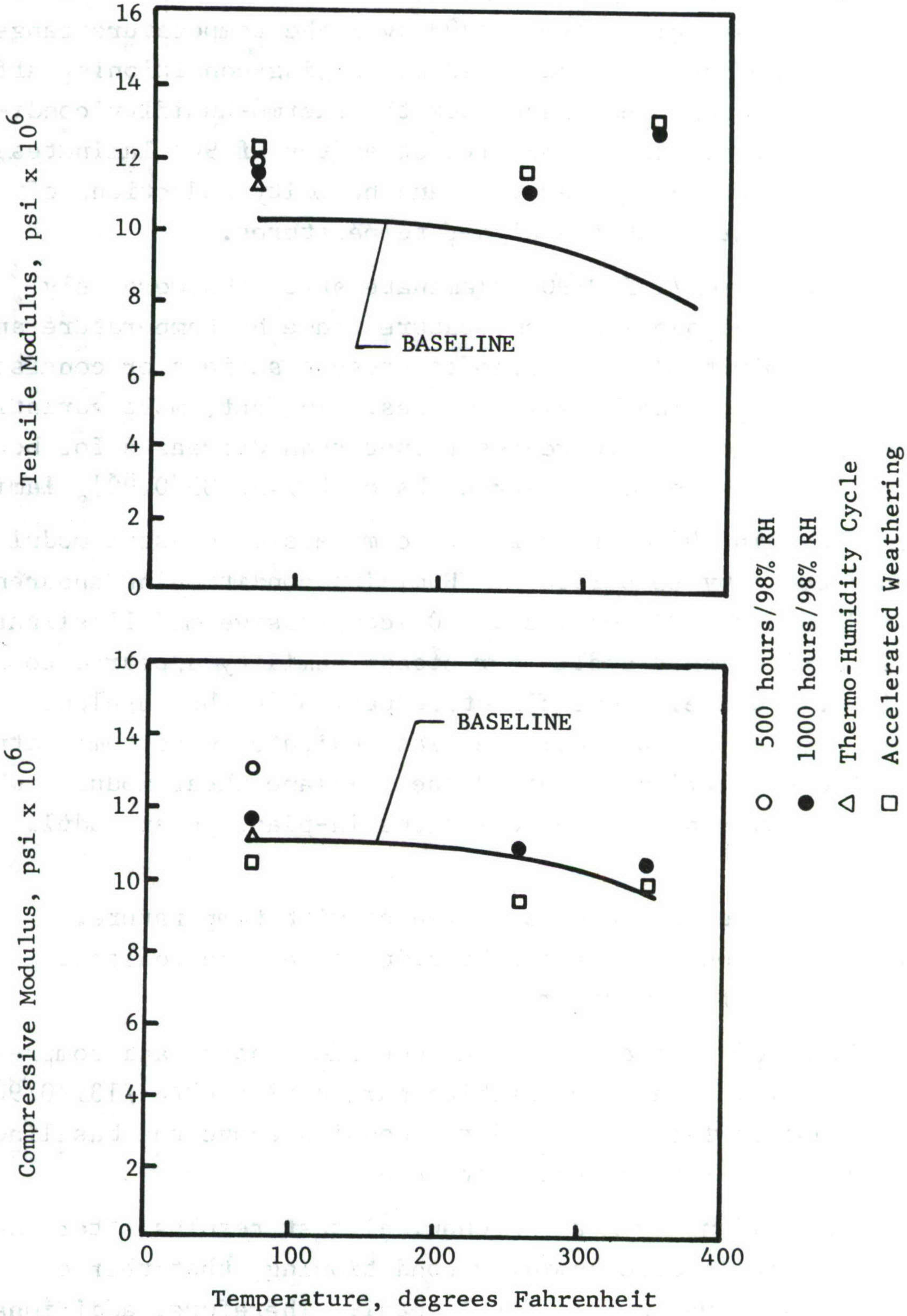

Fig. 9 EFFECT OF HUMIDITY CONDITIONING ON ELASTIC MODULI OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - $[0/45/135/0/\overline{90}]_s$

There is a steady decline in the 90° static tensile strength of Thornel 300 Graphite/Narmco 5208 over the temperature range of 70°F to 350°F of 50%. Accelerated weathering conditioning affects the tensile strength less than does the thermo-humidity conditioning. The baseline compressive strengths of 90° laminates were less affected by temperature and humidity reductions of 20% were encountered at the higher temperatures.

Baseline $[0/45/135/0/\overline{90}]_s$ laminate strengths were only slightly affected over the temperature range by temperature and humidity. Humidity did not seem to cause a serious or consistent reduction from the baseline values. In fact, most variations from the baseline were increases rather than decreases for both the tensile and compressive strengths of $[0/45/135/0/\overline{90}]_s$ laminates.

The baseline 0° tensile and 0° compressive elastic moduli were unaffected by temperature. Humidity conditioning apparently decreased both the 0° tensile and 0° compressive moduli slightly (5 to 10% and neither cyclic nor steady humidity appeared to be significantly worse. Some slight reduction in the in-plane shear modulus of the 0° laminates was indicated with temperature. Accelerated weathering increased the in-plane shear moduli, while steady humidity exposure decreased the in-plane shear moduli slightly.

The baseline 90° modulus decreased with temperature. Humidity conditioning made the baseline data more constant over the range of temperatures.

Humidity did not adversely affect the tension and compressive moduli of Thornel 300 Graphite/Narmco 5208 $[0/45/135/0/\overline{90}]_s$ laminates and in fact increased the modulus above the baseline values for a majority of the test data.

It was evident from the mechanical test results after the steady-state and cyclic humidity conditioning, that thermo-humidity cycling was highly detrimental. Therefore, additional testing was performed using protective coatings on the Thornel

300 Graphite/Narmco 5208 to establish the effect that these coatings would have on static mechanical properties after thermal-humidity conditioning.

A polyurethane coating* was selected for these studies. The coated samples were conditioned and then statically tested. Table VII presents a summary of the test results.

Substantial protection to the composites was provided by the polyurethane coatings through the thermo-humidity conditioning cycle. The elevated temperature tensile properties of the coated 0° composites were improved over the uncoated composites almost to the levels of the unconditioned composites. Both the 90° laminates and the $[0/45/135/0/\overline{90}]_s$ laminates showed resistances matching or exceeding the unconditioned values. This could have been due to repair of microscopic edge cracks in the samples. Overall the polyurethane coatings appear to provide protection against the rigors of the thermo-humidity cycle.

It can be seen in Figs. 10 and 11 that steady-state thermal conditioning produces only slight changes in the strengths and moduli of Thornel 300 Graphite/Narmco 5208 composites.

Figures 12 to 14 show the effect of steady state thermal exposure on the strengths of 0°, 90° and $[0/45/135/0/\overline{90}]_s$ laminates respectively, of Thornel 300 Graphite/Narmco 5208. There is practically no change from the baseline behavior for any of the three composites except in the cases of in-plane shear strength, 90° tensile strengths and $[0/45/135/0/\overline{90}]_s$ compressive strengths slightly, primarily because of the dependence of these properties on matrix properties. Some data for the 90° compressive properties is missing because several specimens were broken during environmental conditioning.

Figures 15 to 17 show the effect of steady state thermal exposure on the elastic moduli of Thornel 300 Graphite/Narmco 5208

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* Super - Desothane, A Product of DeSoto, Inc.
  See also Ref. 1

TABLE VII

SUMMARY OF TENSILE TESTS AT SEVERAL TEMPERATURES
ON COMPOSITES WITH VARIOUS ORIENTATION OF THORNEL 300 GRAPHITE/NARMCO 5208
COATED WITH SUPER DESOTHANE POLYURETHANE AND
SUBJECTED TO THE THERMO-HUMIDITY CONDITIONING CYCLE

FIBER ORIENTATION	CONDITION	ULTIMATE STRENGTHS AT VARIOUS TEMPS.		
		RTD	260°F	350°F
0°	Bare/unexposed	218	214	208
	Bare/Th. Hum. Cyc.	213	186	154
	Coated/Th. Hum. Cyc.	208	204	187
90°	Bare/unexposed	5.9	4.1	2.9
	Bare/Th. Hum. Cyc.	4.6	2.8	1.5
	Coated/Th. Hum. Cyc.	6.9	4.6	3.9
$[0/45/135/0/\overline{90}]_s$	Bare/unexposed	104	99	87
	Bare/Th. Hum. Cyc.	108	85	86
	Coated/Th. Hum. Cyc.	117	105	89

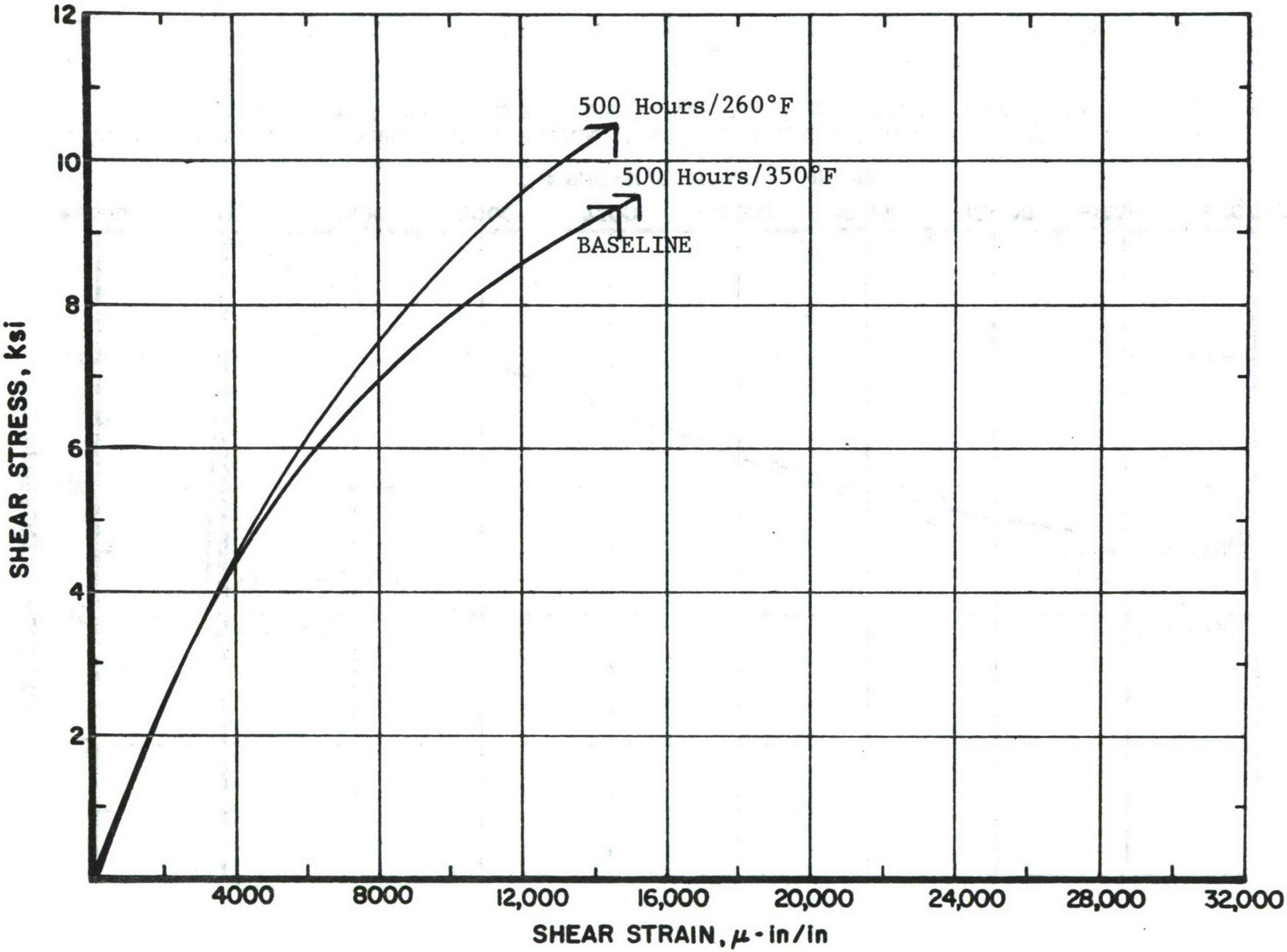


Fig. 10 COMPARATIVE SHEAR BEHAVIOR OF 0° THORNEL 300 GRAPHITE/NARMCO 5208 TESTED AT ROOM TEMPERATURE BEFORE AND AFTER EXPOSURE TO VARIOUS STEADY STATE THERMAL CONDITIONING

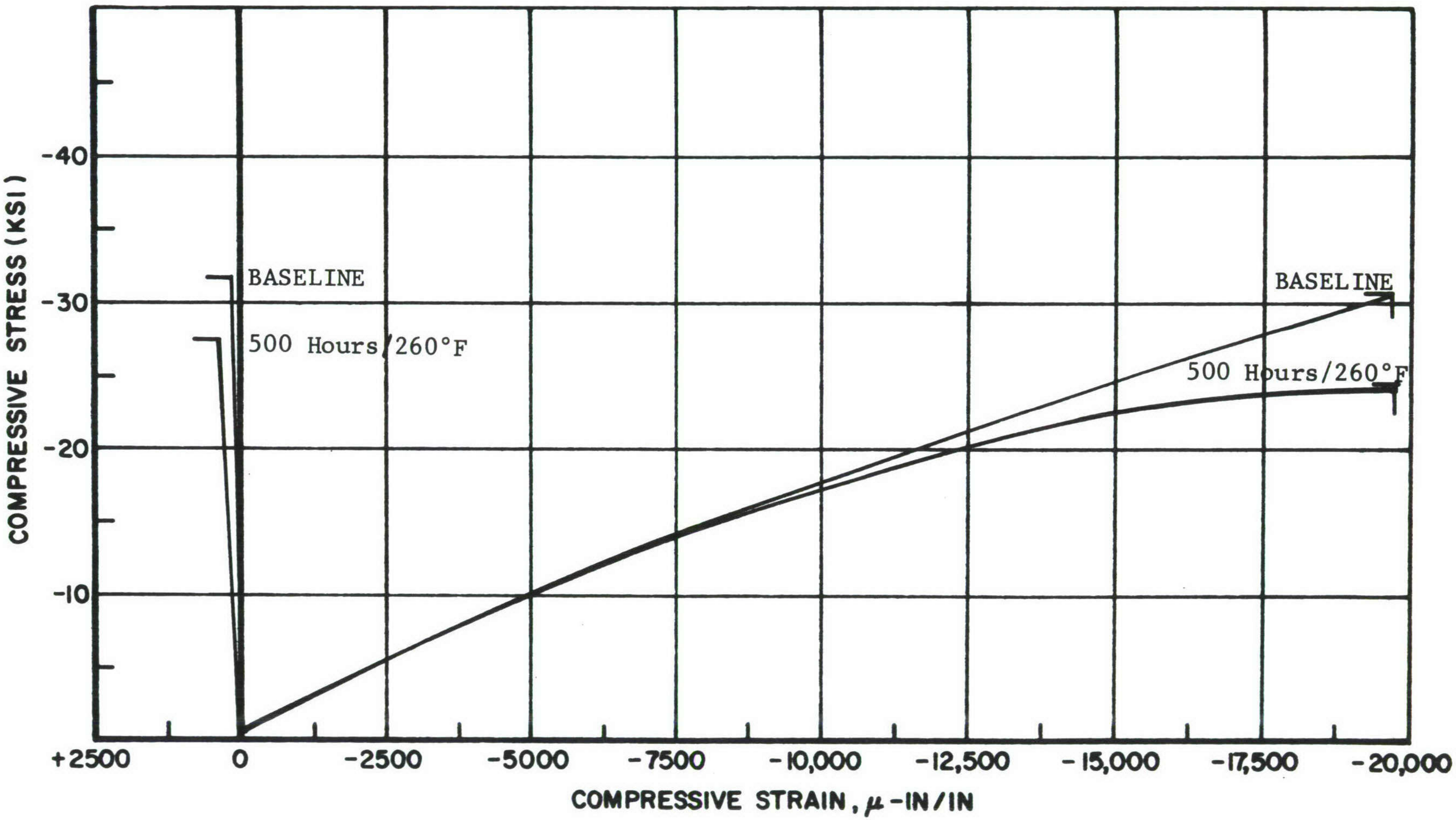


Fig. 11 COMPARATIVE COMPRESSION BEHAVIOR OF 90° THORNEL 300 GRAPHITE/NARMCO 5208 TESTED AT 260°F BEFORE AND AFTER EXPOSURE TO VARIOUS STEADY STATE THERMAL CONDITIONING

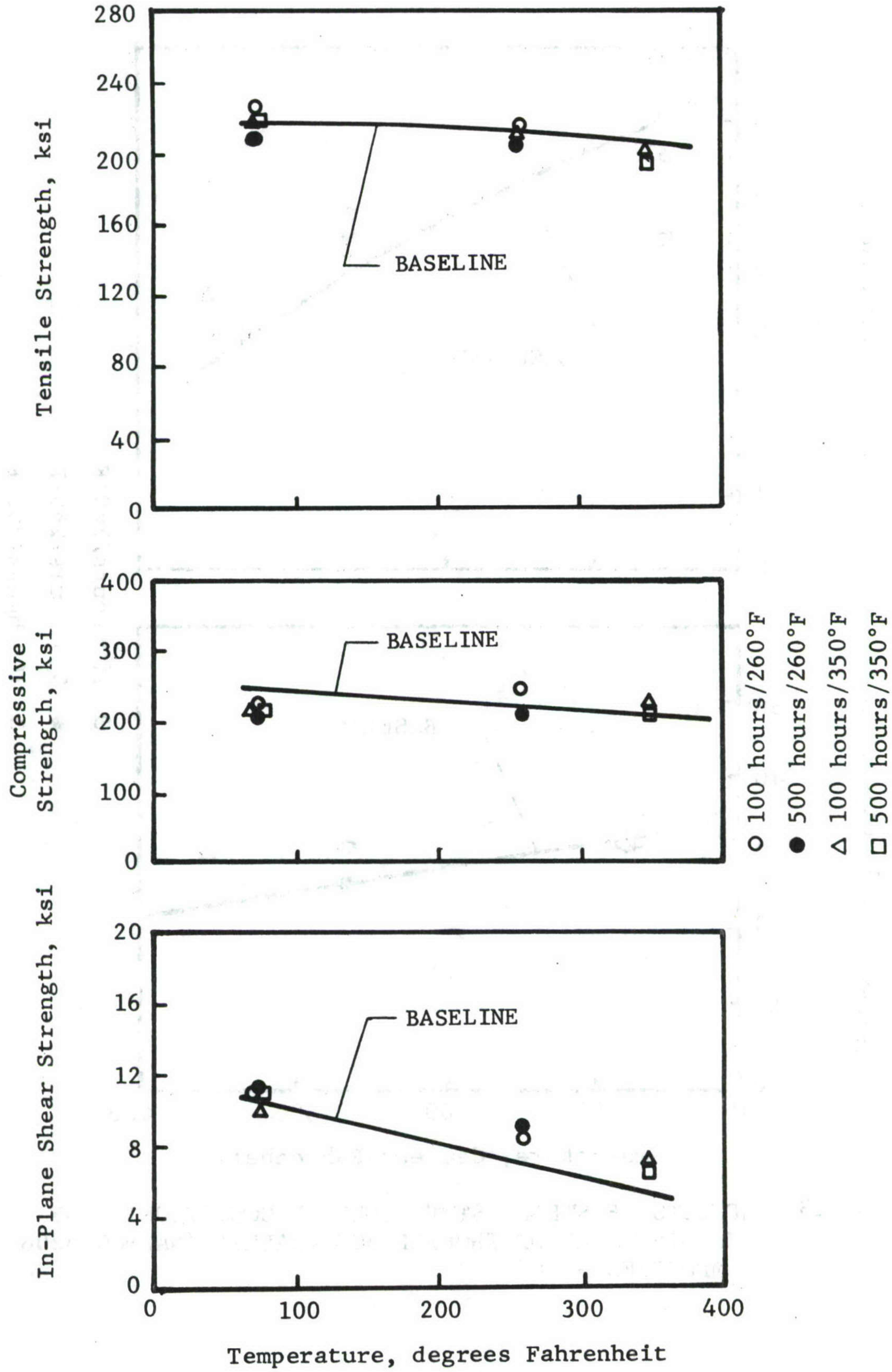


Fig. 12 EFFECTS OF STEADY STATE THERMAL CONDITIONING ON THE STRENGTHS OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 0°

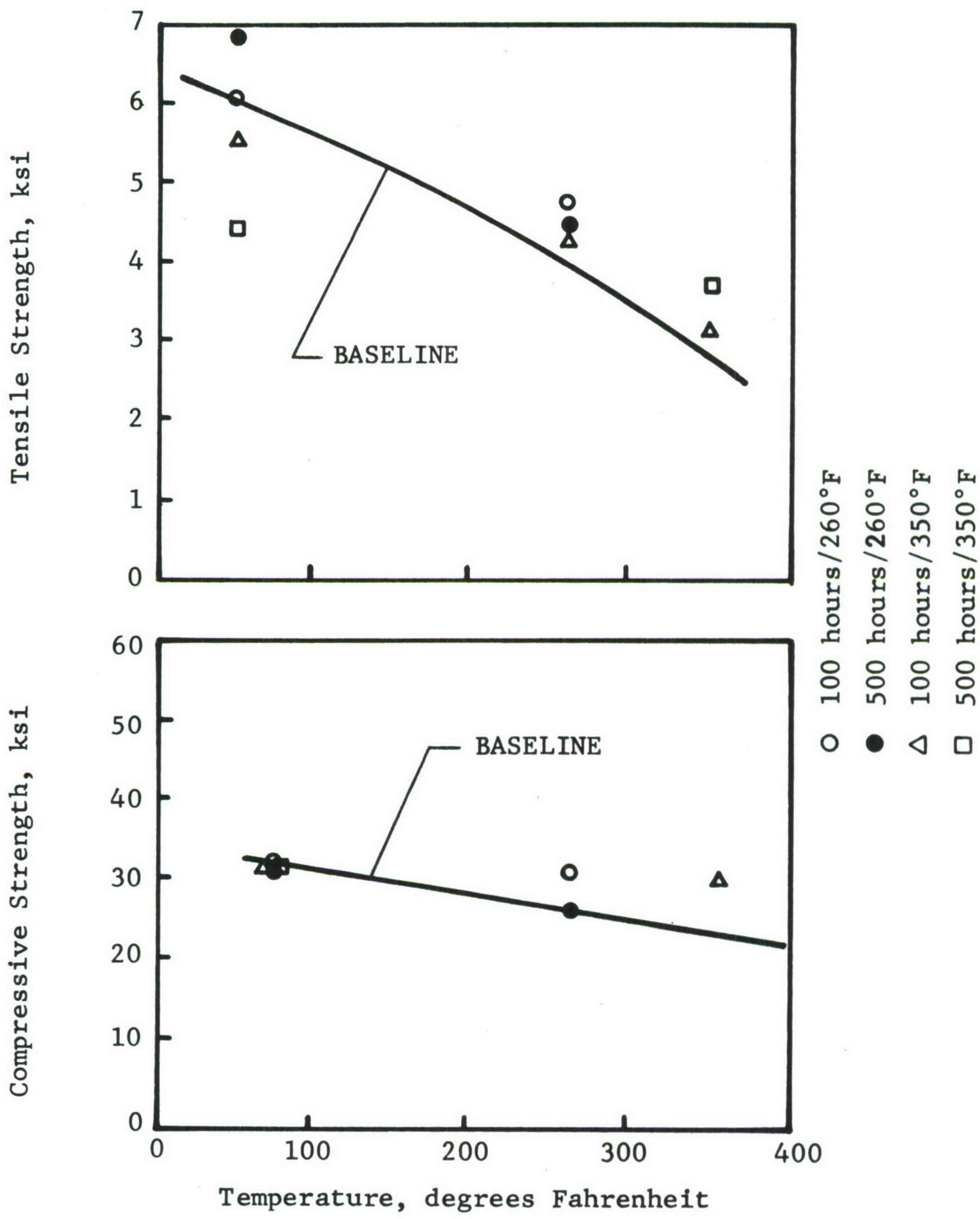


Fig. 13 EFFECTS OF STEADY STATE THERMAL CONDITIONING OF THE STRENGTHS OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 90°

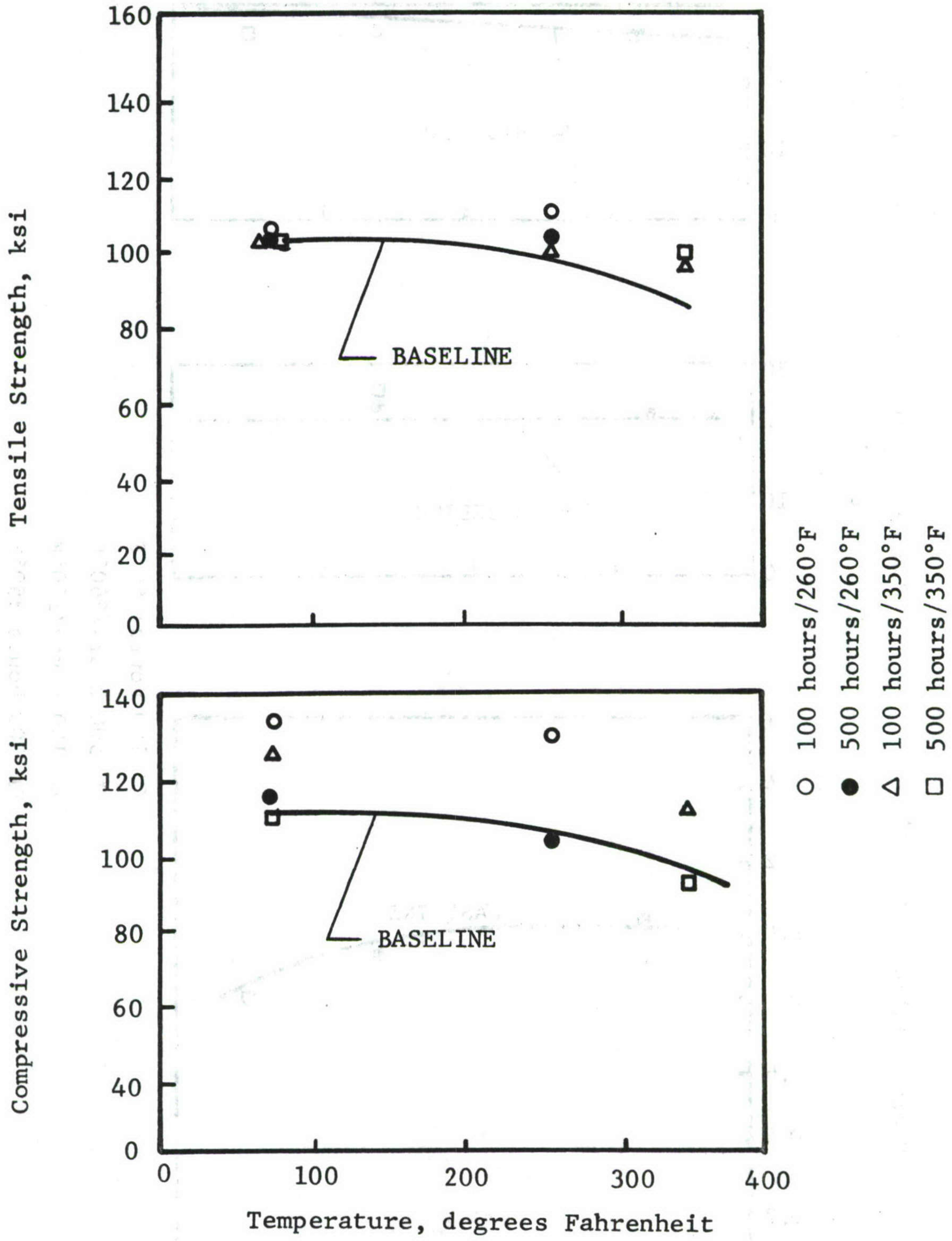


Fig. 14 EFFECTS OF STEADY-STATE THERMAL CONDITIONING ON THE STRENGTHS OF THORNEL 300 GRAPHITE/NARMCO 5208 LAMINATES - $[0/45/135/0/\overline{90}]_s$

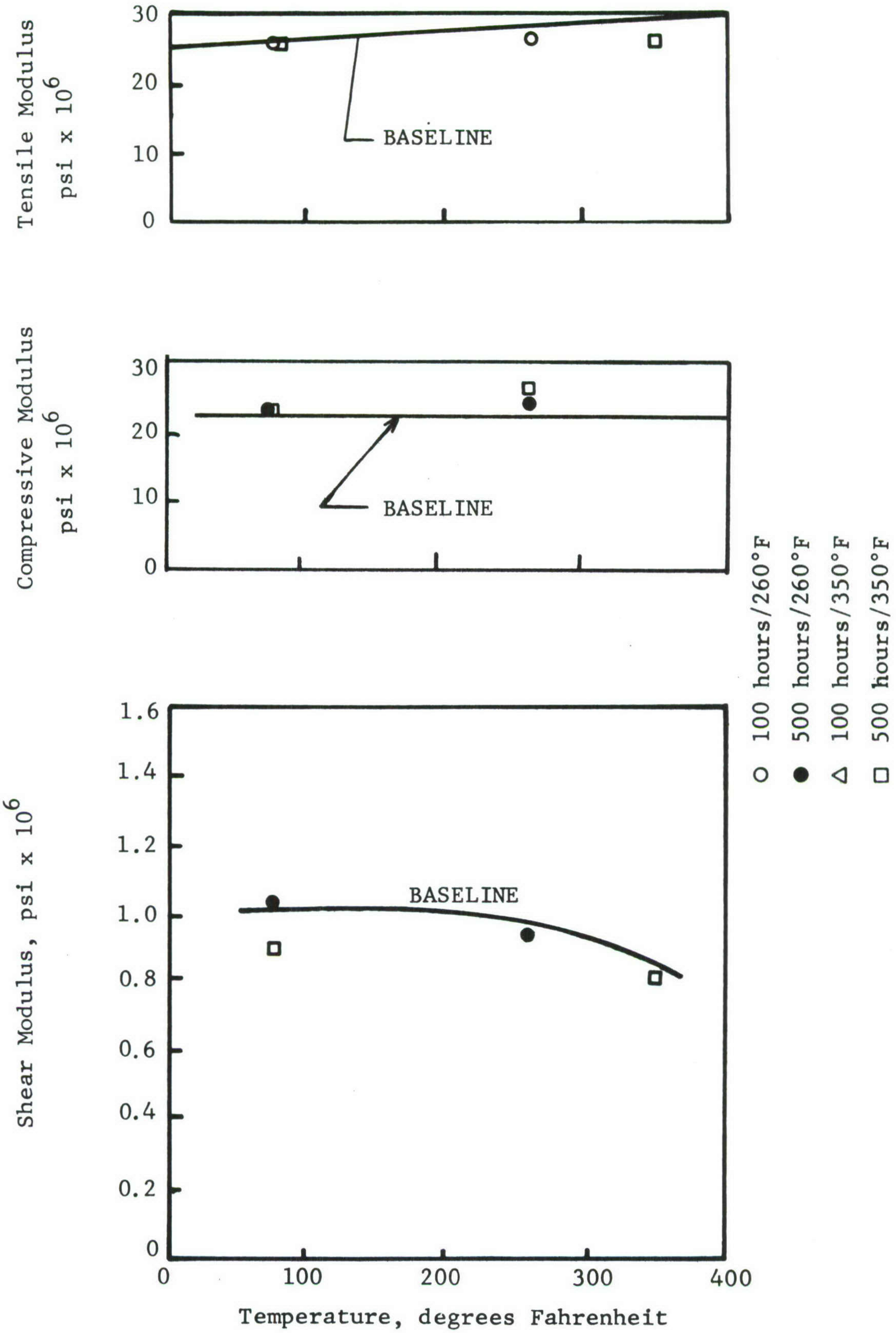


Fig. 15 EFFECT OF STEADY STATE THERMAL CONDITIONING ON THE MODULI OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 0°

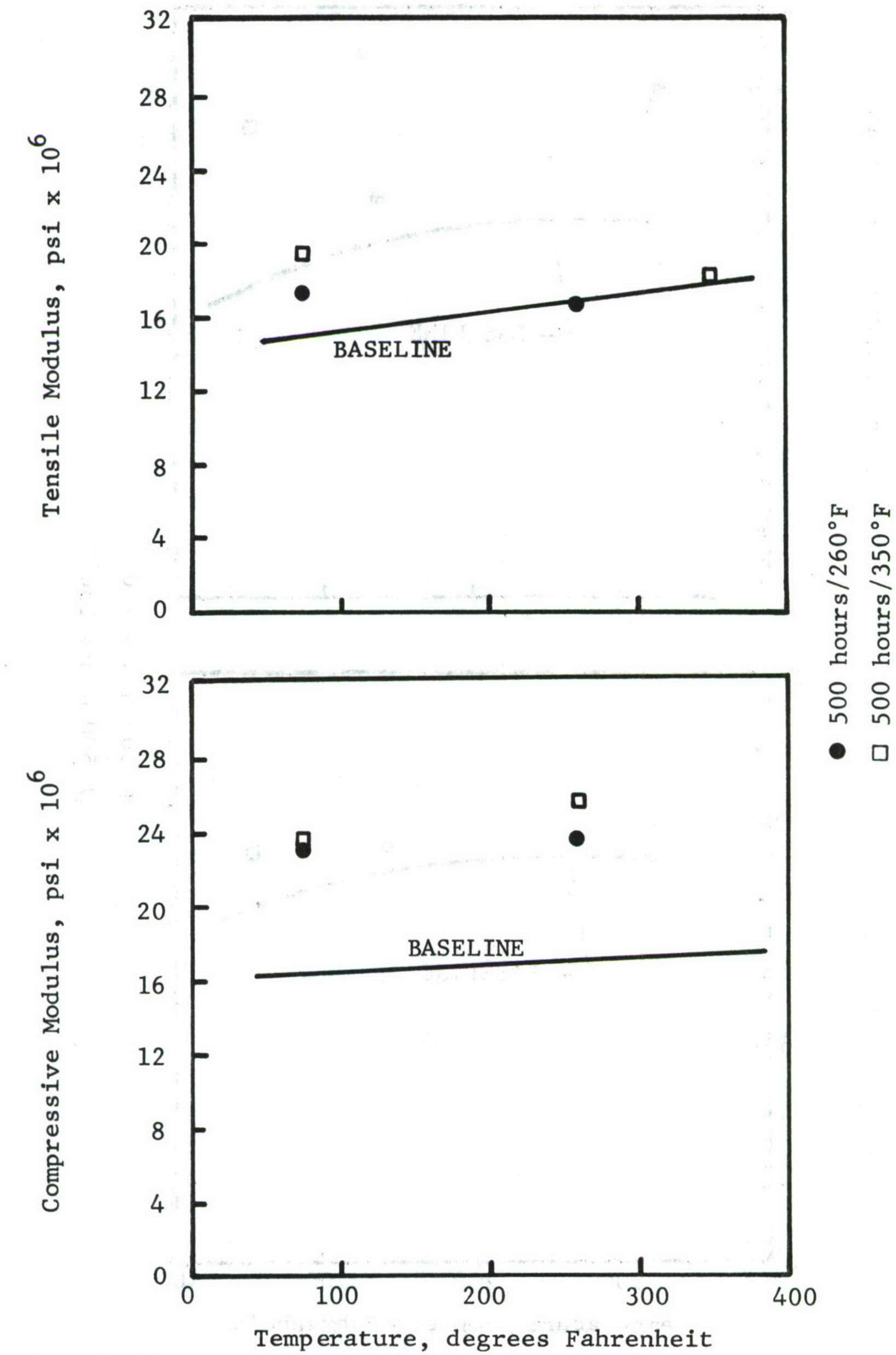


Fig. 16 EFFECT OF STEADY STATE THERMAL CONDITIONING ON THE ELASTIC MODULI OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 90°

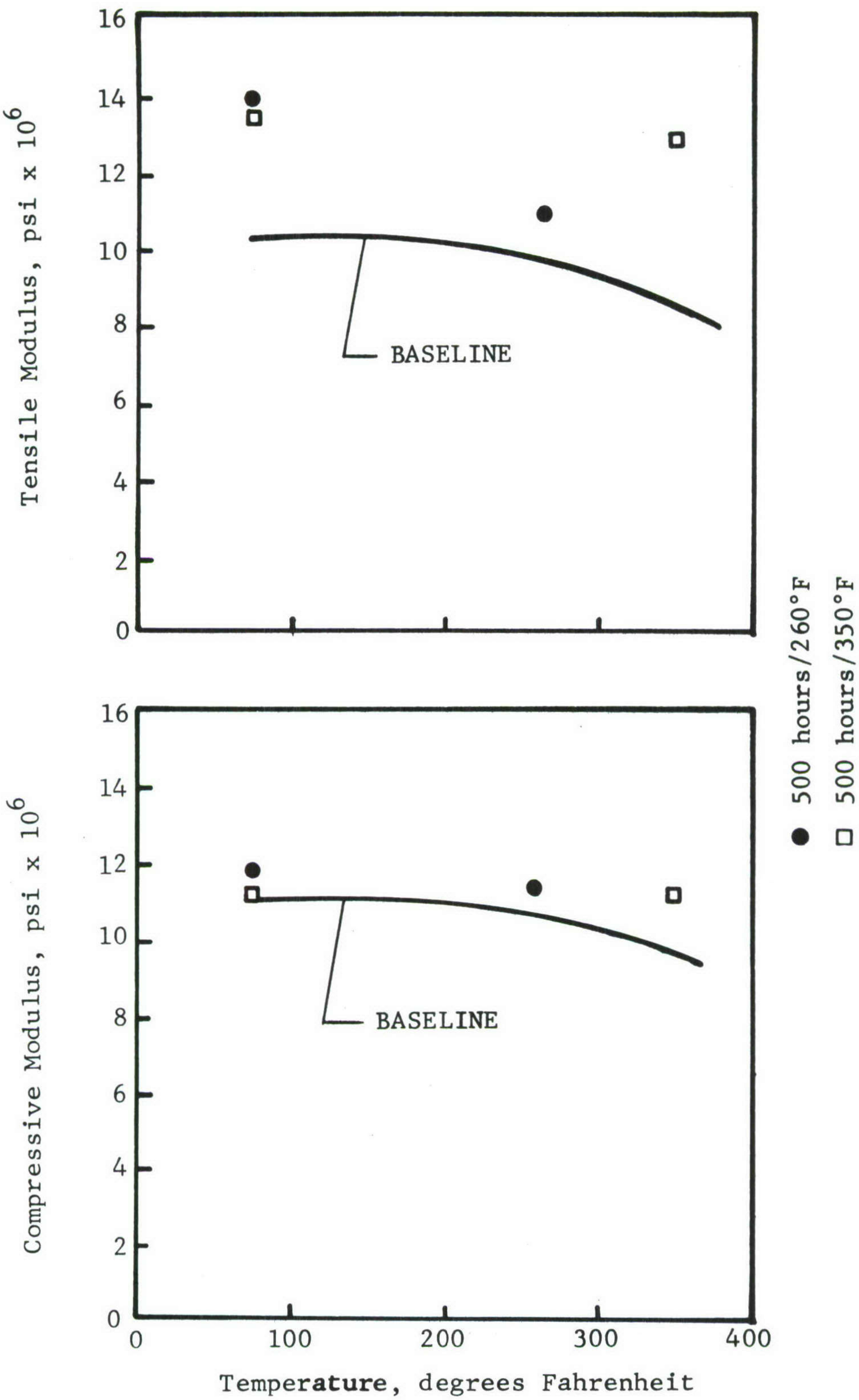


Fig. 17 EFFECT OF STEADY STATE THERMAL CONDITIONING ON THE ELASTIC MODULI OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - $[0/45/135/0/\overline{90}]_s$

for 0°, 90° and $[0/45/135/0/\overline{90}]_s$ composites respectively. Confirmation of the effect of thermal exposure on those properties most sensitive to matrix properties is also seen here. Most other properties changed only slightly.

Figures 18 and 19 show how the stress strain curves for Thornel 300 Graphite/Narmco 5208 are influenced by cyclic thermal conditioning.

The effect of cyclic thermal conditioning on the strengths of Thornel 300 Graphite/Narmco 5208 is shown in Figs. 20 to 22 for 0°, 90° and $[0/45/135/0/\overline{90}]_s$ laminates respectfully. The most significantly affected strength was the compressive strength of the $[0/45/135/0/\overline{90}]_s$ laminates. Losses up to 50% at room temperature were noted for the 1000 cycles to 350°F conditioning.

The effects of cyclic thermal conditioning on the elastic moduli are shown in Figs. 23 to 25 for 0°, 90° and $[0/45/135/0/\overline{90}]_s$ composites respectively. Greater variability (increases) are shown at the higher test temperatures as a result of cyclic thermal conditioning.

Interlaminar shear strengths as a function of test temperature are shown in Fig. 26. The separate effects of prior humidity, steady state thermal and cyclic thermal exposures are also shown. The greatest degradation from the baseline interlaminar shear strengths were shown for prior humidity conditioning. Steady thermal exposure had practically no effect or showed improvements. Cyclic thermal effects showed more degradation at the higher test temperatures than at room temperature.

2.5 Fatigue Properties

Individual S-N fatigue curves are presented in Appendix II. In addition to the baseline fatigue determinations, S-N curves were obtained after various conditioning treatments had been applied. Figures 27 to 32 show the comparison for prior humidity conditioning, prior steady-state thermal conditioning and prior cyclic thermal conditioning. The humidity results show considerable scatter of effects and inconsistent degradation

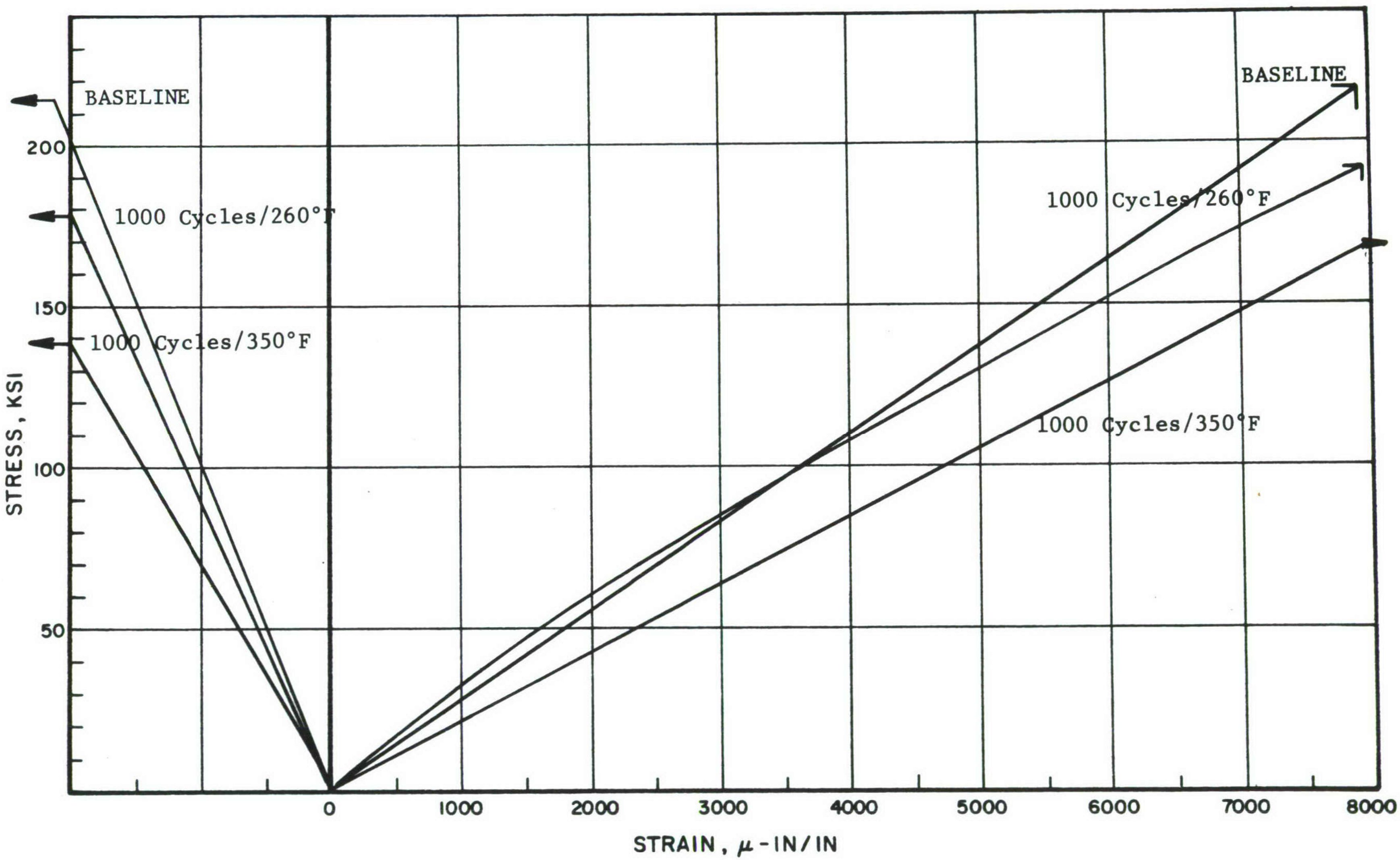


Fig. 18 COMPARATIVE TENSILE BEHAVIOR OF 0° THORNEL 300 GRAPHITE/NARMCO 5208 TESTED AT ROOM TEMPERATURE BEFORE AND AFTER EXPOSURE TO VARIOUS CYCLIC THERMAL CONDITIONING

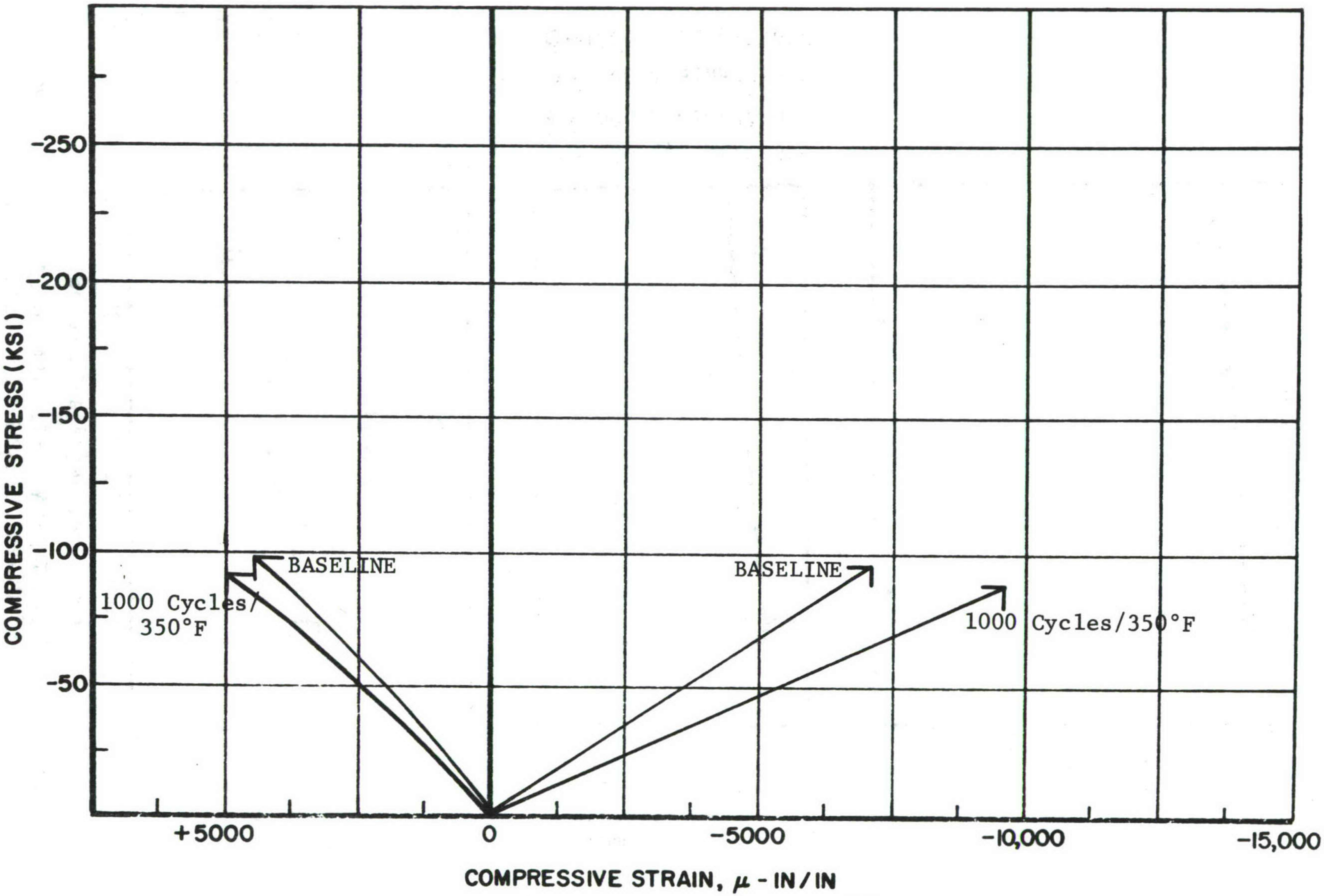


Fig. 19 COMPARATIVE COMPRESSION BEHAVIOR OF $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 TESTED AT 350°F BEFORE AND AFTER EXPOSURE TO VARIOUS CYCLIC THERMAL CONDITIONING

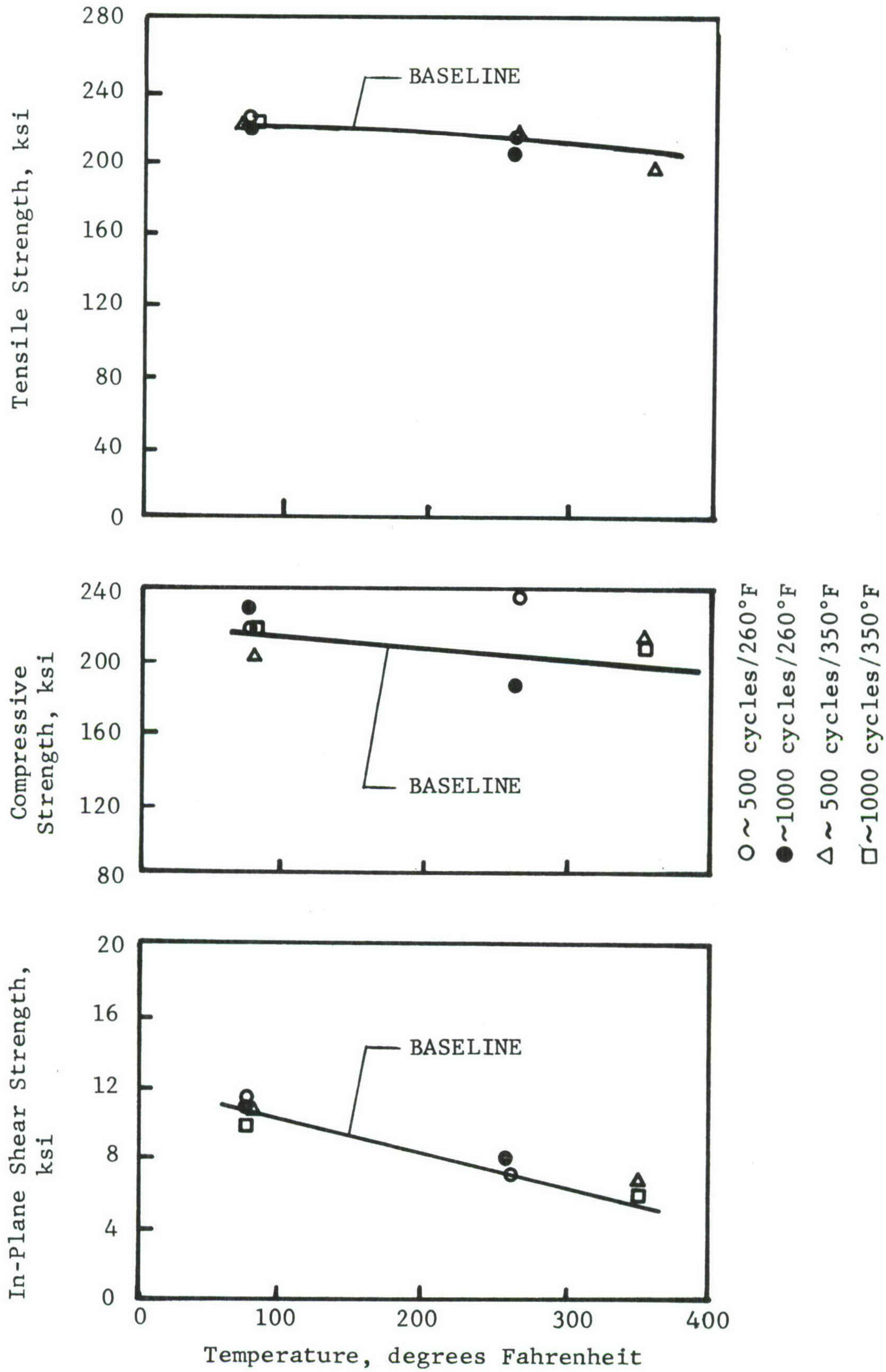


Fig. 20 EFFECT OF CYCLIC THERMAL CONDITIONING ON THE STRENGTHS OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 0°

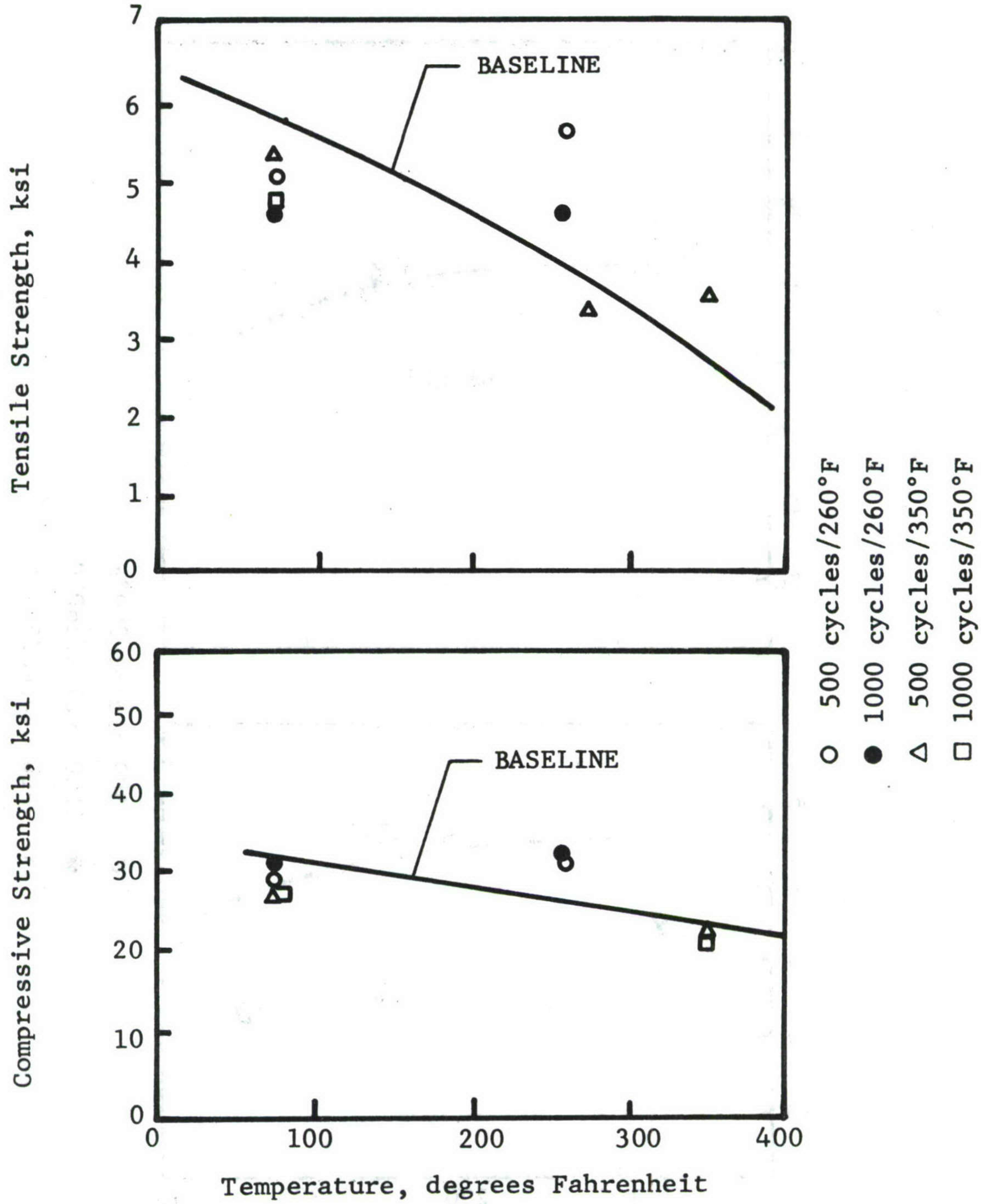


Fig. 21 EFFECTS OF CYCLIC THERMAL CONDITIONING ON THE STRENGTHS OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 90°

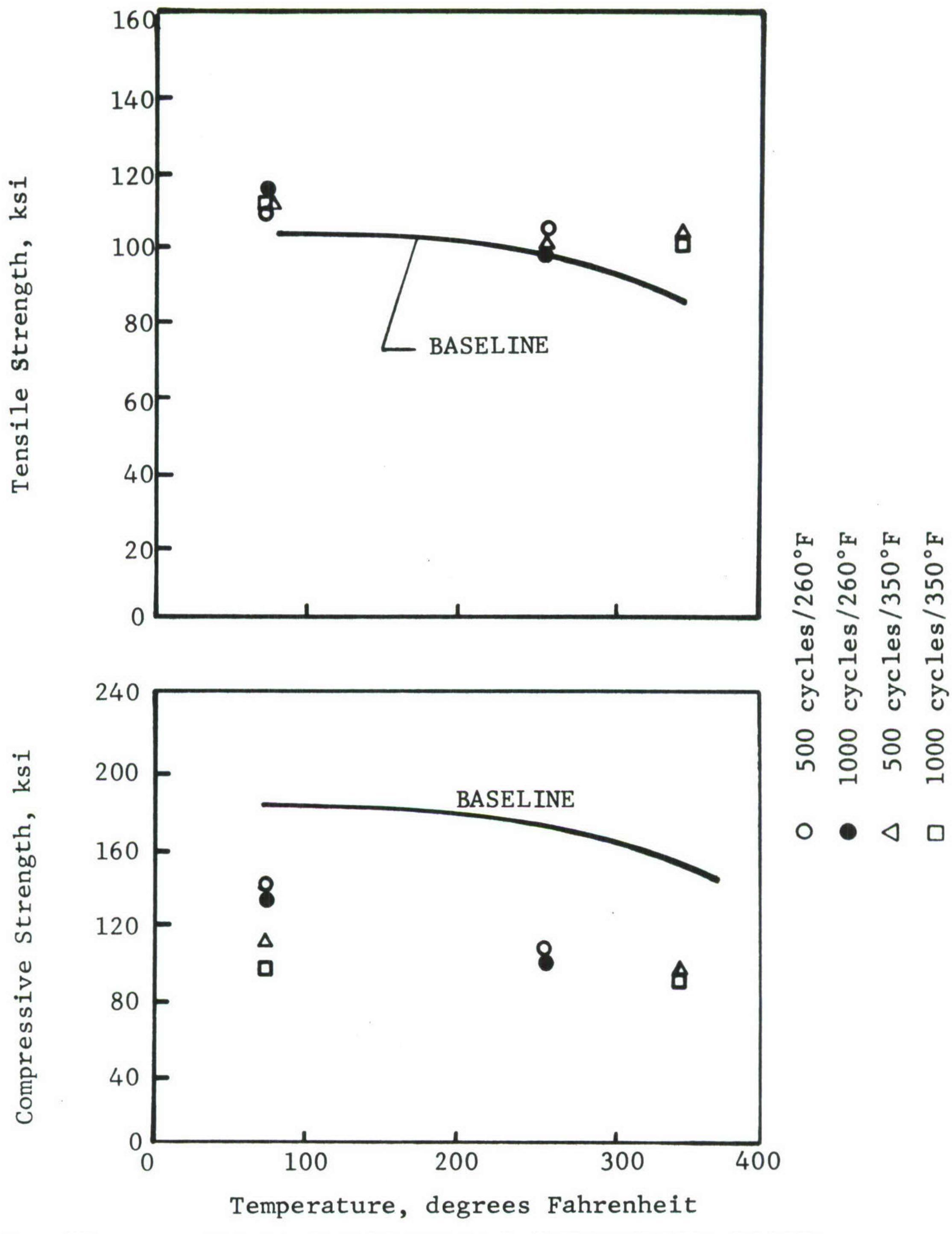


Fig. 22 EFFECTS OF CYCLIC THERMAL CONDITIONING ON THE STRENGTHS OF THORNEL 300 GRAPHITE/NARMCO 5208 LAMINATES - $[0/45/135/0/\overline{90}]_s$

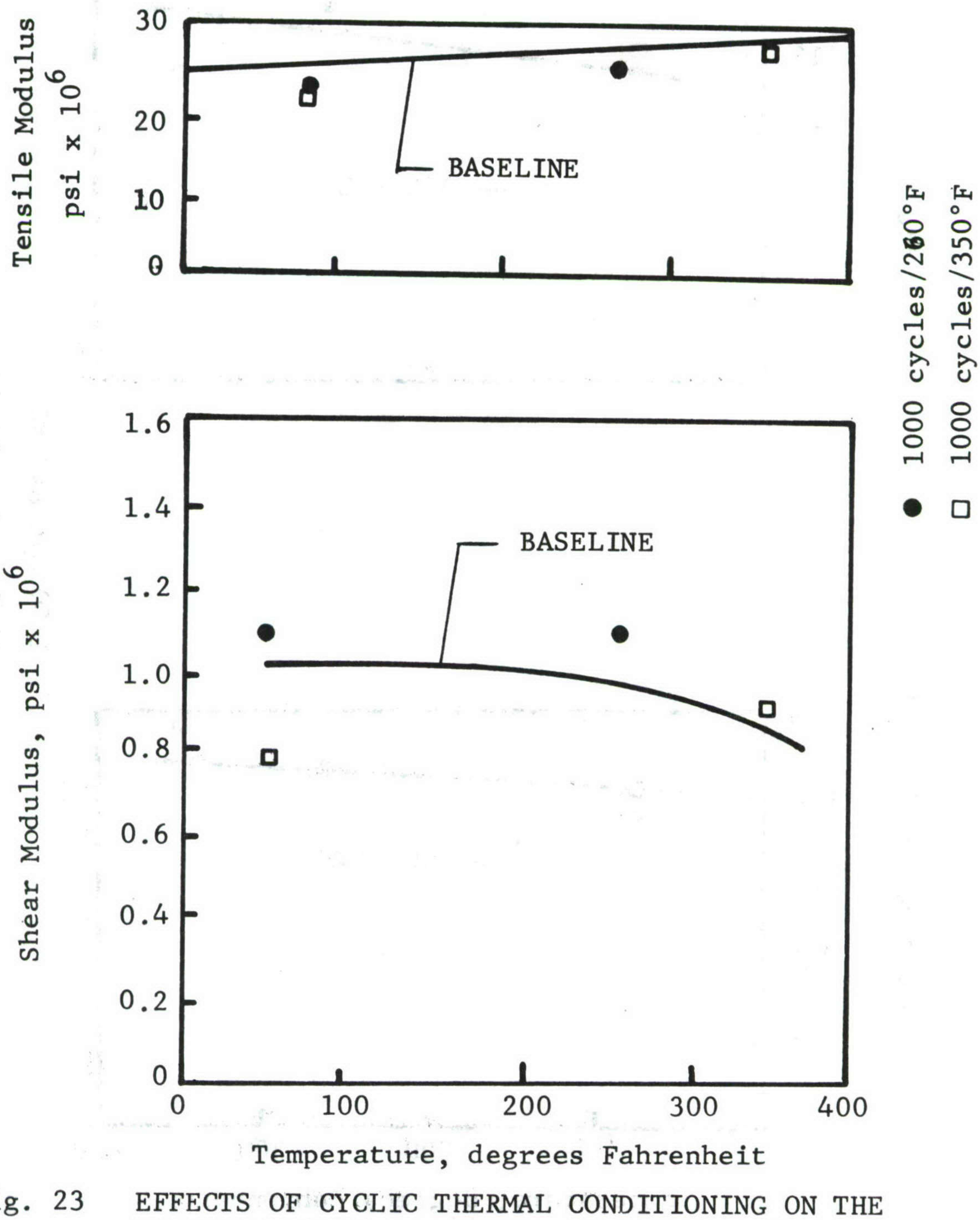


Fig. 23 EFFECTS OF CYCLIC THERMAL CONDITIONING ON THE ELASTIC MODULI OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 0°

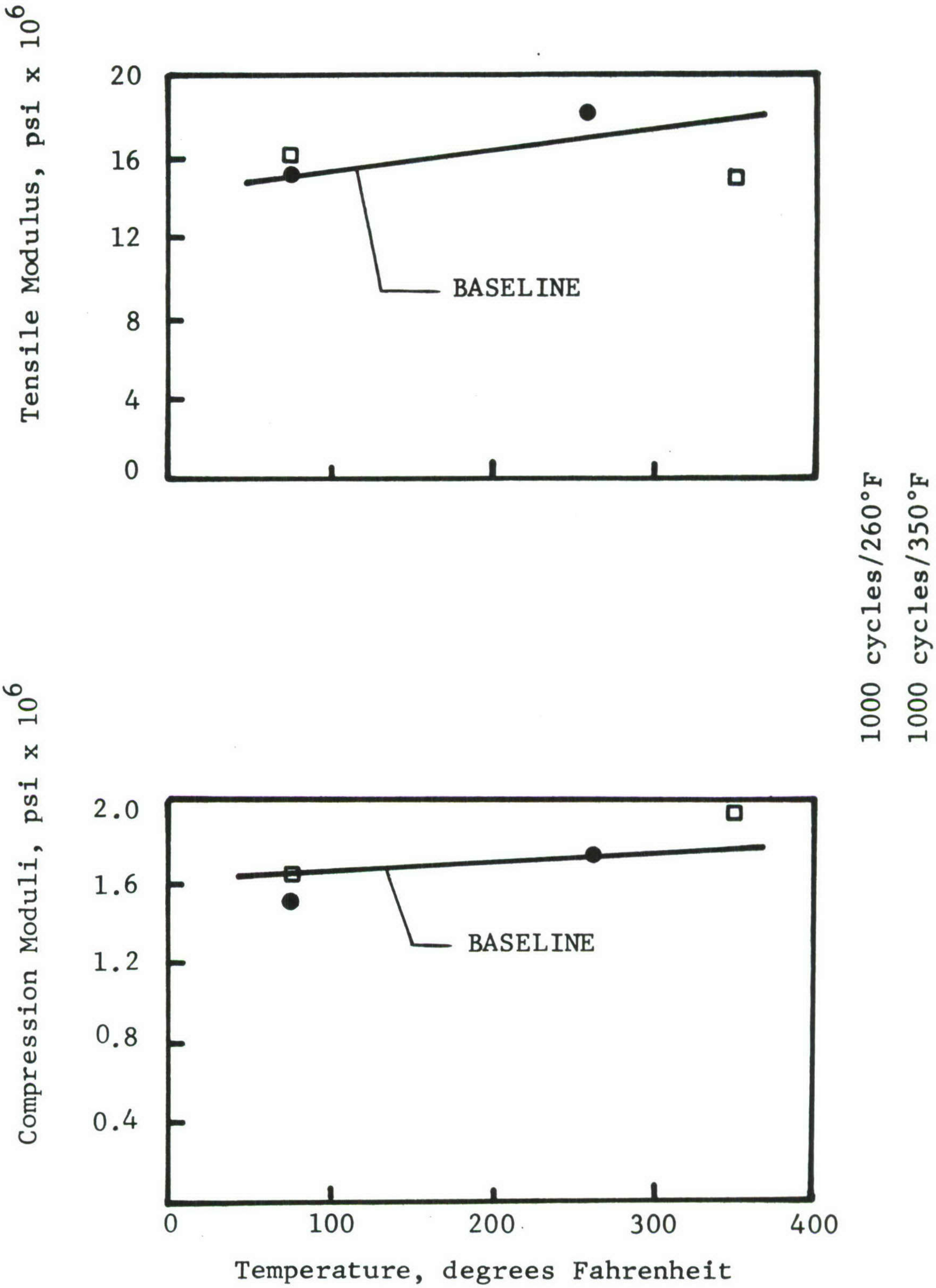


Fig. 24 EFFECT OF CYCLIC THERMAL CONDITIONING ON THE ELASTIC MODULI OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 90°

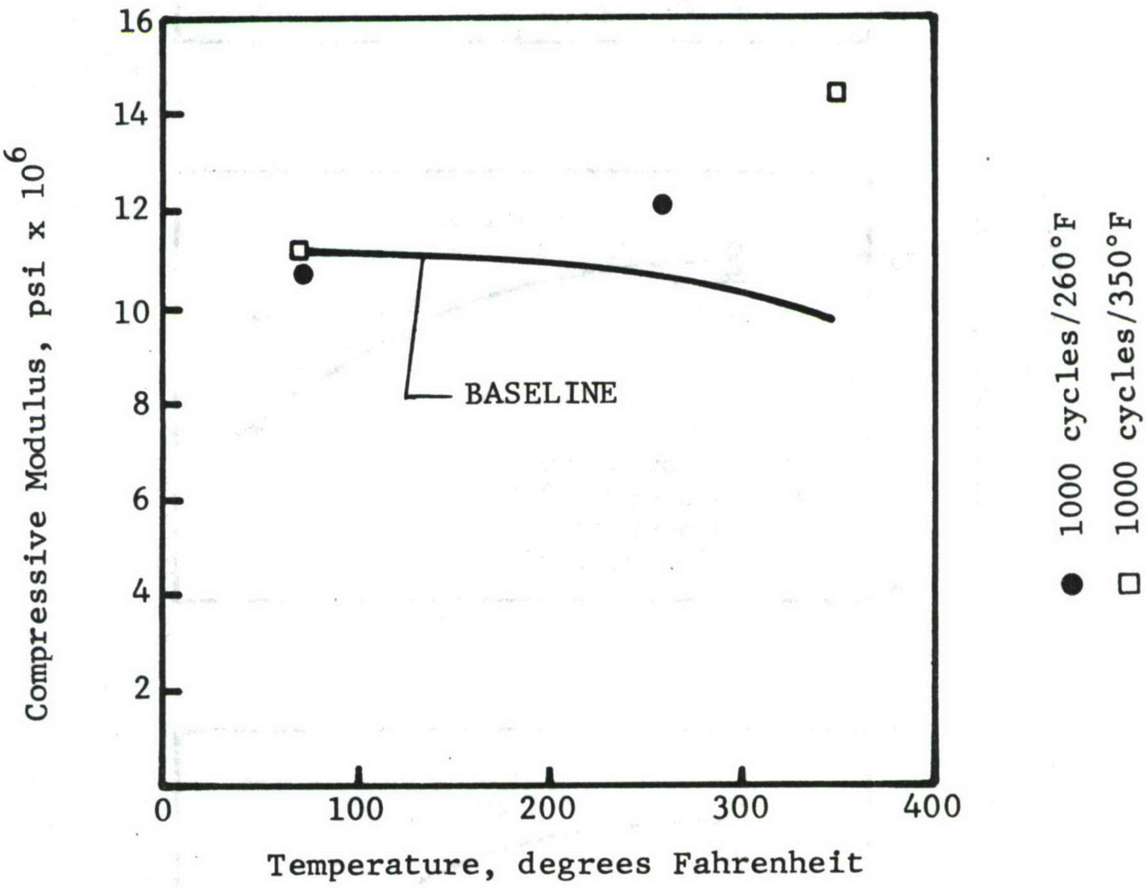


Fig. 25 EFFECTS OF CYCLIC THERMAL CONDITIONING ON THE ELASTIC MODULI OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - $[0/45/135/0/\overline{90}]_s$

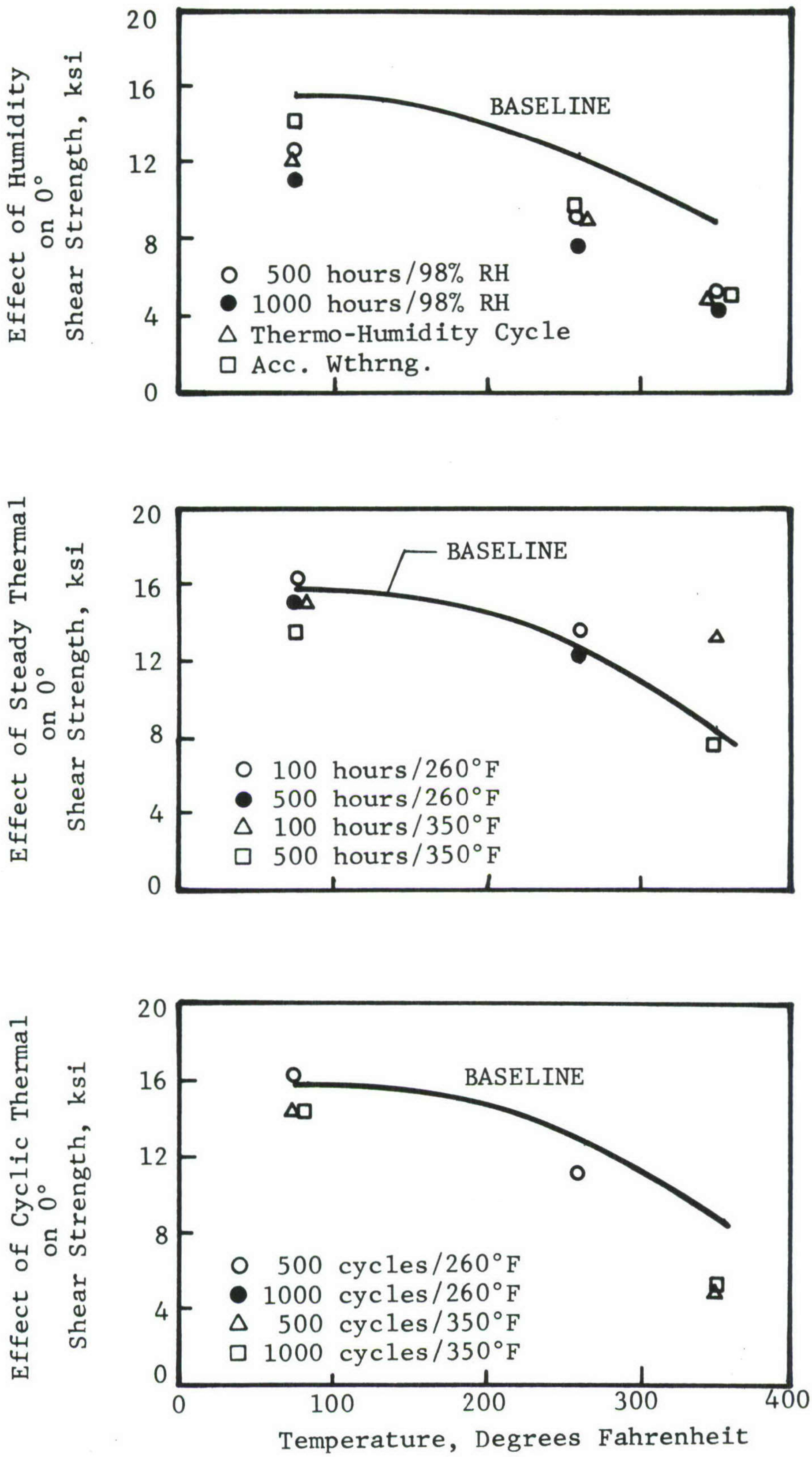


Fig. 26 EFFECT OF VARIOUS ENVIRONMENTAL CONDITIONING ON THE INTERLAMINAR SHEAR STRENGTH OF THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

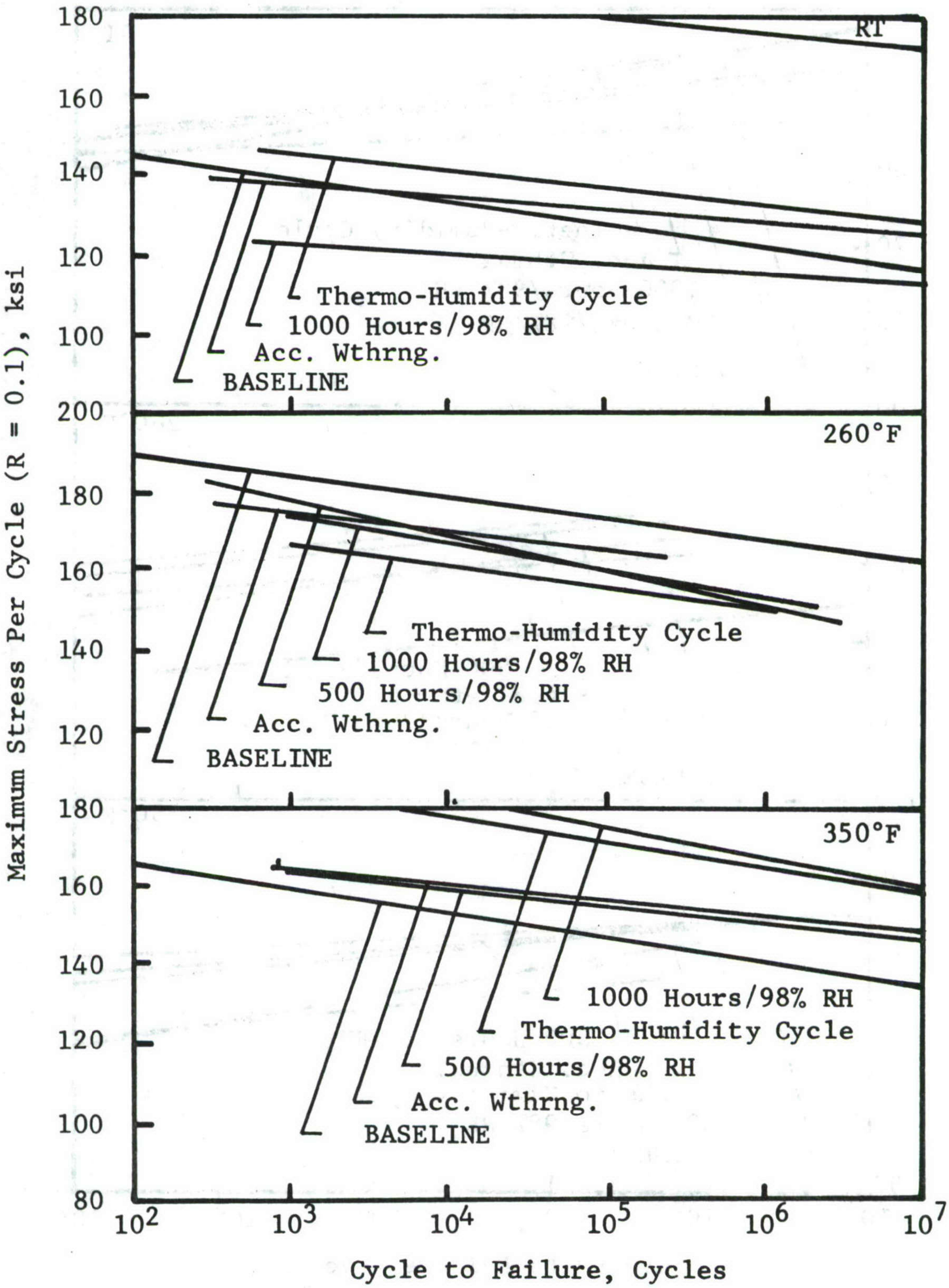


Fig. 27 EFFECT OF HUMIDITY CONDITIONING ON THE FATIGUE SN CURVES FOR THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES - 0°

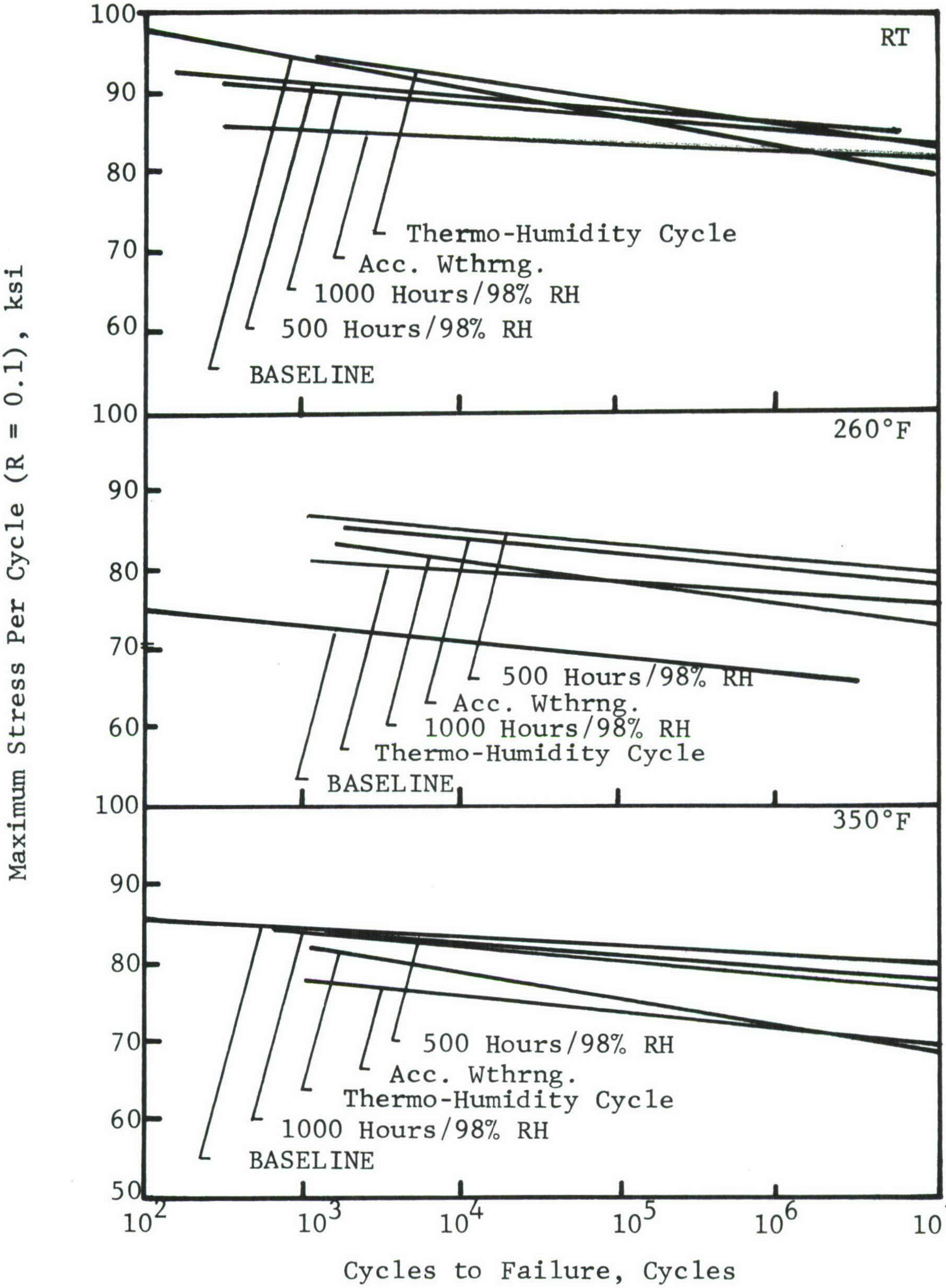


Fig. 28 EFFECT OF HUMIDITY CONDITIONING ON THE FATIGUE SN CURVES FOR THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - [$0/45/135/0/\overline{90}]_s$

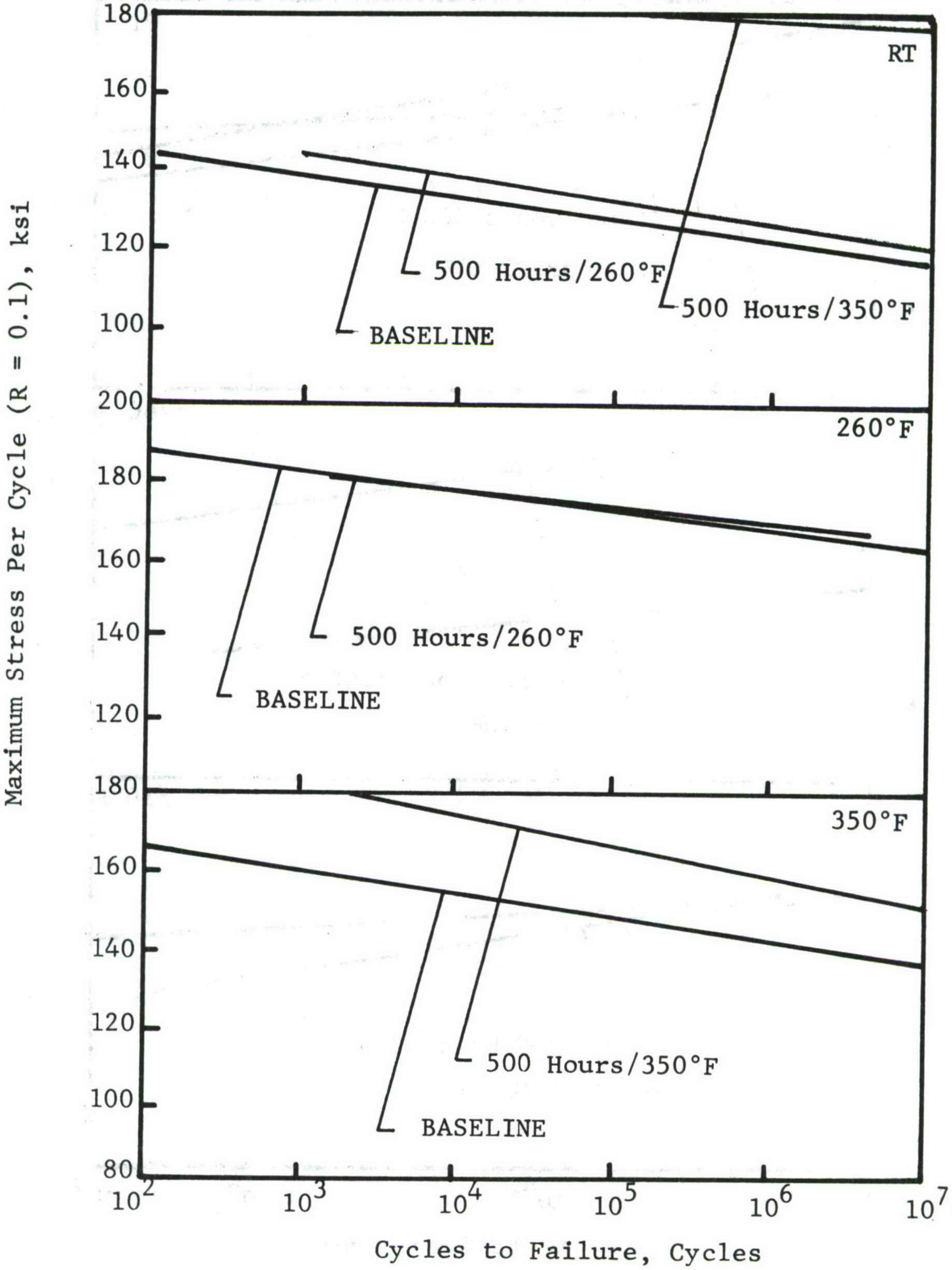


Fig. 29 EFFECT OF STEADY STATE THERMAL CONDITIONING ON THE FATIGUE SN CURVES FOR THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 0°

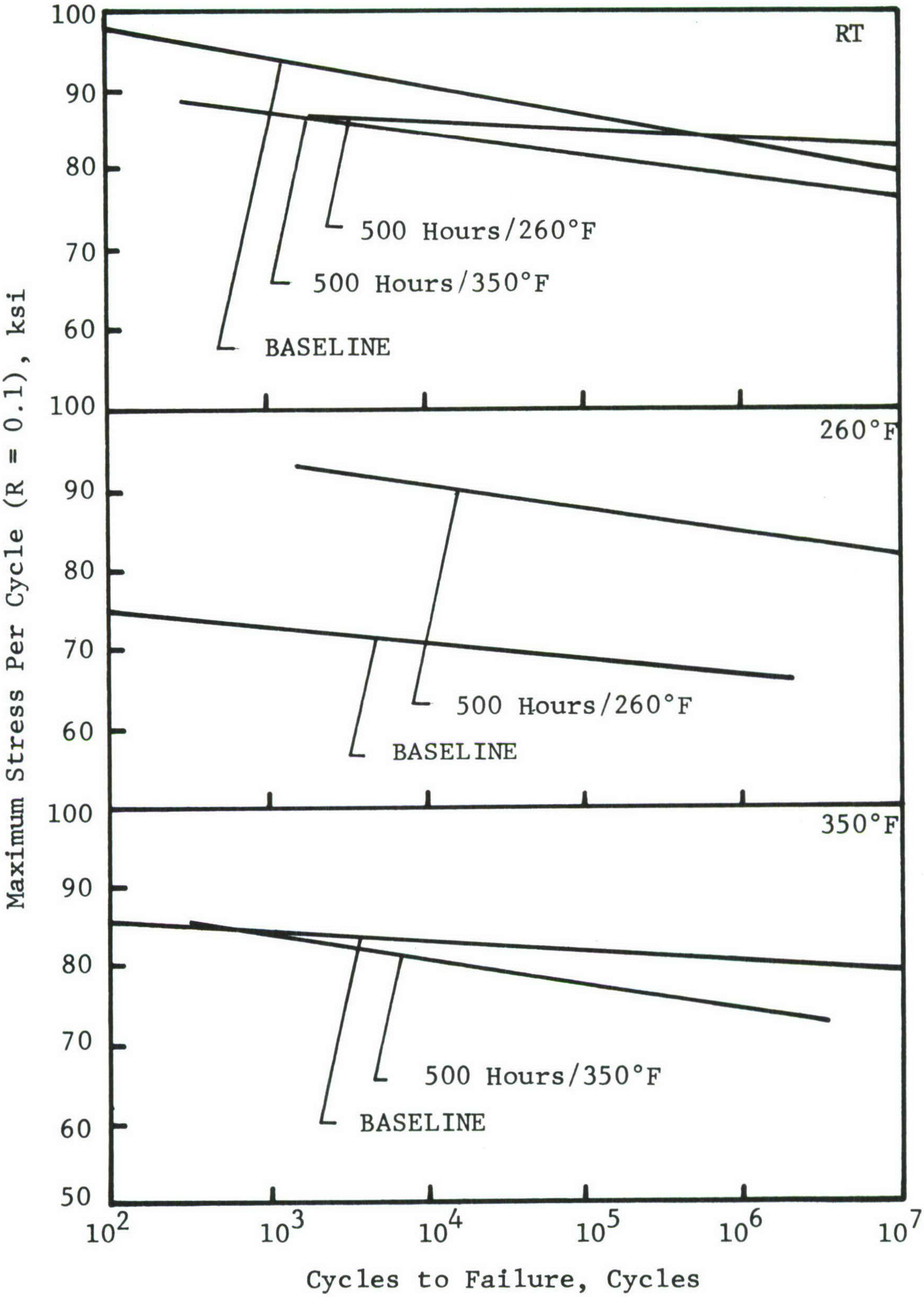


Fig. 30 EFFECT OF STEADY STATE THERMAL CONDITIONING ON THE FATIGUE SN CURVES FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$

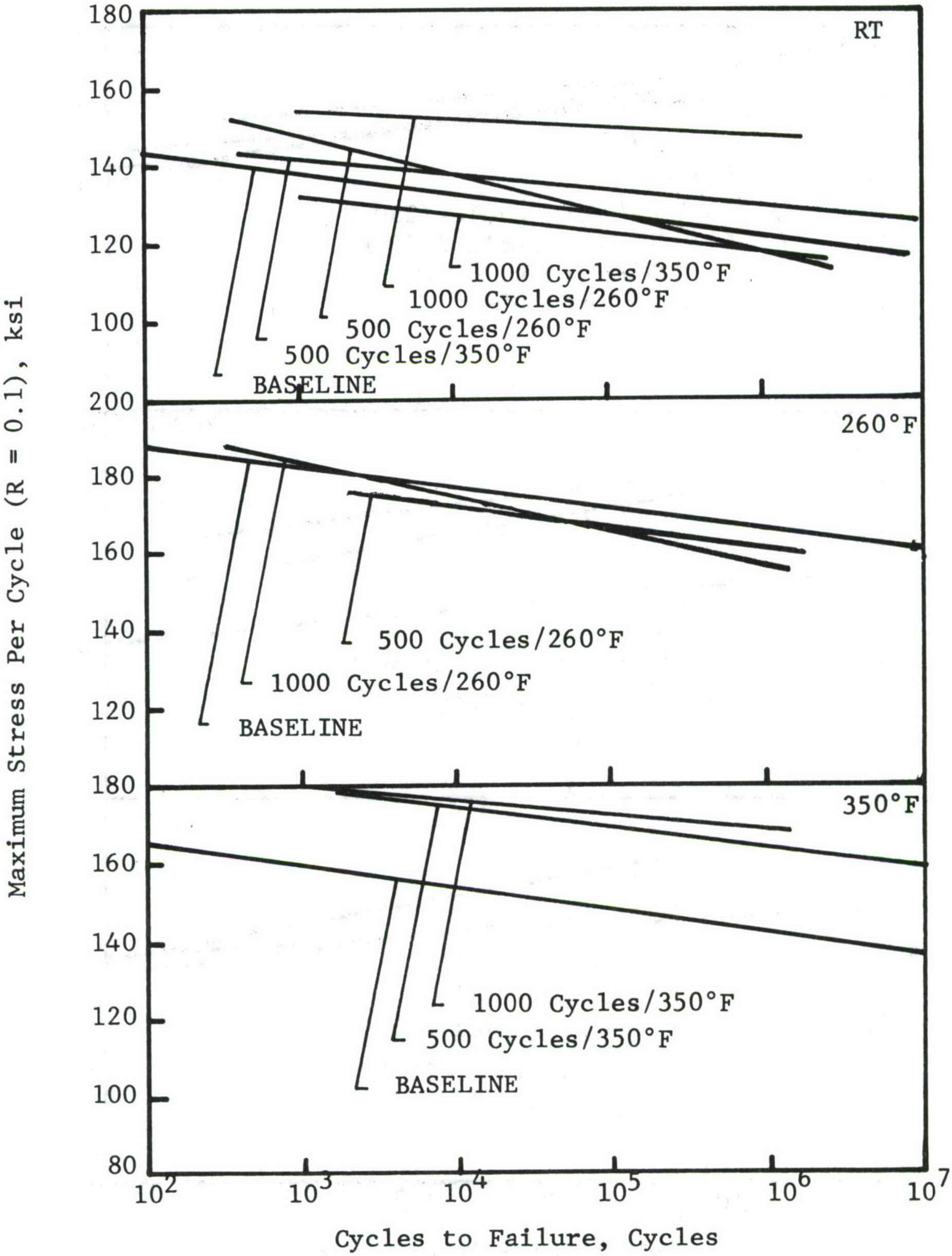


Fig. 31 EFFECT OF CYCLIC THERMAL CONDITIONING ON THE FATIGUE SN CURVES FOR THORNEL 300 GRAPHITE NARMCO 5208 COMPOSITES - 0°

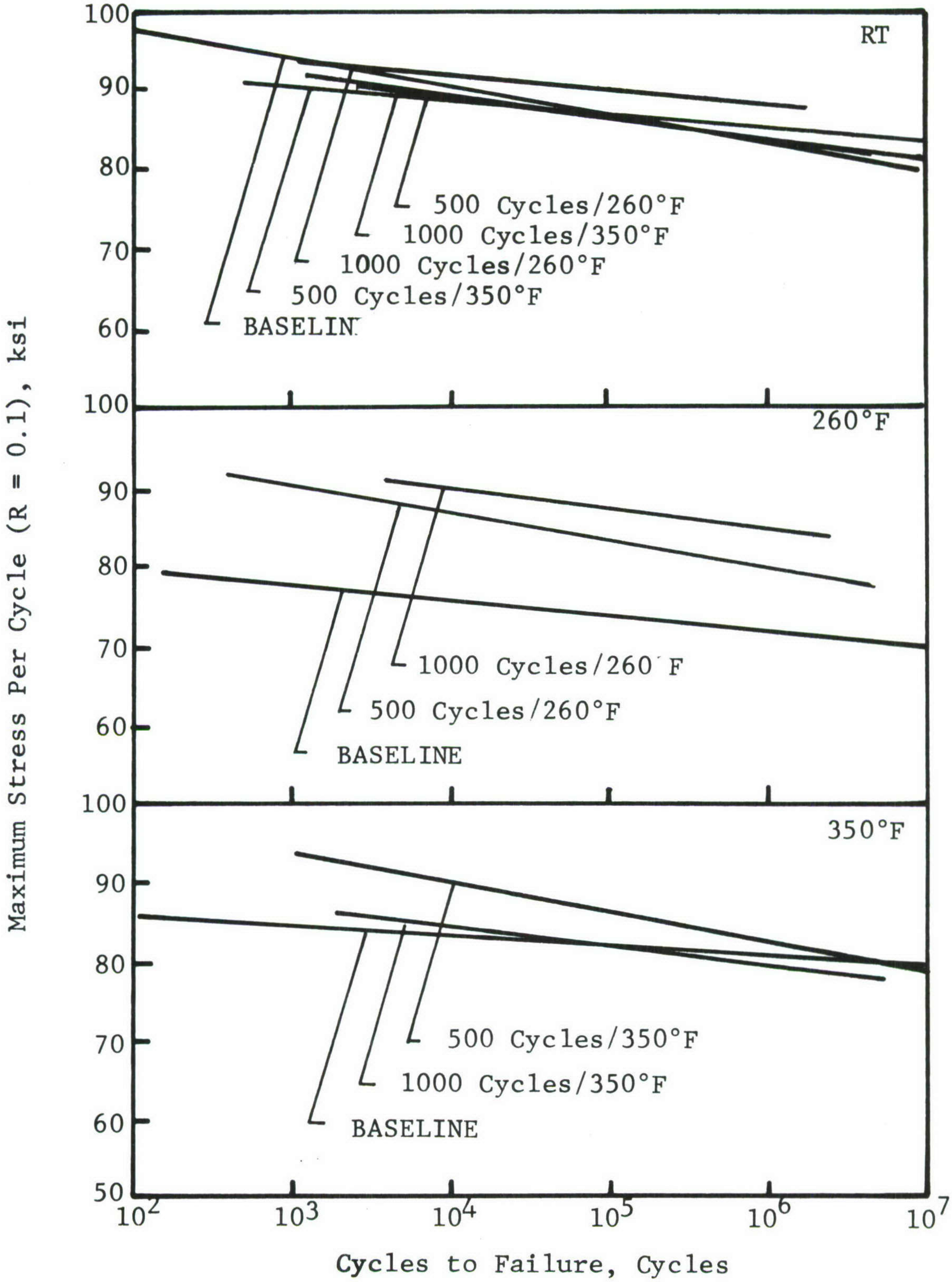


Fig. 32 EFFECT OF CYCLIC THERMAL CONDITIONING ON THE FATIGUE SN CURVES FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$

or improvement, although losses or gains of 10 to 15% are common. Prior thermal (steady state) conditioning generally showed improvement in the 0° fatigue performance of from 5 to 15% and 5 to 10% losses in strength for the $[0/45/135/0/\overline{90}]_s$ laminates. Cyclic thermal conditioning generally produced some improvement in fatigue resistance, particularly in the case of the $[0/45/135/0/\overline{90}]_s$ laminates.

2.6 Creep And Stress-Rupture Properties

The creep and stress-rupture data are presented in Appendix II for individual orientations and conditioning treatments. Figures 33 to 38 show the effects of humidity, steady-state thermal and cyclic thermal conditioning on the stress-rupture behavior of 0° and $[0/45/135/0/\overline{90}]_s$ laminates of Thornel 300 Graphite/Narmco 5208. Humidity conditioning causes the stress-rupture resistance to increase as seen in Figs. 33 and 34. The steady-state conditioning increases the resistance of both the 0° and $[0/45/135/0/\overline{90}]_s$ composites to stress-rupture fracturing as does the cyclic thermal conditioning.

Overall the various conditioning treatments uniformly improved the stress-rupture resistance of the Thornel 300 Graphite/Narmco 5208 composites by approximately 5 to 25%.

2.7 Thermo-Physical Properties

Thermal expansion measurements were made on Thornel 300 Graphite/Narmco 5208 materials in the 0°, 90° and $[0/45/135/0/\overline{90}]_s$ fiber orientations. Expansion samples consisted of single 1/2 x 2-inch laminates, the expansion measurement being made in the longitudinal direction. Samples were cycles twice in air from ambient RT to 350°F at 4°F/min. employing a NETZSCH automatic recording quartz pushrod dilatometer. The linear coefficient of thermal expansion was derived from a continuous recording of

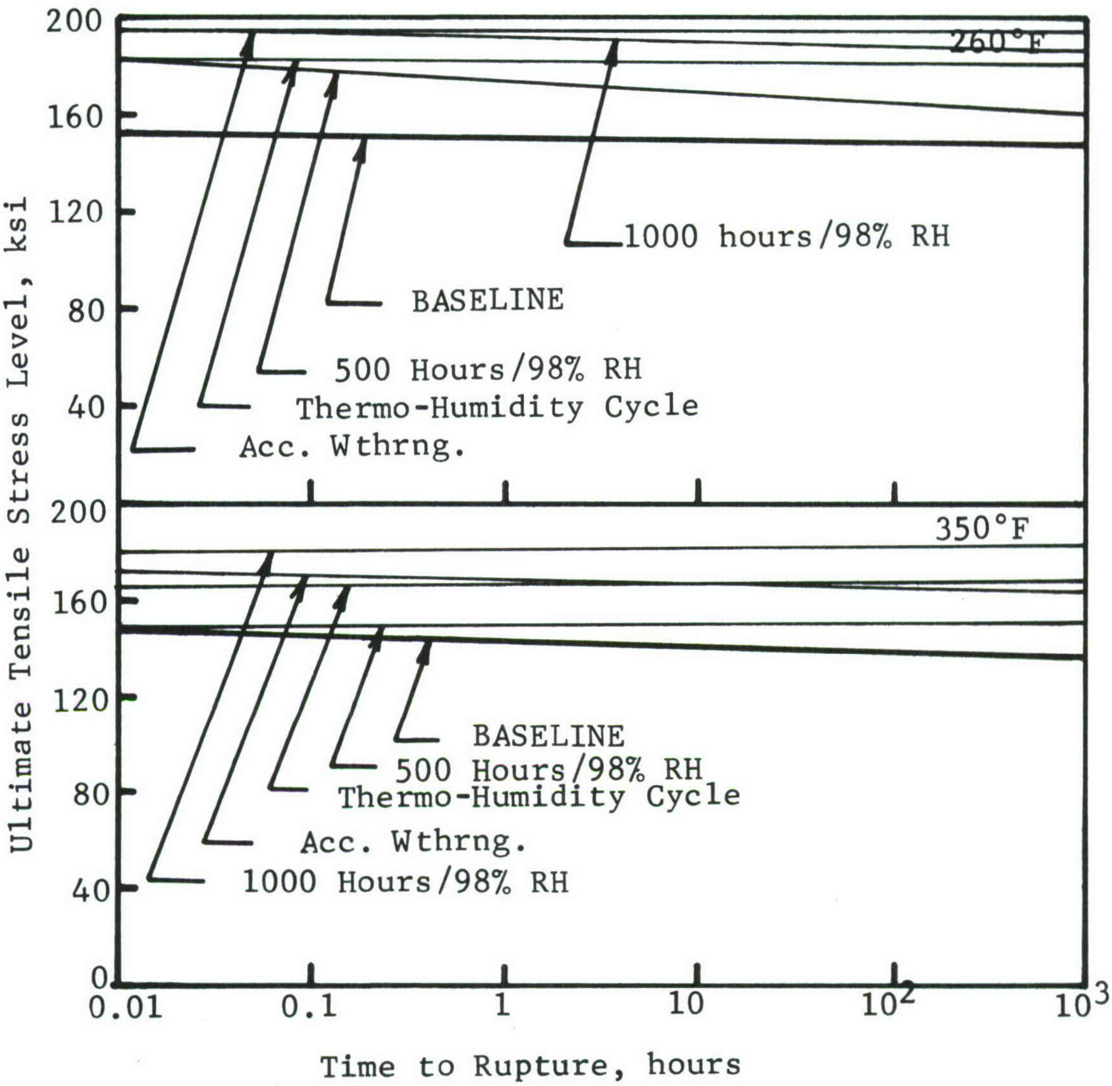


Fig. 33 EFFECT OF HUMIDITY CONDITIONING ON THE STRESS RUPTURE BEHAVIOR OF THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES - 0°

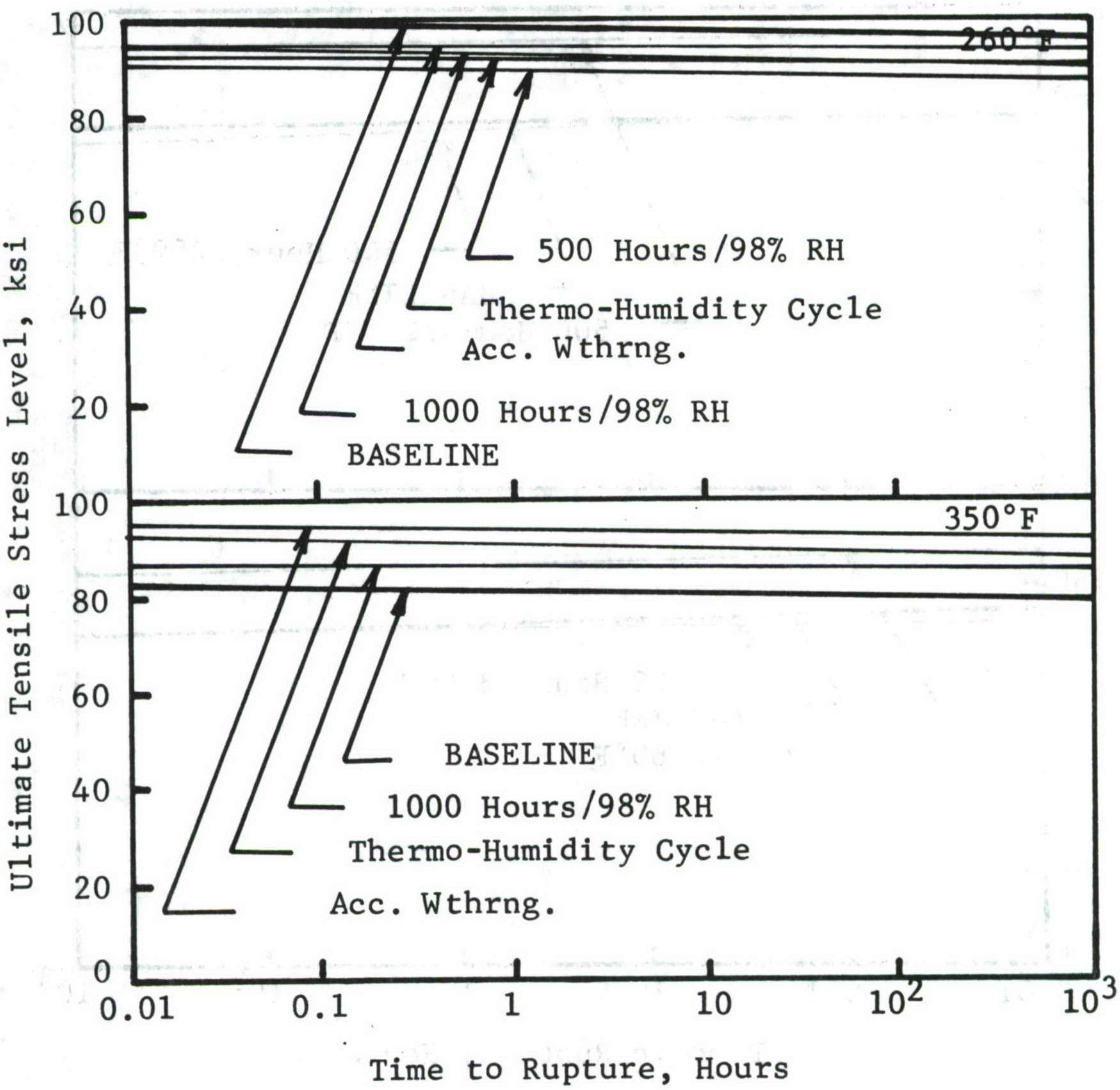


Fig. 34 EFFECT OF HUMIDITY CONDITIONING ON THE STRESS RUPTURE BEHAVIOR OF THORNEL 300 GRAPHITE/ NARMCO 5208 $[0/45/135/0/\overline{90}]_s$

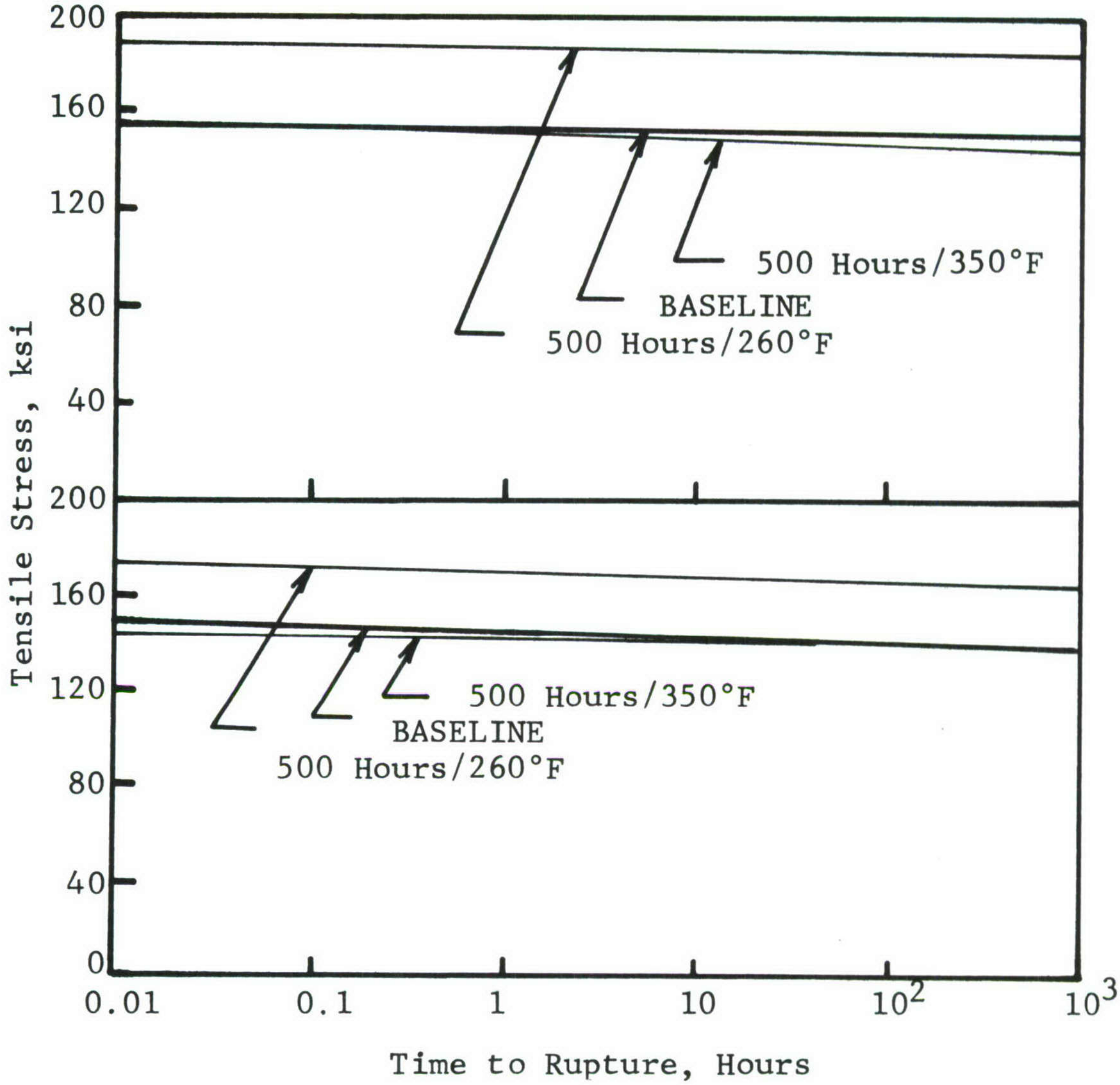


Fig. 35 EFFECTS OF STEADY-STATE THERMAL CONDITIONING ON THE STRESS RUPTURE BEHAVIOR OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES - 0°

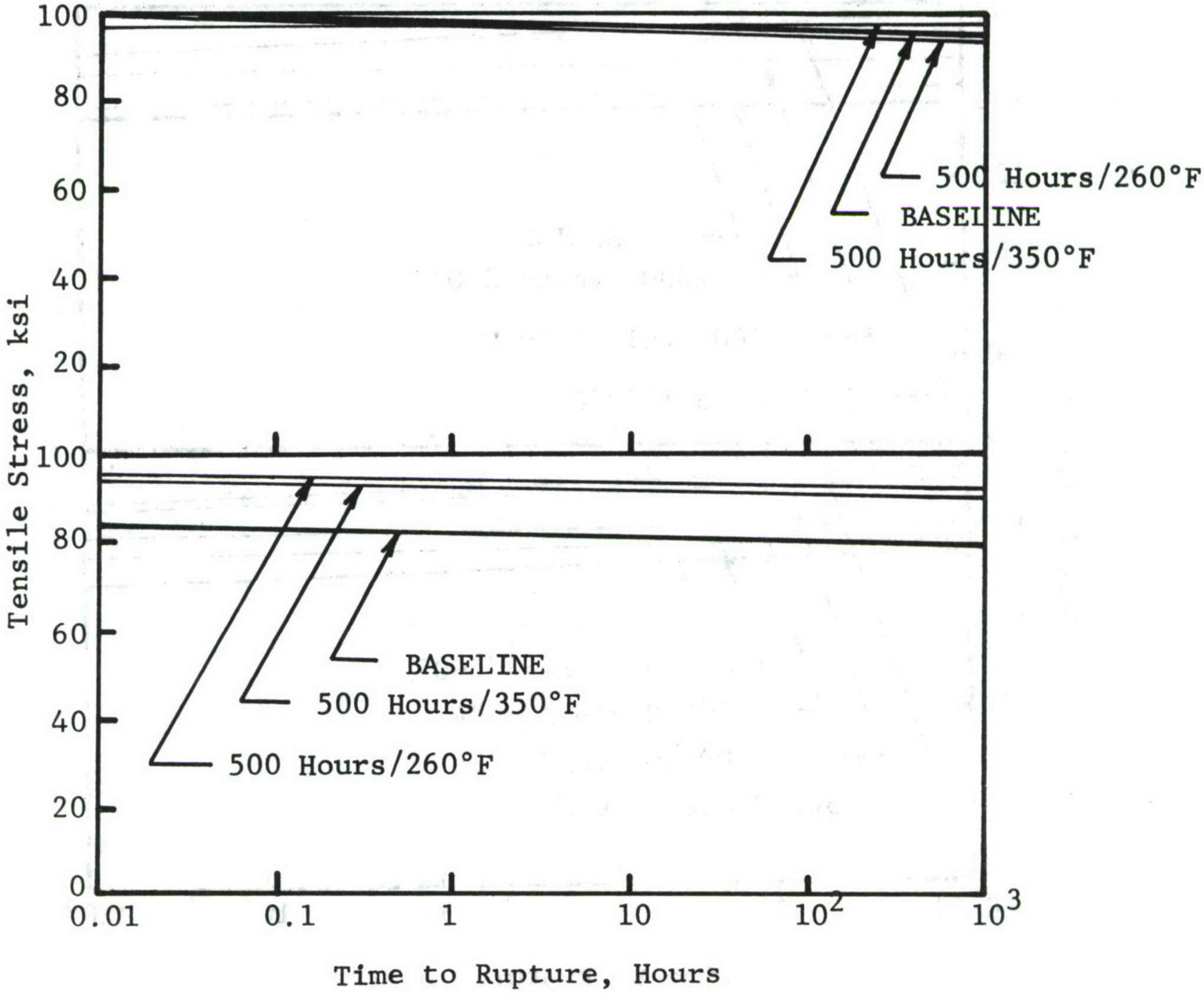


Fig. 36 EFFECTS OF STEADY-STATE THERMAL CONDITIONING ON THE STRESS RUPTURE BEHAVIOR OF THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$

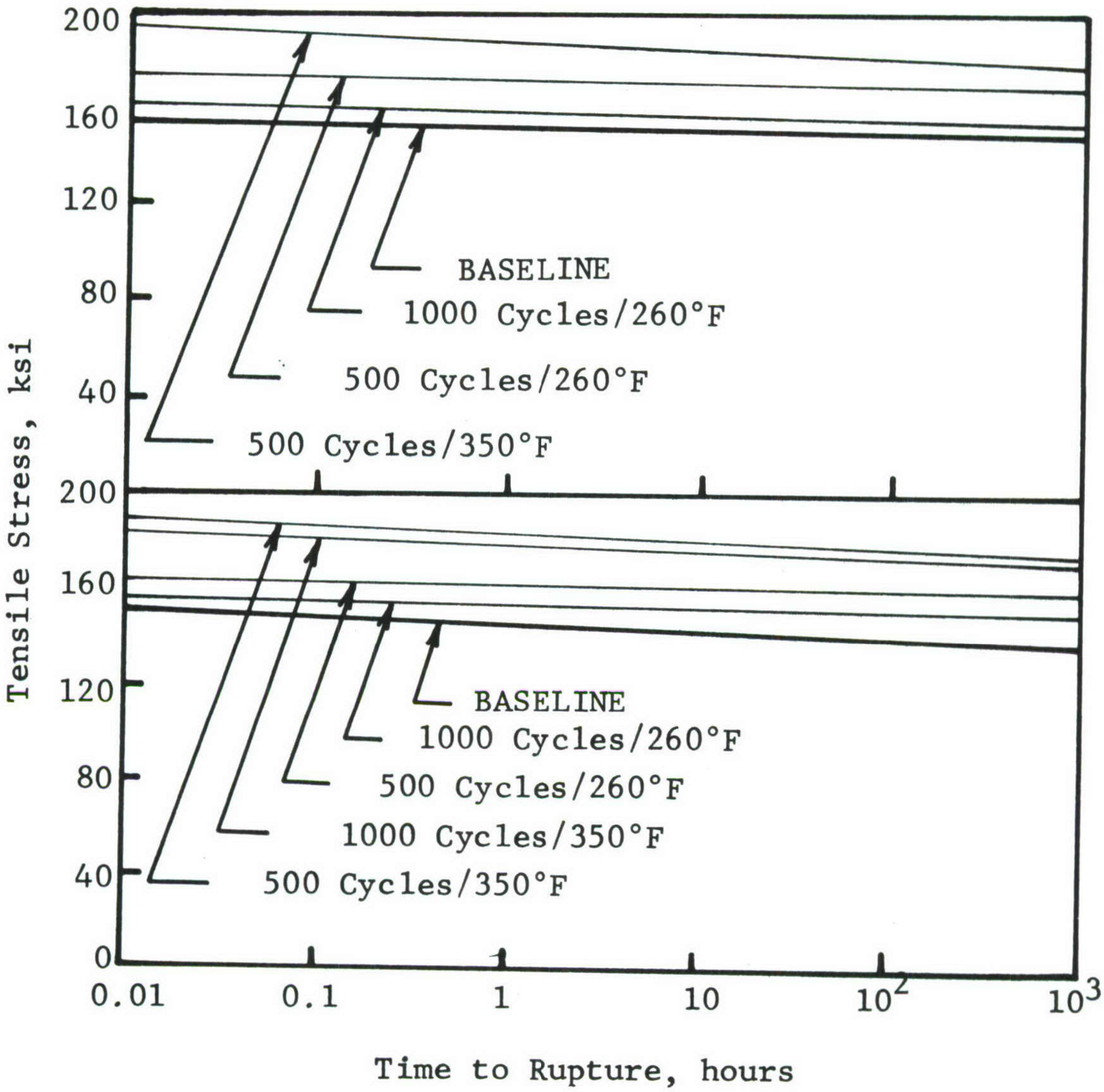


Fig. 37 EFFECT OF CYCLIC THERMAL CONDITIONING ON THE STRESS RUPTURE BEHAVIOR OF THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES - 0°

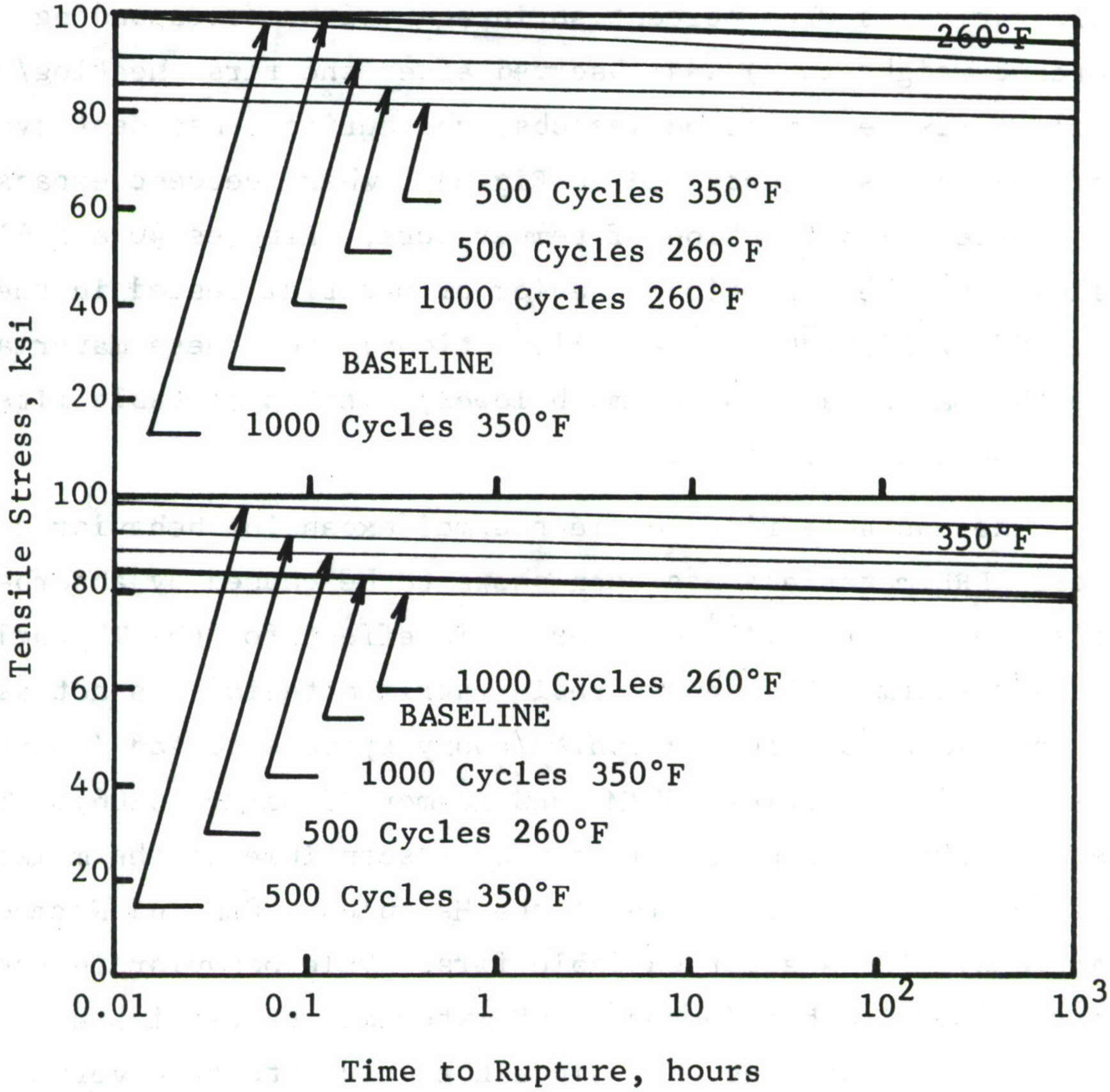


Fig. 38 EFFECT OF CYCLIC THERMAL CONDITIONING ON THE STRESS RUPTURE BEHAVIOR OF THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$

the change in sample length. This was done throughout the heating and cooling cycles using a precision LVDT system exhibiting 0.1 micron resolution.

For material tested in the transverse direction (90° fiber orientation) a 0.05 percent shrinkage (with corresponding 0.08 percent weight loss) was observed after the first heating/cooling cycle. Stable expansion was observed during subsequent cycles. This effect is illustrated in Fig. 39, where percent expansion is plotted as a function of temperature. Figures 40 and 41 illustrate the expansion behavior of material tested in the 0° and $[0/45/135/0/\overline{90}]_s$ fiber orientations. For these materials the thermal expansion was much lower, with no unstable first cycle behavior detected.

The unstable first cycle thermal expansion behavior in these GFRE materials has been shown to be caused by absorbed moisture evolution.(1) However, this effect for the Thornel 300 Graphite/Narmco 5208 epoxy resin matrix materials is not as pronounced as previous graphite/epoxy systems tested (Courtaulds HMS Graphite/Hercules 3002M, and Modmor II/Narmco 5206). The Narmco 5208 resin matrix is not as susceptible to the moisture absorption-evolution cycle as the Hercules 3002M and Narmco 5206 matrices. The smaller unstable first cycle behavior in the Thornel 300 Graphite/Narmco 5208 materials tested in the 90° orientation indicates this since the composite transverse behavior is controlled mainly by the matrix properties (see below). For the previously tested Courtaulds HMS Graphite/Hercules 3002M and Modmor II Graphite/Narmco 5206 materials, this unstable first cycle behavior was also detected in the 0° (longitudinal) direction. Since longitudinal GFRE material expansion behavior is primarily controlled by the properties of

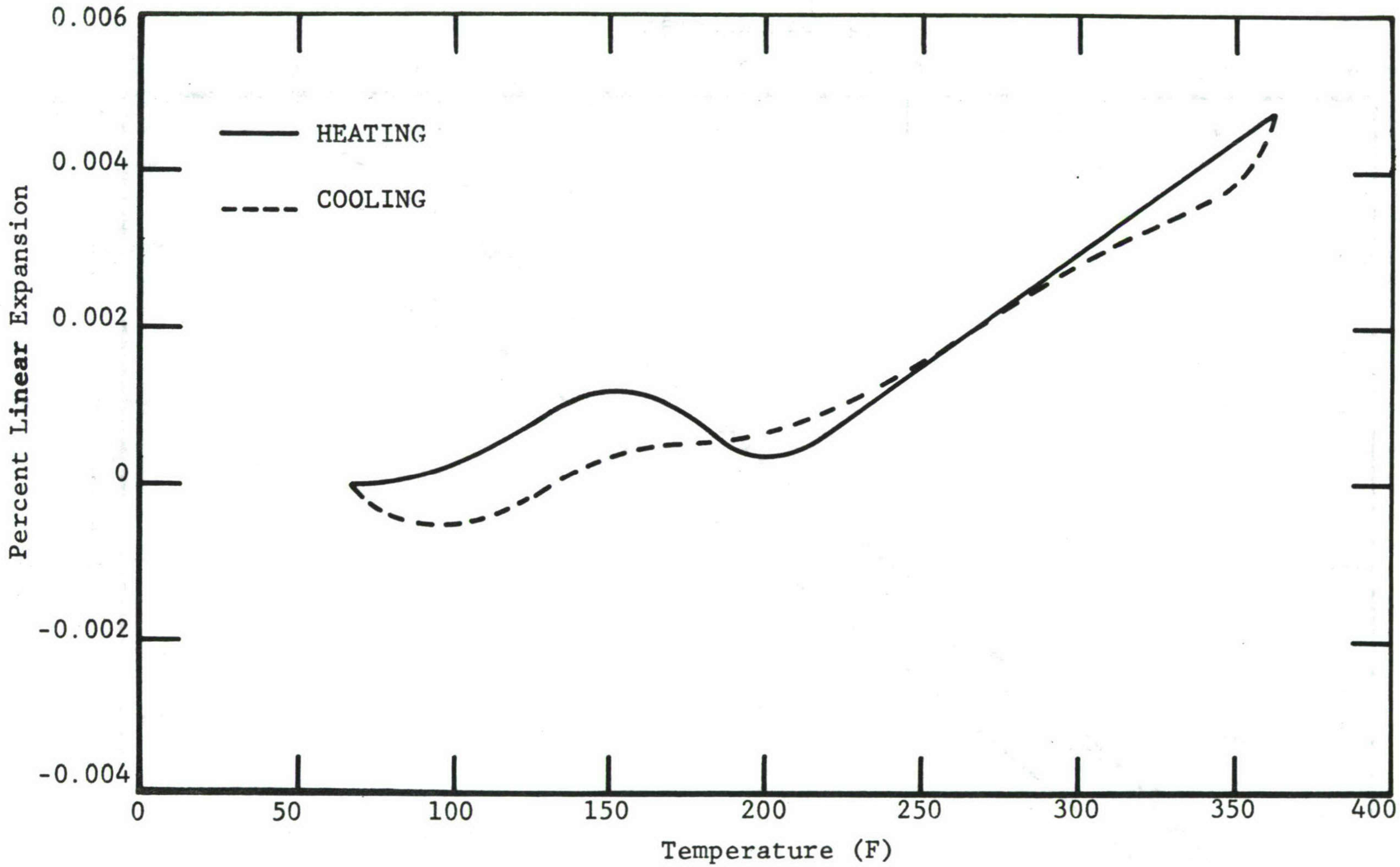


FIGURE 39 THERMAL EXPANSION BEHAVIOR OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES (0° FIBER ORIENTATION)

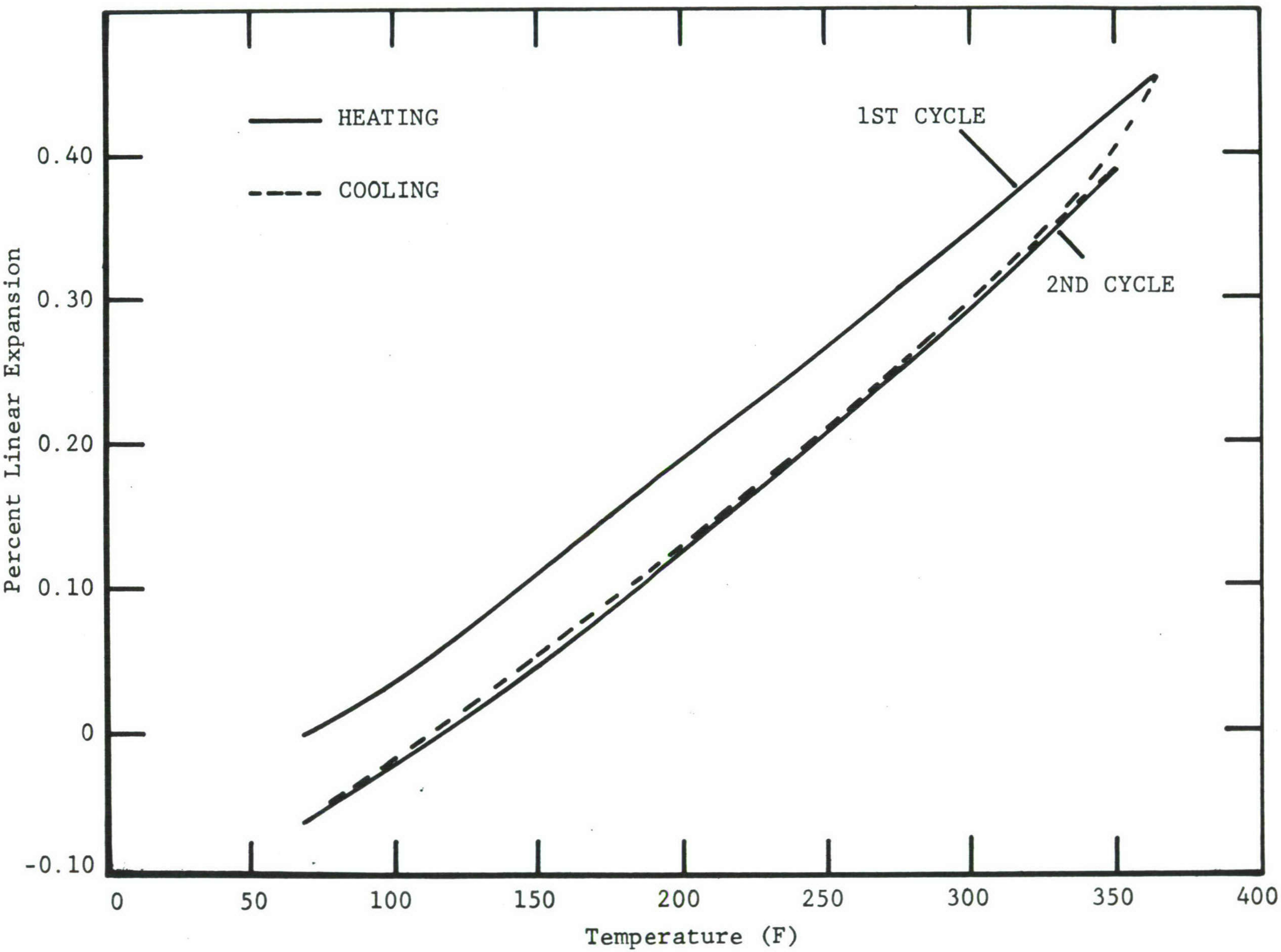


FIGURE 40 THERMAL EXPANSION BEHAVIOR OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES (90° FIBER ORIENTATION)

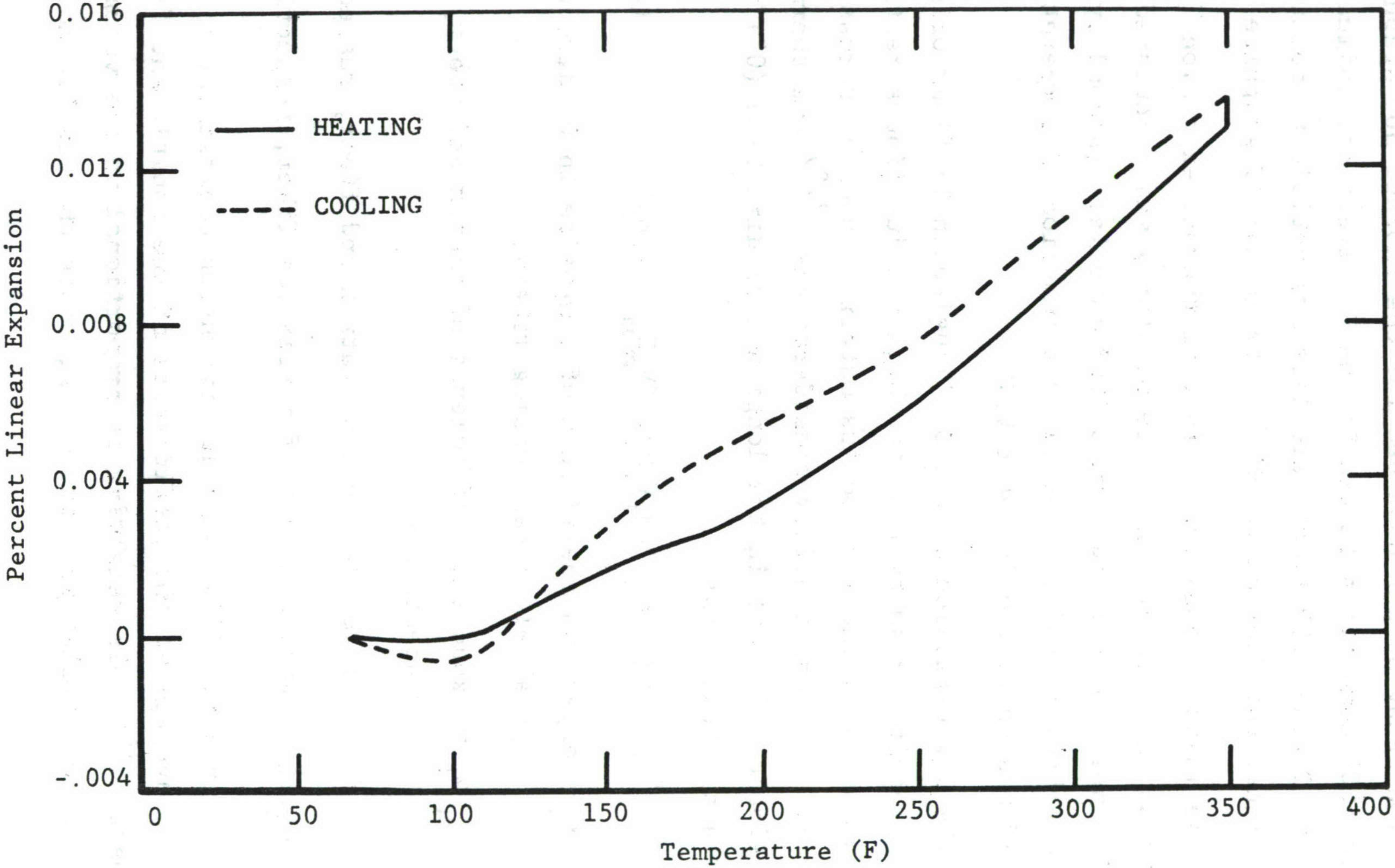


FIGURE 41 THERMAL EXPANSION BEHAVIOR OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES $[0/45/135/0/\overline{90}]_s$ ORIENTATION

the reinforcing fibers (see below), this tends to indicate that moisture is also present in the fiber bundles. No unstable expansion behavior was observed for the Thornel 300 Graphite/Narmco 5208 composites tested in the 0° direction, indicating that the Thornel 300 fibers are less susceptible to moisture than either the Courtaulds HMS or the Modmor II graphite fibers.

The instantaneous coefficient of thermal expansion (slope of expansion curve at a given temperature) was calculated for the Thornel 300 Graphite/Narmco 5208 materials (second cycle, stable behavior) and is plotted as a function of temperature in Fig. 42 and tabulated in Table VIII.

The low expansion of the 0° (longitudinal) fiber orientation composites results from the high modulus fibers restricting the expansion of the low modulus matrix. Based on stress equilibrium-strain compatability considerations [2,3] the thermal expansion coefficient in the longitudinal direction (0°) is given analytically as:

$$\alpha_L = (\alpha_m V_m E_m + \alpha_f V_f E_f)/(V_m E_m + V_f E_f) \qquad (1)$$

where α_L = expansion coefficient of composite in 0° direction (parallel to reinforcing fibers)

α_m, α_f = expansion coefficients of matrix and fiber, respectively

V_m, V_f = volume fractions of matrix and fiber, respectively

E_m, E_f = Young's moduli of matrix and fiber, respectively.

The uniaxial (0°) composite expansion coefficient is a weighted average of the coefficients of the constituent fibers and matrix.[4] This weighting is proportional to the volume fraction tensile modulus product. Thus, since the tensile modulus

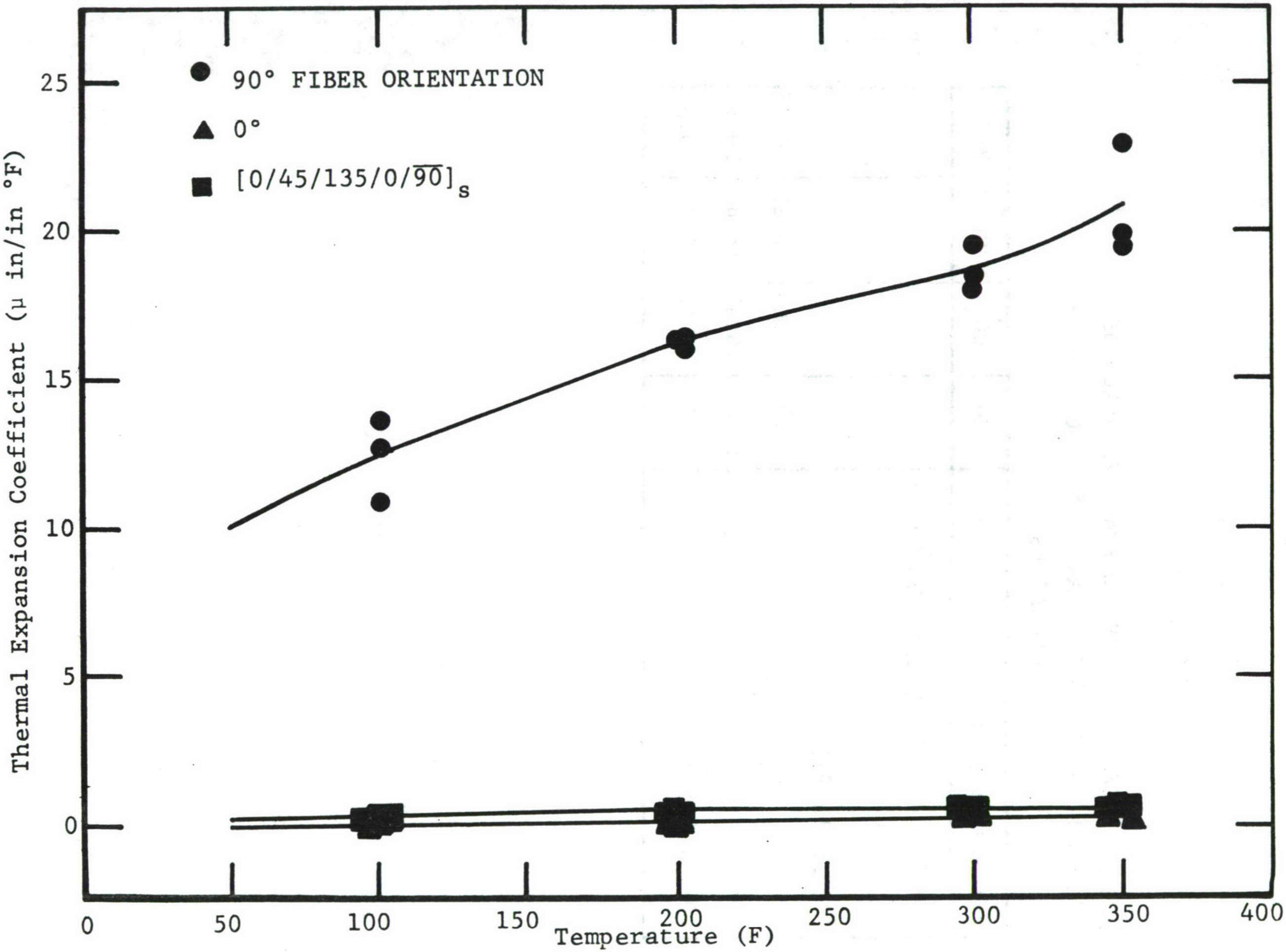


FIGURE 42 COEFFICIENT OF THERMAL EXPANSION FOR THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES

TABLE VIII

AVERAGE COEFFICIENT OF THERMAL EXPANSION OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE MATERIALS

Temperature, °F	100	200	300	350
Coefficient of Thermal Expansion (μ in/in °F)				
Fiber Orientation				
0°	0.01	0.03	0.22	0.25
90°	12.48	16.41	18.6	20.83
$[0/45/135/0/\overline{90}]_s$	0.21	0.42	0.52	0.54

of the graphite fibers is two to three orders of magnitude greater than the modulus of the epoxy matrix material, the fiber properties control the uniaxial (0°) behavior. It would then be expected that the measured expansion coefficients for the resin-matrix material studied be similar to the corresponding expansion coefficient of the graphite reinforcing fiber. This expectation was realized experimentally as evidenced by the data in Table VIII and Fig. 42. Typical graphite fiber systems used in GFRE materials exhibit uniaxial expansion coefficients close to zero, or even negative.[5,6] The composite 0° expansion coefficient for the Thornel 300 Graphite/Narmco 5208 materials is, however, slightly higher than observed for similar GFRE systems tested at IITRI.[1] This indicates that along with the slightly lower tensile modulus for the Thornel 300 graphite fibers (as compared to the Courtaulds HMS and Modmor II Graphite fibers that were used in the previously tested GFRE systems), the Thornel 300 Graphite fibers possess slightly higher uniaxial thermal expansion. Figure 42 illustrates that the strong reinforcing effect of the graphite fibers extends over the entire useful temperature range for this material.

The large expansion coefficients for the 90° (transverse) fiber orientation are mainly the result of matrix expansion without restraint effects produced by the fiber reinforcement. In the transverse direction the composite expansion coefficient, α_T, is given analytically by Kreider and Patarini[7] as:

$$\alpha_T = (1+\nu_m)\alpha_m v_m + (1+\nu_f)\alpha_f v_f - \alpha_L \nu_c$$

where α = coefficient of thermal expansion

v = volume fraction

ν = Poisson's ratio

and subscripts m, f, T and L refer to matrix, fiber, composite transverse and composite longitudinal, respectively. It can be seen that in the transverse direction the individual constituent fiber and matrix properties control the composite expansion behavior more proportionately than in the longitudinal direction. Inserting typical materials properties into Equation 2 indicates the predicted dominance of the matrix expansion coefficient on the composite transverse expansion behavior. This expectation was confirmed in the experimentally generated data shown in Table VIII. Data for the transverse (90°) orientation composite exhibit the general magnitude and temperature dependence of typical epoxy materials. Transverse composite expansion behavior is a bit more difficult to predict, however, than the uniaxial expansion behavior in reinforced epoxy composites owing to a) the relatively high sensitivity on the exact fiber-matrix configuration, and b) the present-day uncertainty in transverse fiber expansion data, α_f. Comparing the Thornel 300 Graphite/ Narmco 5208 data with other fiber reinforced epoxies studied at IITRI,[1] it is seen that the data for Thornel 300 Graphite/ Narmco 5208 is closer to the Boron/Avco 5505 than to either Courtaulds HMS Graphite/Hercules 3002M or Modmor II Graphite/ Narmco 5206.

In the $[0/45/135/0/\overline{90}]_s$ fiber orientation the composite expansion coefficient is low, similar to the 0° composite. In this material the 45° lamina as well as the 0° lamina offer significant reinforcement to the composite structure. This observation is based on the work of Fahmy and Ragai,[4] where thermal expansion behavior was studied for similar angle-ply composites as a function of ply angle. As shown in Fig. 42 this reinforcement effect extends over the entire temperature range tested. These experimental results indicate that it is feasible to tailor the laminate orientations in a manner that will provide a structure with exceptional two dimensional thermal stability (i.e. low expansion) over a wide temperature range.

THERMAL CONDUCTIVITY TEST RESULTS

Thermal conductivity measurements were made on Thornel 300 Graphite/ Narmco 5208 epoxy resin matrix materials in the 0°, 90° and $[0/45/135/0/\overline{90}]_s$ fiber orientations. Test samples consisted of several 1/2 x 2-inch laminates sandwiched together to form a 1/2 x 1/2 x 2-inch specimen. Testing was conducted in air from ambient room temperature to 350°F using a guarded steady state longitudinal heat flow technique. Heat was constrained to flow axially along a stack consisting of the sample placed between two standard reference materials of known thermal conductivity. Sample thermal conductivity was determined in terms of sample heat flow, geometry, and resulting temperature gradient. Sample heat flow was measured by both absolute and comparative methods, with appropriate radial heat loss/gain corrections applied. Details of the measurement technique were described previously.(1)

Thermal conductivity results for Thornel 300 Graphite/ Narmco 5208 composites are presented in Fig. 43. The thermal conductivity in the 0° direction (parallel to fibers) is higher than in the transverse (90°) direction (owing to less tortuous heat conduction path), with the mixed ply $[0/45/135/0/\overline{90}]_s$ orientation data falling in-between. Typical thermal conductivity data scatter for these composite materials ranged from $\pm$ 5 to $\pm$ 10% maximum deviation from the representation shown in Fig. 43.

The increasing thermal conductivity with increasing temperature is similar to that observed for other GFRE systems studied a at IITRI.(1) The magnitude of the thermal conductivity for the Thornel 300 Graphite/Narmco 5208 materials, however, is seen to be more like the previously studied(1) Boron/Avco 5505 system than the two graphite reinforced systems (Courtaulds HMS graphite/Hercules 3002M and Modmor II graphite/Narmco 5206). This

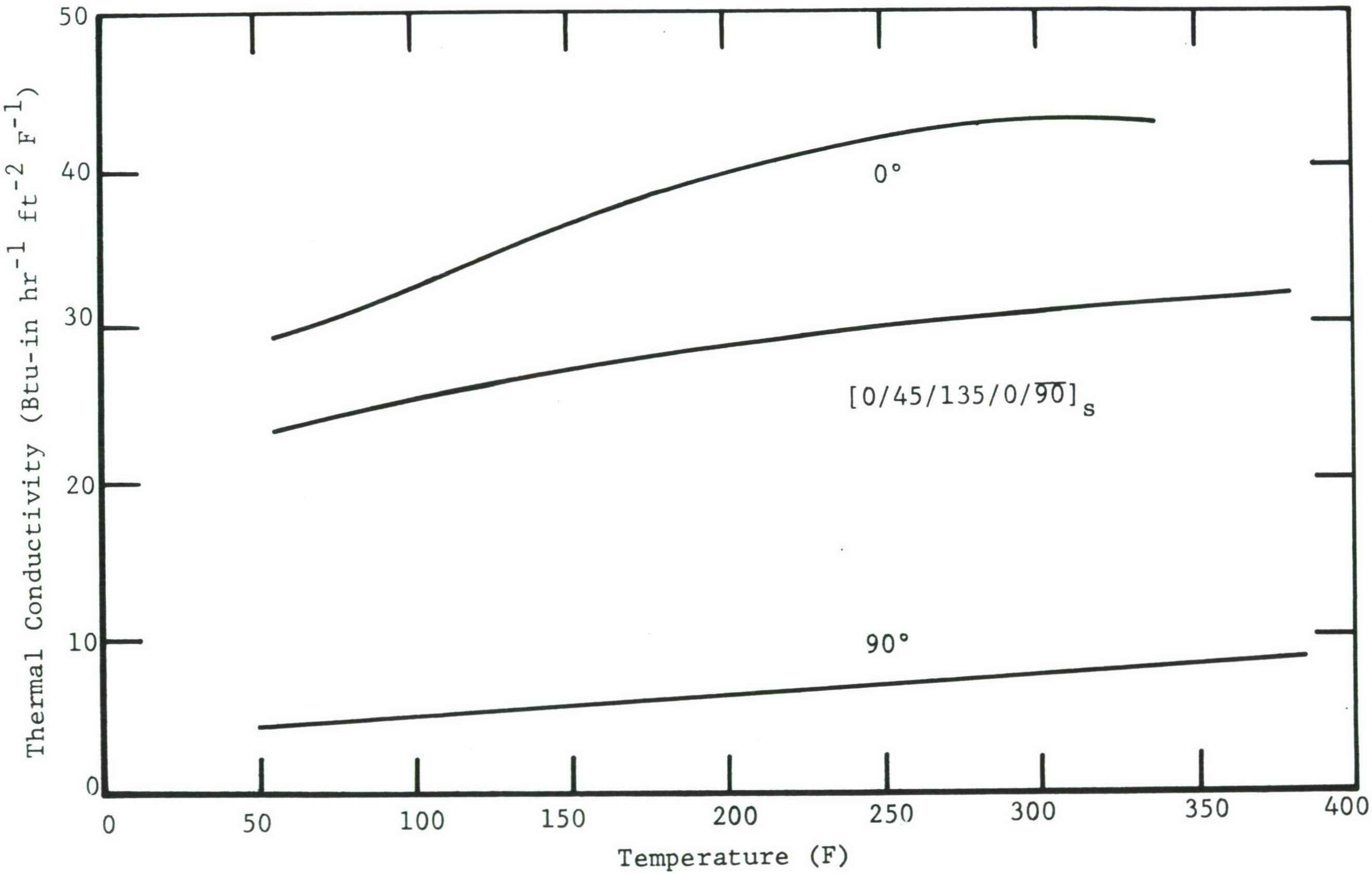


FIGURE 43 THERMAL CONDUCTIVITY OF THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES

observation for thermal conductivity agrees with the observation for the Thornel 300 Graphite/Narmco 5208 transverse thermal expansion data discussed above. The thermal conductivity of the Thornel 300 Graphite/Narmco 5208 materials is lower than the previously studied GFRE systems primarily because the axial fiber thermal conductivity is lower.[8,9] The Thornel 300 Graphite fibers have a higher degree of phonon scattering (thermal conductivity of graphitic materials is determined primarily by the scattering of quantized lattice vibrations). The lower thermal conductivity obtained in this manner, however, also leads to a lower fiber tensile modulus (modulus related to system order, crystallite orientation). For instance the tensile modulus of the low conductivity Thornel 300 Graphite fiber is 34×10^6, whereas the tensile modulus of the high conductivity Courtaulds HMS Graphite fiber is over 50×10^6.

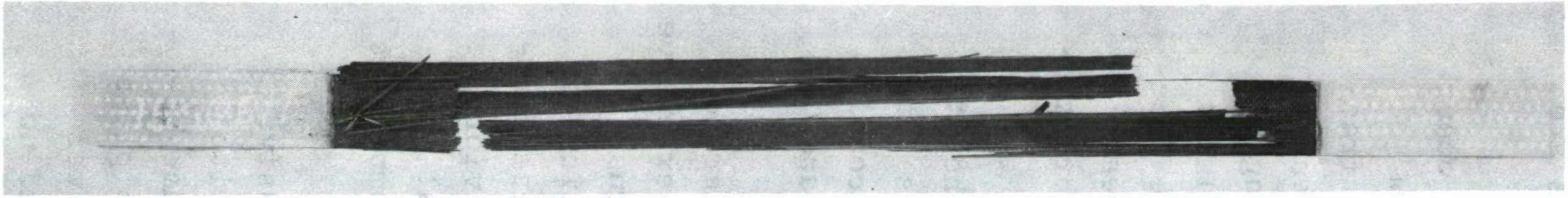
Using the analytical thermal conductivity prediction techniques for unidirectional 0° and 90° composites described by Springer and Tsai[10] and Rosen[11], the predicted longitudinal and transverse thermal conductivity were roughly 25% higher than measured (for ambient room temperature), using Kalnin's[9] data for the thermal conductivity of the Thornel 300 fibers. If, however, the present measured data for the Thornel 300 Graphite/Narmco 5208 composites are used to calculate the thermal conductivity of the Thornel 300 Graphite fibers, a value 25% less than Kalnin's value is obtained. It is significant that IITRI's calculated fiber thermal conductivity is less than that of Kalnin, since the objective of Kalnin's work, in part, was to produce low thermal conductivity carbon/graphite fibers, without significantly decreasing the modulus.

For complex plied GFRE material, IITRI[12] has proposed a technique for predicting thermal conductivity. Utilizing the IITRI measured 0° and 90° data for the Thornel 300 Graphite/Narmco 5208 materials described herein, this technique predicts a room temperature thermal conductivity within 10% of the measured value for the $[0/45/135/0/\overline{90}]_s$ complex ply material shown in Fig. 43. This good agreement of measured and predicted thermal conductivity of complex plies materials indicates that it is now feasible for materials development organizations to not only design in two dimensional thermal stability through control of thermal expansion in fiber reinforced systems, but to also control conduction heat transfer in these materials as well.

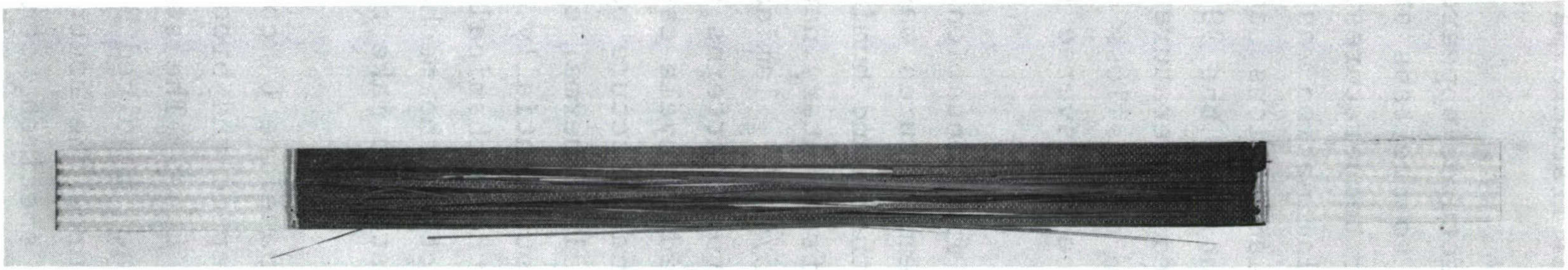
2.8 Fracture Characteristics

The failure patterns for Thornel 300 Graphite/Narmco 5208 composites depended on the mode and type of loading and on the prior conditioning. The 0° static tension showed long slivery fractures at room temperature with considerable fiber pullout. Most slivers were from 1/16 inch to 1/8 inch wide and the entire length of the gage section of the specimen. At 260°F the same slivery effect was noted but the slivers were considerably thinner and numerous cases of fiber pullout were seen. At 350°F the fractures were almost shreaded in appearance with numerous slivers and fibers pulling away from the fractured pieces. These fracture patterns are typical of what might be expected if the resin were breaking down locally under elevated temperature. This is coupled with the high temperature loss of shear carrying capability which leads to the propagation of longitudinal cracks upon a sudden release of stored energy such as occurs at fracture. (See Fig. 44)

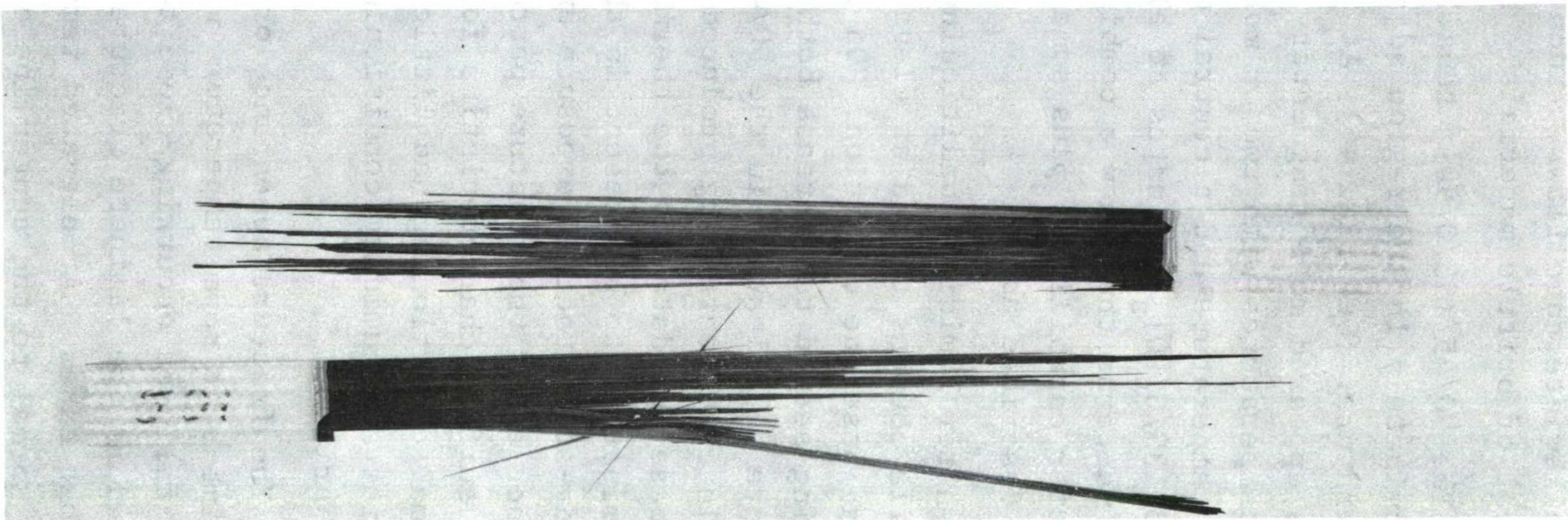
The 90° tension fractures were all straight and the fracture planes were normal to the centerline of the specimen at all temperatures. At 260°F most specimens appeared to have more than one fracture plane simultaneously. Little if any



0° Tensile Coupon Tested at RT



0° Tensile Coupon Tested at 260°F



0° Tensile Coupon Tested at 350°F

Fig. 44 TYPICAL STATIC TENSION FRACTURE PATTERNS FOR UNCONDITIONED SPECIMENS ability is observed for the 90° composites to yield slightly and alleviate edge flaws. Such normal fracture patterns are typical of brittle materials.

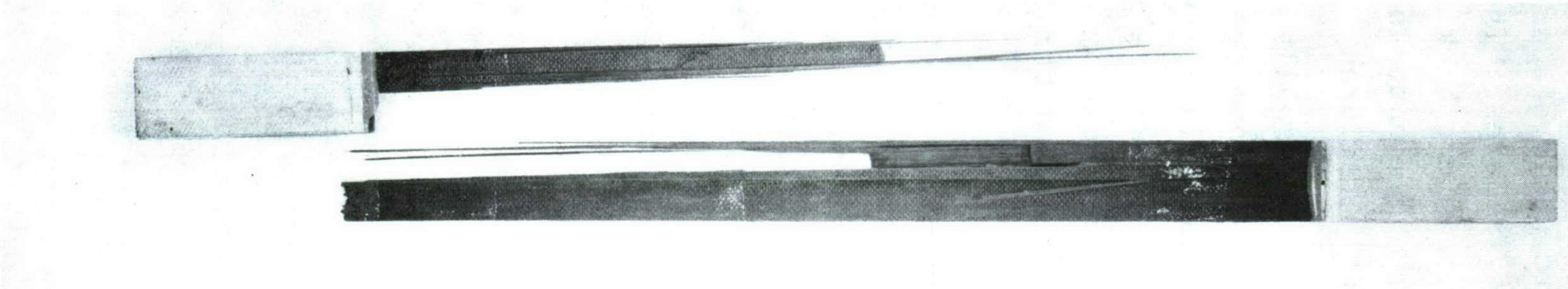
The $[0/45/135/0/\overline{90}]_s$ tensile fractures appeared to occur predominately in the region adjacent to the tabs at room temperature. (See Fig. 44) At higher temperatures, the fractures appeared more fragmentary. Delamination was evident at all temperatures with two or more delaminations occurring at room temperature and a central one (next to the 90° ply) for $[0/45/135/0/\overline{90}]_s$ laminates at elevated temperature. The fracture patterns thus show a combination of the loss of shear transfer capabilities plus some of the transverse (90) brittleness described above.

After humidity conditioning the fragmentation of the 0° tensile coupons tested at elevated temperatures was less than in the baseline condition. On the other hand humidity conditioning seemed to increase both the fragmentary nature and promote delamination in the $[0/45/135/0/\overline{90}]_s$ laminates. Accelerated weathering produced fracture patterns similar to the baseline data and the thermo-humidity cycle caused extensive delamination to be present in the final fracture patterns. Steady-state thermal exposure and cyclic thermal conditioning did not alter the fracture patterns substantially. These fracture surface characteristics follow the mechanical behavior, thermal conditioning had little effect on the mechanical properties and humidity conditioning tested to make the composites less brittle.

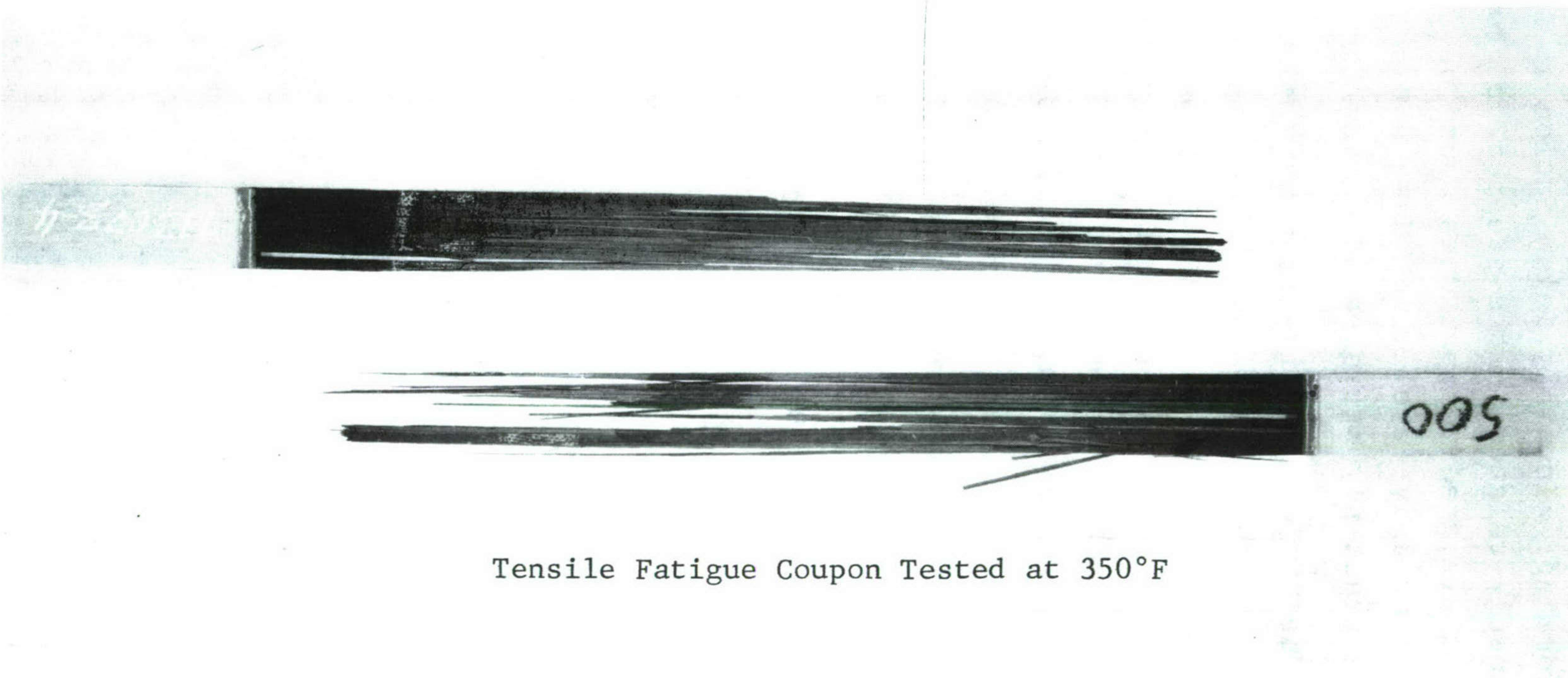
The fracture appearance of the baseline 0° compressive specimens at room temperature was stepped and broomed with most failures occurring close to the tabs. The step that occurred in the laminate fracture surface involved 3 to 6 plies in most cases. At elevated temperatures the fractures were more normal to the centerline of the specimen, contained no steps and there was a noticeable lack of fiber pullout caused by brooming. Interply delamination at failure would appear to be closely related to the stepped or brooming failures. The lack at elevated temperatures could be due to a micro buckling on the intraply level which does not permit the laminate to attain trans-ply stresses necessary for interply failures.

The 90° compressive fractures were planar and usually oblique to the centerline of the specimen although some specimens had fractures more nearly normal to the centerline of the specimen. The $[0/45/135/0/\overline{90}]_s$ compressive fractures were mixed with substantial brooming and delamination present at room temperature and predominantly delamination at the elevated temperatures.

Typical fatigue and creep fracture patterns are shown in Fig. 45. The fatigue fractures show behavior similar to high temperature fracture patterns. The creep fracture patterns present long individual exposed fibers and tows giving the appearance of fiber pullout over a considerable length. The creep fracture patterns with exposed individual fibers show circumfibril fracture slow growth over a prolonged time period.



Tensile Creep Coupon Tested at 260°F



Tensile Fatigue Coupon Tested at 350°F

Fig. 45 TYPICAL FATIGUE AND CREEP FRACTURE PATTERNS

SECTION III

3.0 CONCLUSIONS

Thornel 300 Graphite/Narmco 5208 has been subjected to a wide variety of mechanical, thermal and physical tests under an extensive range of conditioning treatments. The test matrix employed is identical to the matrix utilized on a prior AFML program* and thus provides a unique opportunity to compare several graphite/epoxy composite materials with each other over a wide range of test and conditioning parameters.

Most engineers, aerospace component designers and test engineers who will utilize the information contained in this report in preliminary or advanced designs will be particularly interested in the response of the materials to particular environments. This summary section has therefore been organized so as to address these particular needs. The following conclusions are therefore organized by environmental conditioning treatments.

Steady-State Humidity Exposure, Thermo-Humidity and Accelerated Weathering Exposures

Thornel 300 Graphite/Narmco 5208 showed considerably less scatter in the strength data after moisture conditioning than either Modmor II/Narmco 5206 or Courtaulds HMS Graphite/Hercules 3002 epoxy composites. In addition the data for T300 Graphite/Narmco 5208 shows relatively little influence of moisture on 0° on $[0/45/135/0/\overline{90}]_s$ laminates strengths, although some effect on the mechanical properties affected most by the resin (such as transverse (90°) or in-plane shear strengths) is seen for Thornel 300 Graphite/Narmco 5208. But the 25% losses in the transverse strengths of T300 should be compared to 50% for Modmor II/Narmco 5206 and up to 75% at some temperatures for Courtaulds HMS Graphite/Hercules 3002M epoxies.

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* AFML-TR-72-205 (See Ref. 1)

A similar comparison can be made for the longitudinal and transverse moduli of T300 graphite/Narmco 5208 versus those of Modmor II Graphite/Narmco 5206 and Courtaulds HMS Graphite/Hercules 3002M composites. Consistency of data over temperature and after moisture conditioning is more evident for the T300 graphite/Narmco 5208 epoxy composites than the two graphites composites studied earlier.

The fatigue life of Thornel 300 Graphite/Narmco 5208 decreased about 10 to 15% after humidity conditioning while the stress-rupture resistance increased by about the same amount. It is interesting to note that these same effects were also noted for both graphites studied earlier, i.e. increases in the stress-rupture resistances and a decrease in the fatigue resistance of the graphite/epoxy systems exposed to humidity conditioning.

Steady State Thermal Exposure

The steady-state thermal exposure caused practically no change in the strengths or moduli of Thornel 300 Graphite/Narmco 5208. This is in marked contrast to the previous two systems which showed a mixed enhancement or degradation due to steady-state thermal exposure.

The fatigue strengths of T300 Graphite/Narmco 5208 showed mixed behavior after steady-state thermal conditioning but generally decreases of from 5 to 10%. The stress rupture resistances of T300 Graphite/Narmco 5208 were uniformly increased after steady state thermal conditioning by from 10 to 15%. These same general trends were evident for the Courtaulds HMS graphite system studied previously but the fatigue resistance of Modmor II graphite/Narmco 5206 increased slightly and in general the stress-rupture behavior decreased slightly after steady state thermal exposure.

Cyclic Thermal Exposure

Cyclic thermal exposure affected the compressive strengths of the Thornel 300 Graphite/Narmco 5208 $[0/45/135/0/\overline{90}]_s$ laminates substantially (50% losses). The moduli of Thornel 300 Graphite/Narmco 5208 were not affected by cyclic thermal conditioning except in the case of $[0/45/135/0/\overline{90}]_s$ laminates where the moduli increased at elevated temperatures in compression, by approximately 15%. Both the fatigue and stress-rupture resistances increased by approximately 10% after cyclic thermal conditioning.

In the previous two graphite/epoxy systems studied, the fatigue and stress-rupture resistances had generally been adversely affected by cyclic thermal conditioning.

Overall, the Thornel 300 Graphite/Narmco 5208 system performed consistently over ranges of temperature and after a variety of conditioning treatments. A rapid reading of the feasibility of utilizing Thornel 300 Graphite/Narmco 5208 for a given application might be gained through a study of the above properties.

APPENDIX I

QUALITY ASSURANCE TEST REPORTS

AND

SELECTED ULTRASONIC C-SCANS OF

THORNEL 300 GRAPHITE/NARMCO 5208 LAMINATES

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Appendix I

TABLE IX QUALITY ASSURANCE TEST REPORT FOR BATCH NUMBER 53 OF THORNEL 300 GRAPHITE/NARMCO 5208 THREE INCH WIDE PREPREG TAPE

Whittaker CORPORATION

CERTIFIED TEST REPORTS

NARMCO MATERIALS DIVISION
600 Victoria Street • Costa Mesa, California 92627

SOLD TO

IIT Research Institute
Purchasing Dept.
10 West 35th Street
Chicago, Illinois 60616

COSTA MESA
LIBERTY 8-1144
TWX
213-273-4192

NO. 66- 28207	INVOICE NUMBER
DATE 7/31/73	PAGE 1 OF 1
CUST ORDER NO. 10458 Anderson	DATE 6/25/73

TESTING RESULTS

MATERIAL Rigidite 5208 Thornel 300

Batch # 53

Roll	Amount	Resin(Solids) Content	Mfg. Date	Test Date
1	4.71 lbs.	40%	7/13/73	7/24/73
2	4.76	40		
3	4.12	41		
4	1.01	41		
5	4.71	40		
6	4.71	40		
7	4.71	43		
8	5.04	43		
9	4.75	40		
10	4.71	40		
16	4.71	*37		
17	4.75	*37		
18	4.71	*37		
19	5.14	39		
Volatiles:		0.3%	RT	350 °F.
Longitudinal (0°) Flexure,			304,400 psi	241,990 psi
Long. Flex Mod.			21.91×10^6	24.78×10^6 psi
Horizontal Shear			15,530 psi	8190 psi

Nominal Cured Ply Thickness: .0053"

*NOTE: Customer accepts as is per telecon Bob Meadows/Ken Hoffer. 7/31/73

Warranty expires: 10/31/73

This is to certify that the above material was manufactured, tested and found to conform to Specification FMS 2023, Ty III, Form A w/exceptions and terms of the purchase agreement as indicated by the above test results.

Quality Control Representative

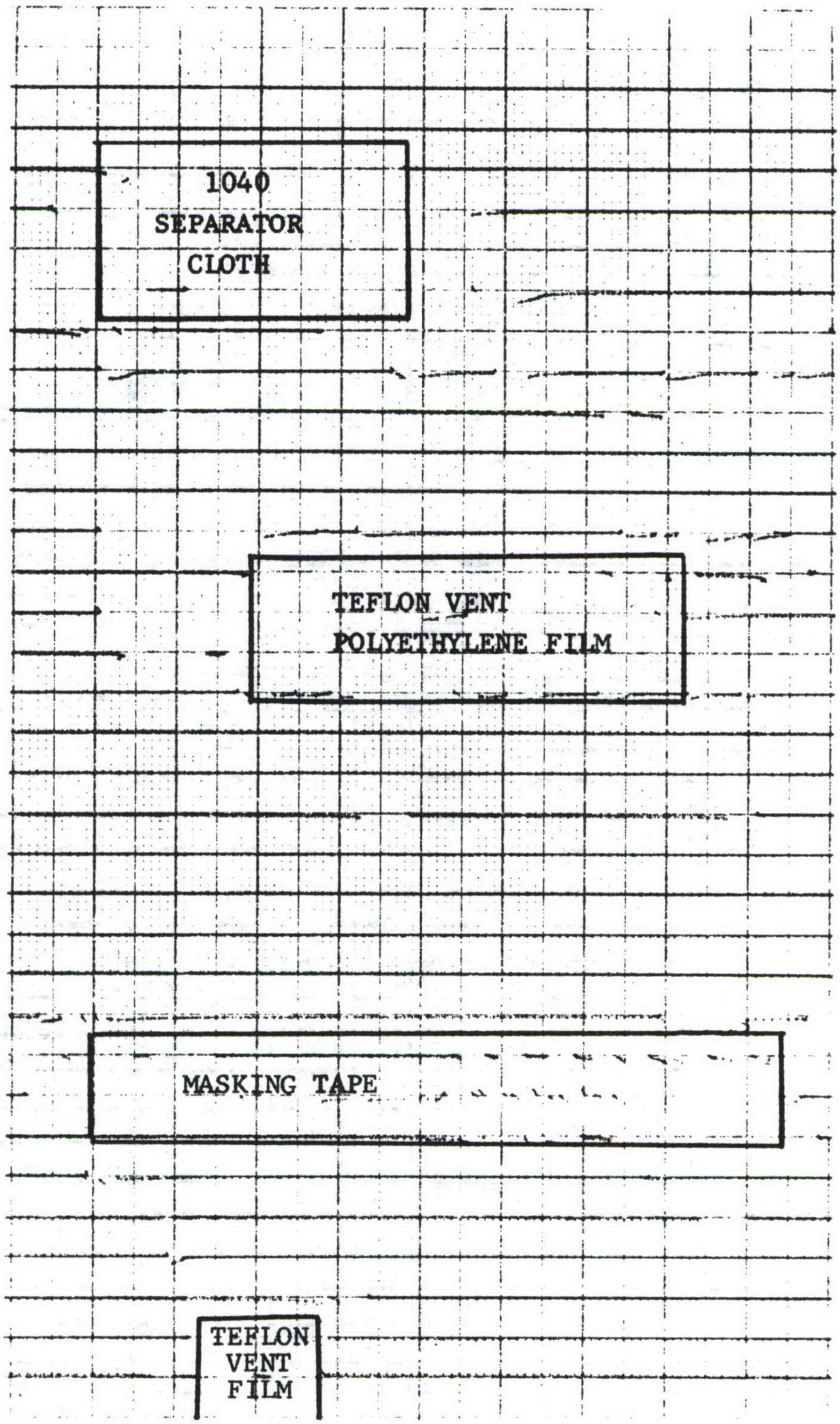

Fig. 46 ULTRASONIC C-SCAN OF TEST PANEL

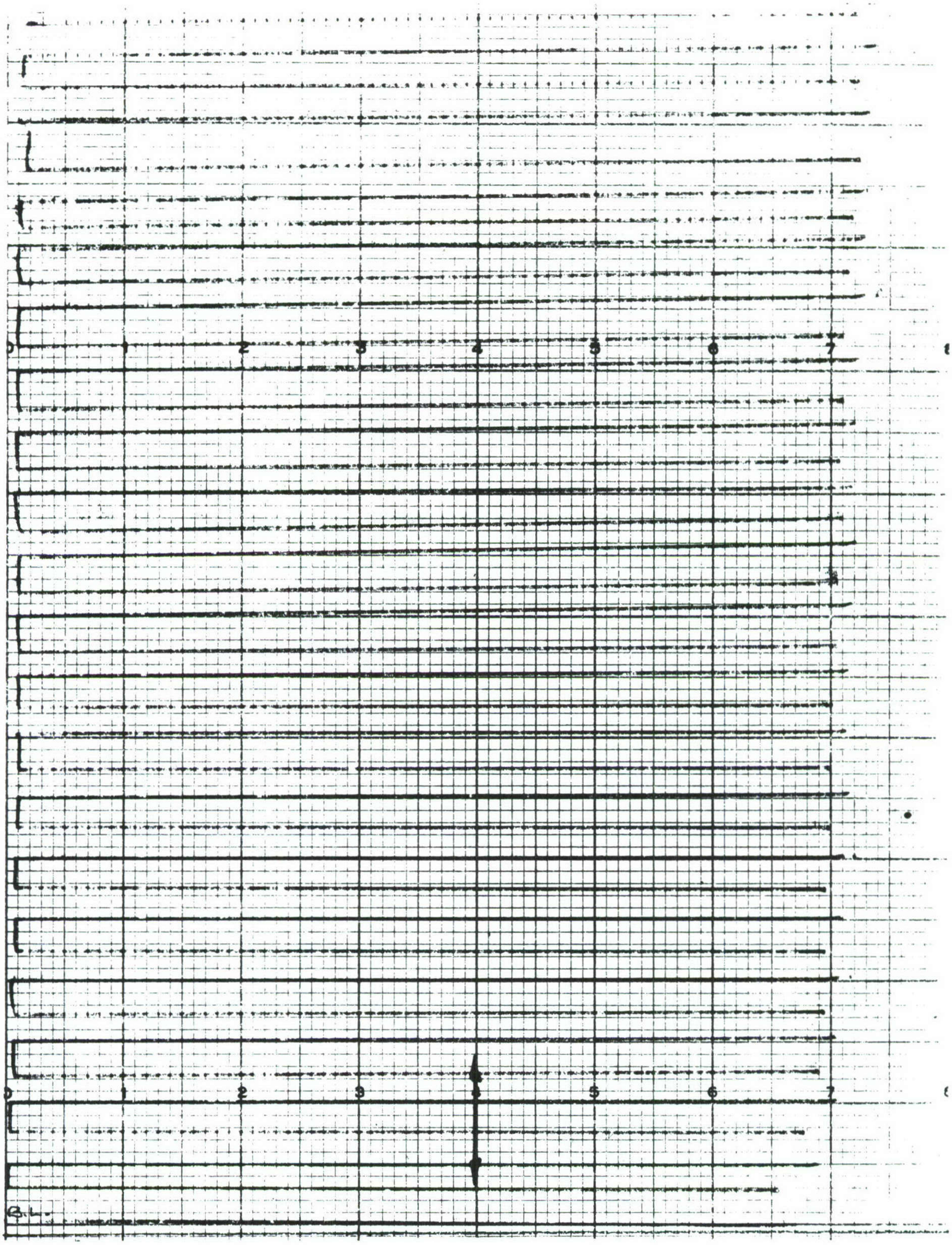

Fig. 47 ULTRASONIC C-SCAN OF ACCEPTABLE PANEL 1304A (EIGHT PLY 90° LAMINATE). THE 0° DIRECTION IS SHOWN BY THE ARROW.

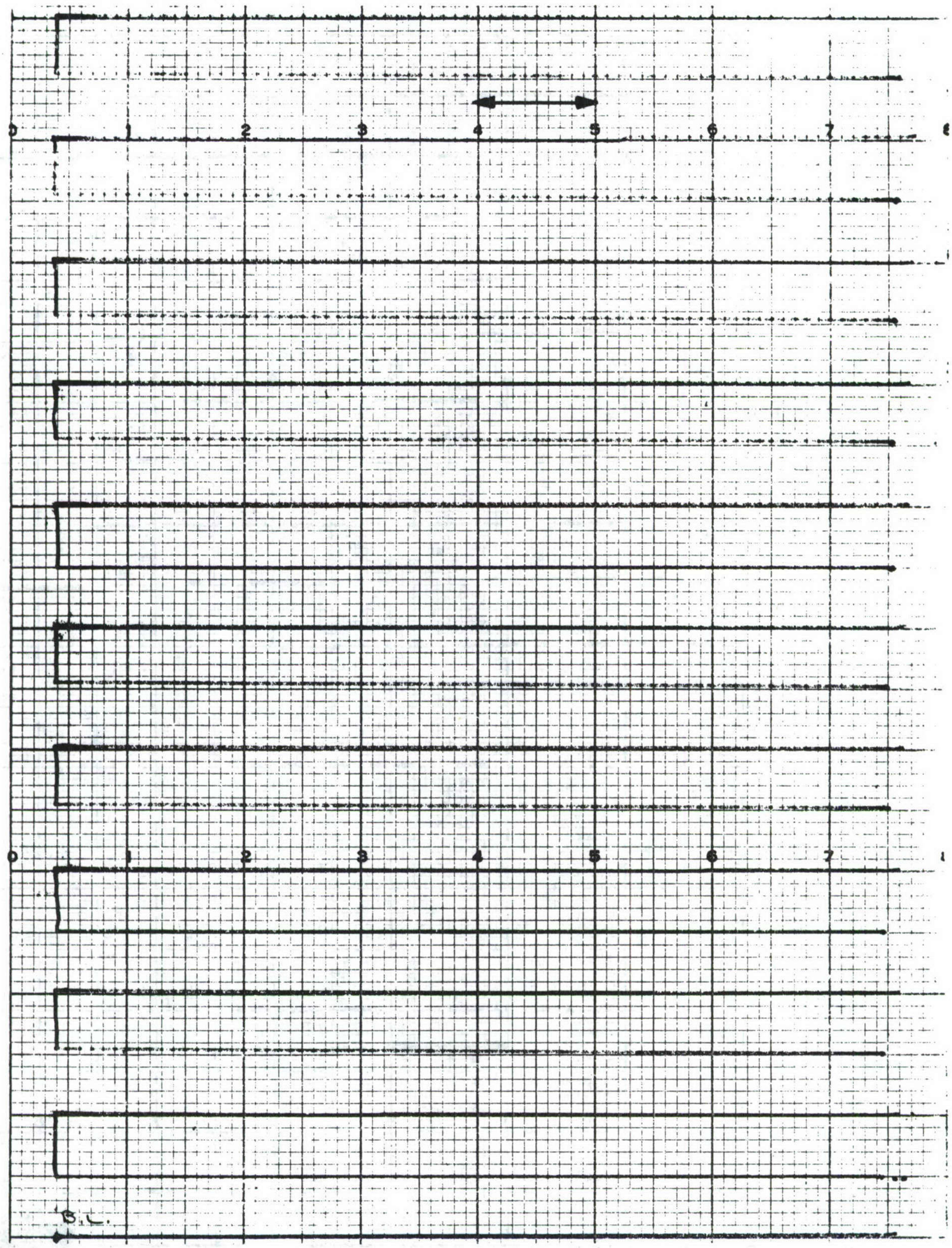

Fig. 48 ULTRASONIC C-SCAN OF ACCEPTABLE PANEL 1329A (NINE PLY $[0/45/-45/0/\overline{90}]_s$ LAMINATE), THE 0° DIRECTION IS SHOWN BY THE ARROW.

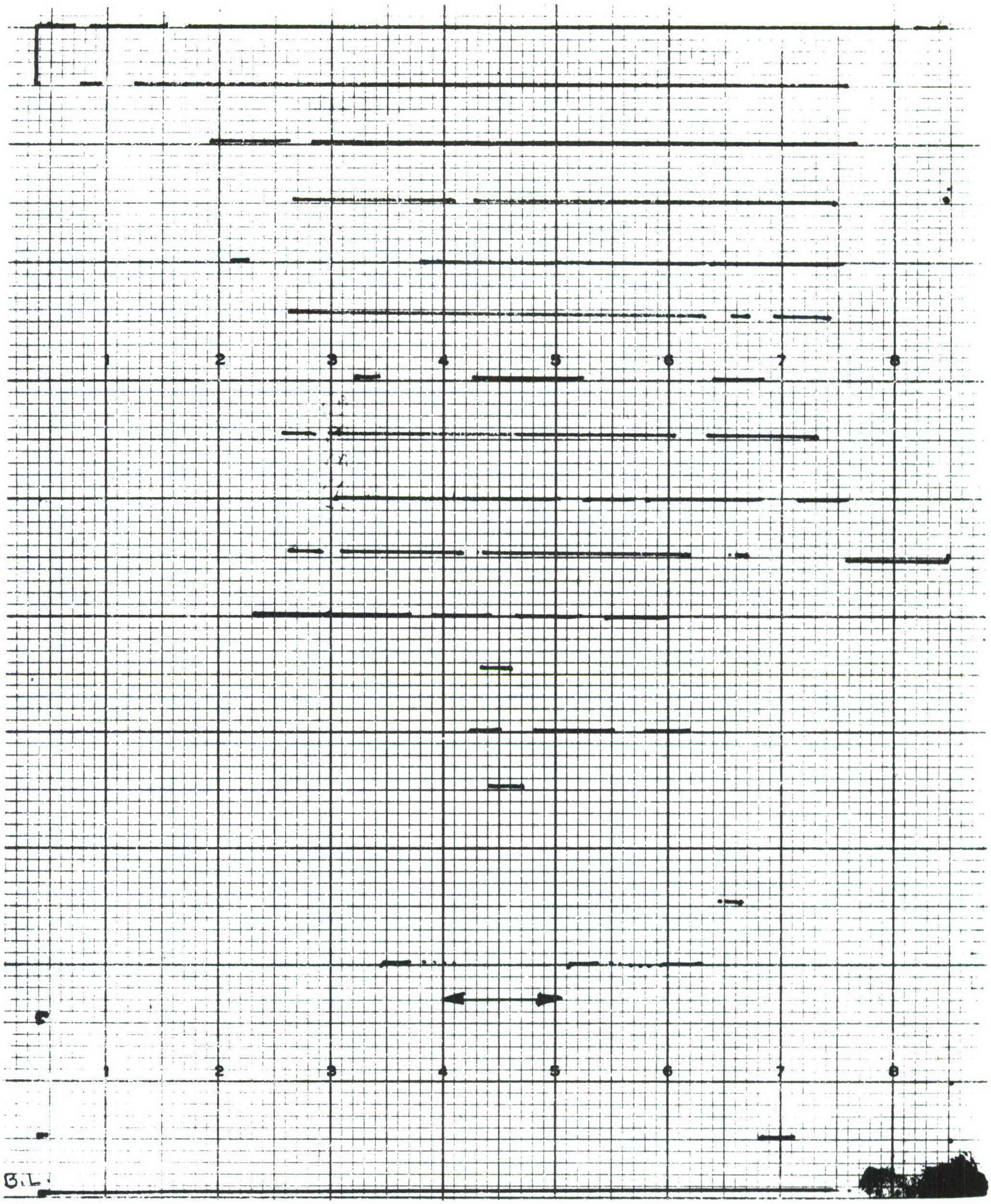

Fig. 49 ULTRASONIC C-SCAN OF UNACCEPTABLE PANEL T1333B (NINE PLY $[0/45/-45/0/\overline{90}]_s$ LAMINATE), 0° DIRECTION SHOWN BY ARROWS.

APPENDIX II

<u>DATA SUMMARY FOR THORNEL 300</u>
<u>GRAPHITE/NARMCO 5208</u>

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APPENDIX II

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
0°	Tension	None	RTD	26.3	0.28	218	7960
0°	Tension	None	260°F	29.8	0.31	214	7610
0°	Tension	None	350°F	28.5	0.26	208	7350
90°	Tension	None	RTD	1.50	0.01	5.85	3750
90°	Tension	None	260°F	1.68	0.01	4.11	2490
90°	Tension	None	350°F	1.78	0.01	2.89	1690
$[0/45/135/0/\overline{90}]_s$	Tension	None	RTD	13.9	0.40	104	7400
$[0/45/135/0/\overline{90}]_s$	Tension	None	260°F	14.3	0.45	99	7320
$[0/45/135/0/\overline{90}]_s$	Tension	None	350°F	14.8	0.47	87	5640
0°	Compression	None	RTD*	23.0	0.39	247	14,210
0°	Compression	None	RTD	23.0	0.34	218	9490
0°	Compression	None	260°F	21.7	0.30	208	11,590
0°	Compression	None	350°F*	21.4	0.50	214	12,980
0°	Compression	None	350°F	22.5	0.31	206	12,770
90°	Compression	None	RTD*	1.76	0.02	35.7	23,600
90°	Compression	None	RTD	1.64	0.01	36.3	24,950
90°	Compression	None	260°F	1.68	0.01	32.6	21,350
90°	Compression	None	350°F*	1.76	0.03	28.6	21,670
90°	Compression	None	350°F	1.60	0.01	30.4	22,930

* Sandwich Beam Data

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
$[0/45/135/0/\overline{90}]_s$	Compression	None	RTD*	12.3	0.43	111	11,100
$[0/45/135/0/\overline{90}]_s$	Compression	None	RTD	12.5	0.48	114	9,900
$[0/45/135/0/\overline{90}]_s$	Compression	None	260°F	11.9	0.48	106	10,200
$[0/45/135/0/\overline{90}]_s$	Compression	None	350°F*	12.0	0.46	96	10,200
$[0/45/135/0/\overline{90}]_s$	Compression	None	350°F	14.1	0.53	96	6,984
0°	In-Plane Shear	None	RTD	1.04	-	9.8	14,670
0°	In-Plane Shear	None	260°F	0.99	-	7.2	11,810
0°	In-Plane Shear	None	350°F	0.87	-	5.5	18,570
0°	Int. Shear	None	RTD	-	-	15.9	-
0°	Int. Shear	None	260°F	-	-	12.5	-
0°	Int. Shear	None	350°F	-	-	8.9	-
$[0/45/135/0/\overline{90}]_s$	Int. Shear	None	RTD	-	-	9.2	-
$[0/45/135/0/\overline{90}]_s$	Int. Shear	None	260°F	-	-	7.1	-
$[0/45/135/0/\overline{90}]_s$	Int. Shear	None	350°F	-	-	5.2	-
0°	Flex	None	RTD	-	-	247	-
0°	Flex	None	260°F	-	-	227	-
0°	Flex	None	350°F	-	-	196	-
90°	Flex	None	RTD	-	-	10.1	-
90°	Flex	None	260°F	-	-	7.0	-
90°	Flex	None	350°F	-	-	3.8	-
$[0/45/135/0/\overline{90}]_s$	Flex	None	RTD	-	-	147	-
$[0/45/135/0/\overline{90}]_s$	Flex	None	260°F	-	-	141	-
$[0/45/135/0/\overline{90}]_s$	Flex	None	350°F	-	-	137	-

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ϵ_{ult} (μ-in./in.)
0°	Tension	98% RH / 500 Hrs.	RTD	22.2	0.34	211	8690
0°	Tension	98% RH / 500 Hrs.	260°F	-	-	178	-
0°	Tension	98% RH / 500 Hrs.	350°F	-	-	151	-
0°	Tension	98% RH / 1000 Hrs.	RTD	22.0	0.34	193	8740
0°	Tension	98% RH / 1000 Hrs.	260°F	22.1	0.37	194	8730
0°	Tension	98% RH / 1000 Hrs.	350°F	23.8	0.39	172	7280
0°	Tension	Thermo-Humidity Cycle	RTD	22.3	0.33	213	9730
0°	Tension	Thermo-Humidity Cycle	260°F	-	-	186	-
0°	Tension	Thermo-Humidity Cycle	350°F	-	-	154	-
0°	Tension	Acc. Wthrng.	RTD	21.7	0.29	227	9880
0°	Tension	Acc. Wthrng.	260°F	22.7	0.28	203	8720
0°	Tension	Acc. Wthrng.	350°F	23.8	0.33	177	7340
90°	Tension	98% RH / 500 Hrs.	RTD	1.49	0.00	4.68	2700
90°	Tension	98% RH / 500 Hrs.	260°F	-	-	2.68	-
90°	Tension	98% RH / 500 Hrs.	350°F	-	-	1.46	-
90°	Tension	98% RH / 1000 Hrs.	RTD	1.58	0.00	5.79	3490
90°	Tension	98% RH / 1000 Hrs.	260°F	1.68	0.00	2.74	1330
90°	Tension	98% RH / 1000 Hrs.	350°F	1.60	0.02	2.75	1360
90°	Tension	Thermo-Humidity Cycle	RTD	1.50	0.03	4.63	3000
90°	Tension	Thermo-Humidity Cycle	260°F	-	-	2.85	-
90°	Tension	Thermo-Humidity Cycle	350°F	-	-	1.47	-

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
90°	Tension	Acc. Wthrng.	RTD	1.58	0.02	5.4	3400
90°	Tension	Acc. Wthrng.	260°F	1.67	0.03	2.9	1670
90°	Tension	Acc. Wthrng.	350°F	1.71	0.02	2.7	1630
$[0/45/135/0/\overline{90}]_s$	Tension	98% RH / 500 Hrs.	RTD	12.0	0.39	108	9180
$[0/45/135/0/\overline{90}]_s$	Tension	98% RH / 500 Hrs.	260°F	-	-	85	-
$[0/45/135/0/\overline{90}]_s$	Tension	98% RH / 500 Hrs.	350°F	-	-	92	-
$[0/45/135/0/\overline{90}]_s$	Tension	98% RH / 1000 Hrs.	RTD	11.6	0.39	106	9320
$[0/45/135/0/\overline{90}]_s$	Tension	98% RH / 1000 Hrs.	260°F	11.1	0.55	98	9030
$[0/45/135/0/\overline{90}]_s$	Tension	98% RH / 1000 Hrs.	350°F	12.8	0.57	97	7970
$[0/45/135/0/\overline{90}]_s$	Tension	Thermo-Humidity Cycle	RTD	11.5	0.40	108	9580
$[0/45/135/0/\overline{90}]_s$	Tension	Thermo-Humidity Cycle	260°F	-	-	85	-
$[0/45/135/0/\overline{90}]_s$	Tension	Thermo-Humidity Cycle	350°F	-	-	86	-
$[0/45/135/0/\overline{90}]_s$	Tension	Acc. Wthrng.	RTD	12.3	0.40	116	9000
$[0/45/135/0/\overline{90}]_s$	Tension	Acc. Wthrng.	260°F	11.7	0.50	95	8770
$[0/45/135/0/\overline{90}]_s$	Tension	Acc. Wthrng.	350°F	13.0	0.45	98	7970

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
0°	Compression	98% RH / 500 Hrs.	RTD	20.2	0.30	211	10860
0°	Compression	98% RH / 500 Hrs.	260°F	-	-	200	-
0°	Compression	98% RH / 500 Hrs.	350°F	--------SPECIMENS BROKEN DURING CONDITIONING ----------------			
0°	Compression	98% RH / 1000 Hrs.	RTD	17.9	0.30	212	12560
0°	Compression	98% RH / 1000 Hrs.	260°F	19.8	0.33	211	12720
0°	Compression	98% RH / 1000 Hrs.	350°F	--------SPECIMENS BROKEN DURING CONDITIONING ----------------			
0°	Compression	Thermo-Humidity Cycle	RTD	22.6	0.33	187	9060
0°	Compression	Thermo-Humidity Cycle	260°F	-	-	194	-
0°	Compression	Thermo-Humidity Cycle	350°F	--------SPECIMENS BROKEN DURING CONDITIONING ----------------			
0°	Compression	Acc. Wthrng.	RTD	21.7	0.28	200	10850
0°	Compression	Acc. Wthrng.	260°F	19.5	0.33	207	9150
0°	Compression	Acc. Wthrng.	350°F	--------SPECIMENS BROKEN DURING CONDITIONING ----------------			
90°	Compression	98% RH / 500 Hrs.	RTD	--------SPECIMENS BROKEN DURING CONDITIONING ----------------			
90°	Compression	98% RH / 500 Hrs.	260°F	-	-	27.3	-
90°	Compression	98% RH / 500 Hrs.	350°F	-	-	20.8	-
90°	Compression	98% RH / 1000 Hrs.	RTD	--------SPECIMENS BROKEN DURING CONDITIONING ----------------			
90°	Compression	98% RH / 1000 Hrs.	260°F	1.36		29.8	32000
90°	Compression	98% RH / 1000 Hrs.	350°F	--------SPECIMENS BROKEN DURING CONDITIONING ----------------			
90°	Compression	Thermo-Humidity Cycle	RTD	--------SPECIMENS BROKEN DURING CONDITIONING ----------------			
90°	Compression	Thermo-Humidity Cycle	260°F	-	-	26.6	-
90°	Compression	Thermo-Humidity Cycle	350°F	-	-	21.6	-

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
90°	Compression	Acc. Wthrng.	RTD	--------SPECIMENS BROKEN DURING CONDITIONING ------------------			
90°	Compression	Acc. Wthrng.	260°F	--------SPECIMENS BROKEN DURING CONDITIONING ------------------			
90°	Compression	Acc. Wthrng.	350°F	--------SPECIMENS BROKEN DURING CONDITIONING ------------------			
$[0/45/135/0/\overline{90}]_s$	Compression	98% RH / 500 Hrs.	RTD	13.1	0.45	102	9920
$[0/45/135/0/\overline{90}]_s$	Compression	98% RH / 500 Hrs.	260°F	-	-	116	-
$[0/45/135/0/\overline{90}]_s$	Compression	98% RH / 500 Hrs.	350°F	-	-	104	-
$[0/45/135/0/\overline{90}]_s$	Compression	98% RH / 1000 Hrs.	RTD	11.7	0.50	111	12600
$[0/45/135/0/\overline{90}]_s$	Compression	98% RH / 1000 Hrs.	260°F	10.9	0.52	100	8950
$[0/45/135/0/\overline{90}]_s$	Compression	98% RH / 1000 Hrs.	350°F	10.4	0.45	97	12680
$[0/45/135/0/\overline{90}]_s$	Compression	Thermo-Humidity Cycle	RTD	11.1	0.50	98	11060
$[0/45/135/0/\overline{90}]_s$	Compression	Thermo-Humidity Cycle	260°F	-	-	111	-
$[0/45/135/0/\overline{90}]_s$	Compression	Thermo-Humidity Cycle	350°F	-	-	108	-
$[0/45/135/0/\overline{90}]_s$	Compression	Acc. Wthrng.	RTD	10.4	0.58	116	11510
$[0/45/135/0/\overline{90}]_s$	Compression	Acc. Wthrng.	260°F	9.4	0.35	109	13960
$[0/45/135/0/\overline{90}]_s$	Compression	Acc. Wthrng.	350°F	9.9	0.40	108	12880
0°	In-Plane Shear	98% RH / 500 Hrs.	RTD	0.94	-	9.4	16440
0°	In-Plane Shear	98% RH / 500 Hrs.	260°F	-	-	6.0	-
0°	In-Plane Shear	98% RH / 500 Hrs.	350°F	-	-	5.5	-
0°	In-Plane Shear	98% RH / 1000 Hrs.	RTD	0.89	-	9.7	15660
0°	In-Plane Shear	98% RH / 1000 Hrs.	260°F	0.75	-	6.7	19917
0°	In-Plane Shear	98% RH / 1000 Hrs.	350°F	0.82	-	6.5	28850

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
0°	In-Plane Shear	Thermo-Humidity Cycle	RTD	1.05	-	9.8	15,470
0°	In-Plane Shear	Thermo-Humidity Cycle	260°F	-	-	5.6	-
0°	In-Plane Shear	Thermo-Humidity Cycle	350°F	-	-	5.2	-
0°	In-Plane Shear	Acc. Wthrng.	RTD	1.2	-	10.0	13,710
0°	In-Plane Shear	Acc. Wthrng.	260°F	1.02	-	9.2	20,880
0°	In-Plane Shear	Acc. Wthrng.	350°F	0.99	-	8.2	34,130
0°	Int. Shear	98% RH / 500 Hrs.	RTD	-		12.8	-
0°	Int. Shear	98% RH / 500 Hrs.	260°F	-		9.2	-
0°	Int. Shear	98% RH / 500 Hrs.	350°F	-		5.7	-
0°	Int. Shear	98% RH / 1000 Hrs.	RTD	-		11.3	-
0°	Int. Shear	98% RH / 1000 Hrs.	260°F	-		7.9	-
0°	Int. Shear	98% RH / 1000 Hrs.	350°F	-		4.3	-
0°	Int. Shear	Thermo-Humidity Cycle	RTD	-		12.2	-
0°	Int. Shear	Thermo-Humidity Cycle	260°F	-		8.9	-
0°	Int. Shear	Thermo-Humidity Cycle	350°F	-		5.4	-
0°	Int. Shear	Acc. Wthrng.	RTD	-		14.3	-
0°	Int. Shear	Acc. Wthrng.	260°F	-		9.8	-
0°	Int. Shear	Acc. Wthrng.	350°F	-		5.4	-

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
0°	Tension	260°F/100 hrs.	RTD	-	-	229	-
0°	Tension	260°/100 hrs.	260°F	-	-	214	-
0°	Tension	260°/100 hrs.	350°F	-	-		-
0°	Tension	260°F/500 hrs.	RTD	25.5	0.28	212	8170
0°	Tension	260°F/500 hrs.	260°F	26.8	0.29	207	7730
0°	Tension	260°F/500 hrs.	350°F	-	-	-	-
0°	Tension	350°F/100 hrs.	RTD	-	-	219	-
0°	Tension	350°F/100 hrs.	260°F	-	-	209	-
0°	Tension	350°F/100 hrs.	350°F	-	-	203	-
0°	Tension	350°F/500 hrs.	RTD	25.8	0.26	213	8160
0°	Tension	350°F/500 hrs.	-	-	-	-	-
0°	Tension	350°F/500 hrs.	350°F	26.0	0.29	196	6560
90°	Tension	260°F/100 hrs.	RTD	-	-	6.0	-
90°	Tension	260°F/100 hrs.	260°F	-	-	4.7	-
90°	Tension	260°F/100 hrs.	350°F	-	-	-	-
90°	Tension	260°F/500 hrs.	RTD	1.73	0.01	6.9	4000
90°	Tension	260°F/500 hrs.	260°F	1.67	0.04	4.4	2550
90°	Tension	260°F/500 hrs.	350°F	-	-	-	-
90°	Tension	350°F/100 hrs.	RTD	-	-	5.5	-
90°	Tension	350°F/100 hrs.	260°F	-	-	4.3	-
90°	Tension	350°F/100 hrs.	350°F	-	-	3.1	-

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
90°	Tension	350°F/500 hrs.	RTD	1.93	0.01	4.4	2380
90°	Tension	350°F/500 hrs.	350°F	1.82	0.02	3.7	1990
$[0/45/135/0/\overline{90}]_s$	Tension	260°F/100 hrs.	RTD	-	-	105	-
$[0/45/135/0/\overline{90}]_s$	Tension	260°F/100 hrs.	260°F	-	-	109	-
$[0/45/135/0/\overline{90}]_s$	Tension	260°F/500 hrs.	RTD	13.8	0.40	101	7540
$[0/45/135/0/\overline{90}]_s$	Tension	260°F/500 hrs.	260°F	10.9	0.40	101	9700
$[0/45/135/0/\overline{90}]_s$	Tension	350°F/100 hrs.	RTD	-	-	103	-
$[0/45/135/0/\overline{90}]_s$	Tension	350°F/100 hrs.	260°F	-	-	100	-
$[0/45/135/0/\overline{90}]_s$	Tension	350°F/100 hrs.	350°F	-	-	95	-
$[0/45/135/0/\overline{90}]_s$	Tension	350°F/500 hrs.	RTD	13.4	0.42	100	7930
$[0/45/135/0/\overline{90}]_s$	Tension	350°F/500 hrs.	350°F	12.8	0.44	98	7790
0°	Compression	260°F/100 hrs.	RTD	-	-	224	-
0°	Compression	260°F/100 hrs.	260°F	-	-	244	-
0°	Compression	260°/500 hrs.	RTD	23.8	0.31	206	10,090
0°	Compression	260°F/500 hrs.	260°F	24.0	0.27	210	13,220
0°	Compression	350°F/100 hrs.	RTD	-	-	222	-
0°	Compression	350°F/100 hrs.	350°F	-	-	221	-
0°	Compression	350°F/500 hrs.	RTD	23.7	0.31	209	9840
0°	Compression	350°F/500 hrs.	350°F	25.9	0.34	219	8730

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
90°	Compression	260°F/100 hrs.	RTD	-	-	31.1	-
90°	Compression	260°F/100 hrs.	260°F	-	-	31.7	-
90°	Compression	260°F/500 hrs.	RTD	1.24	0.02	30.5	22,880
90°	Compression	260°F/500 hrs.	260°F	2.23	0.12	27.1	28,850
90°	Compression	350°F/100 hrs.	RTD	-	-	30.5	-
90°	Compression	350°F/100 hrs.	350°F	-	-	27.7	-
90°	Compression	350°F/500 hrs.	RTD	2.12	0.02	28.7	20,000
90°	Compression	350°F/500 hrs.	350°F	--------SPECIMENS BROKE DURING CONDITIONING -----------------			
$[0/45/135/0/\overline{90}]_s$	Compression	260°F/100 hrs.	RTD	-	-	134	-
$[0/45/135/0/\overline{90}]_s$	Compression	260°F/100 hrs.	260°F	-	-	130	-
$[0/45/135/0/\overline{90}]_s$	Compression	260°F/500 hrs.	RTD	11.7	0.49	114	10,850
$[0/45/135/0/\overline{90}]_s$	Compression	260°F/500 hrs.	260°F	11.3	0.37	102	9400
$[0/45/135/0/\overline{90}]_s$	Compression	350°F/100 hrs.	RTD	-	-	126	-
$[0/45/135/0/\overline{90}]_s$	Compression	350°F/100 hrs.	350°F	-	-	110	-
$[0/45/135/0/\overline{90}]_s$	Compression	350°F/500 hrs.	RTD	11.0	0.35	108	11,050
$[0/45/135/0/\overline{90}]_s$	Compression	350°F/500 hrs.	350°F	11.1	0.30	91	8740

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
0°	In-Plane Shear	260°F/100 hrs.	RTD	-	10.4	-
0°	In-Plane Shear	260°F/100 hrs.	260°F	-	8.4	-
0°	In-Plane Shear	260°F/500 hrs.	RTD	1.04	11.5	14,770
0°	In-Plane Shear	260°F/500 hrs.	260°F	0.94	9.3	18,140
0°	In-Plane Shear	350°F/100 hrs.	RTD	-	10.2	
0°	In-Plane Shear	350°F/100 hrs.	360°F	-	7.4	-
0°	In-Plane Shear	350°F/500 hrs.	RTD	0.90	10.6	15,213
0°	In-Plane Shear	350°F/500 hrs.	350°F	0.82	6.7	17,820
0°	Int. Shear	260°F/100 hrs.	RTD	-	16.4	-
0°	Int. Shear	260°F/100 hrs.	260°F	-	13.7	-
0°	Int. Shear	260°F/500 hrs.	RTD	-	15.5	-
0°	Int. Shear	260°F/500 hrs.	260°F	-	12.6	-
0°	Int. Shear	350°F/100 hrs.	RTD	-	15.7	-
0°	Int. Shear	350°F/100 hrs.	260°F	-	13.3	-
0°	Int. Shear	350°F/500 hrs.	RTD	-	13.7	-
0°	Int. Shear	350°F/500 hrs.	350°F	-	7.9	-

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
0°	Tension	260°F/500 cycles	RTD	-	-	224	-
0°	Tension	260°F/500 cycles	260°F	-	-	214	-
0°	Tension	260°F/1000 cycles	RTD	22.7	0.32	218	8,960
0°	Tension	260°F/1000 cycles	260°F	25.8	0.29	203	8,240
0°	Tension	350°F/500 cycles	RTD	21.5	0.33	216	9,690
0°	Tension	350°F/500 cycles	260°F	-	-	219	-
0°	Tension	350°F/500 cycles	350°F	24.2	0.31	201	8,170
0°	Tension	350°F/1000 cycles	RTD	21.5	0.33	203	9,690
0°	Tension	350°F/1000 cycles	350°F	27.1	0.29	195	7,000
90°	Tension	260°F/500 cycles	RTD	-	-	5.0	-
90°	Tension	260°F/500 cycles	260°F	-	-	5.6	-
90°	Tension	260°F/1000 cycles	RTD	1.5	0.02	4.5	2,190
90°	Tension	260°F/1000 cycles	260°F	1.8	0.03	4.5	2,500
90°	Tension	350°F/500 cycles	RTD	1.91	0.02	5.3	2,920
90°	Tension	350°F/500 cycles	260°F	-	-	3.3	-
90°	Tension	350°F/500 cycles	350°F	1.60	0.02	3.5	2,140
90°	Tension	350°F/1000 cycles	RTD	1.37	0.02	4.7	2,910
90°	Tension	350°F/1000 cycles	350°F	----------SPECIMENS BROKEN DURING CONDITIONING------------			

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
$[0/45/135/0/\overline{90}]_s$	Tension	260°F/500 cycles	RTD	-	-	107	-
$[0/45/135/0/\overline{90}]_s$	Tension	260°F/500 cycles	260°F	-	-	103	-
$[0/45/135/0/\overline{90}]_s$	Tension	260°F/1000 cycles	RTD	12.4	0.44	114	9,290
$[0/45/135/0/\overline{90}]_s$	Tension	260°F/1000 cycles	260°F	13.6	0.44	97	7,400
$[0/45/135/0/\overline{90}]_s$	Tension	350°F/500 cycles	RTD	11.5	0.39	107	9,470
$[0/45/135/0/\overline{90}]_s$	Tension	350°F/500 cycles	260°F	-	-	100	-
$[0/45/135/0/\overline{90}]_s$	Tension	350°F/500 cycles	350°	12.2	0.42	103	8,720
$[0/45/135/0/\overline{90}]_s$	Tension	350°F/1000 cycles	RTD	11.2	0.40	112	9,770
$[0/45/135/0/\overline{90}]_s$	Tension	350°F/1000 cycles	350°F	12.8	0.44	100	8,140
0°	Compression	260°F/500 cycles	RTD	-	-	217	-
0°	Compression	260°F/500 cycles	260°F	-	-	238	-
0°	Compression	260°F/1000 cycles	RTD	23.4	0.34	228	11,240
0°	Compression	260°F/1000 cycles	260°F	18.3	0.26	185	9,280
0°	Compression	350°F/ 500 cycles	RTD	20.3	0.35	200	11,770
0°	Compression	350°F/500 cycles	350°F	-	-	215	-
0°	Compression	350°F/1000 cycles	RTD	22.2	0.30	217	13,520
0°	Compression	350°F/1000 cycles	350°F	27.1	0.27	209	10,080

TABLE X STATIC PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	ν (in/in)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
90°	Compression	260°F/500 cycles	RTD	-	-	30.3	-
90°	Compression	260°F/500 cycles	260°F	-	-	32.2	-
90°	Compression	260°F/1000 cycles	RTD	1.56	0.02	32.3	21890
90°	Compression	260°F/1000 cycles	260°F	1.77	0.00	32.4	21400
90°	Compression	350°F/500 cycles	RTD	-	-	28.7	-
90°	Compression	350°F/500 cycles	350°F	-	-	24.5	-
90°	Compression	350°F/1000 cycles	RTD	1.65	0.00	28.4	18,390
90°	Compression	350°F/1000 cycles	350°F	1.95	0.00	23.4	23,920
$[0/45/135/0/\overline{90}]_s$	Compression	260°F/500 cycles	RTD	-	-	136	-
$[0/45/135/0/\overline{90}]_s$	Compression	260°F/500 cycles	260°F	-	-	102	-
$[0/45/135/0/\overline{90}]_s$	Compression	260°F/1000 cycles	RTD	10.7	0.46	130	14,170
$[0/45/135/0/\overline{90}]_s$	Compression	260°F/1000 cycles	260°F	12.2	0.42	99	9,053
$[0/45/135/0/\overline{90}]_s$	Compression	350°F/500 cycles	RTD	10.7	0.34	106	11,570
$[0/45/135/0/\overline{90}]_s$	Compression	350°F/500 cycles	350°F	14.7	0.45	92	7,780
$[0/45/135/0/\overline{90}]_s$	Compression	350°F/1000 cycles	RTD	-	0.48	93	10,600
$[0/45/135/0/\overline{90}]_s$	Compression	350°F/1000 cycles	350°F	14.4	0.55	88	9,710

TABLE X STATIC PROPERTIES SUMMARY -
THORNEL 300 GRAPHITE/
NARMCO 5208 COMPOSITES

Orientation	Type Load	Prior Conditioning	Test Temp. (°F)	E (psi x 10^6)	σ_{ult} (ksi)	ε_{ult} (μ-in./in.)
0°	In-Plane Shear	260°F/500 cycles	RTD	0.76	11.5	18,050
0°	In-Plane Shear	260°F/500 cycles	260°F	-	7.5	-
0°	In-Plane Shear	260°F/1000 cycles	RTD	1.06	11.0	17,000
0°	In-Plane Shear	260°F/1000 cycles	260°F	2.06	8.0	16,230
0°	In-Plane Shear	350°/500 cycles	RTD	0.80	10.3	18,300
0°	In-Plane Shear	350°F/500 cycles	350°F	0.77	7.2	21,974
0°	In-Plane Shear	350°F/1000 cycles	RTD	0.90	9.9	14,180
0°	In-Plane Shear	350°F/1000 cycles	350°F	-	6.2	-
0°	Int. Shear	260°F/500 cycles	RTD	-	16.2	-
0°	Int. Shear	260°F/500 cycles	260°F	-	11.7	-
0°	Int. Shear	260°F/1000 cycles	RTD	-		-
0°	Int. Shear	260°F/1000 cycles	260°F	-		-
0°	Int. Shear	350°F/500 cycles	RTD	-	14.3	-
0°	Int. Shear	350°F/500 cycles	350°F	-	5.1	-
0°	Int. Shear	350°F/1000 cycles	RTD	-	14.3	-
0°	Int. Shear	350°F/1000 cycles	350°F	-	5.4	-

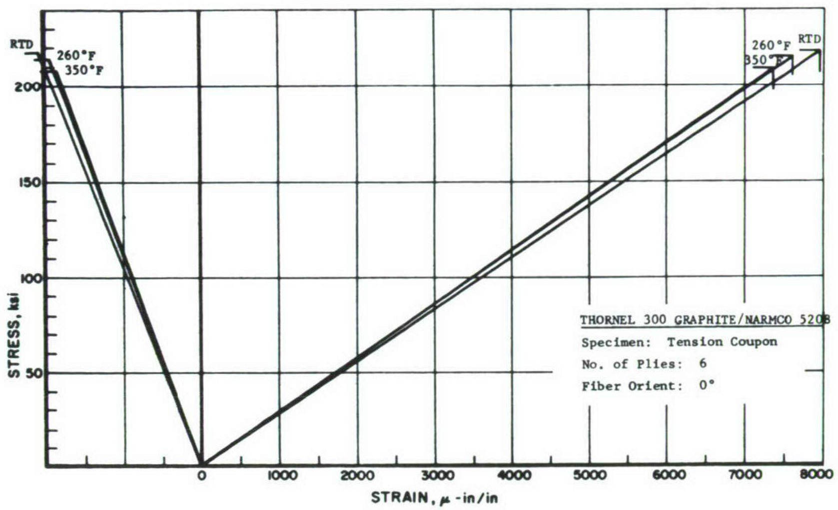

Fig. 50 TENSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES

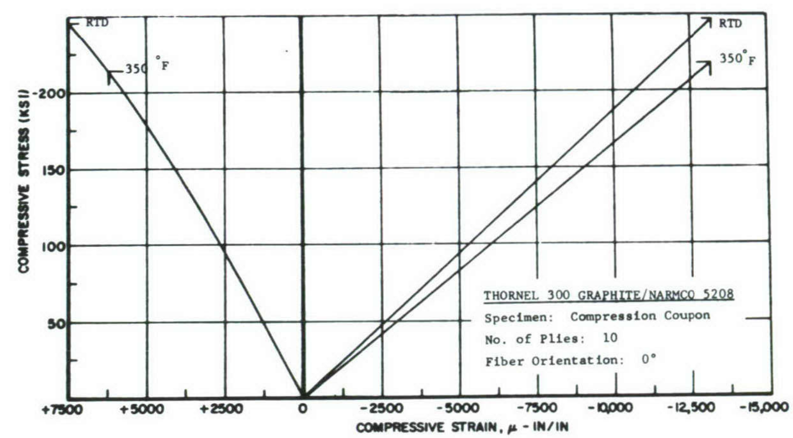

Fig. 51 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE AT VARIOUS TEMPERATURES (From Sandwich Beam Specimens)

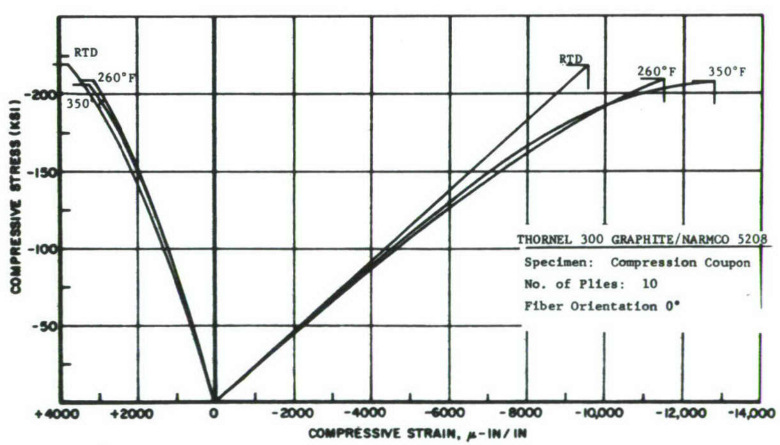

FIG. 52 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES

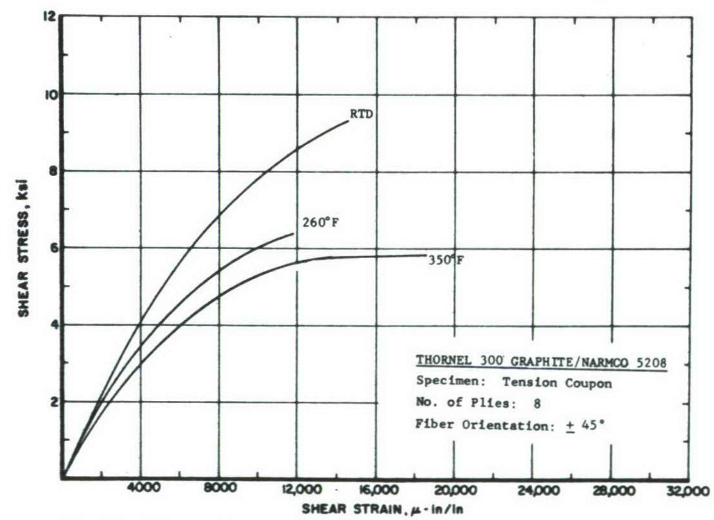

Fig. 53 SHEAR STRESS-STRAIN DIAGRAMS FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES

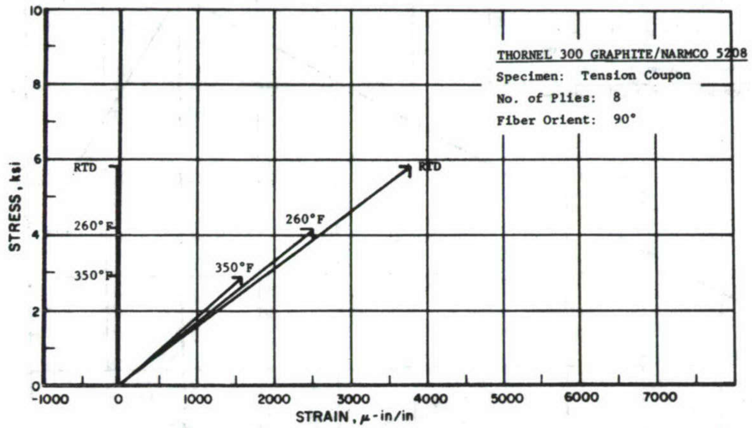

Fig. 54 TENSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITES TESTED AT VARIOUS TEMPERATURES

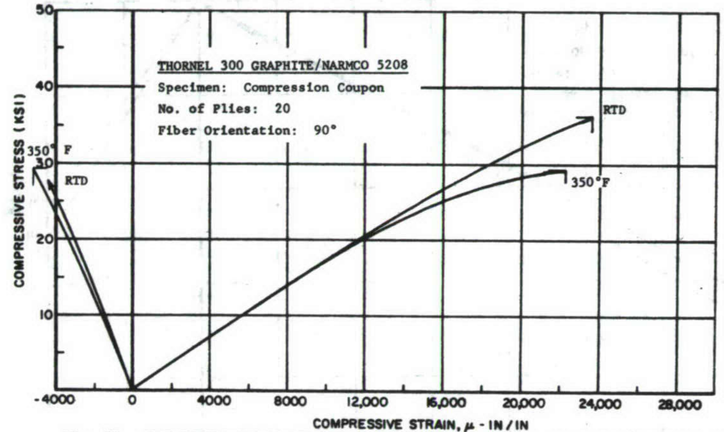

Fig. 55 COMPRESSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE AT VARIOUS TEMPERATURES (From Sandwich Beam Specimens)

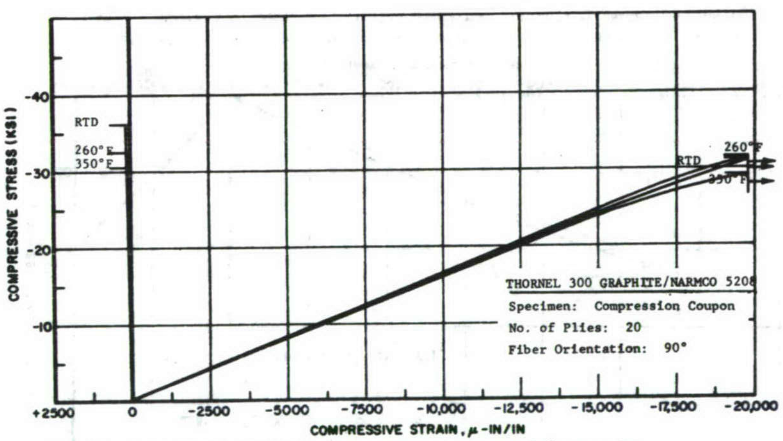

FIG. 56 COMPRESSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES

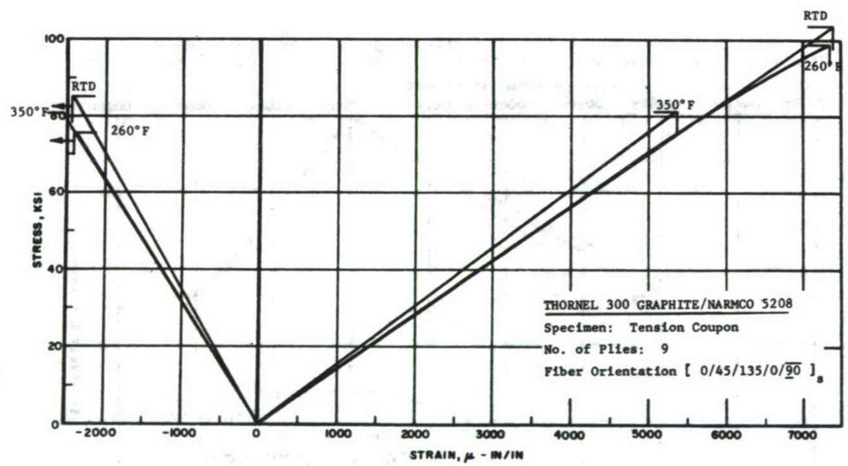

Fig. 57 TENSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 [0/45/135/0/$\overline{90}$]$_s$ LAMINATE TESTED AT VARIOUS TEMPERATURES

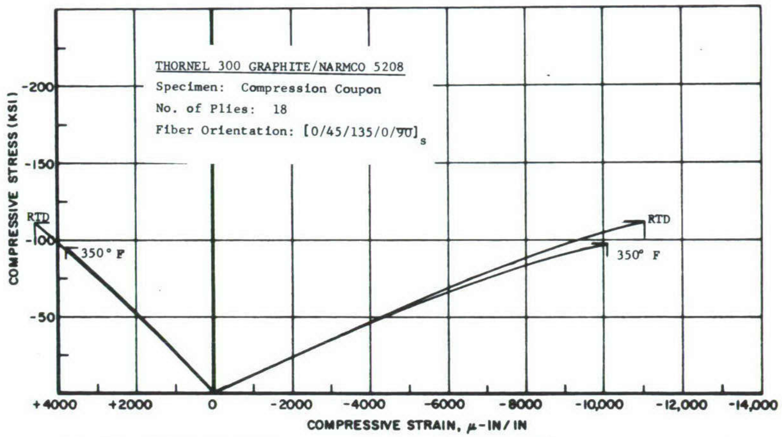

Fig. 58 COMPRESSION STRESS-STRAIN DIAGRAM FOR [0/45/135/0/$\overline{90}$]$_s$ THORNEL 300 GRAPHITE/NARMCO 5208 LAMINATE AT VARIOUS TEMPERATURES (From Sandwich Beam Specimens)

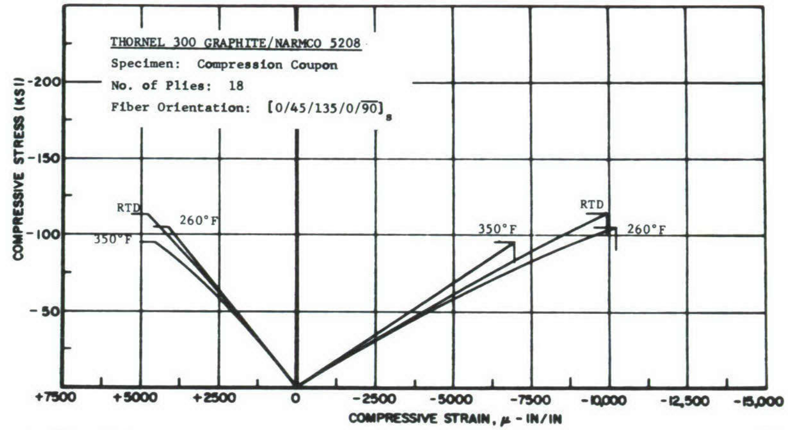

Fig. 59 COMPRESSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 [0/45/135/0/$\overline{90}$]$_s$ LAMINATE TESTED AT VARIOUS TEMPERATURES

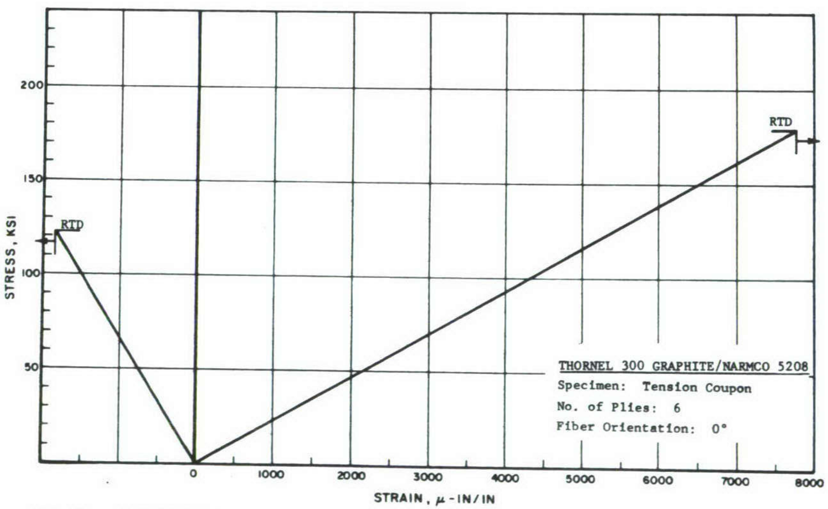

Fig. 60 TENSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT ROOM TEMPERATURE AFTER 500 HOURS EXPOSURE TO 98% R.H.

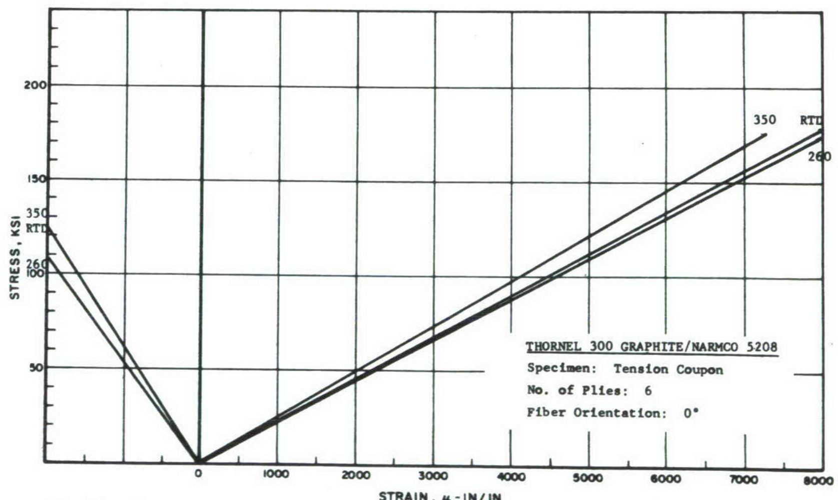

Fig. 61 TENSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 HOURS EXPOSURE TO 98% R. H.

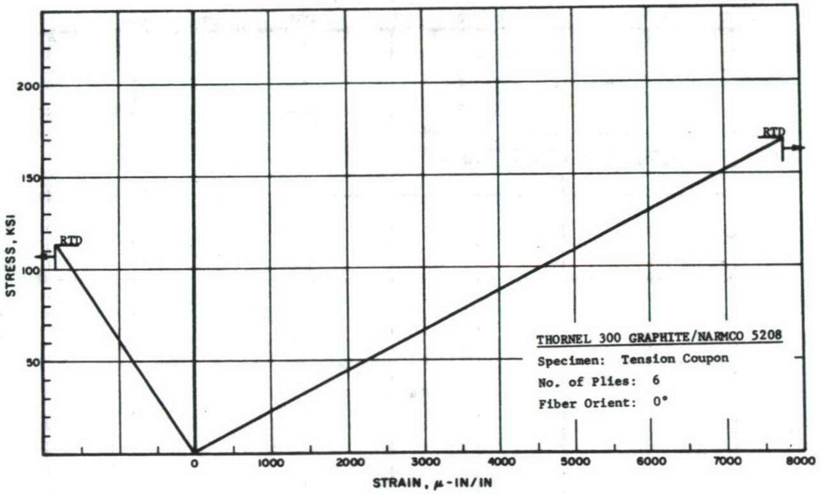

Fig. 62 TENSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT ROOM TEMPERATURE AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-Humidity Cycle)

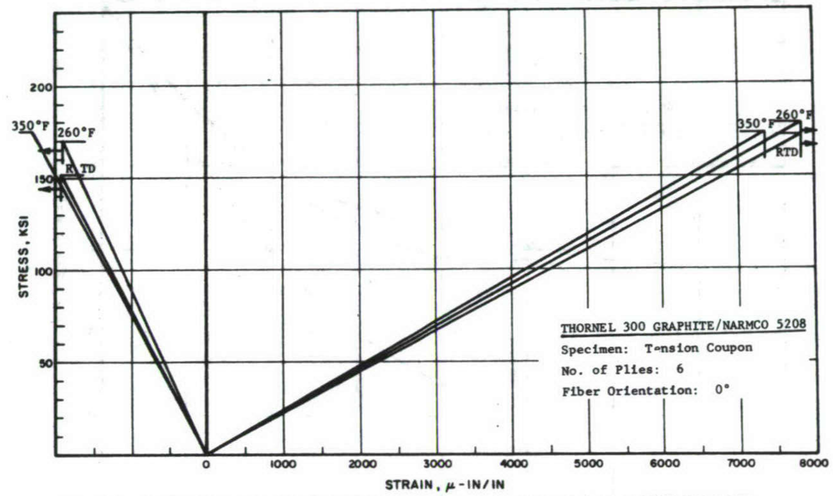

Fig. 63 TENSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (Accelerated Weathering)

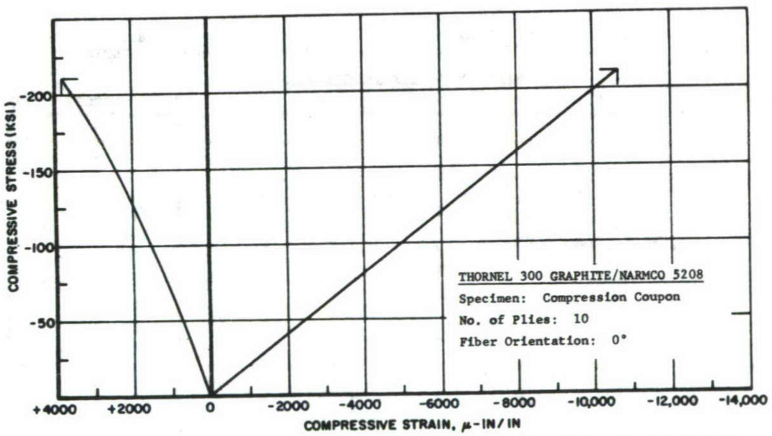

Fig. 64 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT ROOM TEMPERATURE AFTER 500 HOURS EXPOSURE TO 98% R.H.

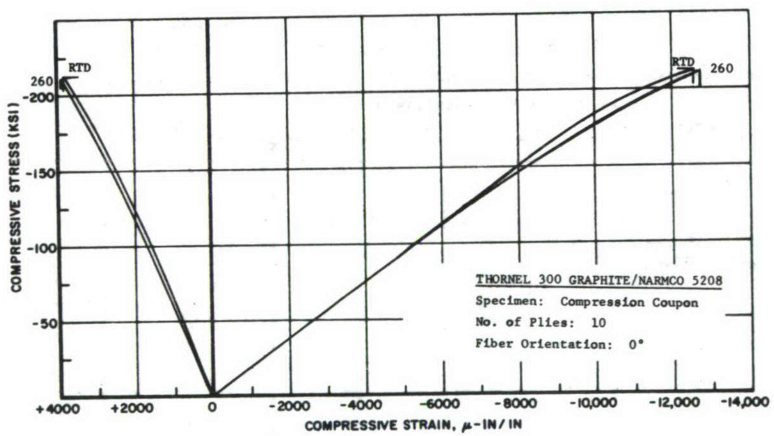

Fig. 65 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 HOURS EXPOSURE TO 98% R. H.

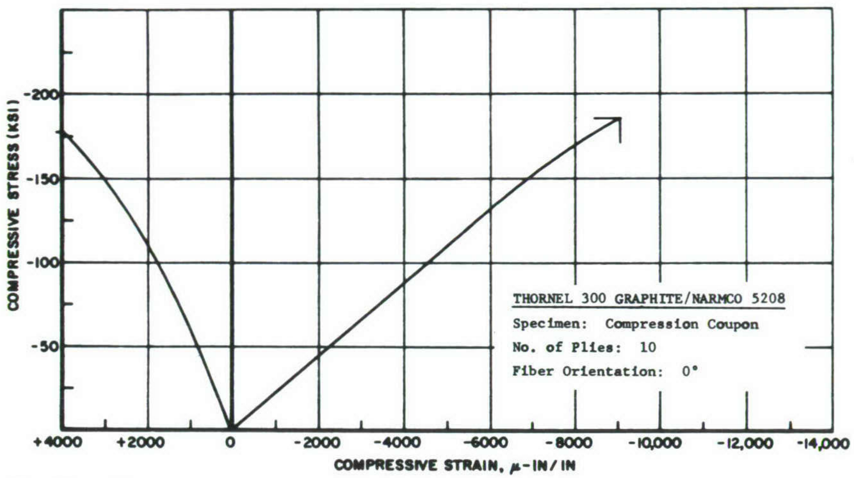

Fig. 66 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT ROOM TEMPERATURE AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-Humidity Cycle)

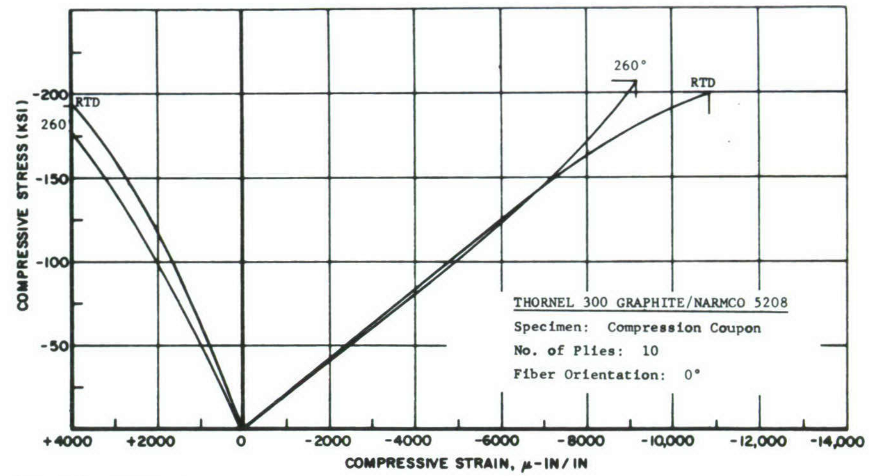

Fig. 67 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (ACCELERATED WEATHERING)

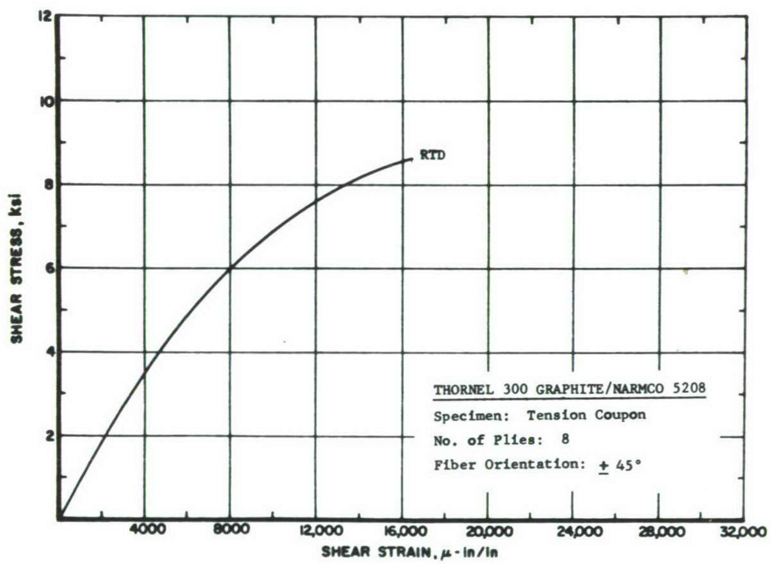

Fig. 68 SHEAR STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 LAMINATE TESTED AT ROOM TEMPERATURE AFTER 500 HOURS EXPOSURE TO 98% R.H.

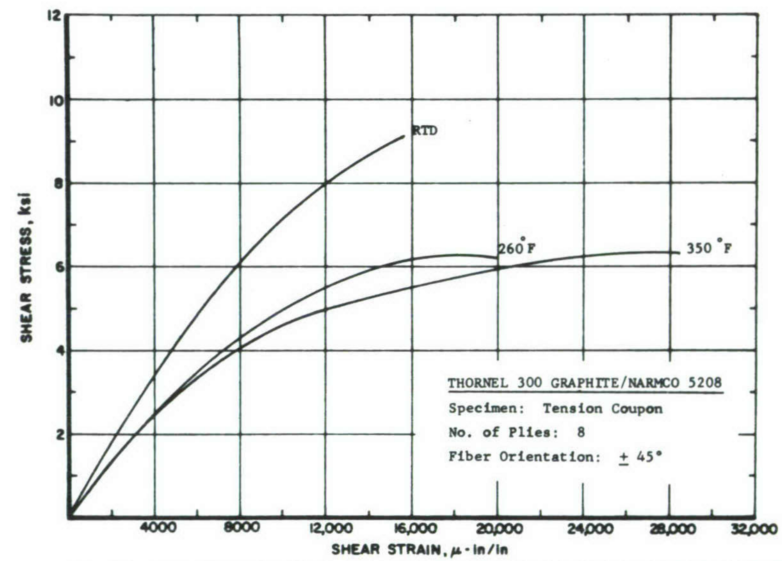

Fig. 69 SHEAR STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 HOURS EXPOSURE TO 98% R.H.

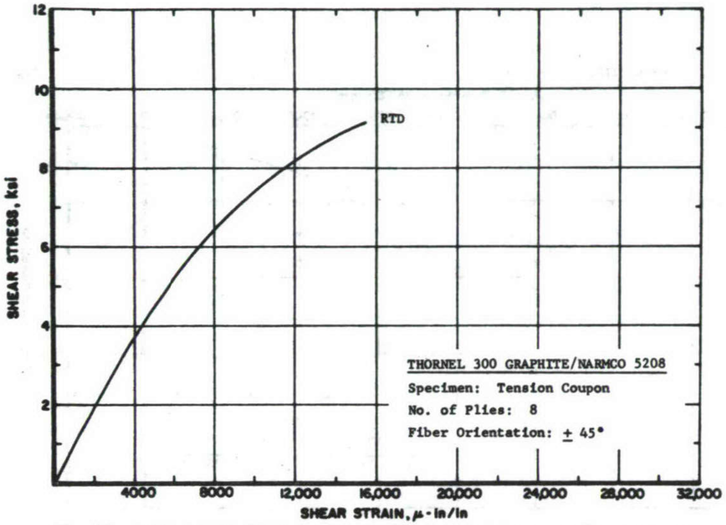

Fig. 70 SHEAR STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT ROOM TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE NO. 1 (Thermo-Humidity Cycle)

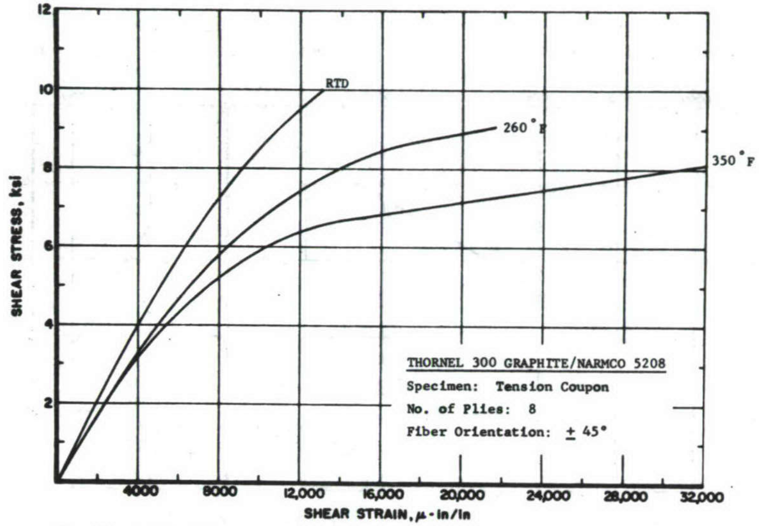

Fig. 71 SHEAR STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (Accelerated Weathering)

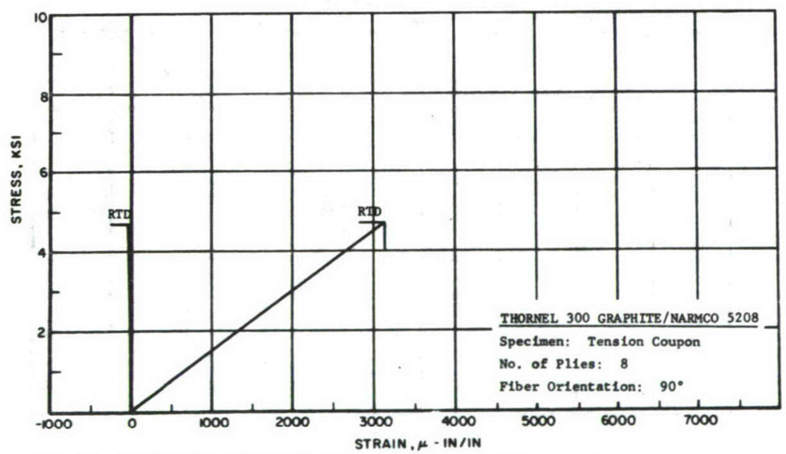

Fig. 72 TENSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT ROOM TEMPERATURE AFTER 500 HOURS EXPOSURE TO 98% R. H.

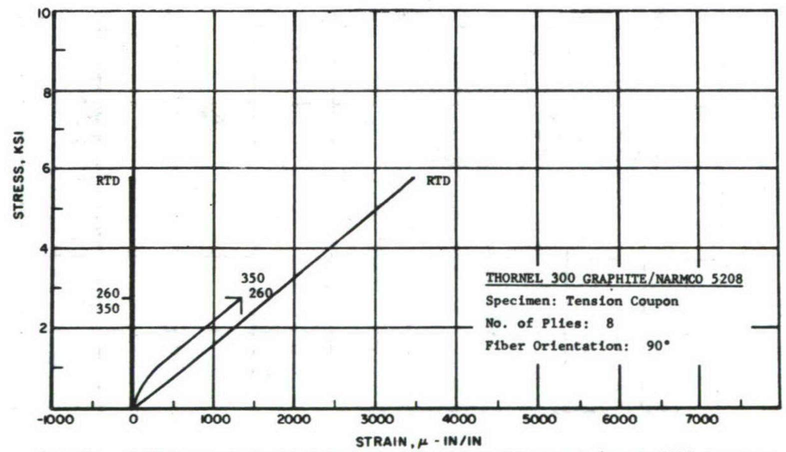

Fig. 73 TENSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 HOURS EXPOSURE TO 98% R. H.

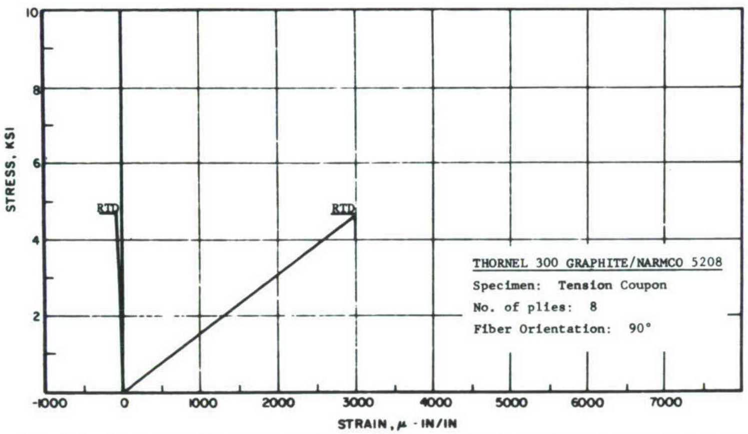

Fig. 74 TENSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT ROOM TEMPERATURE AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-Humidity Cycle)

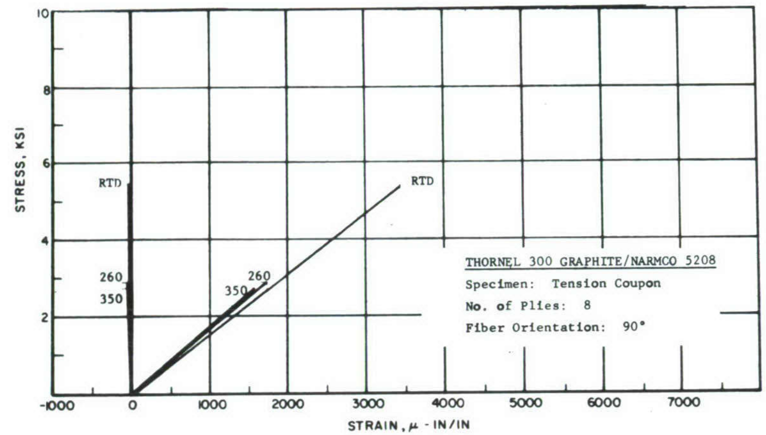

Fig. 75 TENSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (Accelerated Weathering)

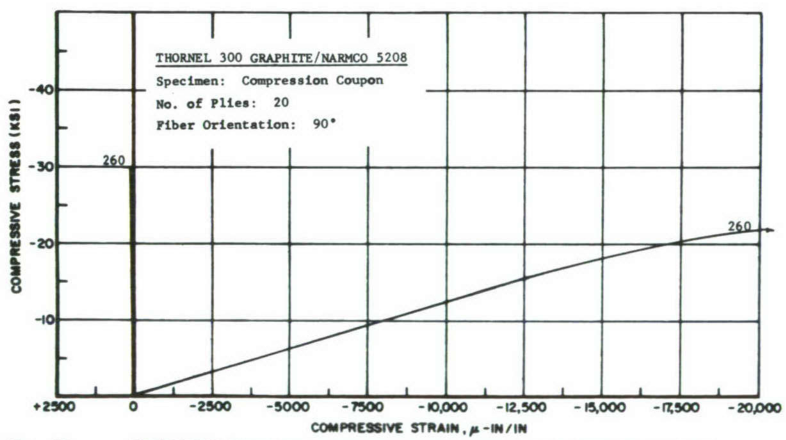

Fig. 76 COMPRESSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTFD AT 260°F AFTER 1000 HOURS EXPOSURE TO 98% RH

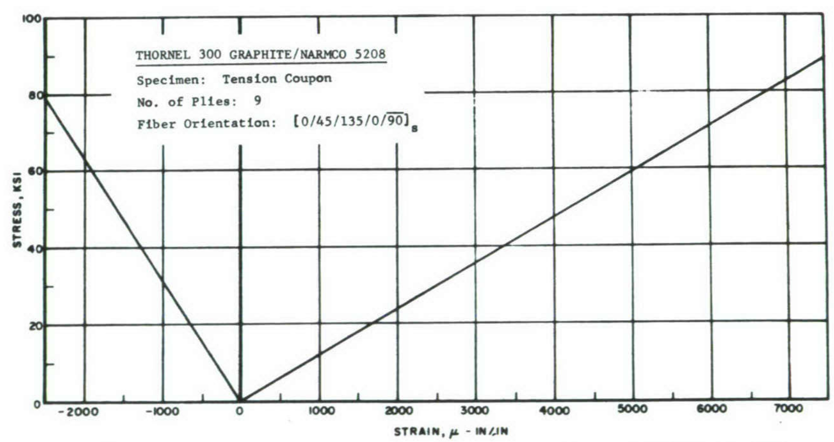

Fig. 77 TENSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT ROOM TEMPERATURE AFTER 500 HOURS EXPOSURE TO 98% R. H.

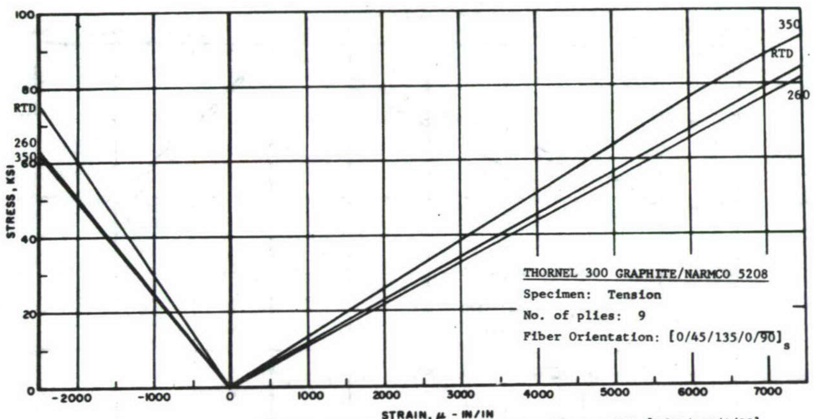

Fig. 78 TENSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/90]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 HOURS EXPOSURE TO 98% R. H.

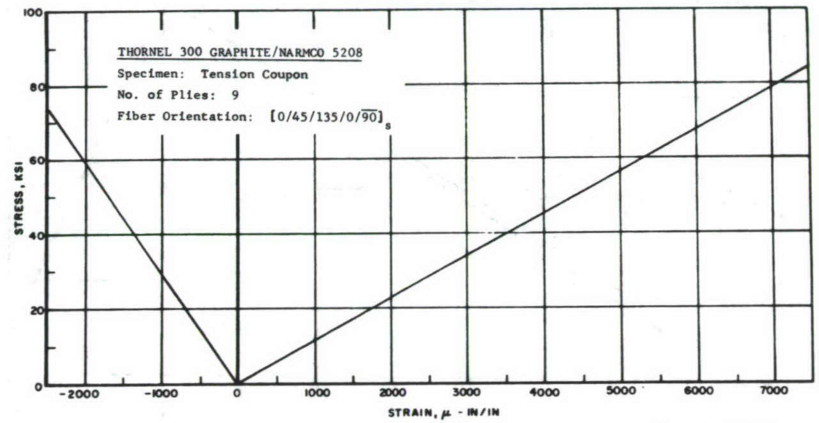

Fig. 79 TENSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/90]_s$ LAMINATE, TESTED AT ROOM TEMPERATURE AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-Humidity Cycle)

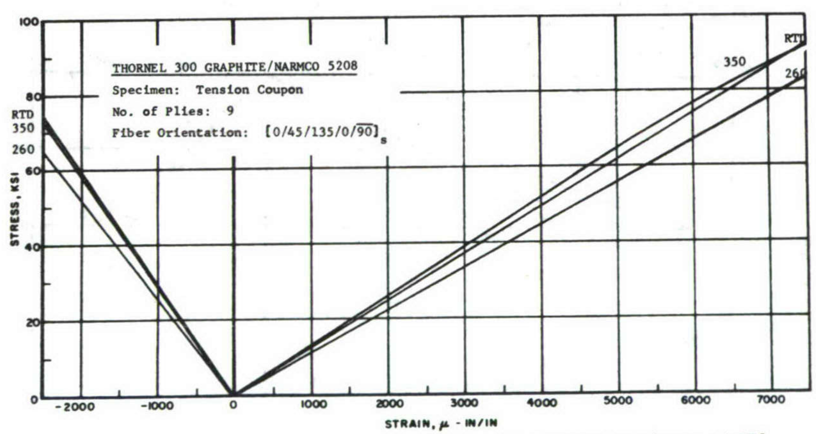

Fig. 80 TENSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (Accelerated Weathering)

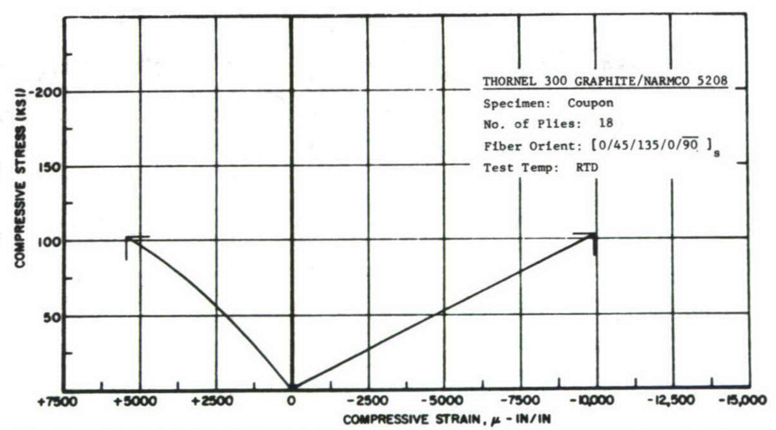

Fig. 81 COMPRESSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE TESTED AT ROOM TEMPERATURE AFTER 500 HOURS EXPOSURE TO 98% R. H.

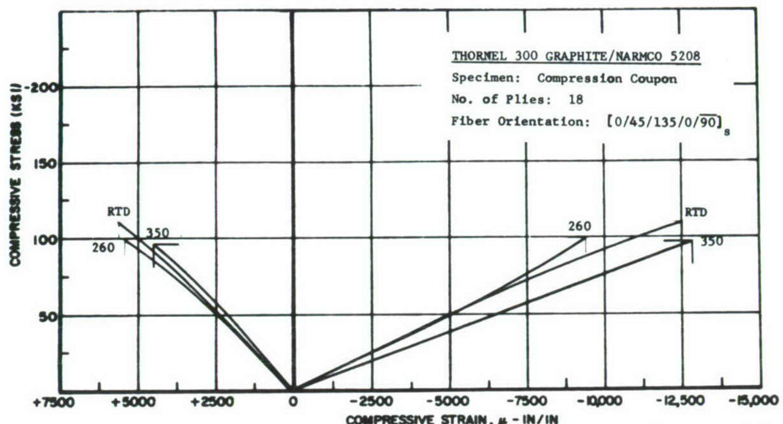

Fig. 82 COMPRESSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 [0/45/135/0/$\overline{90}$]$_s$ LAMINATE TESTED AT VARIOUS TEMPERATURES AFTER 1000 HOURS EXPOSURE TO 98% R. H.

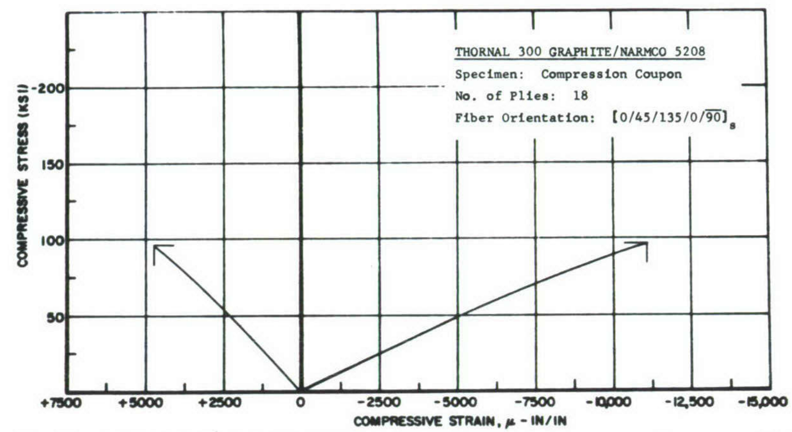

Fig. 83 COMPRESSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 [0/45/135/0/$\overline{90}$]$_s$ LAMINATE TESTED AT ROOM TEMPERATURE AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-Humidity Cycle)

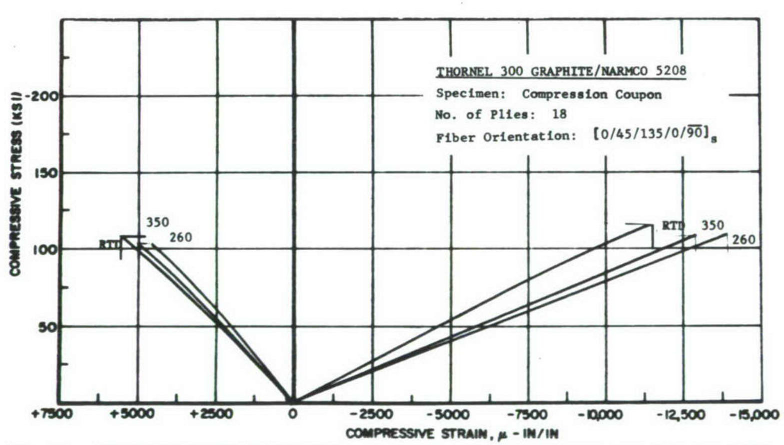

Fig. 84 COMPRESSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 [0/45/135/0/$\overline{90}$]$_s$ LAMINATE TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (Accelerated Weathering)

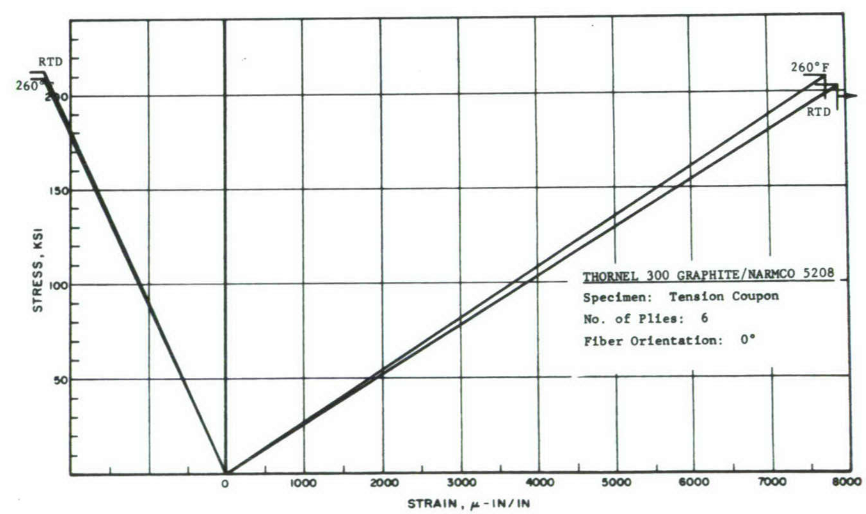

FIG. 85 TENSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F

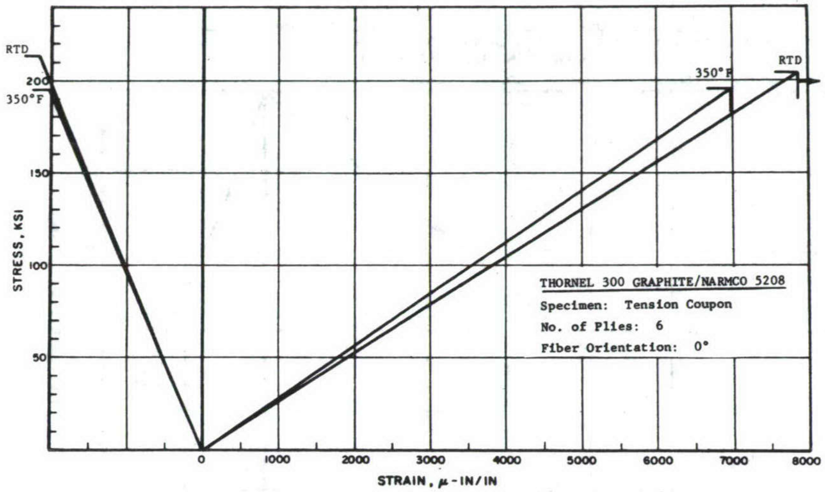

FIG. 86 TENSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

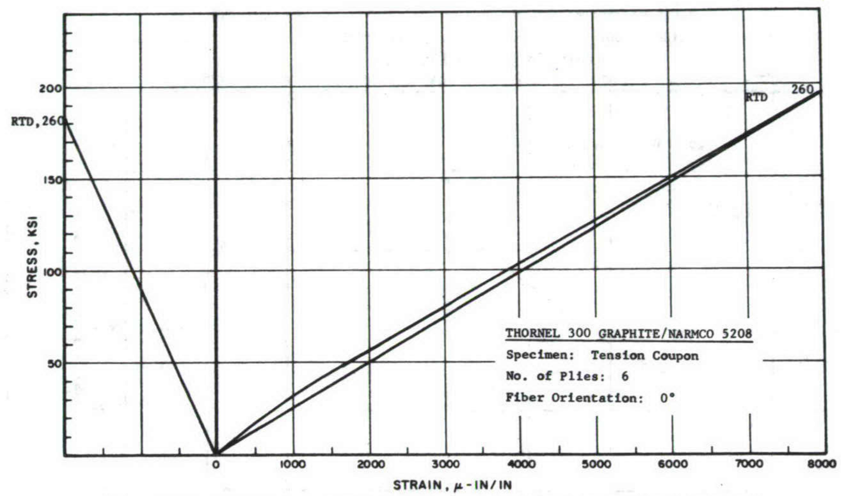

Fig. 87 TENSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F

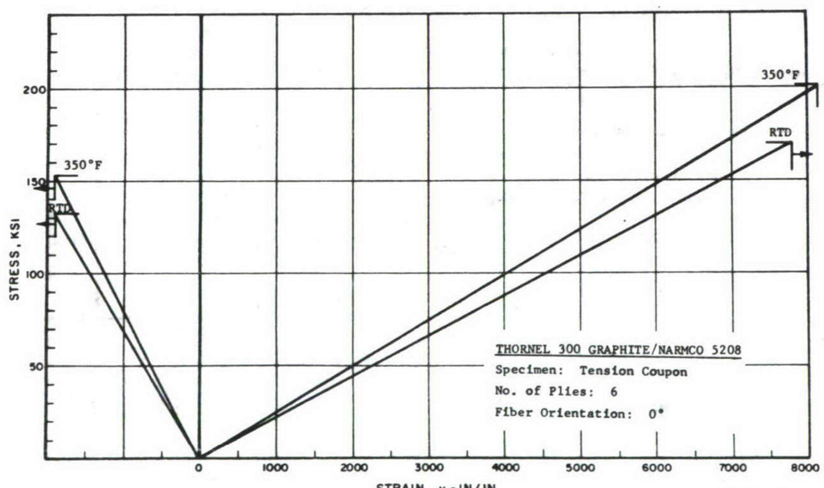

Fig. 88 TENSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO 350°F FOR 500 CYCLES

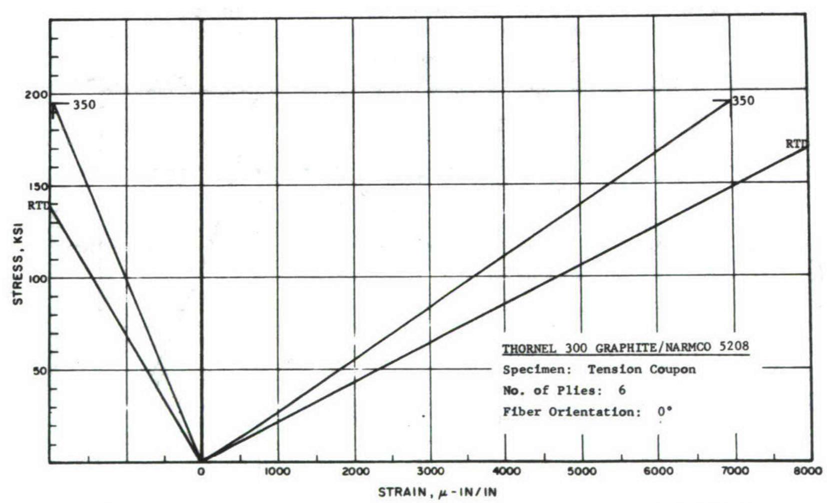

Fig. 89 TENSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 350°F

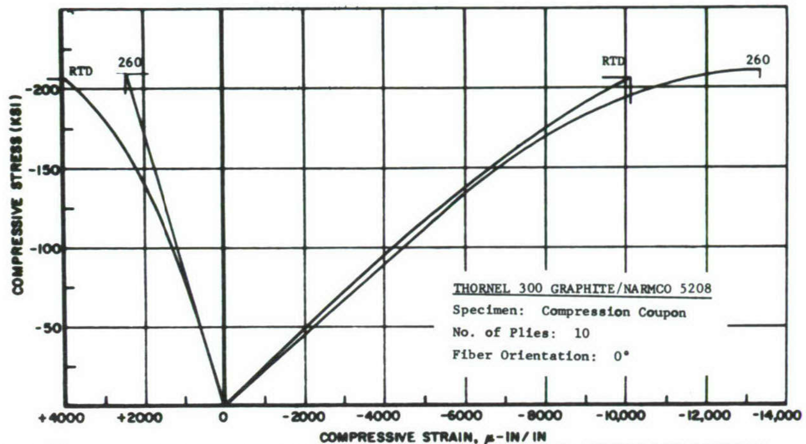

Fig. 90 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F

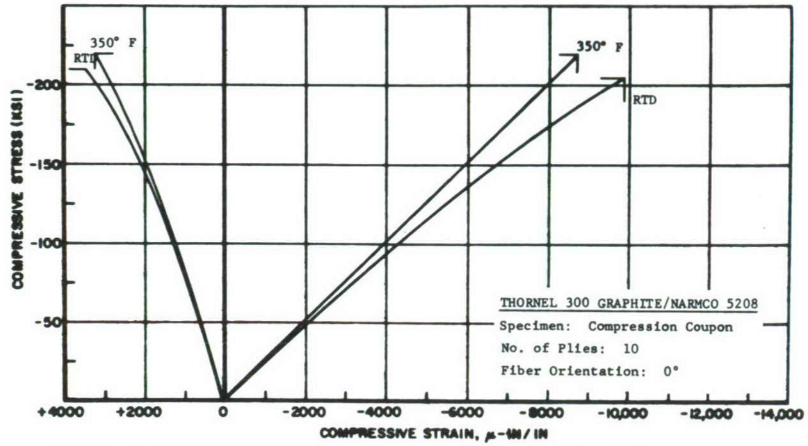

Fig. 91 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

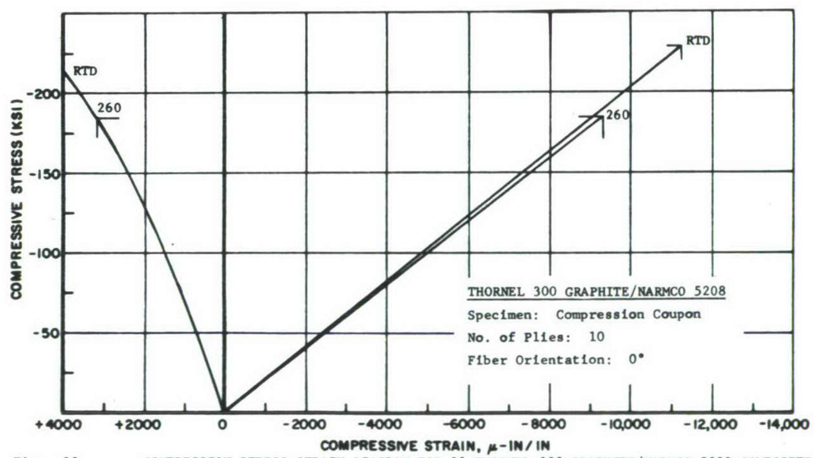

Fig. 92 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F

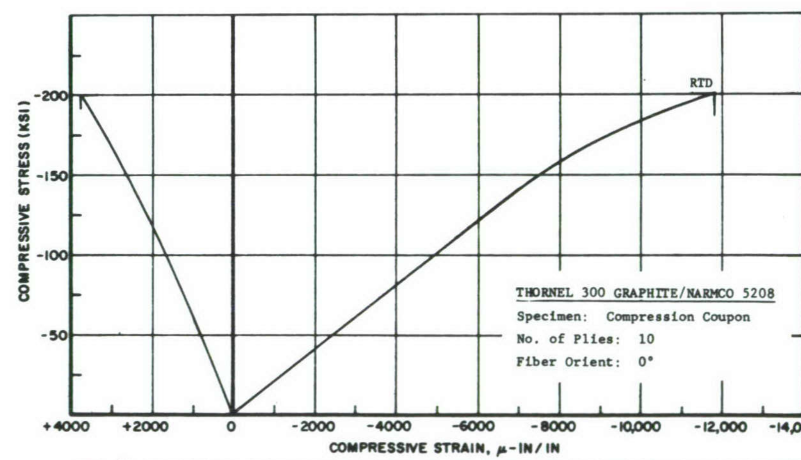

Fig. 93 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT ROOM TEMPERATURE AFTER 500 CYCLES EXPOSURE TO 350°F

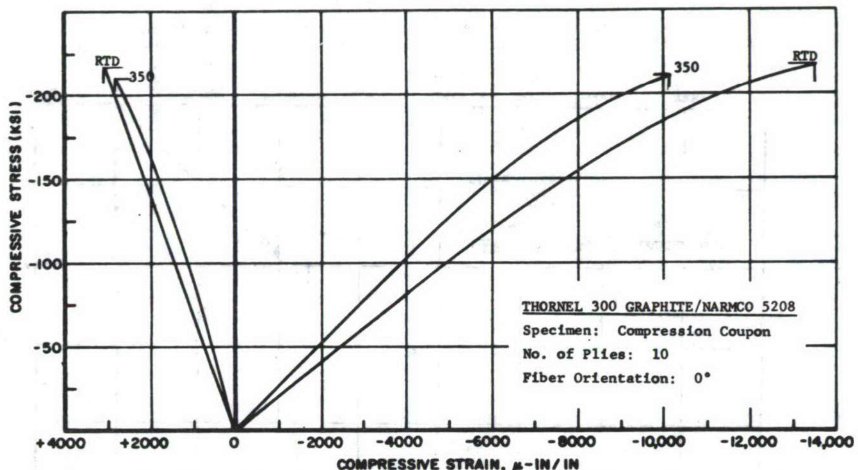

Fig. 94 COMPRESSION STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 350°F

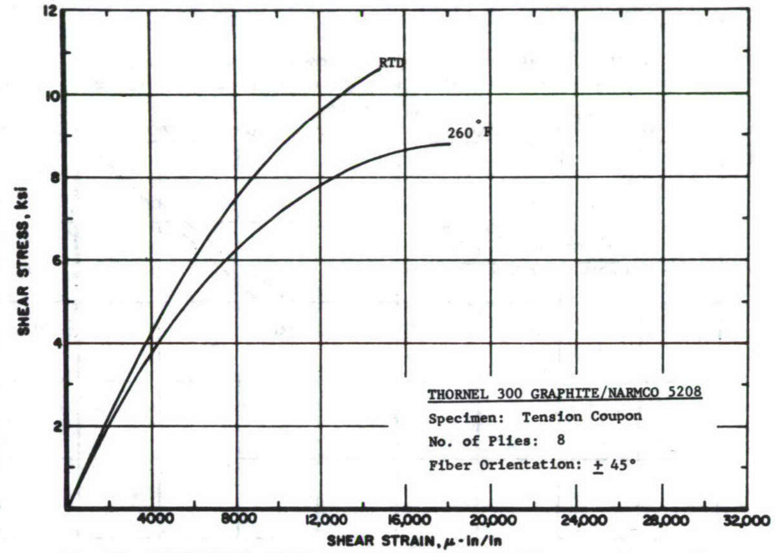

Fig. 95 SHEAR STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 LAMINATE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F

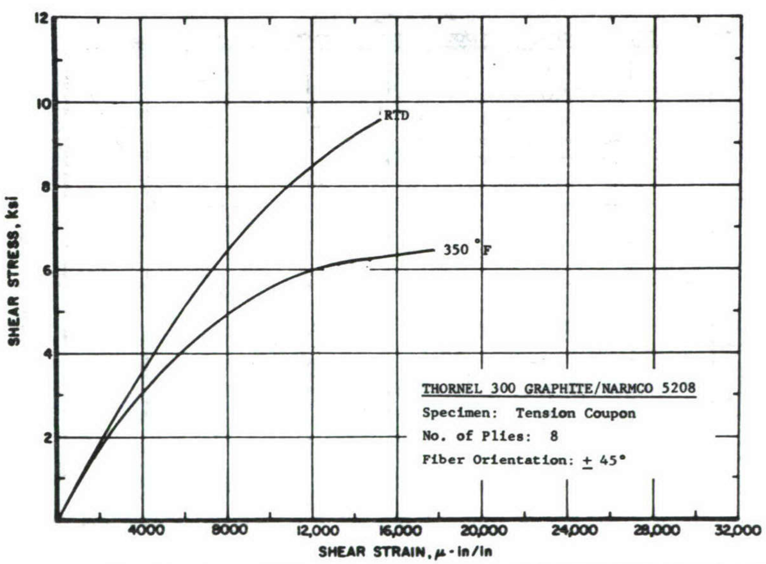

Fig. 96 SHEAR STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 LAMINATE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

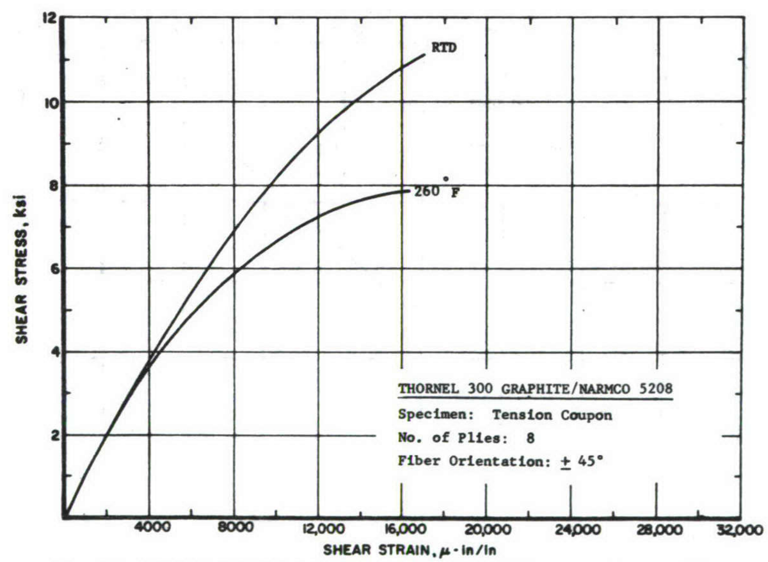

Fig. 97 SHEAR STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F

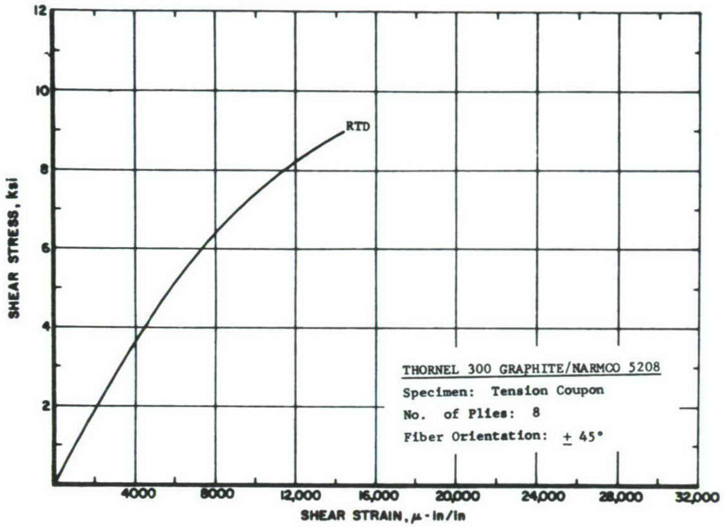

Fig. 98 SHEAR STRESS-STRAIN DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 LAMINATE TESTED AT TOOM TEMPERATURE AFTER 1000 CYCLES EXPOSURE TO 350°F

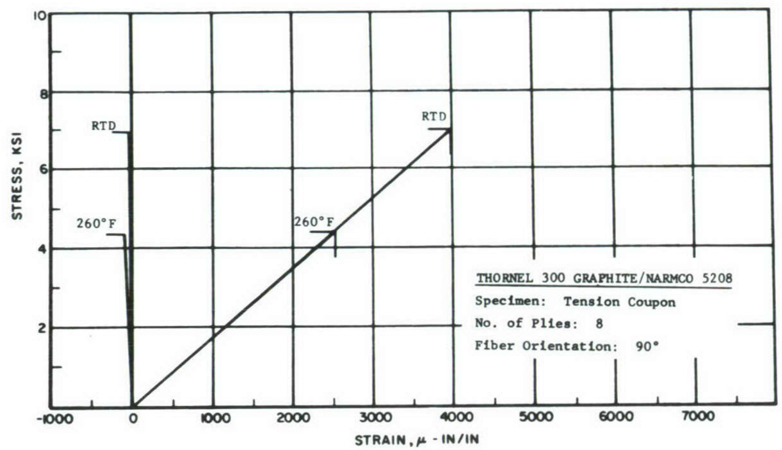

FIG. 99 TENSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F

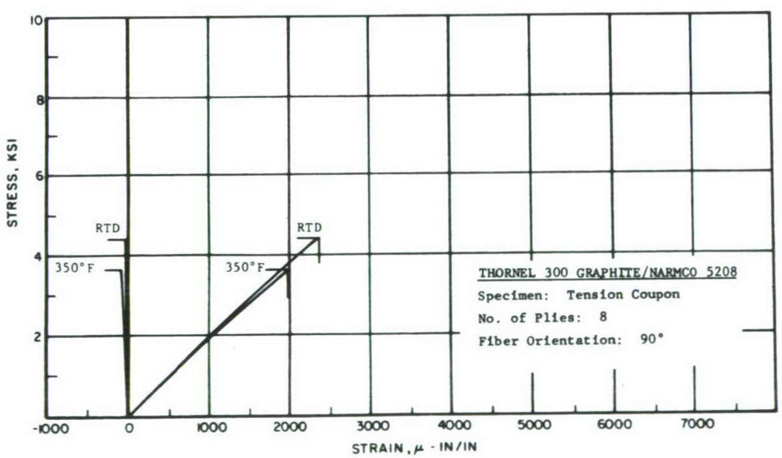

Fig. 100 TENSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

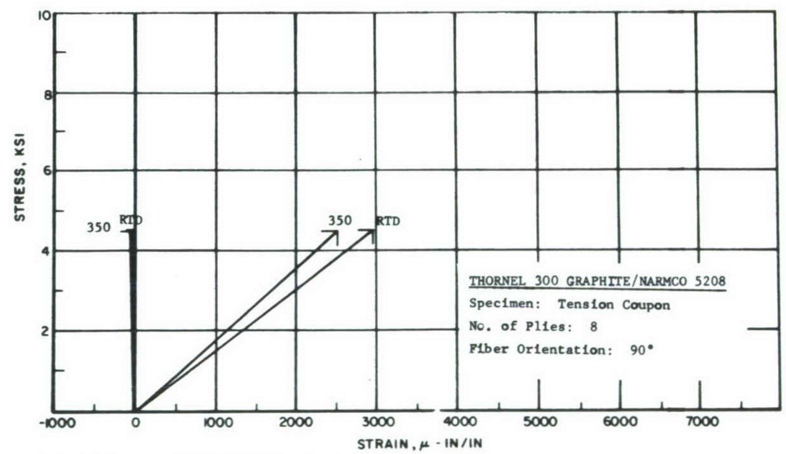

Fig. 101 TENSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F

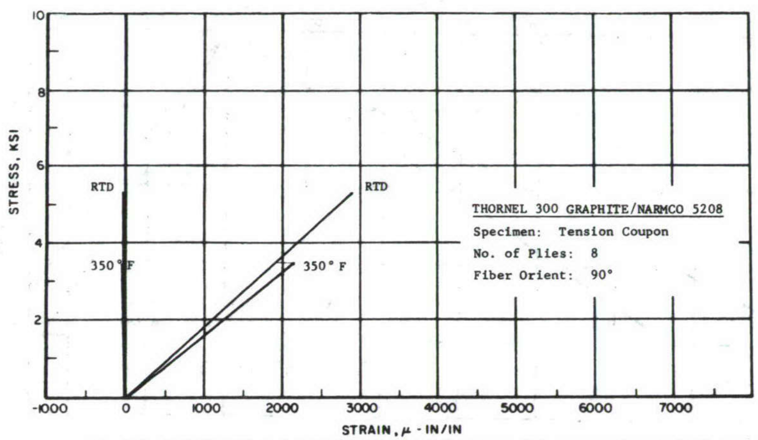

Fig. 102 TENSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT ROOM TEMPERATURE AFTER 500 CYCLES EXPOSURE TO 350°F

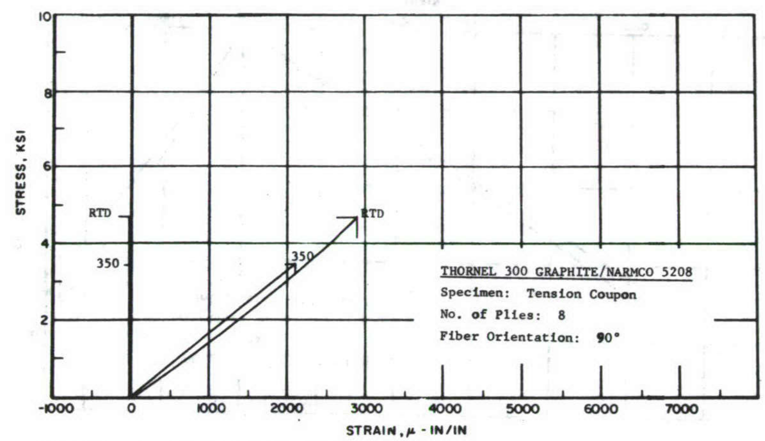

Fig. 103 TENSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 350°F

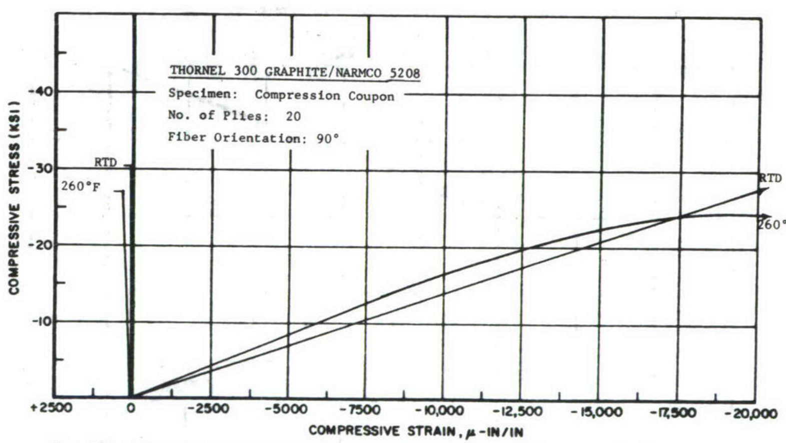

Fig. 104 COMPRESSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F

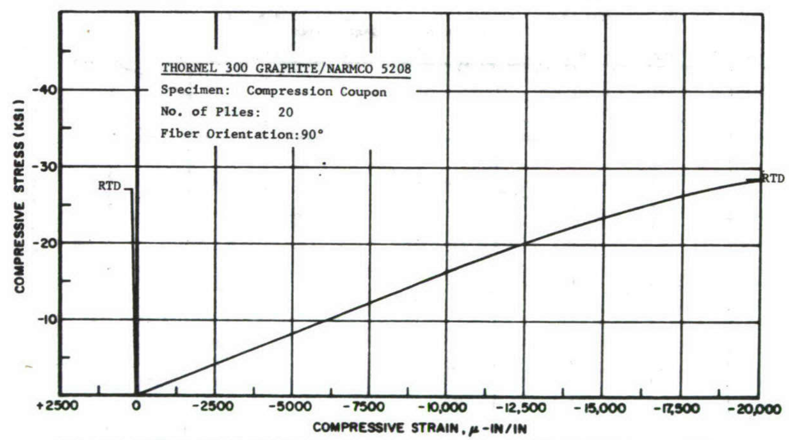

Fig. 105 COMPRESSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

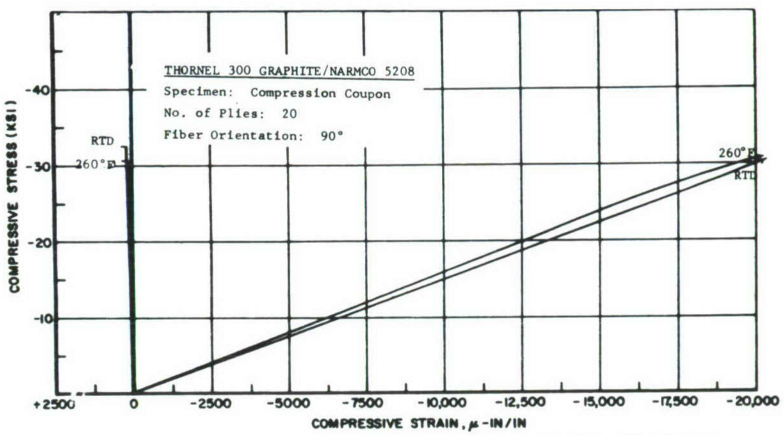

Fig. 106 COMPRESSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F

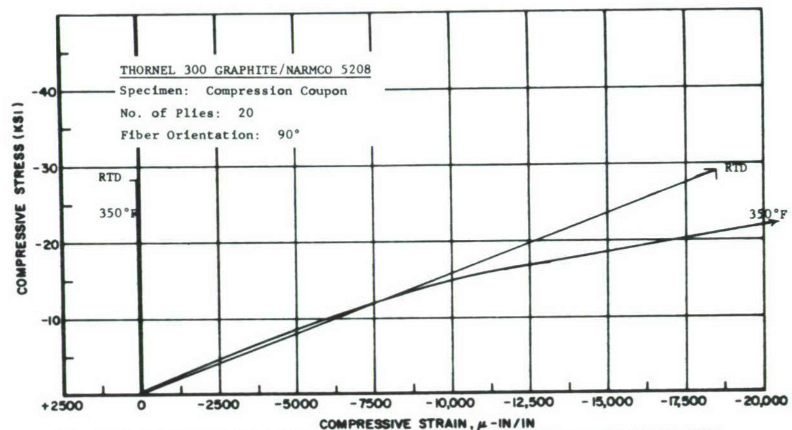

Fig. 107 COMPRESSION STRESS-STRAIN DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 350°F

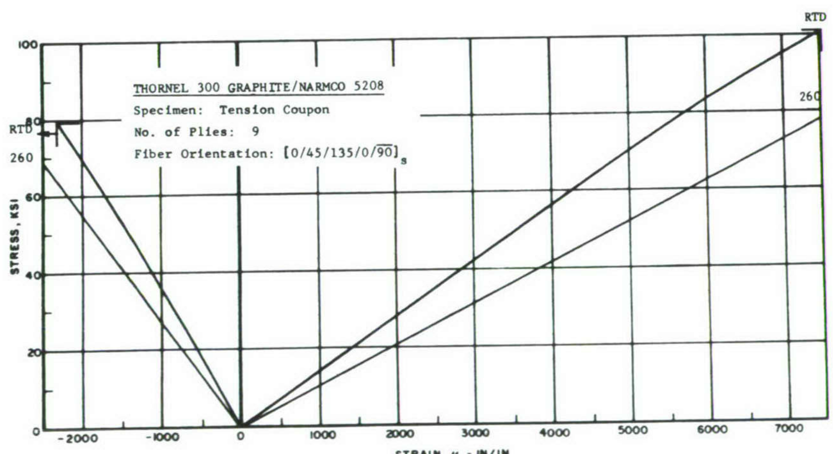

Fig. 108 TENSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F

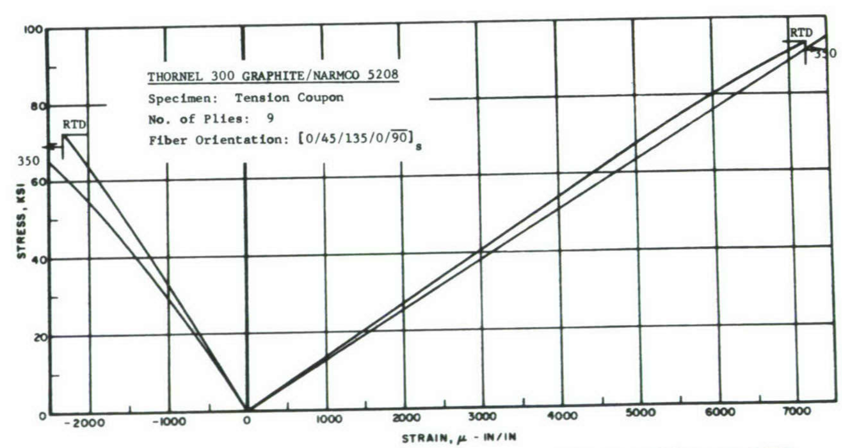

Fig. 109 TENSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

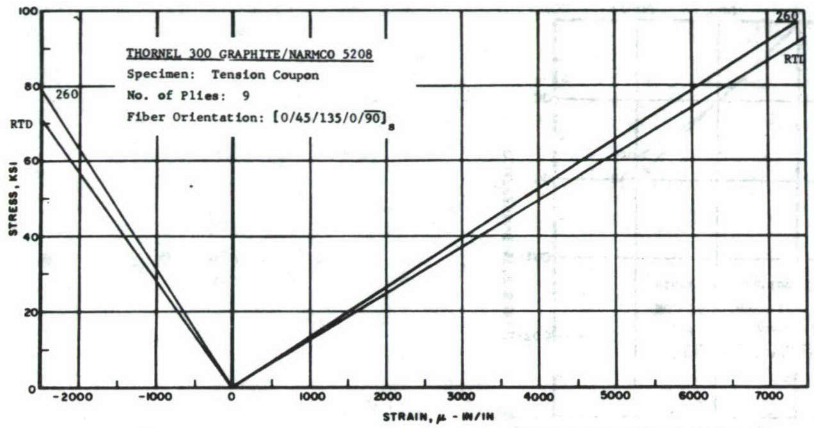

Fig. 110 TENSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 [0/45/135/0/90]$_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F

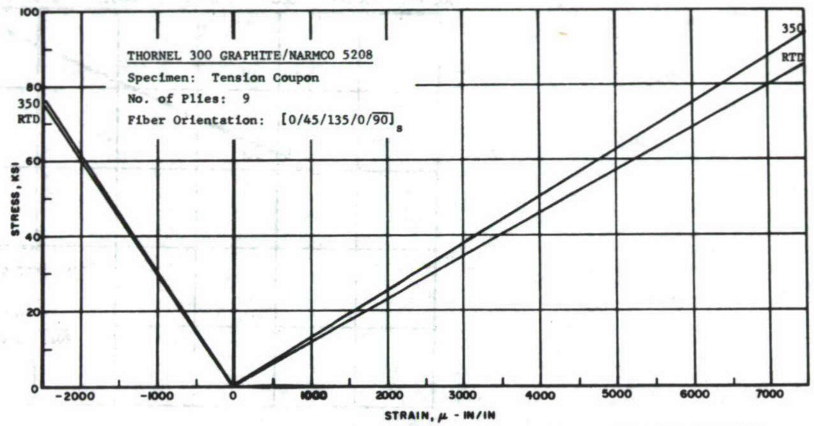

Fig. 111 TENSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 [0/45/135/0/$\overline{90}$]$_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 350°F

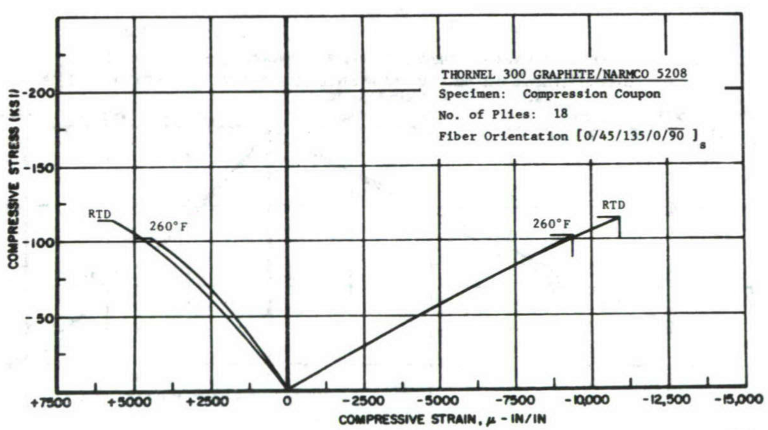

Fig. 112 COMPRESSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 [0/45/135/0/$\overline{90}$]$_s$ LAMINATE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F

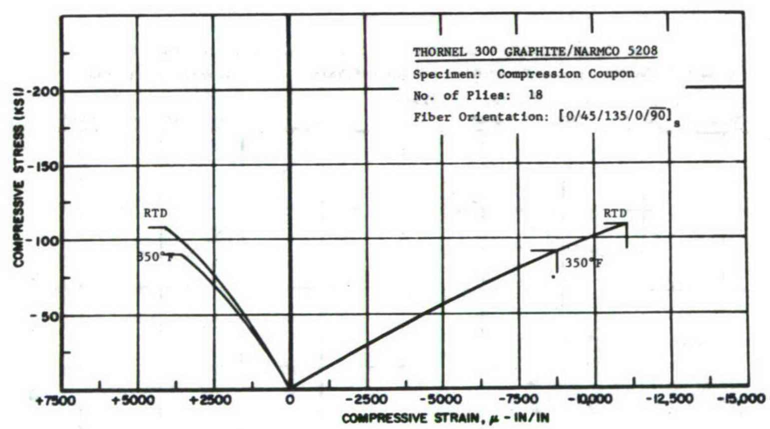

Fig. 113 COMPRESSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 [0/45/135/0/$\overline{90}$]$_s$ LAMINATE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

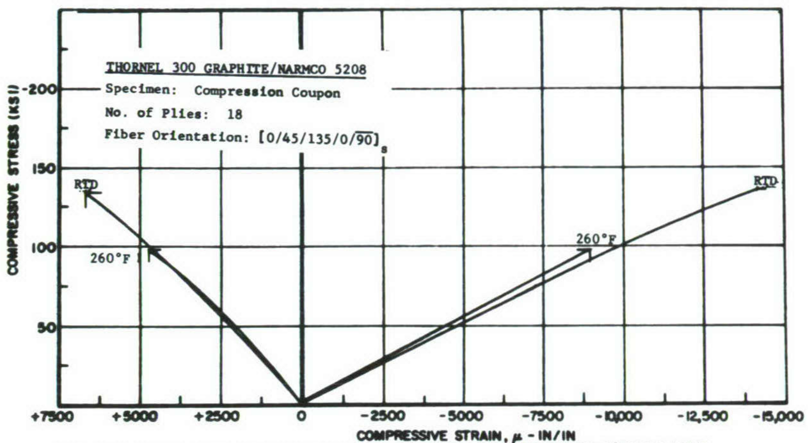

Fig. 114 COMPRESSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F

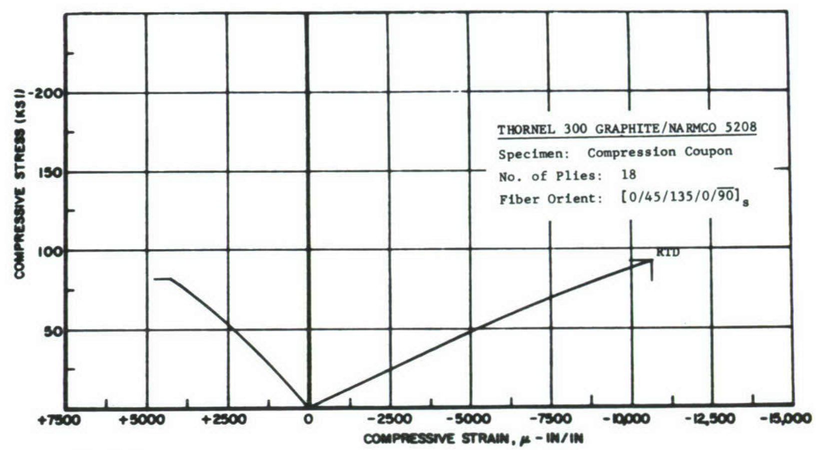

Fig. 115 COMPRESSION STRESS-STRAIN DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT ROOM TEMPERATURE AFTER EXPOSURE TO 350°F FOR 500 CYCLES.

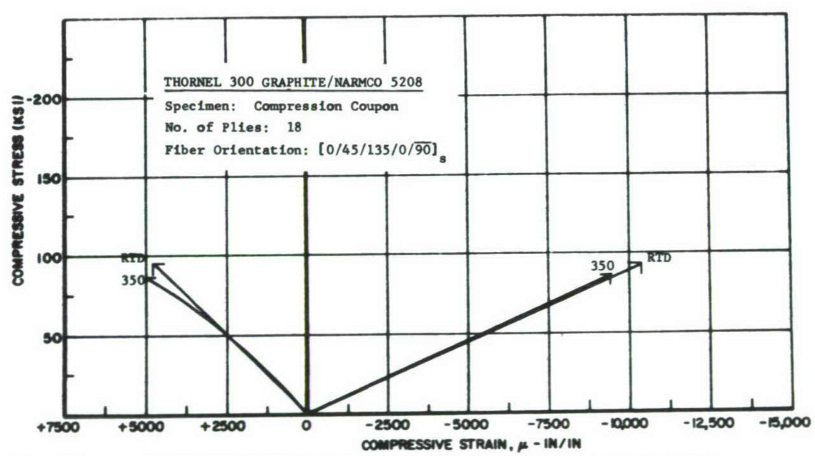

Fig. 116 COMPRESSION STRESS-STRAIN DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 350°F

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	PRIOR CONDITIONING Duration	Test Temp. (°F)	Stress Level ($\%\sigma$ult)	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1305A-6	6 - 0.033	0°	None	-	RTD	82.5	180	-	-	-	Immediate Failure
T1305A-7	6 - 0.032	0°	None	-	RTD	64.3	140	8,000	-	-	
T1305A-8	6 - 0.033	0°	None	-	RTD	55	120	57,000	-	-	
T1305A-9	6 - 0.035	0°	None	-	RTD	51.4	110	-	7.355×10^6	184	
T1305A-10	6 - 0.033	0°	None	-	RTD	57.4	125	4,000	-	-	
T1305A-11	6 - 0.034	0°	None	-	RTD	59.6	130	9,000	-	-	
T1305A-12	6 - 0.033	0°	None	-	RTD	52.8	115	-	2.08×10^6	202.1	
T1305A-13	6 - 0.034	0°	None	-	RTD	61.8	135	2,000	-	-	
T1305A-14	6 - 0.034	0°	None	-	RTD	54.2	118	3,659,000	-	-	
T1305A-15	6 - 0.032	0°	None	-	RTD	61.8	135	-	-	-	Tab Failure
T1302-6	8 - 0.041	90°	None	-	RTD	78.8	4.6	33,000	-	-	
T1302-7	8 - 0.043	90°	None	-	RTD	85.5	5.0	4,000	-	-	
T1302-8	8 - 0.040	90°	None	-	RTD	82.1	4.8	30,000	-	-	
T1302-9	8 - 0.040	90°	None	-	RTD	82.1	4.8	52,000	-	-	
T1302-10	8 - 0.042	90°	None	-	RTD	68.5	4.0	182,000	-	-	
T1302-11	8 - 0.042	90°	None	-	RTD	73.5	4.3	44,000	-	-	
T1302-12	8 - 0.042	90°	None	-	RTD	80.3	4.7	5,000	-	-	
T1302-13	8 - 0.042	90°	None	-	RTD	80.3	4.7	26,000	-	-	
T1302-14	8 - 0.042	90°	None	-	RTD	83.8	4.9	8,000	-	-	
T1302-15	8 - 0.042	90°	None	-	RTD	75.2	4.4	11,000	-	-	
T1327A-6	9 - 0.046	$[0/45/135/0/\overline{90}]_s$	None	-	RTD	57.8	60	-	2.59×10^6	72	Tab Area Failure
T1327A-7	9 - 0.047	$[0/45/135/0/\overline{90}]_s$	None	-	RTD	67.4	70	9,482,000	-	-	Tab Area Failure
T1327A-8	9 - 0.048	$[0/45/135/0/\overline{90}]_s$	None	-	RTD	86.5	90	-	-	-	Immediate Failure
T1327A-9	9 - 0.047	$[0/45/135/0/\overline{90}]_s$	None	-	RTD	77	80	-	-	-	Immediate Failure
T1327A-10	9 - 0.047	$[0/45/135/0/\overline{90}]_s$	None	-	RTD	78.8	82	-	2.501×10^6	105.1	
T1327A-11	9 - 0.047	$[0/45/135/0/\overline{90}]_s$	None	-	RTD	72.1	75	-	2.401×10^6	110.1	
T1327B-1	9 - 0.047	$[0/45/135/0/\overline{90}]_s$	None	-	RTD	81.6	85	118,000	-	-	
T1327B-2	9 - 0.048	$[0/45/135/0/\overline{90}]_s$	None	-	RTD	86.5	90	23,000	-	-	
T1327B-3	9 - 0.048	$[0/45/135/0/\overline{90}]_s$	None	-	RTD	91.3	95	6,000	-	-	
T1327B-4	9 - 0.048	$[0/45/135/0/\overline{90}]_s$	None	-	RTD	77	80	984,000	-	-	

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	PRIOR CONDITIONING Duration	Test Temp. (°F)	Stress Level ($\%\sigma$ult)	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1307A-11	6 - 0.031	0°	None	None	260°F	82.5	180	14,000	-	-	
T1307A-12	6 - 0.032	0°	None	None	260°F	78.0	170	195,000	-	-	
T1307A-13	6 - 0.032	0°	None	None	260°F	75.2	164	60,000	-	-	Possible Tab Failure
T1307A-14	6 - 0.032	0°	None	None	260°F	78.0	170	166,000	-	-	
T1307A-15	6 - 0.030	0°	None	None	260°F	85.0	185	8,000	-	-	
T1307A-16	6 - 0.030	0°	None	None	260°F	85.0	185	2,000	-	-	Tab Failure
T1307A-17	6 - 0.030	0°	None	None	260°F	75.2	164		2,020,000		
T1307A-18	6 - 0.031	0°	None	None	260°F	80.2	175	125,000	-	-	
T1307A-19	6 - 0.031	0°	None	None	260°F	76.6	167	432,000	-	-	
T1307A-20	6 - 0.031	0°	None	None	260°F	82.5	180	1,000	-	-	Tab Failure
T1313-11	8 - 0.047	90°	None	None	260°F	85.1	3.5	1,000	-	-	
T1313-12	8 - 0.040	90°	None	None	260°F	77.9	3.2	15,000	-	-	
T1313-13	8 - 0.041	90°	None	None	260°F	73.0	3.0	47,000	-	-	
T1313-14	8 - 0.040	90°	None	None	260°F	77.9	3.2	22,000	-	-	
T1313-15	8 - 0.039	90°	None	None	260°F	80.3	3.3	15,000	-	-	
T1313-16	8 - 0.041	90°	None	None	260°F	68.1	2.8	127,000	-	-	
T1313-17	8 - 0.039	90°	None	None	260°F	61.0	2.5	10,077,000	-	-	
T1313-18	8 - 0.041	90°	None	None	260°F	73.0	3.0	17,000	-	-	
T1314-1	8 - 0.047	90°	None	None	260°F	82.7	3.4	-	-	-	Immediate Failure
T1314-2	8 - 0.045	90°	None	None	260°F	70.6	2.9	2,000	-	-	
T1333B-2	9 - 0.050	$[0/45/135/0/\overline{90}]_s$	None	None	260°F	91.3	90	8,000	-	-	
T1333B-3	9 - 0.048	$[0/45/135/0/\overline{90}]_s$	None	None	260°F	86.4	85	167,000	-	-	
T1333B-4	9 - 0.046	$[0/45/135/0/\overline{90}]_s$	None	None	260°F	88.3	87	Immediate Failure		-	
T1333B-5	9 - 0.048	$[0/45/135/0/\overline{90}]_s$	None	None	260°F	88.3	87	105,000	-	-	
T1333B-6	9 - 0.047	$[0/45/135/0/\overline{90}]_s$	None	None	260°F	88.3	87	63,000	-	-	
T1333B-7	9 - 0.050	$[0/45/135/0/\overline{90}]_s$	None	None	260°F	91.3	90	2,000	-	-	
T1333B-8	9 - 0.050	$[0/45/135/0/\overline{90}]_s$	None	None	260°F	86.4	85	743,000	-	-	
T1333B-9	9 - 0.048	$[0/45/135/0/\overline{90}]_s$	None	None	260°F	87.3	86	2,659,000	-	-	
T1333B-10	9 - 0.050	$[0/45/135/0/\overline{90}]_s$	None	None	260°F	89.3	88	5,000	-	-	
T1333B-11	9 - 0.050	$[0/45/135/0/\overline{90}]_s$	None	None	260°F	88.5	87.5	3,000	-	-	

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies)	Thickness (In.)	Orientation	PRIOR CONDITIONING Type	PRIOR CONDITIONING Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$)	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1307B-1	6	0.033	0°	None	None	350°F	88.0	183	Immediate Failure		-	
T1307B-2	6	0.032	0°	None	None	350°F	82.0	170	2,000	-	-	
T1307B-3	6	0.034	0°	None	None	350°F	77.0	160	3,000	-	-	
T1307B-4	6	0.034	0°	None	None	350°F	70.0	145	91,000	-	-	
T1307B-5	6	0.030	0°	None	None	350°F	72.1	150	8,000	-	-	
T1307B-6	6	0.032	0°	None	None	350°F	67.3	140	6,000	-	-	
T1307B-7	6	0.033	0°	None	None	350°F	65.0	135	230,000	-	-	
T1307B-8	6	0.035	0°	None	None	350°F	73.0	152	2,000	-	-	
T1307B-9	6	0.035	0°	None	None	350°F	62.5	130	-	2,022,000	197.1	
T1307B-10	6	0.030	0°	None	None	350°F	72.1	150	1,687,000	-	-	
T1314-3	8	0.038	90°	None	None	350°F	86.5	2.5	2,000	-	-	
T1314-4	8	0.039	90°	None	None	350°F	79.6	2.3	3,000	-	-	
T1314-5	8	0.038	90°	None	None	350°F	69.2	2.0	166,000	-	-	
T1314-6	8	0.037	90°	None	None	350°F	83.0	2.4	-	-	-	Tab Failure
T1314-7	8	0.038	90°	None	None	350°F	76.1	2.2	8,000	-	-	
T1314-8	8	0.038	90°	None	None	350°F	72.7	2.1	2,000	-	-	
T1314-9	8	0.036	90°	None	None	350°F	62.2	1.8	160,000	-	-	
T1314-10	8	0.038	90°	None	None	350°F	34.6	1.0	-	2,000,000	2.89	
T1314-11	8	0.038	90°	None	None	350°F		-	-	-	-	Broken in Handling
T1314-12	8	0.037	90°	None	None	350°F		-	-	-	-	Broken in Handling
T1334A-1	9	0.047	$[0/45/135/0/\overline{90}]_s$	None	None	350°F		70	-	2,520,000	100.1	
T1334A-2	9	0.047	$[0/45/135/0/\overline{90}]_s$	None	None	350°F		85	85,000	-	-	
T1334A-3	9	0.048	$[0/45/135/0/\overline{90}]_s$	None	None	350°F		82	2,043,000	-	-	
T1334A-4	9	0.048	$[0/45/135/0/\overline{90}]_s$	None	None	350°F		88	94,000	-	-	
T1334A-5	9	0.047	$[0/45/135/0/\overline{90}]_s$	None	None	350°F		86	37,000	-	-	
T1334A-6	9	0.047	$[0/45/135/0/\overline{90}]_s$	None	None	350°F		84	1,000	-	-	
T1334A-7	9	0.047	$[0/45/135/0/\overline{90}]_s$	None	None	350°F		83	18,000	-	-	
T1334A-8	9	0.048	$[0/45/135/0/\overline{90}]_s$	None	None	350°F		80	95,000	-	-	
T1334A-9	9	0.047	$[0/45/135/0/\overline{90}]_s$	None	None	350°F		87	Immediate Failure		-	
T1334A-10	9	0.047	$[0/45/135/0/\overline{90}]_s$	None	None	350°F		81	222,000	-	-	

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma$ult)	(ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1305B-7	6 - 0.033	0°	98% RH /	500 Hrs.	RTD	80.5	170	693,000	-	-	
T1305B-8	6 - 0.034	0°	98% RH /	500 Hrs.	RTD	87.6	185	28,000	-	-	
T1305B-9	6 - 0.031	0°	98% RH /	500 Hrs.	RTD	85.3	180	704,000	-	-	
T1305B-10	6 - 0.033	0°	98% RH /	500 Hrs.	RTD	90.0	190	1,000	-	-	
T1305B-11	6 - 0.032	0°	98% RH /	500 Hrs.	RTD	89.0	188	Immediate Failure			
T1308B-15	6 - 0.032	0°	98% RH /	500 Hrs.	260°F	95.5	170	6,000	-	-	
T1308B-16	6 - 0.028	0°	98% RH /	500 Hrs.	260°F		180	1,000	-	-	Tab Failure
T1308B-17	6 - 0.030	0°	98% RH /	500 Hrs.	260°F	92.6	165	-	-	-	Immediate Failure
T1308B-18	6 - 0.032	0°	98% RH /	500 Hrs.	260°F	89.8	160	11,000	-	-	Tab Failure
T1308B-19	6 - 0.032	0°	98% RH /	500 Hrs.	260°F	84.2	150	-	2,202,000	199.7	Possible Tab Failure
T1309A-15	6 - 0.029	0°	98% RH /	500 Hrs.	350°F	105.9	160	3,000	-	-	
T1309A-16	6 - 0.033	0°	98% RH /	500 Hrs.	350°F	99.3	150	4,165,000	-	-	
T1309A-17	6 - 0.031	0°	98% RH /	500 Hrs.	350°F	102.6	155	60,000	-	-	
T1309A-18	6 - 0.032	0°	98% RH /	500 Hrs.	350°F	101.3	153	7,000	-	-	
T1309A-19	6 - 0.029	0°	98% RH /	500 Hrs.	350°F	102.0	154	7,000	-	-	
T1305B-12	6 - 0.032	0°	98% RH /	1000 Hrs.	RTD	72.5	140	1,000	-	-	
T1305B-13	6 - 0.033	0°	98% RH /	1000 Hrs.	RTD	64.8	125	2,000	-	-	
T1305B-14	6 - 0.032	0°	98% RH /	1000 Hrs.	RTD	57.0	110	-	2,340,000	146.1	
T1305B-15	6 - 0.033	0°	98% RH /	1000 Hrs.	RTD	62.2	120	4,000	-	-	
T1305B-16	6 - 0.033	0°	98% RH /	1000 Hrs.	RTD	60.0	115	39,000	-	-	
T1308B-20	6 - 0.032	0°	98% RH /	1000 Hrs.	260°F	87.6	170	3,000	-	-	Possible Tab Failure
T1309A-1	6 - 0.029	0°	98% RH /	1000 Hrs.	260°F	85.1	165	15,000	-	-	Possible Tab Failure
T1309A-2	6 - 0.032	0°	98% RH /	1000 Hrs.	260°F	82.5	160	15,000	-	-	Possible Tab Failure
T1309A-3	6 - 0.033	0°	98% RH /	1000 Hrs.	260°F	79.9	155	813,000	-	-	Tab Failure
T1309A-4	6 - 0.033	0°	98% RH /	1000 Hrs.	260°F	81.0	157	13,000	-	-	Tab Failure
T1309A-20	6 - 0.031	0°	98% RH /	1000 Hrs.	350°F	87.2	150	-	2,340,000	255.4	
T1309B-1	6 - 0.031	0°	98% RH /	1000 Hrs.	350°F	95.9	165	2,141,000	-	-	
T1309B-2	6 - 0.031	0°	98% RH /	1000 Hrs.	350°F	101.7	175	-	2,455,000	245.4	
T1309B-3	6 - 0.029	0°	98% RH /	1000 Hrs.	350°F	107.6	185	9,000	-	-	
T1309B-4	6 - 0.031	0°	98% RH /	1000 Hrs.	350°F	104.7	180	81,000	-	-	

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma$ult)	(ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1305B-17	6 - 0.030	0°	Thermo-Humidity	Cycle	RTD	56.3	120	1,000	-	-	
T1305B-18	6 - 0.031	0°	Thermo-Humidity	Cycle	RTD	79.8	170	6,000	-	-	
T1305B-19	6 - 0.031	0°	Thermo-Humidity	Cycle	RTD	75.1	160	14,000	-	-	
T1305B-20	6 - 0.032	0°	Thermo-Humidity	Cycle	RTD	65.7	140	93,000	-	-	
T1305B-21	6 - 0.032	0°	Thermo-Humidity	Cycle	RTD	58.7	125	2,086,000	-	-	
T1309A-5	6 - 0.034	0°	Thermo-Humidity	Cycle	260°F	91.4	170	1,000	-	-	Tab Failure
T1309A-6	6 - 0.029	0°	Thermo-Humidity	Cycle	260°F	88.7	165	-	-	-	Immediate Tab Failure
T1309A-7	6 - 0.031	0°	Thermo-Humidity	Cycle	260°F	83.3	155	428,000			Tab Failure
T1309A-8	6 - 0.029	0°	Thermo-Humidity	Cycle	260°F	86.0	160	4,000			Tab Failure
T1309A-9	6 - 0.032	0°	Thermo-Humidity	Cycle	260°F	81.0	150	748,000			Tab Failure
T1309B-5	6 - 0.032	0°	Thermo-Humidity	Cycle	350°F	104.0	160	1,545,000	-	-	
T1309B-6	6 - 0.030	0°	Thermo-Humidity	Cycle	350°F	110.3	170	262,000	-	-	
T1309B-7	6 - 0.031	0°	Thermo-Humidity	Cycle	350°F	120.1	185	2,000	-	-	
T1309B-8	6 - 0.031	0°	Thermo-Humidity	Cycle	350°F	113.6	175	-	2,015,000	224.0	
T1309B-9	6 - 0.032	0°	Thermo-Humidity	Cycle	350°F	116.9	180	6,000	-	-	
T1305C-1	6 - 0.033	0°	Acc.	Wthrng.	RTD	74.9	170	Immediate Failure		-	
T1305C-2	6 - 0.032	0°	Acc.	Wthrng.	RTD	66.0	150	2,000	-	-	
T1305C-3	6 - 0.033	0°	Acc.	Wthrng.	RTD	57.3	130	2,000	-	-	
T1305C-4	6 - 0.032	0°	Acc.	Wthrng.	RTD	52.9	120	-	2,366,000	167.1	
T1305C-5	6 - 0.032	0°	Acc.	Wthrng.	RTD	55.1	125	2,000	-	-	
T1309A-10	6 - 0.035	0°	Acc.	Wthrng.	260°F	86.2	175	1,000	-	-	
T1309A-11	6 - 0.031	0°	Acc.	Wthrng.	260°F	83.7	170	30,000	-	-	Tab Failure
T1309A-12	6 - 0.032	0°	Acc.	Wthrng.	260°F	81.3	165	32,000	-	-	Tab Failure
T1309A-13	6 - 0.030	0°	Acc.	Wthrng.	260°F	85.7	174	3,000	-	-	Tab Failure
T1309A-14	6 - 0.029	0°	Acc.	Wthrng.	260°F	79.0	160	9,000	-	-	Tab Failure
T1309B-10	6 - 0.032	0°	Acc.	Wthrng.	350°F	76.3	135	-	4,280,000	238.9	
T1309B-11	6 - 0.032	0°	Acc.	Wthrng.	350°F	93.2	165	15,000	-	-	
T1309B-12	6 - 0.032	0°	Acc.	Wthrng.	350°F	84.7	150	-	2,405,000	204.6	
T1309B-13	6 - 0.031	0°	Acc.	Wthrng.	350°F	93.4	160	451,000	-	-	
T1309B-14	6 - 0.030	0°	Acc.	Wthrng.	350°F	92.1	163	1,000	-	-	

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	PRIOR CONDITIONING Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$)	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1328A-6	9 - 0.049	$[0/45/135/0/\overline{90}]_s$	98% RH /	500 Hrs.	RTD	78.7	85	2,003,000	-	-	
T1328A-7	9 - 0.047	"	98% RH /	500 Hrs.	RTD	83.3	90	11,000	-	-	
T1328A-8	9 - 0.048	"	98% RH /	500 Hrs.	RTD	80.5	87	237,000	-	-	
T1328A-9	9 - 0.048	"	98% RH /	500 Hrs.	RTD	81.5	88	355,000	-	-	
T1328A-10	9 - 0.047	"	98% RH /	500 Hrs.	RTD	84.3	91	1,000	-	-	
T1335B-1	9 - 0.048	"	98% RH /	500 Hrs.	260°F		90	9,000	-	-	
T1335B-2	9 - 0.050	"	98% RH /	500 Hrs.	260°F		85	9,000	-	-	
T1335B-3	9 - 0.047	"	98% RH /	500 Hrs.	260°F		80	3,007,000	-	-	
T1335B-4	9 - 0.049	"	98% RH /	500 Hrs.	260°F		84	41,000	-	-	
T1335B-5	9 - 0.049	"	98% RH /	500 Hrs.	260°F		82	126,000	-	-	
T1336B-1	9 - 0.045	"	98% RH /	500 Hrs.	350°F	92.7	85		Failed Under Static Load		
T1336B-2	9 - 0.049	"	98% RH /	500 Hrs.	350°F	87.3	80	62,000	-	-	
T1336B-3	9 - 0.048	"	98% RH /	500 Hrs.	350°F	91.7	84	11,000	-	-	
T1336B-4	9 - 0.048	"	98% RH /	500 Hrs.	350°F	81.9	75	1,097,000	-	-	
T1336B-5	9 - 0.049	"	98% RH /	500 Hrs.	350°F	85.2	78	-	2,460,000	119.2	
T1328A-11	9 - 0.047	"	98% RH /	1000 Hrs.	RTD	87.7	93	3,000	-	-	
T1328B-1	9 - 0.048	"	98% RH /	1000 Hrs.	RTD	80.2	85	1,772,000	-	-	
T1328B-2	9 - 0.049	"	98% RH /	1000 Hrs.	RTD	85.0	90	33,000	-	-	
T1328B-3	9 - 0.049	"	98% RH /	1000 Hrs.	RTD	82.1	87	2,000	-	-	
T1328B-4	9 - 0.045	"	98% RH /	1000 Hrs.	RTD	81.1	86	21,000	-	-	
T1335B-6	9 - 0.048	"	98% RH /	1000 Hrs.	260°F	80.2	85	21,000	-	-	
T1335B-7	9 - 0.048	"	98% RH /	1000 Hrs.	260°F	90.1	88	36,000	-	-	
T1335B-8	9 - 0.050	"	98% RH /	1000 Hrs.	260°F	85.0	83	17,000	-	-	
T1335B-9	9 - 0.048	"	98% RH /	1000 Hrs.	260°F	82.0	80	13,000	-	-	
T1335B-10	9 - 0.049	"	98% RH /	1000 Hrs.	260°F	77.0	75	200,000	-	-	
T1336B-6	9 - 0.048	"	98% RH /	1000 Hrs.	350°F	88.0	85	2,000	-	-	
T1336B-7	9 - 0.047	"	98% RH /	1000 Hrs.	350°F	77.5	75	1,354,000	-	-	
T1336B-8	9 - 0.048	"	98% RH /	1000 Hrs.	350°F	82.7	80	527,000	-	-	
T1336B-9	9 - 0.048	"	98% RH /	1000 Hrs.	350°F	85.0	82	118,000	-	-	
T1336B-10	9 - 0.049	$[0/45/135/0/\overline{90}]_s$	98% RH /	1000 Hrs.	350°F	86.0	83	3,000	-	-	

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$)	(ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1328B-5	9 - 0.049	$[0/45/135/0/\overline{90}]_s$	Thermo-Humidity	Cycle	RTD	78.7	85	3,991,000	-	-	
T1328B-6	9 - 0.048	"	Thermo-Humidity	Cycle	RTD	83.3	90	47,000	-	-	
T1328B-7	9 - 0.046	"	Thermo-Humidity	Cycle	RTD	80.5	87	302,000	-	-	
T1328B-8	9 - 0.049	"	Thermo-Humidity	Cycle	RTD	88.0	95	3,000	-	-	
T1328B-9	9 - 0.049	"	Thermo-Humidity	Cycle	RTD	85.2	92	16,000	-	-	
T1336A-1	9 - 0.048	"	Thermo-Humidity	Cycle	260°F	93.8	80	3,000	-	-	
T1336A-2	9 - 0.048	"	Thermo-Humidity	Cycle	260°F	88.0	75	79,000	-	-	
T1336A-3	9 - 0.045	"	Thermo-Humidity	Cycle	260°F	90.3	77	Immediate Failure		-	
T1336A-4	9 - 0.048	"	Thermo-Humidity	Cycle	260°F	84.4	72		2,302,000	105.8	
T1336A-5	9 - 0.049	"	Thermo-Humidity	Cycle	260°F	96.1	82	133,000	-	-	
T1337A-1	9 - 0.049	"	Thermo-Humidity	Cycle	350°F	99.0	85	2,000	-	-	
T1337A-2	9 - 0.047	"	Thermo-Humidity	Cycle	350°F	93.0	80	8,000	-	-	
T1337A-3	9 - 0.048	"	Thermo-Humidity	Cycle	350°F	76.6	65	1,280,000	-	-	
T1337A-4	9 - 0.048	"	Thermo-Humidity	Cycle	350°F	81.4	70	45,000	-	-	
T1337A-5	9 - 0.049	"	Thermo-Humidity	Cycle	350°F	87.2	75	1,692,000	-	-	
T1328B-10	9 - 0.049	"	Acc. Wthrng.		RTD	64.6	75	-	2,606,000	112.8	
T1328B-11	9 - 0.046	"	Acc. Wthrng.		RTD	73.3	85	3,000	-	-	
T1329A-1	9 - 0.046	"	Acc. Wthrng.		RTD	69.0	80	-	2,471,000	103.5	
T1329A-2	9 - 0.046	"	Acc. Wthrng.		RTD	73.3	85	2,000	-	-	
T1329A-3	9 - 0.048	"	Acc. Wthrng.		RTD	71.0	82	-	2,000,000	101.6	
T1336A-6	9 - 0.047	"	Acc. Wthrng.		260°F	89.3	85	6,000	-	-	
T1336A-7	9 - 0.049	"	Acc. Wthrng.		260°F	84.0	80	79,000	-	-	
T1336A-8	9 - 0.049	"	Acc. Wthrng.		260°F	81.0	77	-	2,242,000	106	
T1336A-9	9 - 0.048	"	Acc. Wthrng.		260°F	86.0	82	128,000	-	-	
T1336A-10	9 - 0.048	"	Acc. Wthrng.		260°F	83.0	79	269,000	-	-	
T1337A-6	9 - 0.048	"	Acc. Wthrng.		350°F	86.6	85	7,000	-	-	
T1337A-7	9 - 0.047	"	Acc. Wthrng.		350°F	76.4	75	1,000	-	-	
T1337A-8	9 - 0.048	"	Acc. Wthrng.		350°F	71.3	70	1,871,000	-	-	
T1337A-9	9 - 0.049	"	Acc. Wthrng.		350°F	81.5	80	23,000	-	-	
T1337A-10	9 - 0.050	$[0/45/135/0/\overline{90}]_s$	Acc. Wthrng.		350°F	76.4	75	42,000	-	-	

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	PRIOR CONDITIONING Duration	Test Temp. (°F)	Stress Level (%σ_{ult}) (ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1306A-9	6 - 0.033	0°	Steady	260°F / 500 Hrs.	RTD	180	Immediate Failure		-	
T1306A-10	6 - 0.034	0°	Steady	260°F / 500 Hrs.	RTD	165	1,000	-	-	
T1306A-11	6 - 0.034	0°	Steady	260°F / 500 Hrs.	RTD	145	2,000	-	-	
T1306A-12	6 - 0.032	0°	Steady	260°F / 500 Hrs.	RTD	135	16,000	-	-	
T1306A-13	6 - 0.028	0°	Steady	260°F / 500 Hrs.	RTD	125	-	2,300,000	169.2	
T1306A-14	6 - 0.031	0°	Steady	350°F / 500 Hrs.	RTD	150	-	2,002,000	193.5	
T1306A-15	6 - 0.031	0°	Steady	350°F / 500 Hrs.	RTD	175	2,632,000	-	-	
T1306A-16	6 - 0.032	0°	Steady	350°F / 500 Hrs.	RTD	190	1,000	-	-	
T1306A-17	6 - 0.031	0°	Steady	350°F / 500 Hrs.	RTD	180	-	3,470,000	216.2	
T1306A-18	6 - 0.033	0°	Steady	350°F / 500 Hrs.	RTD	185	2,000	-	-	
T1306A-19	6 - 0.034	0°	Cyclic	260°F / 500 Cyc.	RTD	170	-	-	-	Immediate Tab Failure
T1306A-20	6 - 0.033	0°	Cyclic	260°F / 500 Cyc.	RTD	155	-	-	-	Immediate Tab Failure
T1306B-1	6 - 0.033	0°	Cyclic	260°F / 500 Cyc.	RTD	150	1,000	-	-	Tab Failure
T1306B-2	6 - 0.032	0°	Cyclic	260°F / 500 Cyc.	RTD	130	55,000	-	-	Tab Failure
T1306B-3	6 - 0.034	0°	Cyclic	260°F / 500 Cyc.	RTD	120	-	2,174,000	223.3	
T1306B-4	6 - 0.030	0°	Cyclic	260°F / 1000 Cyc.	RTD	150	26,000	-	-	Tab Failure
T1306B-5	6 - 0.029	0°	Cyclic	260°F / 1000 Cyc.	RTD	140	4,000	-	-	Tab Failure
T1306B-6	6 - 0.030	0°	Cyclic	260°F / 1000 Cyc.	RTD	130	-	2,035,000	176.4	Tab Failure
T1306B-7	6 - 0.029	0°	Cyclic	260°F / 1000 Cyc.	RTD	135	7,000	-	-	Tab Failure
T1306B-8	6 - 0.031	0°	Cyclic	260°F / 1000 Cyc.	RTD	145	1,000	-	-	Tab Failure
T1306B-9	6 - 0.032	0°	Cyclic	350°F / 500 Cyc.	RTD	180	-	-	-	Immediate Tab Failure
T1306B-10	6 - 0.030	0°	Cyclic	350°F / 500 Cyc.	RTD	170	-	-	-	Immediate Tab Failure
T1306B-11	6 - 0.033	0°	Cyclic	350°F / 500 Cyc.	RTD	150	-	-	-	Immediate Tab Failure
T1306B-12	6 - 0.033	0°	Cyclic	350°F / 500 Cyc.	RTD	130	2,000	-	-	Tab Failure
T1306B-13	6 - 0.029	0°	Cyclic	350°F / 500 Cyc.	RTD	120	545,000	-	-	Tab Failure
T1306B-14	6 - 0.032	0°	Cyclic	350°F / 1000 Cyc.	RTD	165	Immediate Failure		-	
T1306B-15	6 - 0.034	0°	Cyclic	350°F / 1000 Cyc.	RTD	140	3,000	-	-	
T1306B-16	6 - 0.033	0°	Cyclic	350°F / 1000 Cyc.	RTD	125	-	7,126,000	164.5	
T1306B-17	6 - 0.034	0°	Cyclic	350°F / 1000 Cyc.	RTD	130	-	2,575,000	204.3	
T1306B-18	6 - 0.028	0°	Cyclic	350°F / 1000 Cyc.	RTD	137	Immediate Failure		-	

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	PRIOR CONDITIONING Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$) (ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1311A-5	6 - 0.029	0°	260°F	/ 500 Cyc.	260°F	160	-	2,007,000	240.6	
T1311A-6	6 - 0.028	0°	260°F	/ 500 Cyc.	260°F	180	4,000	-	-	
T1311A-7	6 - 0.031	0°	260°F	/ 500 Cyc.	260°F	175	6,000	-	-	Tab Failure
T1311A-8	6 - 0.032	0°	260°F	/ 500 Cyc.	260°F	170	7,000	-	-	Tab Failure
T1311A-9	6 - 0.032	0°	260°F	/ 500 Cyc.	260°F	165	200,000	-	-	
T1311A-10	6 - 0.031	0°	260°F	/ 500 Hrs.	260°F	180	7,000	-	-	Possible Tab Failure
T1311A-11	6 - 0.032	0°	260°F	/ 500 Hrs.	260°F	160	932,000	-	-	
T1311A-12	6 - 0.030	0°	260°F	/ 500 Hrs.	260°F	170	6,000	-	-	Possible Tab Failure
T1311A-13	6 - 0.031	0°	260°F	/ 500 Hrs.	260°F	175	20,000	-	-	
T1311A-14	6 - 0.032	0°	260°F	/ 500 Hrs.	260°F	165	2,437,000	-	-	
T1311A-15	6 - 0.029	0°	260°F	/ 1000 Cyc.	260°F	160	527,000	-	-	
T1311A-16	6 - 0.028	0°	260°F	/ 1000 Cyc.	260°F	180	39,000	-	-	
T1311A-17	6 - 0.029	0°	260°F	/ 1000 Cyc.	260°F	185	1,000	-	-	Tab Failure
T1311A-18	6 - 0.030	0°	260°F	/ 1000 Cyc.	260°F	177	17,000	-	-	
T1311A-19	6 - 0.031	0°	260°F	/ 1000 Cyc.	260°F	170	32,000	-	-	
T1311B-1	6 - 0.029	0°	350°F	/ 500 Cyc.	350°F	170	45,000	-	-	
T1311B-2	6 - 0.030	0°	350°F	/ 500 Cyc.	350°F	180	2,000	-	-	
T1311B-3	6 - 0.029	0°	350°F	/ 500 Cyc.	350°F	160	22,000	-	-	
T1311B-4	6 - 0.031	0°	350°F	/ 500 Cyc.	350°F	175	46,000	-	-	
T1311B-5	6 - 0.030	0°	350°F	/ 500 Cyc.	350°F	165	393,000	-	-	
T1311B-6	6 - 0.028	0°	350°F	/ 500 Hrs.	350°F	140	679,000	-	-	
T1311B-7	6 - 0.028	0°	350°F	/ 500 Hrs.	350°F	150	1,288,000	-	-	
T1311B-8	6 - 0.027	0°	350°F	/ 500 Hrs.	350°F	160	630,000	-	-	
T1311B-9	6 - 0.031	0°	350°F	/ 500 Hrs.	350°F	170	61,000	-	-	
T1311B-10	6 - 0.033	0°	350°F	/ 500 Hrs.	350°F	180	3,000	-	-	
T1311B-11	6 - 0.031	0°	350°F	/ 1000 Cyc.	350°F	170	41,000	-	-	
T1311B-12	6 - 0.030	0°	350°F	/ 1000 Cyc.	350°F	160	2,366,000	-	-	
T1311B-13	6 - 0.030	0°	350°F	/ 1000 Cyc.	350°F	180	9,000	-	-	
T1311B-14	6 - 0.032	0°	350°F	/ 1000 Cyc.	350°F	165	636,000	-	-	
T1311B-15	6 - 0.032	0°	350°F	/ 1000 Cyc.	350°F	168		2,530,000	233.7	

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$) (ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1330B-1	9 - 0.048	$[0/45/135/0/\overline{90}]_s$	260°F /	500 Hrs.	RTD	80	-	2,826,000	108.8	
T1330B-2	9 - 0.047	"	260°F /	500 Hrs.	RTD	87	15,000	-	-	
T1330B-3	9 - 0.048	"	260°F /	500 Hrs.	RTD	85	16,000	-	-	
T1330B-4	9 - 0.046	"	260°F /	500 Hrs.	RTD	82	-	2,034,000	113.5	
T1330B-5	9 --0.046	"	260°F /	500 Hrs.	RTD	84	-	1,833,000	-	
T1330B-6	9 - 0.048	"	350°F /	500 Hrs.	RTD	80	917,000	-	-	
T1330B-7	9 - 0.048	"	350°F /	500 Hrs.	RTD	81	Immediate Failure		-	
T1330B-8	9 - 0.047	"	350°F /	500 Hrs.	RTD	90	1,000	-	-	
T1330B-9	9 - 0.048	"	350°F /	500 Hrs.	RTD	85	2,000	-	-	
T1330B-10	9 - 0.047	"	350°F /	500 Hrs.	RTD	83	Immediate Failure		-	
T1331A-1	9 - 0.047	"	260°F /	500 Cyc.	RTD	90	3,000	-	-	Tab Failure
T1331A-2	9 - 0.048	"	260°F /	500 Cyc.	RTD	85	101,000	-	-	Tab Failure
T1331A-3	9 - 0.048	"	260°F /	500 Cyc.	RTD	80	-	2,582,000	115.0	
T1331A-4	9 - 0.049	"	260°F /	500 Cyc.	RTD	87	-	2,418,000	107.5	
T1331A-5	9 - 0.050	"	260°F /	500 Cyc.	RTD	93	4,000	-	-	Tab Failure
T1331A-6	9 - 0.049	"	260°F /	1000 Cyc.	RTD	85	392,000	-	-	
T1331A-7	9 - 0.049	"	260°F /	1000 Cyc.	RTD	95	3,000	-	-	Possible Tab Failure
T1331A-8	9 - 0.049	"	260°F /	1000 Cyc.	RTD	90	456,000	-	-	
T1331A-9	9 - 0.049	"	260°F /	1000 Cyc.	RTD	93	41,000	-	-	
T1331A-10	9 - 0.049	"	260°F /	1000 Cyc.	RTD	87	105,000	-	-	
T1330A-8	9 - 0.047	"	350°F /	1000 Cyc.	RTD	90	32,000	-	-	
T1330A-9	9 - 0.047	"	350°F /	1000 Cyc.	RTD	85	99,000	-	-	
T1330A-10	9 - 0.047	"	350°F /	1000 Cyc.	RTD	80		2,422,000	111.6	
T1331B-1	9 - 0.049	"	350°F /	1000 Cyc.	RTD	87	506,000	-	-	
T1331B-2	9 - 0.049	"	350°F /	1000 Cyc.	RTD	92	79,000	-	-	
T1331B-3	9 - 0.049	"	350°F /	500 Cyc.	RTD	85	972,000	-	-	
T1331B-4	9 - 0.049	"	350°F /	500 Cyc.	RTD	90	2,000	-	-	
T1331B-5	9 - 0.050	"	350°F /	500 Cyc.	RTD	87	587,000	-	-	
T1331B-6	9 - 0.050	"	350°F /	500 Cyc.	RTD	88	986,000	-	-	
T1331B-7	9 - 0.049	$[0/45/135/0/\overline{90}]_s$	350°F /	500 Cyc.	RTD	89	985,000	-	-	

TABLE XI FATIGUE PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	PRIOR CONDITIONING Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$) (ksi)	Cycles to Failure (cycles)	Cycles Applied without Failure (cycles)	Residual Strength (ksi)	Comment
T1340A-1	9 - 0.048	$[0/45/135/0/\overline{90}]_s$	260°F	/ 500 Hrs.	260°F	85	155,000	-	-	
T1340A-2	9 - 0.048	"	260°F	/ 500 Hrs.	260°F	80	1,883,000	-	-	
T1340A-3	9 - 0.049	"	260°F	/ 500 Hrs.	260°F	90	238,000	-	-	
T1340A-4	9 - 0.049	"	260°F	/ 500 Hrs.	260°F	88	175,000	-	-	
T1340A-5	9 - 0.049	"	260°F	/ 500 Hrs.	260°F	93	9,000	-	-	
T1340A-6	9 - 0.049	"	260°F	/ 500 Cyc.	260°F	80		2,587,000	90.8	
T1340A-7	9 - 0.048	"	260°F	/ 500 Cyc.	260°F	90	1,000	-	-	
T1340A-8	9 - 0.050	"	260°F	/ 500 Cyc.	260°F	85	-	-	-	Immediate Tab Failure
T1340A-9	9 - 0.048	"	260°F	/ 500 Cyc.	260°F	87	226,000	-	-	
T1340A-10	9 - 0.050	"	260°F	/ 500 Cyc.	260°F	83	-	-	-	Immediate Tab Failure
T1340B-1	9 - 0.049	"	260°F	/ 1000 Cyc.	260°F	85	138,000	-	-	Tab Failure
T1340B-2	9 - 0.047	"	260°F	/ 1000 Cyc.	260°F	90	104,000			
T1340B-3	9 - 0.048	"	260°F	/ 1000 Cyc.	260°F	80	1,468,000			
T1340B-4	9 - 0.048	"	260°F	/ 1000 Cyc.	260°F	95	24,000			Tab Failure
T1340B-5	9 - 0.048	"	260°F	/ 1000 Cyc.	260°F	84	679,000			
T1340B-6	9 - 0.049	"	350°F	/ 500 Hrs.	350°F	80	79,000	-	-	
T1340B-7	9 - 0.049	"	350°F	/ 500 Hrs.	350°F	85	1,000	-	-	
T1340B-8	9 - 0.049	"	350°F	/ 500 Hrs.	350°F	82	2,000	-	-	
T1340B-9	9 - 0.049	"	350°F	/ 500 Hrs.	350°F	75	374,000	-	-	
T1340B-10	9 - 0.049	"	350°F	/ 500 Hrs.	350°F	83	2,000	-	-	
T1341A-6	9 - 0.049	"	350°F	/ 500 Cyc.	350°F	78	7,294,000	-	-	
T1341A-7	9 - 0.048	"	350°F	/ 500 Cyc.	350°F	85	47,000	-	-	
T1341A-8	9 - 0.049	"	350°F	/ 500 Cyc.	350°F	90	38,000	-	-	
T1341A-9	9 - 0.049	"	350°F	/ 500 Cyc.	350°F	95	2,000	-	-	
T1341A-10	9 - 0.049	"	350°F	/ 500 Cyc.	350°F	83	298,000	-	-	
T1341A-1	9 - 0.048	"	350°F	/ 1000 Cyc.	350°F	80	1,434,000	-	-	
T1341A-2	9 - 0.048	"	350°F	/ 1000 Cyc.	350°F	90	13,000	-	-	
T1341A-3	9 - 0.049	"	350°F	/ 1000 Cyc.	350°F	83	15,000	-	-	
T1341A-4	9 - 0.049	"	350°F	/ 1000 Cyc.	350°F	93	6,000	-	-	
T1341A-5	9 - 0.049	$[0/45/135/0/\overline{90}]_s$	350°F	/ 1000 Cyc.	350°F	86	45,000	-	-	

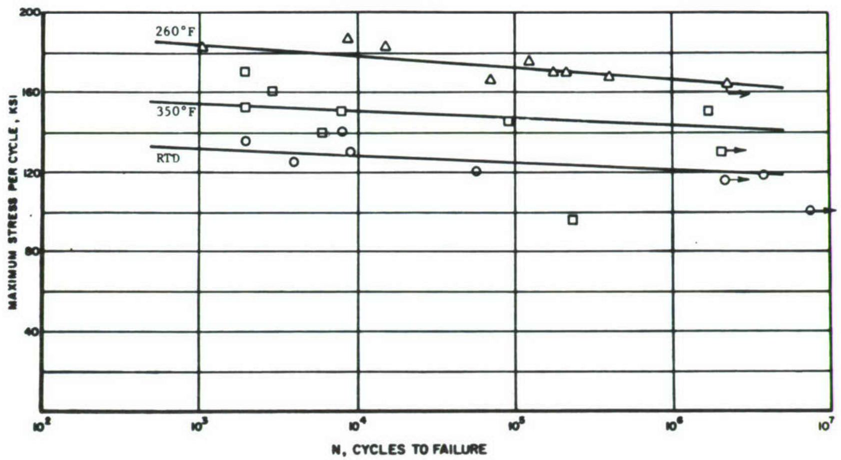

Fig. 117 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES (R = 0.1, Φ = 1800 CPM)

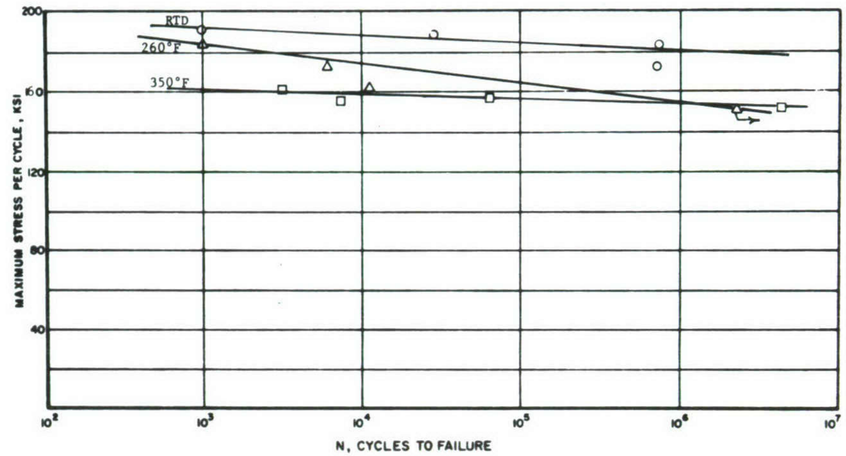

Fig. 118 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 98% R.H. (R = 0.1, Φ = 1800 CPM)

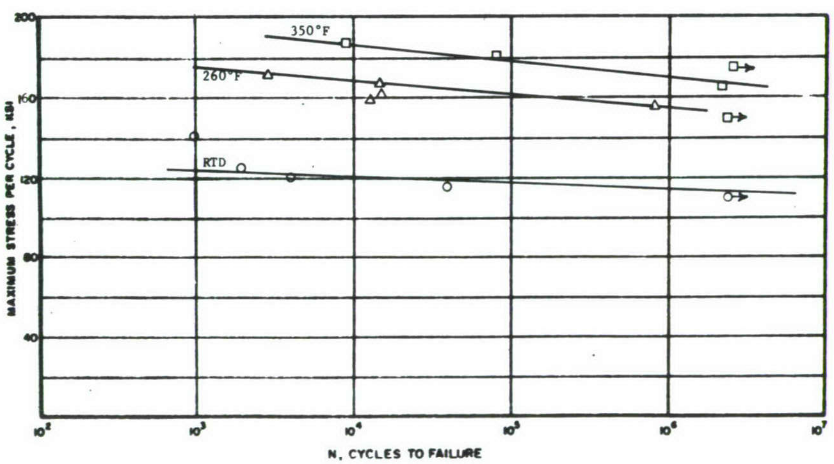

Fig. 119 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 HOURS EXPOSURE TO 98% R.H. (R = 0.1, Φ = 1800 CPM)

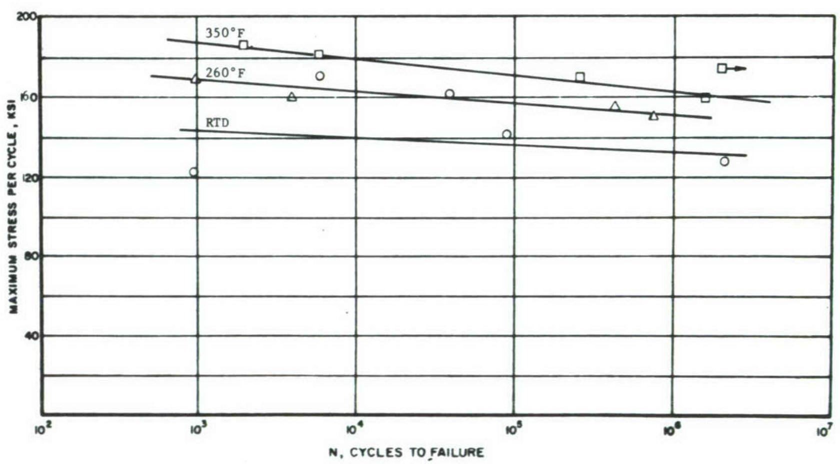

Fig. 120 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-Humidity Cycle) (R = 0.1, Φ = 1800 CPM)

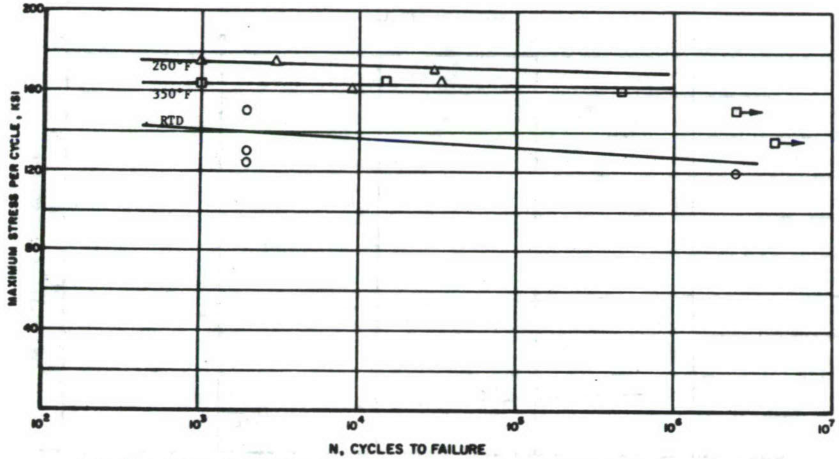

Fig. 121 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (Accelerated Weathering)($R = 0.1$, $\Phi = 1800$ CPM)

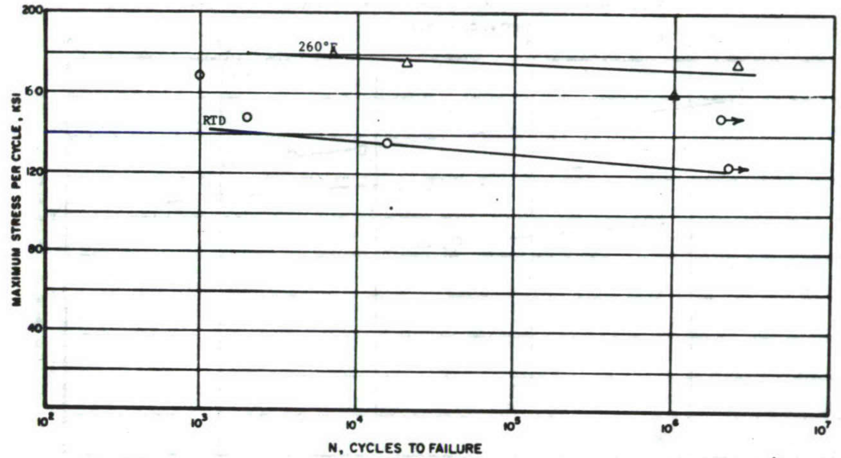

Fig. 122 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F ($R = 0.1$, $\Phi = 1800$ CPM)

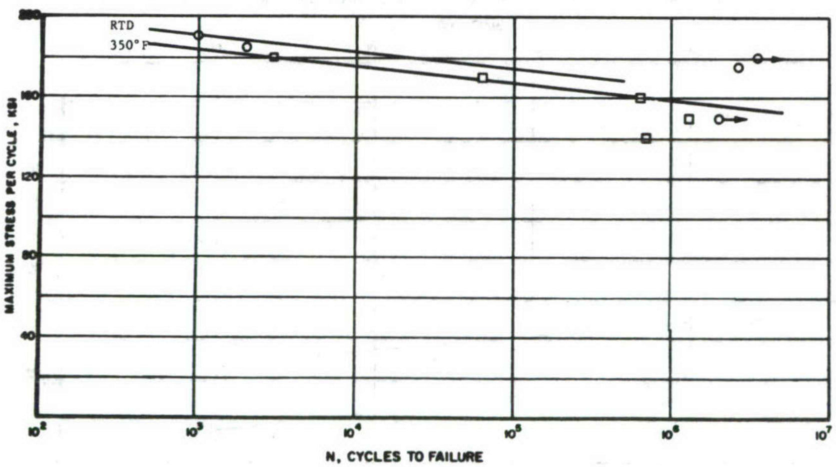

Fig. 123 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

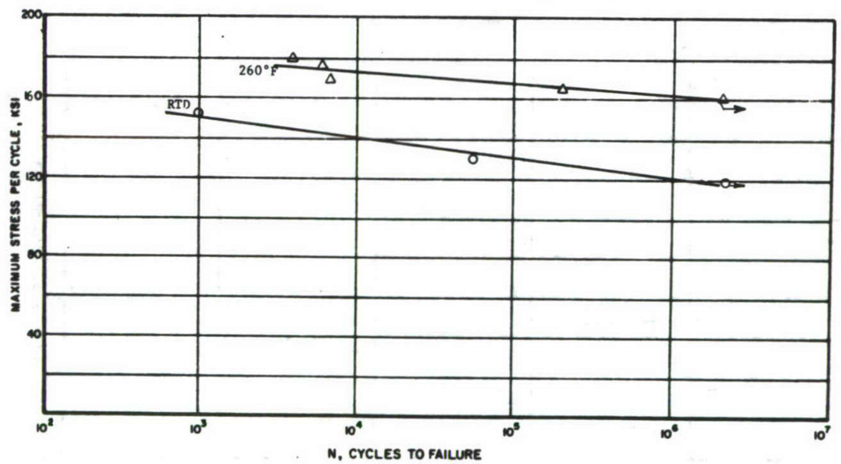

Fig. 124 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 500 CYCLES EXPOSURE TO 260°F ($R = 0.1$, $\Phi = 1800$ cpm)

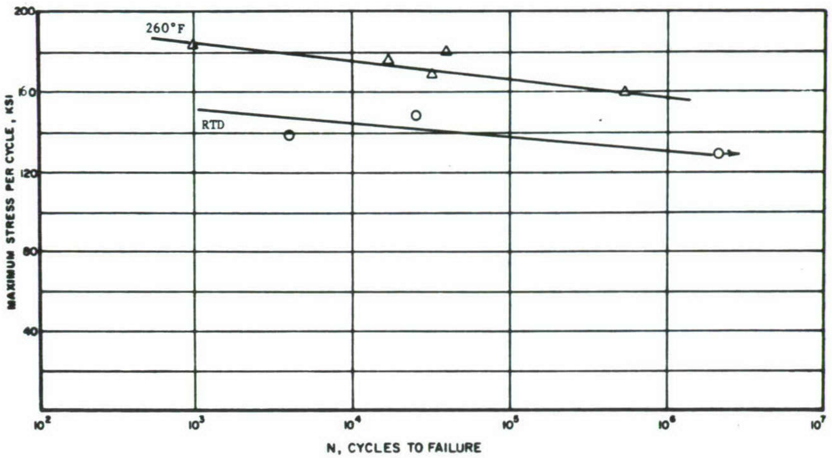

Fig. 125 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F (R = 0.1, Φ = 1800 CPM)

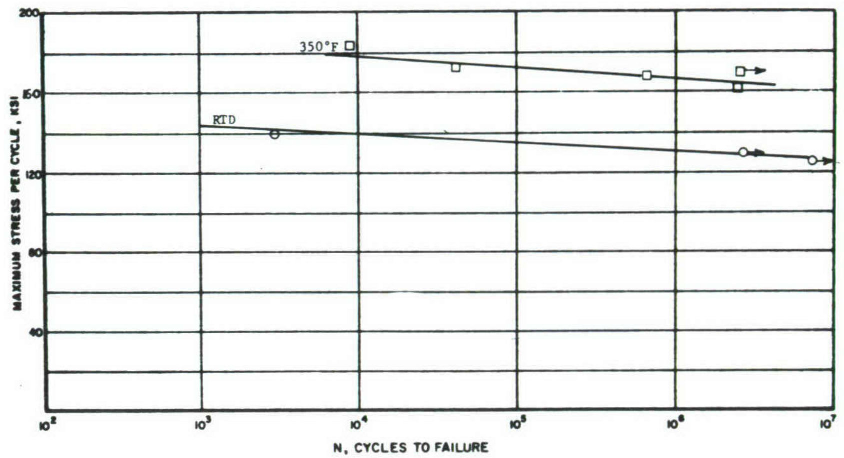

Fig. 126 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES AFTER 500 CYCLES EXPOSURE TO 350°F (R = 0.1, Φ = 1800 CPM)

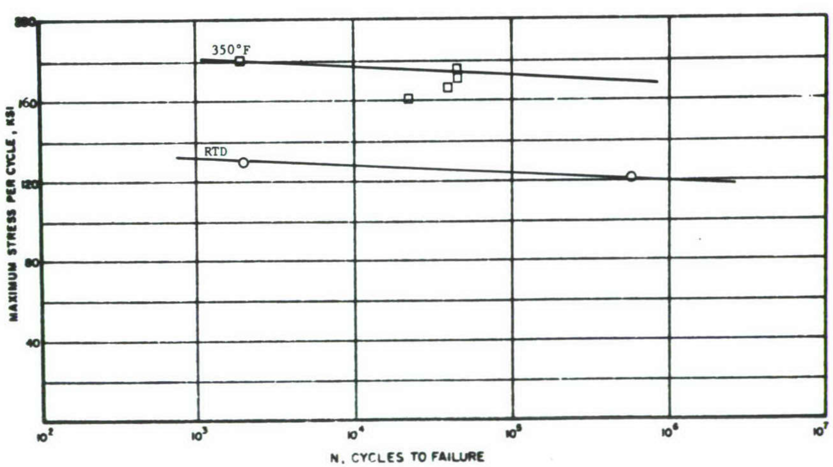

Fig. 127 FATIGUE S-N DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 350°F (R = 0.1, Φ = 1800 CPM)

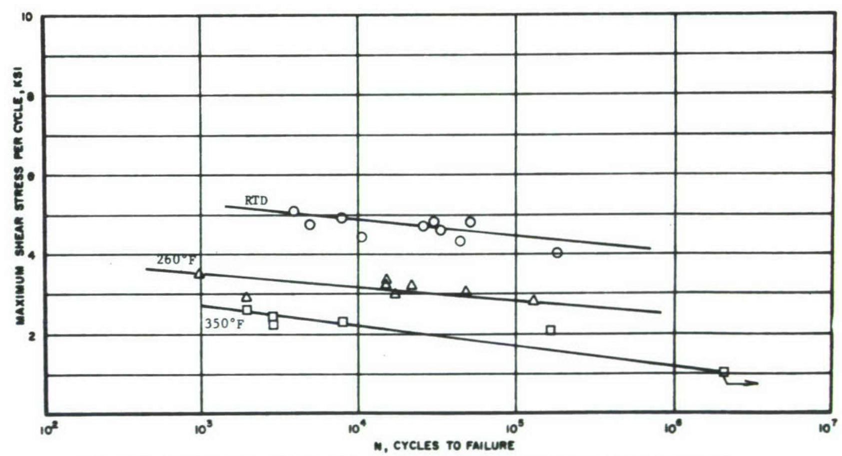

Fig. 128 FATIGUE S-N DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE, TESTED AT VARIOUS TEMPERATURES (R = 0.1, Φ = 1800 CPM)

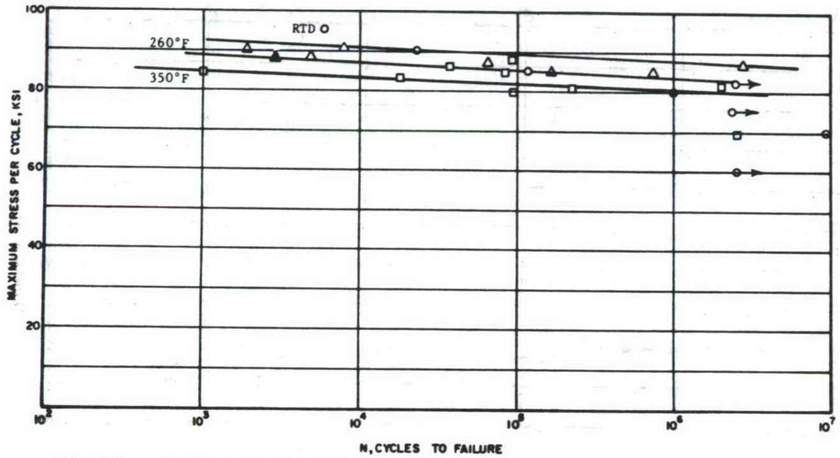

Fig. 129 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES (R = 0.1, Φ = 1800 CPM)

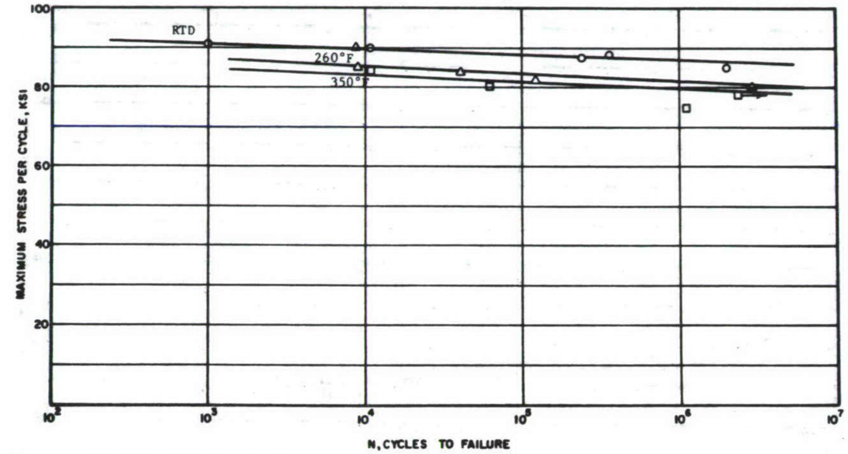

Fig. 130 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_S$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 98% R.H. (R = 0.1, Φ = 1800 CPM)

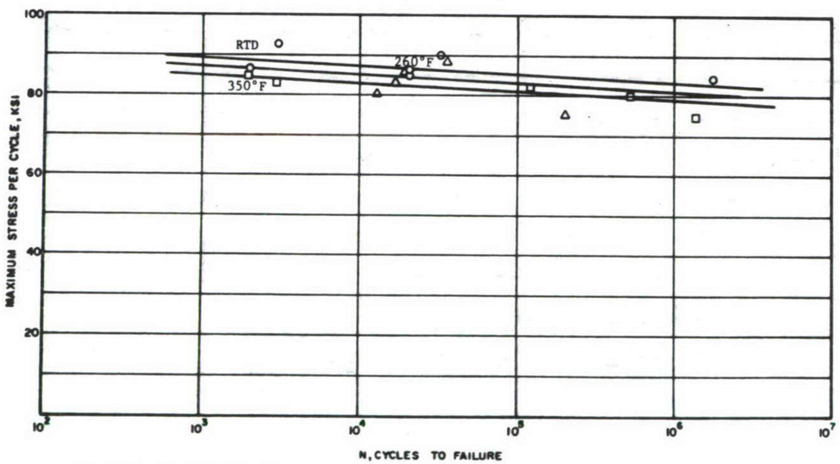

Fig. 131 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 HOURS EXPOSURE TO 98% R.H. (R = 0.1, : = 1800 CPM)

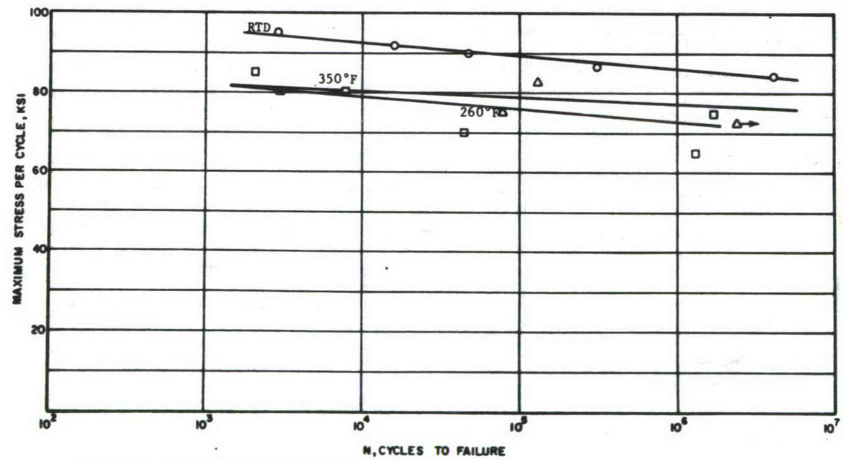

Fig. 132 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/ NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-Humidity Cycle) (R = 0.1, Φ = 1800 CPM)

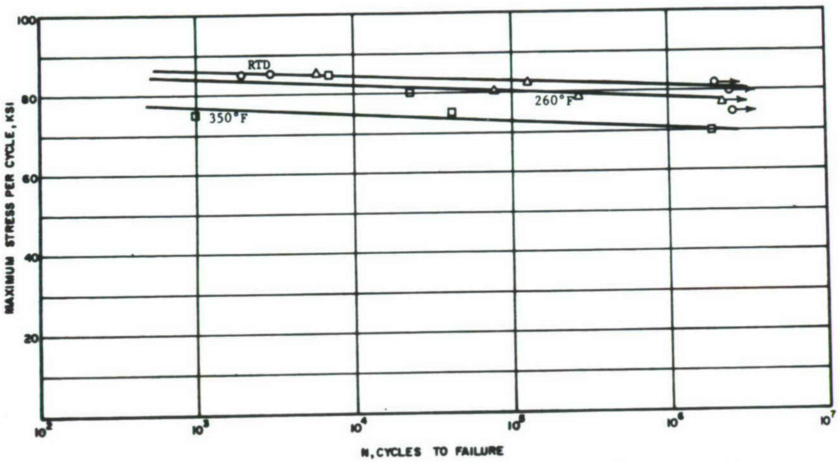

Fig. 133 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/90]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE no. 2 (Accelerated Weathering) (R = 0.1, Φ = 1800 CPM)

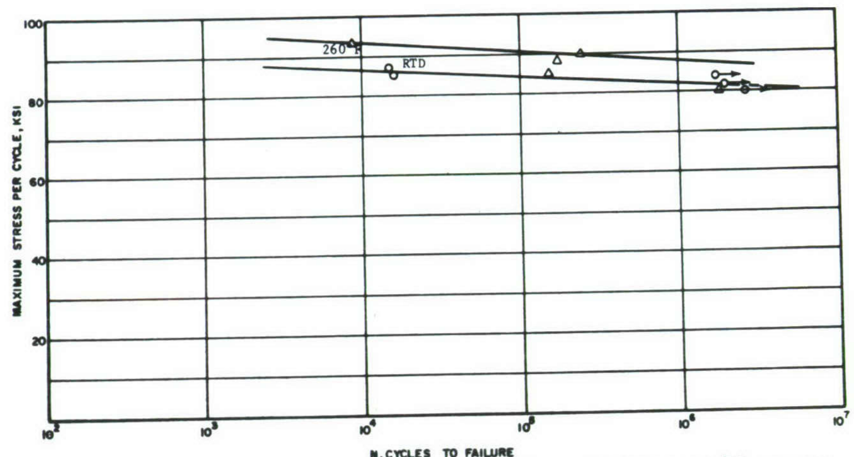

Fig. 134 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F (R = 0.1, Φ = 1800 CPM)

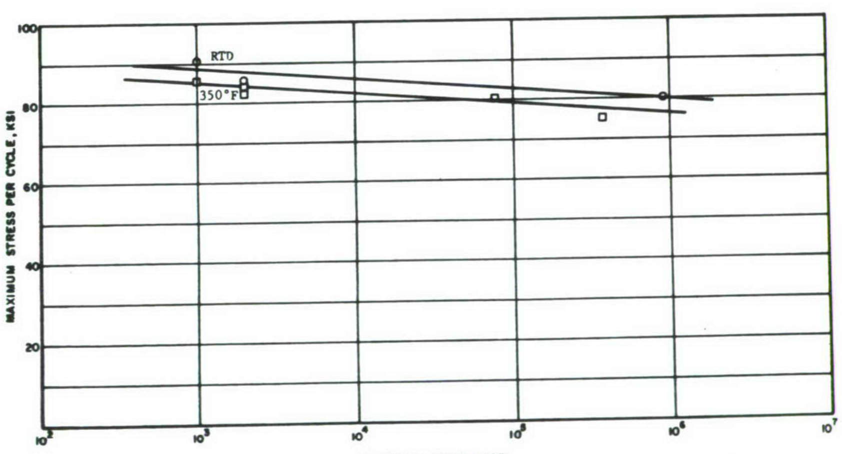

Fig. 135 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

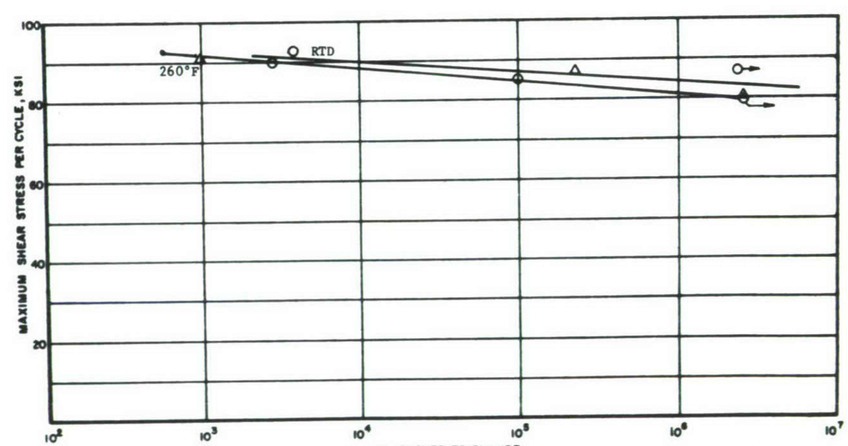

Fig. 136 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 500 CYCLES EXPOSURE TO 260°F (R = 0.1, Φ = 1800 cpm)

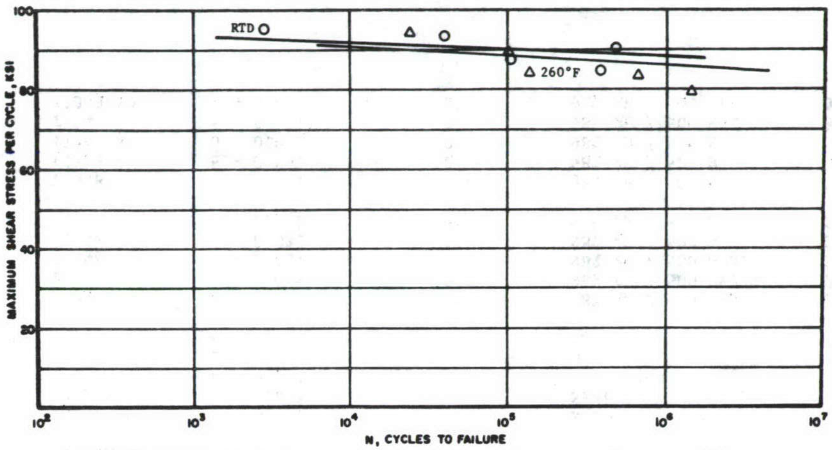

Fig. 137 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F (R = 0.1, Φ = 1800 CPM)

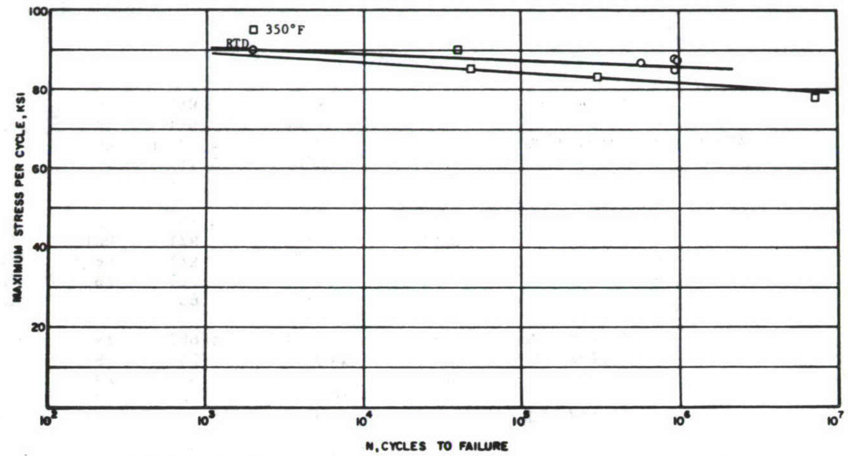

Fig. 138 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 500 CYCLES EXPOSURE TO 350°F (R = 0.1, Φ = 1800 CPM)

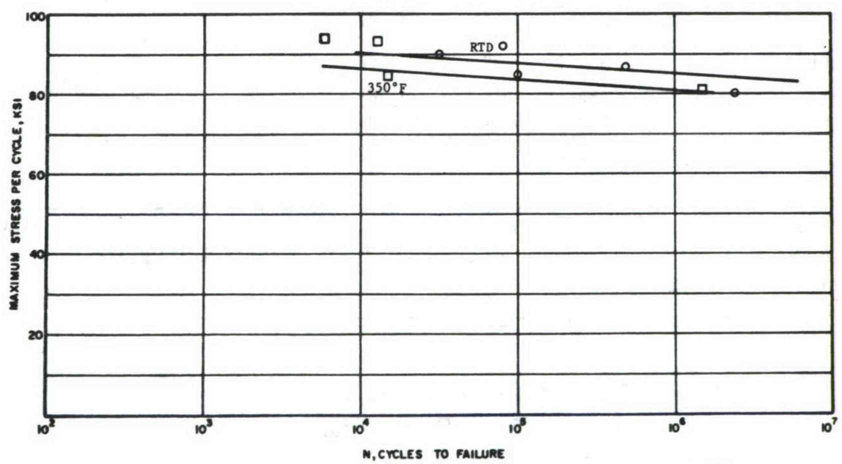

Fig. 139 FATIGUE S-N DIAGRAM FOR THORNEL 300 GRAPHITE/NARMCO 5208 $[0/45/135/0/\overline{90}]_s$ LAMINATE, TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 350°F (R = 0.1, Φ = 1800 CPM)

TABLE XII CREEP PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	PRIOR CONDITIONING Duration	Test Temp. (°F)	Stress Level (%σ_{ult})	Stress Level (ksi)	Time to Failure (Hours)	Time Applied without Failure (Hours)	Comment
T1307B-11	6 - 0.033	0°	None		260°F	80	171.2	-	1008	-
T1307B-12	6 - 0.034	0°	None		260°F	70	149.8	16	-	-
T1307B-13	6 - 0.032	0°	None		260°F	70	149.8	.167	-	Tab Failure
T1307B-14	6 - 0.032	0°	None		260°F	75	160.5	-	1004	-
T1307B-15	6 - 0.032	0°	None		260°F	67	143.4	-	1006	-
T1307B-16	6 - 0.034	0°	None		260°F	68	145.5	-	1002	-
T1307B-17	6 - 0.037	0°	None		260°F	70	149.8	.9	-	-
T1307B-18	6 - 0.035	0°	None		260°F	70	149.8	1.5	-	-
T1307B-19	6 - 0.035	0°	None		260°F	69	147.6	3.0	-	-
T1307B-20	6 - 0.033	0°	None		260°F	66	141.2	-	-	Broke during loading - Tab Failure
T1308A-1	6 - 0.031	0°	None		350°F	80	166.4	.033	-	Tab Failure
T1308A-2	6 - 0.033	0°	None		350°F	70	145.6	11.1	-	Broke at Tab
T1308A-3	6 - 0.033	0°	None		350°F	75	156	-	-	Broke during loading - Tab Failure
T1308A-4	6 - 0.032	0°	None		350°F	70	145.6	.7	-	Tab Failure
T1308A-5	6 - 0.031	0°	None		350°F	70	145.6	.35	-	Tab Failure
T1308A-6	6 - 0.027	0°	None		350°F	68	141.4	.41	-	Tab Failure
T1308A-7	6 - 0.031	0°	None		350°F	67	139.4	.010	-	-
T1308A-8	6 - 0.033	0°	None		350°F	67	139.4	-	1009	-
T1308A-9	6 - 0.033	0°	None		350°F	68	141.4	.033	-	Tab Failure
T1308A-10	6 - 0.033	0°	None		350°F	67	139.4	17	-	Broke at Tab
T1348-1	6 - 0.031	0°	98% RH	/ 500 Hrs.	260°F	95	169	-	1000	-
T1348-2	6 - 0.031	0°	98% RH	/ 500 Hrs.	260°F	97	172	-	1000	-
T1348-3	6 - 0.031	0°	98% RH	/ 500 Hrs.	260°F	99	175	282	-	-
T1348-4	6 - 0.031	0°	98% RH	/ 500 Hrs.	260°F	100	178	-	1000	-
T1348-5	6 - 0.031	0°	98% RH	/ 500 Hrs.	260°F	102	181.5	-	1000	-
T1348-6	6 - 0.031	0°	98% RH	/ 500 Hrs.	350°F	95	143.4	-	1000	-
T1348-7	6 - 0.031	0°	98% RH	/ 500 Hrs.	350°F	97	146.5	0.02	-	-
T1348-8	6 - 0.031	0°	98% RH	/ 500 Hrs.	350°F	97	146.5	1.0	-	Gage Lost Immediately
T1348-9	6 - 0.031	0°	98% RH	/ 500 Hrs.	350°F	96	145	633.7	-	-
T1348-10	6 - 0.031	0°	98% RH	/ 500 Hrs.	350°F	98	148	1.3	-	Tab Failure

TABLE XII CREEP PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$)	(ksi)	Time to Failure (Hours)	Time Applied without Failure (Hours)	Comment
T1309B-15	6 - 0.031	0°	98% RH	/ 1000 Hrs.	260°F	95	184.3	14.3	-	-
T1309B-16	6 - 0.032	0°	98% RH	/ 1000 Hrs.	260°F	97	188.1	.49	-	-
T1309B-17	6 - 0.030	0°	98% RH	/ 1000 Hrs.	260°F	99	192	1.4	-	Tab Failure
T1309B-18	6 - 0.029	0°	98% RH	/ 1000 Hrs.	260°F	96	186.2	.055	-	-
T1309B-19	6 - 0.032	0°	98% RH	/ 1000 Hrs.	260°F	87	168.7	-	1000	-
T1310A-5	6 - 0.031	0°	98% RH	/ 1000 Hrs.	350°F	95	172.4	-	1000	-
T1310A-6	6 - 0.029	0°	98% RH	/ 1000 Hrs.	350°F	97	166.8	-	1000	-
T1310A-7	6 - 0.030	0°	98% RH	/ 1000 Hrs.	350°F	98	148.5	-	1000	-
T1310A-8	6 - 0.030	0°	98% RH	/ 1000 Hrs.	350°F	101	173.7	3.8	-	-
T1310A-9	6 - 0.030	0°	98% RH	/ 1000 Hrs.	350°F	104	178.7	2.7	-	Tab Failure
T1348-11	6 - 0.031	0°	Thermo-Humidity	Cycle	260°F	90	167.4	-	1000	-
T1348-12	6 - 0.031	0°	Thermo-Humidity	Cycle	260°F	95	176.7	-	1000	-
T1348-13	6 - 0.031	0°	Thermo-Humidity	Cycle	260°F	97	180.4	.3	-	-
T1348-14	6 - 0.031	0°	Thermo-Humidity	Cycle	260°F	96	178.5	-	-	Broke during loading
T1348-15	6 - 0.029	0°	Thermo-Humidity	Cycle	260°F	85	158	-	1000	Broke during loading
T1348-16	6 - 0.030	0°	Thermo-Humidity	Cycle	350°F	97	149.3	-	1000	-
T1348-17	6 - 0.030	0°	Thermo-Humidity	Cycle	350°F	99	152.4	1.6	-	Tab Failure
T1348-18	6 - 0.031	0°	Thermo-Humidity	Cycle	350°F	85	130.9	-	1000	-
T1348-19	6 - 0.034	0°	Thermo-Humidity	Cycle	350°F	90	138.6	182	-	-
T1348-20	6 - 0.031	0°	Thermo-Humidity	Cycle	350°F	95	146.3	-	1000	-
T1309B-20	6 - 0.032	0°	Acc. Wthrng.		260°F	95	192.8	187	-	-
T1310A-1	6 - 0.032	0°	Acc. Wthrng.		260°F	93	188.8	.3	-	-
T1310A-2	6 - 0.031	0°	Acc. Wthrng.		260°F	91	184.7	.5	-	-
T1310A-3	6 - 0.029	0°	Acc. Wthrng.		260°F	85	172.6	.7	-	-
T1310A-4	6 - 0.031	0°	Acc. Wthrng.		260°F	90	182.7	-	1000	-
T1310A-10	6 - 0.030	0°	Acc. Wthrng.		350°F	80	141.6	-	1000	-
T1310A-11	6 - 0.030	0°	Acc. Wthrng.		350°F	93	164.6	2.1	-	-
T1310A-12	6 - 0.029	0°	Acc. Wthrng.		350°F	85	150.4	-	1000	-
T1310A-13	6 - 0.032	0°	Acc. Wthrng.		350°F	90	159.3	-	1000	-
T1310A-14	6 - 0.032	0°	Acc. Wthrng.		350°F	91	161.1	1.7	-	-

TABLE XII CREEP PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$)	(ksi)	Time to Failure (Hours)	Time Applied without Failure (Hours)	Comment
T1311B-16	6 - 0.031	0°	260°F /	500 Hrs.	260°F	75	155.2	-	1000	-
T1311B-17	6 - 0.028	0°	260°F /	500 Hrs.	260°F	80	165.6	-	1000	-
T1311B-18	6 - 0.030	0°	260°F /	500 Hrs.	260°F	85	176.0	-	1000	-
T1311B-19	6 - 0.026	0°	260°F /	500 Hrs.	260°F	90	186.3	2.8	-	Broke at Tab
T1311B-20	6 - 0.031	0°	260°F /	500 Hrs.	260°F	67	138.7	-	1000	-
T1312A-16	6 - 0.032	0°	260°F /	500 Hrs.	350°F	90	181.8	-	-	Broke during loading - Tab Failure
T1312A-17	6 - 0.032	0°	260°F /	500 Hrs.	350°F	77	155.5	-	1000	-
T1312A-18	6 - 0.033	0°	260°F /	500 Hrs.	350°F	85	171.7	27.4	-	Broke at Tab
T1312A-19	6 - 0.031	0°	260°F /	500 Hrs.	350°F	87	175.7	25.6		Broke at Tab
T1312A-20	6 - 0.033	0°	260°F /	500 Hrs.	350°F	80	161.6	26.8	-	-
T1312A-1	6 - 0.029	0°	350°F /	500 Hrs.	260°F	75	153	.012	-	-
T1312A-2	6 - 0.031	0°	350°F /	500 Hrs.	260°F	73	148.9	-	1000	-
T1312A-3	6 - 0.033	0°	350°F /	500 Hrs.	260°F	74	151	317	-	-
T1312A-4	6 - 0.029	0°	350°F /	500 Hrs.	260°F	80	163	-	-	Broke during loading
T1312A-5	6 - 0.033	0°	350°F /	500 Hrs.	260°F	75	153	500	-	-
T1312B-1	6 - 0.029	0°	350°F /	500 Hrs.	350°F	67	131	-	-	Grips not aligned caused failure
T1312B-2	6 - 0.033	0°	350°F /	500 Hrs.	350°F	67	131	-	1000	-
T1312B-3	6 - 0.031	0°	350°F /	500 Hrs.	350°F	70	137	3.8	-	-
T1312B-4	6 - 0.032	0°	350°F /	500 Hrs.	350°F	69	135	-	1000	-
T1312B-5	6 - 0.032	0°	350°F /	500 Hrs.	350°F	85	166	39.8	-	Broke at Tab
T1348-21	6 - 0.032	0°	260°F /	500 Cyc.	260°F	78	166.9	138.2	-	-
T1348-22	6 - 0.032	0°	260°F /	500 Cyc.	260°F	80	171.2	0.37	-	-
T1348-23	6 - 0.032	0°	260°F /	500 Cyc.	260°F	75	160.5	202.9	-	-
T1348-24	6 - 0.032	0°	260°F /	500 Cyc.	260°F	78	166.9	-	-	Broke during loading
T1348-25	6 - 0.032	0°	260°F /	500 Cyc.	260°F	77	164.8	-	602	-

TABLE XII CREEP PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma$ult)	(ksi)	Time to Failure (Hours)	Time Applied without Failure (Hours)	Comment
T1348-26	6 - 0.032	0°	260°F /	500 Cyc.	350°F	77	160.9	16.8	-	-
T1348-27	6 - 0.033	0°	260°F /	500 Cyc.	350°F	85	177.6	-	-	Broke during loading
T1348-28	6 - 0.032	0°	260°F /	500 Cyc.	350°F	78	163	1.0	-	-
T1348-29	6 - 0.032	0°	260°F /	500 Cyc.	350°F	83	173.5	-	-	Broke during loading
T1348-30	6 - 0.032	0°	260°F /	500 Cyc.	350°F	80	167.2	-	-	Broke during loading
T1312B-6	6 - 0.031	0°	260°F /	1000 Cyc.	260°F	79	160.4	-	435	-
T1312B-7	6 - 0.032	0°	260°F /	1000 Cyc.	260°F	75	155.2	174.4	-	Tab Failure
T1312B-8	6 - 0.033	0°	260°F /	1000 Cyc.	260°F	77	156.3	-	556	-
T1312B-9	6 - 0.033	0°	260°F /	1000 Cyc.	260°F	80	162.4			Broke during loading
T1312B-10	6 - 0.033	0°	260°F /	1000 Cyc.	260°F	78	158.4	27.2	-	-
T1312B-11	6 - 0.032	0°	260°F /	1000 Cyc.	350°F	79	156.4	-	432	-
T1312B-12	6 - 0.032	0°	260°F /	1000 Cyc.	350°F	82	162.4	0.03	-	-
T1312B-13	6 - 0.032	0°	260°F /	1000 Cyc.	350°F	80	158.4	0.12	-	-
T1312B-14	6 - 0.032	0°	260°F /	1000 Cyc.	350°F	75	148.5	-	507	-
T1312B-15	6 - 0.032	0°	260°F /	1000 Cyc.	350°F	78	154.4	16.1	-	-
T1348-31	6 - 0.027	0°	350°F /	500 Cyc.	260°F	90	197.1	-	-	Broke during loading
T1348-32	6 - 0.032	0°	350°F /	500 Cyc.	260°F	80	175.2	-	1000	-
T1348-33	6 - 0.033	0°	350°F /	500 Cyc.	260°F	78	170.8	-	1000	-
T1348-34	6 - 0.027	0°	350°F /	500 Cyc.	260°F	82	179.6	-	1000	-
T1348-35	6 - 0.032	0°	350°F /	500 Cyc.	260°F	79	173.0	-	1000	-
T1348-36	6 - 0.030	0°	350°F /	500 Cyc.	350°F	85	181.9	0.02	-	-
T1348-37	6 - 0.031	0°	350°F /	500 Cyc.	350°F	82	175.5	-	-	Broke during loading
T1348-38	6 - 0.030	0°	350°F /	500 Cyc.	350°F	81	173.3	0.8	-	-
T1348-39	6 - 0.032	0°	350°F /	500 Cyc.	350°F	80	171.2	-	1000	-
T1348-40	6 - 0.031	0°	350°F /	500 Cyc.	350°F	81	173.3	-	1000	-

TABLE XII CREEP PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	PRIOR CONDITIONING Duration	Test Temp. (°F)	Stress Level ($\%\sigma$ult)	Stress Level (ksi)	Time to Failure (Hours)	Time Applied without Failure (Hours)	Comment
T1348-21	6 - 0.032	0°	350°F /	1000 Cyc.	260°F	88	176	-	645	-
T1348-22	6 - 0.033	0°	350°F /	1000 Cyc.	260°F	85	170	-	1000	-
T1348-23	6 - 0.033	0°	350°F /	1000 Cyc.	260°F	90	180	-	603	-
T1348-24	6 - 0.033	0°	350°F /	1000 Cyc.	260°F	95	190			
T1348-25	6 - 0.031	0°	350°F /	1000 Cyc.	260°F	87	174	-	605	
T1312A-6	6 - 0.033	0°	350°F /	1000 Cyc.	350°F	85	165.8	2.3	-	-
T1312A-7	6 - 0.033	0°	350°F /	1000 Cyc.	350°F	84	163.8	-	1000	-
T1312A-8	6 - 0.034	0°	350°F /	1000 Cyc.	350°F	85	165.8	-	1000	-
T1312A-9	6 - 0.030	0°	350°F /	1000 Cyc.	350°F	86	167.7	-	1000	
T1312A-10	6 - 0.033	0°	350°F /	1000 Cyc.	350°F	87	189.6	-	-	Broke during loading
T1317-13	8 - 0.042	90°	None		260°F	70	2.88	.2	-	-
T1317-14	8 - 0.042	90°	None		260°F	70	2.88	1	-	
T1317-15	8 - 0.042	90°	None		260°F	-	-	-	-	Broke during handling
T1317-16	8 - 0.042	90°	None		260°F	69	2.83	-	1000	-
T1317-17	8 - 0.041	90°	None		260°F	67	2.75	-	1006	-
T1317-18	8 - 0.042	90°	None		260°F	90	3.69	30.6	-	-
T1318-1	8 - 0.042	90°	None		260°F	80	3.28	257	-	
T1318-2	8 - 0.042	90°	None		260°F	60	2.46	-	1000	-
T1318-3	8 - 0.042	90°	None		260°F	50	2.1	-	1000	-
T1318-4	8 - 0.042	90°	None		260°F	70	2.87	359	-	-
T1318-5	8 - 0.042	90°	None		350°F	67	1.94	140	-	-
T1318-6	8 - 0.042	90°	None		350°F	67	1.94	-	-	Broke during loading
T1318-7	8 - 0.040	90°	None		350°F	64	1.86	.9	-	-
T1318-8	8 - 0.042	90°	None		350°F	50	1.45	266	-	-
T1318-9	8 - 0.042	90°	None		350°F	60	1.74	-	1000	-
T1318-10	8 - 0.041	90°	None		350°F	-	-	-	-	Broke during handling
T1318-11	8 - 0.041	90°	None		350°F	70	2.03	88.7	-	-
T1318-12	8 - 0.042	90°	None		350°F	49	1.42	-	1000	-
T1318-13	8 - 0.041	90°	None		350°F	60	1.74	-	-	Broke during loading
T1318-14	8 - 0.040	90°	None		350°F	70	2.03	71	-	-

TABLE XII CREEP PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$)	(ksi)	Time to Failure (Hours)	Time Applied without Failure (Hours)	Comment
T1334B-1	9 - 0.048	$[0/45/135/0/\overline{90}]_s$	None		260°F	67	66.3	-	1003	-
T1334B-2	9 - 0.047	"	None		260°F	80	79.2	-	1002	-
T1334B-3	9 - 0.047	"	None		260°F	90	89.1	-	1007	-
T1334B-4	9 - 0.047	"	None		260°F	85	84.1	-	1028	-
T1334B-5	9 - 0.047	"	None		260°F	75	74.2	-	1001	-
T1334B-6	9 - 0.047	"	None		260°F	97	96	-	1000	-
T1334B-7	9 - 0.048	"	None		260°F	100	99	-	1000	Strain gage failed after 118 hrs.
T1334B-8	9 - 0.047	"	None		260°F	100	99	-	-	Broke during loading
T1334B-9	9 - 0.048	"	None		260°F	99	98	-	1000	-
T1334B-10	9 - 0.046	"	None		260°F	95	94	-	1000	-
T1335A-1	9 - 0.050	"	None		350°F	67	58.3	-	1005	-
T1335A-2	9 - 0.050	"	None		350°F	80	69.6	-	1001	-
T1335A-3	9 - 0.050	"	None		350°F	90	78.3	17.7	-	Broke at Tab
T1335A-4	9 - 0.050	"	None		350°F	70	60.9	-	1006	-
T1335A-5	9 - 0.050	"	None		350°F	75	65.2	-	1006	-
T1335A-6	9 - 0.050	"	None		350°F	83	72.2	-	1000	-
T1335A-7	9 - 0.050	"	None		350°F	85	73.9	11.4	-	Broke at Tab
T1335A-8	9 - 0.050	"	None		350°F	84	73.1	-	1000	-
T1335A-9	9 - 0.051	"	None		350°F	93	80.9	1.5	-	Broke at Tab
T1335A-10	9 - 0.050	"	None		350°F	82	71.3	32	-	Broke at Tab
T1350-1	9 - 0.048	"	98% RH	/ 500 Hrs.	260°F	97	81.9	-	1000	-
T1350-2	9 - 0.047	"	98% RH	/ 500 Hrs.	260°F	95	80.2	-	1000	-
T1350-3	9 - 0.047	"	98% RH	/ 500 Hrs.	260°F	100	84.5	-	1000	-
T1350-4	9 - 0.047	"	98% RH	/ 500 Hrs.	260°F	99	83.7	-	1000	-
T1350-5	9 - 0.049	"	98% RH	/ 500 Hrs.	260°F	98	82.8	-	1000	-
T1350-6	9 - 0.048	"	98% RH	/ 500 Hrs.	350°F	-	-	-	-	Spec. Broke during Conditioning
T1350-7	9 - 0.049	"	98% RH	/ 500 Hrs.	350°F	-	-	-	-	Spec. Broke during Conditioning
T1350-8	9 - 0.048	"	98% RH	/ 500 Hrs.	350°F	-	-	-	-	Spec. Broke during Conditioning
T1350-9	9 - 0.048	"	98% RH	/ 500 Hrs.	350°F	-	-	-	-	Spec. Broke during Conditioning
T1350-10	9 - 0.049	$[0/45/135/0/\overline{90}]_s$	98% RH	/ 500 Hrs.	350°F	-	-	-	-	Spec. Broke during Conditioning

TABLE XII CREEP PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$)	(ksi)	Time to Failure (Hours)	Time Applied without Failure (Hours)	Comment
T1337B-1	9 - 0.047	$[0/45/135/0/\overline{90}]_s$	98% RH /	1000 Hrs.	260°F	95	92.8	-	-	Broke during loading
T1337B-2	9 - 0.046	"	98% RH /	1000 Hrs.	260°F	85	83.0	-	1000	-
T1337B-3	9 - 0.048	"	98% RH /	1000 Hrs.	260°F	90	87.9	6.7	-	-
T1337B-4	9 - 0.050	"	98% RH /	1000 Hrs.	260°F	92	89.8	-	1000	-
T1337B-5	9 - 0.048	"	98% RH /	1000 Hrs.	260°F	93	90.8	-	-	Broke during loading
T1338A-1	9 - 0.048	"	98% RH /	1000 Hrs.	350°F	95	91.8	-	-	Broke during loading
T1338A-2	9 - 0.048	"	98% RH /	1000 Hrs.	350°F	90	87	2.0	-	-
T1338A-3	9 - 0.048	"	98% RH /	1000 Hrs.	350°F	92	88.9	142.1	-	-
T1338A-4	9 - 0.048	"	98% RH /	1000 Hrs.	350°F	94	90.8	0.1	-	-
T1338A-5	9 - 0.047	"	98% RH /	1000 Hrs.	350°F	93	89.9	229.4	-	-
T1342A-2-11	9 - 0.046	"	Thermo-Humidity	Cycle	260°F	97	82.7	32.3	-	-
T1342A-2-12	9 - 0.046	"	Thermo-Humidity	Cycle	260°F	100	85.3	-	1000	-
T1342A-2-13	9 - 0.046	"	Thermo-Humidity	Cycle	260°F	102	87.0	-	1000	-
T1342A-2-14	9 - 0.048	"	Thermo-Humidity	Cycle	260°F	95	81	-	1000	-
T1342A-2-15	9 - 0.048	"	Thermo-Humidity	Cycle	260°F	99	84.3	-	1000	-
T1342A-16	9 - 0.047	"	Thermo-Humidity	Cycle	350°F	96	79.6	-	1000	Lost Gage at 121 hours
T1342A-17	9 - 0.047	"	Thermo-Humidity	Cycle	350°F	98	84.2	1.7	-	-
T1342A-18	9 - 0.047	"	Thermo-Humidity	Cycle	350°F	90	77.4	-	1000	-
T1342A-19	9 - 0.046	"	Thermo-Humidity	Cycle	350°F	95	81.7	-	1000	-
T1342A-20	9 - 0.047	"	Thermo-Humidity	Cycle	350°F	97	83.4	-	-	Oven overheated
T1337B-6	9 - 0.045	"	Acc. Wthrng.		260°F	95	90.4	-	-	Broke during loading
T1337B-7	9 - 0.047	"	Acc. Wthrng.		260°F	90	85.7	549.3	-	-
T1337B-8	9 - 0.046	"	Acc. Wthrng.		260°F	93	88.5	-	-	Broke during loading
T1337B-9	9 - 0.048	"	Acc. Wthrng.		260°F	91	87.6	-	-	Immediate Failure
T1337B-10	9 - 0.048	"	Acc. Wthrng.		260°F	92	88	.05	-	-
T1338A-6	9 - 0.049	"	Acc. Wthrng.		350°F	95	93.2	107.2	-	-
T1338A-7	9 - 0.049	"	Acc. Wthrng.		350°F	98	96.2	.41	-	Strain gage Failed
T1338A-8	9 - 0.046	"	Acc. Wthrng.		350°F	96	94.1	73.4	-	-
T1338A-9	9 - 0.046	"	Acc. Wthrng.		350°F	97	95.1	-	-	Broke during loading
T1338A-10	9 - 0.047	$[0/45/135/0/\overline{90}]_s$	Acc. Wthrng.		350°F	96	94.2	-	-	Broke during loading

TABLE XII CREEP PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$)	(ksi)	Time to Failure (Hours)	Time Applied without Failure (Hours)	Comment
T1341B-1	9 - 0.049	$[0/45/135/0/\overline{90}]_s$	260°F /	500 Hrs.	260°F	95	96	.15	-	Broke at Tab
T1341B-2	9 - 0.048	"	260°F /	500 Hrs.	260°F	90	90.9	-	1000	-
T1341B-3	9 - 0.049	"	260°F /	500 Hrs.	260°F	94	94.9	408	-	-
T1341B-4	9 - 0.048	"	260°F /	500 Hrs.	260°F	95	96	-	1000	-
T1341B-5	9 - 0.048	"	260°F /	500 Hrs.	260°F	96	97	-	-	Broke during loading
T1341B-6	9 - 0.049	"	260°F /	500 Hrs.	350°F	90	90	239.4	-	-
T1341B-7	9 - 0.049	"	260°F /	500 Hrs.	350°F	94	94	4.3	-	-
T1341B-8	9 - 0.049	"	260°F /	500 Hrs.	350°F	95	95	15	-	-
T1341B-9	9 - 0.048	"	260°F /	500 Hrs.	350°F	85	85	-	1000	-
T1341B-10	9 - 0.049	"	260°F /	500 Hrs.	350°F	93	93	281.2	-	-
T1342B-1	9 - 0.046	"	350°F /	500 Hrs.	260°F	98	96.5	1.4	-	-
T1342B-2	9 - 0.045	"	350°F /	500 Hrs.	260°F	67	66	-	1000	-
T1342B-3	9 - 0.047	"	350°F /	500 Hrs.	260°F	80	78.8	-	1000	-
T1342B-4	9 - 0.047	"	350°F /	500 Hrs.	260°F	95	93.6	420	-	-
T1342B-5	9 - 0.047	"	350°F /	500 Hrs.	260°F	97	95.5	-	-	Broke during loading
T1342B-6	9 - 0.048	"	350°F /	500 Hrs.	350°F	67	65.5	-	1000	-
T1342B-7	9 - 0.048	"	350°F /	500 Hrs.	350°F	80	78.2	-	1000	-
T1342B-8	9 - 0.048	"	350°F /	500 Hrs.	350°F	90	87.7	-	1000	-
T1342B-9	9 - 0.048	"	350°F /	500 Hrs.	350°F	85	83	402	-	-
T1342B-10	9 - 0.046	"	350°F /	500 Hrs.	350°F	95	92.8	.083	-	-
T1350A-21	9 - 0.048	"	260°F /	500 Cyc.	260°F	82	84.5	0.05	-	-
T1350A-22	9 - 0.049	"	260°F /	500 Cyc.	260°F	90	92.7	0.13	-	-
T1350A-23	9 - 0.050	"	260°F /	500 Cyc.	260°F	85	87.6	-	-	Broke during loading
T1350A-24	9 - 0.049	"	260°F /	500 Cyc.	260°F	80	82.4	536.9	-	-
T1350A-25	9 - 0.050	"	260°F /	500 Cyc.	260°F	81	83.4	-	-	Broke during loading
T1350A-26	9 - 0.046	"	260°F /	500 Cyc.	350°F	85	83.3	1.2	-	-
T1350A-27	9 - 0.046	"	260°F /	500 Cyc.	350°F	83	81.3	35.0	-	-
T1350A-28	9 - 0.046	"	260°F /	500 Cyc.	350°F	85	83.3	202.3	-	-
T1350A-29	9 - 0.046	"	260°F /	500 Cyc.	350°F	84	82.3	-	1000	-
T1350A-30	9 - 0.046	$[0/45/135/0/\overline{90}]_s$	260°F /	500 Cyc.	350°F	86	84.3	-	1000	-

TABLE XII CREEP PROPERTIES SUMMARY - THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITES

Specimen Number	Thickness (Plies) (In.)	Orientation	PRIOR CONDITIONING Type	Duration	Test Temp. (°F)	Stress Level ($\%\sigma_{ult}$)	(ksi)	Time to Failure (Hours)	Time Applied without Failure (Hours)	Comment
T1342A-1	9 - 0.049	$[0/45/135/0/\overline{90}]_s$	Cyclic 260°F	/ 1000 Cyc.	260°F	85	82.4	-	467	-
T1342A-2	9 - 0.050	"	Cyclic 260°F	/ 1000 Cyc.	260°F	88	85.3	239.2	-	-
T1342A-3	9 - 0.050	"	Cyclic 260°F	/ 1000 Cyc.	260°F	89	86.2	-	-	Broke during loading
T1342A-4	9 - 0.049	"	Cyclic 260°F	/ 1000 Cyc.	260°F	87	84.3	-	436	-
T1342A-5	9 - 0.049	"	Cyclic 260°F	/ 1000 Cyc.	260°F	88	85.3	-	411	-
T1342A-6	9 - 0.048	"	Cyclic 260°F	/ 1000 Cyc.	350°F	85	78.1	30.5	-	-
T1342A-7	9 - 0.049	"	Cyclic 260°F	/ 1000 Cyc.	350°F	87	80.0	0.5	-	-
T1342A-8	9 - 0.049	"	Cyclic 260°F	/ 1000 Cyc.	350°F	86	79.0	53.6	-	-
T1342A-9	9 - 0.049	"	Cyclic 260°F	/ 1000 Cyc.	350°F	86	79	-	-	-
T1342A-10	9 - 0.049	"	Cyclic 260°F	/ 1000 Cyc.	350°F	87	80	111.2	-	-
T1342-1	9 - 0.045	"	Cyclic 350°F	/ 500 Cyc.	260°F	90	93.6	-	-	Broke during loading
T1342-2	9 - 0.047	"	Cyclic 350°F	/ 500 Cyc.	260°F	78	77.8	-	1000	-
T1342-3	9 - 0.048	"	Cyclic 350°F	/ 500 Cyc.	260°F	80	83.2	0.07	-	-
T1342-4	9 - 0.048	"	Cyclic 350°F	/ 500 Cyc.	260°F	80	79.8	-	1000	-
T1342-5	9 - 0.047	"	Cyclic 350°F	/ 500 Cyc.	260°F	85	84.7	-	1000	-
T1342-6	9 - 0.048	"	Cyclic 350°F	/ 500 Cyc.	350°F	94	96.8	2.8	-	-
T1342-7	9 - 0.048	"	Cyclic 350°F	/ 500 Cyc.	350°F	93	95.8	-	-	Broke during loading
T1342-8	9 - 0.047	"	Cyclic 350°F	/ 500 Cyc.	350°F	90	92.7	-	-	Broke during loading
T1342-9	9 - 0.048	"	Cyclic 350°F	/ 500 Cyc.	350°F	87	89	0.25	-	-
T1342-10	9 - 0.048	"	Cyclic 350°F	/ 500 Cyc.	350°F	95	97.8	2.5	-	-
T1350C-31	9 - 0.047	"	Cyclic 350°F	/ 1000 Cyc.	260°F	85	89.2	0.8	-	-
T1350C-32	9 - 0.047	"	Cyclic 350°F	/ 1000 Cyc.	260°F	82	86.1	-	1000	-
T1350C-33	9 - 0.047	"	Cyclic 350°F	/ 1000 Cyc.	260°F	83	87.2	590.4	-	-
T1350C-34	9 - 0.047	"	Cyclic 350°F	/ 1000 Cyc.	260°F	84	88.2	-	1000	-
T1350C-35	9 - 0.047	"	Cyclic 350°F	/ 1000 Cyc.	260°F	86	90.3	-	1000	-
T1342C-36	9 - 0.047	"	Cyclic 350°F	/ 1000 Cyc.	350°F	85	85	396.2	-	-
T1342C-37	9 - 0.047	"	Cyclic 350°F	/ 1000 Cyc.	350°F	90	90	-	644	-
T1342C-38	9 - 0.047	"	Cyclic 350°F	/ 1000 Cyc.	350°F	80	80	-	1000	-
T1342C-39	9 - 0.046	"	Cyclic 350°F	/ 1000 Cyc.	350°F	91	91	0.09	-	-
T1342C-40	9 - 0.047	$[0/45/135/0/\overline{90}]_s$	Cyclic 350°F	/ 1000 Cyc.	350°F	92	92	0.03	-	-

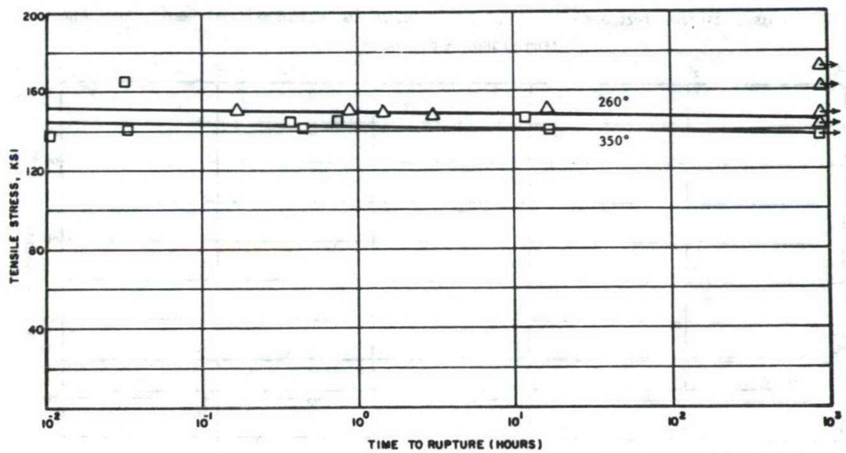

Fig. 140 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES

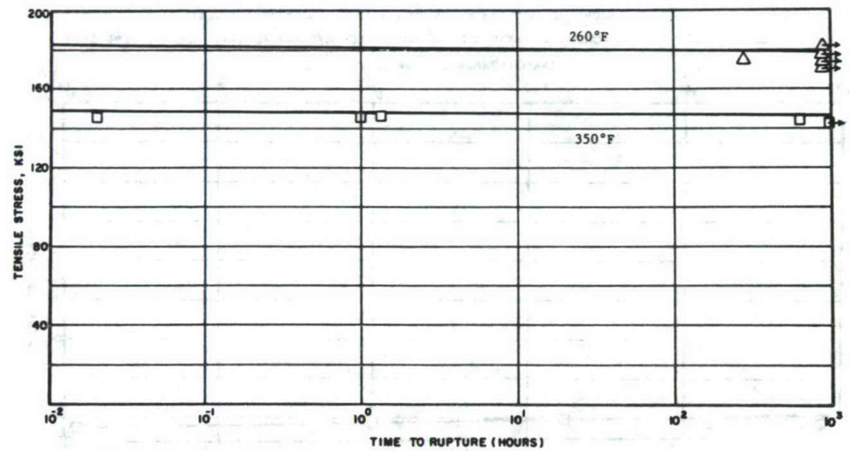

Fig. 141 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 98% R.H.

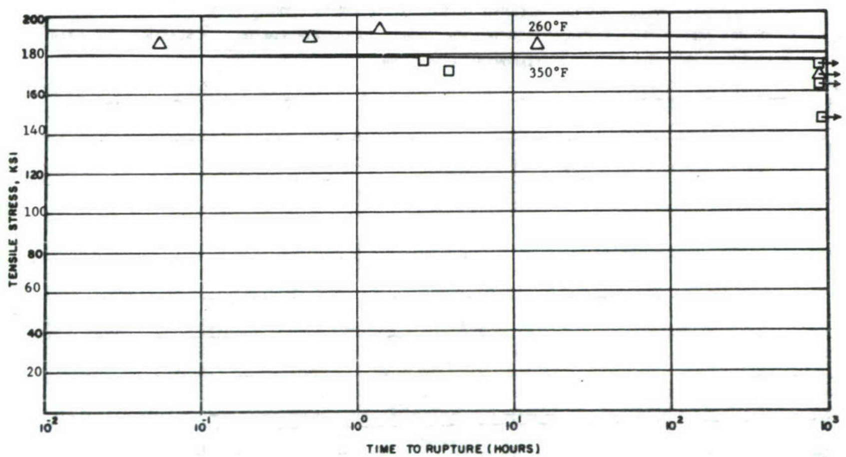

Fig. 142 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 HOURS EXPOSURE TO 98% R. H.

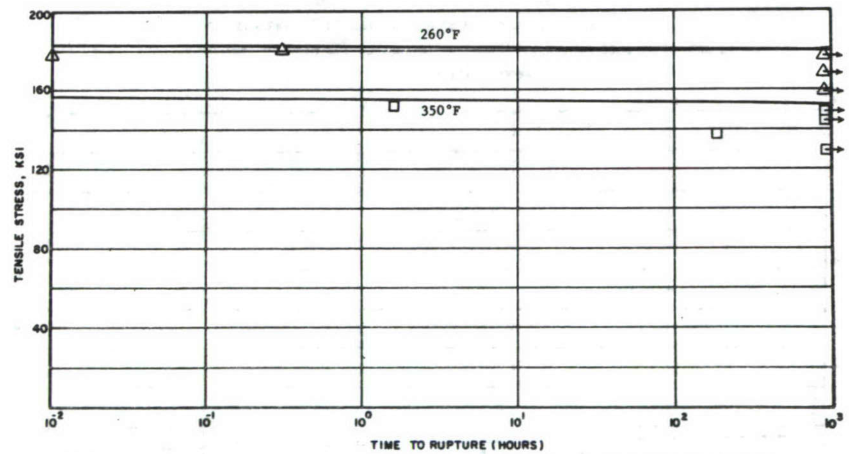

Fig. 143 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-humidity Cycle)

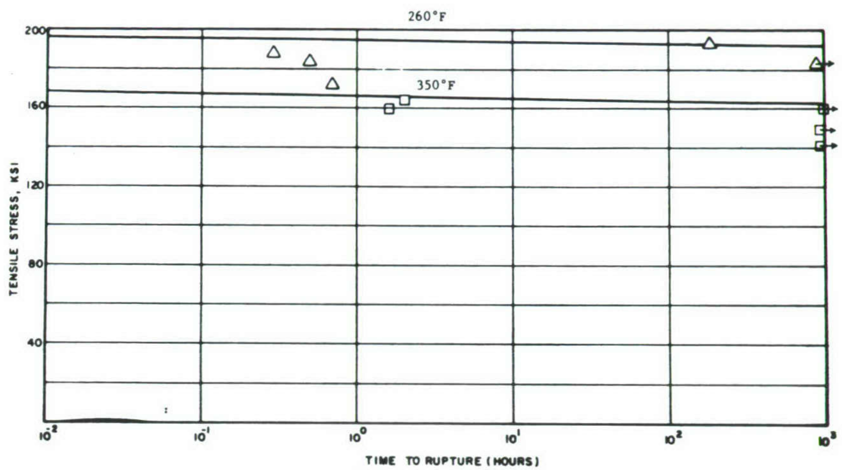

Fig. 144 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (Accelerated Weathering)

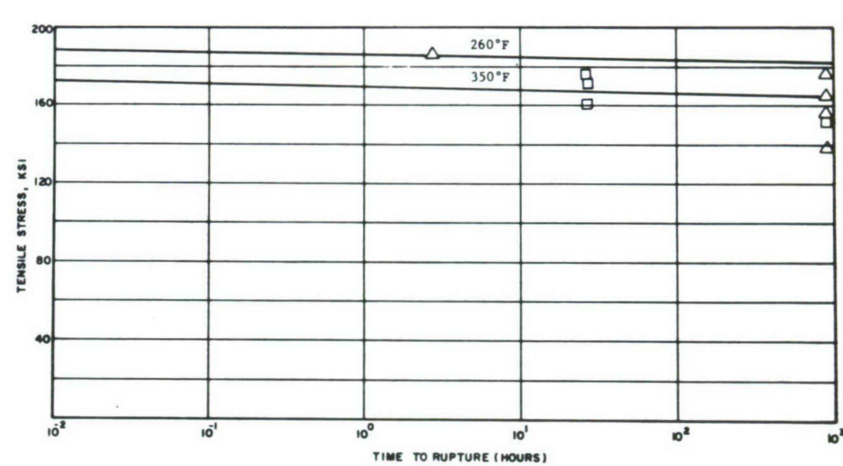

Fig. 145 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F

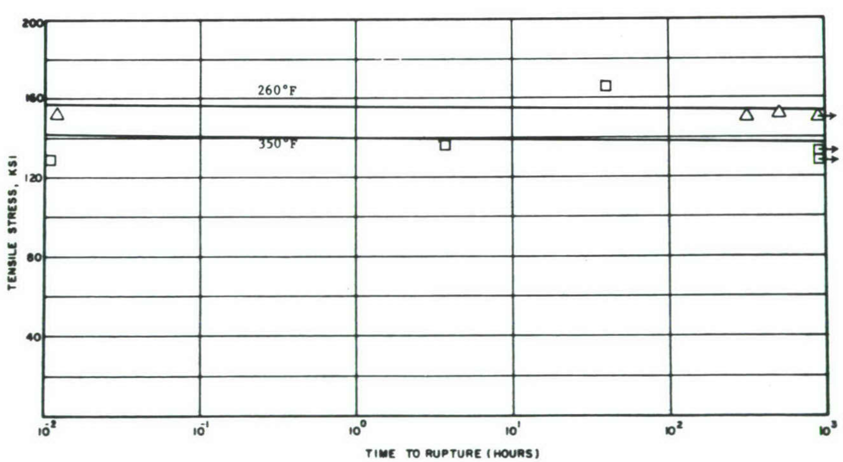

Fig. 146 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

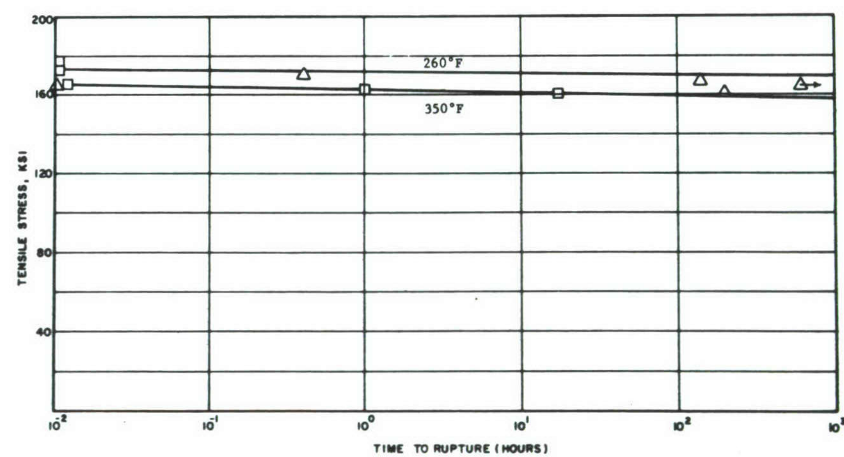

Fig. 147 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 CYCLES EXPOSURE TO 260°F

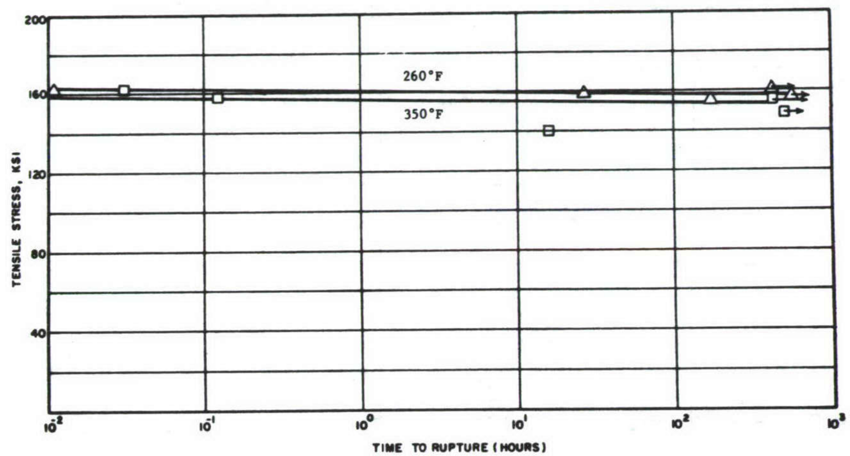

Fig. 148 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F

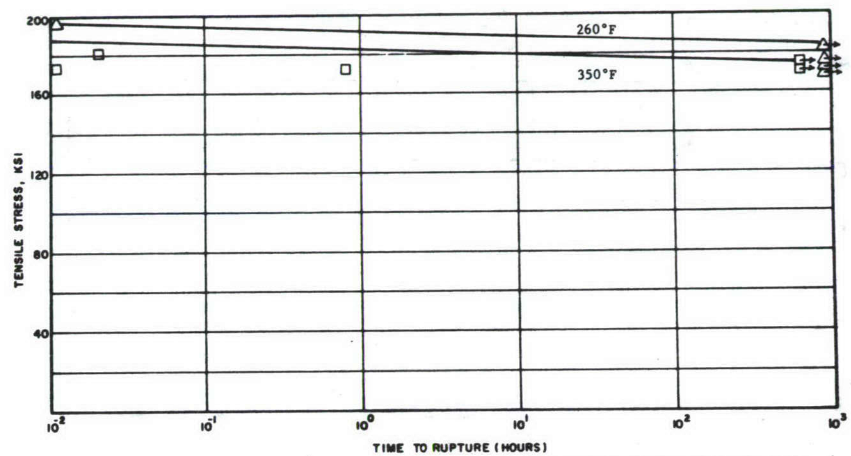

Fig. 149 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 CYCLES EXPOSURE TO 350°F

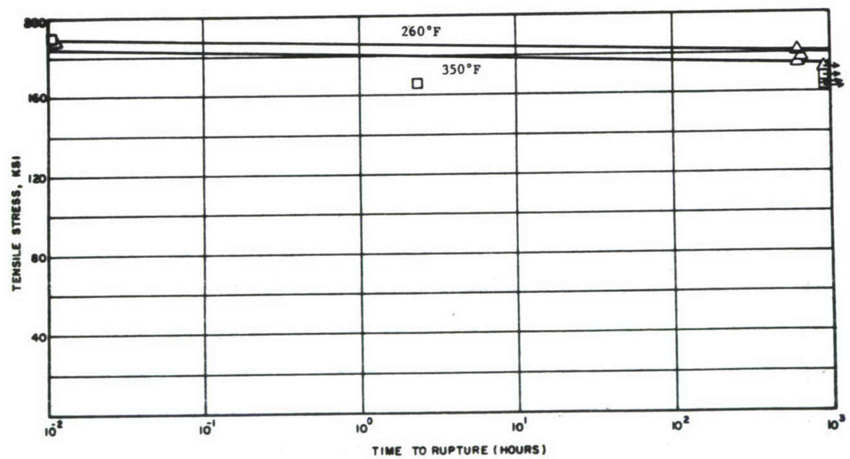

Fig. 150 STRESS RUPTURE DIAGRAM FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 350°F

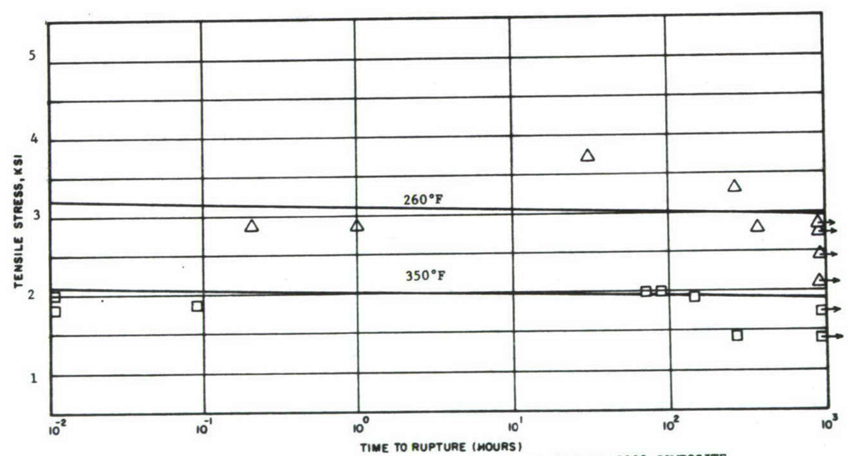

Fig. 151 STRESS RUPTURE DIAGRAM FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES

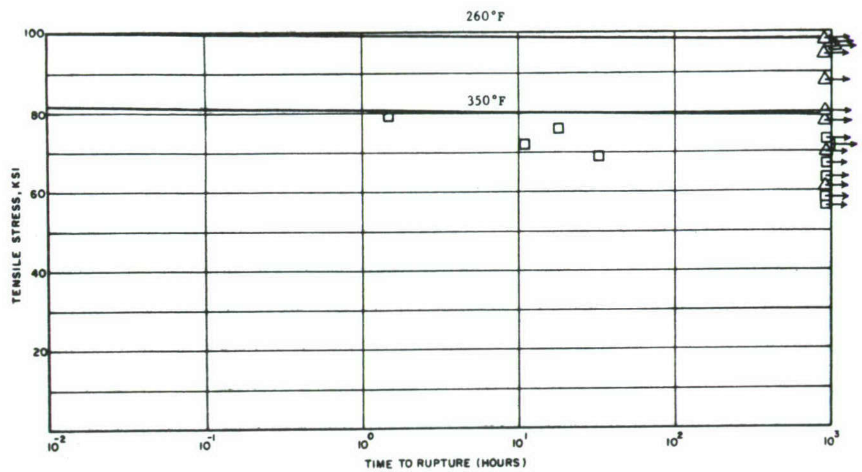

Fig. 152 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES

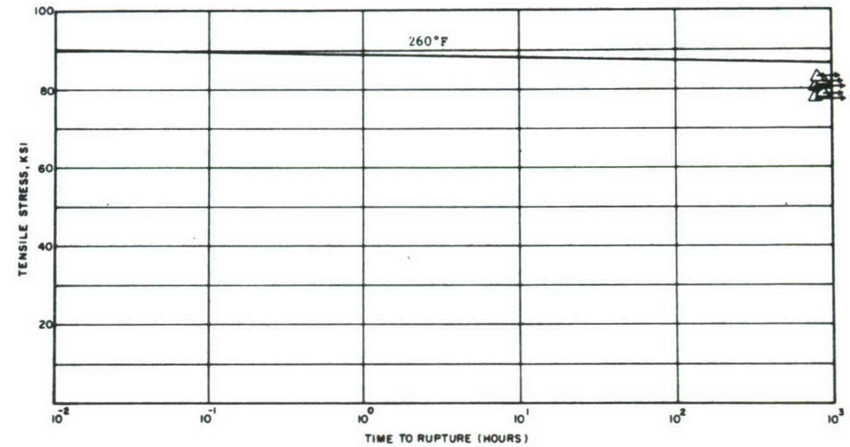

Fig. 153 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 HOURS EXPOSURE TO 98% R. H.

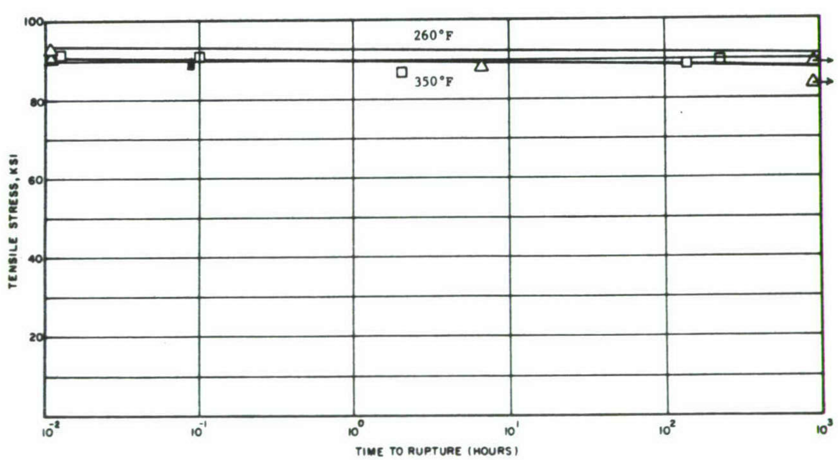

Fig. 154 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 HOURS EXPOSURE to 98% R. H.

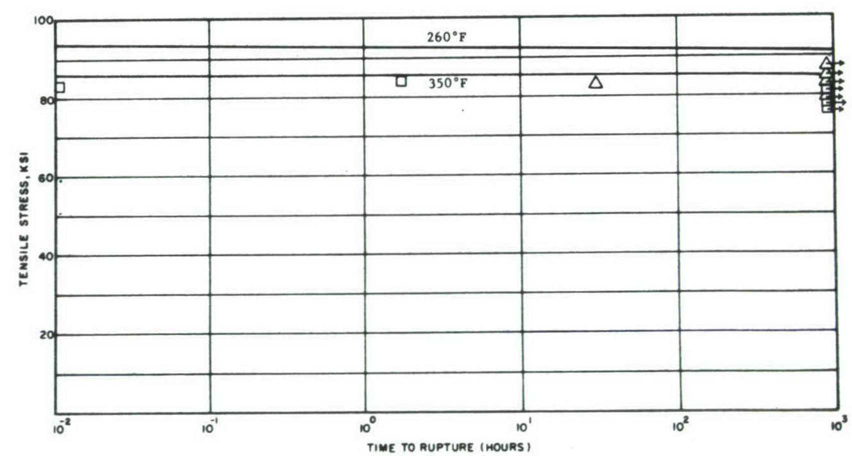

Fig. 155 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-Humidity Cycle)

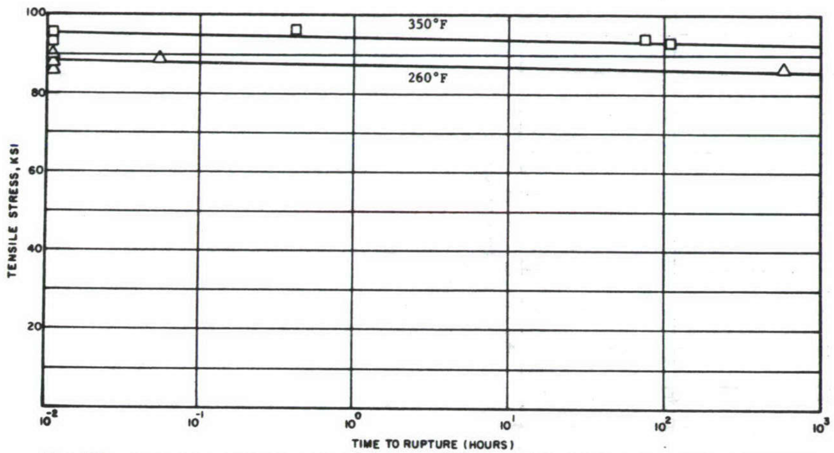

Fig. 156 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (Accelerated Weathering)

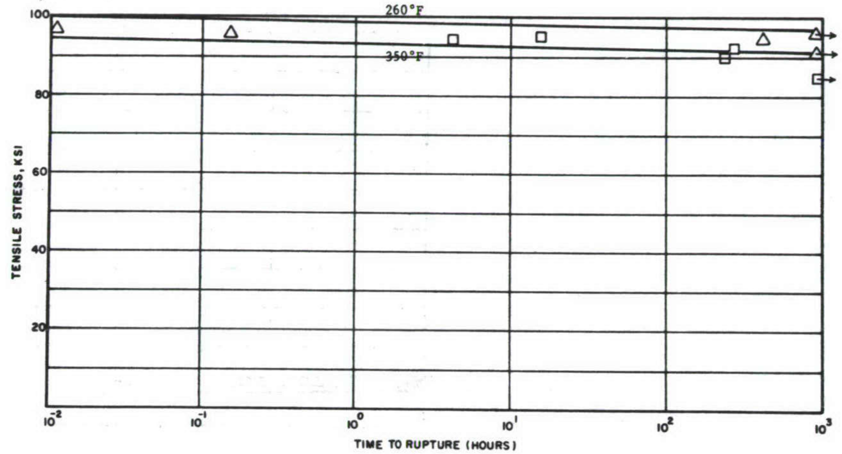

Fig. 157 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 260°F

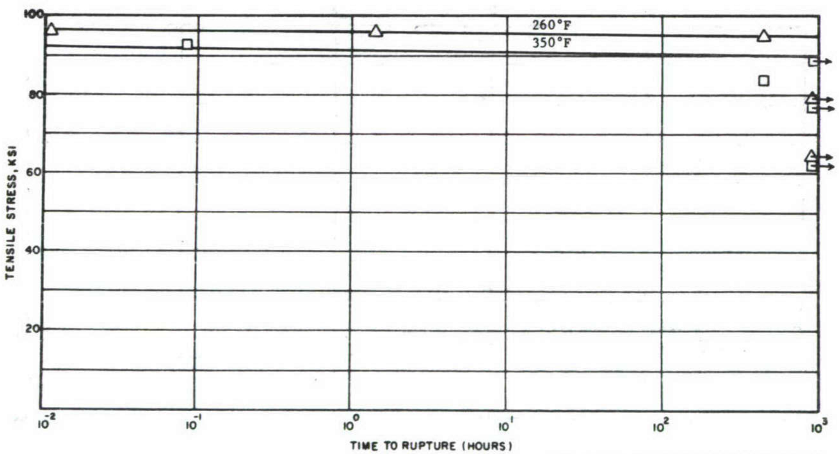

Fig. 158 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 HOURS EXPOSURE TO 350°F

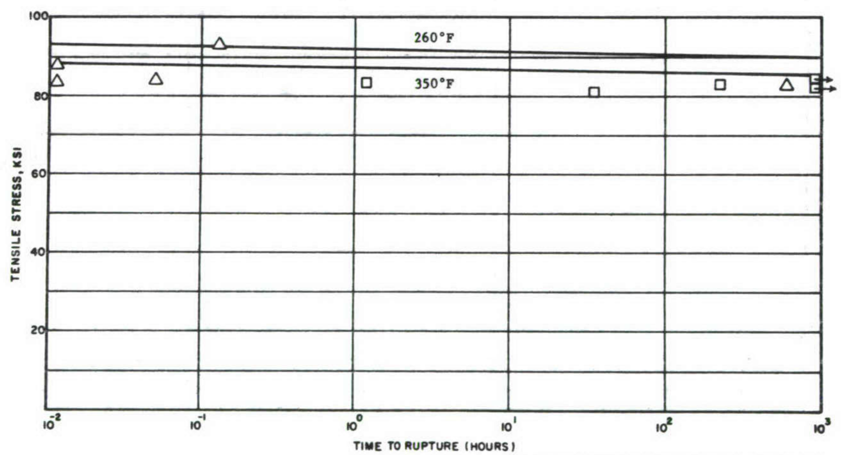

Fig. 159 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 CYCLES EXPOSURE TO 260°F

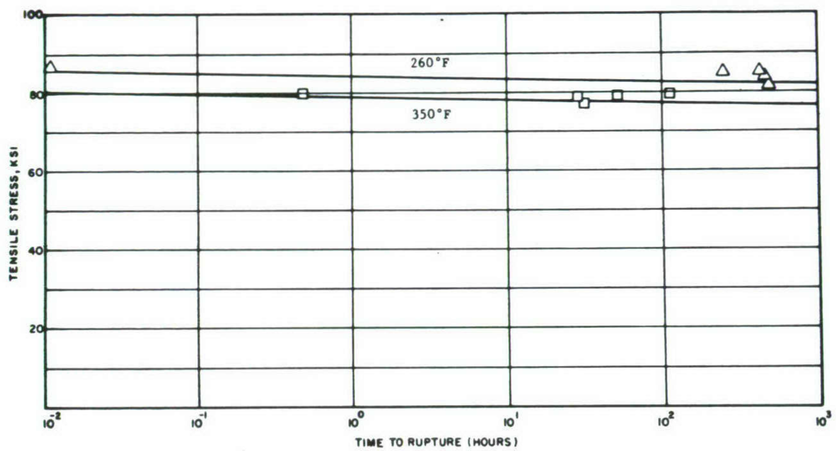

Fig. 160 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 260°F

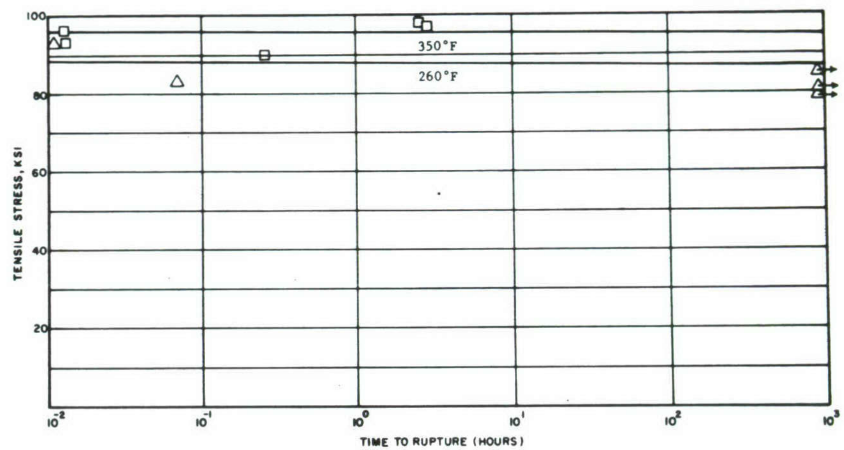

Fig. 161 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 500 CYCLES EXPOSURE TO 350°F

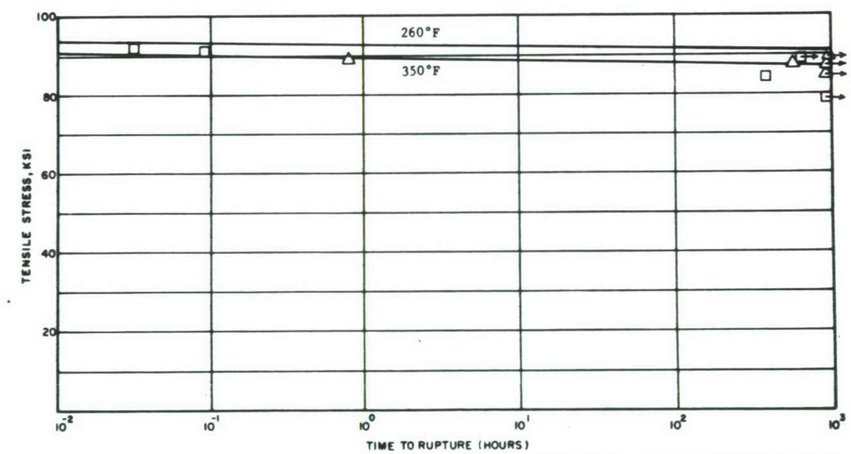

Fig. 162 STRESS RUPTURE DIAGRAM FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT VARIOUS TEMPERATURES AFTER 1000 CYCLES EXPOSURE TO 350°F

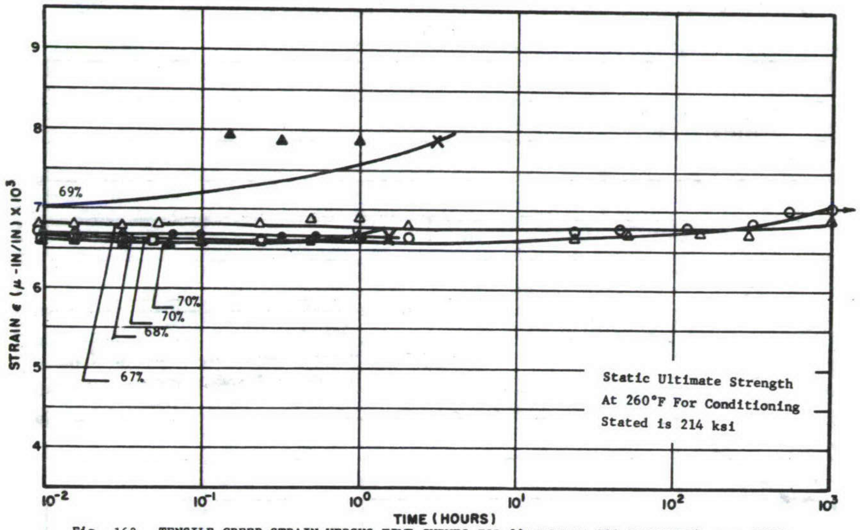

Fig. 163 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F

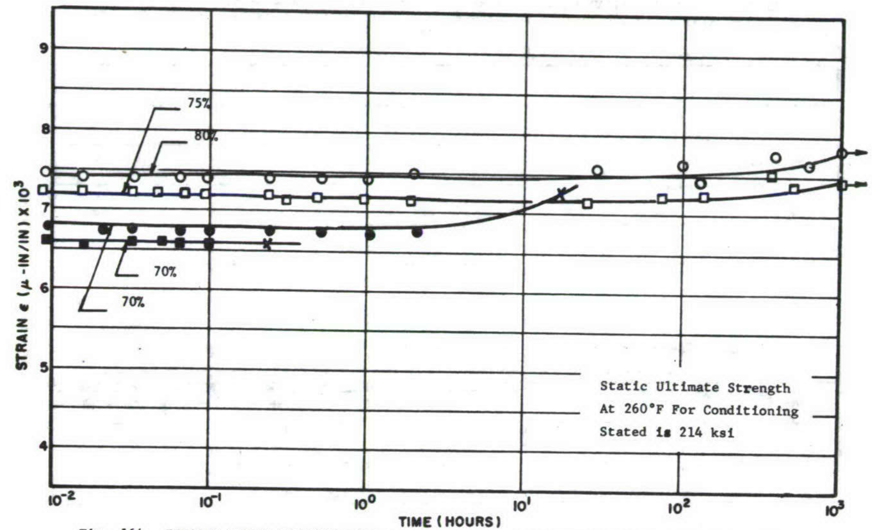

Fig. 164 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F

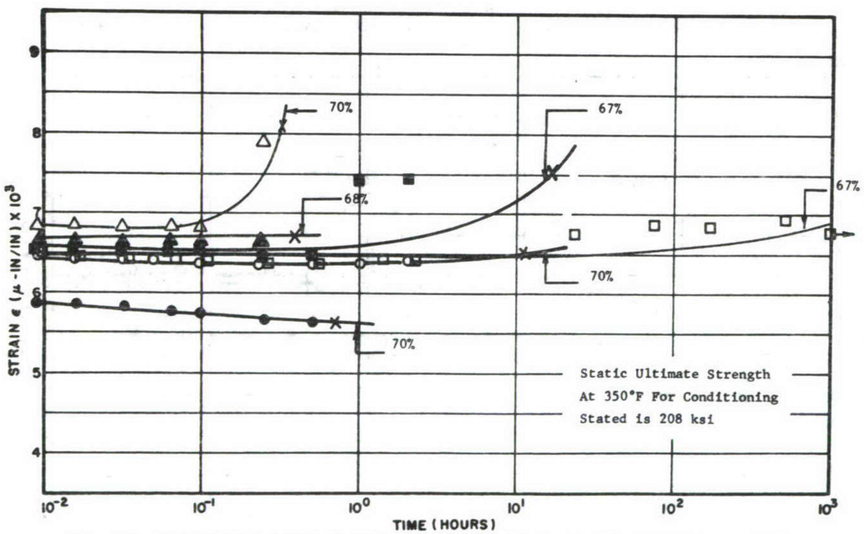

Fig. 165 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F

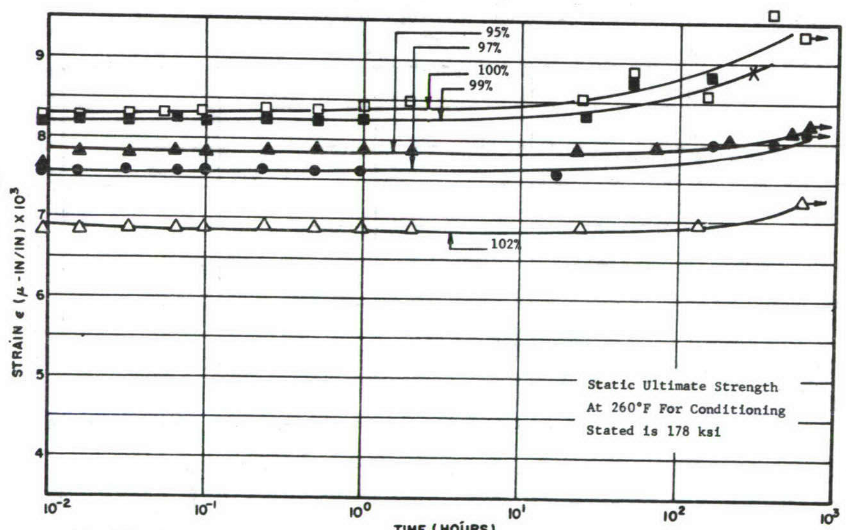

Fig. 166 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 HOURS EXPOSURE TO 98% RH

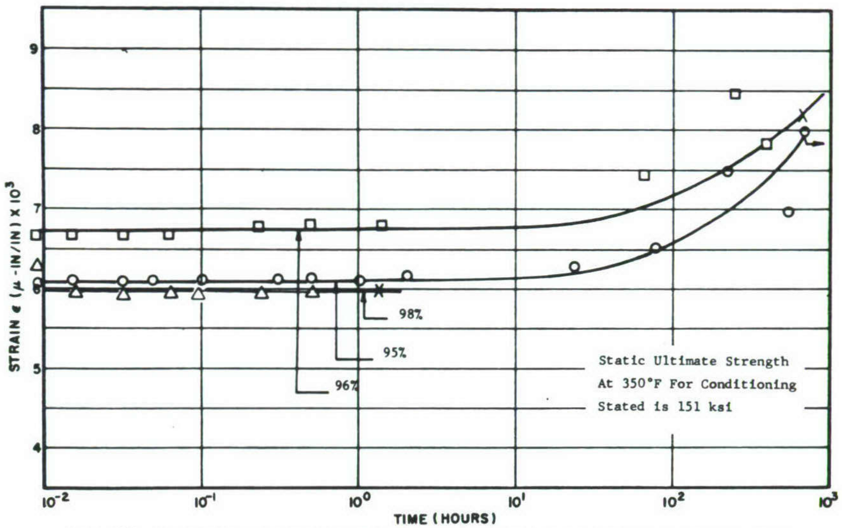

Fig. 167 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 500 HOURS EXPOSURE TO 98% RH

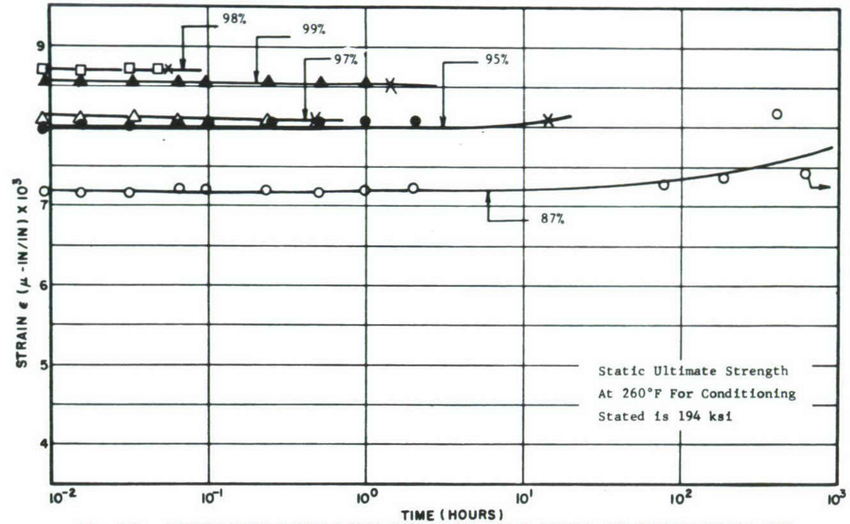

Fig. 168 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 1000 HOURS EXPOSURE TO 98% RH

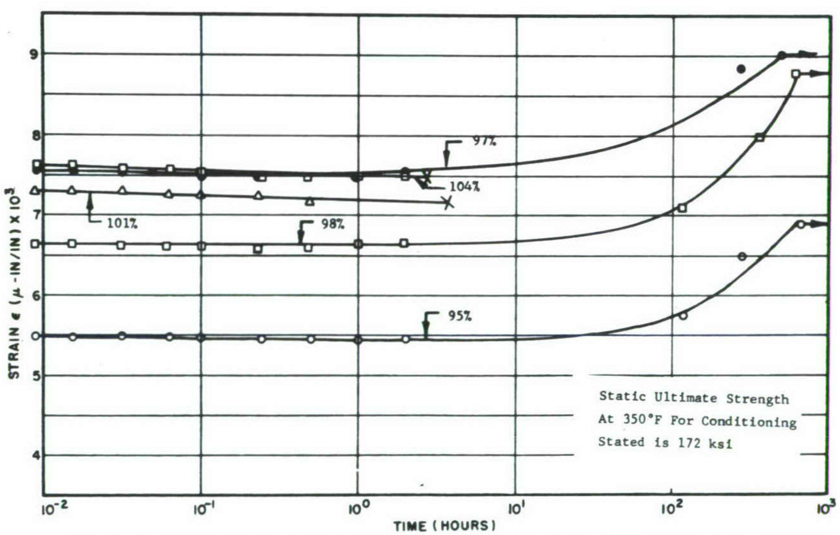

Fig. 169 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 1000 HOURS EXPOSURE TO 98% R. H.

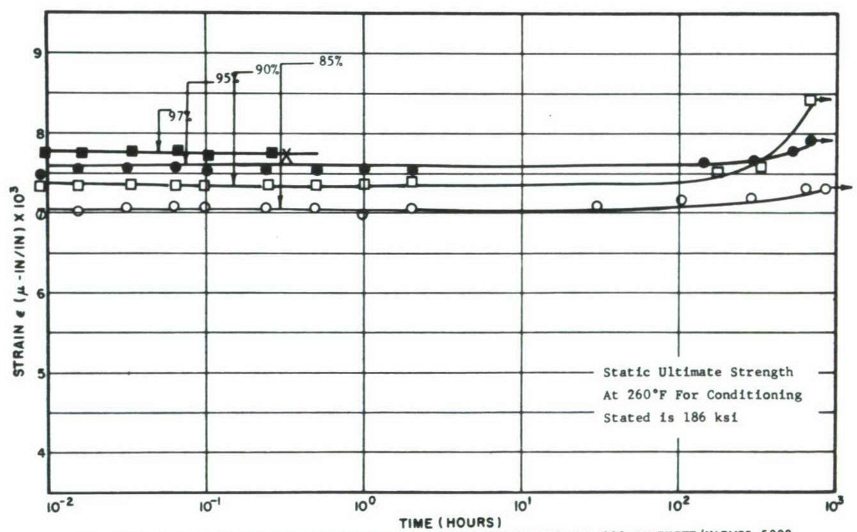

Fig. 170 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER EXPOSURE TO HUMIDITY CYCLE 1 (THERMO-HUMIDITY CYCLE)

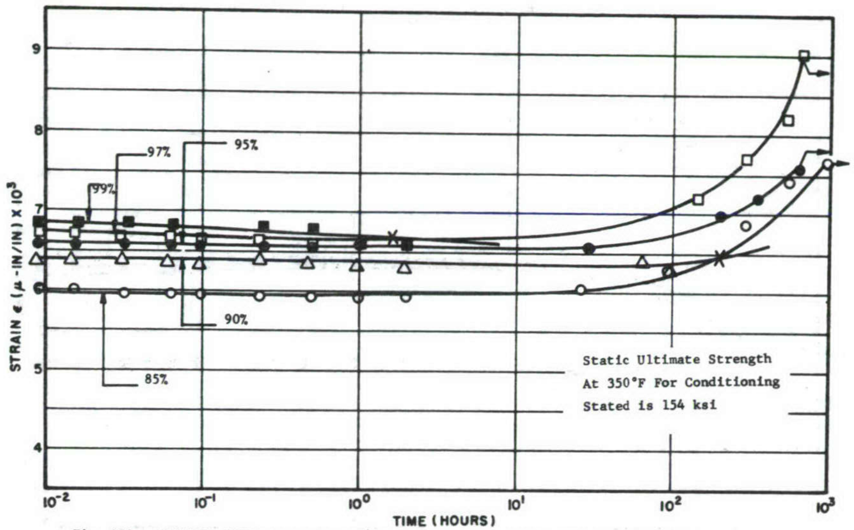

Fig. 171 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER EXPOSURE TO HUMIDITY CYCLE 1 (THERMO-HUMIDITY CYCLE)

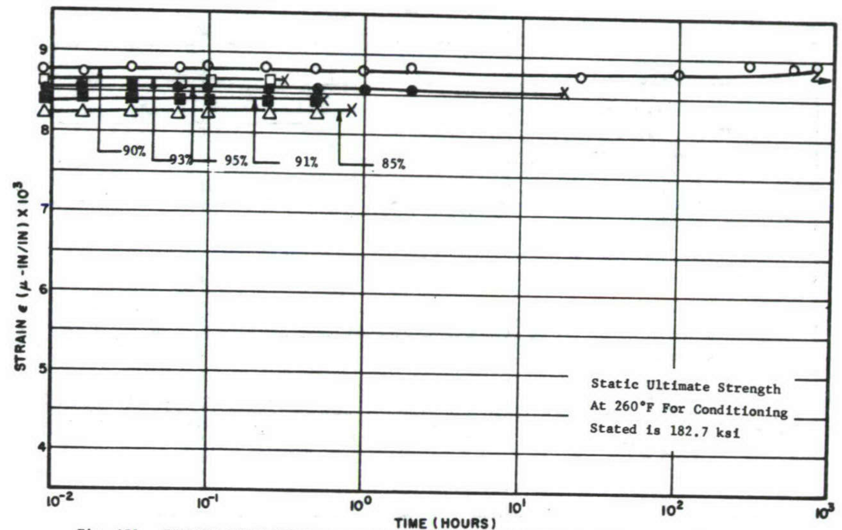

Fig. 172 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER EXPOSURE TO HUMIDITY CYCLE 2 (Accelerated Weathering)

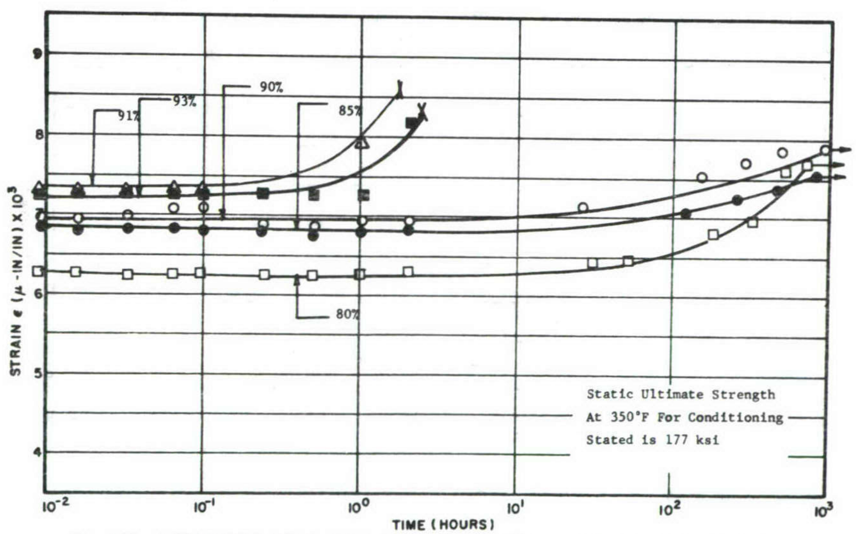

Fig. 173 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER EXPOSURE TO HUMIDITY CYCLE NO. 2 (ACCELERATED WEATHERING)

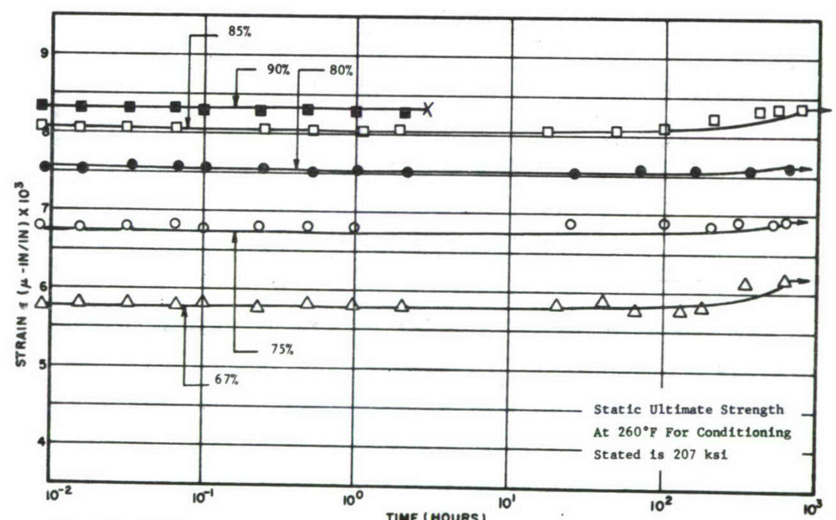

Fig. 174 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 HOURS EXPOSURE TO 260°F

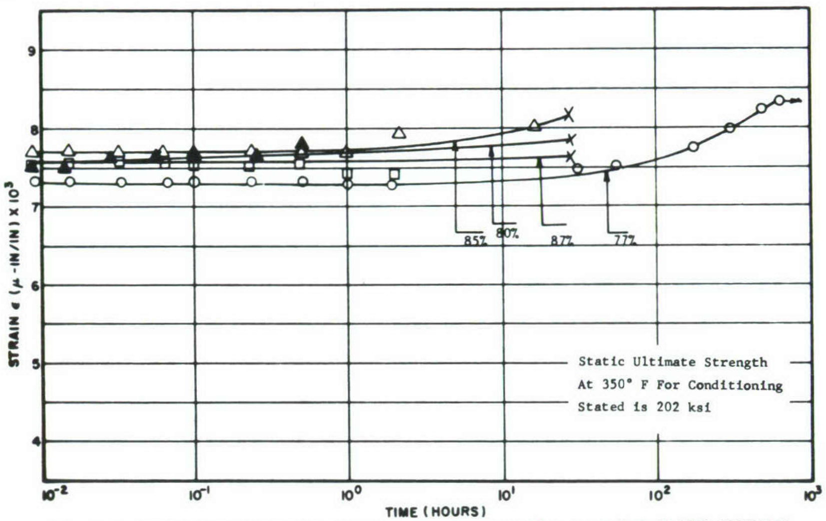

Fig. 175 TENSILE CREEP STRAIN TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 500 HOURS EXPOSURE TO 260°F

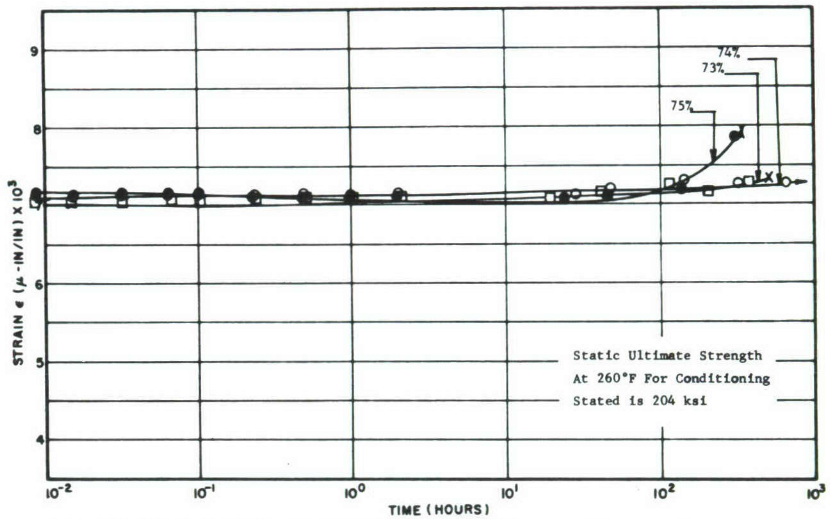

Fig. 176 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 HOURS EXPOSURE TO 350°F

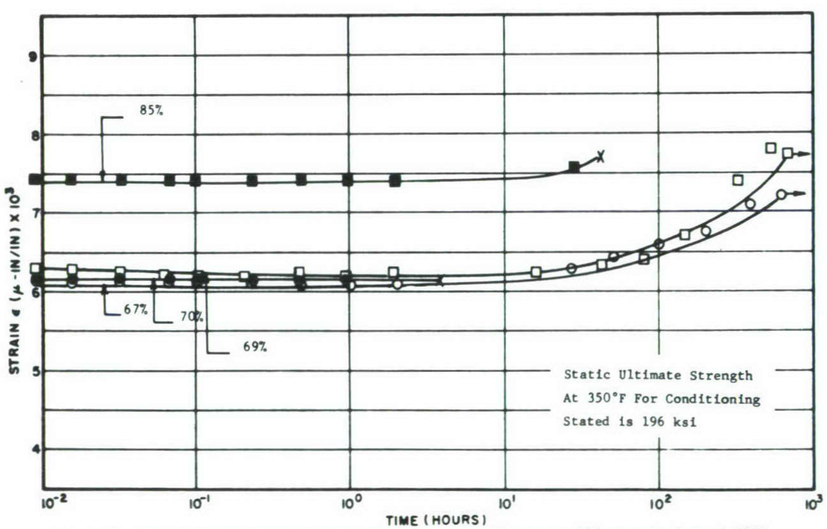

Fig. 177 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 500 HOURS EXPOSURE TO 350°F

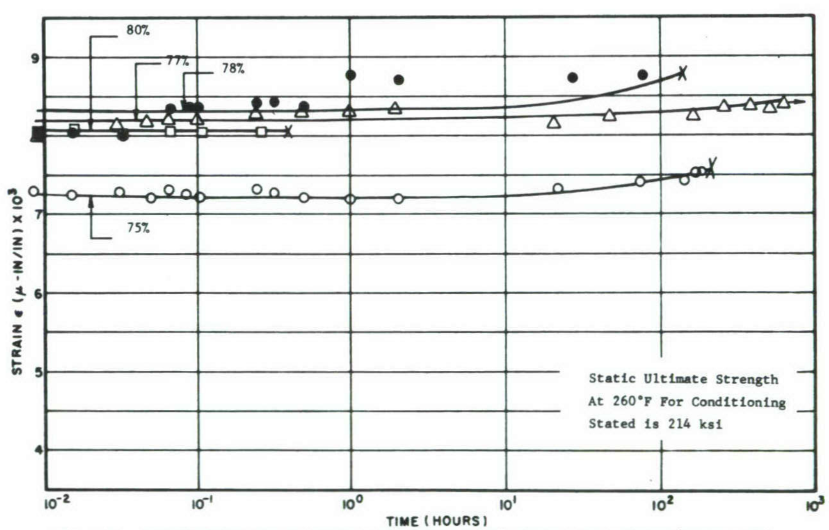

Fig. 178 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 CYCLES EXPOSURE TO 260°F

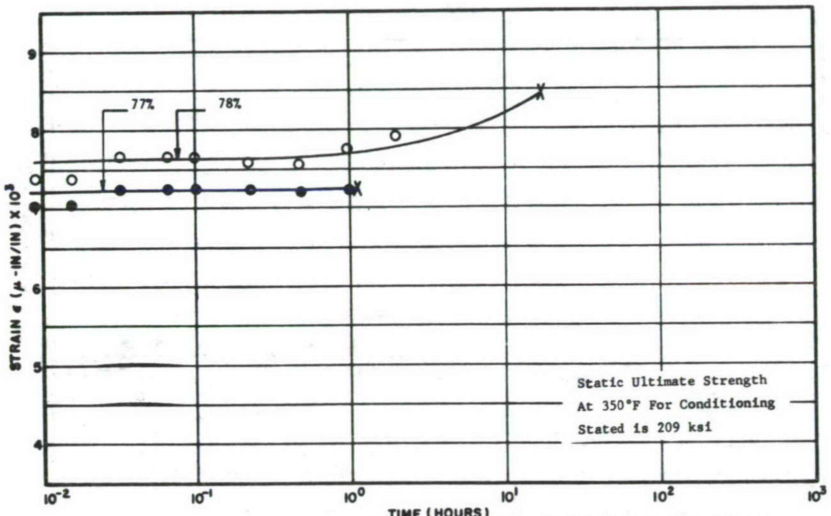

Fig. 179 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 500 CYCLES EXPOSURE TO 260°F

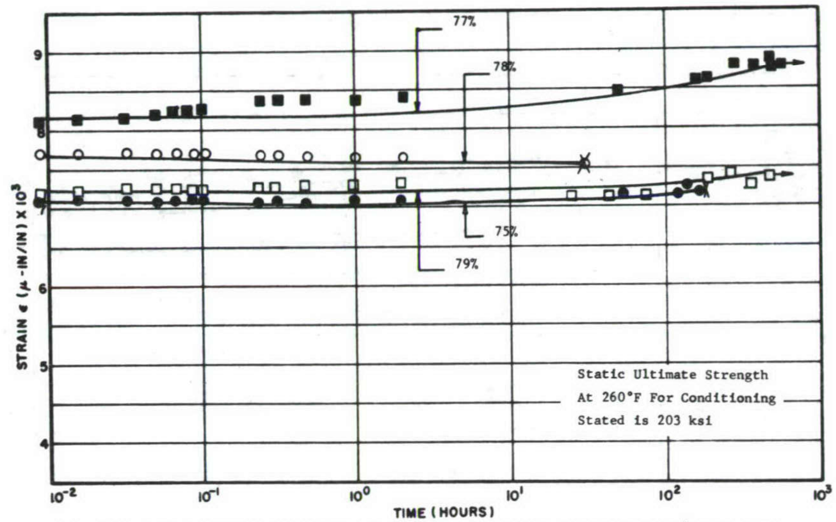

Fig. 180 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 1000 CYCLES EXPOSURE TO 260°F

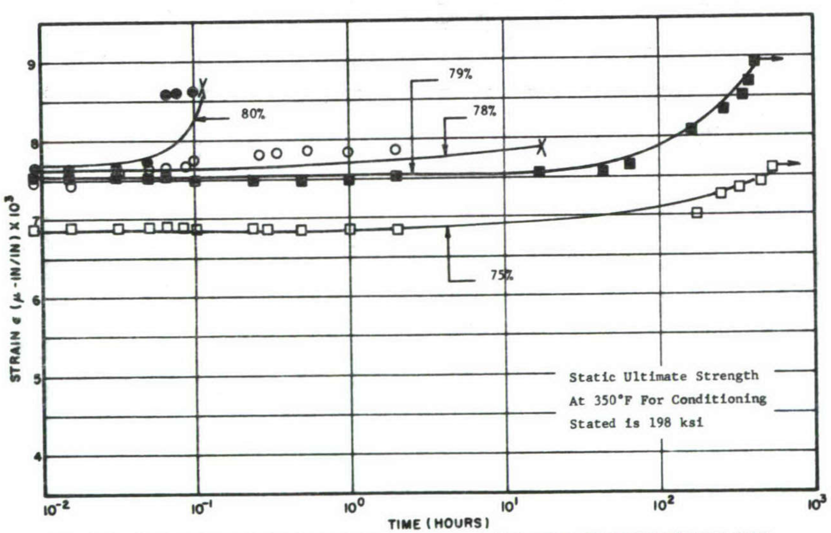

Fig. 181 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 1000 CYCLES EXPOSURE TO 260°F

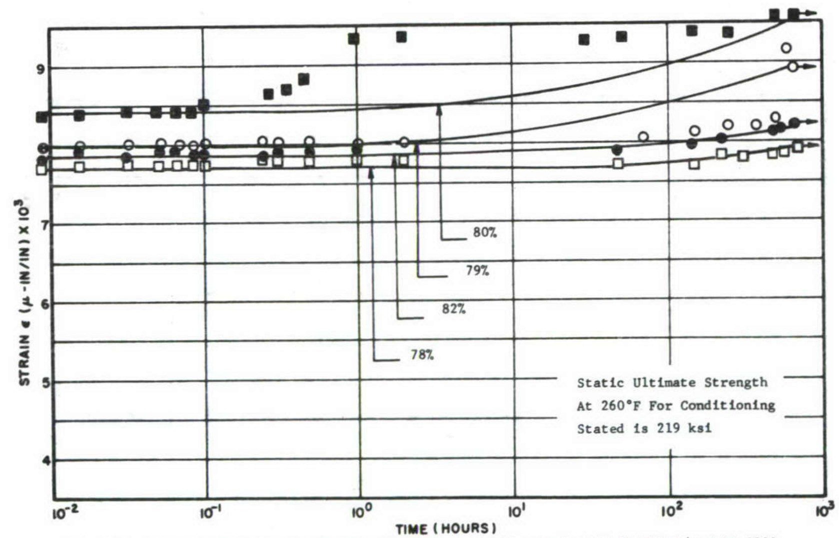

Fig. 182 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 CYCLES EXPOSURE TO 350°F

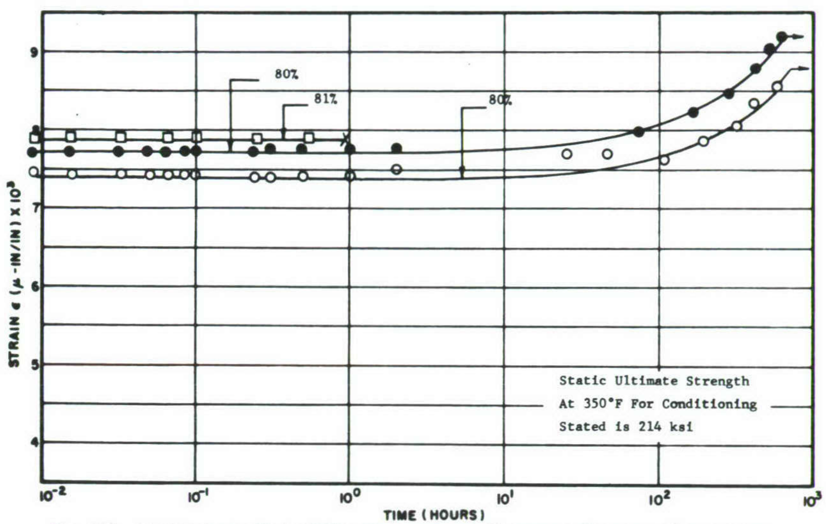

Fig. 183 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 500 CYCLES EXPOSURE TO 350°F

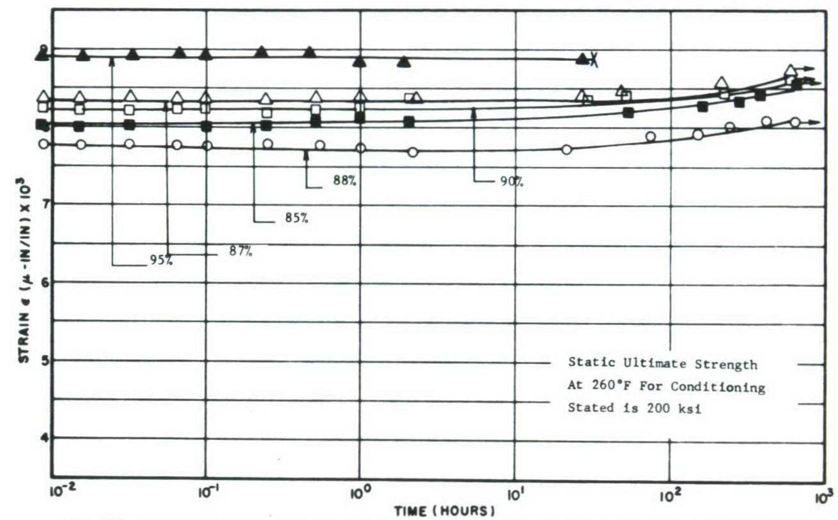

Fig. 184 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 1000 CYCLES EXPOSURE TO 350°F

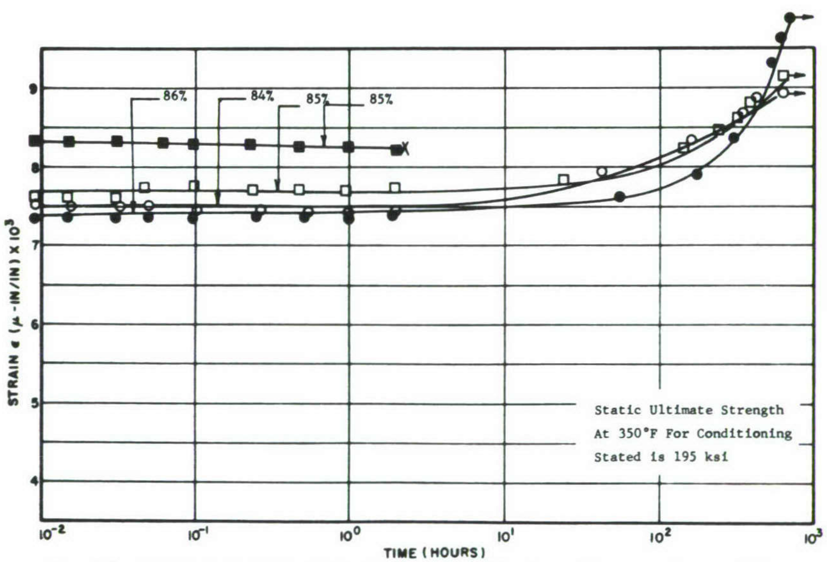

Fig. 185 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 0° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 1000 CYCLES EXPOSURE TO 350°F

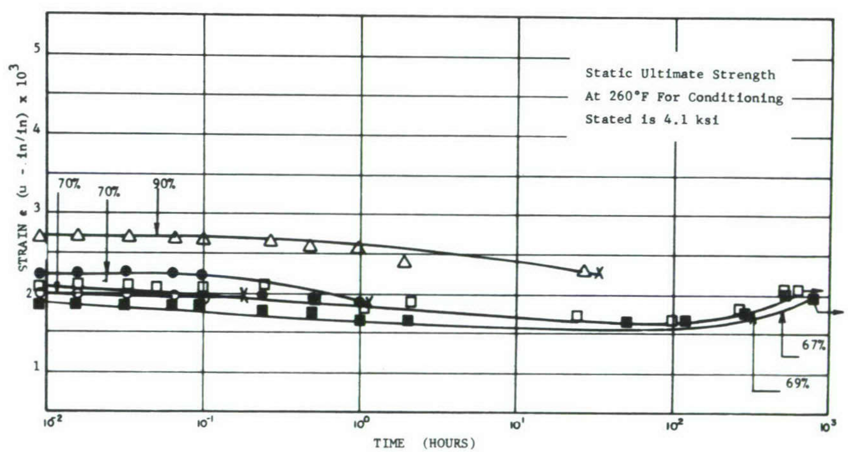

Fig. 186 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F

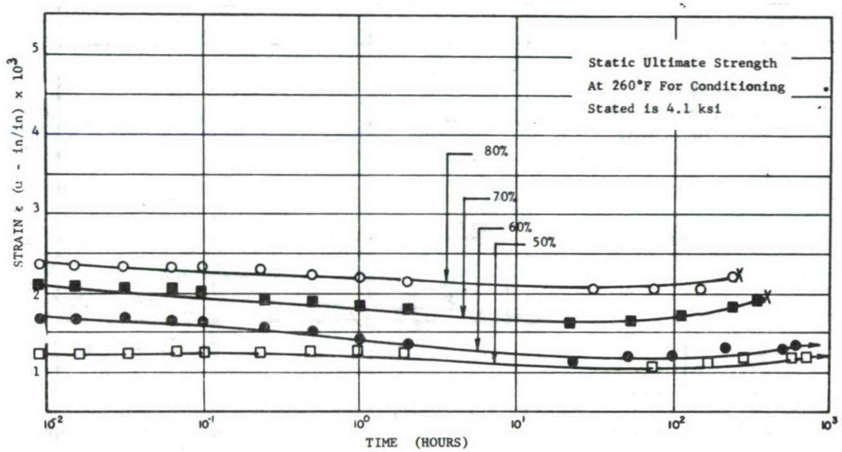

Fig. 187 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°

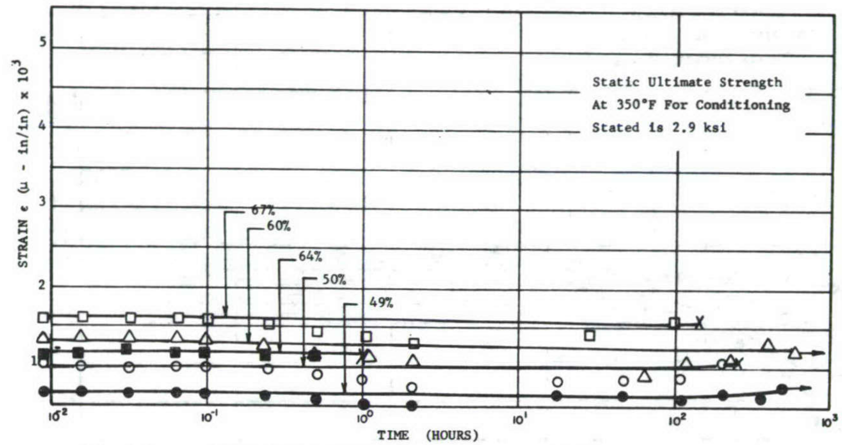

Fig. 188 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F

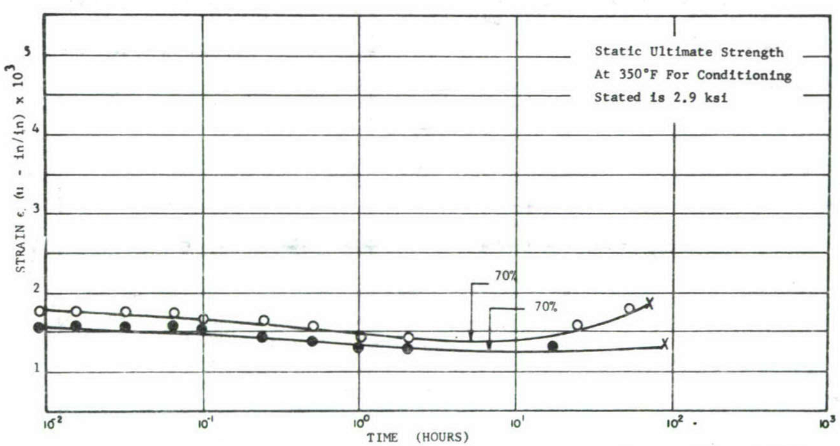

Fig. 189 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR 90° THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F

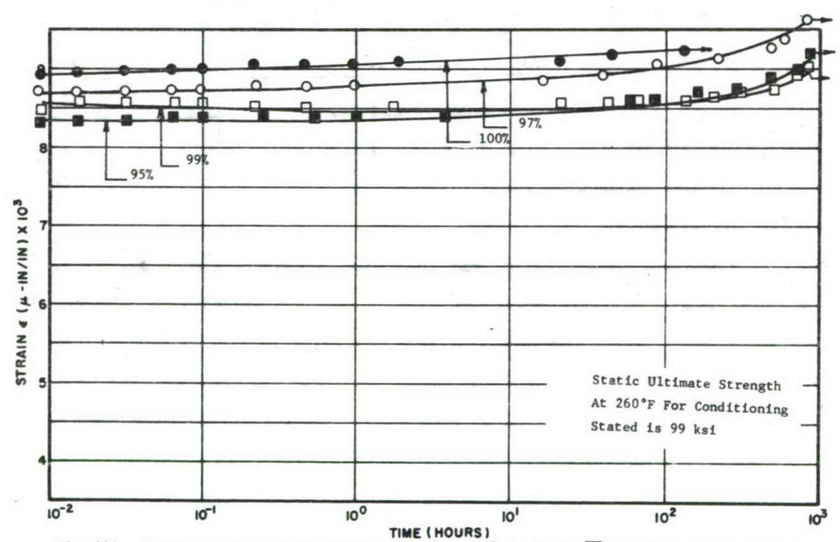

Fig. 190 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F

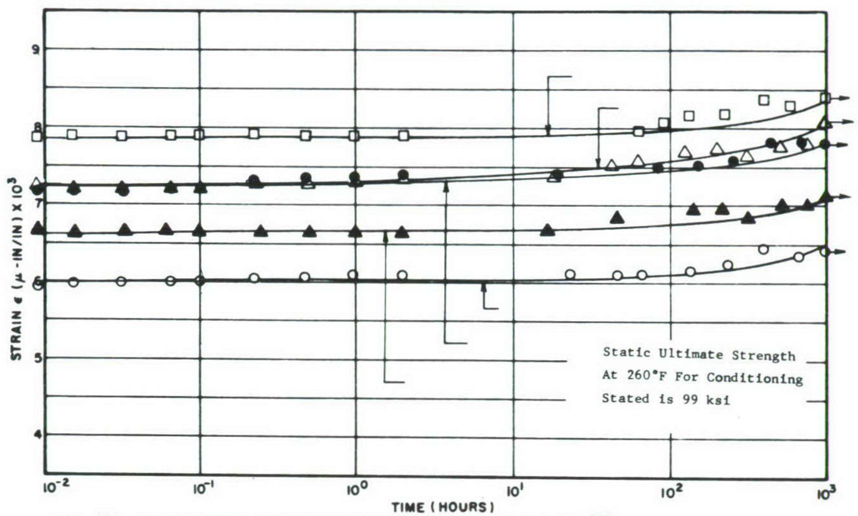

Fig. 191 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 TESTED AT 260°F

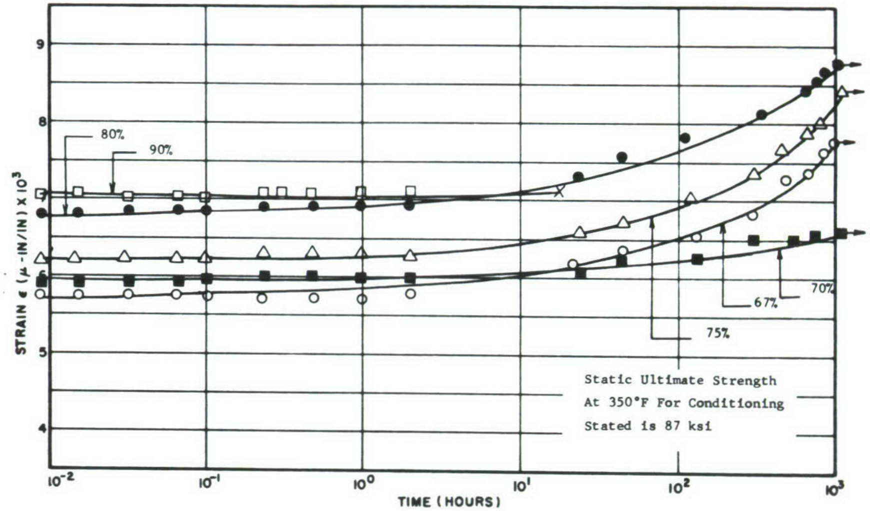

Fig. 192 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 LAMINATE TESTED AT 350°F

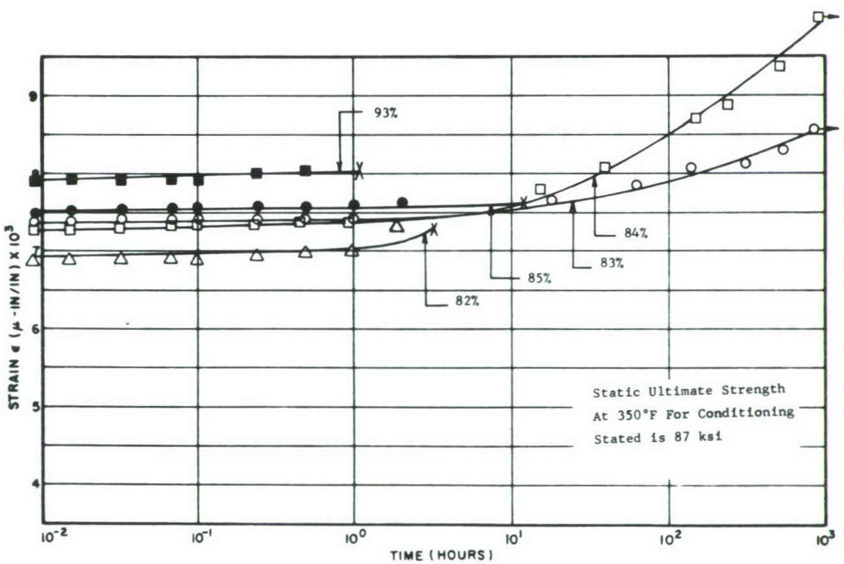

Fig. 193 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 LAMINATE TESTED AT 350°F

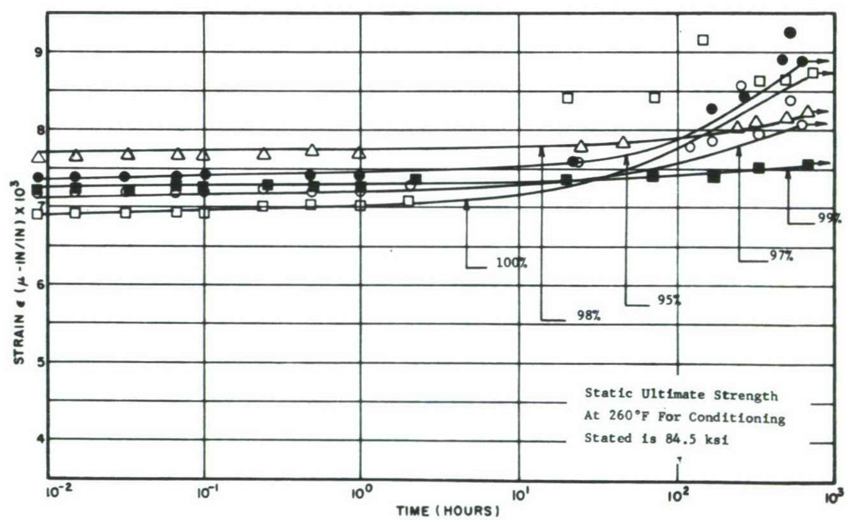

Fig. 194 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 HOURS EXPOSURE TO 98% R. H.

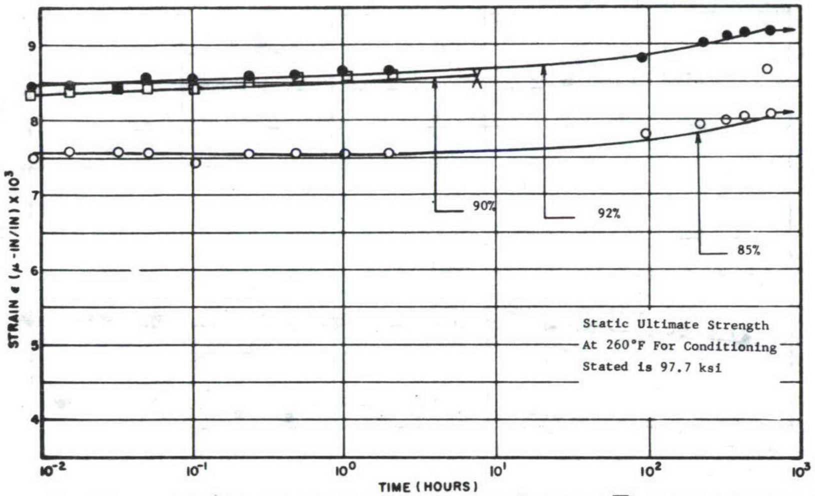

Fig. 195 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 1000 HOURS EXPOSURE TO 98% R. H.

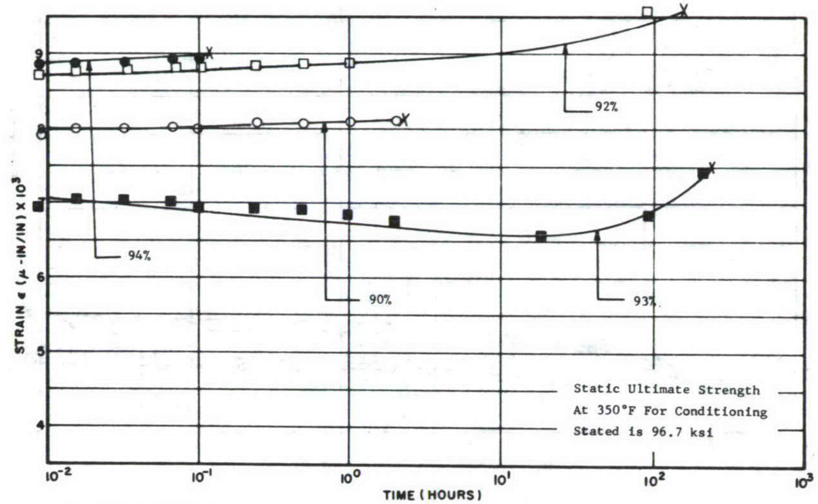

Fig. 196 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 1000 HOURS EXPOSURE TO 98% R. H.

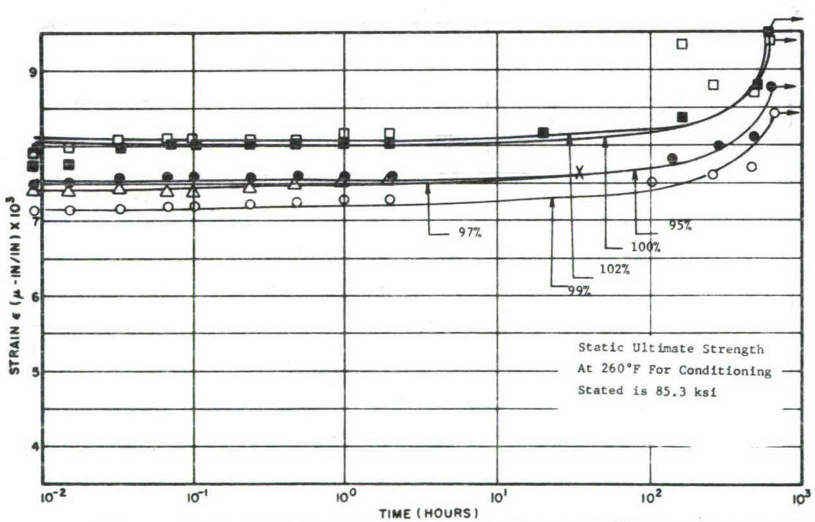

Fig. 197 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-humidity Cycle)

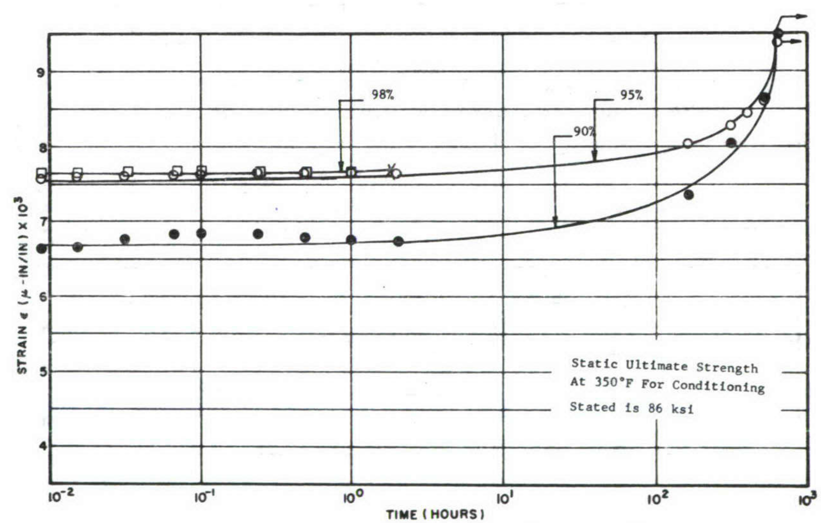

Fig. 198 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER EXPOSURE TO HUMIDITY CYCLE No. 1 (Thermo-Humidity Cycle)

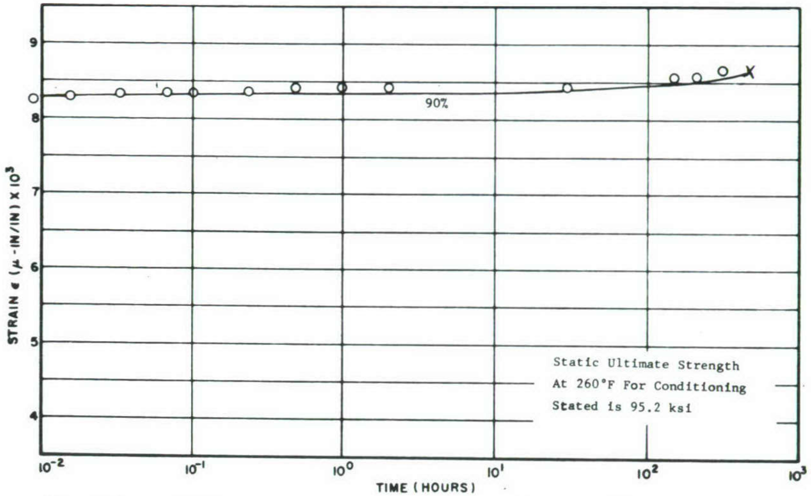

Fig. 199 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (Accelerated Weathering)

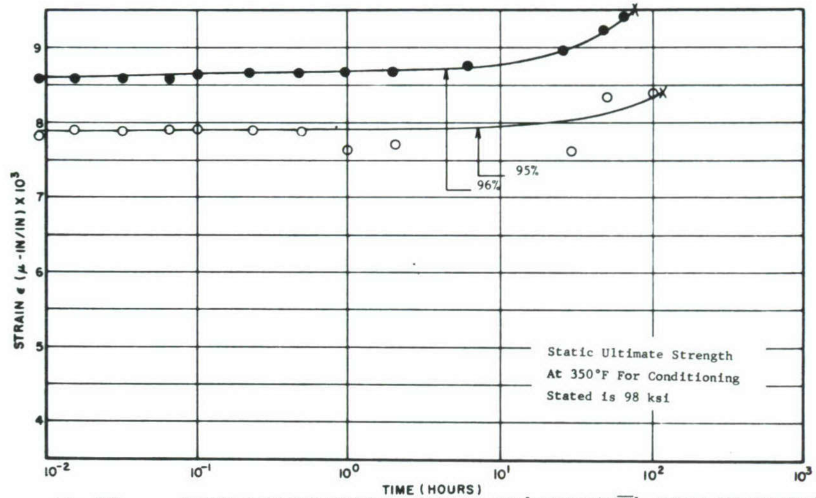

Fig. 200 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER EXPOSURE TO HUMIDITY CYCLE No. 2 (Accelerated Weathering)

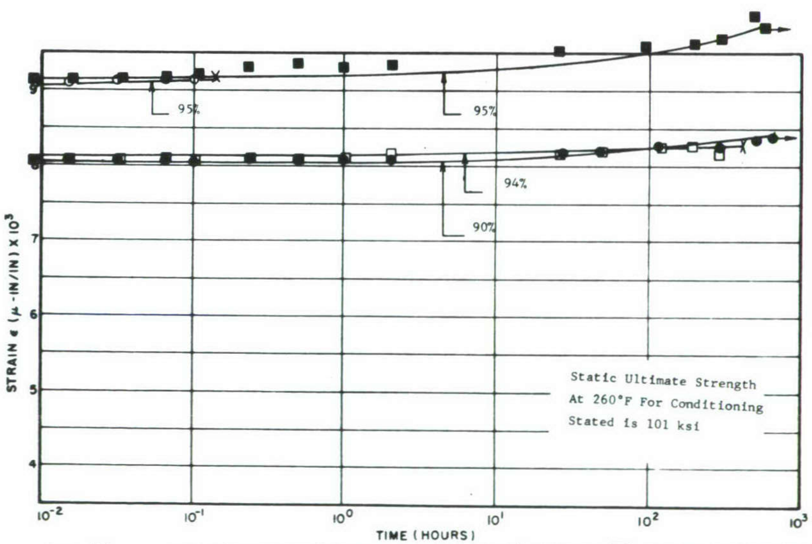

Fig. 201 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 HOURS EXPOSURE TO 260°F

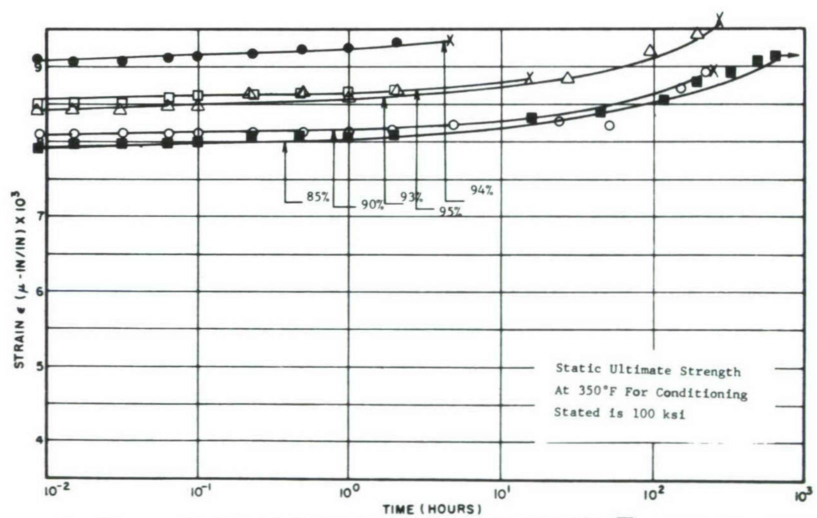

Fig. 202 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 500 HOURS EXPOSURE TO 260°F

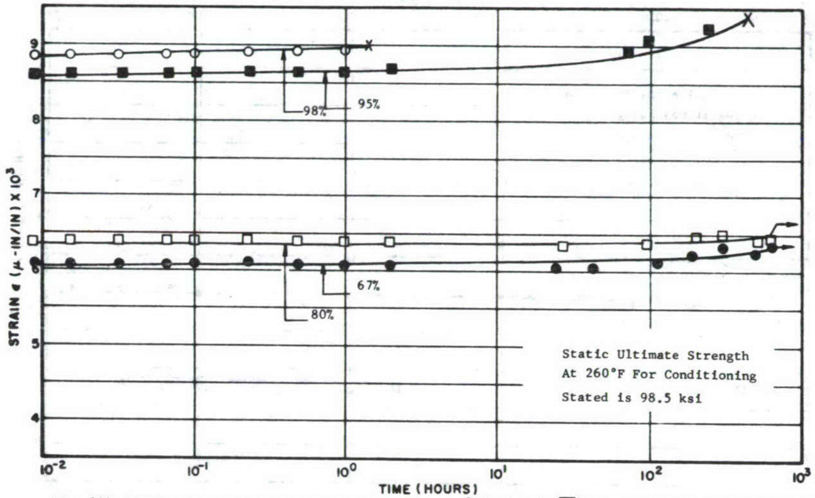

Fig. 203 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 HOURS EXPOSURE TO 350°F

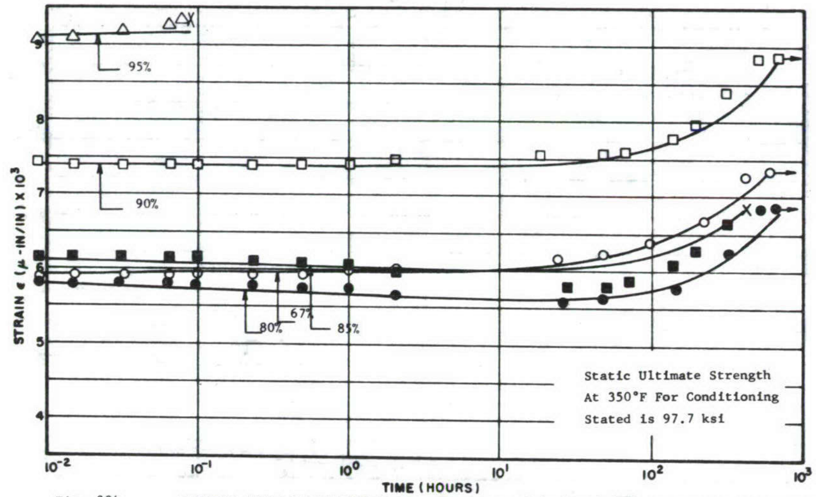

Fig. 204 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 500 HOURS EXPOSURE TO 350°F

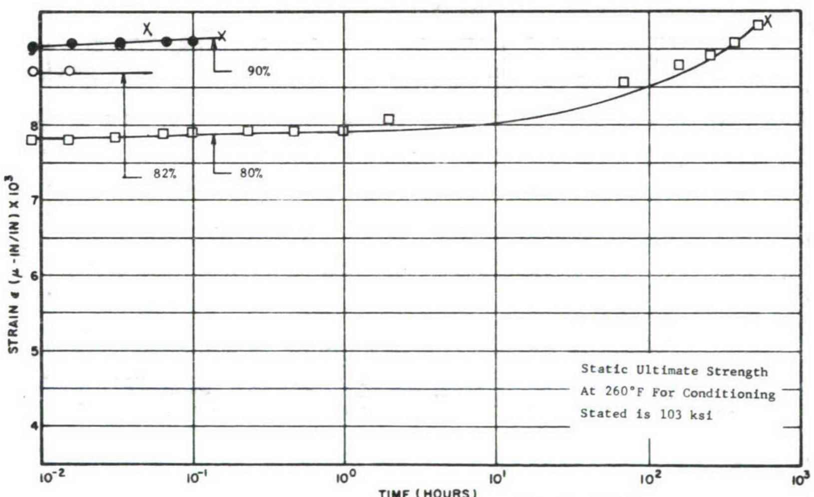

Fig. 205 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 CYCLES EXPOSURE TO 260°F

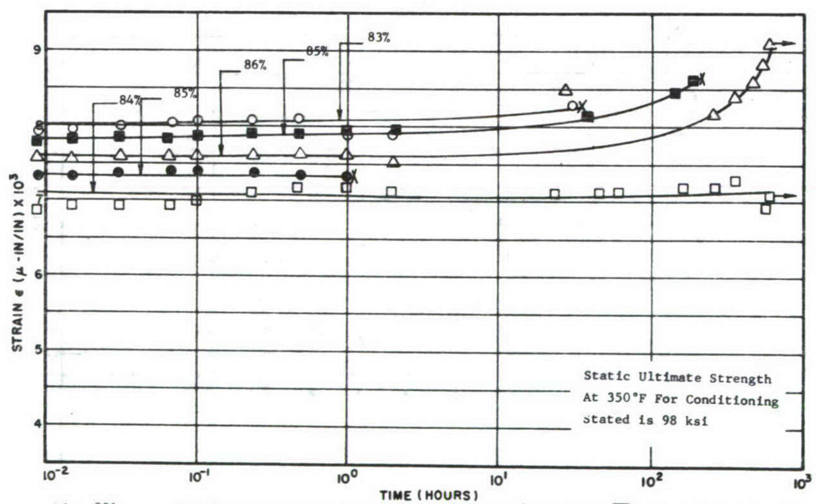

Fig. 206 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 500 CYCLES EXPOSURE TO 260°F

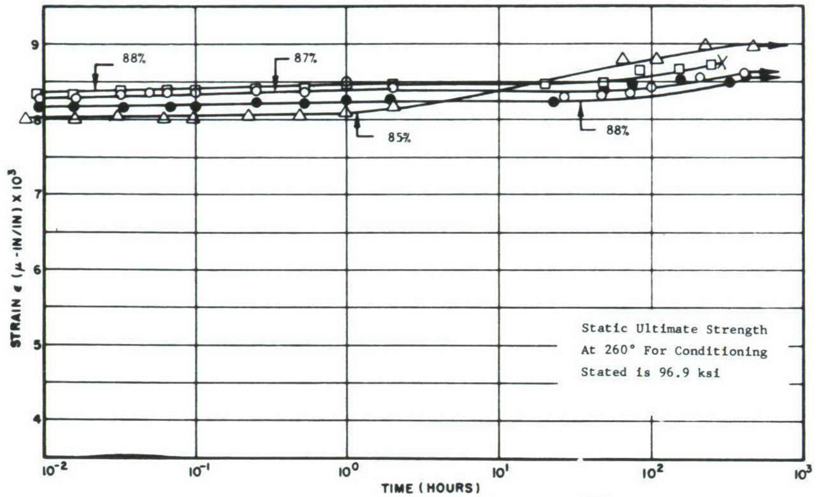

Fig. 207 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 1000 CYCLES EXPOSURE TO 260°F

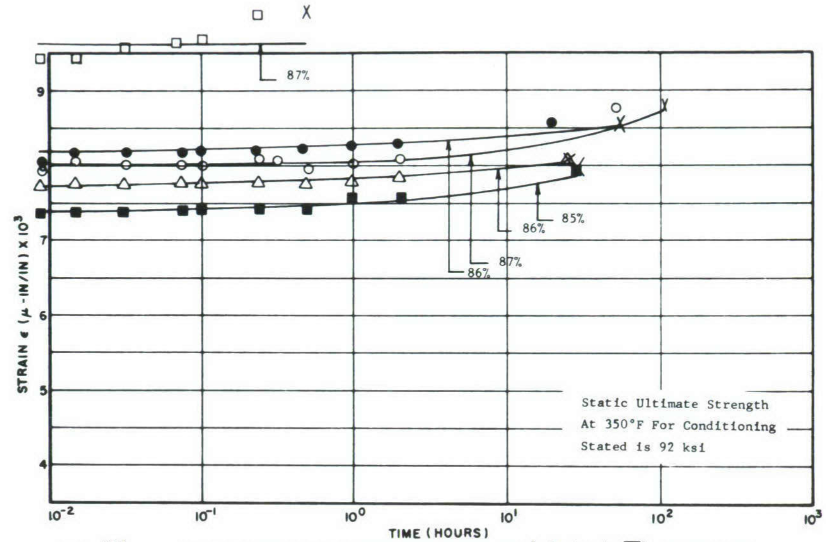

Fig. 208 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 1000 CYCLES EXPOSURE TO 260°F

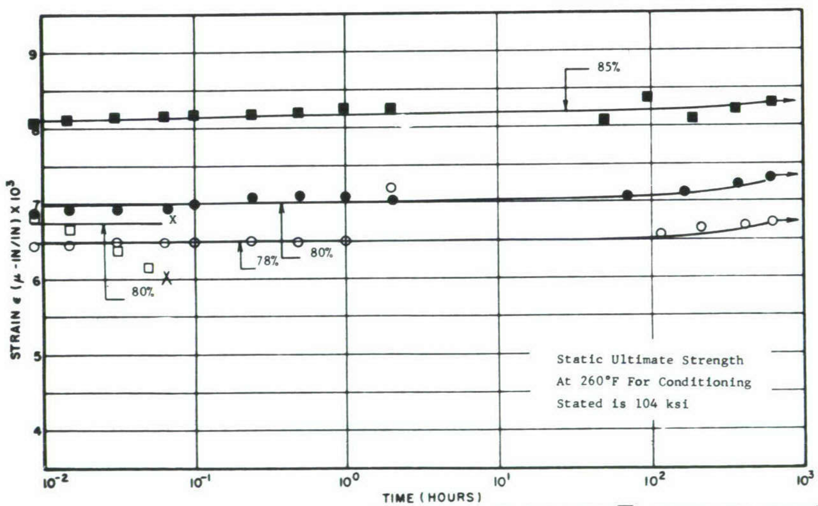

Fig. 209 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 500 CYCLES EXPOSURE TO 350°F

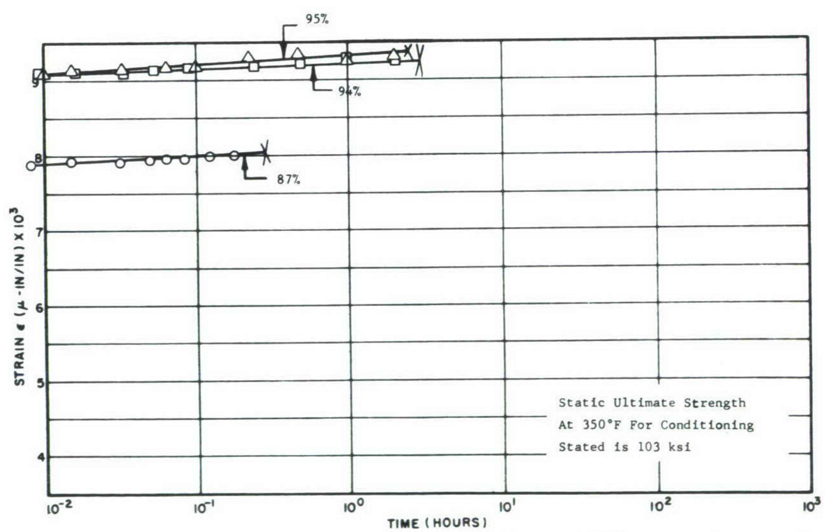

Fig. 210 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 500 CYCLES EXPOSURE TO 350°F

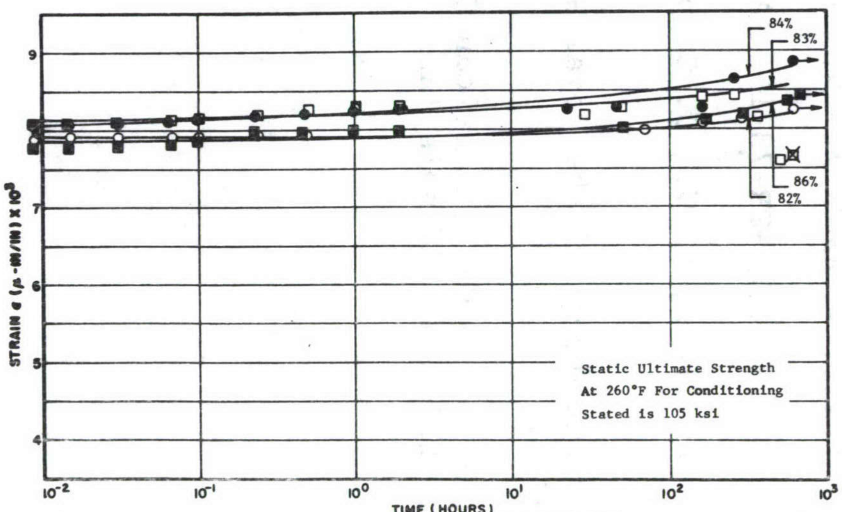

Fig. 211 TENSILE CREEP STRAIN VERSUS TIME CURVES FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 260°F AFTER 1000 CYCLES EXPOSURE TO 350°F

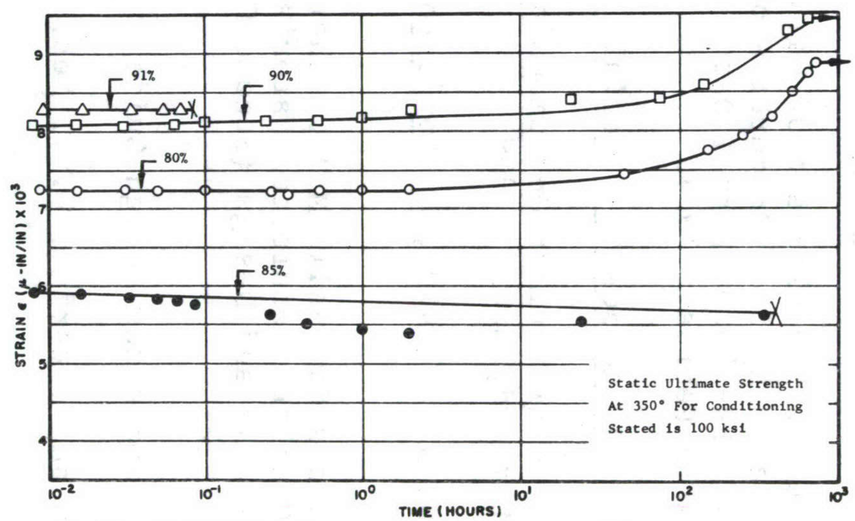

Fig. 212 TENSILE CREEP STRAIN VERSUS TIME CURVE FOR $[0/45/135/0/\overline{90}]_s$ THORNEL 300 GRAPHITE/ NARMCO 5208 COMPOSITE TESTED AT 350°F AFTER 1000 CYCLES EXPOSURE TO 350°F

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