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Evaluation and Test of Improved Fire-Resistant Fluid Lubricants for Water Reactor Coolant Pump Motors

Volume 2: Fluid/Metal Compatibility

EPRI

EPRI NP-1447
Volume 2
Project 893-1
Interim Report
July 1980

Keywords:
- Main Coolant Pump
- Reactor Coolant Pump
- Fire Retardant Lubricant
- Containment Fires

Prepared by
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

ELECTRIC POWER RESEARCH INSTITUTE

Evaluation and Test of Improved Fire-Resistant Fluid Lubricants for Water Reactor Coolant Pump Motors
Volume 2: Fluid/Metal Compatibility

NP-1447, Volume 2
Research Project 893-1

Interim Report, July 1980
Work Completed, March 1980

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NOTICE

Prepared by
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

EPRI PERSPECTIVE

PROJECT DESCRIPTION

This project was initiated after a number of in-containment lubricating oil fires occurred at nuclear power plants. The oil used to lubricate the primary system pump motor bearings leaked onto hot primary system piping and flashed into a flaming fire. The pump motor is a large (8000 horsepower) vertical shaft motor with 260 gallons of oil in the upper bearing oil pot and 50 gallons of oil in the lower bearing oil pot. Oil is pressurized in the oil lift system and can be sprayed onto surrounding pipes if leaks occur.

This project surveyed a large number of suppliers for candidate fluids which had lubrication qualities equal to oil and which would have fire retardant properties at the temperatures encountered in nuclear primary system piping. These fluids were then tested for properties which were essential for this use, such as: radiation resistance, good lubrication, lift-off or stationary shaft lubrication, compatibility with expected materials, good fire resistance and service lifetime.

PROJECT OBJECTIVE

The objective was to identify an existing fire-resistant lubricant which would adequately perform as a lubricant in the primary system pump motor.

PROJECT RESULTS

The following report is quite detailed and technical in nature. It is intentionally explicit in the testing performed so that its results would be of use to other motor manufacturers and to potential users of fire retardant fluids.

The report is designated as an interim report since the fluid has one property which so far has prevented our recommending its use for an in-containment lubricant. When the fluid degrades due to contamination by water or other contaminants, it forms acid products which act as catalysts for further degradation. This is not instantaneous, but significant degradation can occur over a number of weeks. Since remote operation in containment can require weeks of operation without contact with the fluid, a means of remotely determining fluid condition is essential. Fullers earth or activated alumina filters can restore the fluid if the condition is identified. Work is continuing in this area.

With this exception, a good fire-resistant fluid has been identified with adequate lubricating qualities and with material compatibilities which can be made acceptable by proper choices of gaskets, paints, and other materials.

This report will be of interest to operating and engineering personnel--and especially to fire protection personnel--since it identifies an area where the standard tests for autoignition temperature do not apply. An alternate applicable test is identified.

R. Swanson, Project Manager
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ABSTRACT

Fires within nuclear containment have occurred when the lubricants used in reactor coolant pump motors have leaked or spilled onto the hot insulated main coolant piping. This project was directed toward determining the applicability of commercially available fire resistant fluid lubricants to the lubrication of the bearings of a reactor coolant pump motor. This report describes the evaluation of candidate fluids, the testing of these fluids, and the selection of a lubricant for use in a standard reactor coolant pump motor test. The test results indicated that the phosphate ester lubricants, when properly inhibited and maintained, are acceptable for use. Recommendations are presented for further work necessary to the successful application of the fire resistant fluid lubricant.

FOREWORD

This is the Interim Report for EPRI Contract RP893-1, Evaluation and Test of Improved Fire Resistant Fluid Lubricants for Water Reactor Coolant Pump Motors. The Interim Report has been prepared by the Generator Systems Department of the Steam Turbine Generator Technical Operations Division, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

The Interim Report consists of two volumes:

Volume One--Fluid Evaluation, Bearing Model Tests, Motor Tests and Fire Tests

Volume Two--Fluid/Material Compatibility

This is Volume Two.

CONTRIBUTIONS

This Final Report is the result of contributions from the Westinghouse Project Team as follows:

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Many others contributed to specific tasks.

H. E. Pietsch
(W) Project Manager

CONTRACTOR'S NOTE

The draft of this final report was dated May 1, 1979. After it was reviewed by EPRI and by the Design Review Committee on June 6, 1979, the report was revised by Dr. H. E. Pietsch, Project Manager. Subsequently, the report was edited and revised by Mr. J. G. Partlow, the successor to Dr. Pietsch, prior to the reissue of the report in March, 1980. This final revision was made at EPRI's request to add comments from the Design Review Committee's meeting. At the same time, some up-dating was included along with clarifications and typographical corrections.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

SUMMARY

13.0 SUMMARY

Sections 13.1 and 13.2 are the same as Sections 1.1 and 1.2 in Volume One. It is repeated here for the convenience of the reader.

13.1 EXECUTIVE SUMMARY

The use of a fire resistant fluid lubricant in the electric utility industry has been proposed and investigated for various applications since the early 1920's. It has long been recognized that the leakage of petroleum oil lubricants creates a fire hazard. Fires have occurred over the years in steam turbine generator installations. In the early 1970's several fires occurred in nuclear reactor coolant loops. The fires were caused by leaks or spills of the petroleum oil from the reactor coolant pump motors. A fire resistant fluid lubricant for the reactor coolant pump motor would eliminate these fires.

Although the earlier investigations for using fire resistant fluids did not provide sufficient data to guarantee the applicability of fire resistant lubricants for reactor coolant pump motors, they provided general guidelines and indicated the problems which required solution.

The application of a fire resistant fluid to a system with the unique operating characteristics and with the very different environment of a reactor coolant pump motor requires a detailed study. EPRI requested such a study and Westinghouse, under contract RP 893-1, performed testing and evaluation of fire resistant fluid lubricants.

The purpose of project RP 893-1 is to develop a fire resistant fluid lubricant for use in reactor coolant pump motors which will be compatible with the material, lifetime, and lubrication requirements but will not ignite and burn at or below the reactor operating temperature of 550^{o}F.

The fluid evaluation and tests have identified Fyrquel RCP*, a phosphate ester fluid manufactured by Stauffer Chemical Company; as the most suitable fluid presently available. The results are:

- The required fire properties are realized with Fyrquel RCP.
- The lubricating capability of Fyrquel RCP is equal to or better than that of a good quality petroleum based turbine oil.
- The radiation resistance of Fyrquel RCP is adequate for 18 month fuel cycles.
- Thermal and oxidative stability are better for Fyrquel RCP than for petroleum oil.
- Because of its additive package, Fryquel RCP has better hydrolytic stability than petroleum oil.
- The compatibility of Fyrquel RCP has presented no unresolvable problems. Gaskets and seals are commercially available that can be used with the fluid. Electrical insulation, such as well consolidated epoxy mica systems, will withstand phosphate ester attack under normal operating conditions. Paints are available that are not attacked by phosphate esters. Compatibility must be considered before the fluid is utilized in existing or new motors to prevent significant problems from arising.

Successful use of Fyrquel RCP in reactor coolant pump motors to eliminate the fire hazards may be achieved. A remote fluid condition monitoring system will be required before the fluid can be used inside containment because of the auto catalytic nature of the fluid degradation processes. EPRI has initiated a project for the development of such a monitoring system. The fluid properties should now be confirmed in long term demonstrations outside containment before it is used inside containment.

13.2 TECHNICAL SUMMARY

The purpose of Project RP 893-1 is to develop a fire resistant reactor coolant pump motor lubricant which will be compatible with the material, lifetime, and lubrication requirements of the motor but which will not ignite and burn at or

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* See Volume One, Section 2.4 for definition of the trade names Fryquel RCP, Fyrquel GT and Fryquel VPF, as used in this report.

below the reactor operating temperature of 550°F. To accomplish the purpose, five tasks were performed:

Task 1 - Evaluation of Lubricants
Task 2 - Laboratory Tests
Task 3 - Selection of Lubricant
Task 4 - Test Operation
Task 5 - Recommendations and Final Report

13.2.1 TASK 1 - EVALUATION OF LUBRICANTS

In Task 1 suppliers and users of fire resistant fluid lubricants were contacted and pertinent data were obtained. The evaluation of commercially available lubricating fluids identified the phosphate ester fluid class as the prime candidate for this application. Two other fluid classes, the silicone lubricating fluids and the diester lubricating fluids, were considered to be back-up candidates. Representative test fluids from these three classes were tested in the laboratory to develop sufficient data to permit a fluid selection for actual motor test operation.

13.2.2 TASK 2 - LABORATORY TESTS

Fluids representative of the chosen classes were tested to determine their physical and chemical properties. The test results were used to decide whether to continue to include the fluids in the remainder of the project. These fluids were:

- Phosphate Esters
  - Fyrquel GT -- Stauffer Chemical Company
  - Fyrquel RCP -- Stauffer Chemical Company
  - Turbinol 1122 -- Monsanto Industrial Chemicals
  - Houghto-Safe 1115 -- E. F. Houghton
  - Houghto-Safe 1115LP -- E. F. Houghton

- Diester
  - Anderol 495 -- Tenneco

- Silicone
  - SF #1147 -- General Electric Company

- Petroleum Oil (Control)
  - Teresstic 46 -- Exxon
  - Regal B R & O -- Texaco

A test was developed to evaluate the fire resistant properties of the candidate fluids. It is the soaked cube fire test. Phosphate ester fluids performed better in this test than did either the silicone fluid or the diester fluid. Petroleum oil was found to exotherm at oven temperatures of 375 to 425^{O}F, well below the coolant pipe temperature of 550^{O}F. Also having exotherm temperatures below the coolant pipe temperature were the silicone fluid (400^{O}F), the diester fluid (425^{O}F), and a phosphate ester (450^{O}F). Two phosphate ester fluids showed exotherm temperatures (575^{O}F and 625^{O}F) well above the other fluids tested and, more importantly, above the coolant pipe temperature. It should be noted that these values are significantly below the standard auto ignition temperatures for these fluids. Most of the remaining tests were performed with one or both of these fluids.

Radiation test results show that, when no other degrading influences exist, 3.5 years would be required in a radiation field of 50 rad/hour before the phosphate ester fluids would require active earth filtration.

Two bearing tests of short duration were made. These tests were a machining wear test and a test of the fluid's boundary lubrication properties. In these tests, the phosphate ester fluid was equal to or better than the petroleum oil tested for direct comparison.

Several tests were performed to evaluate very specific fluid properties. The properties evaluated included foaming tendency, rusting, compatibility with elastomers and paints, fluid contamination with water and several standard tests for thermal, oxidative and hydrolytic stability.

The compatibility of several epoxy and polyester insulation systems with the fluid was evaluated. There were varying degrees of attack at extremes of exposure to the phosphate ester fluid. The epoxies offer a more stable system than do the polyesters. It is expected on the basis of this examination that the insulation systems will perform satisfactorily for the design life of the motor under normal conditions of use with the phosphate ester fluid.

No evidence of galvanic attack was observed on the pairs of dissimilar joined metals under test. Also, no evidence of susceptibility to stress-corrosion cracking was observed. The corrosion rates of the ferrous alloys indicated that there will be no problem with their exposure to the phosphate ester fluid. Copper and copper alloys exhibited high corrosive rates which appear to have a dependency on the acid number of the phosphate ester fluid. However, a properly inhibited phosphate ester reduces the copper corrosion to acceptably low levels. The additive package controls this effect as long as the fluid is prevented from degrading and over-riding this control.

Most of the gasket materials presently being utilized in reactor coolant pump motors are unsatisfactory for long term use with the phosphate ester fluid. The exception to this is Viton 90, which is commercially available and may be substituted for the materials presently being used.

13.2.3 TASK 3 - SELECTION OF LUBRICANT

The fluid selected for final testing was Fyrquel RCP, a phosphate ester fluid manufactured by Stauffer Chemical Company. It is expected that other phosphate ester fluids can be manufactured and provided with an additive package such that they will perform to the level exhibited by the tested fluid. The project results indicate the following characteristics for Fyrquel RCP:

- Required fire properties have been realized.
- Lubricating capability is equal to or better than that of a good quality petroleum based turbine oil.
- Radiation resistance is adequate for 18 month fuel cycles.
- Thermal and oxidative stability are better than for petroleum oils.
- Because of its additive package, its hydrolytic stability is better than that of petroleum oil.
- Compatibility presents no unresolvable problems. Gaskets and seals that can be used with the fluid are commercially available. Electrical insulation, such as well consolidated epoxy mica systems, will withstand phosphate ester attack under normal operating conditions. Paints are available which are not attacked by phosphate esters.

Compatibility must be considered prior to the use of a phosphate ester in either a new or existing motor.

- Longer term degradation of the fluid is a problem if the fluid cannot be periodically tested since the degraded fluid accelerates further fluid degradation.

13.2.4 TASK 4 - TEST OPERATION

Full scale motor tests were performed to evaluate the selected lubricant. Fyrquel RCP performed well in the testing (100 hours) in an uncoupled reactor coolant pump motor. It also performed well in the testing (four tests of approximately 28 hours each) of the lubricant in a reactor coolant pump motor coupled to the reactor coolant pump in the pump test loops.

13.2.5 TASK 5 - RECOMMENDATION AND FINAL REPORT

A Design Review Committee was established to review and evaluate the progress of the project. Two Design Review Committee Meetings were held at the milestone events represented by the completion of Tasks 1 and 3. In addition meetings were held during the interim period with individual Design Review Committee members to discuss project accomplishments and future direction. A final Design Review Committee Meeting was held on June 6, 1979 to present this final report. Recommendations for further development are given in Section 21.0.

13.3 SUMMARY OF CONTENTS OF VOLUME TWO

This is Volume Two of the two volumes comprising the final report. Its title is "Fluid/Material Compatibility." It discusses in detail the following topics:

Compatibility Testing of Metallic Systems .... Section 14.0

Consideration of Insulation and Stator Winding Components .... Section 15.0

Compatibility Testing of Electrical Insulation Systems .... Section 16.0

Compatibility Testing of Corona Suppression System .... Section 17.0

Compatibility Testing of Organic Structural Components.................................. Section 18.0

Additional Testing of Insulation Components.. Section 19.0

Compatibility Testing of Paints and Elastomers... Section 20.0

Discussion and Recommendations.......................... Section 21.0

As a part of this study other motor manufacturers were requested to suggest materials for compatibility testing. General Electric and Brown Boveri did not participate. Allis Chalmers suggested the following materials:

- Air cooler aluminum fin material (ASTM 1100-0)
- Asbestos tape - Atlas Textile Company 411-A1
- Anti-corona paint - GE #9921
- Keeler and Long paint system #7107
- W.C. Richards Company E-4183 Yellow Oxide Casting Sealer
- Zummach Paint Corporation Buff Primer U-3001

A final sample was submitted by AEG (Kleiber & Schultz, Inc.). It consisted of a short coil section. These samples were tested and the results are reported in the appropriate sections.

SECTION 14.0

COMPATIBILITY TESTING OF METALLIC SYSTEMS

14.0 COMPATIBILITY TESTING OF METALLIC SYSTEMS

14.1 GENERAL DISCUSSION

A testing program has been conducted to evaluate the compatibility of the metallic systems of a reactor coolant pump motor with the phosphate ester fluids represented by Fyrquel GT and by a modified version, Fyrquel RCP. Potential sources of compatibility problems are the degradation products of the fluid which may result from causes such as hydrolysis, radiation and high temperatures. The products of fluid degradation are mainly acid diphenyl phosphates and phenols. When the levels of these deleterious agents are kept low by periodic fluid sampling and active earth filtration, compatibility problems have been reported to be minor. However, the use of the fluid in an inaccessible application, such as in a reactor coolant pump motor, is critical; so any problem might possibly lead to a serious condition. Thus the compatibility of the metallic systems has been investigated in each of three categories:

1. Immersion
2. Galvanic coupling
3. Stress corrosion cracking

Immersion testing was performed to measure the aggressiveness of the fluid environment on coupons of individual materials as a function of time. The exposure of a material for increasing lengths of time is important in that corrosion rates, as measured by weight loss per unit area, can vary with time. In some instances the rate can increase exponentially; in others the material can exhibit weight loss for some period of time, then cease corroding altogether. The first instance may be represented, by a case where oxidation of the metal catalyzes further breakdown of the lubricant, thus enhancing corrosion. The second instance may be represented by the case where a cohesive protective layer of corrosion product forms on the metal surface, preventing further oxidation.

Galvanic testing was performed to evaluate the electrochemical effect produced by the presence of two dissimilar metals in physical or metallurgical contact in a conducting medium. Due to differences in potential, one of the metals will act as the anode, and the other will act as the cathode to form a galvanic cell. Current is carried between the metals by a conducting fluid medium. In the galvanic cell, the anode will experience a loss of metal, and the cathode will be galvanically protected against corrosion or pitting.

Parts which are stressed in tension and exposed to a deleterious environment can fail by stress corrosion cracking. The stresses involved may be either applied or residual. The environment of concern may be only mildly aggressive in terms of general immersion testing. In fact, stress corrosion cracking favors a weak or dilute corrodant, because preferential attack is required. A strong corrodant produces general attack which reduces the cross section of the material but does not necessarily produce cracking. Therefore, the fact that the fluids are mild corrodants could conceivably present some potential problems.

Individual materials representative of the classes of metals used in the fabrication of a reactor coolant pump motor were chosen for the testing program. These classes of metals are:

1. Copper and copper alloys
2. Carbon steel
3. Alloyed steel
4. Stainless steel
5. Cast iron
6. Babbitt material

14.2 IMMERSION TESTING PROCEDURE

Each test was performed by placing three coupons (2" x 1" x 1/8") of the material to be tested into a 200 ml beaker containing 150 ml of the phosphate ester fluid. Each coupon was cleaned and weighed to the nearest 0.1 mg before the test. The beaker containing the coupons was placed in a forced air oven which had been stabilized at 100^{o}C. 100^{o}C was chosen as the test temperature since it is the highest temperature to which the fluid is exposed. This high temperature increases the rate of attack and the mobility of the aggressive agents in the fluid. For each material, test exposure times of 1, 2, 4, 8, 16 and 24 weeks were scheduled. At the completion of each exposure period, a beaker of test coupons was removed from the oven. The coupons were stripped of corrosion deposits by chemical or mechanical methods and then were reweighed to determine weight loss. The corrosion product was removed from the coupon surface for three reasons:

1. There is no assurance that a corrosion product that is formed will adhere to the surface.
2. Any surface deposit may not survive the attempts to remove the phosphate ester fluid from the coupon.
3. Without detailed analysis, the corrosion product cannot be identified so as to evaluate definitely the extent of attack upon the coupon.

To insure that the cleaning procedures did not contribute to a measured weight loss, unexposed samples were cleaned at the same time. Any weight loss exhibited by the unexposed sample was due to the cleaning procedure, and the weight loss of the test coupon was adjusted accordingly. It was noted that for steel specimens, deposits were built up, rather than removed, by the conventional cleaning operation. Thus a mechanical method using a hard gum eraser was substituted in the cleaning procedure for the steel specimens.

14.3 IMMERSION TEST RESULTS USING FYRQUEL GT

The test results for the copper and copper alloys tested against Fyrquel GT are shown in Table 14.1 and Figures 14.1 thru 14.5. The corrosion data generally indicates an exponential rate. An exponential corrosion rate implies that a renewable agressive agent is available to attack the coupon. This implies a dependency of the corrosion rate on the fluid acid number, as shown by the acid number data of Figures 14.1 thru 14.4. Additives and/or fluid reconditioning must be utilized in the presence of copper or copper alloys for successful use of the fluid.

Table 14-1

WEIGHT LOSS OF COPPER AND COPPER ALLOYS EXPOSED TO FYRQUEL GT AT 100°C

Exposure Time (Weeks)	Weight Loss (mg/cm^2)				
	CDA 110ETP	CDA 120	CDA 260	CDA 706	CDA 937
1	.0550	.0971	.0356	.0830	.0936
	.0647	.440	.0194	.0717	.0635
	.0647	.133	.0194	.0943	.0368
2	.0906	.181	.0291	.143	.0134
	.116	.181	.0227	.147	.0234
	.126	.149	.0356	.113	.0234
4	.136	.246	.0679	.0755	.134
	.139	.239	.0874	.117	.160
	.0906	.258	.0874	.106	.0970
8	.194	.311	.880	.0981	.281
	.201	.317	.832	.0868	.258
	.236	.311	1.06	.0906	.221
16	1.88	1.14	3.38	.170	.344
	1.41	.498	3.57	.204	.254
	1.71	1.01	3.91	.155	.324
*	7.50	6.27	8.64	.173	.281
	10.7	9.18	9.38	.188	.274
	9.60	4.48	8.25	.177	.284

*CDA 110ETP	23 Weeks	4 Days
CDA 120	23 Weeks	5 Days
CDA 260	23 Weeks	6 Days
CDA 706	20 Weeks	1 Day
CDA 937	19 Weeks	1 Day

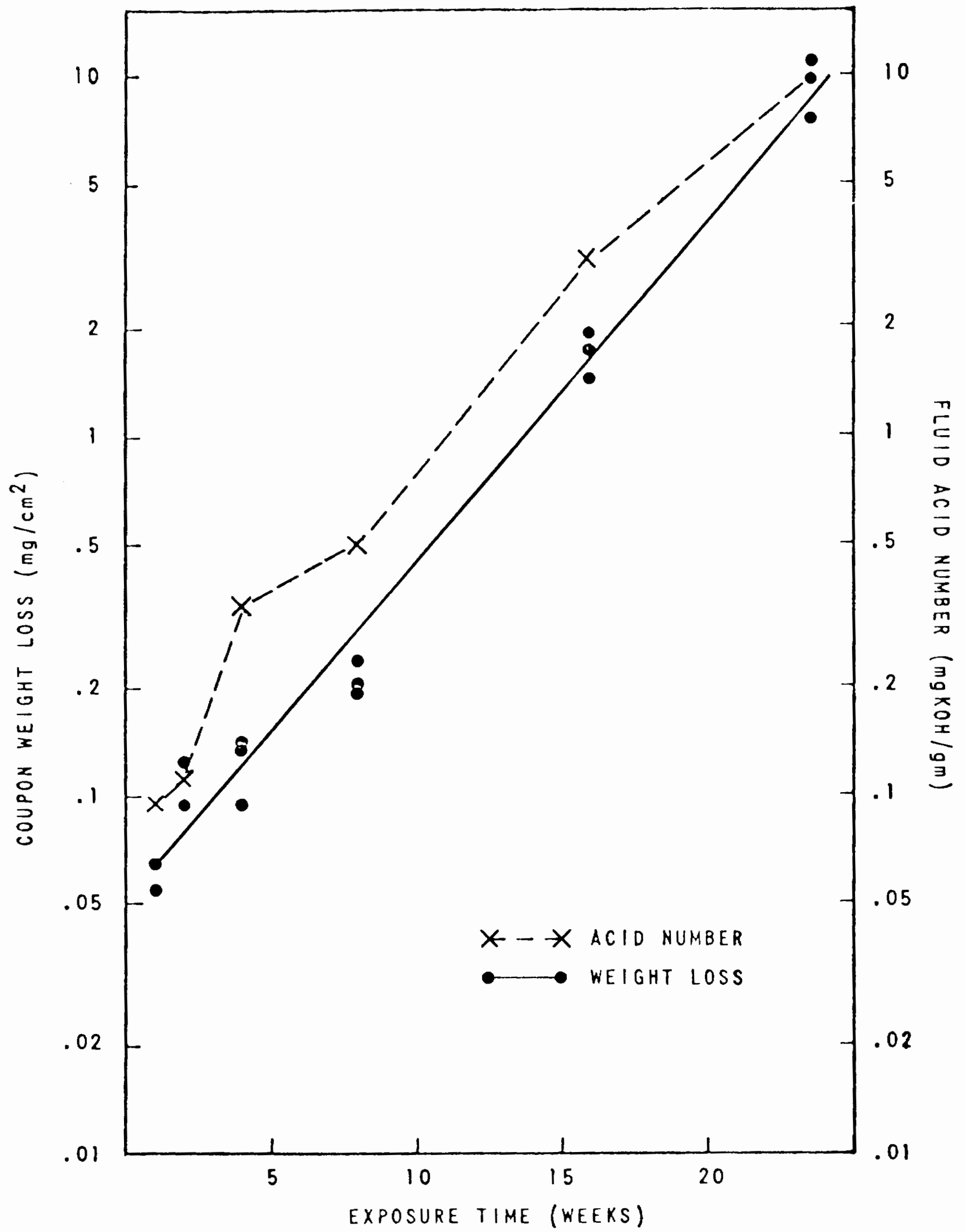

FIGURE 14.1 CORROSION OF CDA 110 ETP (ELECTROLYTIC TOUGH PITCH COPPER) IN FYRQUEL GT

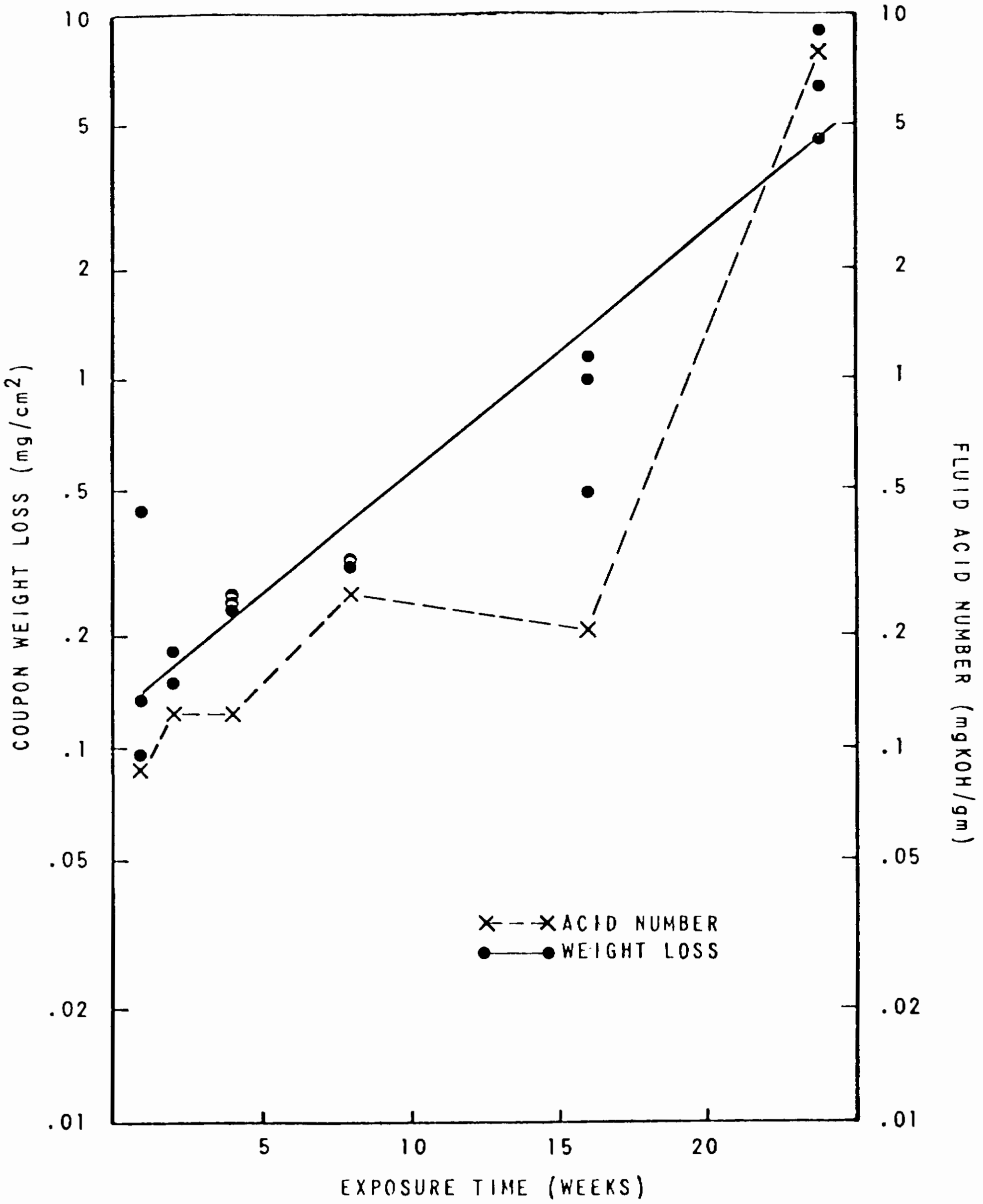

FIGURE 14.2 CORROSION OF CDA 120 (DEOXIDIZED LOW RESIDUAL PHOSPHOROUS COPPER) IN FYRQUEL GT

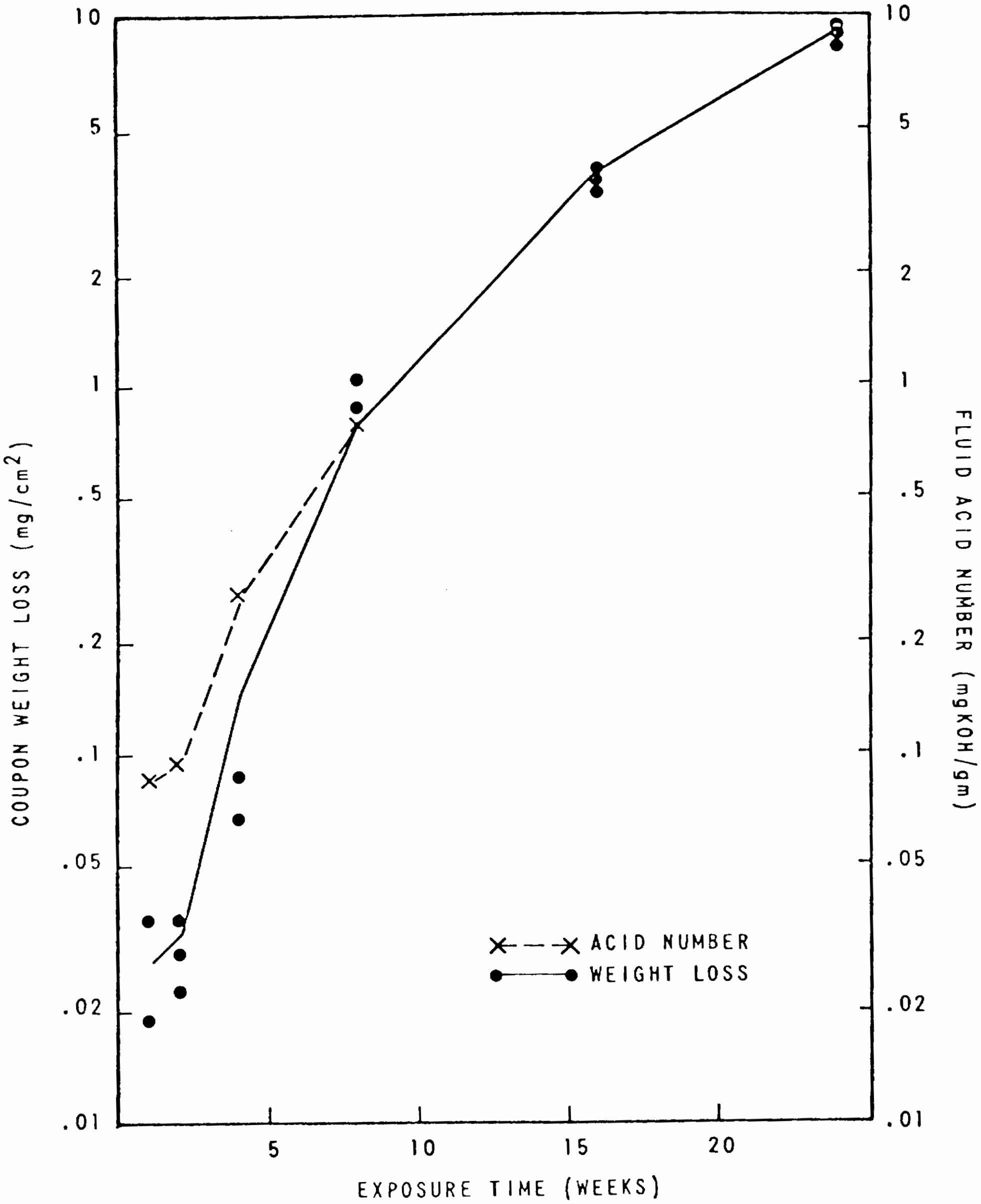

FIGURE 14.3 CORROSION OF CDA 260 (ADMIRALTY BRASS) IN FYRQUEL GT

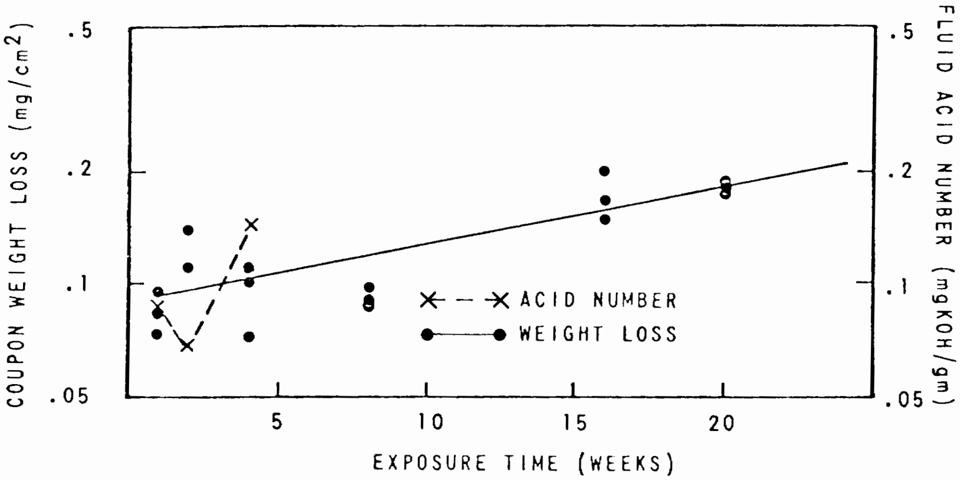

FIGURE 14.4 CORROSION OF CDA 706 (90/10 COPPER-NICKEL) IN FYRQUEL GT

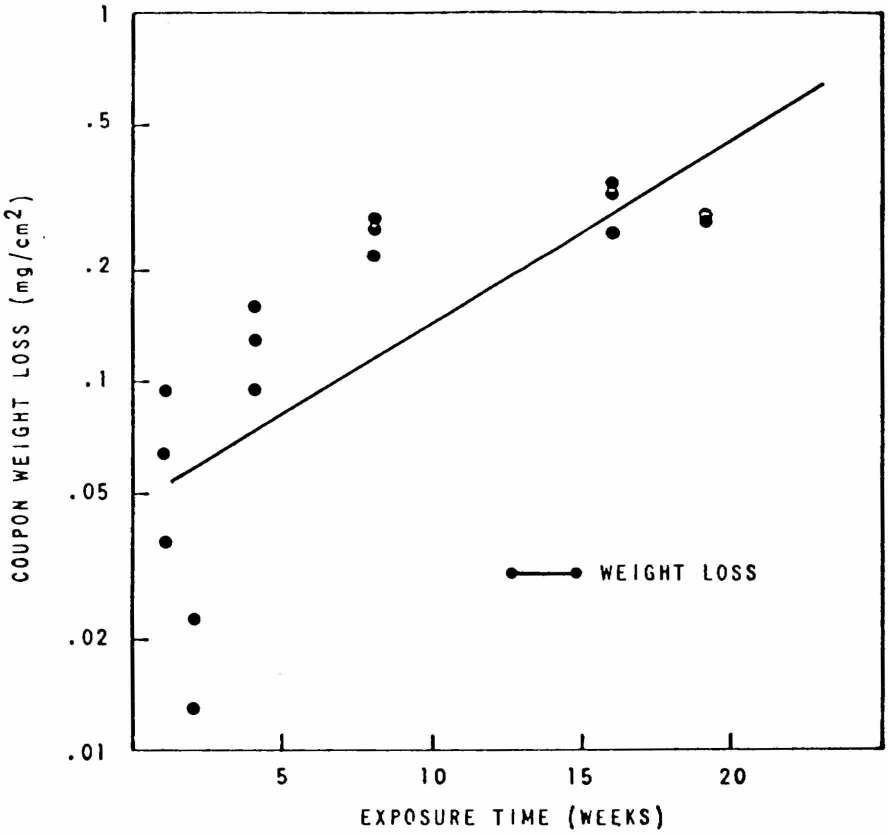

FIGURE 14.5 CORROSION OF CDA 937 (CAST COPPER ALLOY) IN FYRQUEL GT

CDA 260 (Admiralty brass) is the only copper alloy tested which departs from the exponential corrosion rate (Figure 14.3). This copper alloy is commonly used for heat exchanger tubing. The data suggest that a film is being formed which inhibits further corrosion or that the corrosion process is utilizing all of the available aggressive agent in the fluid and is approaching a steady state condition. If the corrosion were to cease, the high initial weight loss would probably not be a detrement to the use of CDA 260. However, CDA 706 (90/10 copper-nickel) is a common replacement for CDA 260 and has a superior corrosion resistance (Figure 14.4).

The test results for the two babbitt materials tested against Fyrquel GT are shown in Table 14.2 and Figures 14.6 and 14.7.

Lead babbitt does not appear to have an exponential corrosion rate although this is based primarily on data that are close to the measurement limits. In addition, this material was cast which introduces the possibility of segregation of the materials used in the alloy. This material segregation can promote microscopic galvanic attack which leads to preferential corrosion or pitting. What appeared to be pits on the surface of some lead babbitt specimens were found to be pores that were created in the casting process and that were opened by the corrosion process.

Tin babbitt showed the most severe corrosion rate of any metal tested after exhibiting very minimal corrosion for the first eight weeks. Acid number data available suggests that there is a threshold value for the acid number below which corrosion will be minimal. Inspection of Figure 14.7 reveals minimal weight loss below an acid number of 1.41 mg KOH/gm fluid. The operating criterion suggested by fluid manufacturers is to limit the acid number to an upper value of 0.5 mg KOH/gm of fluid.

The test results for the ferrous materials tested against Fyrquel GT are shown in Tables 14.3 and 14.4 and in Figures 14.8 thru 14.12.

In general, little or no problem is to be expected from the use of these ferrous materials. The higher carbon steels (AISI 1040 and 1095) as well as the

TABLE 14.2

WEIGHT LOSS OF BABBITT MATERIALS
EXPOSED TO FYRQUEL GT AT 100°C

Exposure Time (Weeks)	Weight Loss (mg/cm^2)	
	Tin Babbitt	Lead Babbitt
1	.00971	.0259
	< .00971	.0103
	< .00971	< .00971
2	.0129	.0485
	.00971	.0453
	< .00971	.0421
4	.0129	< .00971
	.0129	.0291
	.0162	.0162
8	.0324	.110
	.0194	.0870
	.0291	.0550
16	7.25	.0388
	6.75	.0388
	6.61	.0388
*	11.8	.158
	13.4	.158
	5.95	.181

*23 Weeks 4 Days for lead babbitt
23 Weeks 5 Days for tin babbitt

TABLE 14.3

WEIGHT LOSS OF CARBON STEELS
EXPOSED TO FYRQUEL GT AT 100°C

Exposure Time (Weeks)	Weight Loss (mg/cm^2) AISI 1020	Weight Loss (mg/cm^2) AISI 1040	Weight Loss (mg/cm^2) AISI 1095
1	< .00938	< .00971	.0406
	< .00938	< .00971	.0344
	< .00938	< .00971	.0562
2	.0188	< .00971	.0438
	.0188	< .00971	.0344
	.0344	< .00971	.0438
4	.0312	.0324	.0375
	.0250	.0421	.0500
	.0469	.0388	.0250
8	.0156	.0226	.0312
	.0312	.0194	.0406
	.0375	.0259	.0281
16	.0312	.00971	.0250
	.0344	.0162	.0281
	.0219	.0194	.0344
*	.0438	.0162	.0125
	.0344	< .00971	< .00938
	.0406	< .00971	.00938

*AISI 1020 23 Weeks
AISI 1040 23 Weeks 4 Days
AISI 1095 22 Weeks 6 Days

TABLE 14.4

WEIGHT LOSS OF OTHER FERROUS MATERIALS EXPOSED TO FYRQUEL GT AT 100°C

Exposure Time (Weeks)	Weight Loss (mg/cm^2)				
	AISI 1135	AISI 4140	AISI 304	Malleable Iron	AISI M22
1	< .00938	< .00971	< .00971	.0282	.0288
	< .00938	< .00971	< .00971	.0226	.0504
	< .00938	< .00971	< .00971	< .0169	.0504
2	.00938	.0227	< .00971	.0282	.0432
	< .00938	.0162	< .00971	< .0169	.0360
	.0156	.00971	< .00971	< .0169	.0432
4	< .00938	.0388	< .00971	Small Weight Gains	.0396
	< .00938	.0258	< .00971		.0360
	< .00938	.0324	< .00971		.0432
8	< .00938	.0194	.0550		.0360
	< .00938	.0227	.0226		.0576
	< .00938	.0162	.0324		.0576
16	.00938	.0162	< .00971		.0468
	< .00938	.0162	.00971		.0396
	.00938	.0129	< .00971		.0504
*	.0250	.0162	.0194		.0540
	.0219	.0227	< .00971		.0432
	.0125	.00971	< .00971		.0647

*AISI 1135	23 Weeks	
AISI 4140	23 Weeks	4 Days
AISI 304	23 Weeks	4 Days
Malleable Iron	20 Weeks	2 Days
AISI M22	19 Weeks	4 Days

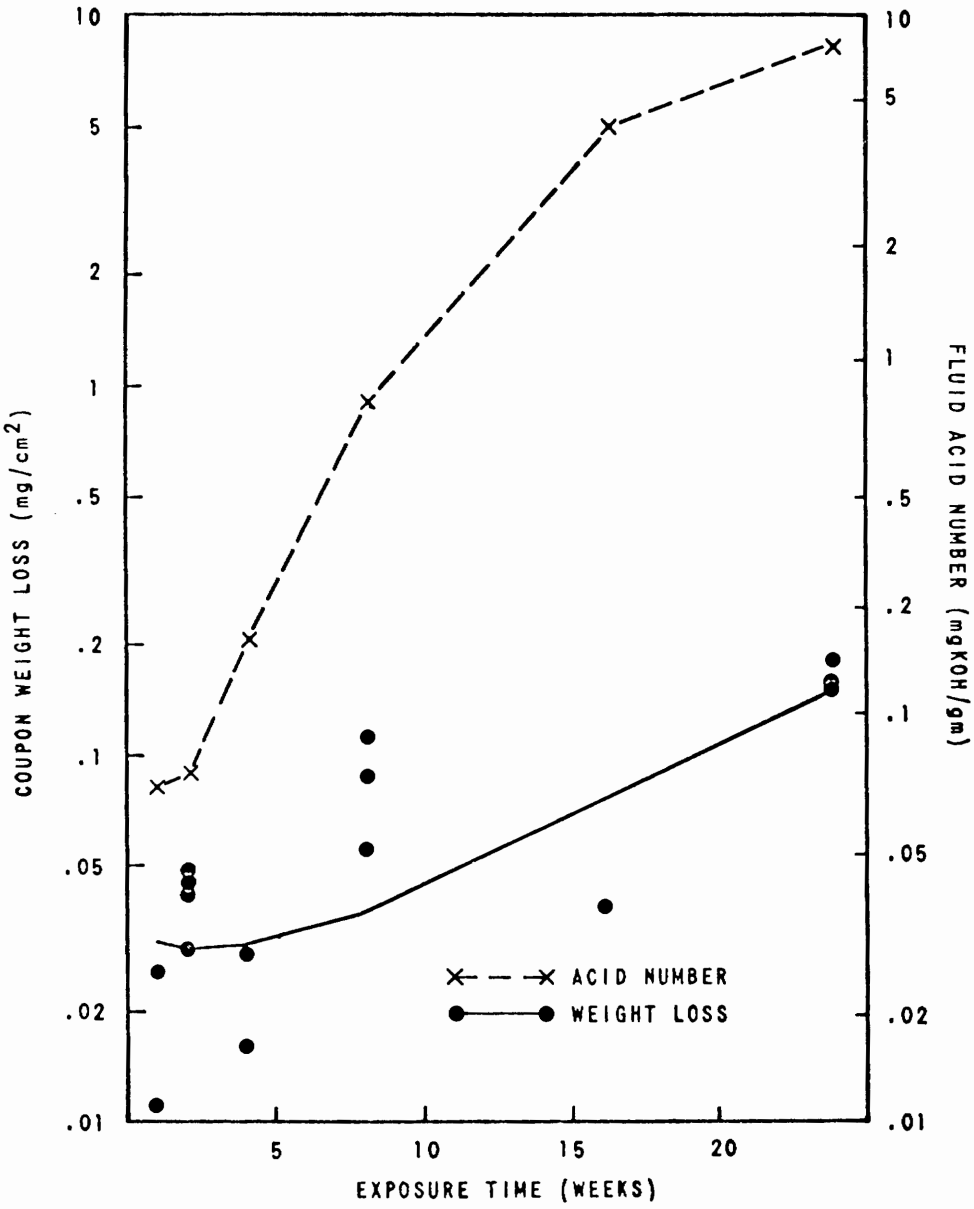

FIGURE 14.6 CORROSION OF LEAD BABBITT IN FYRQUEL GT

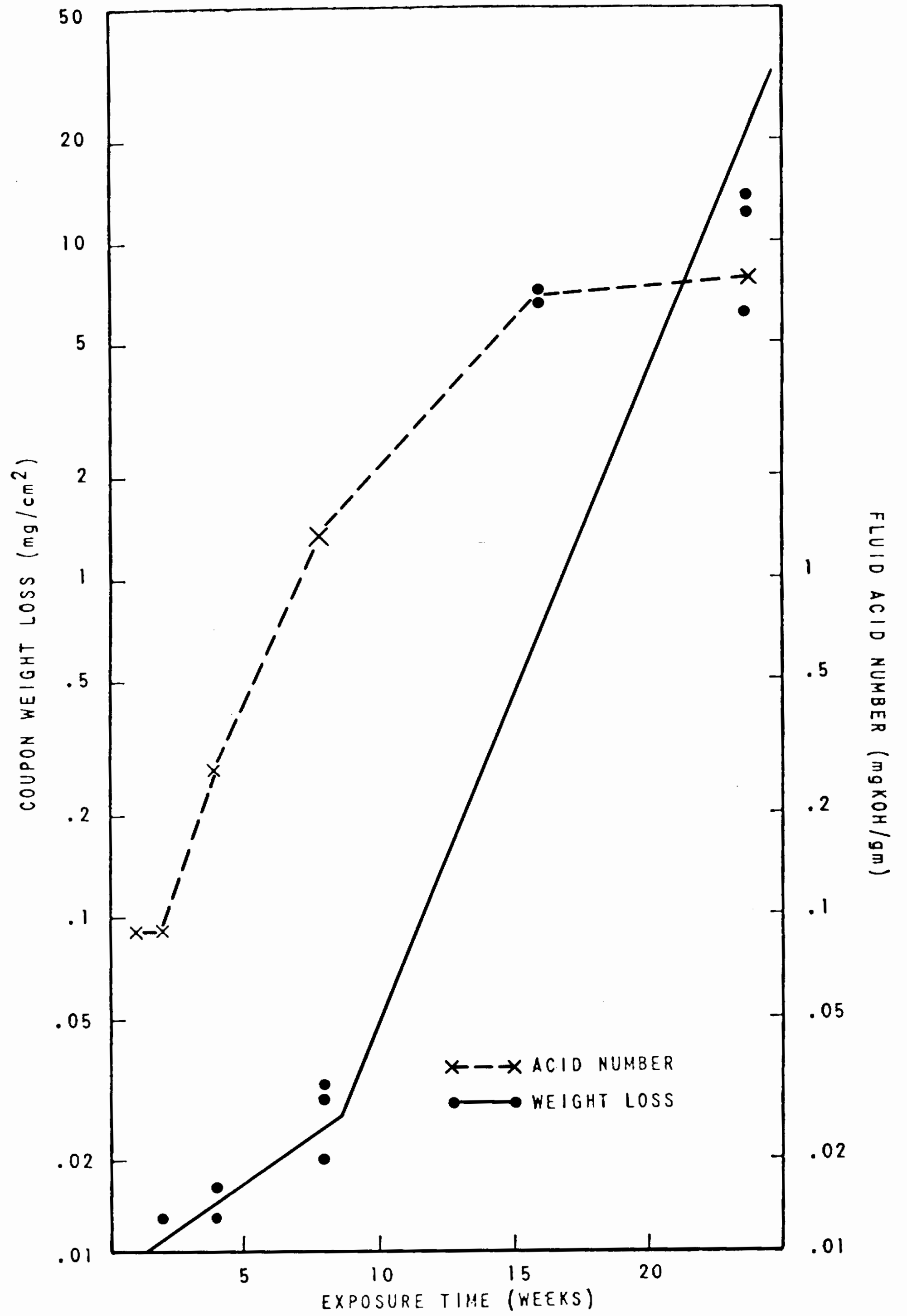

FIGURE 14.7 CORROSION OF TIN BABBITT IN FYRQUEL GT

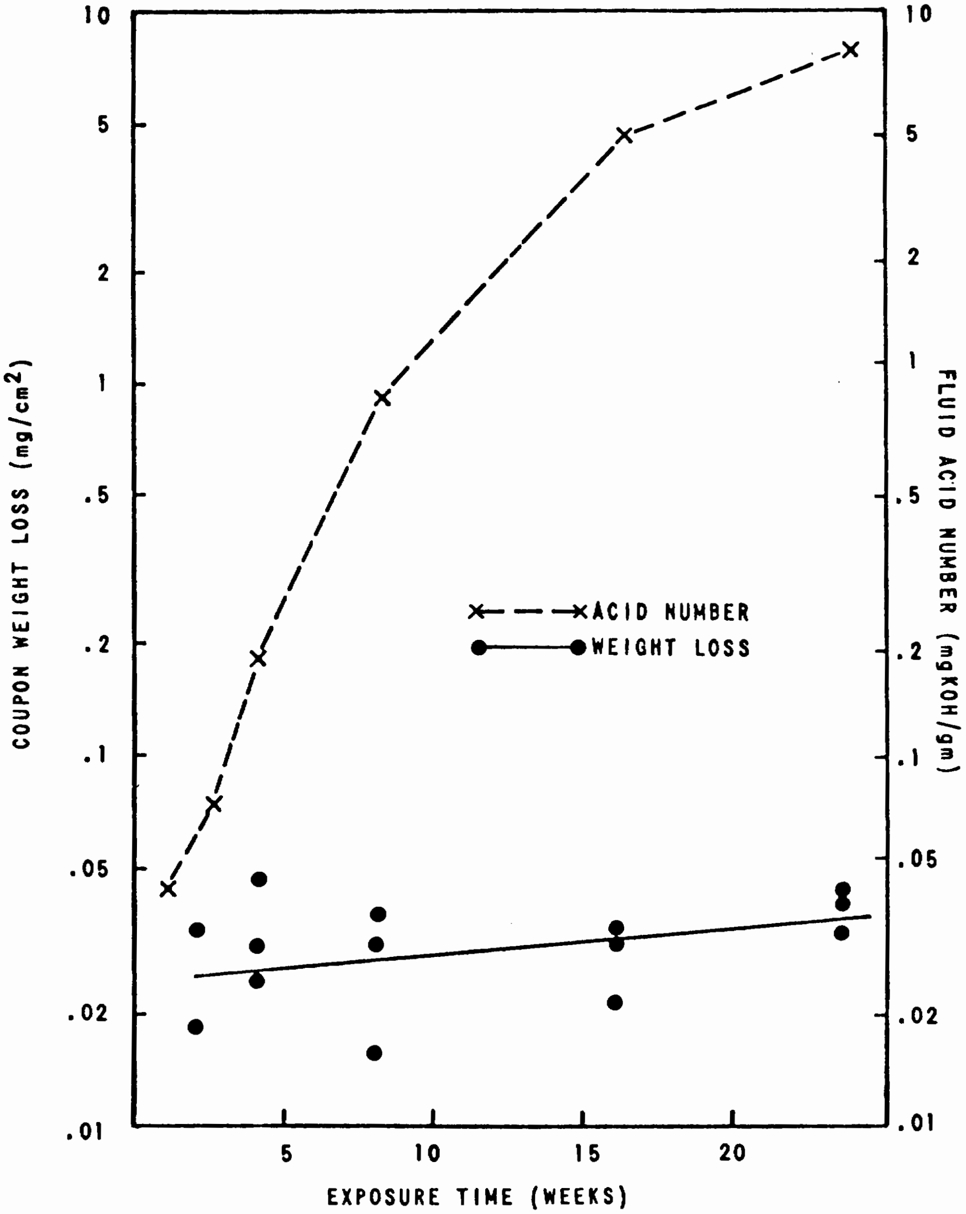

FIGURE 14.8 CORROSION OF AISI 1020 (CARBON STEEL) IN FYRQUEL GT

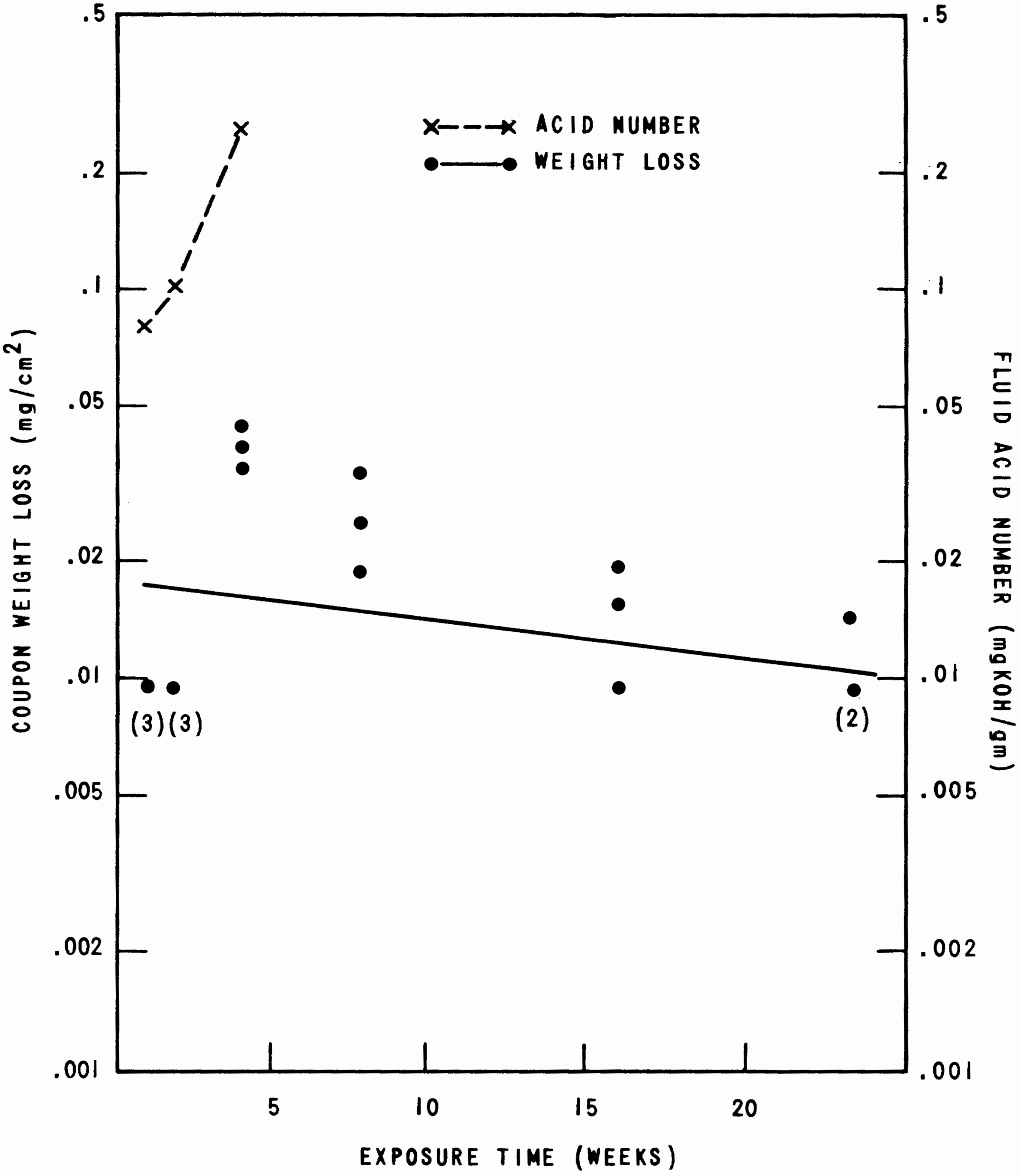

FIGURE 14.9 CORROSION OF AISI 1040 (CARBON STEEL) IN FYRQUEL GT

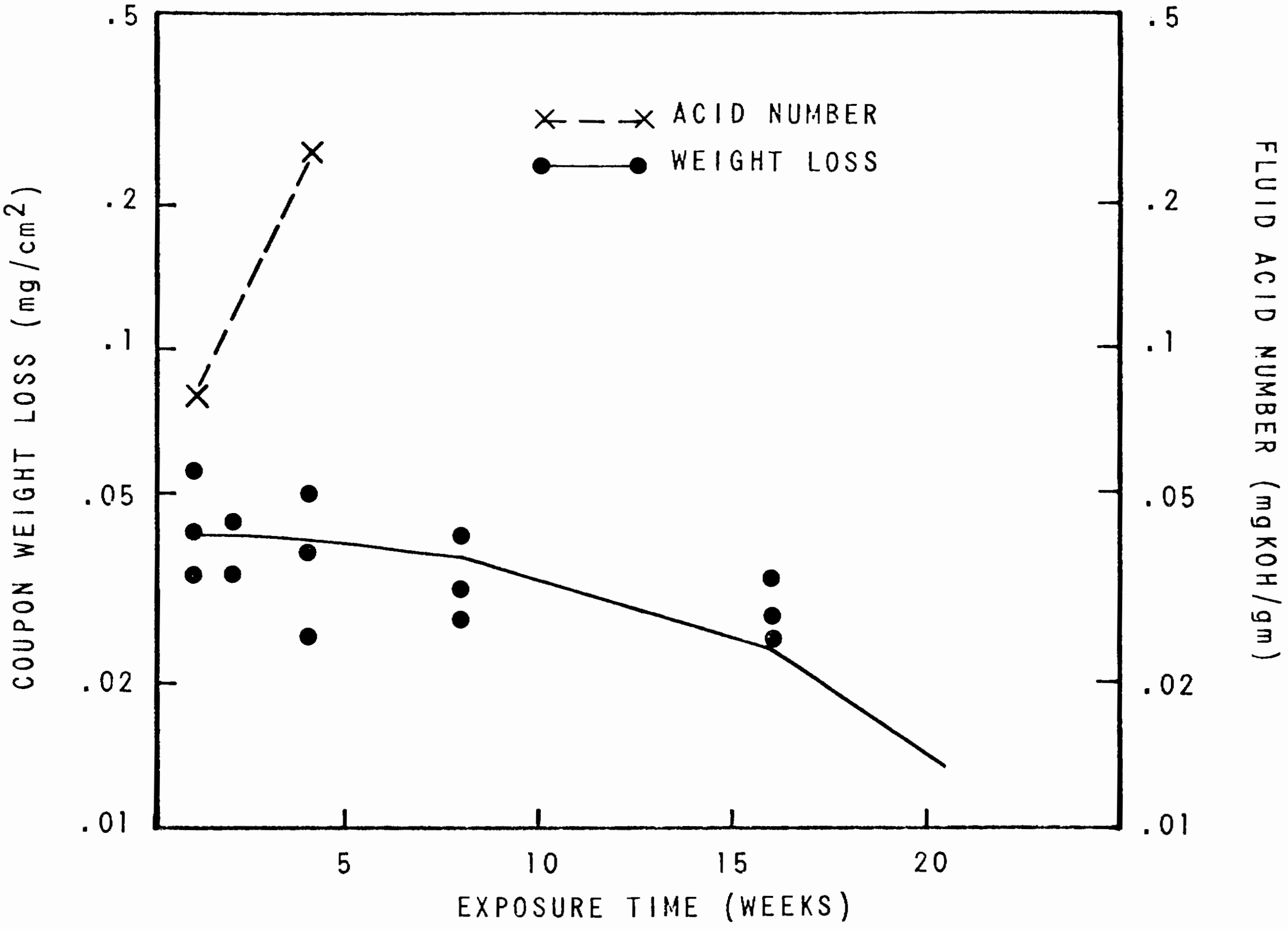

FIGURE 14.10 CORROSION OF AISI 1095 (CARBON STEEL) IN FYRQUEL GT

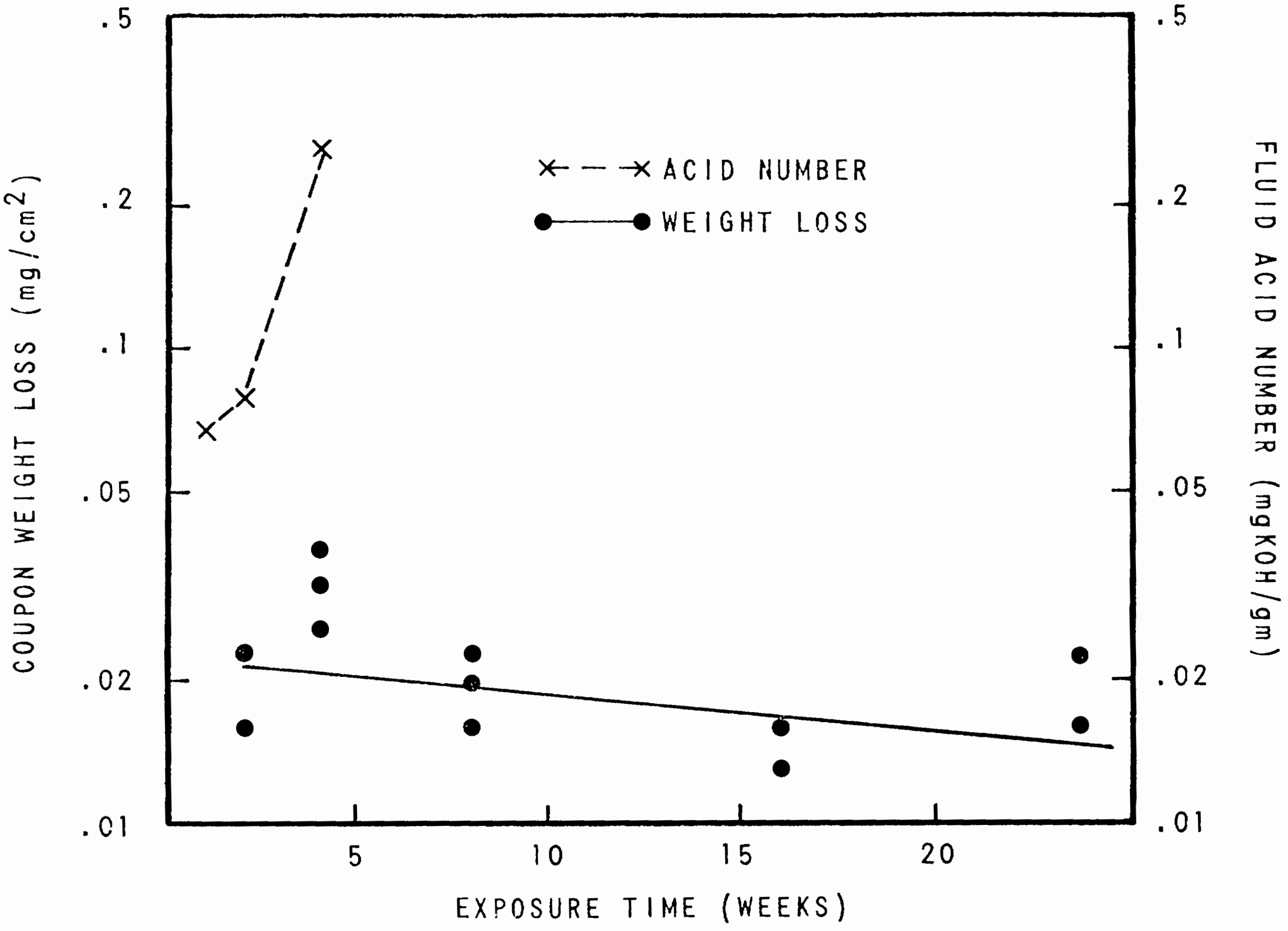

FIGURE 14.11 CORROSION OF AISI 4140 (ALLOYED STEEL) IN FYRQUEL GT

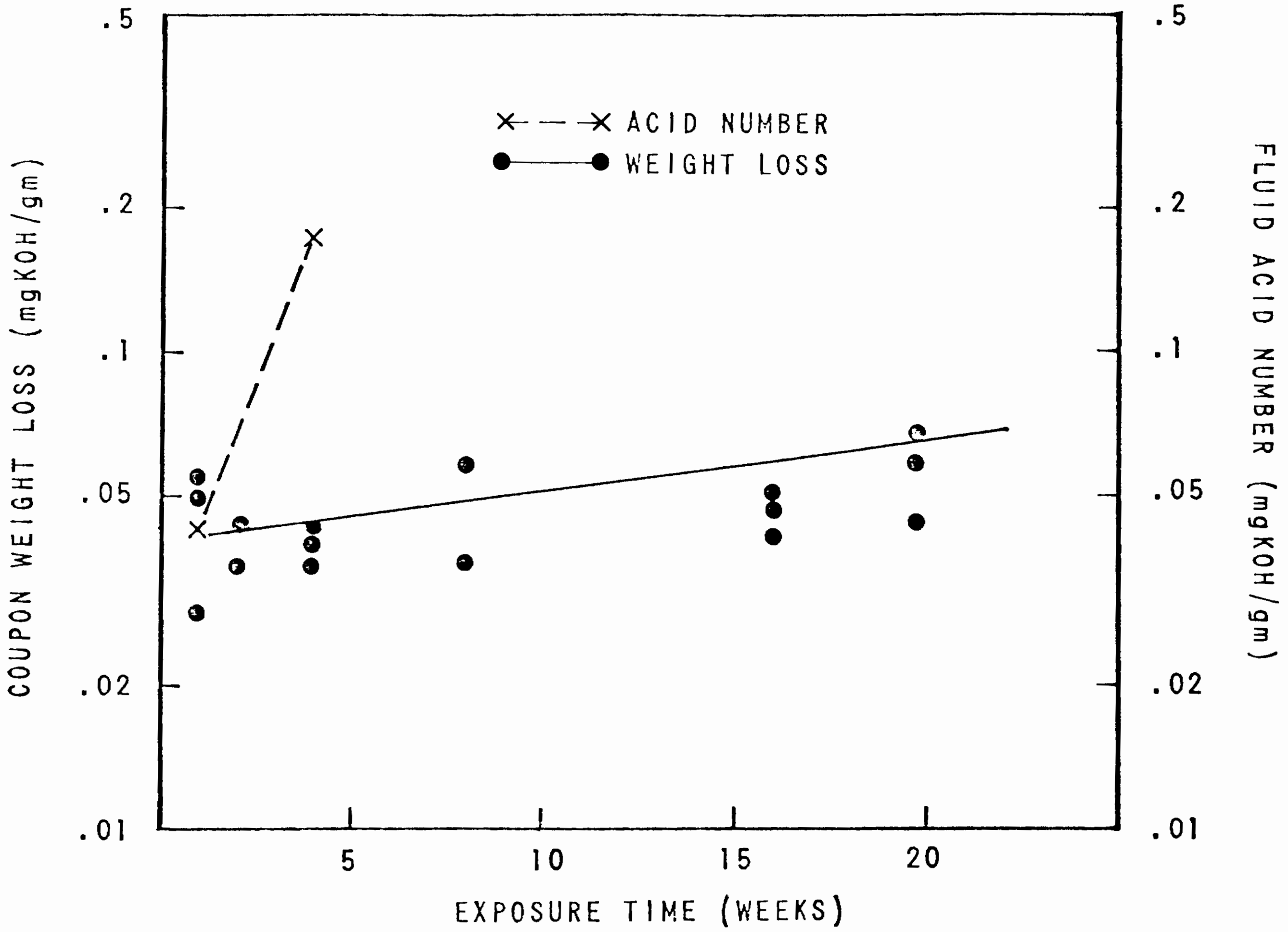

FIGURE 14.12 CORROSION OF AISI M22 (ELECTRICAL SHEET STEEL) IN FYRQUEL GT

alloyed steel (AISI 4140) showed a gradual weight gain after the initial loss. It is possible that an adherent protective film is being built up on the surface of these specimens. The observed weight changes do not appear to have any dependency on the fluid acid number.

Several control tests were performed over a short time period to evaluate the following:

1. Acid number increase with time at 100°C without any corrosion coupon.
2. Corrosion rate at a lower temperature.
3. Corrosion rate in a larger fluid volume.
4. Corrosion rate in a petroleum oil.

The control test material was chosen to be CDA 110ETP. The choice was made after the copper specimens were observed to be adversely affected by the exposure to Fyrquel GT at 100°C.

The increases in acid number with time at 100°C were found to be comparable to those measured with the fluid in contact with the metal coupons.

The corrosion rate at room temperature (22°C) was determined using three preweighed coupons which were withdrawn after 1, 2 and 4 weeks of exposure, respectively. The results are shown in Table 14.5.

The significantly higher weight loss at the higher temperature indicates that temperature can accelerate the rate of corrosion.

The corrosion rate of the copper exposed to a larger fluid volume was determined using three preweighed coupons which were withdrawn after 1, 2 and 4 weeks of exposure, respectively. The three coupons were placed in an 800 ml beaker containing 600 ml of Fyrquel GT. The exposure temperature was 100°C. The results are shown in Table 14.6.

TABLE 14.5

COMPARISON OF WEIGHT LOSS OF CDA 110 ETP (COPPER) IN FYRQUEL GT AT 100°C AND AT 22°C

Exposure Time (Weeks)	Weight Loss (mg/cm^2) At 100°C Average Loss from Table 14.1	At 22°C
1	.0615	.0162
2	.111	.0162
4	.122	Weight Gain

TABLE 14.6

COMPARISON OF WEIGHT LOSS OF CDA 110 ETP (COPPER) AT 100°C IN 150 ml AND IN 600 ml OF FYRQUEL GT

Exposure Time (Weeks)	Weight Loss (mg/cm^2) In 150 ml Average Loss from Table 14.1	In 600 ml
1	.0615	.178
2	.111	.343
4	.122	.414

There is significantly higher weight loss in the larger fluid volume. This may indicate that the availability of the aggressive agents in the fluid is a limiting factor in the immersion test. Another possibility is that the larger surface area exposed to the air may have promoted the production of fluid acid which would then be available to attack the copper. A third possibility is that the larger surface area exposed to the humidity in the air resulted in the hydrolysis of the fluid and a higher acid number which promoted the copper corrosion.

The corrosion rate of copper (CDA 110 ETP) in a conventional lubricant was determined using three preweighed coupons in 150 ml of Exxon Teresstic 46 at 100°C. The three coupons were removed at the end of exposure times of 1, 2 and 4 weeks, respectively. The results are shown in Table 14.7.

Copper (CDA 110 ETP) has a significantly greater weight loss when exposed to Fyrquel GT at 100°C than when exposed to a petroleum oil under the same conditions. This again indicates that fluid conditioning will be required for the motor application when Fyrquel GT is utilized.

TABLE 14.7

COMPARISON OF WEIGHT LOSS OF COPPER (CDA 110 ETP)
AT 100°C IN FYRQUEL GT AND IN TERESSTIC 46

	Weight Loss (mg/cm^2)	
Exposure Time (Weeks)	In Fyrquel GT Average Loss from Table 14.1	In Teresstic 46
1	.0615	Weight Gain
2	.111	.0227
4	.122	.00647

14.4 IMMERSION TEST RESULTS USING FYRQUEL RCP

There was a reformulation of Fyrquel GT lubricant which was identified as Fyrquel RCP. (Using a still later name change this is now marketed as Fyrquel VPF by the Stauffer Chemical Company). Corrosion rate and acid number studies using Fyrquel GT showed that it was corrosive to tin babbitt and copper. The reformulation by Stauffer was made to correct this corrosion problem; so a re-evaluation of the lubricant was required as part of this Westinghouse study. Corrosion rate and acid number determinations were made on three materials immersed in the Fyrquel RCP lubricant. The materials were:

1. ASTM 1100-0 - Air cooler aluminum fin material obtained from Perfex.
2. CDA 110 - Electrolytic Tough Pitch Copper.
3. Tin Babbitt.

The copper and tin babbitt were selected for the re-evaluation because they showed considerably higher corrosion rates than the other materials in the testing using Fyrquel GT. The aluminum fin material was suggested for test by Allis Chalmers.

The results of the copper and tin babbitt weight loss tests using Fyrquel RCP are compared with the earlier data using Fyrquel GT in Tables 14.8 and 14.9 and in Figures 14.13 and 14.14. The aluminum alloy was not tested during the initial phase of this program; so only weight loss data in Fyrquel RCP are shown in Table 14.10 and in Figure 14.15.

The corrosion rate data of the copper and tin babbitt samples using the Fyrquel RCP show a considerable improvement (by 1 to 2 orders of magnitude) over that obtained using Fyrquel GT. The data for Fyrquel RCP suggest that the corrosion rate is decreasing with time whereas for Fyrquel GT the corrosion rate appears to increase with time.

The aluminum weight loss data was similar to that for the ferrous materials exposed to Fyrquel GT.

TABLE 14.8

WEIGHT LOSS OF CDA 110 ETP COPPER
EXPOSED TO FYRQUEL GT AND FYRQUEL RCP

Exposure Time (Weeks)	Weight Loss (mg/cm^2)	
	Fyrquel GT	Fyrquel RCP
1	.0550	.0421
	.0647	.0583
	.0647	.0453
2	.0906	.0712
	.116	.0615
	.126	.0679
4	.136	.0841
	.139	.1000
	.0906	.0453
8	.194	.1330
	.201	.0679
	.236	.1290
16	1.88	.116
	1.41	.100
	1.71	.113
24	7.50*	.119
	10.7*	.123
	9.60*	.0485

*23 Weeks 4 Days

TABLE 14.9

WEIGHT LOSS OF TIN BABBITT
EXPOSED TO FYRQUEL GT AND FYRQUEL RCP

Exposure Time (Weeks)	Weight Loss (mg/cm^2)	
	Fyrquel GT	Fyrquel RCP
1	.00971	.0485
	< .00971	.0453
	< .00971	.0453
2	.0129	.139
	.00971	.113
	< .00971	.133
4	.0129	.104
	.0129	.100
	.0162	.172
8	.0324	.210
	.0194	.278
	.0291	.220
16	7.25	.203
	6.75	.172
	6.61	.194
24	11.8*	.369
	13.4*	.301
	5.95*	.333

*23 Weeks 5 Days

TABLE 14.10

WEIGHT LOSS OF ALUMINUM
EXPOSED TO FYRQUEL RCP

Exposure Time (Weeks)	Weight Loss (mg/cm^2)
1	.0145
	.000
	.0109
2	.0145
	.0326
	.0507
4	.0254
	.0362
	.0145
8	.00362
	.0181
	.0326
16	.0217
	.000
	.00725
24	.0362
	.000
	.0616

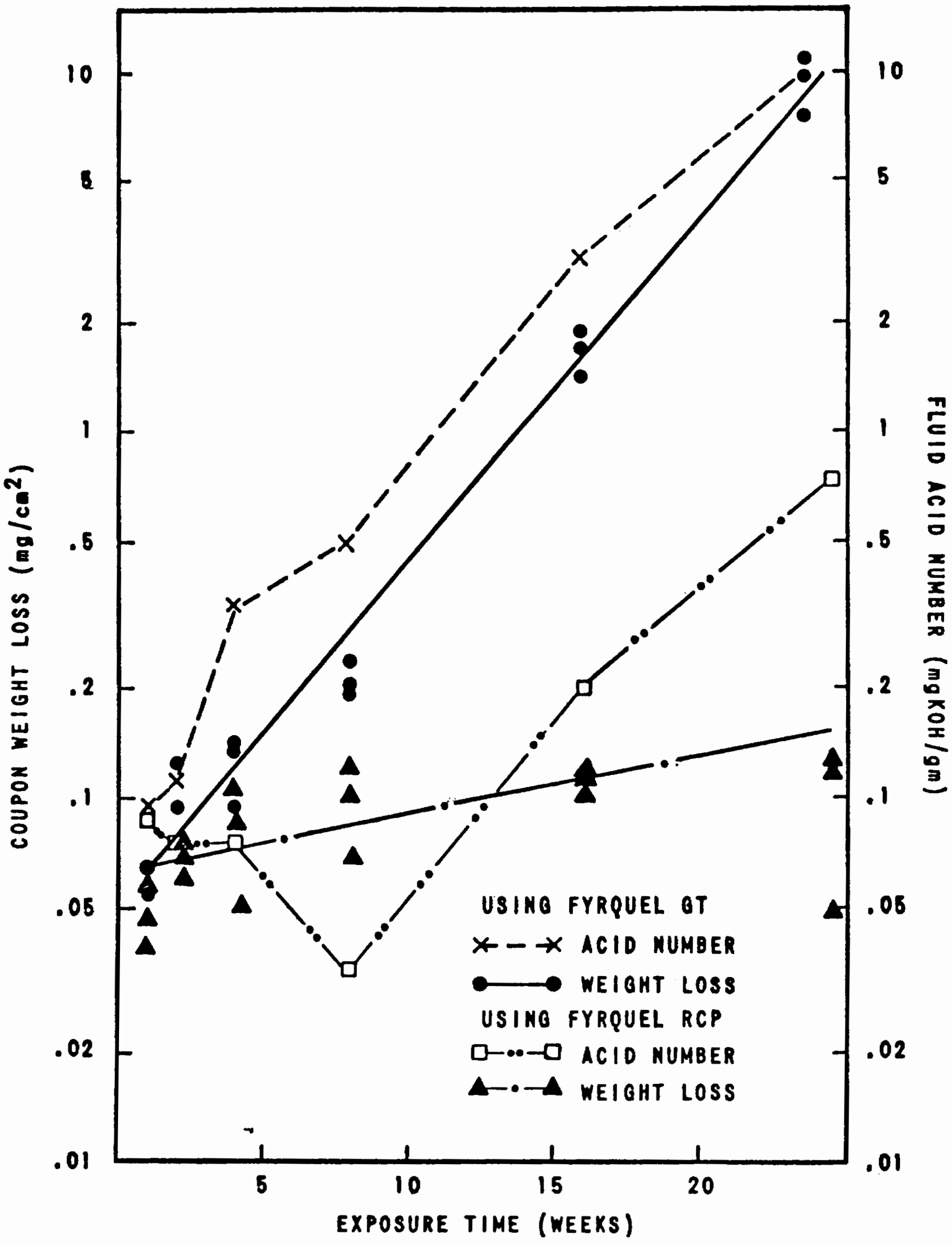

FIGURE 14.13 CORROSION OF CDA 110 ETP (ELECTROLYTIC TOUGH PITCH COPPER) IN FYRQUEL GT AND IN FYRQUEL RCP

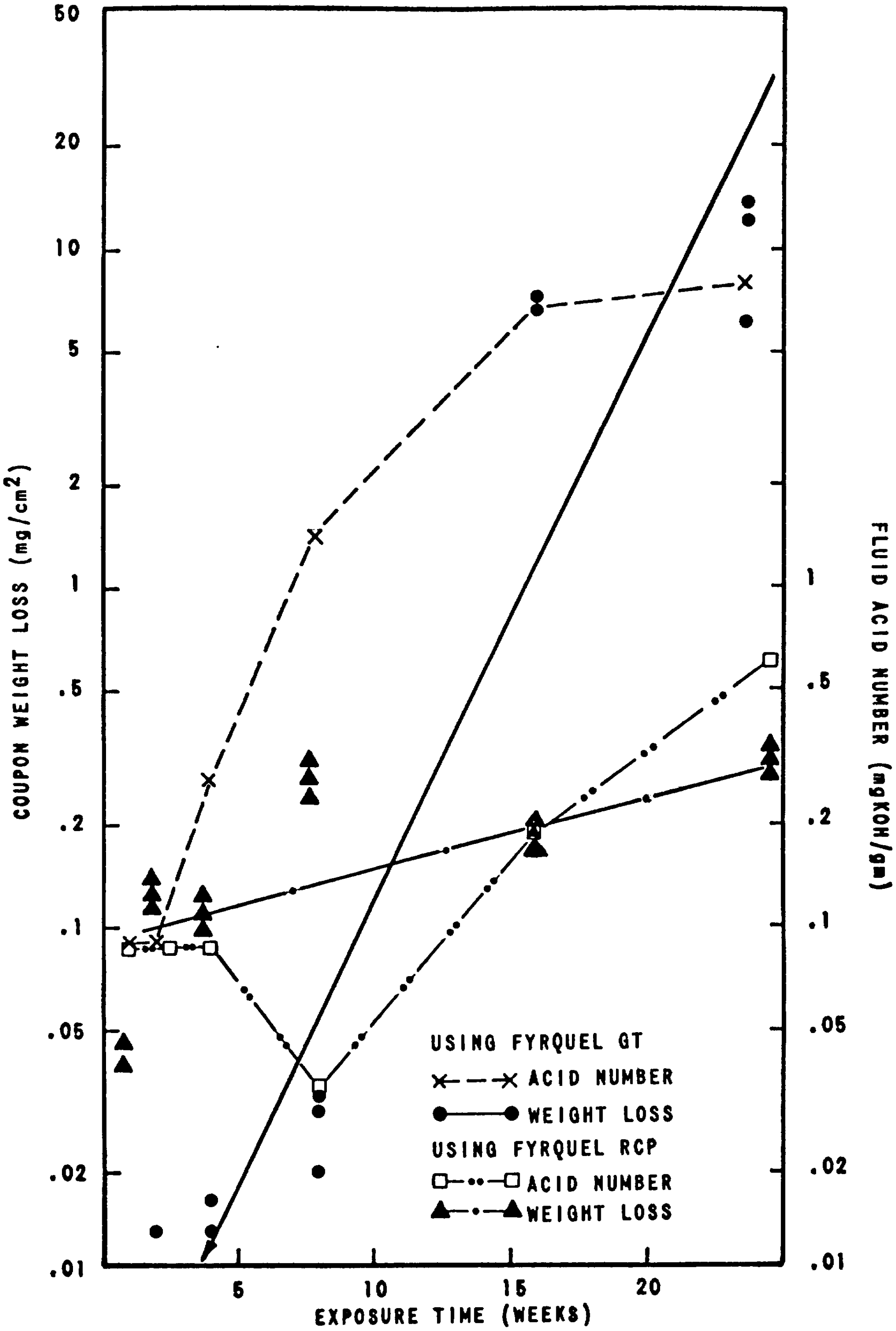

FIGURE 14.14 CORROSION OF TIN BABBITT IN FYRQUEL GT AND IN FYRQUEL RCP

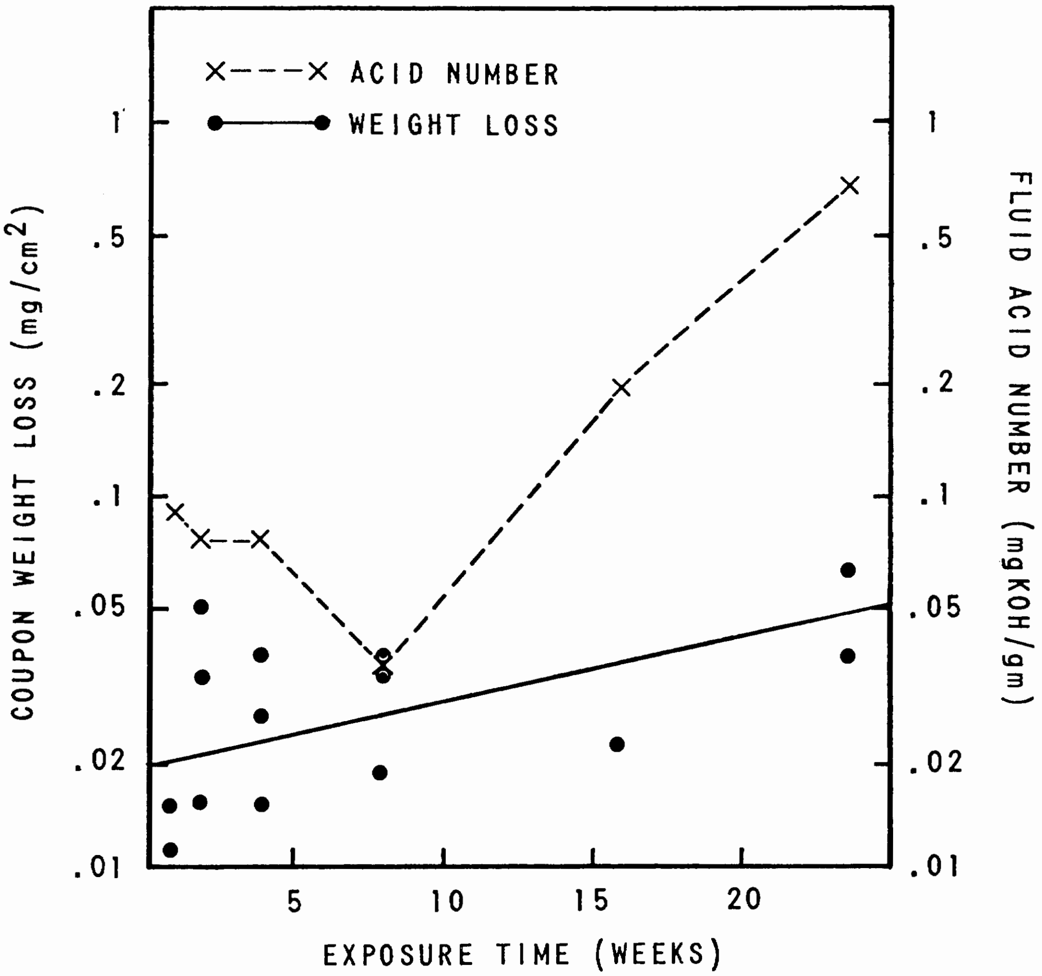

FIGURE 14.15 CORROSION OF ALUMINUM IN FYRQUEL RCP

The results of the acid number determinations on the Fyrquel RCP that was used in the immersion tests did not show the same type of trend that was obtained when Fyrquel GT was used. The Fyrquel RCP acid number was observed to decrease for the first 8 weeks and then to increase at a rate approximately 1/2 to 1/4 of that observed in the tests using Fyrquel GT. The acid number of Fyrquel RCP without corrosion samples showed a similar trend. It is believed that this type of behavior indicated that the acid interceptor in the additive package was being depleted and that after the interceptor had been depleted, the acid content then began to increase. From the experimental results it appears that approximately 8 weeks were required to deplete the acid interceptor in the 150 ml tested. It does appear that once the interceptor has been depleted, Fyrquel RCP is more stable than Fyrquel GT because the rate of acid number increase was lower. Methods for detecting the depletion of the additive package and for replenishment of the additive package were not investigated.

14.5 GALVANIC COUPLE TESTING

There is the potential for galvanic corrosion whenever dissimilar metals are joined, mechanically or metallurgically, in a fluid environment. Table 14.11 gives the metallic systems investigated and the preliminary results of the investigation.

The appropriate galvanic couple test specimens were prepared as shown in Figure 14.16 for the mechanical couples and in Figure 14.17 for the metallurgical couples. Each test specimen was immersed in 150 ml of Fyrquel GT in a 200 ml beaker and placed in an oven stabilized at 100^{o}C. The couples were visually examined periodically for any evidence of corrosion due to galvanic coupling.

The results presented in Table 14.11 show very little evidence of galvanic attack. The materials which corroded in the immersion testing were corroding in this test. However, microscopic and metallographic examinations, used at the end of the scheduled exposure time, confirmed that no galvanic attack had occurred.

TABLE 14.11

GALVANIC COUPLE TESTS OF DISSIMILAR MATERIALS EXPOSED TO FYRQUEL GT

Joined Materials	Exposure Time (Weeks)	Results
	MECHANICAL JOINTS	
CDA 937 to AISI 1020	20	No Attack
Lead Babbitt to AISI 1020	16	Slight Attack - Babbitt
Tin Babbitt to AISI 1020	16	Slight Attack - Babbitt
AISI 4140 to AISI 1020	16	Slight Attack - AISI 4140
*CDA 110 ETP to AISI 1020	16	Considerable Attack - CDA 110 ETP Slight Attack - AISI 1020
AISI 304 to AISI 1020	16	No Attack
	SOLDERED JOINT	
CDA 120 to AISI	2	Moderate Attack - CDA 120
	WELDED JOINTS	
AISI 304 to AISI 304	10	No Attack
AISI 1020 to AISI 1020	10	No Attack

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*Examination showed attack was corrosion of each material, not galvanic action.

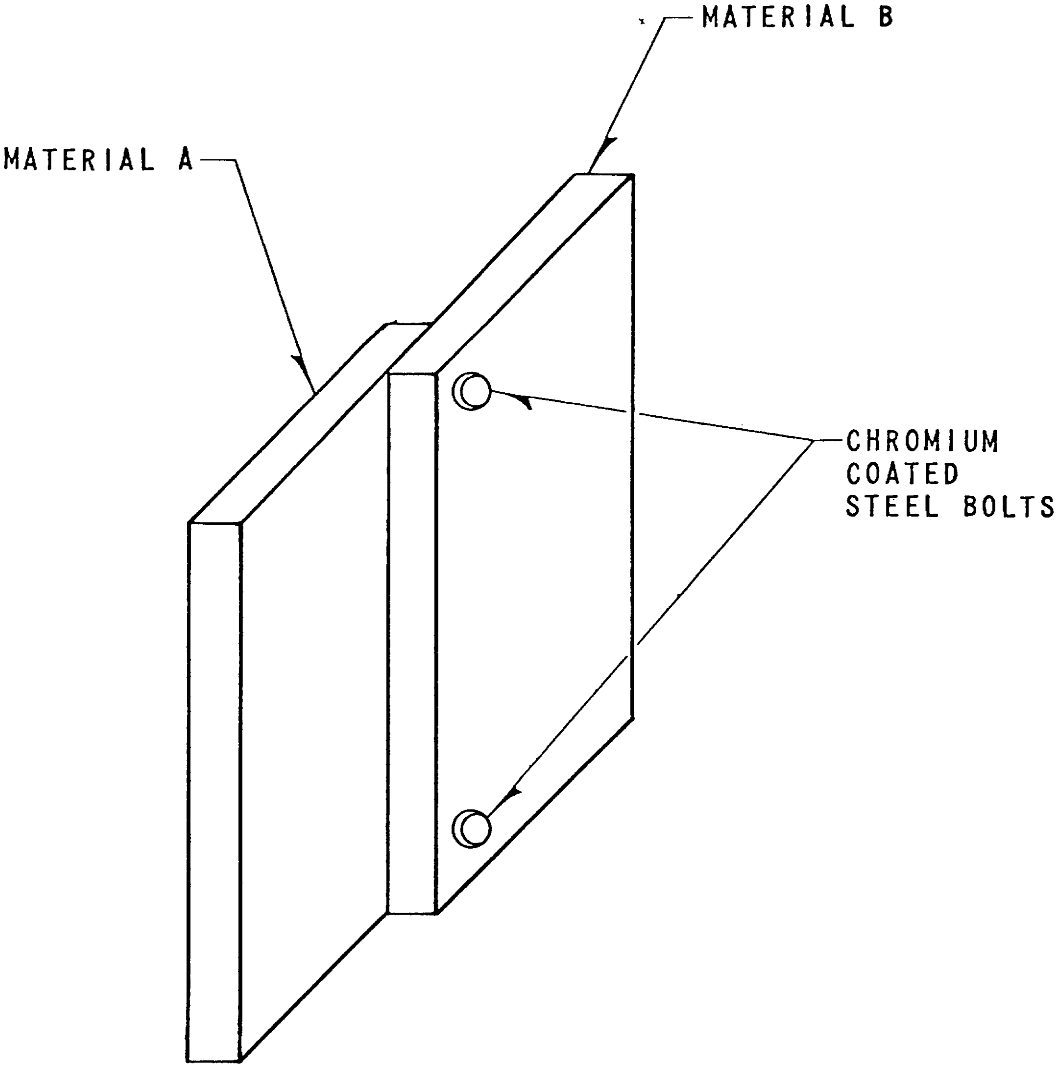


FIGURE 14.16 SCHEMATIC DIAGRAM OF MECHANICAL GALVANIC COUPLE TEST SPECIMEN.

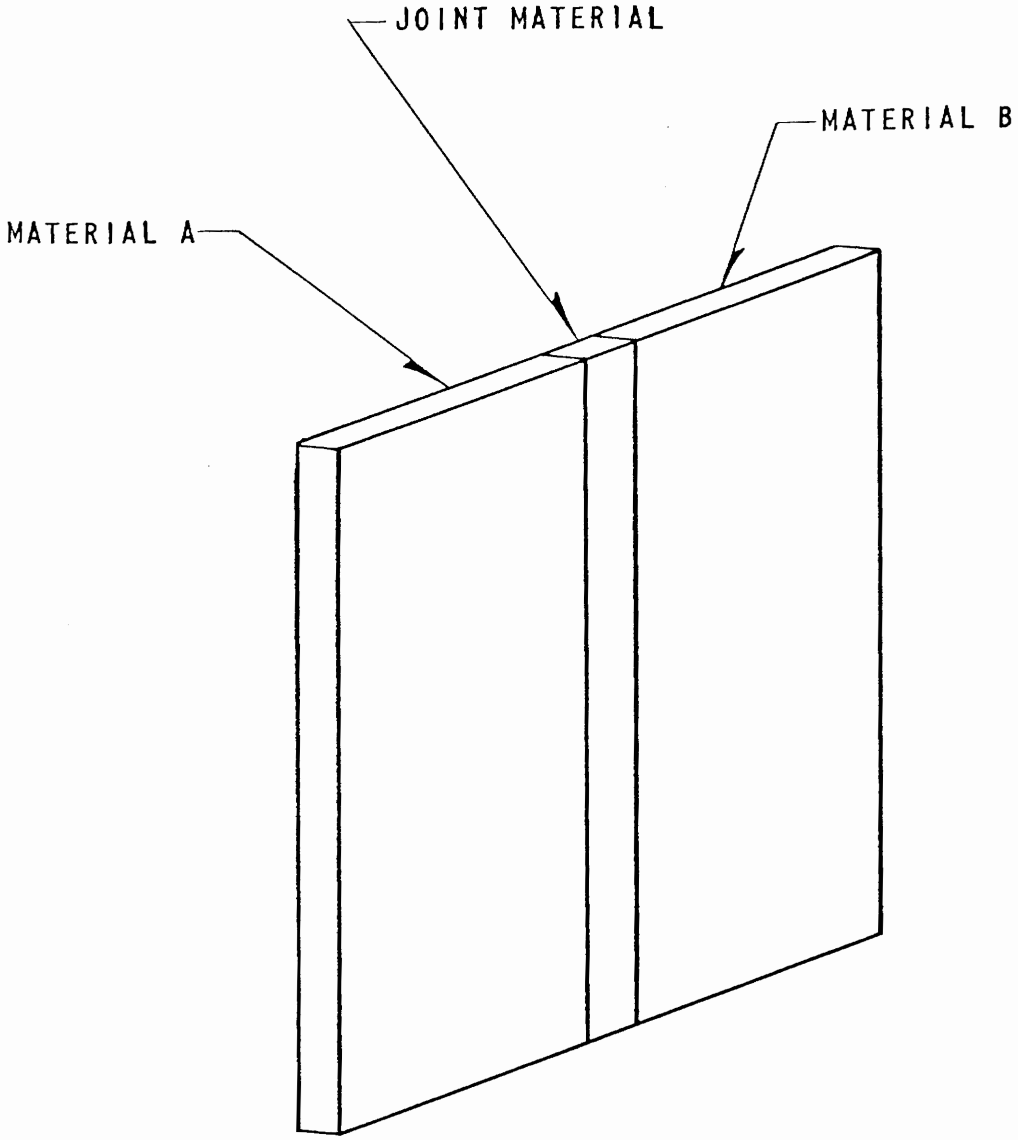


FIGURE 14.17 SCHEMATIC DIAGRAM OF METALLURGICAL GALVANIC COUPLE TEST SPECIMEN

14.6 STRESS CORROSION CRACKING TESTS - USING FYRQUEL GT

There is the potential for a material to crack, even when not loaded to its yield strength, if it is under a tensile stress, either applied or residual, and in a mildly aggressive environment. To test the susceptibility of metals to stress corrosion cracking, the test shown in Figure 14.18 was set up. U-bend specimens were prepared as outlined by ASTM 630. The materials tested were:

- AISI 1020
- AISI 1095
- AISI 1135
- AISI 304
- AISI 4140
- CDA 110 ETP
- CDA 120
- CDA 260

Each test specimen was suspended from a stiff wire so as to be partially immersed in 150 ml of Fyrquel GT in a 200 ml beaker. The beakers were placed in an oven stabilized at 100^{o}C. The specimens were periodically examined for evidence of cracking along the outside surface of the U-bend. None of the materials exhibited visible cracks.

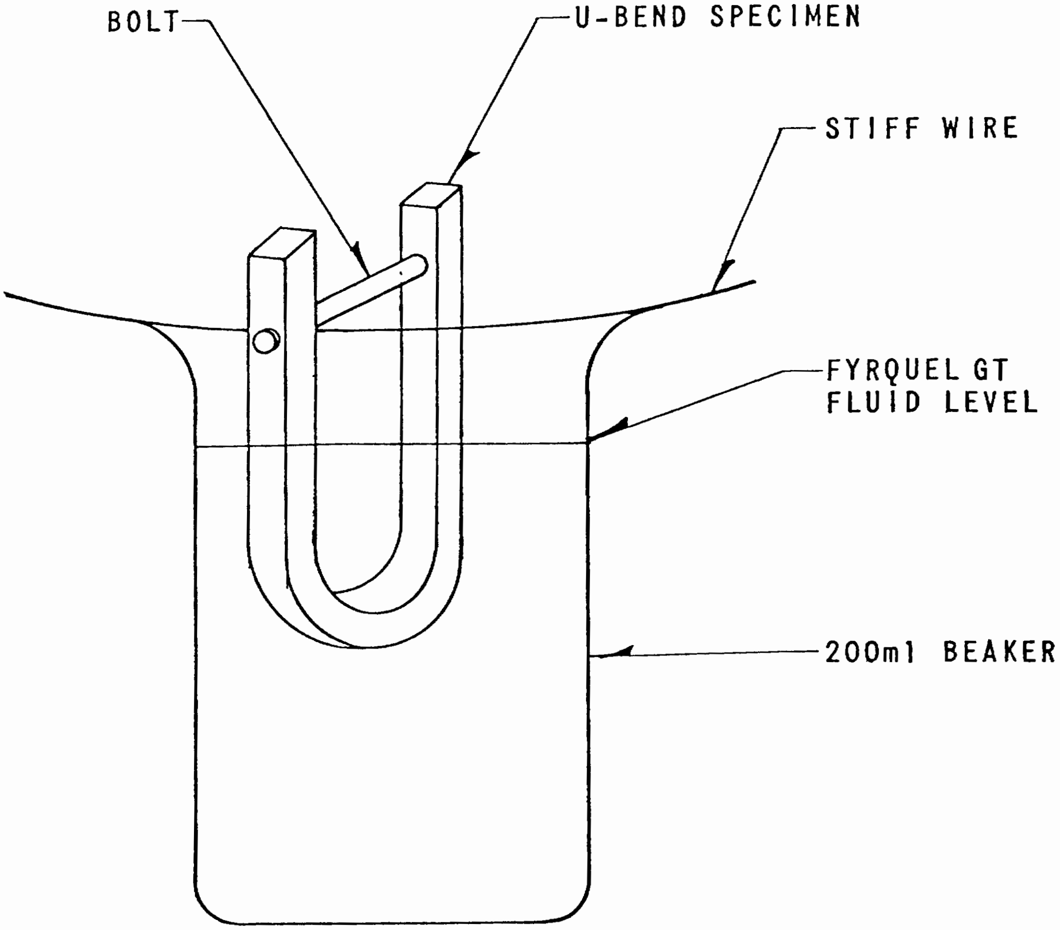


FIGURE 14.18 SCHEMATIC DIAGRAM OF STRESS-CORROSION CRACKING TEST.

SECTION 15.0

CONSIDERATION OF INSULATION AND STATOR WINDING COMPONENTS

15.0 CONSIDERATION OF INSULATION AND STATOR WINDING COMPONENTS

15.1. GENERAL DISCUSSION

A program of evaluation of fire resistant lubricants must include the interacting effects of the lubricant with the organic components of the pump motor. If fire resistant lubricants are to be used in motors, it is inevitable that insulation components and winding bracing components will be exposed to the lubricant in one manner or another. The phosphate esters, as active solvents, will attack most elastomers and finishes and some plastics. This attack can be broadly categorized as moderate to severe. Elevated temperatures, even modest increases in temperature, will intensify the severity and rate of degradation. Therefore, determination of the compatibility of insulating materials that come into contact with or are exposed peripherally to, the fire resistant lubricant was required. A necessary provision of this determination is that the severity of service operation be encompassed, including the factor of temperature.

The intention of the insulation-oriented phase of this project was to conduct a qualitative evaluation of exposure to fire resistant lubricants, specifically a synthetic phosphate ester, of the materials which have relation to the primary insulation. Basically this comprises those organic components physically contained within the stator winding assembly.

15.2 MATERIAL CATEGORIES CONSIDERED

A functional categorization of the critical materials requiring evaluation for compatability with phosphate ester lubricant follows:

- Stator coil major ground wall insulation
- Stator coil end turn insulation
- Stator coil connective insulation

- Stator coil conducting binder or conducting varnish treatment
- Coil stress grading film
- Winding coatings
- Stator coil diamond spacers
- Other end turn bracing
- Wedges
- Slot sticks
- Lead cleats
- Parallel ring cleats and supports
- Parallel cable insulation
- Main lead insulation

Materials which are damaged by small amounts of radiation are not used as insulating components in reactor coolant pump motors and were, therefore, not a part of this study. These include natural fibers, wood, cellulose polymers, Teflon, polyvinyl chloride, butyl rubber, and nylon.

Following is a generic categorization of compounds and materials from which the above components are constituted. Each of these materials was included in the program for evaluation. A specific material may go into the makeup of two of more of the components:

- Mica insulation vacuum pressure impregnated in vinyl monomer modified epoxy
- Mica insulation vacuum pressure impregnated in reactive diluent modified bisphenol A epoxy resin
- Mica insulation vacuum pressure impregnated in solventless polyester resin
- Oleoresinous varnished glass-dacron-tape - amine activated epoxy resin composite
- Mica tape - amine activated epoxy resin composite

- Glass cloth coated with carbon particle loaded phenolic alkyd varnish
- Carbon particle loaded vinyl toluene modified alkyd varnish
- Silicon-carbide containing phenolic varnish
- Epoxy ester-urea heat reactive varnish
- Cotton phenolic laminate
- Melamine glass laminate
- Glass mat polyester laminate
- Glass cloth epoxy laminate

These specific components will be discussed in the following sections:

- Stator electrical insulation systems............Section 16.0
- Corona suppression systems......................Section 17.0
- Non-metallic structural and bracing materials of stator windings....................Section 18.0

15.3 TEST PROCEDURES

In evaluating the effects of fire resistant lubricants on the functionality of these various components, the test procedures used followed, in a very general manner, the provisions of ASTM D543, "Standard Method of Test for Resistance of Plastics to Chemical Reagents". Modifications as to temperatures, extent and form of exposure, and end point criteria were introduced to reflect realistically the unique influences of the lubricant on the functionality of the winding insulation, the winding bracing, and corona stress grading media. The test procedure was to submerge test pieces of all materials in the fire resistant lubricant, initially for a short period and subsequently for longer periods, on the premise that the rate of degradation assumes a logarithmic relationship with time. The schedule was to test initially, and after 1, 4, 12, and 24 weeks' exposure. Testing was to continue for six months unless results at earlier periods were definite. Temperatures of the lubricant and test pieces were kept above use-temperature to achieve acceleration of the degradative effect.

Since the available ovens were not explosion proof, there was some hesitancy in operating them with large quantities of oil, even though the vapor pressure of the fluid was very low and the flash point very high in relation to the aging temperature. To increase the safety margin, test pieces immersed in the lubricant were sealed in a gas-tight aluminum container equipped with an emergency pressure relief valve. A photograph of the oven and container is shown in Figure 15.1. Test pieces were kept small in size to minimize the volume of lubricant required to submerge them.

For those materials which normally are in indirect contact with the lubricant, the above procedure constituted a severe over-test. The acceleration was of such a magnitude that extreme confidence could be placed in those materials which showed no degradation or minimal degradation.

Concurrently, test specimens were subjected to a moderated exposure more representative of service conditions. Since it was expected that contamination of stator winding components would be principally in the form of a vapor or mist settling on the surface, a simulation of this type of exposure was made through the use of an environmental chamber, shown in Figures 15.2 and 15.3.

Exposure of test pieces to the vapors of the lubricant was provided by a fan blowing through wicking material which dipped into an open pan of lubricant. A reservoir of 350 cc of fluid was maintained in the pan. The fluid was converted to vapor at the rate of 2% of its bulk per week. To make the set-up as explosion proof as possible, low watt density heating coils were used. The hottest spot on the coils was located with the help of thermovision, and the temperature of that hot spot was measured by thermocouple to be 160^{o}C. when the chamber was at its highest setting. For added safety, the side of the chamber was provided with a 4-inch diameter rubber plug which would be pushed out if excessive pressures developed within the chamber.

For both the liquid mode and the vapor mode, temperatures were maintained at 135^{o}C. This temperature may appear to be high in relation to the oil pot temperatures. However, the concern was mostly with stator winding components. This temperature was selected to accommodate the maximum coil surface tempera-

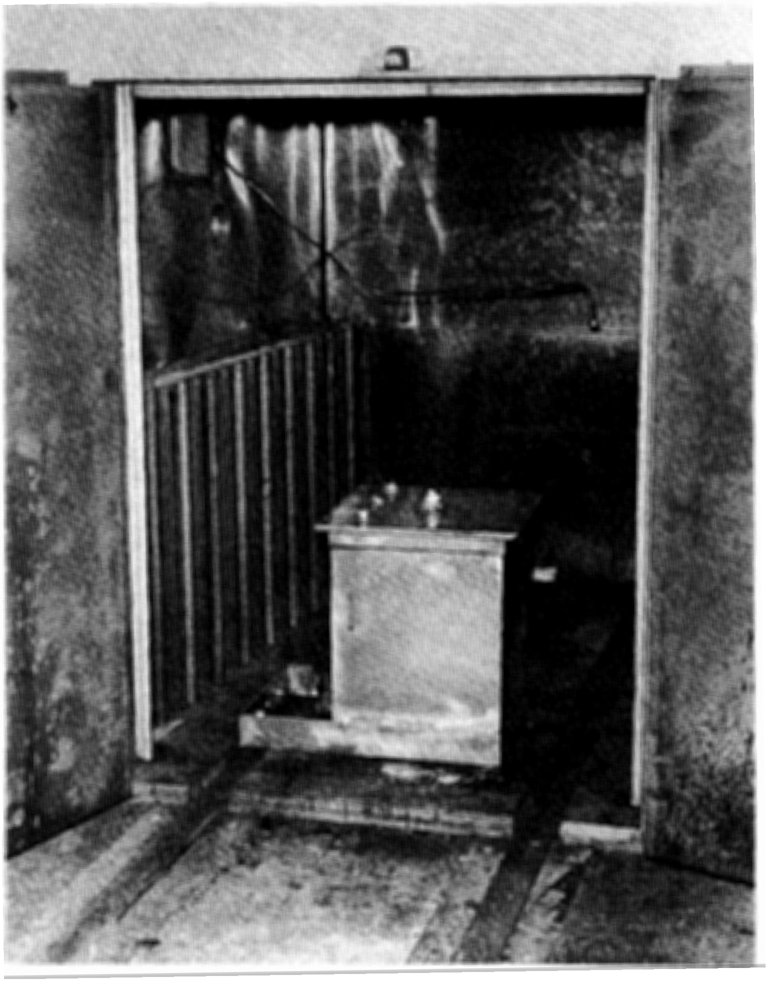


FIGURE 15.1 GAS-SEALED ALUMINUM CONTAINER IN WHICH TEST SPECIMENS WERE SUBMERGED AND HEATED IN THE LUBRICANT

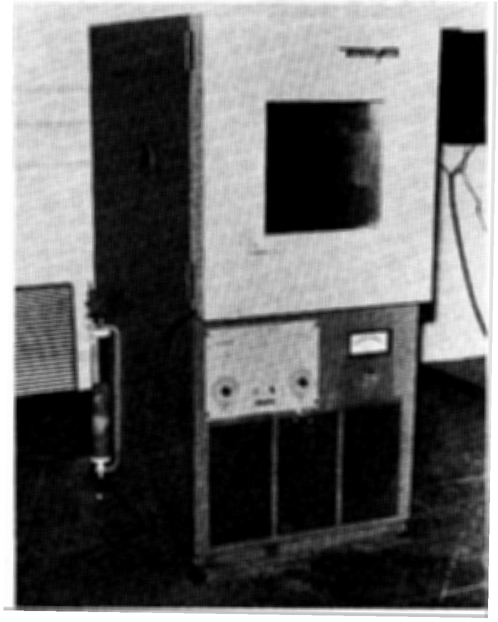


FIGURE 15.2 ENVIRONMENTAL CHAMBER WHICH PROVIDED EXPOSURE OF TEST SPECIMENS TO HEATED LUBRICANT VAPORS

FIGURE 15.3 TEST SPECIMENS UNDERGOING EXPOSURE TO FYRQUEL GT VAPOR IN ENVIRONMENTAL CHAMBER

ture of Class F windings. For Class B windings, this represents a temperature acceleration.

Since temperature alone changes some of the properties which were being monitored, duplicate test pieces were aged at 135°C. to serve as controls.

All the insulation samples were prepared on short aluminum test bars. The ends were potted so that the cross section of the insulation was not open to the lubricant.

Previous studies have demonstrated the importance of not exposing the cross-sectional structure of insulation in tests of this nature, since it creates a unique condition of contaminant ingress which is not normally experienced in operation. The nature of liquid contaminant travel through mica insulation once its cross-sectional structure is exposed is one of capillarity, the capillaries being in a direction effectively parallel with the insulation laminae. This capillary travel is quite rapid. It can be likened to preferential absorption of moisture along an adhesive-adherent interface. As an example, for glass resin laminates, this has been shown to proceed at a rate approximately 500 times faster than permeation through the resin of the laminate.

Since vulnerability is tremendously increased by exposing the insulation laminae, and since this condition does not occur in a good insulation system, the ends of the test bars were sealed by potting them in resin, bringing out through the resin a thin wire soldered to the bar for electrical contact with the bar. Figure 15.4 is a photograph of a typical insulation test specimen.

Test criteria used for insulation systems were change in capacitance, change in dissipation factor, dimension change, as well as observations of swelling, blistering, delamination, and other changes in physical appearance, both external and internal.

Test bars were also the medium for checking the conducting outer binder of the coil, the conducting varnish, and the corona suppressing films. These were prepared both with and without protective coats of varnish. These were moni-

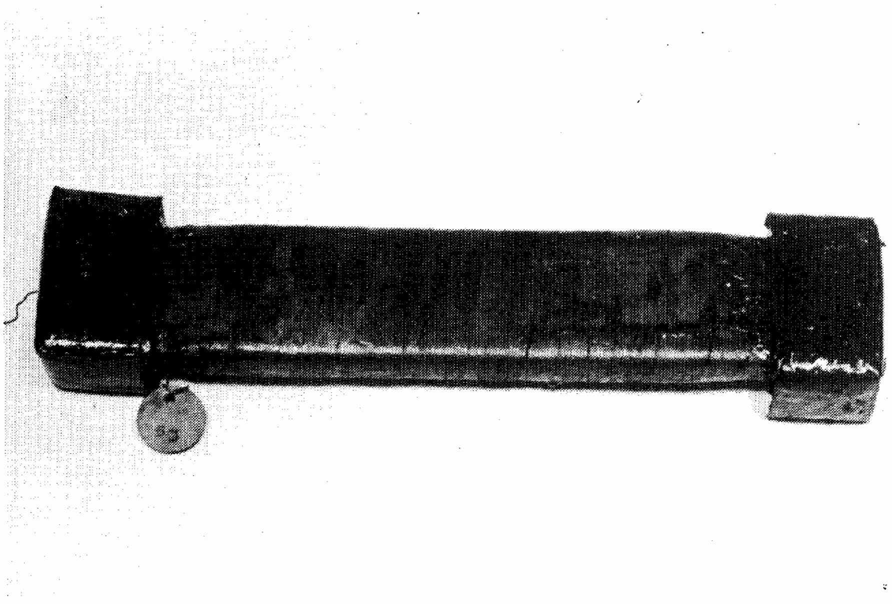


FIGURE 15.4 EXAMPLE OF TEST SPECIMEN WITH POTTED ENDS USED FOR EVALUATING EFFECTS OF FYRQUEL GT LUBRICANT AND VAPOR ON INSULATIONS

tored for changes in surface resistivity as well as for changes in physical appearance.

For laminates from which wedges, cleats, and other supports are made, changes in tensile properties are considered to be the most indicative of physical change. Flexural properties were measured to detect embrittlement. Weight and dimensional changes were also monitored.

SECTION 16.0

COMPATIBILITY TESTING OF ELECTRICAL INSULATION SYSTEMS

16.0 COMPATIBILITY TESTING OF ELECTRICAL INSULATION SYSTEMS

16.1 GENERAL

The use of fire resistant lubricants in motors will result in some exposure of the stator winding insulation to the lubricant, either in the form of vapor or mist, or through accidental spillage. The effects of the exposure will be aggravated by the high operating temperature of the winding.

The insulation systems tested, except as otherwise noted, can be characterized as mica/solventless-resin vacuum-pressure impregnated insulations. Variations in insulation systems are numerous, and these can constitute factors affecting the vulnerability of the insulation to an attack by the lubricant. The resin impregnants are foremost in potential for influencing susceptibility to degradation. The polyester and epoxy resin impregnants which were tested encompass the overwhelming majority of the industry's insulation systems.

Since epoxy systems predominate throughout the industry, three variations of epoxy impregnants were included in the test program:

1) A high viscosity, Lewis acid catalyzed, reactive diluent modified bisphenol A epoxy.
2) A lower viscosity vinyl monomer modified anhydride epoxy.
3) A higher monomer content version of (2) which was formulated to achieve even lower viscosity.

Other variations which could have significance included the type of mica, (whether mica splittings or mica paper) and the form (whether the insulation consists of mica wrappers, where sheets are wrapped around the straight part of the coil, or consists of continuous tape, where multiple layers of narrow width mica tape are spiralled around the coil). Three variations of connection taping were sampled: mica tape impregnated with epoxy resin (simulating the connections of a post impregnated winding), the same mica tape brushed with resin (one method of insulating connections of windings processed with preimpregnated coils), and oleoresinous varnished glass tape brushed with resin.

16.2 TEST PROCEDURE

In appreciation of the primary function of the ground wall as a dielectric, changes in dielectric characteristics were used as the principal criterion for monitoring the effects of the lubricant on the ground wall. Dissipation factor measurements of the insulations were made after increasing periods of exposure to the lubricant. These measurements are sensitive to even minor changes in the dielectric, including intrusion of contaminants, degradation of the resin matrix, and loss of physical integrity of the resin composite.

Insulation specimens duplicating 5000 volt and 13,800 volt insulation were prepared on 0.5" x 2" x 12" aluminum test bars. A thin (.020" diameter) length of wire was attached to the metal at one end of each bar. To seal the cross section of the insulation against the lubricant, both ends of the bars were potted in a filled epoxy resin, with the free end of the wire brought out through the potting to serve as electrical connection to the bar, per Figure 15.4.

Initial measurements of dissipation factor were made on each bar at room temperature, using a Schering bridge, at stresses on the insulation of 25, 50, 75, and 100 volts per mil of insulation thickness. For the initial measurements and all subsequent measurements, six-inch long adhesive aluminum foil was centered on each bar as the ground electrode, and adhesive foil strips as guard electrodes were located .125" from each end of the ground electrode. The foil electrodes were removed after each series of tests.

Groups of three test bars of each variation were immersed in Fyrquel GT lubricant and sealed in a gas tight aluminum container which was placed in an oven with the temperature maintained at 135^{o}C., per Figure 15.1. After exposures of 2 weeks, 4 weeks, 12 weeks, and 24 weeks, the bars were removed, surface oil was wiped off, aluminum foil electrodes were reapplied, and dissipation factor measurements were repeated.

A duplicate number and variety of test bars were subjected to exposure to the vapors of Fyrquel GT lubricant at elevated temperature. An environmental chamber was used for this purpose, per Figures 15.2 and 15.3. Vapor was provided by a fan blowing through wicking material which dipped into an open pan of the lubricant. The same test procedure and schedule as above was followed.

For both the liquid mode and the vapor mode exposures, temperatures were maintained at 135°C. This temperature was selected to accommodate the maximum coil insulation surface temperature of Class F (155°C hot spot) stator windings. For Class B windings, this represents a temperature acceleration.

Since thermal aging changes the properties which were being monitored, duplicate test pieces to serve as controls were aged in a 135°C oven.

To supplement the findings of dissipation factor measurements, thickness change data was also collected. Thicknesses of each of the test specimens above were measured initially at three marked places, and remeasured after subsequent aging periods. At the termination of the tests, selected specimens were cut apart to examine visually the degree and mode of penetration.

16.3 TEST RESULTS

Figures 16.1 through 16.11 plot changes in dissipation factor of the various insulation systems as a function of exposure time to the Fyrquel lubricant and the vapor of the lubricant. Table 16.1 summarizes thickness changes of these same systems, and Figures 16.12 through 16.24 plot thickness changes of each of the systems as they were subjected to successive exposures.

Figures 16.25 through 16.32 are photographs of specimens of different insulation systems after exposures to the Fyrquel lubricant and vapor. Figures 16.33 through 16.36 are photographs of sectioned insulation after completion of the exposure period in the Fyrquel lubricant.

Dissipation factor measurements, thickness data, and the dissected coils indicate that all the insulation systems showed some effect from prolonged immersion in the lubricant at high temperature. This is not unexpected since it constitutes a severe over-test. The exposure time far exceeds the total exposure of this type that could be anticipated during the service life of a motor. The severity of exposure was not intended to establish functional demonstration of the ability of the insulations to withstand degradation in the presence of the lubricant. Rather, it was to provide acceleration for determining in a short time the relative vulnerability of the several insulation systems. Therefore, for systems which were relatively intact after these severe tests, assurance is provided of reliability in the much more moderate exposures expected in service.

A characteristic of cured epoxy resins generally is their chemical inertness. As insulating resins, they provide excellent barriers to the intrusion of contaminants into the insulation composite.

Extremes of exposure indicate that the epoxy resin impregnants are not completely impervious to the lubricant. As can be seen from Figures 16.1 through 16.7, which plot changes in dissipation factor of various epoxy impregnated test bars as a function of the length of exposure, all of the bars that were immersed in the lubricant at 135°C temperature showed some loss in favorable electrical characteristics. Considering the severity of exposure, this loss is moderate. With prolonged immersion, factors which are both non-typical and non-critical affected the dissipation factor measurements. While activity and changes were occurring, these were not compromising the insulation integrity. A distinction must be made between attack of the insulation by the lubricant and penetration of the lubricant into the insulation laminae. The exposure of the cross-sectional laminae of mica insulation increases vulnerability to a tremendous degree, as described in an earlier section. In preparing test specimens, every effort was made to seal the open ends by potting, since this type of penetration is not typical of a good insulation system. However, good seals can impede, but not block, penetrability. Liquid contaminants travel the interfaces of discrete insulating layers. While such interface situations exist in some insulation systems, they are purposely avoided in other insulation systems, i.e., "sealed" systems and post impregnated systems.

The test results are pessimistic to the degree that some non-typical penetration which affects the dielectric characteristics being monitored, occurred along the interface and through the ends of the test bars. As illustrations of this, two test bars exhibiting high dissipation factor readings after the final immersion period (Figures 16.4 and 16.6) were discovered to have developed a splitting away of the potting on one end. This split can be seen in Figure 16.32 which is a photograph of the test bar with the high dissipation factor after 24 weeks immersion, plotted in Figure 16.6. Figure 16.33 is a cut-away view of the insulation of this test bar showing that the lubricant penetrated from the end where the potting was damaged and progressed longitudinally between layers.

An additional factor affecting dissipation factor levels, but of minimal impact on insulation quality, is that traditionally the outer glass binding tape around the insulation is poorer adhesively than are the cohesive mica layers of the main insulation.

With prolonged exposure, liquid penetrates the binder layer and collects between the binder and the main insulation. Figure 16.34, which is a photograph of a test bar after six months' immersion in the lubricant, shows the glass binding tape to be permeated with the lubricant, and a collection of lubricant is evident between the binder and the mica. Figure 16.35, which applies to the same coil with a mica layer lifted away, shows no penetration of the fluid into the mica body.

Exposure to the lubricant vapors, more representative of the type of exposure to be experienced in service, has no effect on the epoxy impregnated insulation systems. This is typified by Figures 16.1 and 16.2 which plot the data of bars that were subjected to the vapor together with control bars that were subjected to thermal aging at the same 135°C temperature. The initial weeks and months of thermal aging of epoxies and other resins constitute a post-curing of the resin with resultant improvements in dissipation factor, as indicated by the curves of the control bars of Figures 16.1 and 16.2. The curves of the bars subjected to lubricant vapor coincide with those of the control bars, showing the same improvement in dissipation factor due to postcuring, with no discernment of any negative counter influence due to lubricant effect. Figures 16.4, 16.5 and 16.6 also trace curves of bars subjected to vapor as following the improvement expected from postcuring of the resin.

As mentioned above, the extremes of exposure provide a means of determining the effects of variations in insulation composition on vulnerability to attack by the lubricant. Looking at changes in properties after six months' immersion in the hot Fyrquel GT lubricant, a number of conclusions can be reached.

Reactive diluents compounded into the epoxy resin formulations to achieve lower viscosities for ease of impregnation, were expected to affect vulnerability unfavorably. There was some concern that the lower ratio of epoxy to (vinyl monomer) diluent (as represented by Figure 16.7 compared to Figure 16.6, and by Figure 16.4 compared to Figure 16.5), would cause the insulation to be less resistant to attack. The dissipation factor data do not indicate this. Thickness data do show greater dimensional change for the higher monomer content resin, (Figure 16.17 compared to Figure 16.18, and Figure 16.16 compared to Figure 16.19). Those differences are small. Differences in relative vulnerability due to diluent content must be concluded to be of minor degree.

Whether the mica form (mica splittings or mica paper) affects vulnerability was also questioned. Dissipation factor data (Figure 16.1 compared to Figure 16.3) do not indicate a difference. In the continuous taping process, the mica paper appears to have some advantage (Figure 16.6 versus Figure 16.5, and Figure 16.7 versus Figure 16.4), but the magnitude is such as to minimize the importance of the mica form. Thickness data show no difference between mica splittings and mica paper in wrapper type insulation (Figures 16.12 and 16.16). Thickness data differences between mica splittings and mica paper in continuously taped coils are small. Variations cannot be considered to be significant; in one instance less swelling was experienced with mica paper

(Figure 16.19 compared to Figure 16.18), and in another instance the reverse was true (Figure 16.16 compared to Figure 16.17).

From dissipation factor data, there is no clear delineation as to whether wrapper type insulation provides a greater barrier to penetration than does continuously taped insulation (Figure 16.2 compared to Figure 16.6). Neither do thickness data offer any significant differences (Figure 16.14 compared to Figure 16.19). However, examination by cutting away the outer binder of insulation which had been immersed for six months in the lubricant suggests that the edges of the mica tape of continuously taped insulation permit ingress of the lubricant into the insulation body (Figure 16.36).

On the basis of extremes of exposure, epoxies offer a more stable system than polyester. However, it is not indicated that polyesters would fail to perform satisfactorily under normal conditions. Figure 16.8 indicates attack of the polyester impregnant when immersed in the lubricant, but bars subjected to the lubricant vapor show only the improvement in dissipation factor expected from the additional curing. An important consideration in the ability of polyester impregnated insulation to withstand attack is the opportunity for ingress of the lubricant into the insulation structure. If the cross section of the insulation were exposed, the danger of entry of the lubricant between tape laminae would be greatly increased.

Vacuum pressure impregnation, providing a compact, well-filled structure, impedes attack by the lubricant. This can be seen from a comparison of Figures 16.9 and 16.10. Perhaps it is more evident by comparing the curves of the vapor exposed bars. This shows that part of the improvement in dissipation factor due to thermal aging is neutralized when the bars have been brushed with resin (Figure 16.10). From this it can be assumed that there is a compensating loss due to attack by the lubricant vapors.

Post impregnation of the entire stator winding provides an initial seal against easy entry of the lubricant into the body of the insulation, since all the connections are impregnated with the coils to provide a continuous unified insulation without interfaces. Where this processing is not utilized and it is necessary to insulate connections of pre-impregnated coils, the high dissipation factor values, and actual electrical failures, shown in Figure 16.11, and the extreme amount of swelling shown by the thickness data of Figure 16.24, indicate that varnished glass insulation, even in combination with an epoxy brushing bond which is chemically inert when cured, is a poor choice. This is verified by photographs of this type of insulation after exposure, Figure 16.30. Mica paper tape with an absorbent backing to retain the epoxy brushing bond (Figure 16.10) provides a less risky alternative, possibly because a more compacted, impervious structure is achieved. Hand brushing of resin between applied layers of tape, however, as contrasted to vacuum pressure impregnation, increases susceptibility to contaminant ingress, as evidenced by thickness data of Figure 16.23.

Analysis of dissipation factor data, review of dimensional change data, and examination of dissected insulation samples upon conclusion of the test program, substantiate the following conclusions:

- Solventless epoxy resin impregnated mica insulation is resistant to degradation from the Fyrquel GT lubricant at maximum service temperatures and exposure. At extremes of exposure, exceeding service contingencies, some effect of the lubricant on the epoxy impregnated insulations is discernible.
- The method of insulation processing has a decided effect on the susceptibility of insulation to attack by the lubricant. Vacuum pressure impregnation provides a more resistant insulation package than if similar components were used with the resin hand applied.
- The above suggests post impregnation as the most desirable alternative for processing stator windings, since all insulation segments, including coil, group and parallel connections are vacuum pressure impregnated.
- Where connection and other tapings are not resin impregnated, the use of mica insulation with resin-absorbent backing with brushed-in epoxy resin is preferable to non-micaceous materials such as varnished glass tape with brushed resin.
- Connections insulated with oleoresinous varnished glass tape and brushed with resin are extremely vulnerable to attack. This construction should be considered unsuitable for use in the presence of fire resistant fluid lubricants, or at least recognized as presenting a hazard of failure.

- Insulation vacuum pressure impregnated in solventless polyester resin is attacked by the lubricant under severe exposure conditions. However, there are indications from moderate exposures to the lubricant vapor, that polyester impregnated resin would perform satisfactorily under normal conditions of operation.

- The relative contributions of mica splittings versus mica paper in resisting degradation are not distinct, and the importance of the mica form must be considered minimal.

- Differences between mica wrapper and continuous mica tape constructions are not discernible and are probably not significant.

TABLE 16.1 THICKNESS CHANGE OF INSULATED BARS AFTER EXPOSURE TO FYRQUEL GT

INSULATION DESCRIPTION	TREATMENT	INITIAL THICKNESS (IN.)	CHANGE IN THICKNESS (IN.)			
			AGED 1 WK.	AGED 4 WKS.	AGED 12 WKS.	AGED 24 WKS.
MICA PAPER WRAPPER IMPREGNATED IN VINYL MONOMER MODIFIED EPOXY RESIN	THERMALLY AGED AT 135°C	.662	+.002	-.001	-.004	+.000
	EXPOSED TO FYRQUEL VAPORS AT 135°C	.666	+.000	+.001	+.002	+005
	IMMERSED IN LUBRICANT AT 135°C	.665	+.015	+.014	+.017	+.026
MICA SPLITTINGS WRAPPER IMPREGNATED IN LEWIS ACID ACTIVATED HIGH VISCOSITY EPOXY RESIN	THERMALLY AGED AT 135°C	.688	-.006	-.006	-.009	-.004
	EXPOSED TO FYRQUEL VAPOR AT 135°C	.675	+.003	+.005	+.003	+.005
	IMMERSED IN LUBRICANT AT 135°C	.681	+.004	+.001	-.002	+.014
MICA PAPER WRAPPER IMPREGNATED IN SOLVENTLESS POLYESTER RESIN	EXPOSED TO FYRQUEL VAPOR AT 135°C	.656	-.004	-.003	-.005	-.003
	IMMERSED IN LUBRICANT AT 135°C	.657	+.009	+.009	+.017	+.030
MICA PAPER END TAPING IMPREGNATED IN VINYL MONOMER MODIFIED ANHYDRIDE EPOXY RESIN	EXPOSED TO FYRQUEL VAPOR AT 135°C	.647	-.002	-.004	-.002	-.001
	IMMERSED IN LUBRICANT AT 135°C	.652	+.010	+.008	+.016	+.033
OLEO RESINOUS VARNISHED GLASS-DACRON TAPE BRUSHED WITH AMINE ACTIVATED EPOXY RESIN	EXPOSED TO FYRQUEL VAPOR AT 135°C	.816	-.031	-.031	-.009	-.004
	IMMERSED IN LUBRICANT AT 135°C	.809	+.041	+.048	+.062	+.081
MICA PAPER END TAPING BRUSHED WITH AMINE ACTIVATED EPOXY RESIN	EXPOSED TO FYRQUEL VAPOR AT 135°C	.732	-.007	-.009	-.012	-.009
	IMMERSED IN LUBRICANT AT 135°C	.736	+.014	+.012	+.006	+.046
MICA PAPER WRAPPER IMPREGNATED IN LEWIS ACID ACTIVATED HIGH VISCOSITY EPOXY RESIN	THERMALLY AGED AT 135°C	.682	-.007	-.011	-.019	-.008
	IMMERSED IN LUBRICANT AT 135°C	.672	+.003	+.002	+.002	+.017
CONTINUOUSLY TAPED MICA PAPER IMPREGNATED IN VINYL MONOMER ANHYDRIDE EPOXY RESIN (13.8 KV)	EXPOSED TO FYRQUEL VAPOR AT 135°C	.860	+.001		+.007	+.007
	IMMERSED IN LUBRICANT AT 135°C	.871	+.011		+.025	+.013
CONTINUOUSLY TAPED MICA PAPER IMPREGNATED IN HIGH MONOMER CONTENT ANHYDRIDE EPOXY RESIN (13.8 KV)	EXPOSED TO FYRQUEL VAPOR AT 135°C	.854	-.004		+.006	+.008
	IMMERSED IN LUBRICANT AT 135°C	.854	+.012		+.039	+.032
CONTINUOUSLY TAPED MICA SPLITTINGS IMPREGNATED IN VINYL MONOMER MODIFIED ANHYDRIDE EPOXY RESIN (13.8 KV)	EXPOSED TO FYRQUEL VAPOR AT 135°C	.769	-.001		+.004	+.002
	IMMERSED IN LUBRICANT AT 135°C	.776	+.017		+.027	+.019
CONTINUOUSLY TAPED MICA SPLITTINGS IMPREGNATED IN HIGH MONOMER CONTENT ANHYDRIDE EPOXY RESIN (13.8 KV)	EXPOSED TO FYRQUEL VAPOR AT 135°C	.758	-.002		+.004	+.001
	IMMERSED IN LUBRICANT AT 135°C	.759	+.008		+.023	+.025

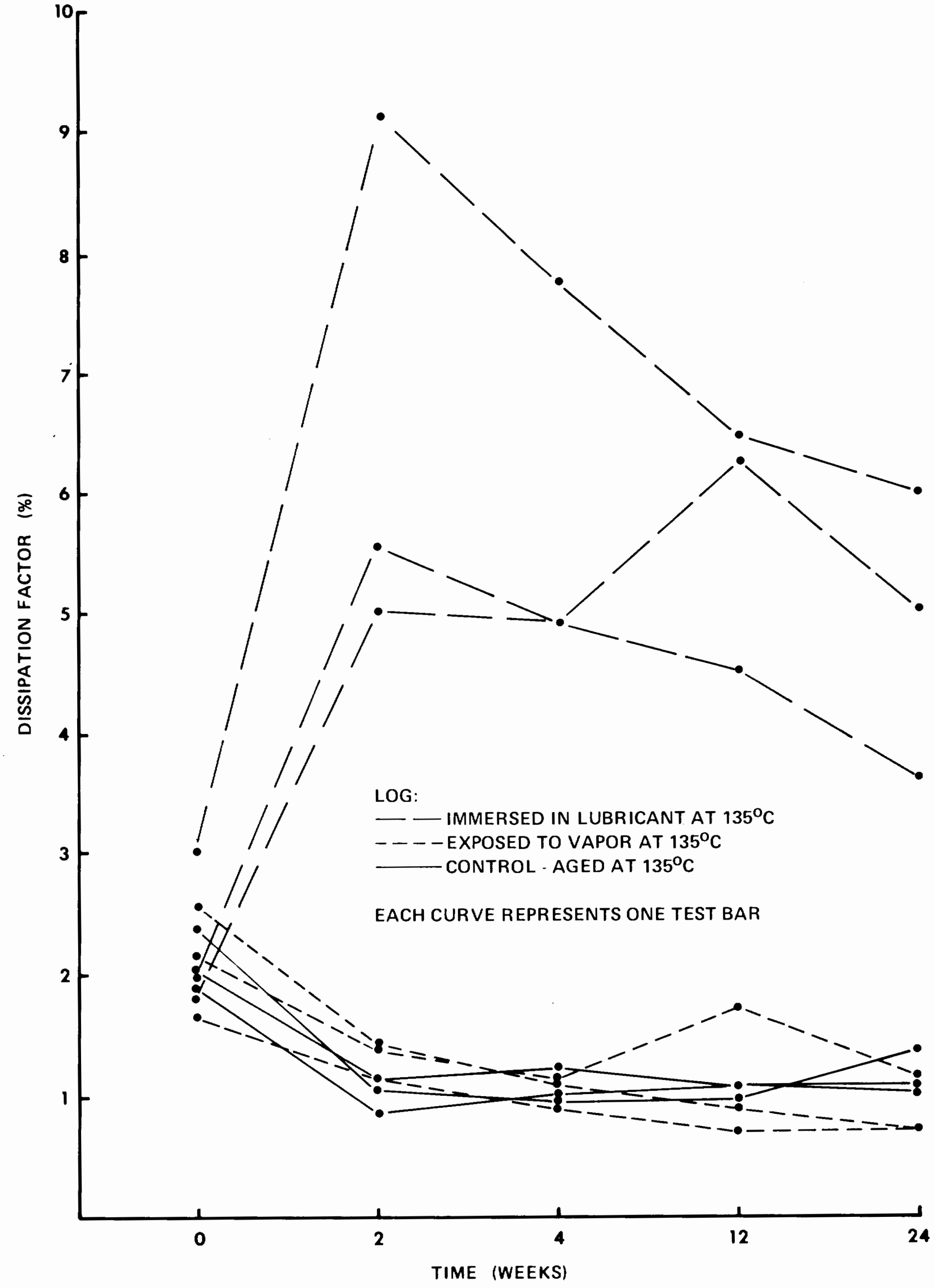


FIGURE 16.1 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, OF MICA SPLITTINGS WRAPPER 5 KV INSULATION IMPREGNATED IN LEWIS ACID ACTIVATED HIGH VISCOSITY EPOXY RESIN.

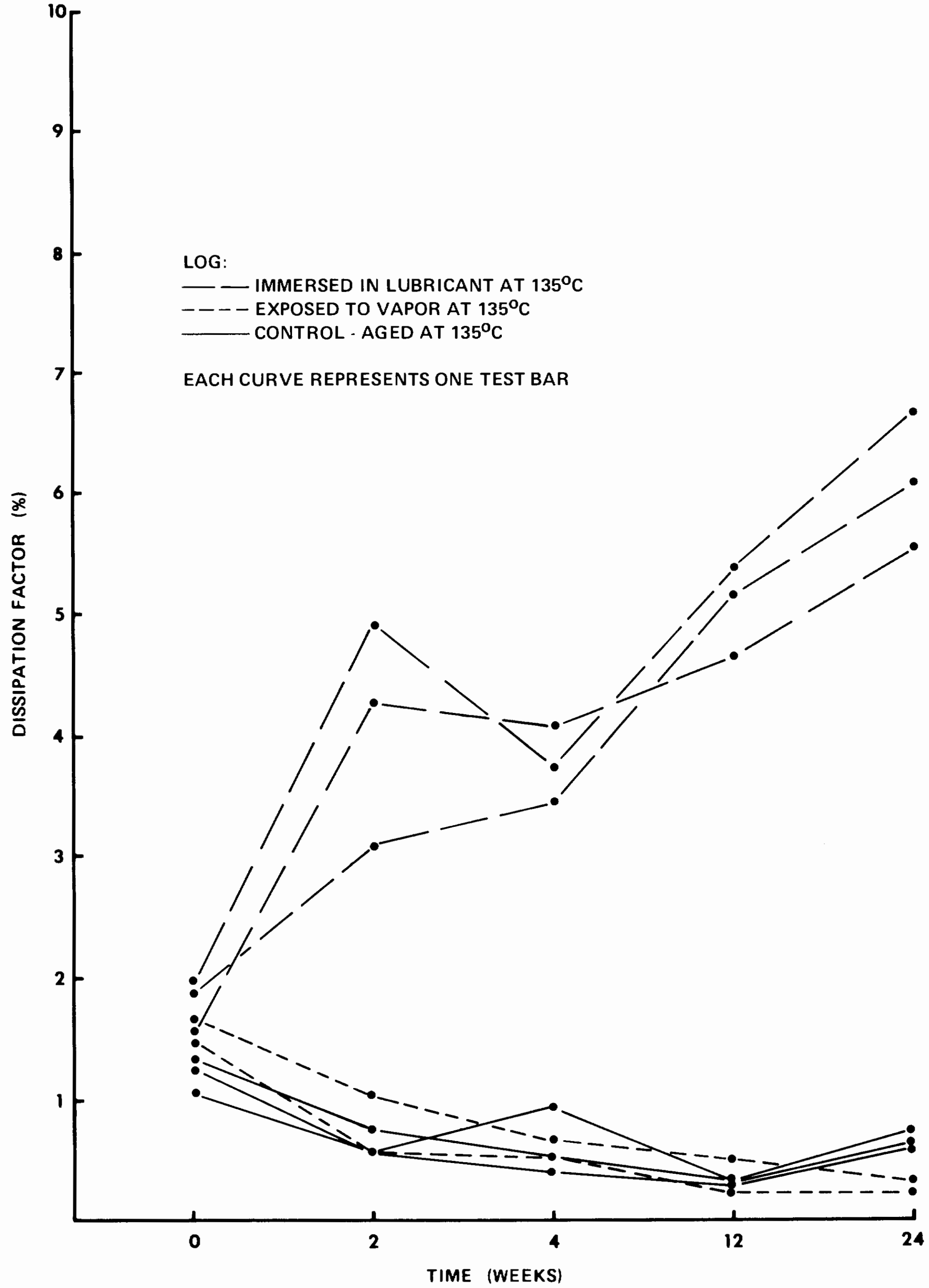


FIGURE 16.2 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, OF MICA PAPER WRAPPER INSULATION IMPREGNATED IN VINYL MONOMER MODIFIED EPOXY RESIN.

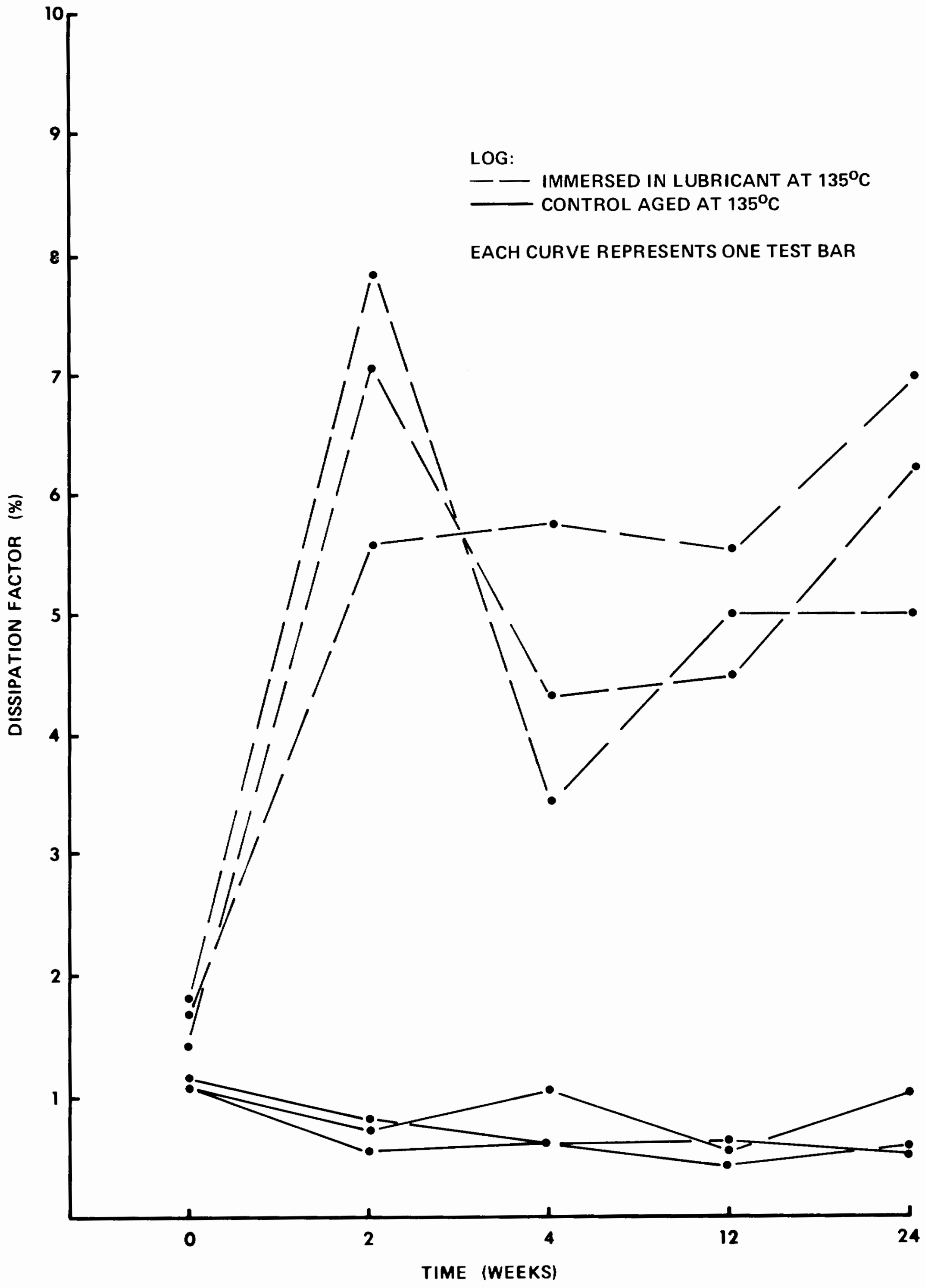


FIGURE 16.3 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, MICA PAPER WRAPPER 5 KV INSULATION IMPREGNATED IN LEWIS ACID ACTIVATED HIGH VISCOSITY EPOXY RESIN.

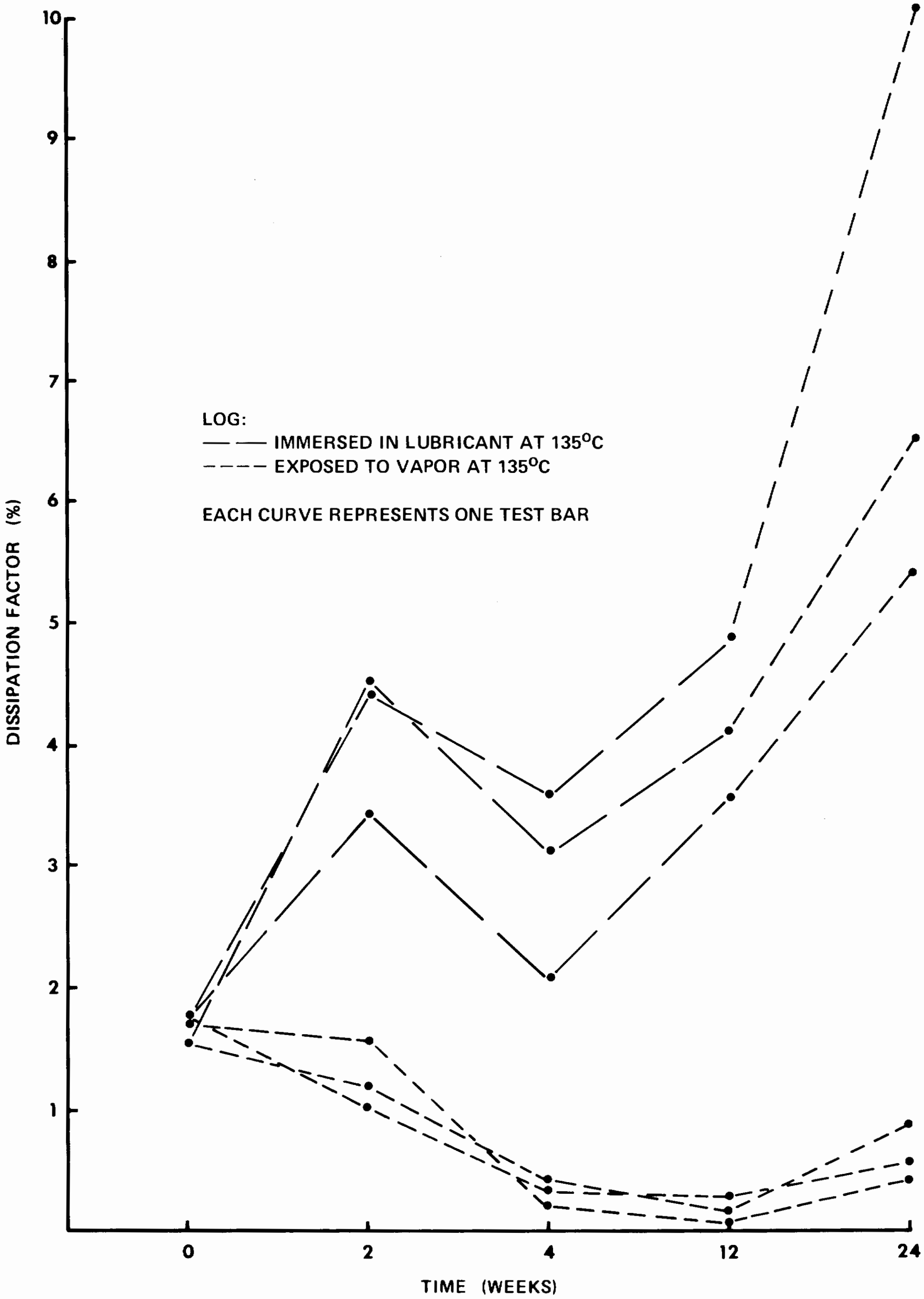


FIGURE 16.4 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, OF CONTINUOUSLY TAPED 13.8 KV MICA SPLITTINGS INSULATION IMPREGNATED IN HIGH MONOMER CONTENT ANHYDRIDE EPOXY RESIN.

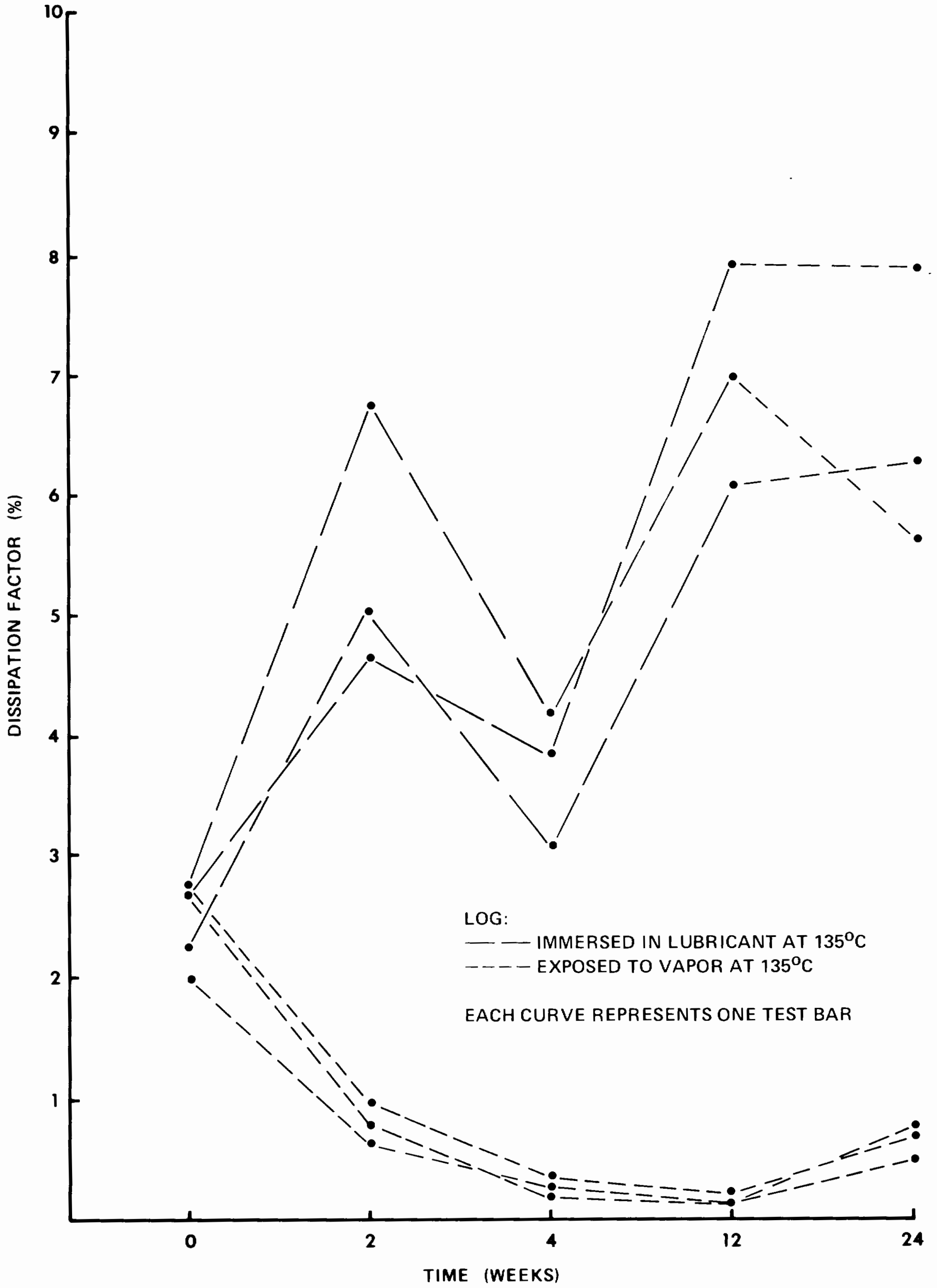


FIGURE 16.5 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, OF CONTINUOUSLY TAPED 13.8 KV MICA SPLITTINGS INSULATION IMPREGNATED IN VINYL MONOMER ANHYDRIDE EPOXY RESIN.

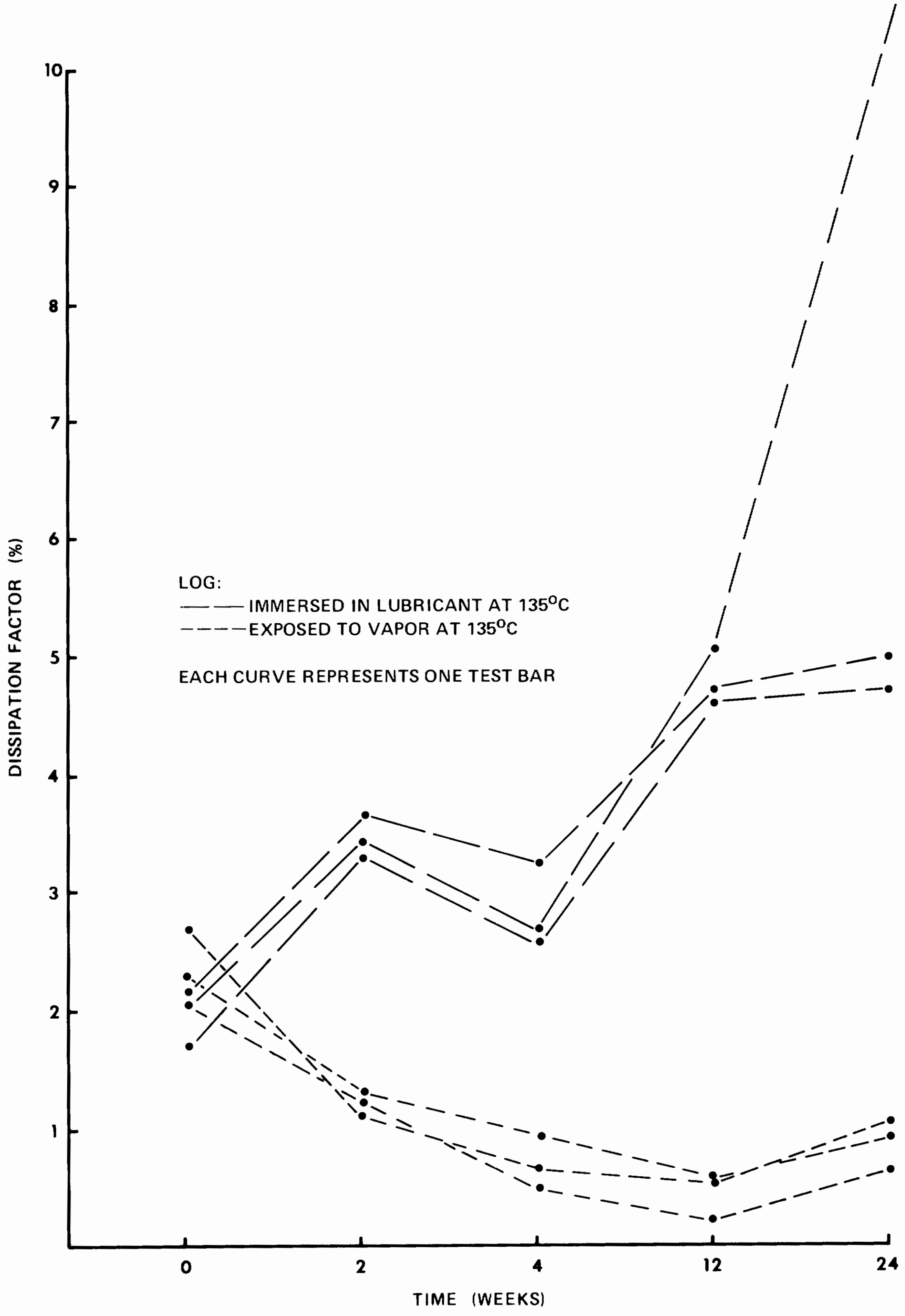


FIGURE 16.6 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, OF CONTINUOUSLY TAPED 13.8 KV INSULATION IMPREGNATED IN VINYL MONOMER MODIFIED ANHYDRIDE EPOXY RESIN.

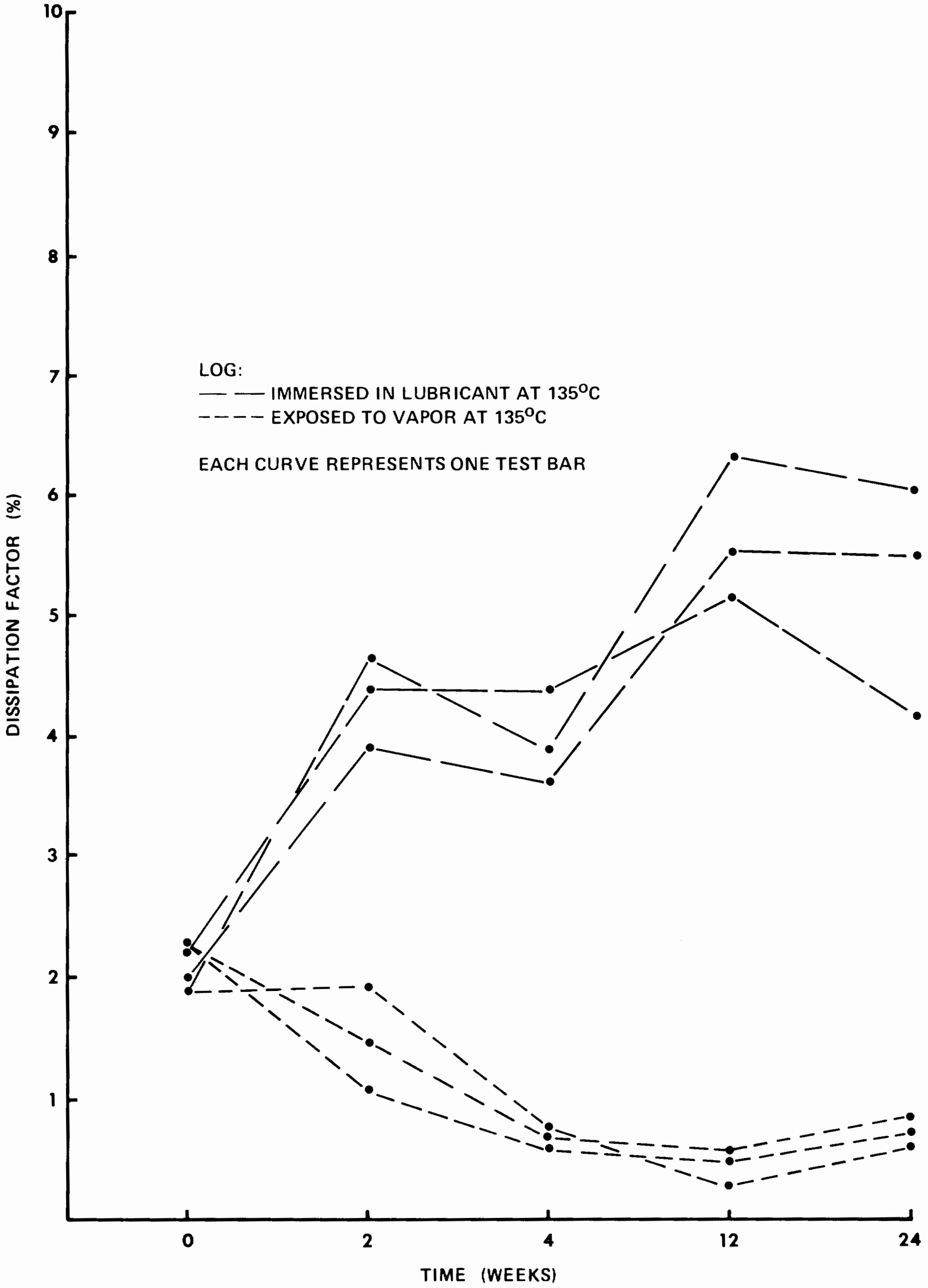


FIGURE 16.7 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, CONTINUOUSLY TAPED 13.8 KV INSULATION IMPREGNATED IN HIGH MONOMER CONTENT ANHYDRIDE EPOXY RESIN.

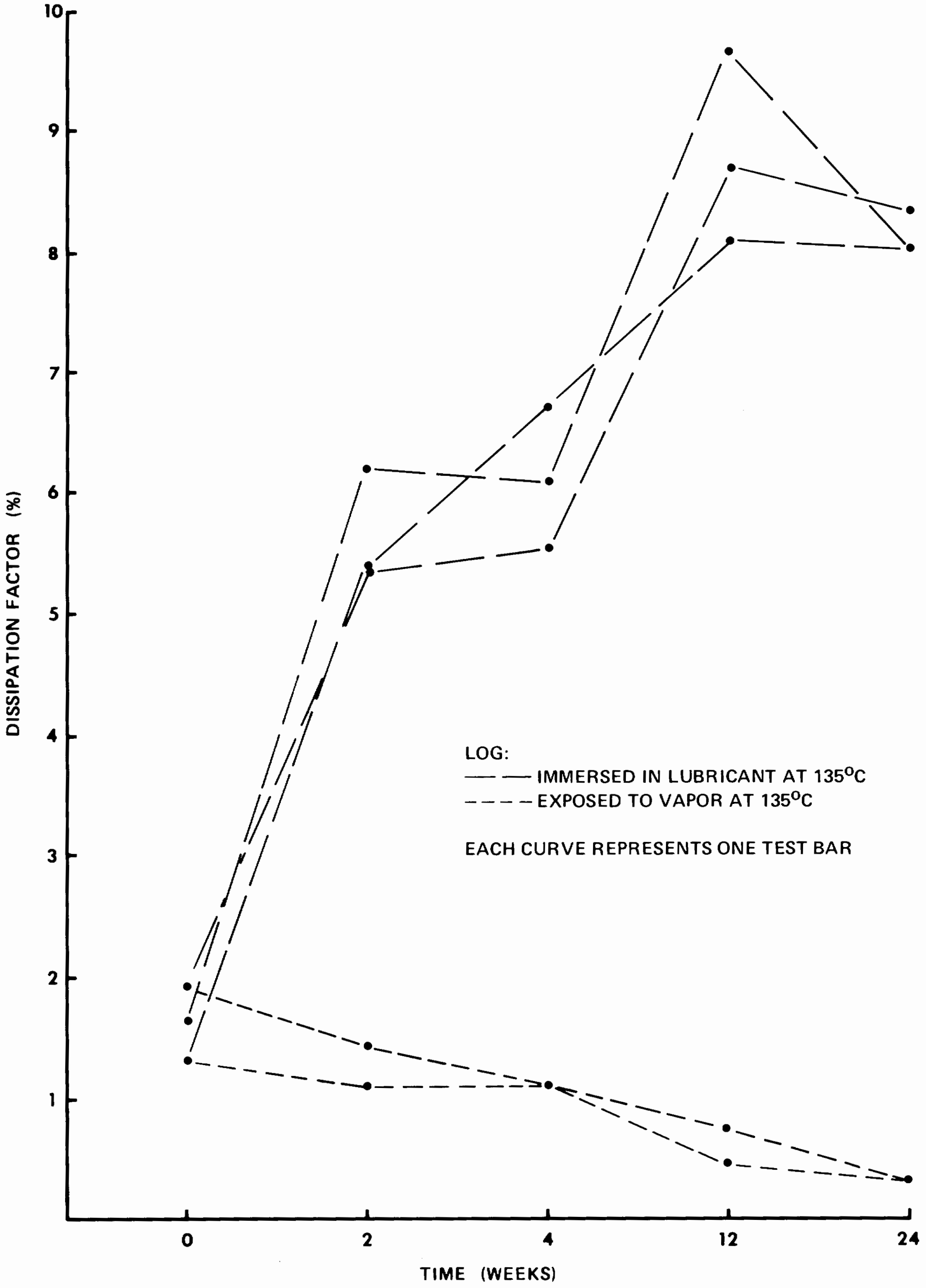


FIGURE 16.8 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, OF MICA SPLITTINGS WRAPPER 5 KV INSULATION IMPREGNATED IN SOLVENTLESS POLYESTER RESIN.

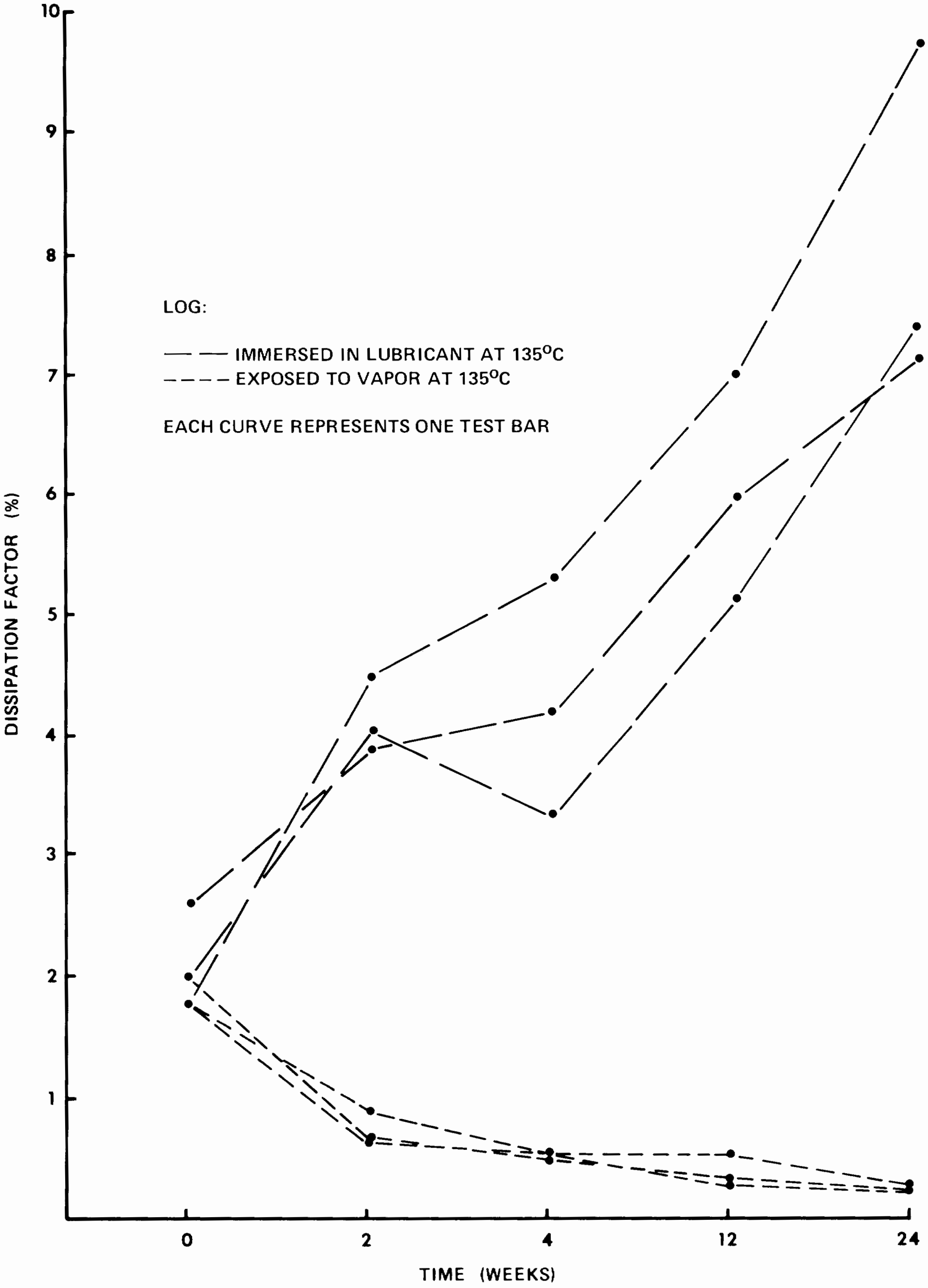


FIGURE 16.9 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, OF 5 KV MICA PAPER END TAPING INSULATION IMPREGNATED IN VINYL MONOMER MODIFIED ANHYDRIDE EPOXY RESIN.

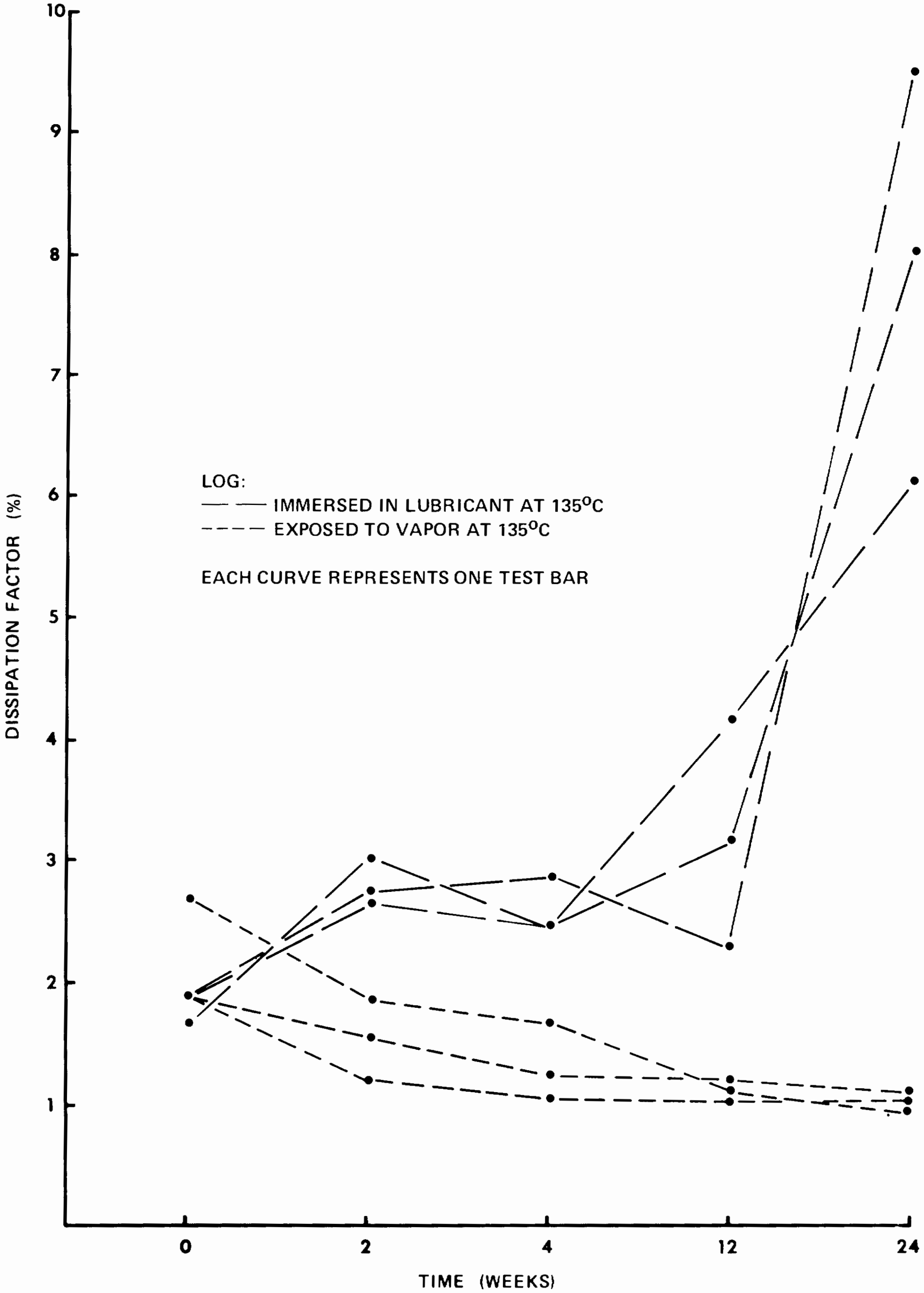


FIGURE 16.10 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, OF 5 KV MICA PAPER END TAPING BRUSHED WITH AMINE ACTIVATED EPOXY RESIN.

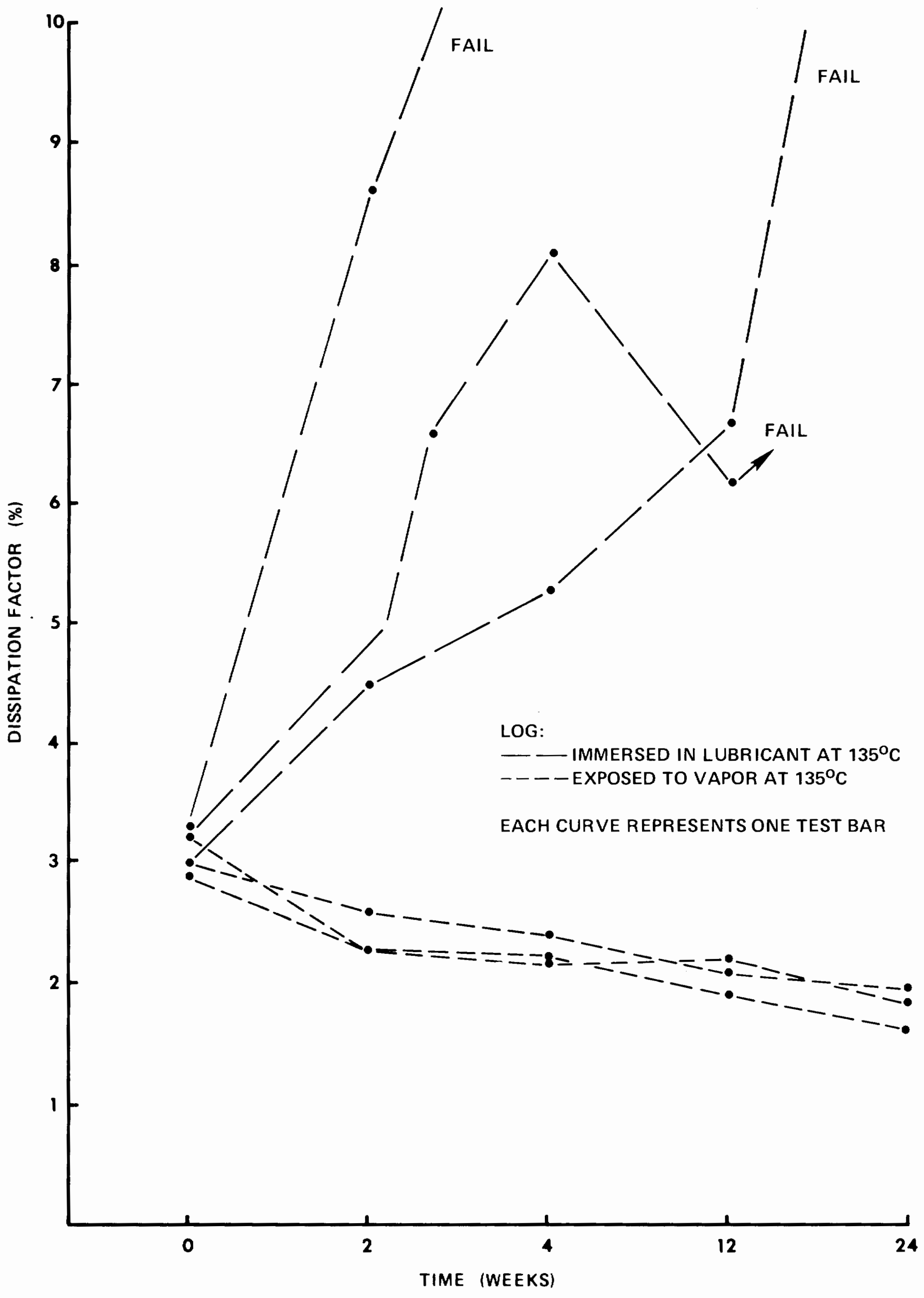


FIGURE 16.11 DISSIPATION FACTOR WHEN EXPOSED TO FYRQUEL GT, OF 5 KV OLEO RESINOUS VARNISHED GLASS - DACRON TAPE BRUSHED WITH AMINE ACTIVATED EPOXY RESIN.

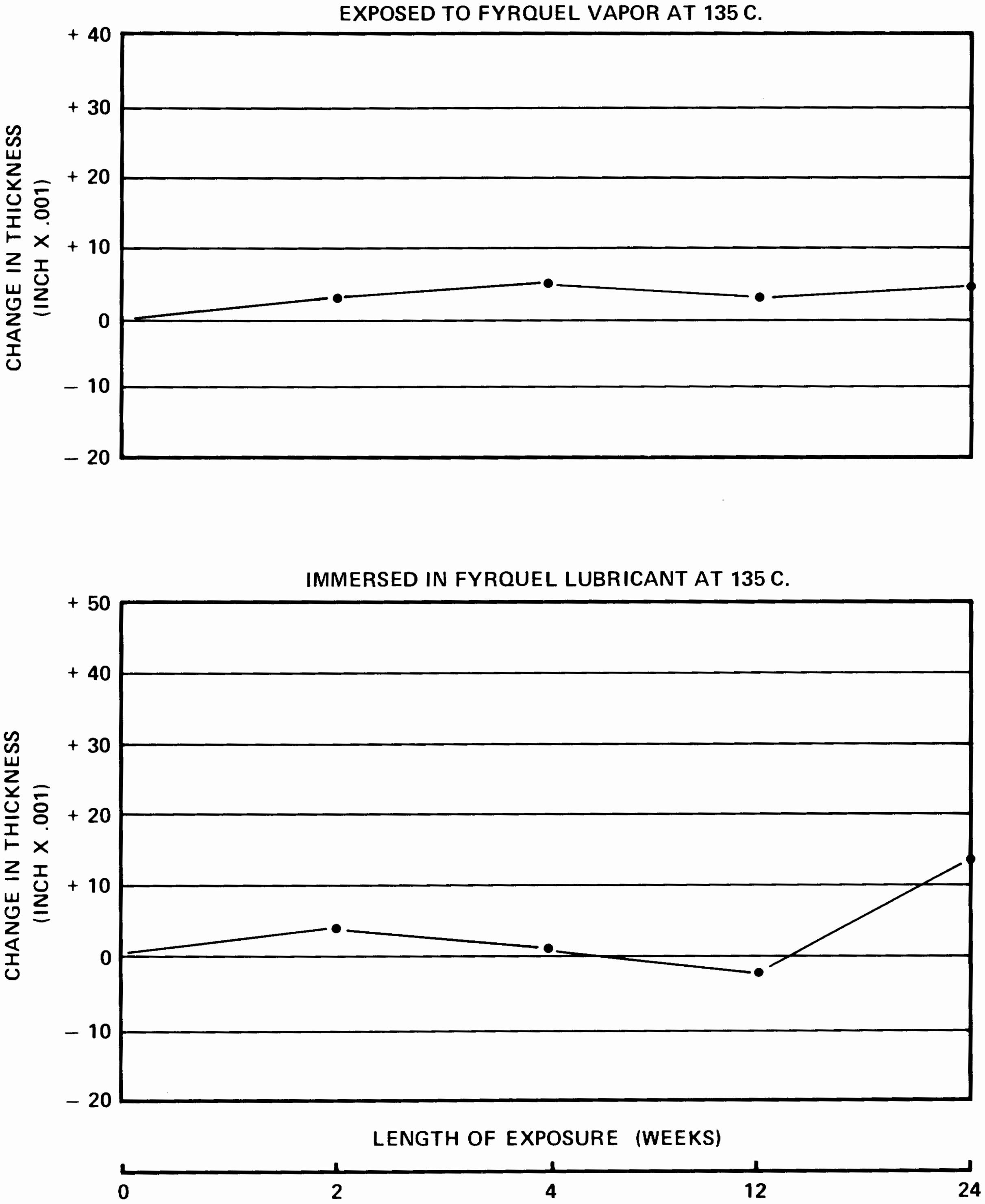


FIGURE 16.12 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED FOR 5 KV WITH MICA SPLITTINGS WRAPPER IMPREGNATED IN LEWIS ACID ACTIVATED HIGH VISCOSITY EPOXY RESIN.

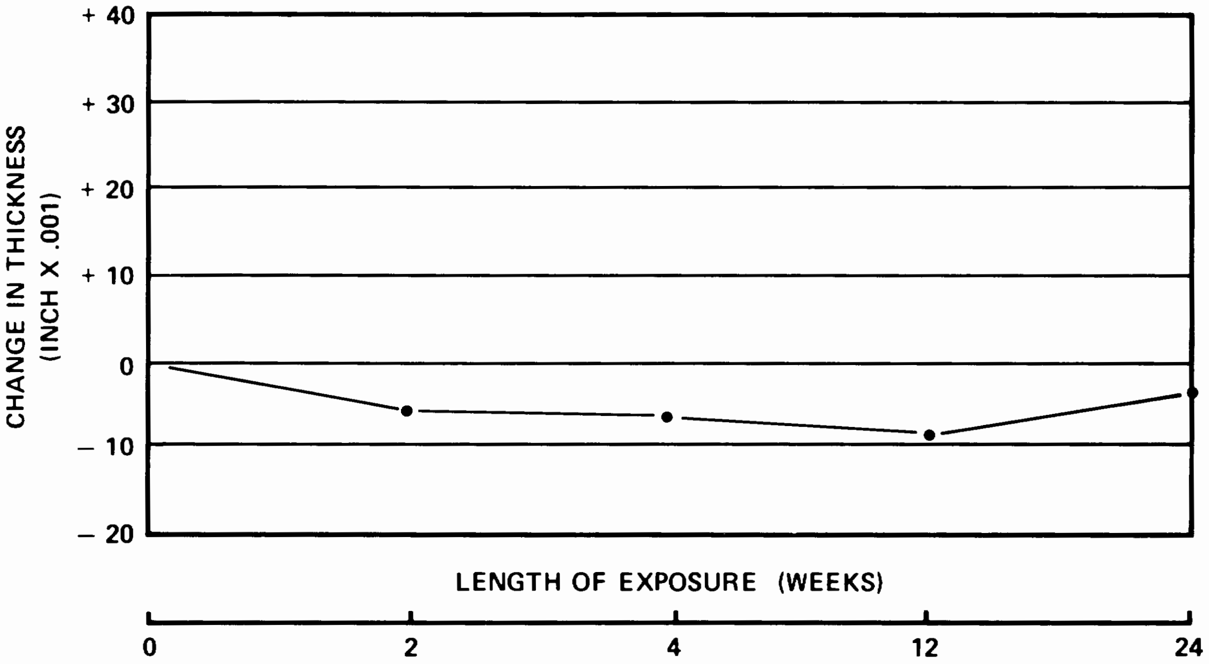
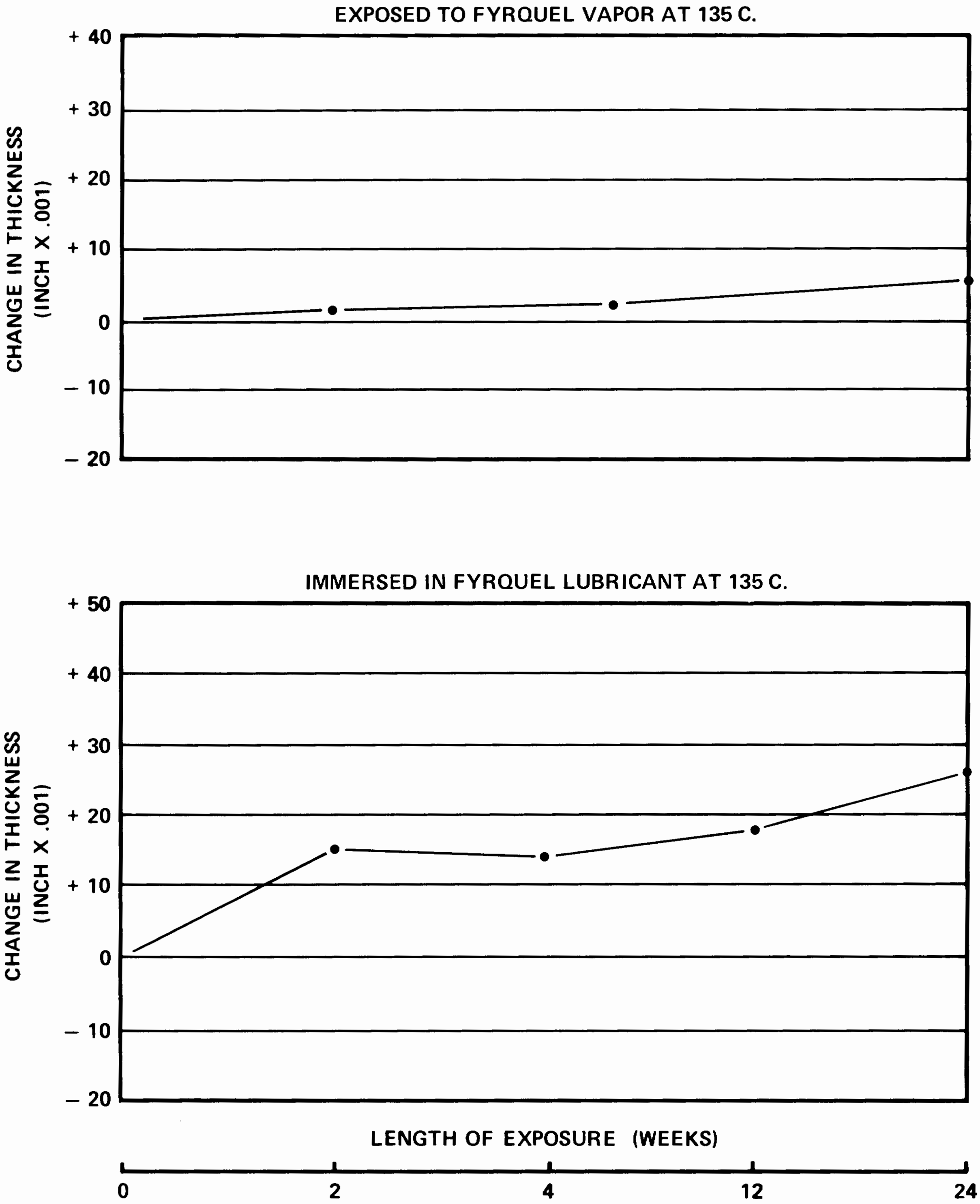


FIGURE 16.13 THICKNESS CHANGE AFTER THERMAL AGING AT 135 C. TEST BARS INSULATED FOR 5 KV WITH MICA SPLITTINGS WRAPPER IMPREGNATED IN LEWIS ACID ACTIVATED HIGH VISCOSITY EPOXY RESIN.



EXPOSED TO FYRQUEL VAPOR AT 135 C.

IMMERSED IN FYRQUEL LUBRICANT AT 135 C.

FIGURE 16.14 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED WITH MICA PAPER WRAPPER IMPREGNATED IN VINYL MONOMER MODIFIED EPOXY RESIN.

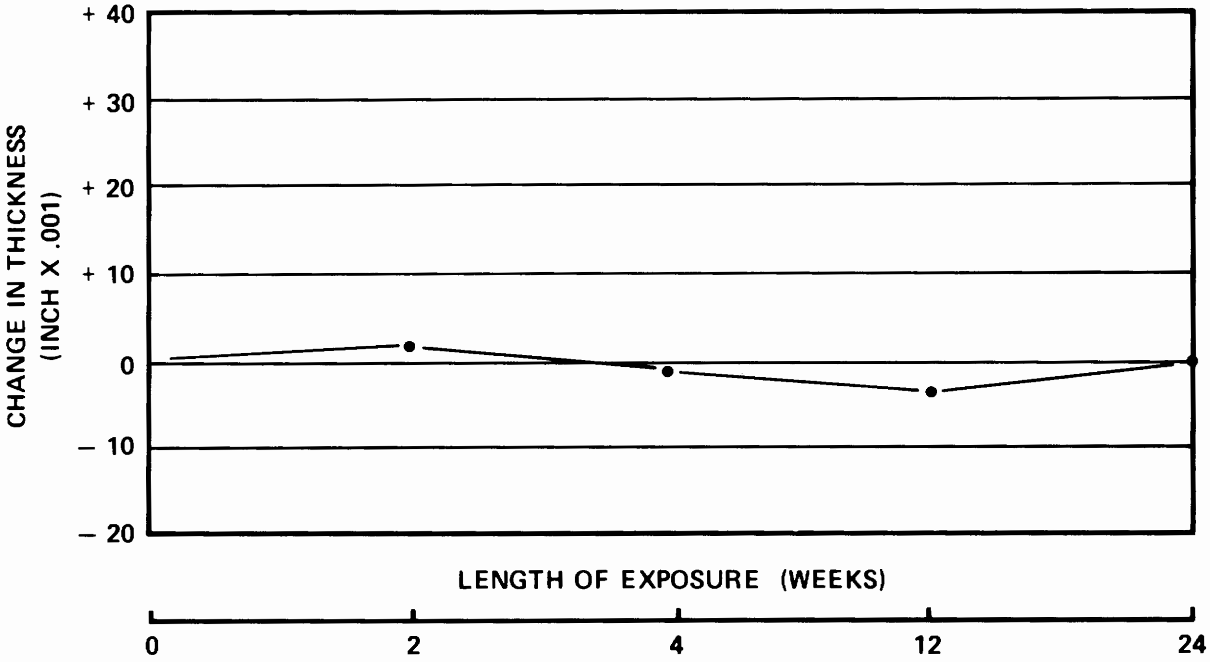


FIGURE 16.15 THICKNESS CHANGE AFTER THERMAL AGING AT 135 C. TEST BARS INSULATED WITH MICA PAPER WRAPPER IMPREGNATED IN VINYL MONOMER MODIFIED EPOXY RESIN.

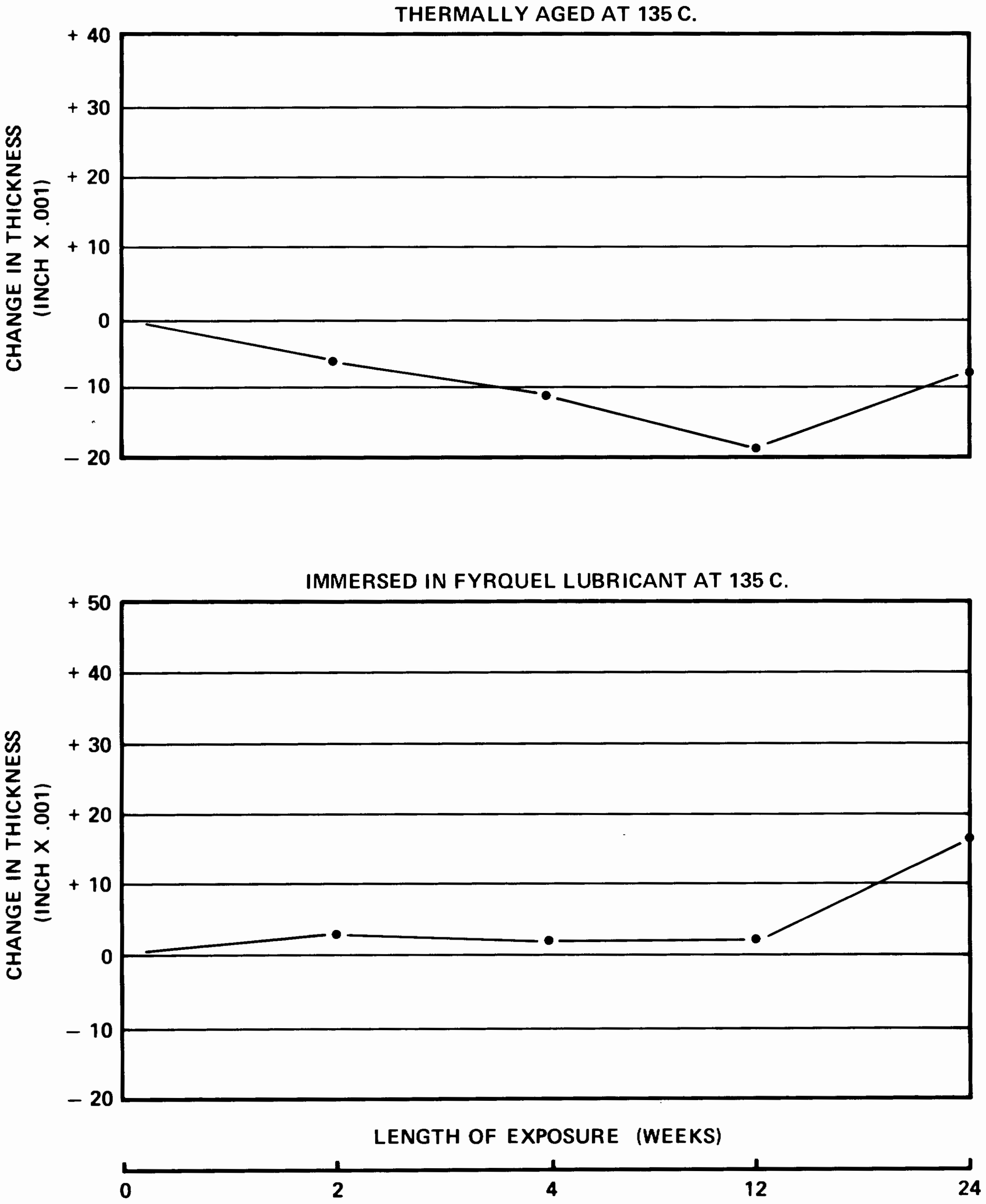
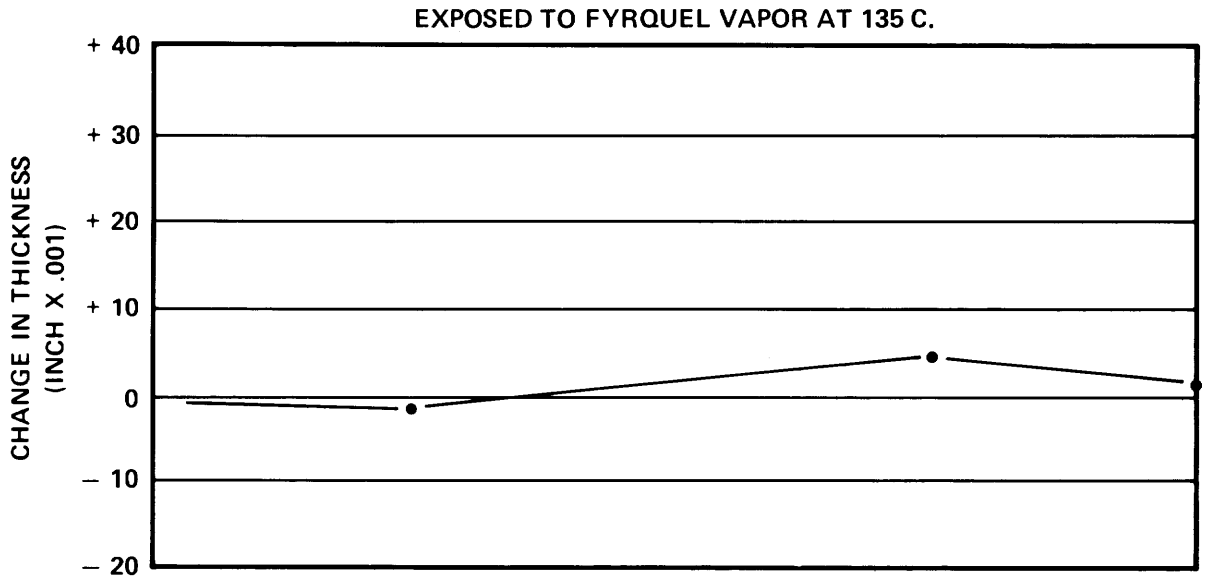
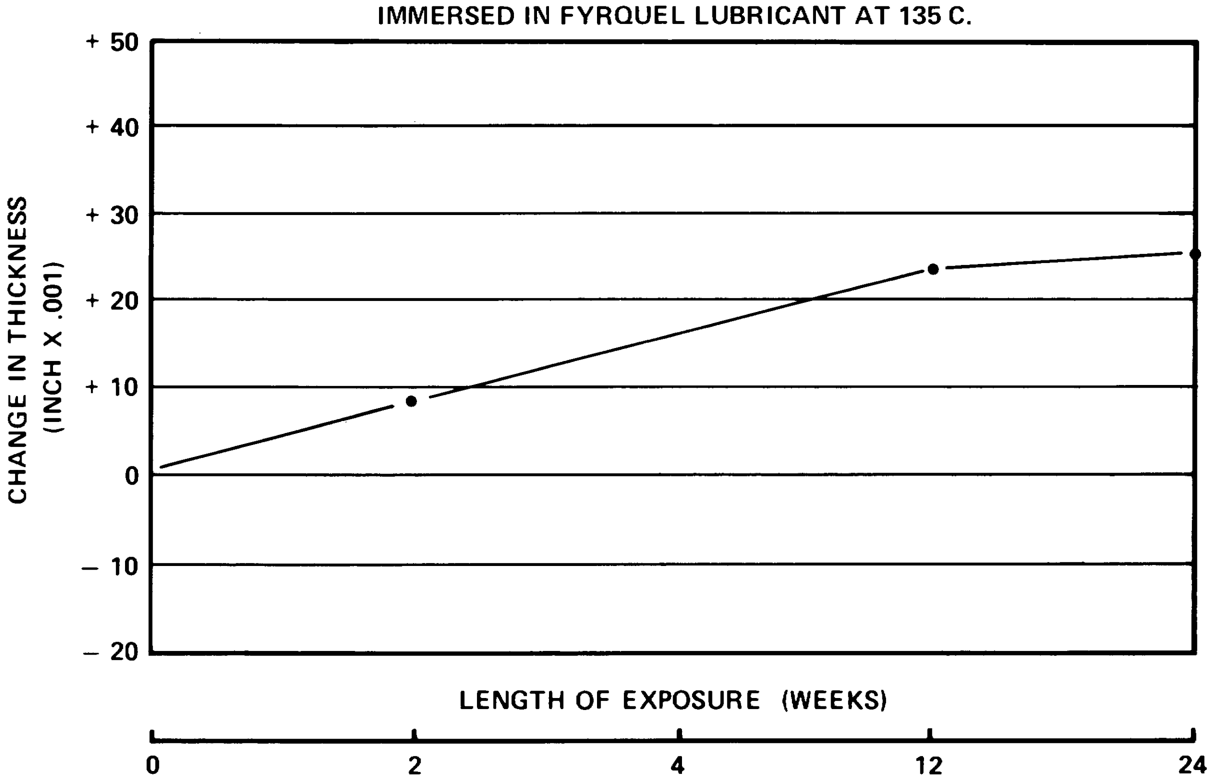


FIGURE 16.16 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED FOR 5 KV WITH MICA PAPER WRAPPER INSULATION IMPREGNATED IN LEWIS ACID ACTIVATED HIGH VISCOSITY EPOXY RESIN.

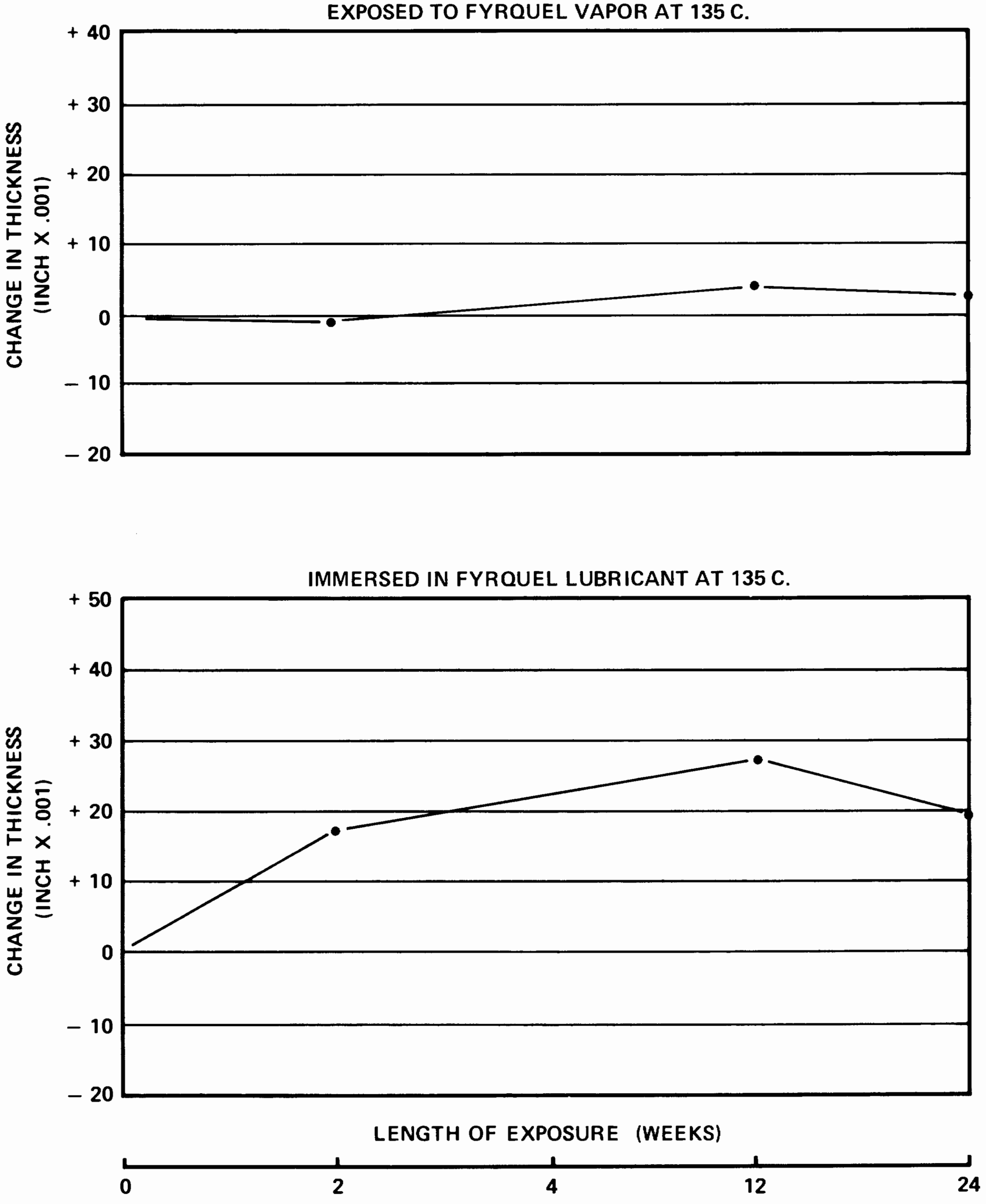


EXPOSED TO FYRQUEL VAPOR AT 135 C.



IMMERSED IN FYRQUEL LUBRICANT AT 135 C.

FIGURE 16.17 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED FOR 13.8 KV WITH CONTINUOUSLY TAPED MICA SPLITTINGS IMPREGNATED IN HIGH MONOMER CONTENT ANHYDRIDE EPOXY RESIN.


EXPOSED TO FYRQUEL VAPOR AT 135 C.

IMMERSED IN FYRQUEL LUBRICANT AT 135 C.

FIGURE 16.18 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED FOR 13.8 KV WITH CONTINUOUSLY TAPED MICA SPLITTINGS IMPREGNATED IN VINYL MONOMER MODIFIED ANHYDRIDE EPOXY RESIN.

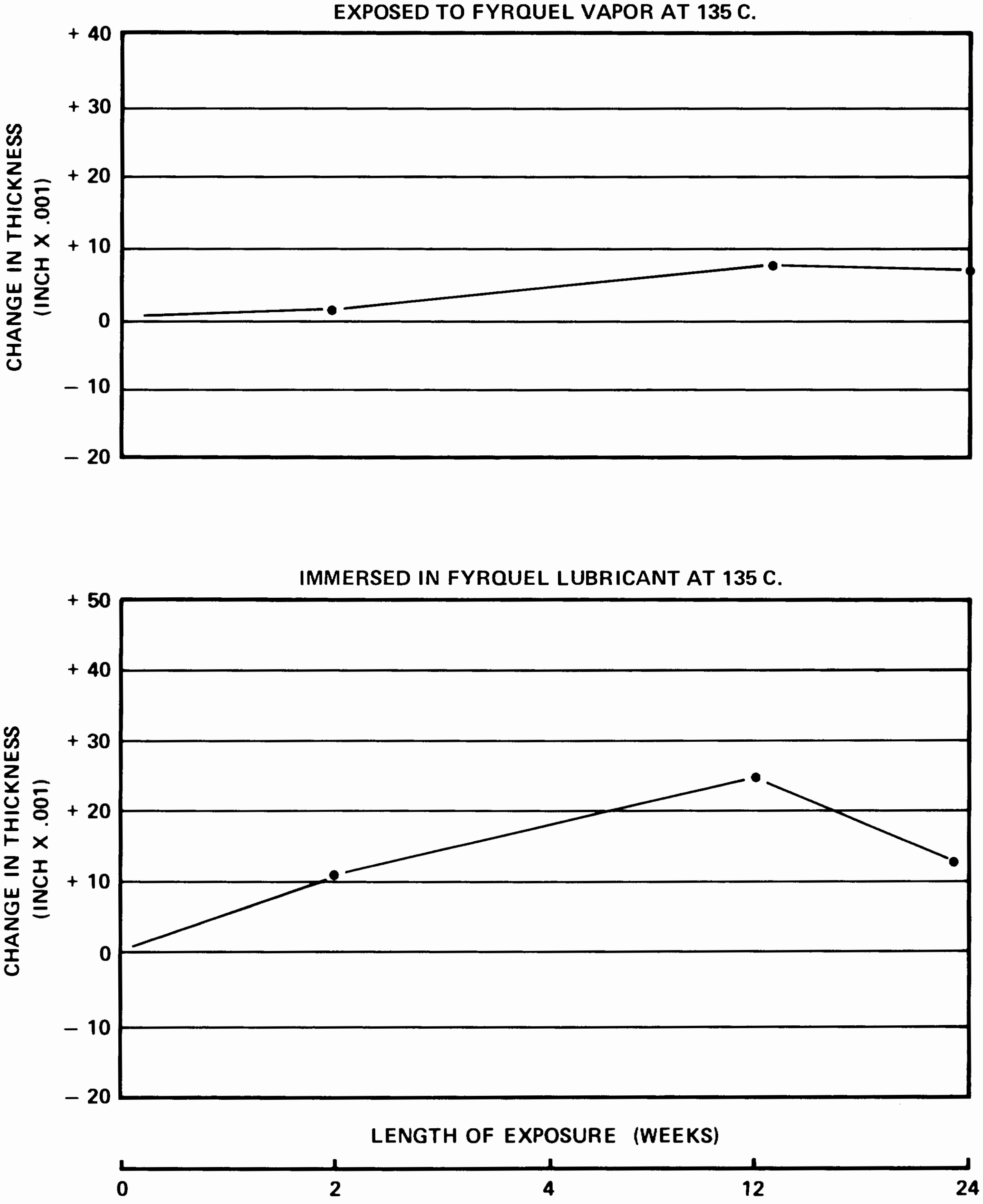


FIGURE 16.19 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED FOR 13.8 KV WITH CONTINUOUSLY TAPED MICA PAPER IMPREGNATED IN VINYL MONOMER ANHYDRIDE EPOXY RESIN.

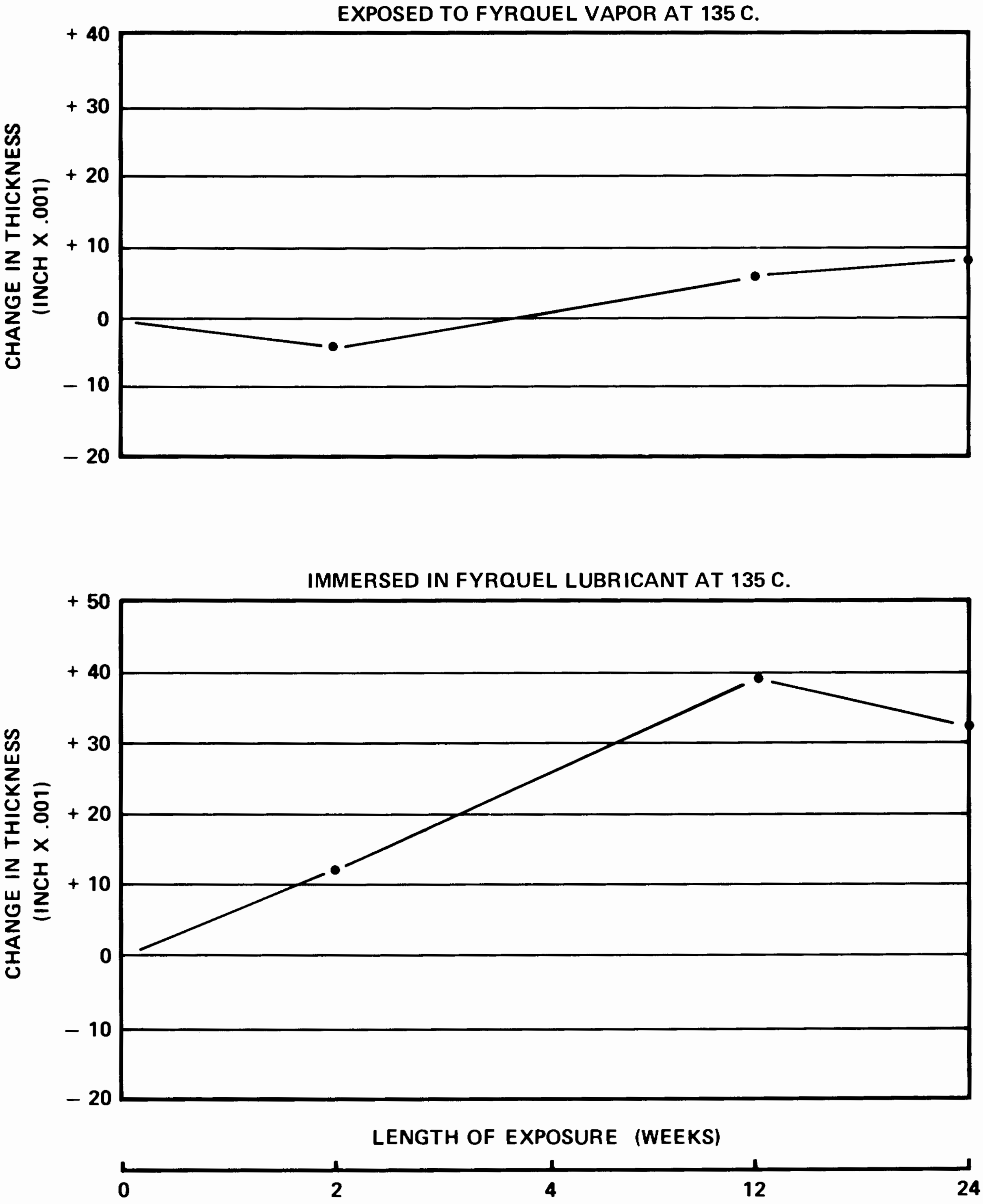
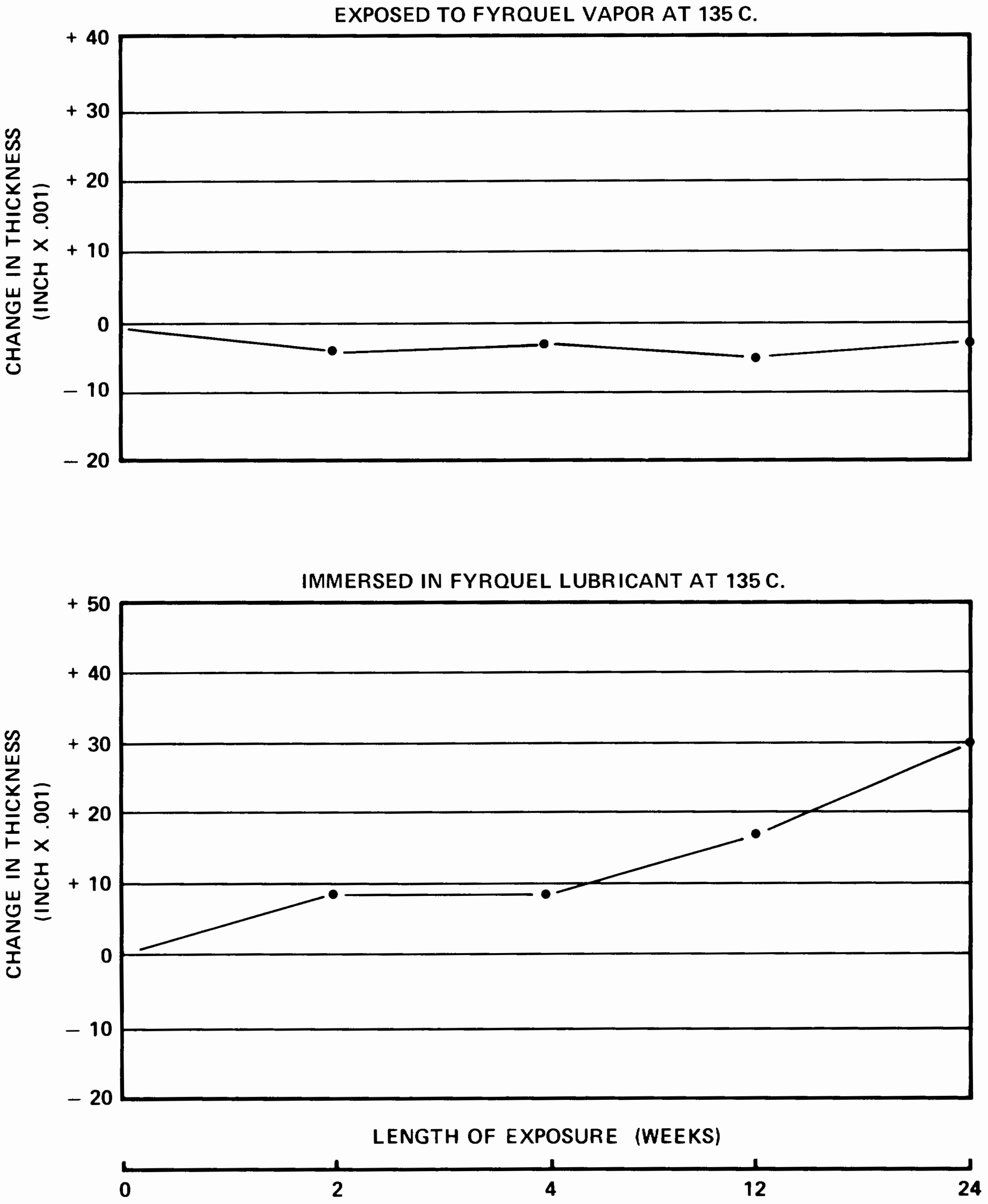


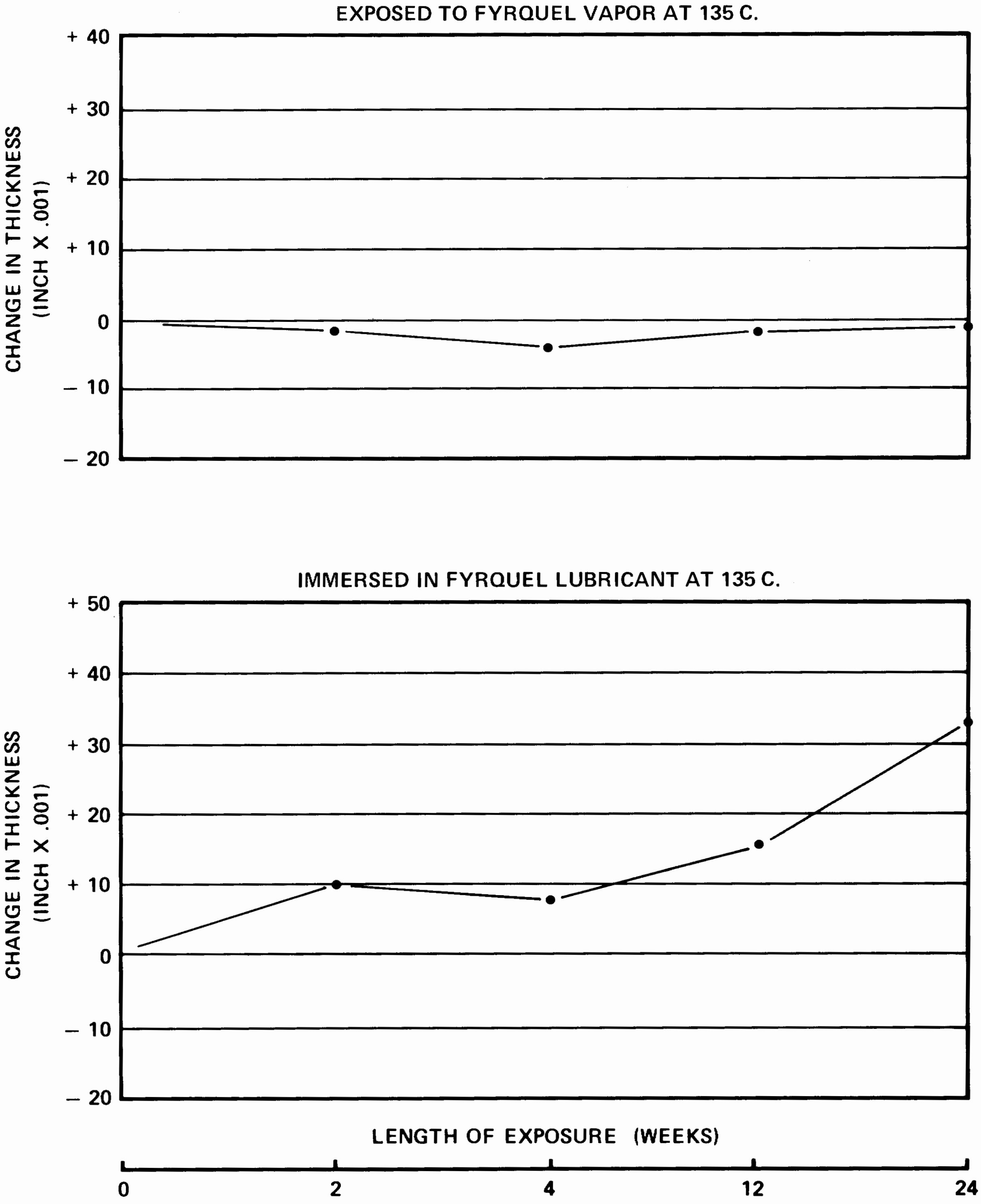
FIGURE 16.20 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED FOR 13.8 KV WITH CONTINUOUSLY TAPED MICA PAPER IMPREGNATED IN HIGH MONOMER CONTENT ANHYDRIDE EPOXY RESIN.



EXPOSED TO FYRQUEL VAPOR AT 135 C.

IMMERSED IN FYRQUEL LUBRICANT AT 135 C.

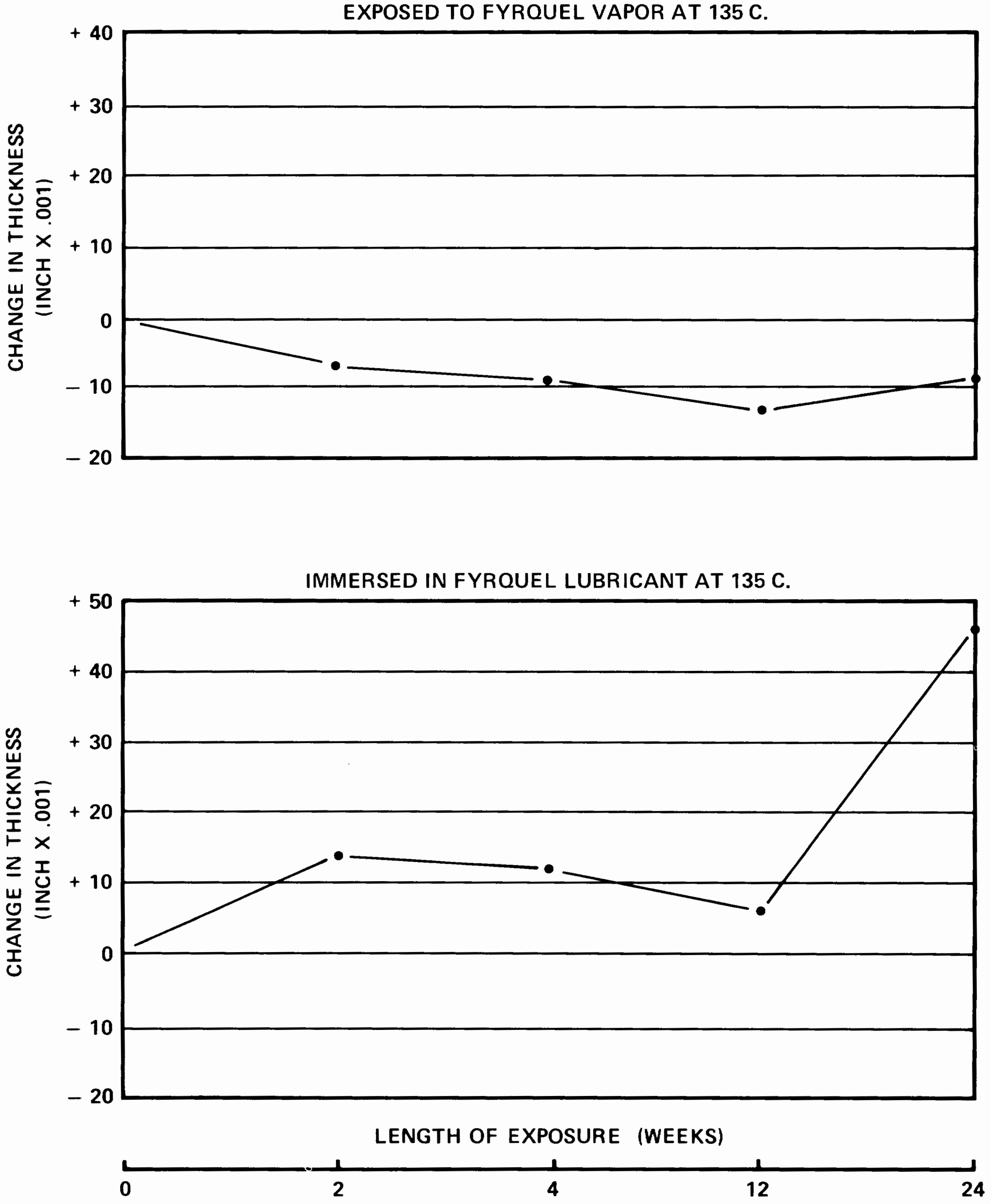
FIGURE 16.21 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED FOR 5 KV WITH MICA WRAPPER IMPREGNATED IN SOLVENTLESS POLYESTER RESIN.



EXPOSED TO FYRQUEL VAPOR AT 135 C.

IMMERSED IN FYRQUEL LUBRICANT AT 135 C.

FIGURE 16.22 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED FOR 5 KV WITH MICA PAPER END TAPING IMPREGNATED IN VINYL MONOMER MODIFIED ANHYDRIDE EPOXY RESIN.


EXPOSED TO FYRQUEL VAPOR AT 135 C.

IMMERSED IN FYRQUEL LUBRICANT AT 135 C.

FIGURE 16.23 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED WITH 5 KV MICA PAPER END TAPING BRUSHED WITH AMINE ACTIVATED EPOXY RESIN.

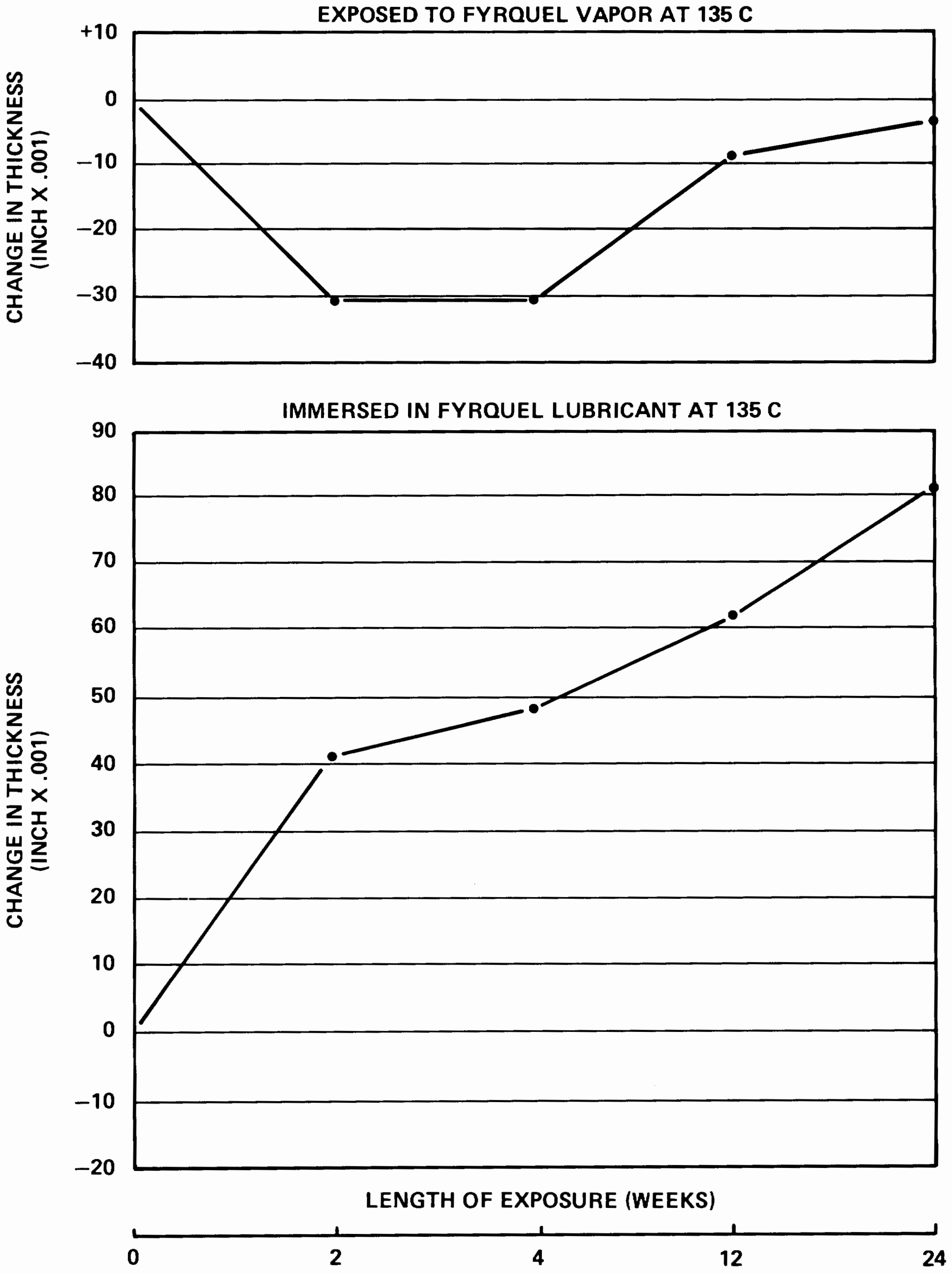
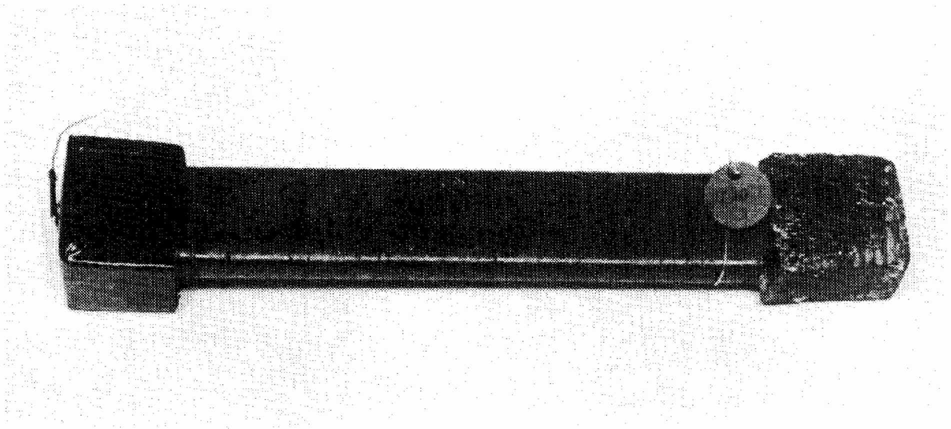
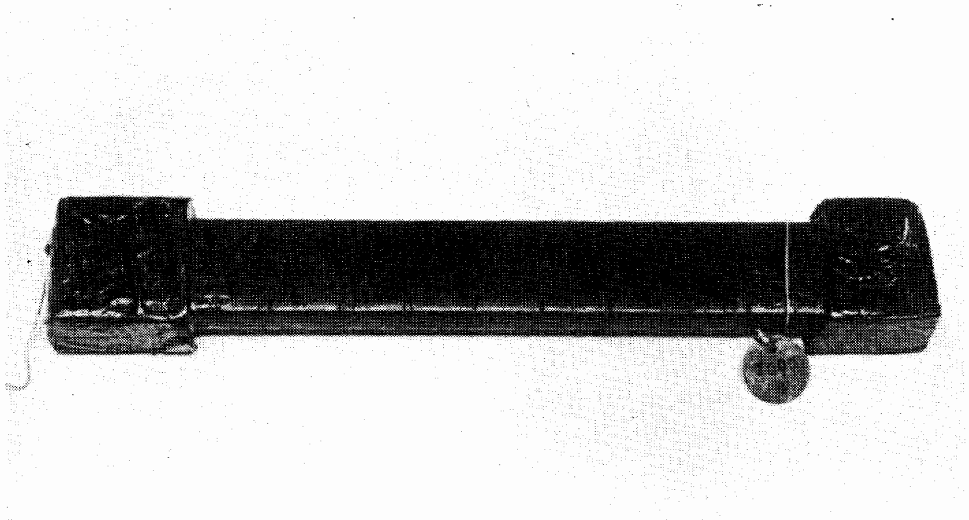


FIGURE 16.24 THICKNESS CHANGE AFTER EXPOSURE TO FYRQUEL GT TEST BARS INSULATED FOR 5 KV WITH OLEO RESINOUS VARNISHED GLASS-DACRON TAPE BRUSHED WITH AMINE ACTIVATED EPOXY RESIN

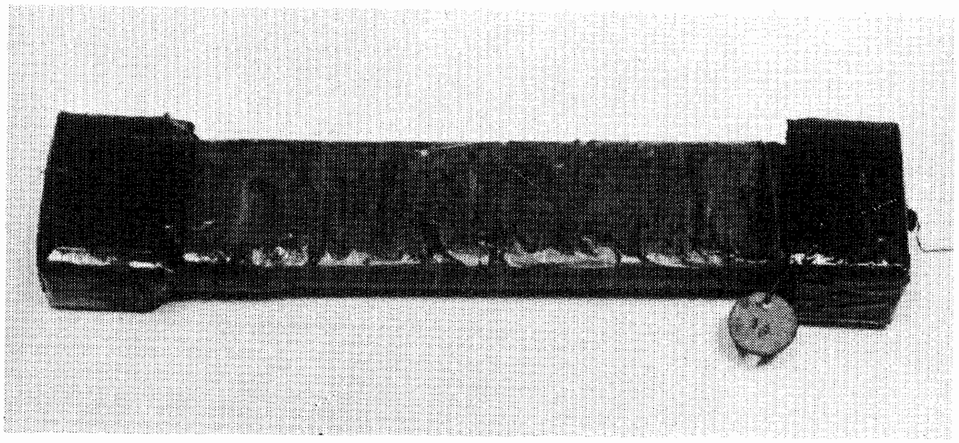


(a) EXPOSED TO FYRQUEL GT VAPOR AT 135°C FOR 24 WEEKS

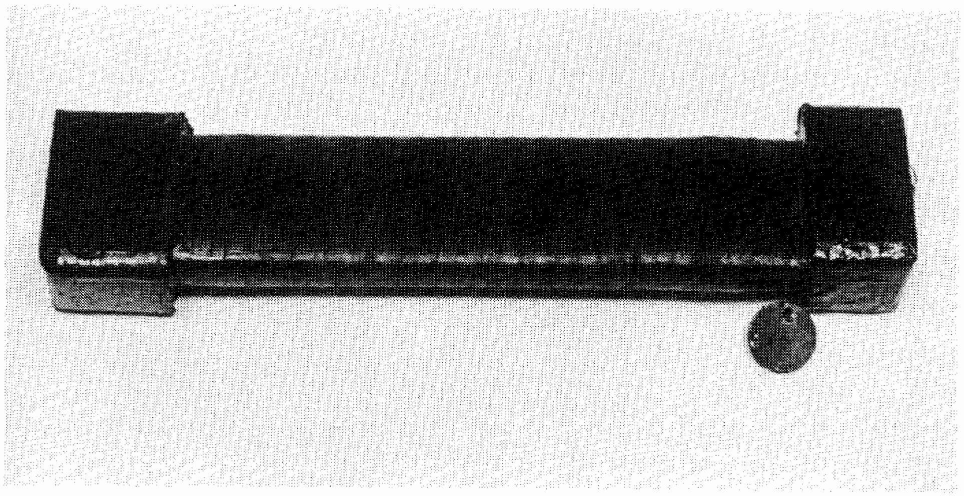


(b) IMMERSED IN FYRQUEL GT LUBRICANT AT 135°C FOR 24 WEEKS

FIGURE 16.25 MICA PAPER WRAPPER INSULATION IMPREGNATED IN VINYL MONOMER MODIFIED EPOXY RESIN

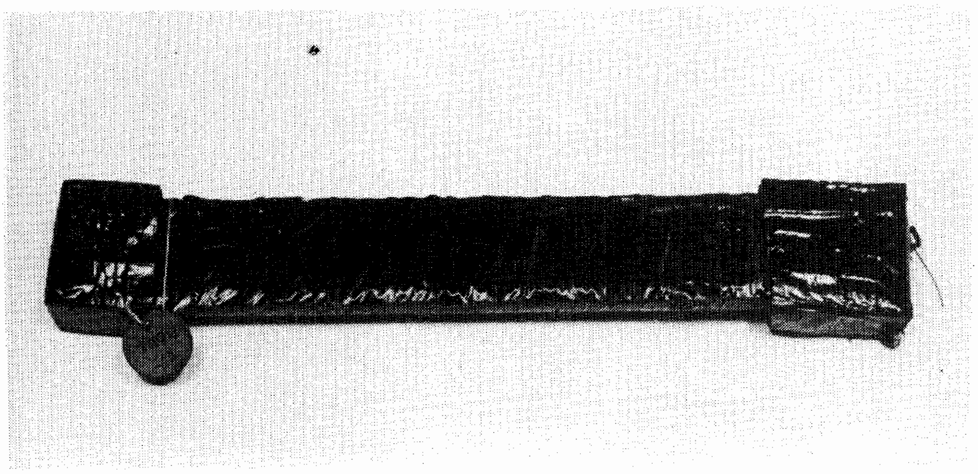


(a) EXPOSED TO FYRQUEL GT VAPOR AT 135°C FOR 24 WEEKS

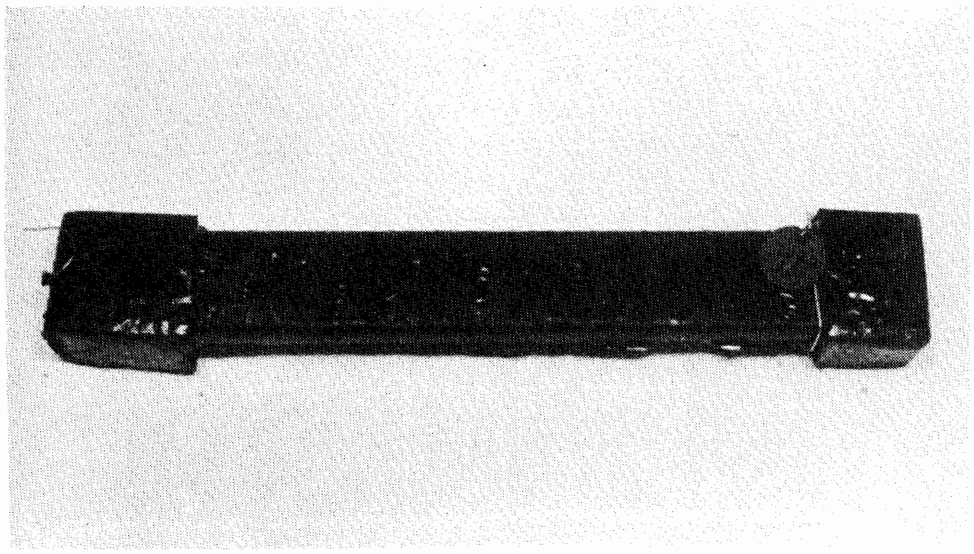


(b) IMMERSED IN FYRQUEL GT LUBRICANT AT 135° FOR 24 WEEKS

FIGURE 16.26 CONTINUOUSLY TAPED MICA PAPER INSULATION IMPREGNATED IN HIGH MONOMER CONTENT ANHYDRIDE EPOXY RESIN

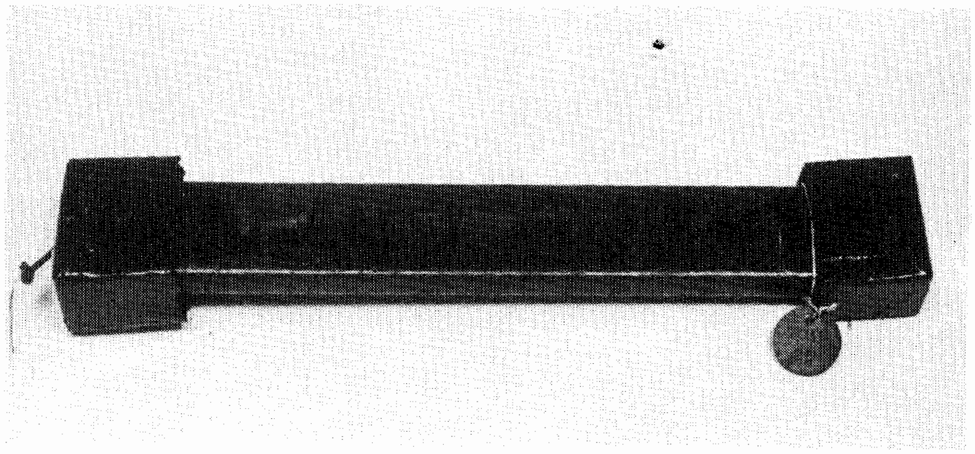


(a) EXPOSED TO FYRQUEL GT VAPOR AT 135°C FOR 24 WEEKS

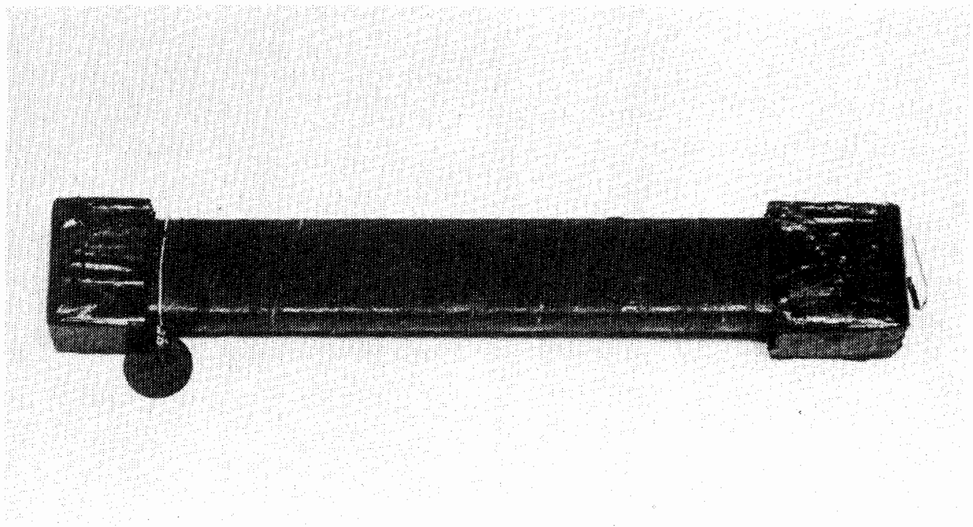


(b) IMMERSED IN FYRQUEL GT LUBRICANT AT 135°C FOR 24 WEEKS

FIGURE 16.27 MICA SPLITTINGS WRAPPER INSULATION IMPREGNATED IN LEWIS ACID ACTIVATED HIGH VISCOSITY EPOXY RESIN

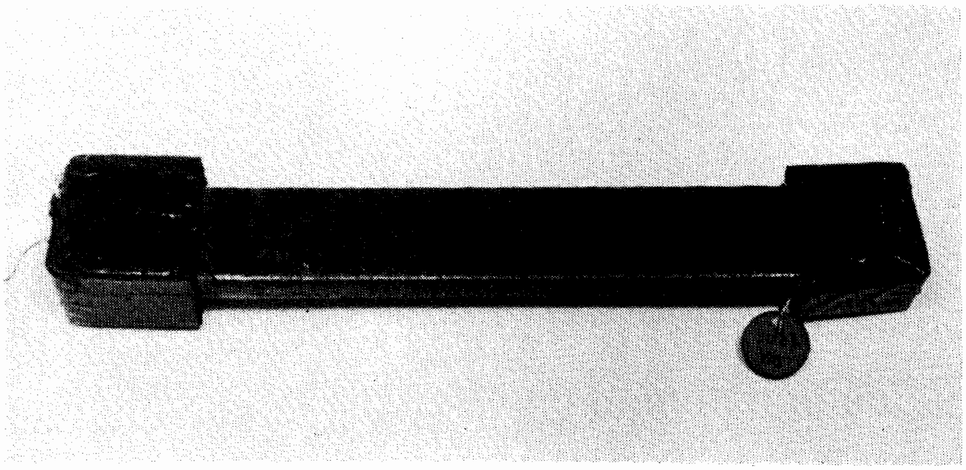


(a) EXPOSED TO FYRQUEL GT VAPOR AT 135°C FOR 24 WEEKS

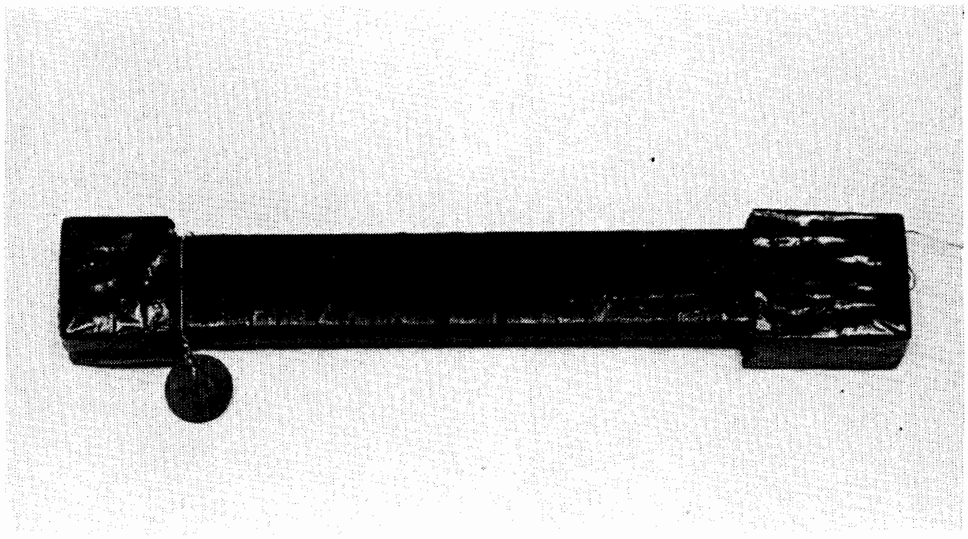


(b) IMMERSED IN FYRQUEL GT LUBRICANT AT 135°C FOR 24 WEEKS

FIGURE 16-28 MICA WRAPPER INSULATION IMPREGNATED IN SOLVENTLESS POLYESTER RESIN

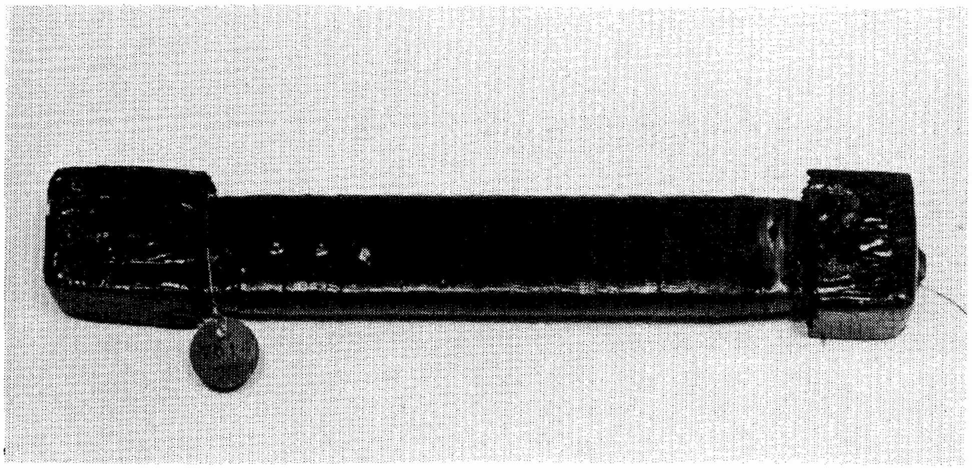


(a) EXPOSED TO FYRQUEL GT VAPOR AT 135°C FOR 24 WEEKS

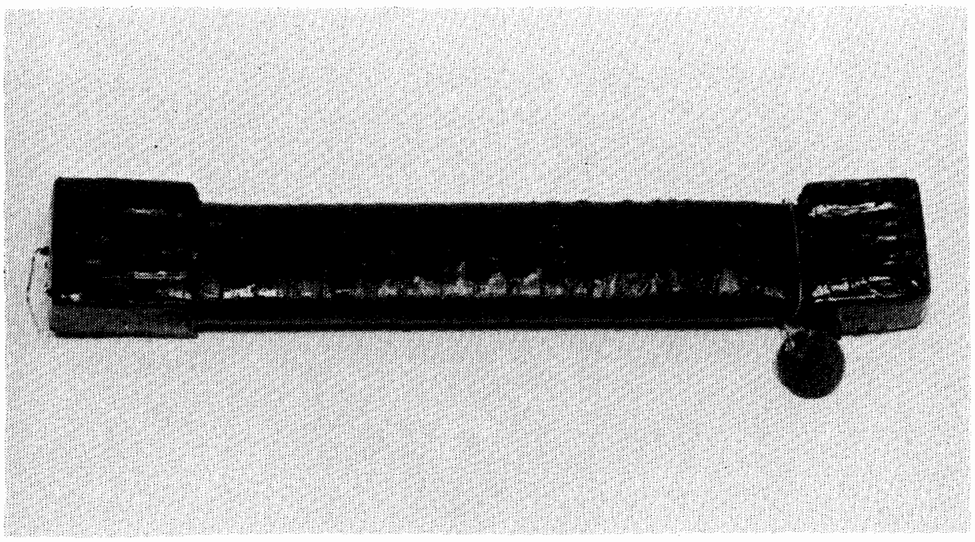


(b) IMMERSED IN FYRQUEL GT LUBRICANT AT 135°C FOR 24 WEEKS

FIGURE 16.29 MICA PAPER END TAPING IMPREGNATED IN VINYL MONOMER MODIFIED ANHYDRIDE EPOXY RESIN

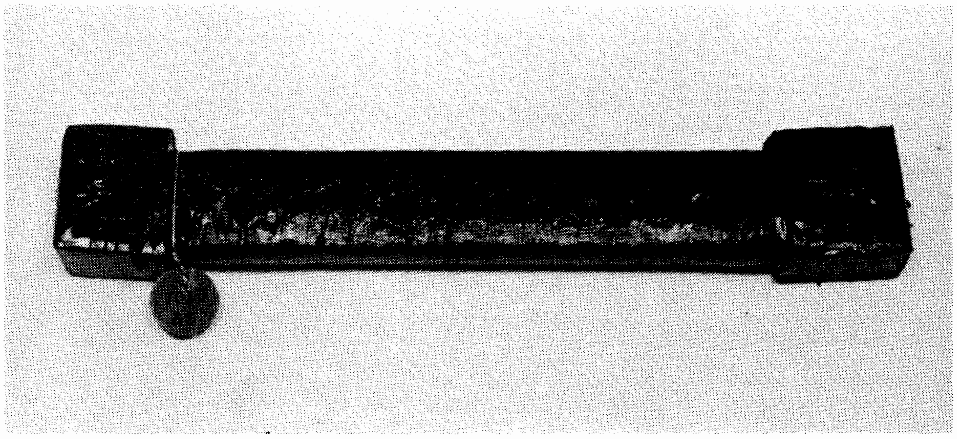


(a) EXPOSED TO FYRQUEL GT VAPOR AT 135°C FOR 24 WEEKS

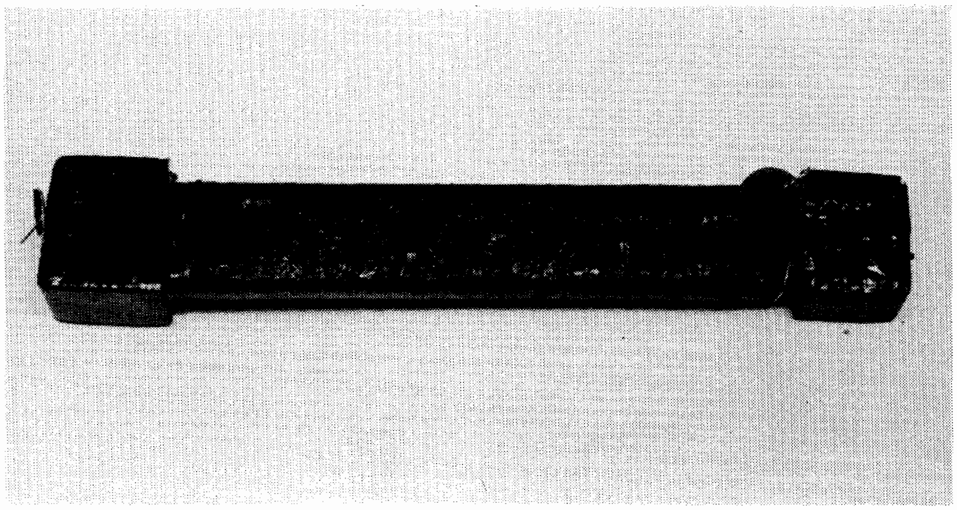


(b) IMMERSED IN FYRQUEL GT LUBRICANT AT 135°C FOR 24 WEEKS

FIGURE 16.30 OLEO RESINOUS VARNISHED GLASS-DACRON END TAPING BRUSHED WITH AMINE ACTIVATED EPOXY RESIN



(a) EXPOSED TO FYRQUEL GT VAPOR AT 135°C FOR 24 WEEKS



(b) IMMERSED IN FYRQUEL GT LUBRICANT AT 135°C FOR 24 WEEKS

FIGURE 16.31 MICA PAPER END TAPING BRUSHED WITH AMINE ACTIVATED EPOXY RESIN

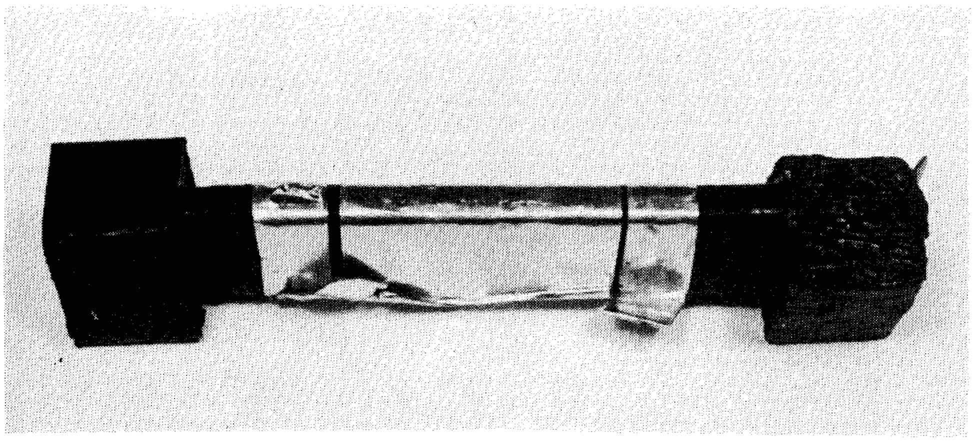


FIGURE 16.32 INSULATED BAR WITH POTTING DAMAGED, ALLOWING INGRESS OF LUBRICANT DURING FINAL IMMERSION PERIOD

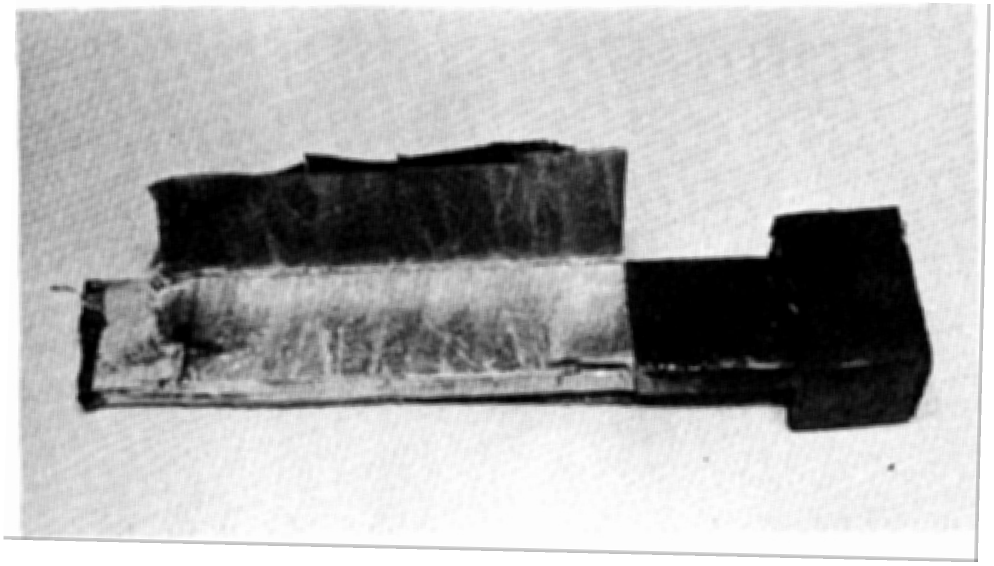


FIGURE 16.33 CUT-AWAY VIEW OF ABOVE COIL INSULATION SHOWING PENETRATION AND PROGRESSION OF LUBRICANT FROM THE DAMAGED END

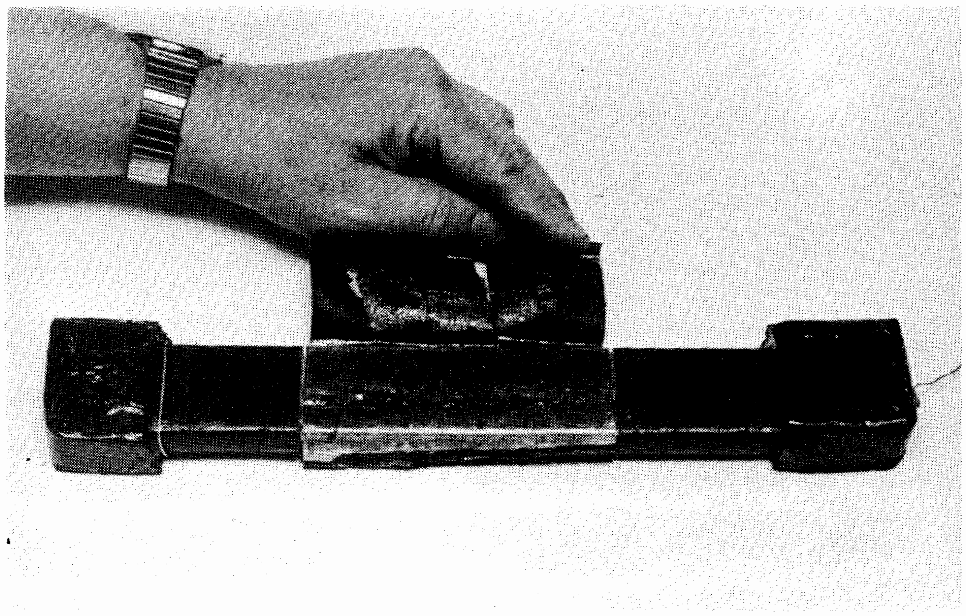


FIGURE 16.34 LUBRICANT PENETRATING OUTER BINDING TAPE AFTER 6 MONTHS' IMMERSION AND COLLECTING BETWEEN BINDER TAPE AND INSULATION BODY

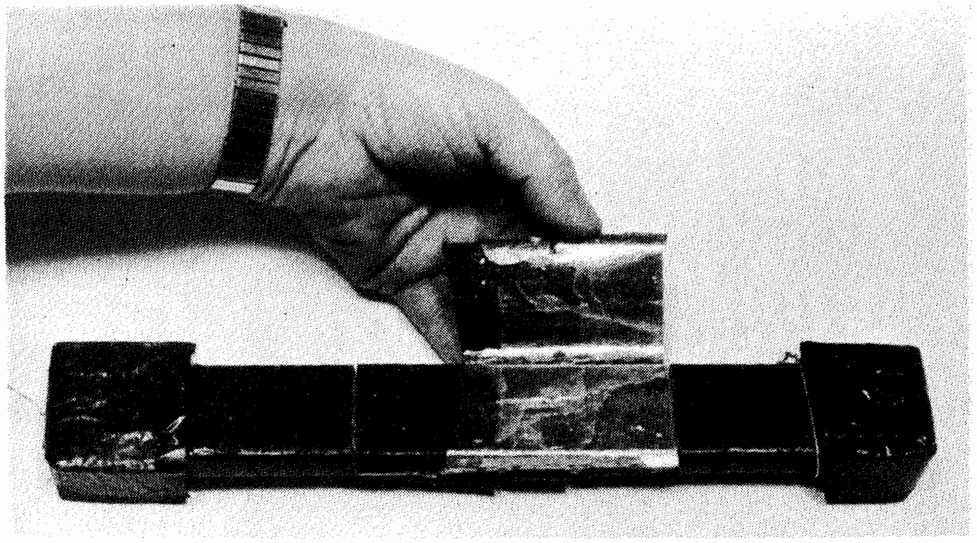


FIGURE 16.35 SAME TEST SPECIMEN AS ABOVE, WITH INSULATION SEPARATED BETWEEN MICA LAYERS, SHOWING NO PENETRATION OF LUBRICANT INTO THE INSULATION BODY

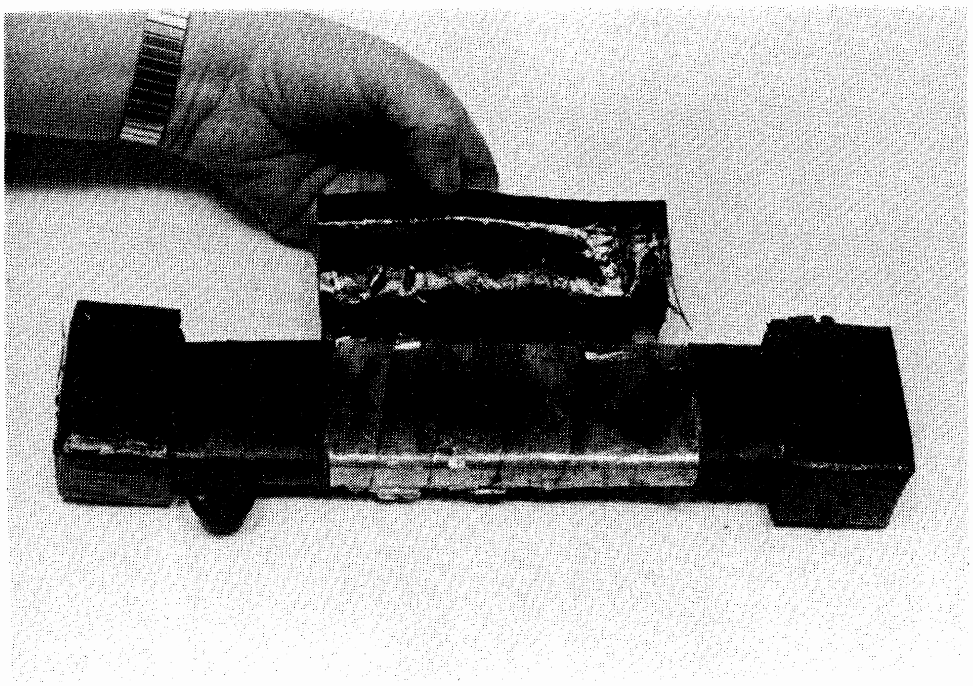


FIGURE 16.36 LUBRICANT SATURATING THROUGH GLASS OUTER BINDING TAPE AFTER 6 MONTHS' IMMERSION IN HOT LUBRICANT, TENDING TO PENETRATE ALONG THE TAPE EDGES OF CONTINUOUSLY TAPED INSULATION

SECTION 17.0

COMPATIBILITY TESTING OF CORONA SUPPRESSION SYSTEMS

17.0 COMPATIBILITY TESTING OF CORONA SUPPRESSION SYSTEMS

17.1 GENERAL

The phosphate esters attack most organic finishes. When fire resistant lubricants are used in motors, it is inevitable that some of the lubricant becomes airborne in the form of a mist or vapor and settles on the stator winding components. The winding finishes will be exposed in this peripheral manner to the lubricant, and the exposure will be intensified by the high operating temperatures of the stator. Of particular concern are the semiconducting varnishes, semiconducting binder tape, and stress gradient paints. Disintegration of these films would endanger the continuing dielectric integrity of the high voltage stator winding.

Anticorona devices are routinely employed to suppress surface discharges in stator windings of machines rated above 7 kV. Surface discharges occur in two specific areas: in the slots as a result of ionization of air spacings between coil surface and punchings, and at the ends of the slots where there is sudden transition from the conducting surface within the slot to a good insulating surface just beyond.

Due to irregularities inherent in assembling laminations to form a core, air spacings between the coil surface and the slot wall are inevitable. At normal operating voltages, the intensity of the electrical field which exists in these gaps exceeds the air breakdown voltage, and discharges occur. Standard practice is to short circuit the gaseous spaces by applying a semiconducting coating to the surfaces of the core portion of the coil. The specific resistance of this coating must be low enough so that the critical intensity of the electrical field is not reached at any point of a gaseous space. It must, however, be high enough not only to avoid short circuits between the core laminations, but to assure that the ohmic loss per unit of surface is below the level where carbonization of the coating will occur.

To insure the proper electrical contact between the coil surface and the slot laminations, a paint of relatively low film resistivity*, in the range of 10^3 to 10^4 ohms per square, is applied as one of the final steps in coil processing. The paint is usually carbon black suspended in an appropriate vehicle, or this paint may be processed into a tape and applied as an outer binding to the coil. This tape may be applied prior to the resin impregnation of the coil. For post impregnated windings it must be applied prior to impregnation, in which case some protection is provided by a thin layer of the impregnant.

The semiconducting paint or binder extends a short distance beyond the slot. To prevent corona discharges because of the very high voltage gradient that exists at the edge of the conducting paint or binder, it is necessary to grade the stress with a high resistivity coating. Commonly used are silicon carbide paints with resistivities in the range of 3000 to 7000 megohms per square. These coatings overlap the terminus of the semiconducting coating and continue onto the surface of the end turn insulation.

In order to suppress corona, the resistivity of the grading coating must be sufficiently low so as to effect a reduction of the electric field at the junction between the high resistance coating and the semiconducting paint. At the same time its resistivity must be sufficiently high that the voltage gradient at the other end of the coating is lower than the corona starting gradient. If resistivity is too high, the gradient paint will act as an insulator and there will be a high electric field at the junction of gradient paint and semiconducting paint which will cause corona in the latter. If resistivity is too low, the gradient paint will behave like a conductor and not drop the voltage sufficiently, causing corona at the edge of the gradient paint extension.

Stress grading and semiconducting coatings applied to high voltage windings not only must have characteristics initially that will enable them to perform the task of corona elimination, but these characteristics must also be suffi-

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* See Section 17.2 for a discussion of film resistivity.

ciently stable so that they will continue to perform satisfactorily over long periods of time.

17.2 FILM RESISTIVITY

Film resistivity, as used in this report, is expressed as "ohms (or megohms) per square." It is the resistance of a square film as measured between two strip electrodes which extend the full width of two opposite edges of the film. The following familiar relationship applies:

$R = \rho \frac{\ell}{A} = \rho \frac{\ell}{wt}$ where

R = resistance of film between electrodes (in ohms).

ρ = volume resistivity of the film material (in ohm-inches).

ℓ = length of the rectangular film between electrodes (in inches).

w = distance along one edge of the film where the strip electrode makes continuous contact (in inches).

t = thickness of the film (in inches).

For a square film:

$\ell = w$

$R = \rho \frac{\ell}{\ell t} = \frac{\rho}{t}$

This shows that film resistivity is independent of the size of the square. The units are actually "ohms" or "meghoms" for any particular film. The terms "ohms per square" or "megohms per square" merely indicate the shape of the film used in the measurement of film resistivity.

17.3 TEST PROCEDURE

Insulation specimens, duplicating 13,800 volt mica/solventless epoxy vacuum pressure impregnated systems, were prepared on 0.5" x 2" x 12" aluminum test bars and coated with high resistance stress grading paints, or low resistance conducting paints or binder, as follows:

- Group A -- Bars were insulated with mica tape, impregnated in a solventless low viscosity vinyl monomer modified anhydride epoxy resin and heat cured. Two bands of copper foil, separated by 3 inches and spaced equidistantly from the midpoint of the bar, were applied circumferentially around the coil. Thin copper wire leads were soldered to each band. A stress grading paint, whose essential components are silicon carbide and a phenolic varnish vehicle, was applied between the bands and overlapping the bands approximately 0.5 inches; the coating was allowed to air dry, and was heat cured. Figure 17.2 shows a typical test specimen.
- Group B -- Bars were processed same as Group A. Two coats of modified epoxy varnish were applied and heat cured after each coat.
- Group C -- Bars were taped with continuous layers of mica tape and a fiber glass outer binding tape. Copper foil bands with leads were assembled same as above. A stress grading paint, same as used in Groups A and B except with modified vehicle, was applied between the bands and overlapping the bands approximately 0.5 inch. The bars were impregnated twice in a version of the above resin having a lower ratio of vinyl monomer, and heat cured.
- Group D -- Bars were processed same as Group C. Two coats of modified epoxy varnish were applied and heat cured after each coat.
- Group E -- Bars were insulated with mica tape, impregnated in a solventless low viscosity vinyl monomer modified anhydride epoxy resin and heat cured. A semiconducting paint, which may be characterized as a carbon particle loaded vinyl toluene modified alkyd varnish, was painted over the center 8 inches of insulated bar length, Figure 17.1. Two bands of copper foil, separated by 6 inches and spaced equidistantly from the midpoint of the bar, were applied circumferentially around the coil. Thin copper leads were soldered to each band. A strip of conducting paint was applied to overlap the copper foil and the existing conducting paint. Bars were air dried and heat cured.
- Group F -- Bars were processed same as Group E. Two coats of modified epoxy varnish were applied and heat cured after each coat.
- Group G -- Bars were insulated, impregnated and cured same as Group E. A half lapped binder of fiber glass tape treated in carbon parti-

cle loaded phenolic alkyd varnish was spiralled around the center 8 inch portion of the bar. Foil electrodes were applied over the semiconducting binder, spaced 6 inches apart. Two coats of modified epoxy varnish were applied and heat cured after each coat.

- Group H -- Bars were taped with continuous layers of mica tape. Copper foil bands with leads were assembled same as Group E. Between the bands of copper foil and overlapping the copper foil, a half lapped binder of the semiconducting tape of Group G was applied. The bars were impregnated twice in the low vinyl monomer content version of the epoxy resin, and heat cured.
- Group J -- Bars were processed same as Group H. Two coats of modified epoxy varnish were applied and heat cured after each coat.

These groups are summarized in Table 17.1.

Groups of three test bars of each variation were immersed in the Fyrquel GT lubricant and sealed in a gas tight aluminum container which was placed in an oven with the temperature maintained at 135^{O}C.

A duplicate number of test bars were subjected to exposure to the vapors of the lubricant at 135^{O}C. An environmental chamber was utilized for this purpose. Vapor was provided by a fan blowing through wicking material which dipped into an open pan of the lubricant.

For both the liquid mode and the vapor mode exposures, temperatures were maintained at 135^{O}C. This temperature was selected to accommodate the maximum coil insulation surface temperature for Class F (155^{O}C hot-spot) stator windings. For Class B windings, this represents a temperature acceleration.

Since thermal aging changes the resistivity characteristics of conducting coatings, duplicate test specimens were aged in a 135^{O}C oven to serve as controls.

Resistance measurements were made as follows:

- For stress grading paints, a dc voltage between the electrode spacing of 3 inches was applied starting at zero and increasing slowly until a current density of 2 microamperes per inch of coating perimeter was reached.

- For semiconducting paints, dc resistance between the electrode spacing of six inches was measured with an ohmmeter.
- At the end of exposures of 1 week, 4 weeks, 12 weeks, and 24 weeks, test specimens were removed, cooled to room temperature, and remeasured.

17.4 TEST RESULTS FOR STRESS GRADING COATINGS

The stress grading (high resistance) coatings appear particularly vulnerable to attack from exposure to Fyrquel GT, possibly because of their poor cohesive and adhesive properties. After one week immersion, all stress grading films of whatever system were attacked to the extent that they were no longer functional.

Stress grading paint applied over preimpregnated insulation (Group A) was the most physically deteriorated. Softening and dissolution of the coating into the lubricant was pronounced. The coating on one bar was completely washed, as shown on the photograph of Figure 17.3(a). Coatings on the other two bars were partially washed; what remained was solvated to the extent that it could be wiped off with a cloth.

Where this same construction was protected with two applications of a modified epoxy heat curing varnish (Group B), the coating was physically less deteriorated by only a slight degree. The protective varnish was completely stripped, and the condition of the coating was similar to that of Group A but less pronounced. (Figure 17.4(a)).

Where the gradient coating was applied prior to impregnating the bar, simulating a post impregnated insulation (Group C), the coating remained reasonably intact physically (Figure 17.5(a)). For the group of bars processed in this manner and overcoated twice with modified epoxy varnish (Group D), the varnish coating was integral, with some leaching evident, affording some additional protection to the stress grading coating (Figure 17.6(a)). The epoxy varnish film on the post impregnation simulated samples, although easily wiped off, was not stripped away in the manner of the varnish film on the preimpregnated specimens. The post impregnation must provide a more satisfactory substrate resulting in better adhesion between it and the varnish, as compared to the adhesion between the varnish and the gradient paint of the preinsulated sample and between the gradient paint and the insulated surface of the preinsulated sample.

For the high resistance coating combinations, the most vulnerable system is Group A (gradient paint over preimpregnated coil insulation), followed very closely by Group B (the same system with protective varnish films). Considerable improvement in physical integrity is attained with the post impregnated specimen, Group C; and a lengthening of the survival of Group C is achieved with overcoatings of varnish, Group D.

The same hierarchy is obtained for the vapor exposed specimens. Increase in resistance on those bars exposed to vapor compared to increase on control samples is greatest when the grading paint is applied over preimpregnated insulation (Table 17.2). The degradation of the above system is considerably retarded with the application of two protective layers of modified epoxy varnish (Table 17.3). Change in resistivity of the post impregnated system (Table 17.4) compared to change in resistivity of control samples appear to be of a smaller order than the previous two systems discussed. (See Table 17.5 for data on control samples.) The added protection of two layers of varnish to the post impregnated specimens (Table 17.5) does not reveal improved protection.

17.5 TEST RESULTS FOR SEMICONDUCTING SURFACE COATINGS

The experience with semiconducting media for the coil slot sections (Figure 17.7) parallel that of the stress grading paint. Semiconducting paint over preimpregnated insulation was destroyed in effectiveness after 1 week's immersion (Table 17.6). The paint was softened and either was completely washed or could be wiped off easily with a cloth (Figure 17.8a). Protected with two coats of varnish, conductivity of the semiconducting film was also destroyed (Table 17.7). The varnish was stripped away, and the physical condition of the conducting coating was the same as above only somewhat less disintegrated (Figure 17.9a).

Where a semiconducting tape was applied over preimpregnated insulation and overcoated with two layers of epoxy varnish (Table 17.8), the varnish film was still present after 1 week's immersion, but some leaching was evident, as was some leaching of the carbon particles and vehicle of the tape (Figure 17.10).

The same semiconducting tape applied over unimpregnated insulation and then impregnated, simulating post impregnated insulation (Table 17.9), was an improvement over the previous system. The resistance readings had increased by two orders, but were still readable. After the second immersion period, resistance was in the megohm range, and vehicle and conducting particles had leached out of the tape (Figure 17.11(a)). This same system protected with two layers of modified epoxy varnish (Table 17.10) maintained a lower resistivity characteristic. After the second immersion period, the varnish film, though darkened, was reasonably intact (Figure 17.12(a)).

Assessment of degradation of semiconducting coatings followed the same order as the degradation experienced with total immersion. The greatest relative change, i.e., comparison of change of resistivity of the vapor exposed samples to change in resistivity of thermally aged control samples, is evidenced by Group E, semiconducting paint applied over preimpregnated insulation (Table 17.6). Using a varnish overcoating, Group F, indicates some protection (Table 17.7). Semiconducting tape applied over preimpregnated insulation (Table 17.8) may be deteriorating at a more moderate rate than conducting paint film applied over the insulation surface (Table 17.7), but the data do not clearly indicate this. The semiconducting tape as part of the post impregnation system, without additional varnish protection, Group H, (Table 17.9), is changing at a slower rate than the same tape applied over cured insulation and protected with two coats of epoxy varnish, Group G, (Table 17.9). Post impregnation with two overcoats of varnish, Group J, provides the most moderate change in resistivity of the semiconducting medium, with increase due to deterioration balancing decrease due to thermal aging (Table 17.10).

17.6 TEST SUMMARY AT CONCLUSION OF 6 MONTH PROGRAM

The data obtained during the six month testing program pointed toward the acceptability of the coatings for use under normal conditions, but the evidence was not conclusive. Further exposure beyond the six month period would provide the required assurances of coating functionality.

Functionality of all the corona suppressive media is rapidly destroyed when they are immersed in fire retardant lubricant Fyrquel GT maintained at a temperature of $135^{o}C$. Solvation and/or softening of the stress grading coatings, semiconducting coatings, and semiconducting tape are pronounced after immersion of one week.

Post impregnation processing provides some extension of the life of the coatings and tape, both when they are immersed in the lubricant and when they are exposed to the lubricant vapor.

Varnish coatings offer from little to no protection under conditions of severe exposure since they themselves are attacked by the lubricant. They do, however, provide a degree of protection under conditions of moderate exposure, serving to lengthen the useful life of the grading system. (Compare Table 17.3 to Table 17.2.)

The degree of protection appears to be a function of varnish adhesion. It is greater for post impregnated insulation where there is good adhesion to the substrate, in comparison to the weak adhesion between the varnish and the conducting paint of the preimpregnated coil or between the conducting paint and the smoothly pressed coil surface of the preimpregnated coil.

The degree of deterioration of films and tape is considerably mitigated when they are exposed only to the vapors of the lubricant. Minimum deterioration is noticeable visually, and resistivity measurements are comfortably within acceptable range. (See Figures 17.3(b) through 17.6(b) and Figures 17.8(b) through 17.12(b).)

17.7 EXTENSION OF TEST PERIOD FOR CORONA RESISTANT COATINGS

Both the semiconducting media and the voltage grading coatings have wide ranges of resistivity over which they remain functional. The practice is to select coatings and extensions to operate at only a fraction of their limiting value. Semiconducting paints decrease in resistivity with thermal aging, and this continues for a long period of time. The degrading influence of the fire resistant lubricant results in an increase in resistivity. A 50-fold increase in the resistivity of the semiconducting film would not render it ineffectual.

In designing the resistance characteristics of stress grading coatings, their behavior during production and maintenance tests is taken into account, as well as behavior during initial service and behavior after prolonged service aging. The span of conditions during service is difficult to evaluate, since resistivity decreases from the prolonged heat of machine operation and increases from the combined effects of high voltage and humidity. Since the effect of exposure to the fire resistant lubricant is to increase the resistivity of the coating, the concern here is with the upper limit of the usable resistance range.

The upper limit to which the resistance of the stress grading paint may ultimately rise is determined by the corona starting voltage on the surface of the stress grading film. The choice of resistance of the film is based upon this value's not being exceeded during testing of the coils during production. Since coil test voltages are nearly five times the phase to ground voltage in service, there is a wide safety margin for allowable increase in resistivity through service degradation.

Concern for the effect of fire resistant lubricants on stress grading coatings (and semiconducting coatings as well) may not be so much a concern about the amount of increase in resistivity, but concern about the fact that resistivity is increasing. Thermal aging causes a drop in the resistances, probably due to shrinkage of the resins, resulting in more intimate electrical association of the conducting particles. Decrease, therefore, provides assurance of sustained electrical continuity of the coatings. Increase in resistivity suggests dissociation of conducting particles which may presage breaks in continuity and resultant danger of local discharges.

The six month data on coil corona resistant media indicated a pronounced leveling off of the effects of the fluid vapors. In general, all systems were tending to decrease in resistivity in line with the control samples which had been aged in air at 135^{o}C. While these data were encouraging, they were not conclusive assurance that stability had been achieved. It was felt that the length of exposure to vapor before the films exceeded the wide limits of permissible resistivity could not be anticipated at that stage. The rate at which deterioration proceeded with continued exposure to the lubricant vapor, whether it moderated or intensified, would be a strong determinant in evaluating whether desired corona suppression characteristics could be maintained under operating conditions over a reasonable machine life.

17.8 FINAL TESTING AND SUMMARY

The test specimens were exposed to the lubricant vapor for an additional 12 weeks. Tables 17.11 through 17.19 superimpose onto existing charts the data of 36 weeks' exposure to the Fyrquel vapor. The major significance of these extended aging data is that a leveling off of the effects of the fluid vapors had occurred and the influence of the thermal aging was dominating. This provides assurance that progressive deterioration of the corona suppressing media, to the extent that they become non-functional, will not occur under service conditions of the motor.

TABLE 17.1

Description of Corona Suppressing Coatings and Tapes Tested After Exposure to FYRQUEL GT Lubricant

Group Designation	Function	Description	Processing Details
A	Stress Grading at Slot Exits	Silicon Carbide in phenolic varnish vehicle	1. Applied over impregnated and cured insulation.
B	"	"	1. Applied over impregnated and cured insulation. 2. Overcoated twice with heat cured modified epoxy varnish.
C.	"	Silicon Carbide in modified phenolic varnish vehicle	1. Applied to "dry" (unimpregnated) coil insulation. 2. After application of the coating, the bar was impregnated in solventless epoxy resin.
D.	"	"	1. Applied to "dry" (unimpregnated) coil insulation. 2. After application of the coating the bar was impregnated in solventless epoxy resin. 3. Overcoated twice with heat cured modified epoxy varnish.
E.	Low resistance paint for coil slot sections	Carbon particle loaded vinyl toluene modified alkyd varnish	1. Applied over impregnated and cured insulation.
F.	"	"	1. Applied over impregnated and cured insulation. 2. Overcoated twice with heat cured modified epoxy varnish.
G	Low resistance outer binding tape for coil slot sections	Fiber Glass tape treated in carbon particle loaded phenolic alkyd varnish	1. Applied over impregnated and cured insulation. 2. Overcoated twice with heat cured modified epoxy varnish.
H	"	"	1. Taped over "dry" (unimpregnated) insulation. 2. After application of the conducting tape, the bar was impregnated in solventless epoxy resin.
J	"	"	1. Taped over "dry" (unimpregnated) insulation. 2. After application of the semiconducting tape, the bar was impregnated in solventless epoxy resin. 3. Overcoated twice with heat cured modified epoxy varnish.

TABLE 17.2

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON STRESS GRADING COATING APPLIED OVER IMPREGNATED INSULATION

	Specimen Iden.	MEGOHMS PER SQUARE				
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	3975	3925	3525	3450	1750
	2	3525	3825	-	-	1900
	3	3600	3825	3525	3225	2900
Immersed in Lubricant Maintained At 135C.	4	3450	>7000	-	-	-
	5	3825	>7000	-	-	-
	6	3325	>7000	-	-	-
Exposed To Vapors In Chamber Maintained At 135C.	7	4125	4750	4425	4425	3775
	8	3825	4425	4425	4525	3825
	9	3525	4425	4350	4125	3150

TABLE 17.3

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON STRESS GRADING COATING APPLIED OVER IMPREGNATED INSULATION, OVERCOATED WITH EPOXY VARNISH

	Specimen Iden.	MEGOHMS PER SQUARE				
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	3125	2475	2600	2675	1900
	2	2900	2450	2600	2600	1900
	3	2675	2300	2525	2600	1875
Immersed in Lubricant Maintained At 135C.	4	2900	>7000	-	-	-
	5	2975	>7000	-	-	-
	6	2675	>7000	-	-	-
Exposed To Vapors In Chamber Maintained At 135C.	7	2900	2525	2750	2900	2900
	8	2900	2850	2675	2825	2075
	9	3050	2825	2675	2825	2900

TABLE 17.4

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON STRESS GRADING COATING APPLIED PRIOR TO IMPREGNATION

	Specimen Iden.	MEGOHMS PER SQUARE				
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	2350	2600	-	5800	3000
	2	2350	3450	-	5650	3125
	3	2350	2600	-	-	-
Immersed in Lubricant Maintained At 135C.	4	2300	>7000	-	-	-
	5	2300	>7000	-	-	-
	6	2350	>7000	-	-	-
Exposed To Vapors In Chamber Maintained At 135C.	7	2350	2675	2900	3200	3025
	8	2400	2450	2450	3150	3125
	9	2325	2300	2525	3050	2950

TABLE 17.5

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON STRESS GRADING COATING APPLIED PRIOR TO IMPREGNATION, OVERCOATED WITH EPOXY VARNISH

	Specimen Iden.	MEGOHMS PER SQUARE				
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	2300	2675	-	-	3050
	2	2300	2450	2750	3275	4825
	3	2300	2375	2675	3200	3125
Immersed in Lubricant Maintained At 135C.	4	2350	>7000	-	-	-
	5	2300	>7000	-	-	-
	6	2350	>7000	-	-	-
Exposed To Vapors In Chamber Maintained At 135C.	7	2325	2600	2600	2675	3100
	8	2325	2750	2825	3525	3300
	9	2325	3050	3050	3050	3325

TABLE 17.6

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON SEMI-CONDUCTING COATING APPLIED OVER IMPREGNATED INSULATION

	Specimen Iden.	OHMS PER SQUARE				
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	4000	4000	3500	2750	3000
	2	4000	2500	2000	1250	1800
	3	6000	4000	3500	2750	4250
Immersed in Lubricant Maintained At 135C.	4	8000	$>10^6$	-	-	-
	5	6000	$>10^6$	-	-	-
	6	5000	$>10^6$	-	-	-
Exposed To Vapors In Chamber Maintained At 135C.	7	4000	3500	3500	3000	3300
	8	5000	4000	3500	2750	3300
	9	5000	4000	3000	2750	4600

TABLE 17.7

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON SEMI-CONDUCTING COATING APPLIED OVER IMPREGNATED INSULATION, OVERCOATED WITH EPOXY VARNISH

	Specimen Iden.	OHMS PER SQUARE				
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	3300	2100	1500	1100	700
	2	4000	2200	1650	1100	900
	3	5100	3100	2250	1850	1300
Immersed in Lubricant Maintained At 135C.	4	4800	$>10^6$	-	-	-
	5	5800	$>10^6$	-	-	-
	6	3000	$>10^6$	-	-	-
Exposed To Vapors In Chamber Maintained At 135C.	7	5600	8500	8000	7000	5000
	8	4600	5500	4200	2800	2000
	9	2500	3000	2500	2100	1400

TABLE 17.8

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON SEMI-CONDUCTING BINDER TAPE APPLIED OVER IMPREGNATED INSULATION, OVERCOATED WITH EPOXY VARNISH

	Specimen Iden.	OHMS PER SQUARE				
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	600	600	550	450	400
	2	620	600	575	425	300
	3	650	550	500	400	600
Immersed in Lubricant Maintained At 135C.	4	750	$>10^6$	-	-	-
	5	800	$>10^6$	-	-	-
	6	850	$>10^6$	-	-	-
Exposed To Vapors In Chamber Maintained At 135C.	7	850	800	950	1100	1700
	8	770	1100	1100	2500	2000
	9	590	850	1050	1700	1600

TABLE 17.9

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON SEMI-CONDUCTING BINDER TAPE APPLIED PRIOR TO IMPREGNATION

	Specimen Iden.	OHMS PER SQUARE				
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	1900	2100	1475	1200	1100
	2	1700	1900	1550	1200	1000
	3	1700	2000	1650	1175	1000
Immersed in Lubricant Maintained At 135C.	4	1400	350,000	$>10^6$	-	-
	5	1500	400,000	$>10^6$	-	-
	6	2000	570,000	$>10^6$	-	-
Exposed To Vapors In Chamber Maintained At 135C.	7	1500	2100	1900	1900	1650
	8	2300	3400	3100	3000	2600
	9	1800	2700	2300	2100	2000

TABLE 17.10

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON SEMI-CONDUCTING BINDER TAPE APPLIED PRIOR TO IMPREGNATION, OVERCOATED WITH EPOXY VARNISH

	Specimen Iden.	OHMS PER SQUARE				
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	1100	-	950	900	600
	2	1200	1600	1250	950	650
	3	1500	1200	1075	1000	700
Immersed in Lubricant Maintained At 135C.	4	1100	180,000	$>10^6$	-	-
	5	1200	210,000	$>10^6$	-	-
	6	1500	320,000	$>10^6$	-	-
Exposed To Vapors In Chamber Maintained At 135C.	7	1000	1200	1100	1100	700
	8	1100	1250	1250	1100	800
	9	1300	1500	1350	1200	1000

TABLE 17.11
EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON STRESS GRADING COATING APPLIED OVER IMPREGNATED INSULATION (GROUP A)

	Specimen Iden.	MEGOHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks	Aged 36 Weeks
Control Specimens - Aged At 135C.	1	3975	3925	3525	3450	1750	
	2	3525	3825			1900	
	3	3600	3825	3525	3225	2900	
Immersed in Lubricant Maintained At 135C.	4	3450	>7000	-	-	-	
	5	3825	>7000	-	-	-	
	6	3325	>7000	-	-	-	
Exposed To Vapors In Chamber Maintained At 135C.	7	4125	4750	4425	4425	3775	2600
	8	3825	4425	4425	4525	3825	2750
	9	3525	4425	4350	4125	3150	2450

TABLE 17.12

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON STRESS GRADING COATING APPLIED OVER IMPREGNATED INSULATION, OVERCOATED WITH EPOXY VARNISH (GROUP B)

	Specimen Iden.	MEGOHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks	Aged 36 Weeks
Control Specimens - Aged At 135C.	1	3125	2475	2600	2675	1900	
	2	2900	2450	2600	2600	1900	
	3	2675	2300	2525	2600	1875	
Immersed in Lubricant Maintained At 135C.	4	2900	>7000	-	-	-	
	5	2975	>7000	-	-	-	
	6	2675	>7000	-	-	-	
Exposed To Vapors In Chamber Maintained At 135C.	7	2900	2525	2750	2900	2900	2000
	8	2900	2850	2675	2825	2075	1900
	9	3050	2825	2675	2825	2900	2075

TABLE 17.13

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON STRESS GRADING COATING APPLIED PRIOR TO IMPREGNATION (GROUP C)

	Specimen Iden.	MEGOHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks	Aged 36 Weeks
Control Specimens - Aged At 135C.	1	2350	2600		5800	3000	
	2	2350	3450		5650	3125	
	3	2350	2600				
Immersed in Lubricant Maintained At 135C.	4	2300	>7000				
	5	2300	>7000				
	6	2350	>7000				
Exposed To Vapors In Chamber Maintained At 135C.	7	2350	2675	2900	3200	3025	2350
	8	2400	2450	2450	3150	3125	2300
	9	2325	2300	2525	3050	2950	2350

TABLE 17.14

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON STRESS GRADING COATING APPLIED PRIOR TO IMPREGNATION, OVERCOATED WITH EPOXY VARNISH (GROUP D)

	Specimen Iden.	MEGOHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks	Aged 36 Weeks
Control Specimens - Aged At 135C.	1	2300	2675			3050	
	2	2300	2450	2750	3275	4825	
	3	2300	2375	2675	3200	3125	
Immersed in Lubricant Maintained At 135C.	4	2350	>7000	-	-	-	
	5	2300	>7000	-	-	-	
	6	2350	>7000	-	-	-	
Exposed To Vapors In Chamber Maintained At 135C.	7	2325	2600	2600	2675	3100	3125
	8	2325	2750	2825	3525	3300	3050
	9	2325	3050	3050	3050	3325	3525

TABLE 17.15

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON SEMI-CONDUCTING COATING APPLIED OVER IMPREGNATED INSULATION (GROUP E)

	Specimen Iden.	OHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks	Aged 36 Weeks
Control Specimens - Aged At 135C.	1	4000	4000	3500	2750	3000	
	2	4000	2500	2000	1250	1800	
	3	6000	4000	3500	2750	4250	
Immersed in Lubricant Maintained At 135C.	4	8000	$>10^6$	-	-	-	
	5	6000	$>10^6$	-	-	-	
	6	5000	$>10^6$	-	-	-	
Exposed To Vapors In Chamber Maintained At 135C.	7	4000	3500	3500	3000	3300	1800
	8	5000	4000	3500	2750	3300	2000
	9	5000	4000	3000	2750	4600	2100

TABLE 17.16

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON SEMI-CONDUCTING COATING APPLIED OVER IMPREGNATED INSULATION, OVERCOATED WITH EPOXY VARNISH (GROUP F)

	Specimen Iden.	OHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks	Aged 36 Weeks
Control Specimens - Aged At 135C.	1	3300	2100	1500	1100	700	
	2	4000	2200	1650	1100	900	
	3	5100	3100	2250	1850	1300	
Immersed in Lubricant Maintained At 135C.	4	4800	$>10^6$	-	-	-	
	5	5800	$>10^6$	-	-	-	
	6	3000	$>10^6$	-	-	-	
Exposed To Vapors In Chamber Maintained At 135C.	7	5600	8500	8000	7000	5000	2250
	8	4600	5500	4200	2800	2000	860
	9	2500	3000	2500	2100	1400	910

TABLE 17.17

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON SEMI-CONDUCTING BINDER TAPE APPLIED OVER IMPREGNATED INSULATION, OVERCOATED WITH EPOXY VARNISH (GROUP G)

	Specimen Iden.	OHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks	Aged 36 Weeks
Control Specimens - Aged At 135C.	1	600	600	550	450	400	
	2	620	600	575	425	300	
	3	650	550	500	400	600	
Immersed in Lubricant Maintained At 135C.	4	750	$>10^6$	-	-		
	5	800	$>10^6$	-	-		
	6	850	$>10^6$	-	-		
Exposed To Vapors In Chamber Maintained At 135C.	7	850	800	950	1100	1700	1000
	8	770	1100	1100	2500	2000	-
	9	590	850	1050	1700	1600	1200

TABLE 17.18

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON SEMI-CONDUCTING BINDER TAPE APPLIED PRIOR TO IMPREGNATION (GROUP H)

	Specimen Iden.	OHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks	Aged 36 Weeks
Control Specimens - Aged At 135C.	1	1900	2100	1475	1200	1100	
	2	1700	1900	1550	1200	1000	
	3	1700	2000	1650	1175	1000	
Immersed in Lubricant Maintained At 135C.	4	1400	350,000	$>10^6$	-	-	
	5	1500	400,000	$>10^6$	-	-	
	6	2000	570,000	$>10^6$	-	-	
Exposed To Vapors In Chamber Maintained At 135C.	7	1500	2100	1900	1900	1650	900
	8	2300	3400	3100	3000	2600	1200
	9	1800	2700	2300	2100	2000	1200

TABLE 17.19

EFFECT OF FYRQUEL GT LUBRICANT AND VAPOR ON SEMI-CONDUCTING BINDER TAPE APPLIED PRIOR TO IMPREGNATION, OVERCOATED WITH EPOXY VARNISH (GROUP J)

	Specimen Iden.	OHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks	Aged 36 Weeks
Control Specimens - Aged At 135C.	1	1100		950	900	600	
	2	1200	1600	1250	950	650	
	3	1500	1200	1075	1000	700	
Immersed in Lubricant Maintained At 135C.	4	1100	180,000	$>10^6$	-	-	
	5	1200	210,000	$>10^6$	-	-	
	6	1500	320,000	$>10^6$	-	-	
Exposed To Vapors In Chamber Maintained At 135C.	7	1000	1200	1100	1100	700	450
	8	1100	1250	1250	1100	800	600
	9	1300	1500	1350	1200	1000	700

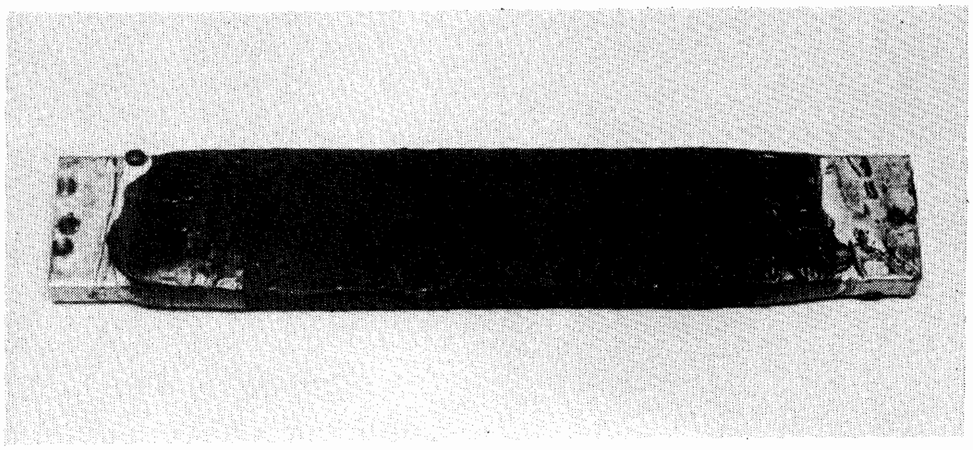


FIGURE 17.1 TEST SPECIMEN WITH CONDUCTING SURFACE TREATMENT APPLIED OVER THE INSULATION

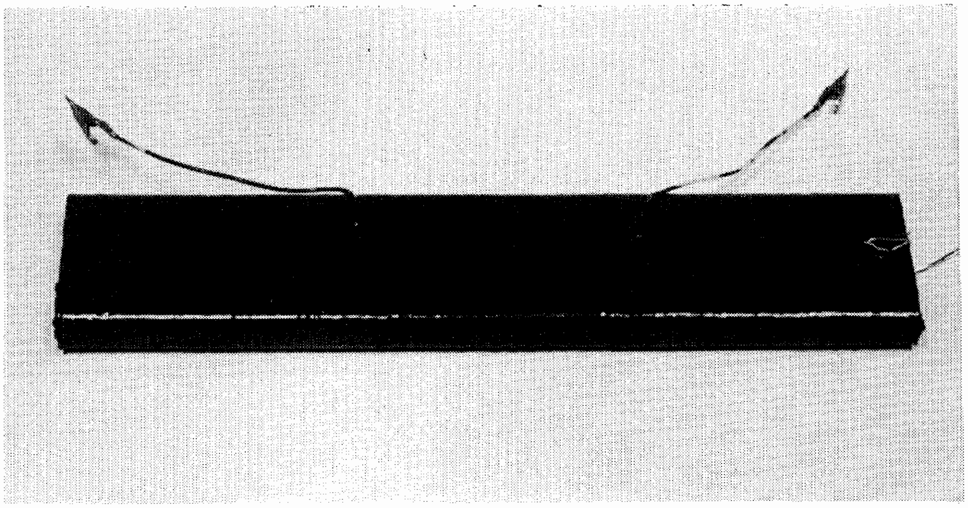
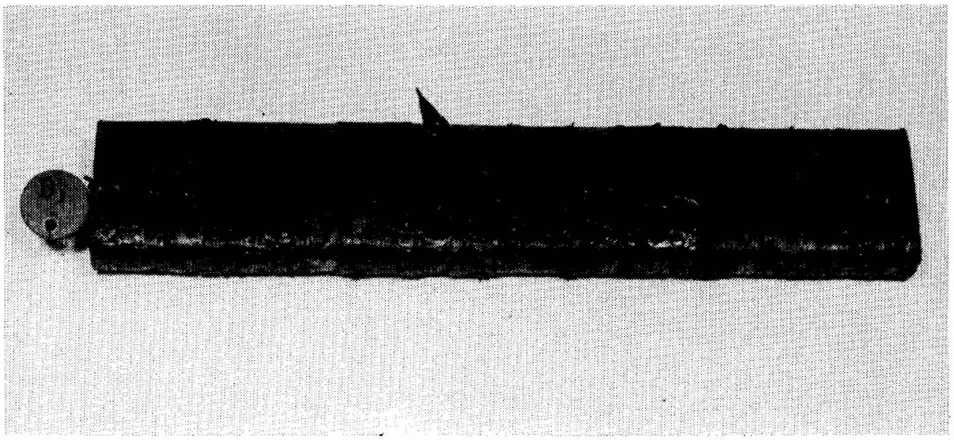
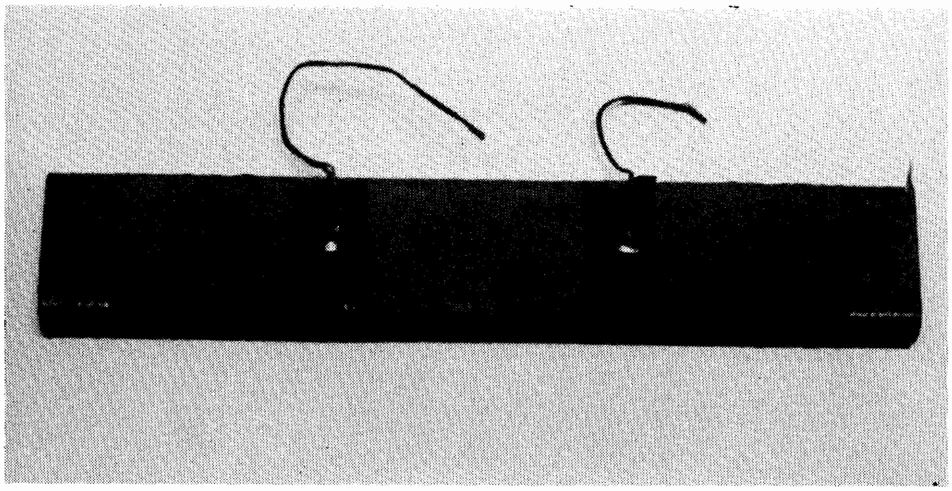


FIGURE 17.2 TEST BAR WITH STRESS GRADING FILM PROTECTED BY VARNISH COATING

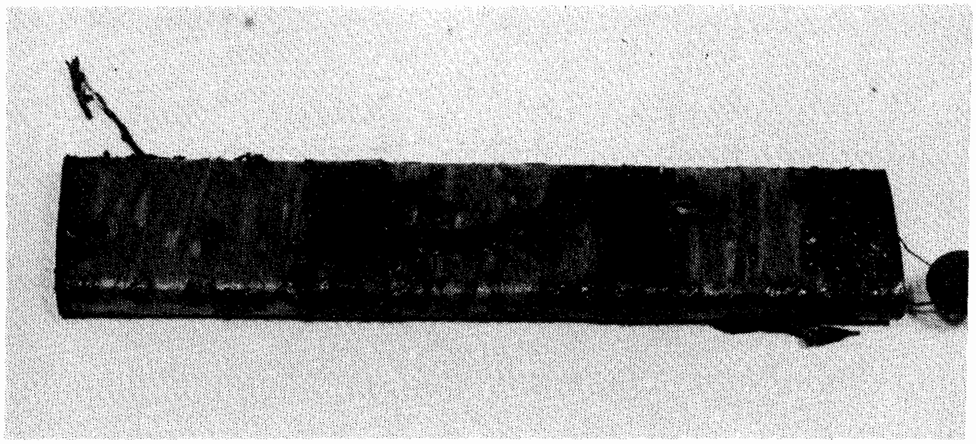


(a) AFTER 1 WEEK'S IMMERSION IN FYRQUEL GT LUBRICANT AT 135°C

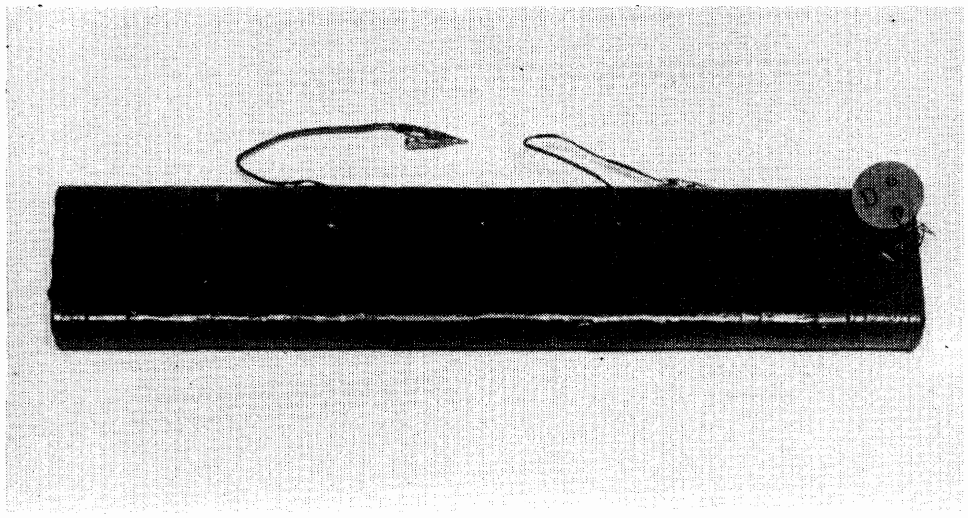


(b) AFTER 36 WEEKS' EXPOSURE TO FYRQUEL GT VAPOR AT 135°C

FIGURE 17.3 STRESS GRADING COATING - SILICON CARBIDE IN PHENOLIC VARNISH VEHICLE APPLIED OVER IMPREGNATED AND CURED INSULATION

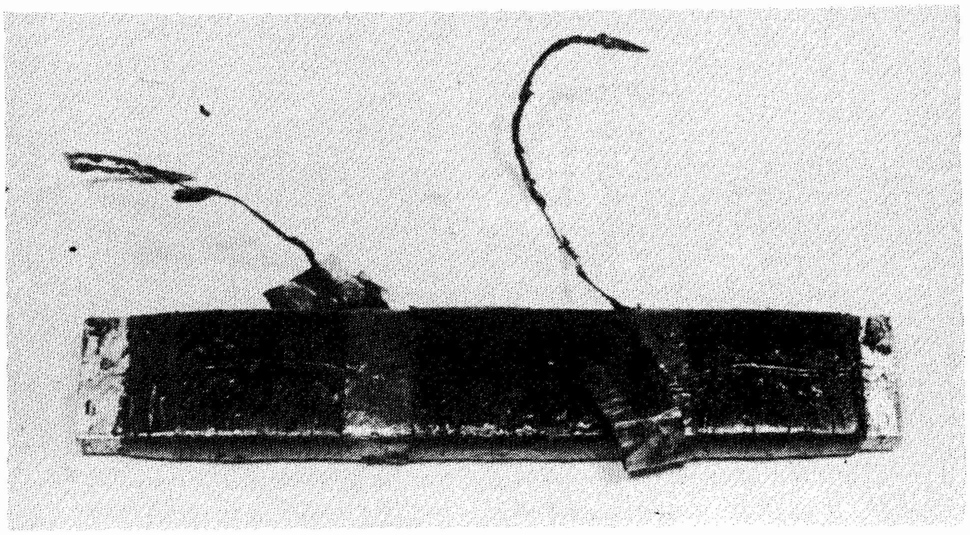


(a) AFTER 1 WEEK'S IMMERSION IN FYRQUEL GT LUBRICANT AT 135°C

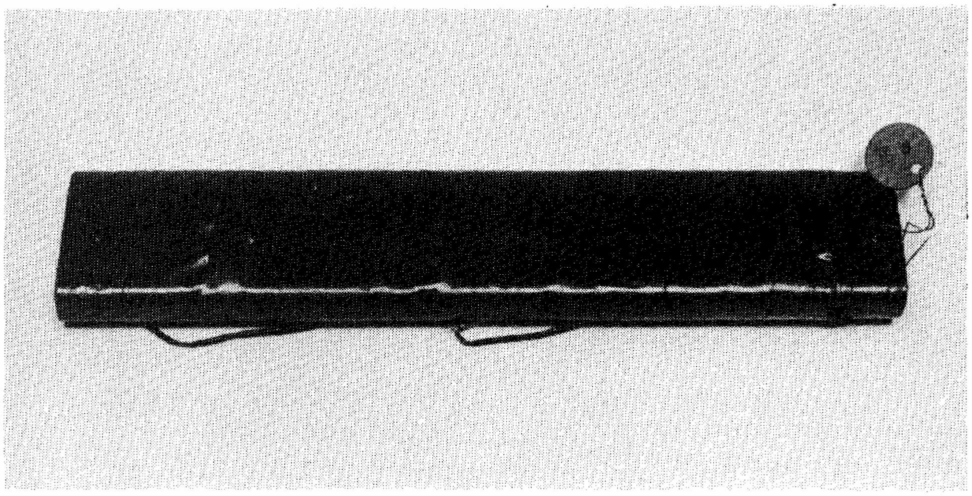


(b) AFTER 36 WEEKS' EXPOSURE TO FYRQUEL GT VAPOR AT 135°C

FIGURE 17.4 STRESS GRADING FILM - SILICON CARBIDE IN PHENOLIC VARNISH VEHICLE APPLIED OVER IMPREGNATED AND CURED INSULATION, PROTECTED WITH TWO COATS OF MODIFIED EPOXY VARNISH

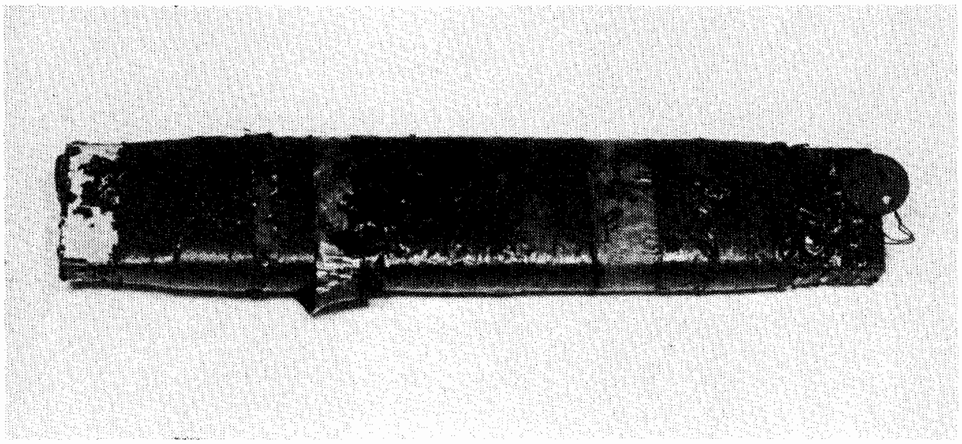


(a) AFTER I WEEK'S IMMERSION IN FYRQUEL GT LUBRICANT AT 135°C

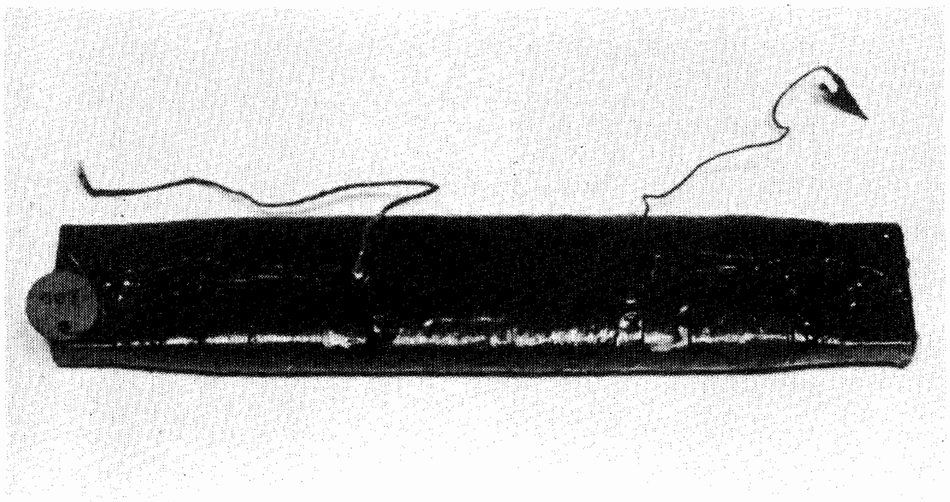


(b) AFTER 36 WEEKS' EXPOSURE TO FYRQUEL GT VAPOR AT 135°C

FIGURE 17.5 SILICON CARBIDE STRESS GRADING PAINT APPLIED TO UNIMPREGNATED COIL INSULATION AND IMPREGNATED WITH THE COIL IN SOLVENTLESS EPOXY RESIN



(a) AFTER I WEEK'S IMMERSION IN FYRQUEL GT LUBRICANT AT 135°C



(b) AFTER 36 WEEKS' EXPOSURE TO FYRQUEL GT VAPOR AT 135°C

FIGURE 17.6 SILICON CARBIDE STRESS GRADING PAINT APPLIED TO UNIMPREGNATED COIL INSULATION AND IMPREGNATED WITH THE COILS IN SOLVENTLESS EPOXY RESIN, OVERCOATED TWICE WITH HEAT CURED MODIFIED EPOXY VARNISH

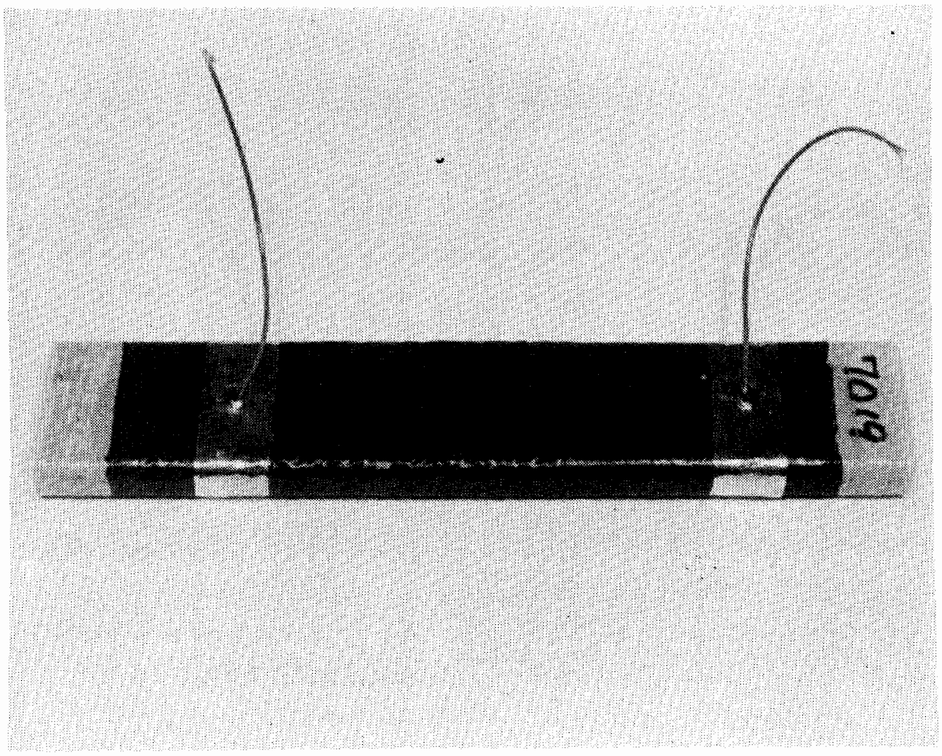
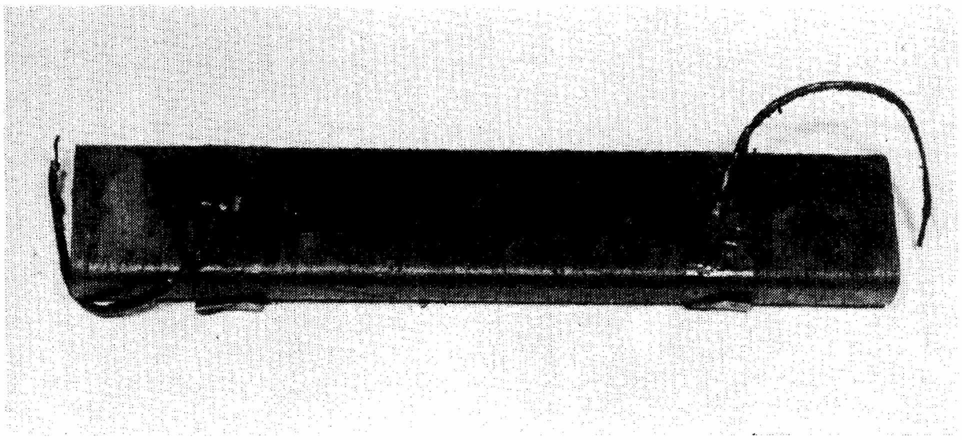
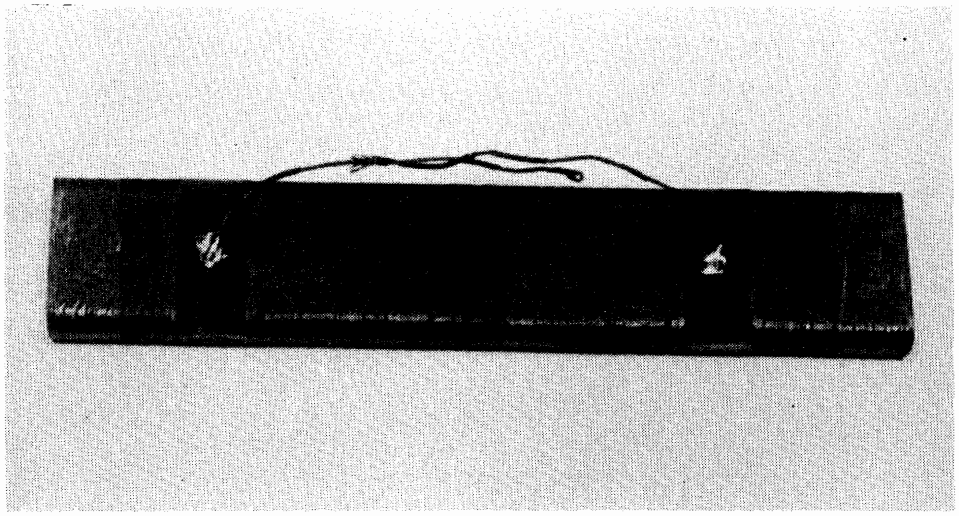


FIGURE 17.7 TEST BAR SPECIMEN FOR EVALUATING RESISTANCE OF CONDUCTING COIL SURFACE TREATMENT TO FIRE RESISTANT LUBRICANT

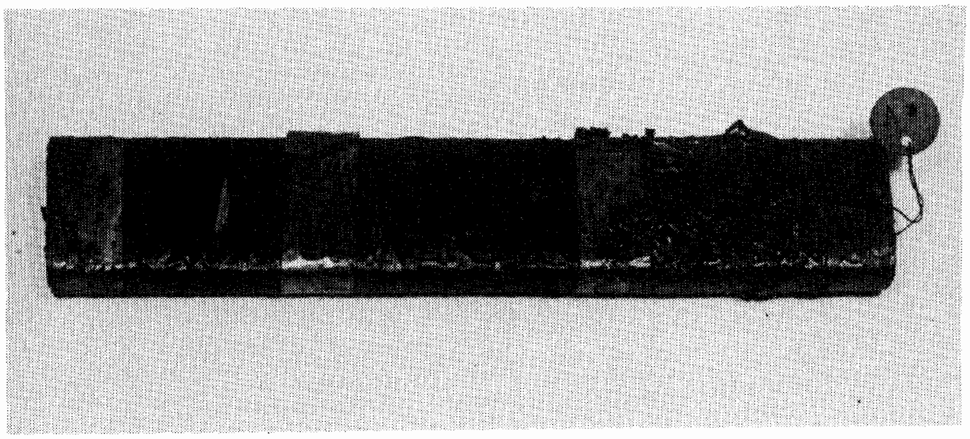


(a) AFTER I WEEK'S IMMERSION IN FYRQUEL GT LUBRICANT AT 135°C

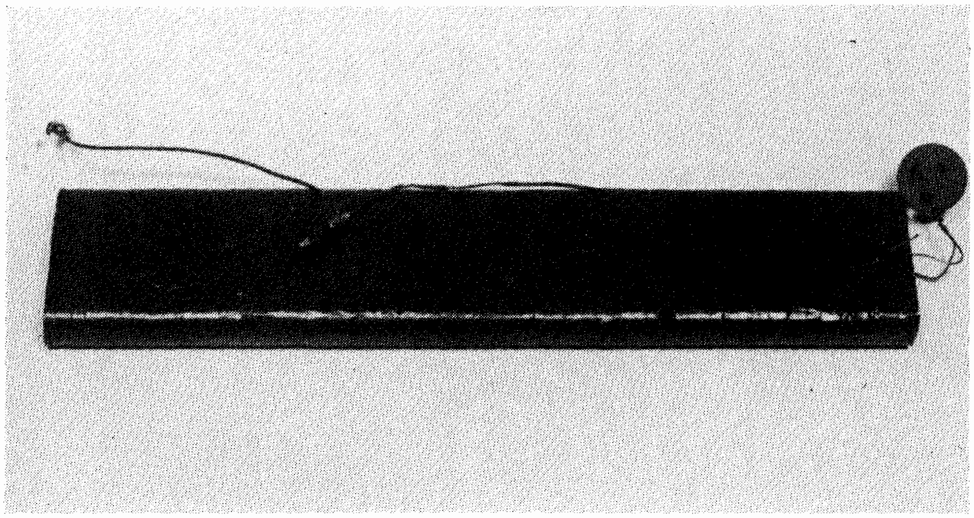


(b) AFTER 36 WEEKS' EXPOSURE TO FYRQUEL GT VAPOR AT 135°C

FIGURE 17.8 LOW RESISTANCE CARBON PARTICLE LOADED COATING APPLIED OVER IMPREGNATED AND CURED INSULATION

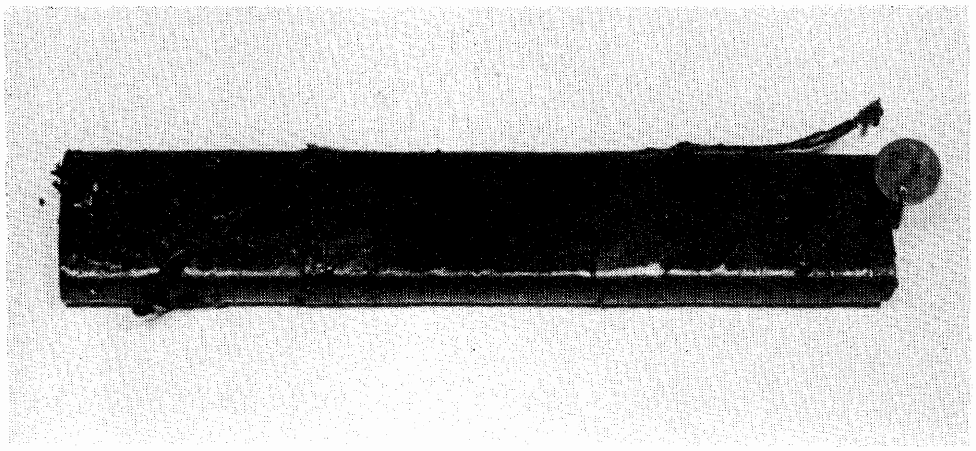


(a) AFTER I WEEK'S IMMERSION IN FYRQUEL GT LUBRICANT AT 135°C

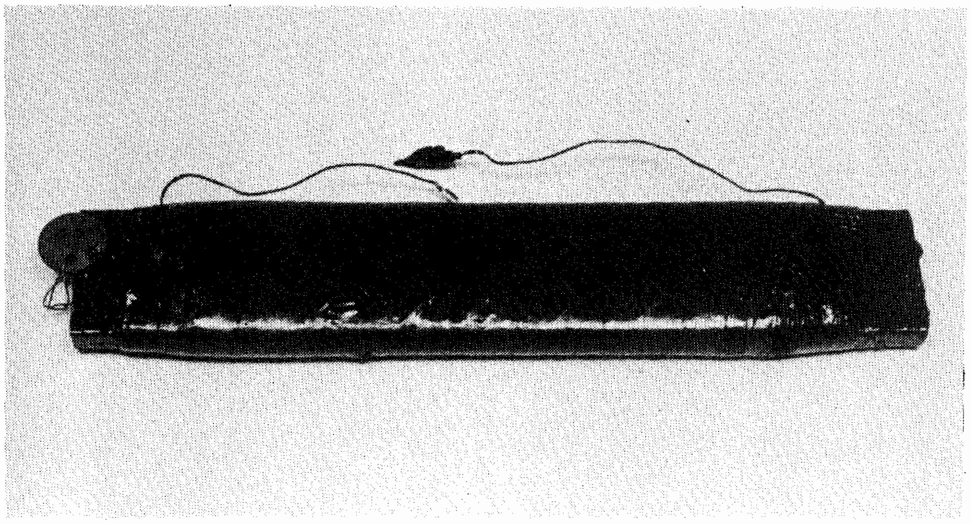


(b) AFTER 36 WEEKS' EXPOSURE TO FYRQUEL GT VAPOR AT 135°C

FIGURE 17.9 LOW RESISTANCE CARBON PARTICLE LOADED COATING APPLIED OVER IMPREGNATED AND CURED INSULATION, OVERCOATED TWICE WITH HEAT CURED MODIFIED EPOXY VARNISH

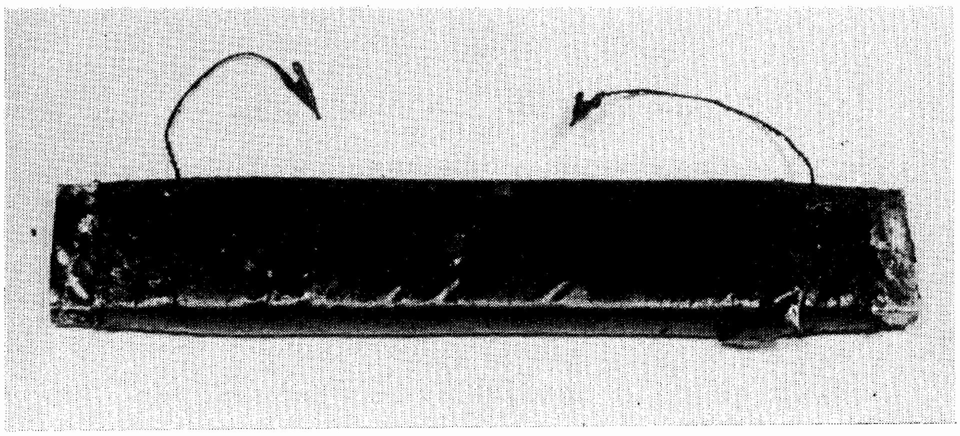


(a) AFTER 1 WEEK'S IMMERSION FYRQUEL GT LUBRICANT AT 135°C

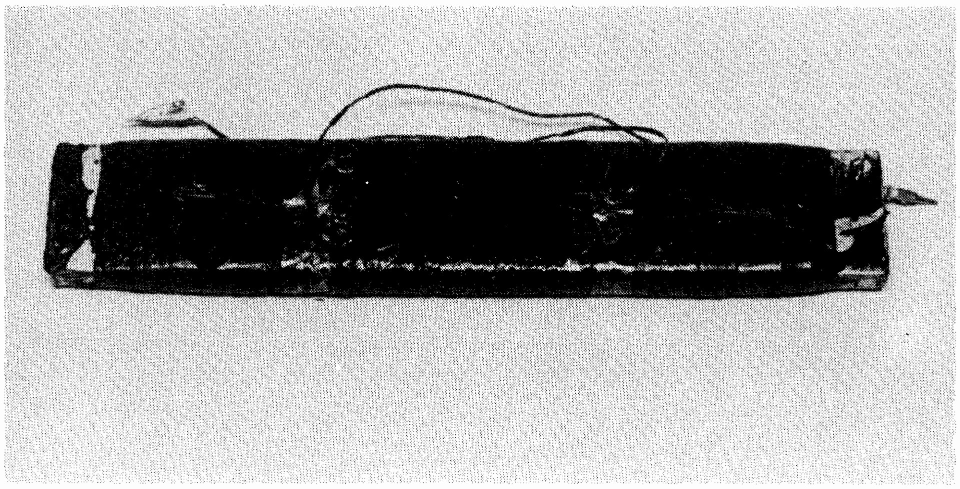


(b) AFTER 36 WEEKS' EXPOSURE TO FYRQUEL GT VAPOR AT 135°C

FIGURE 17.10 SEMICONDUCTING BINDER APPLIED OVER IMPREGNATED AND CURED INSULATION

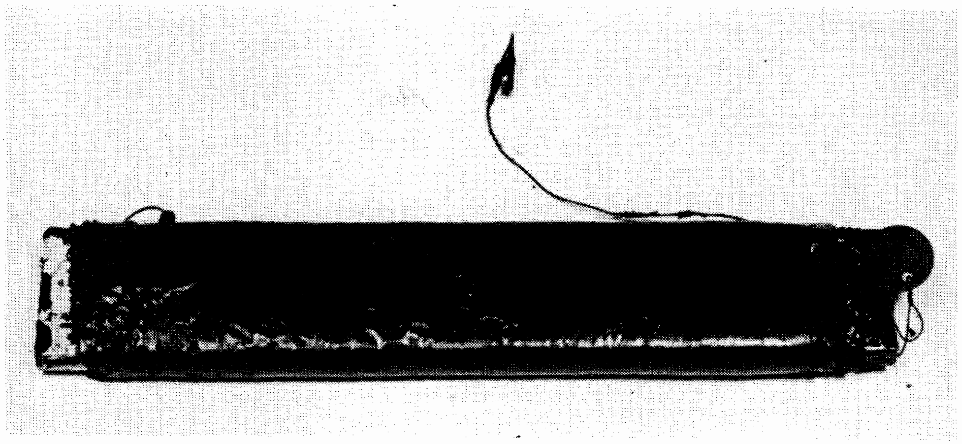


(a) AFTER 4 WEEKS' IMMERSION IN FYRQUEL GT LUBRICANT AT 135°C

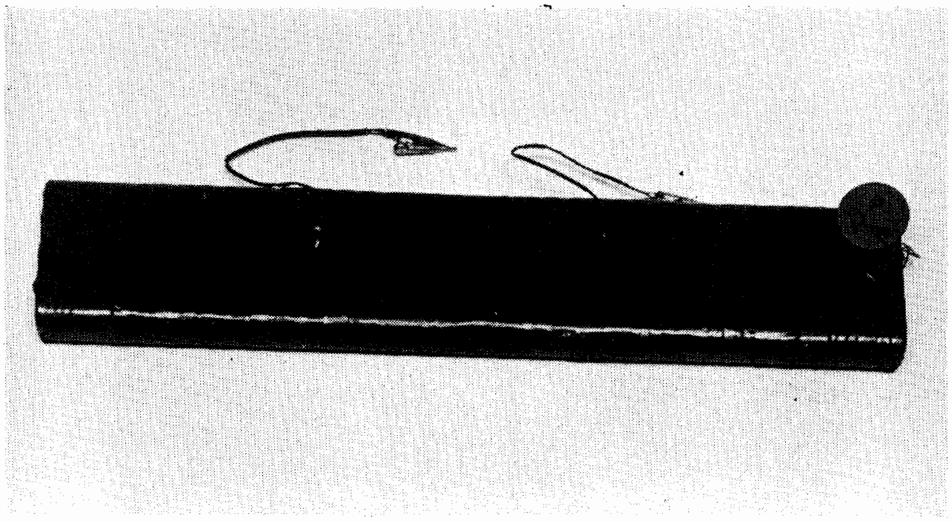


(b) AFTER 36 WEEKS' EXPOSURE TO FYRQUEL GT VAPOR AT 135°C

FIGURE 17.11 SEMICONDUCTING BINDER TAPE APPLIED OVER UNIMPREGNATED INSULATION AND IMPREGNATED WITH THE COIL IN SOLVENTLESS EPOXY RESIN



(a) AFTER 4 WEEKS' IMMERSION IN FYRQUEL GT LUBRICANT AT 135°C



(b) AFTER 36 WEEKS' EXPOSURE TO FYRQUEL GT LUBRICANT AT 135°C

FIGURE 17.12 SEMICONDUCTING BINDER TAPE APPLIED OVER UNIMPREGNATED INSULATION AND IMPREGNATED WITH THE INSULATION IN A SOLVENTLESS EPOXY RESIN, OVERCOATED TWICE WITH HEAT CURED MODIFIED EPOXY VARNISH

SECTION 18.0

COMPATIBILITY TESTING OF ORGANIC STRUCTURAL COMPONENTS

18.0 COMPATIBILITY TESTING OF ORGANIC STRUCTURAL COMPONENTS

18.1 GENERAL

A third functional grouping of critical components is the non-metallic structural materials which function as physical bracing for the stator winding. Included in this group are wedges, coil diamond spacers, slot sticks, lead cleats and parallel ring cleats and supports. While the shapes and structures of these components differ greatly, they are generally fashioned from laminates. Four different laminates, commonly used in the industry for structural components, were studied for compatibility with the Fyrquel GT lubricating fluid:

1. Glass mat polyester laminate - NEMA GRADE GPO-1
2. Cotton phenolic laminate - NEMA GRADE C
3. Glass melamine Laminate - Type GME, NEMA GRADE G-9
4. Glass epoxy laminate - NEMA GRADE G-11

18.2 TEST PROCEDURE

Since the functions of these components are principally mechanical, changes in tensile properties, per ASTM 638, were used as a primary indicator of physical change. Test specimens were prepared from 0.125" thick laminates in accordance with dimensions listed under Type 1, Figure 1 of ASTM procedure D638. Five specimens of each type were tested in tension initially. Twenty specimens of each type were immersed in Fyrquel GT lubricant by sealing in a gas tight aluminum container which was placed in an oven with the temperature maintained at 135^{o}C. After exposures of 2 weeks, 4 weeks, 12 weeks, and 24 weeks, five specimens of each type were removed and tested. A duplicate number and variety of test samples were subjected to exposure to the vapors of Fyrquel GT lubricant at the same elevated temperature. An environmental chamber was used for this purpose, as described in earlier reports. The same test procedure and schedule as above were followed. Since thermal aging alone changes mechanical properties of these laminates, duplicate test pieces to serve as controls were aged in a 135°C oven.

Flexural properties per ASTM procedure D790 were also measured to detect changes related to embrittlement or plastic effect of the lubricant on the laminates. The same number of samples was tested and the same procedure was followed as with the tensile specimens.

In addition to tensile and flexural properties, weight change and thickness change measurements were made (reference ASTM D115). Nine measurements were made initially of the thickness of each laminate type. These were then placed in the liquid at 135°C. Duplicate samples were placed in the environmental chamber where they were subjected to the lubricant vapors, and still others were placed in an oven at 135°C. Thickness measurements were made according to the same schedule previously described. Weight measurements of each type were made, and the same procedure and schedule were followed to determine weight change.

18.3 RESULTS

The relative effects of the Fyrquel GT lubricant on the various laminates are somewhat typified by the dimensional change data listed in Tables 18.1 through 18.4. These data show no effect, even under severest exposure, on the glass epoxy (Table 18.3) and the glass mat polyester (Table 18.1) when immersed for six months in the lubricant at 135°C. However, in neither instance did the specimens exposed to the lubricant vapors differ from the control samples. With each of the laminates, the 135°C temperature was expected to result in some shrinkage. This is indicated by the control samples. The shrinkage loss must be taken into account in determining the total swelling due to exposure to the lubricant liquid or vapor.

In assessing the relative imperviousness of the four laminates to the lubricant, tensile and flexural data, presented in Figures 18.1 through 18.14, confirm that the glass mat polyester is the most vulnerable. Quantitatively, the attack must be considered moderate to minimal.

A study of the tensile data of the glass mat polyester (Figures 18.1 through 18.11) indicate no loss of material strength, when under the severest exposure conditions. (Compare particularly Figure 18.4 with Figure 18.11.) After six months' immersion in the lubricant at 135°C, there was no change in the tensile modulus, and the variations of tensile strength at break reflected sample to sample differences rather than treatment differences. The stress strain curves of test pieces exposed to the lubricant vapors for six months identify closely with those exposed to temperatures for six months. (Compare Figure 18.4 with Figure 18.8.)

The flexural data in Figures 18.12, 18.13 and 18.14 show that the Fyrquel GT has some effect on the glass mat polyester laminate. This is probably an external plasticization which does not appear to have had a weakening action on the tensile strength of the laminate. A comparison of the flexural data in Figure 18.12, with the data in Figure 18.14 from samples immersed in the lubricant at 135°C for 6 months, shows that the breaking load has been advanced by a factor of two-thirds due to seasoning in the lubricant. The flexural modulus has significantly increased. Exposure to the lubricant vapors for 6 months (Figure 18.13) has resulted in much more moderate changes. The curves are closer to those of the control specimens. The flexural modulus has increased a slight extent. The breaking strength has not increased, at least not to the degree that it is discernible above the sample deviation.

Changes in ultimate tensile strength of the glass melamine laminate, Figures 18.15 through 18.26, could not be measured since the strength of the laminate exceeded the capability of the laboratory testing equipment. No change in tensile modulus is discernible due to six months' immersion in the lubricant (Figure 18.26 vs. Figure 18.18). Some loss in flexural properties appears to have occurred after six months' exposure, particularly with specimens immersed in the lubricant (Figure 18.29 vs. Figure 18.27).

Tensile data of the glass epoxy laminate (Figures 18.30 through 18.41) exhibit a pattern similar to that of the glass melamine. Again, the tensile strength of the material, initially and after aging and exposure, exceeds the capability of the laboratory testing equipment. Exposure to the lubricant does not appear to have affected the tensile modulus. Some loss in flexural properties may have resulted from immersion in the hot lubricant (Figure 18.44 vs. Figure 18.42). Exposure to the lubricant vapors, however, gave no indication of any effect on flexural properties within the time frame of the experiment. The curves of Figure 18.43 duplicate the curves of Figure 18.42.

Tensile data on cotton phenolic laminate subjected to a temperature of 135^{o}C show a very pronounced deterioration of the material due to thermal stressing (Figures 18.45 throught 18.48). The thermal stress exceeds the temperature capability of the material. It is interesting to note that the oxidative deterioration is significantly retarded when the laminate is exposed to the lubricant vapors (Figures 18.49 through 18.52), and retarded to an even greater degree when immersed in the lubricant (Figures 18.53 through 18.56). Presumably the lubricant reduces exposure of the low temperature capability component of the laminate to the oxidizing environment. Referring to Table 18.9, weight loss of the cotton phenolic is minimal to the extent that where it appears to be the least affected of the laminates by total immersion in the lubricant. However, its weight loss varies directly in relation to the degree of sealing-off provided by the lubricant. This is more graphically apparent from the last column of Table 18.6. Some loss in flexural properties is indicated due to exposure to the Fyrquel GT (Figure 18.59 vs. Figure 18.57). However, were the material to be used at a temperature of 135^{o}C, the major degradative factor would be thermal rather than exposure to the lubricant.

Weight change data on the four laminates are listed in Tables 18.5 through 18.9. From the data summarized in Table 18.9, excluding the data on cotton phenolic, conclusions are that the glass melamine is least affected by exposure to Fyrquel GT. Weight gain from long time immersion in the lubricant at high temperature is less than that of the glass epoxy and less than that of the glass mat polyester. Weight changes of the glass melamine when exposed to the Fyrquel vapors at 135^{o}C are identical to weight changes of control coupons exposed to temperature alone (Table 18.5), indicating that the temperature effect is not compounded significantly by moderate exposure to the lubricant.

The glass epoxy laminate shows behavior similar to that of the glass melamine with reference to weight change. While the net weight change (Table 18.9) is apparently higher than that of the glass melamine after extended immersion in the hot Fyrquel GT lubricant, the weight changes when exposed to the Fyrquel GT vapors (Table 18.7) exactly duplicate the changes caused by thermal aging alone.

The glass mat polyester laminate exhibits rather high weight change characteristics (Table 18.9) and must be considered to be the most vulnerable to attack by the lubricant. This is reinforced by the conclusions drawn from thickness change data and from tensile and flexural data previously reported. However, the more realistic exposure to the lubricant vapors shows moderate effects when compared to control samples (Table 18.5).

The conclusion is that the laminates, when properly selected to provide the required bracing and structural support functions, are minimally affected by the Fyrquel GT lubricant and will continue to function in an environment which is influenced by Fyrquel GT lubricant.

TABLE 18.1 THICKNESS CHANGES OF GLASS MAT POLYESTER NEMA GPO–1 LAMINATE SUBJECTED TO FYRQUEL GT LUBRICANT AND VAPOR

	THICKNESS (IN.)*				
	INITIAL	AGED 1 WEEK	AGED 4 WEEKS	AGED 12 WEEKS	AGED 24 WEEKS
CONTROL SPECIMENS - AGED AT 135°C	.132	.132	.131	.130	.130
IMMERSED IN LUBRICANT MAINTAINED AT 135°C	.133	.134	.134	.135	.135
EXPOSED TO VAPORS IN CHAMBER MAINTAINED AT 135°C	.132	.131	.130	.131	.130

* EACH FIGURE IS AN AVERAGE OF 9 MEASUREMENTS

TABLE 18.2 THICKNESS CHANGES OF COTTON PHENOLIC NEMA GRADE C LAMINATE SUBJECTED TO FYRQUEL GT LUBRICANT AND VAPOR

	THICKNESS (IN.)*				
	INITIAL	AGED 1 WEEK	AGED 4 WEEKS	AGED 12 WEEKS	AGED 24 WEEKS
CONTROL SPECIMENS - AGED AT 135°C	.133	.131	.131	.129	.128
IMMERSED IN LUBRICANT MAINTAINED AT 135°C	.131	.129	.128	.128	.127
EXPOSED TO VAPORS IN CHAMBER MAINTAINED AT 135°C	.131	.130	.129	.127	.127

* EACH FIGURE IS AN AVERAGE OF 9 MEASUREMENTS

TABLE 18.3 THICKNESS CHANGES OF GLASS EPOXY NEMA G–11 LAMINATE SUBJECTED TO FYRQUEL GT LUBRICANT AND VAPOR

	THICKNESS (IN.)*				
	INITIAL	AGED 1 WEEK	AGED 4 WEEKS	AGED 12 WEEKS	AGED 24 WEEKS
CONTROL SPECIMENS – AGED AT 135°C	.129	.129	.128	.128	.127
IMMERSED IN LUBRICANT, MAINTAINED AT 135°C	.129	.129	.128	.131	.133
EXPOSED TO VAPORS IN CHAMBER MAINTAINED AT 135°C	.129	.129	.128	.126	.127

* EACH FIGURE IS AN AVERAGE OF 9 MEASUREMENTS

TABLE 18.4 THICKNESS CHANGES OF GLASS MELAMINE TYPE GME NEMA GRADE 9 SUBJECTED TO FYRQUEL GT LUBRICANT AND VAPOR

	THICKNESS (IN.)*				
	INITIAL	AGED 1 WEEK	AGED 4 WEEKS	AGED 12 WEEKS	AGED 24 WEEKS
CONTROL SPECIMENS - AGED AT 135°C	.129	.126	.126	.127	.128
IMMERSED IN LUBRICANT MAINTAINED AT 135°C	.130	.128	.128	.128	.129
EXPOSED TO VAPORS IN CHAMBER MAINTAINED AT 135°C	.129	.127	.126	.126	.126

* EACH FIGURE IS AN AVERAGE OF 9 MEASUREMENTS

TABLE 18.5 WEIGHT CHANGE OF LAMINATES UPON EXPOSURE TO FYRQUEL GT LUBRICANT – GLASS MAT POLYESTER NEMA GP01

	SPECIMEN IDENT.	INITIAL WEIGHT (GR.)	WEIGHT CHANGE (%)			
			AGED 1 WEEK	AGED 4 WEEKS	AGED 12 WEEKS	AGED 24 WEEKS
CONTROL SPECIMENS - AGED AT 135°C.	1	11.2869	-1.26	-1.61	-2.47	-2.90
	2	11.0496	-1.30	-1.84	-2.35	-2.85
	3	10.6917	-1.33	-1.41	-1.56	-2.70
	AV		-1.30	-1.62	-1.46	-2.82
IMMERSED IN LUBRICANT MAINTAINED AT 135°C.	1	11.2610	+2.56	+2.81	+3.07	+3.91
	2	11.5072	+3.08	+3.22	+3.57	+4.16
	3	10.9501	+2.56	+2.77	+2.97	+3.30
	AV		+2.73	+2.93	+3.20	+3.79
EXPOSED TO VAPORS IN CHAMBER MAINTAINED AT 135°C.	1	11.0640	-1.11	-1.52	-2.05	-2.15
	2	10.7762	-1.13	-1.87	-2.05	-2.18
	3	11.2201	-1.04	-2.00	-2.07	-2.20
	AV		-1.09	-1.80	-2.06	-2.18

TABLE 18.6 WEIGHT CHANGE OF LAMINATES UPON EXPOSURE TO FYRQUEL GT LUBRICANT – COTTON PHENOLIC NEMA GRADE C

	SPECIMEN IDENT.	INITIAL WEIGHT (GR.)	WEIGHT CHANGE (%)			
			AGED 1 WEEK	AGED 4 WEEKS	AGED 12 WEEKS	AGED 24 WEEKS
CONTROL SPECIMENS - AGED AT 135°C.	1	8.6273	-3.28	-3.30	-3.11	-5.33
	2	8.6661	-3.29	-3.31	-2.66	-4.76
	3	8.8127	-3.24	-3.30	-3.06	-4.85
	AV		-3.27	-3.30	-2.94	-4.98
IMMERSED IN LUBRICANT MAINTAINED AT 135°C.	1	8.6208	-1.98	-2.72	-3.37	-3.92
	2	8.5524	-1.66	-2.55	-3.28	-3.35
	3	8.5133	-1.73	-2.79	-3.02	-3.32
	AV		-1.79	-2.69	-3.33	-3.53
EXPOSED TO VAPORS IN CHAMBER MAINTAINED AT 135°C.	1	8.5912	-3.26	-2.77	-2.01	-2.22
	2	8.6382	-3.19	-2.76	-1.91	-2.54
	3	8.5462	-3.20	-2.57	-2.57	-1.98
	AV		-3.22	-2.70	-1.98	-2.39

TABLE 18.7 WEIGHT CHANGE OF LAMINATES UPON EXPOSURE TO FYRQUEL GT LUBRICANT – GLASS EPOXY NEMA G–11

	SPECIMEN IDENT.	INITIAL WEIGHT (GR.)	WEIGHT CHANGE (%)			
			AGED 1 WEEK	AGED 4 WEEKS	AGED 12 WEEKS	AGED 24 WEEKS
CONTROL SPECIMENS - AGED AT 135°C.	1	11.5825	-0.17	-0.55	-0.70	-0.75
	2	11.9538	-0.17	-0.32	-0.70	-0.74
	3	11.8108	-0.21	-0.40	-0.71	-0.76
	AV		-0.18	-0.38	-0.70	-0.75
IMMERSED IN LUBRICANT MAINTAINED AT 135°C.	1	11.2721	+0.33	+0.60	+1.19	+8.40
	2	11.8792	+0.17	+0.83	+1.30	+2.37
	3	11.8985	+0.29	+0.66	+0.95	+2.91
	AV		+0.26	+0.70	+1.15	+2.98
EXPOSED TO VAPORS IN CHAMBER MAINTAINED AT 135°C.	1	11.9193	-0.22	-0.34	-0.72	-0.73
	2	11.5538	-0.17	-0.39	-0.72	-0.74
	3	11.9014	-0.23	-0.37	-0.74	-0.76
	AV		-0.21	-0.37	-0.73	-0.74

TABLE 18.8 WEIGHT CHANGE OF LAMINATES UPON EXPOSURE TO FYRQUEL GT LUBRICANT – GLASS MELAMINE TYPE GME NEMA GRADE 9

	SPECIMEN IDENT.	INITIAL WEIGHT (GR.)	WEIGHT CHANGE (%)			
			AGED 1 WEEK	AGED 4 WEEKS	AGED 12 WEEKS	AGED 24 WEEKS
CONTROL SPECIMENS - AGED AT 135°C.	1	12.4404	-3.54	-3.54	-2.72	-3.67
	2	12.2830	-3.49	-3.71	-4.63	-4.92
	3	12.2699	-3.51	-3.96	-4.50	-4.78
	AV		-3.51	-3.74	-3.95	-4.46
IMMERSED IN LUBRICANT MAINTAINED AT 135°C.	1	12.3668	-0.79	-1.20	-1.39	-1.25
	2	12.4352	-0.98	-1.37	-1.63	-1.54
	3	12.4817	-1.19	-1.51	-1.79	-1.66
	AV		-0.99	-1.36	-1.60	-1.48
EXPOSED TO VAPORS IN CHAMBER MAINTAINED AT 135°C.	1	12.4132	-3.33	-3.58	-4.20	-4.77
	2	12.3446	-3.33	-3.54	-4.08	-4.70
	3	12.3815	-3.34	-3.77	-4.09	-4.69
	AV		-3.33	-3.63	-4.12	-4.72

TABLE 18.9 EFFECT ON LAMINATES OF EXPOSURE TO FYRQUEL GT LUBRICANT – SUMMARY OF PERCENT CHANGE RELATIVE TO PERCENT CHANGE OF CONTROL SPECIMENS.

LAMINATE	TREATMENT	RELATIVE CHANGE (%) (CHANGE LESS CHANGE DUE TO THERMAL AGING)			
		AGED 1 WK	AGED 4 WKS	AGED 16 WKS	AGED 32 WKS
GLASS MAT POLYESTER NEMA GPO-1	IMMERSED IN LUBRICANT @ 135°C	+4.03	+4.55	+4.66	+6.61
	EXPOSED TO VAPORS @ 135°C	+0.21	-0.18	-0.60	-0.64
COTTON PHENOLIC NEMA GRADE C	IMMERSED IN LUBRICANT @ 135°C	+1.48	+0.61	-0.39	+1.45
	EXPOSED TO VAPORS @ 135°C	+0.05	+0.61	+0.96	+2.59
GLASS EPOXY NEMA G-11	IMMERSED IN LUBRICANT @ 135°C	+0.44	+1.08	+1.85	+3.73
	EXPOSED TO VAPORS @ 135°C	+0.03	+0.01	-0.03	+0.01
GLASS MELAMINE TYPE GME NEMA GRADE 9	IMMERSED IN LUBRICANT @ 135°C	+2.52	+2.38	+2.35	+2.98
	EXPOSED TO VAPORS @ 135°C	+0.18	+0.11	-0.17	-0.26

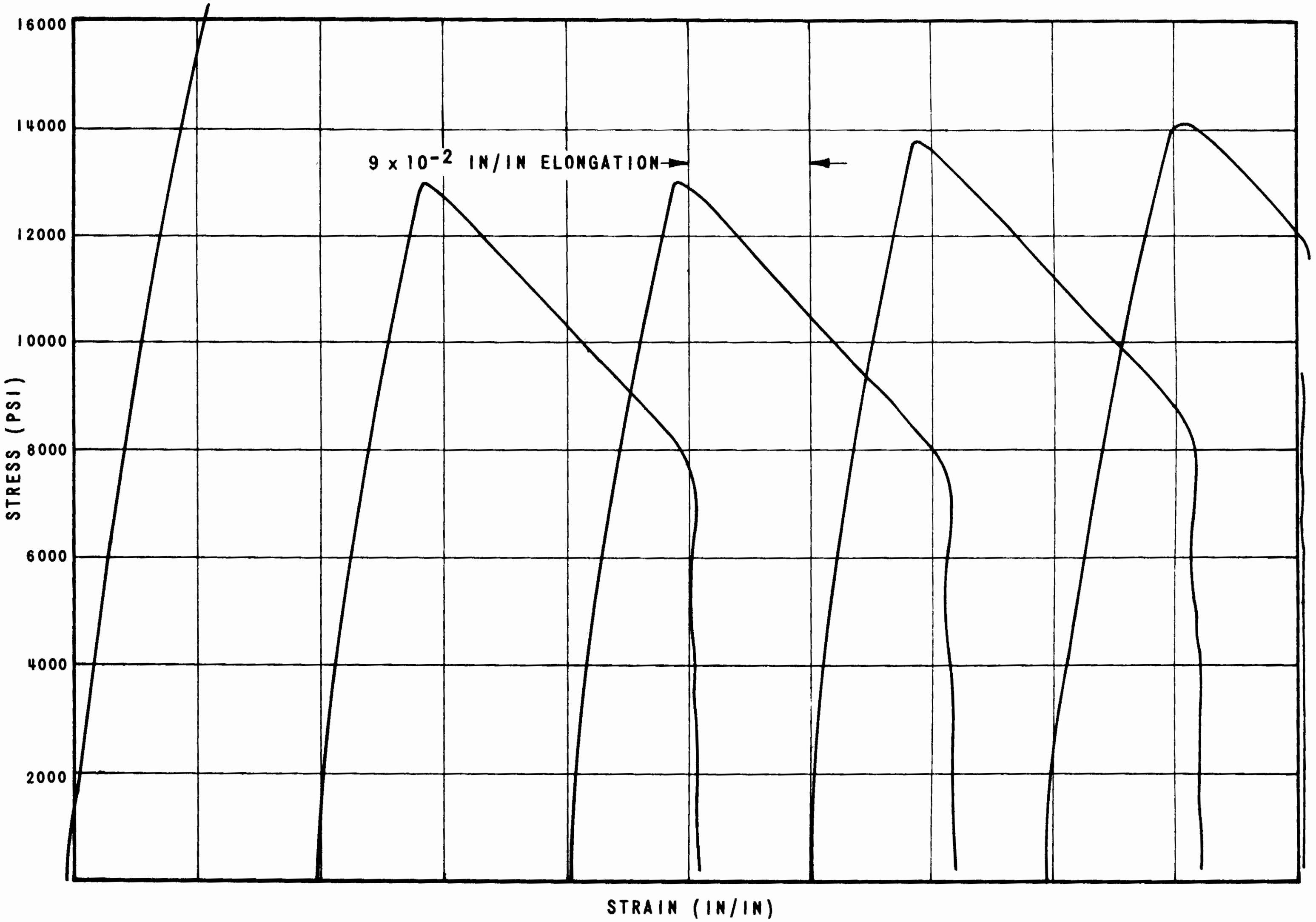


FIGURE 18.1 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C ONE WEEK

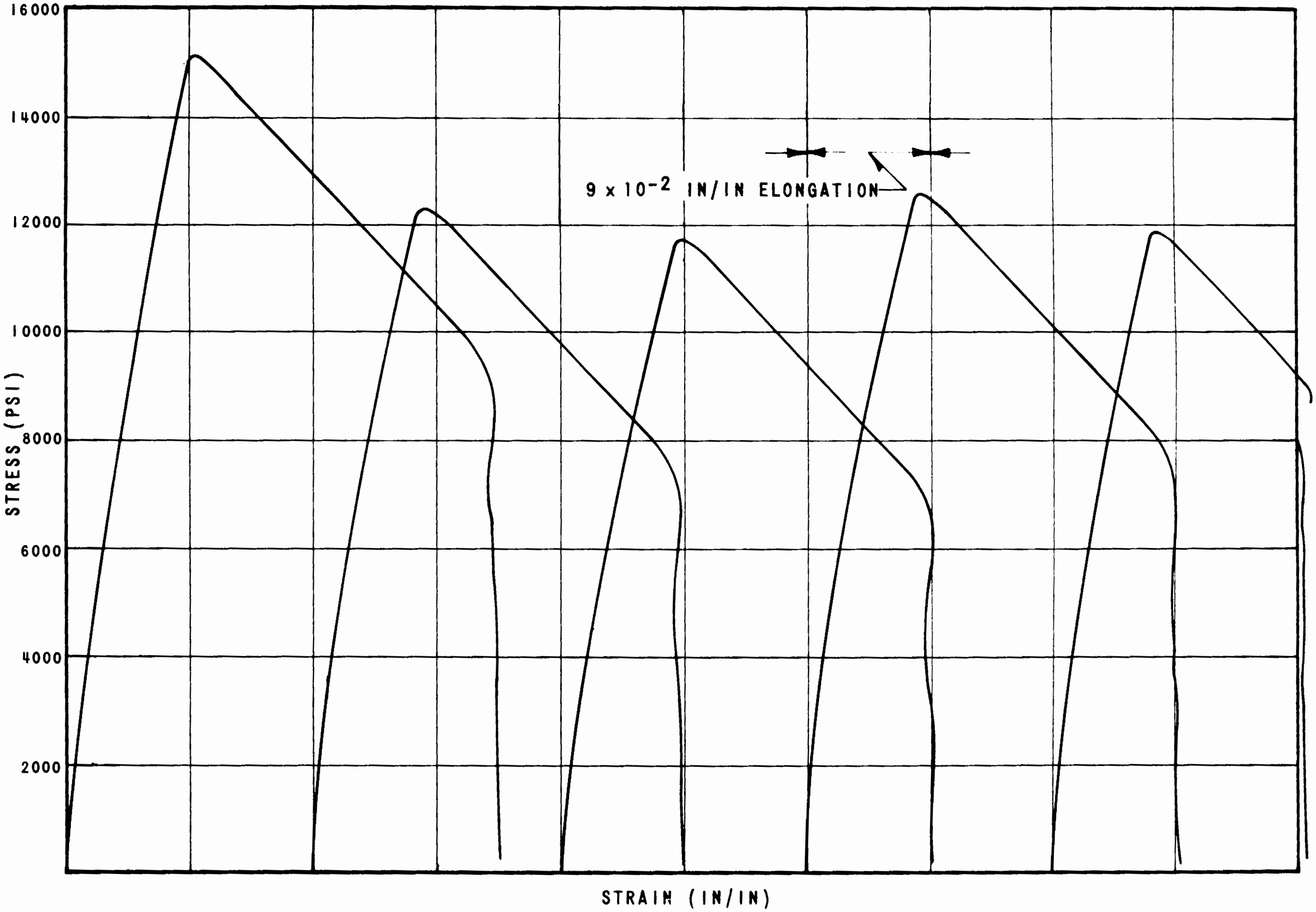


FIGURE 18.2 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C, 4 WEEKS

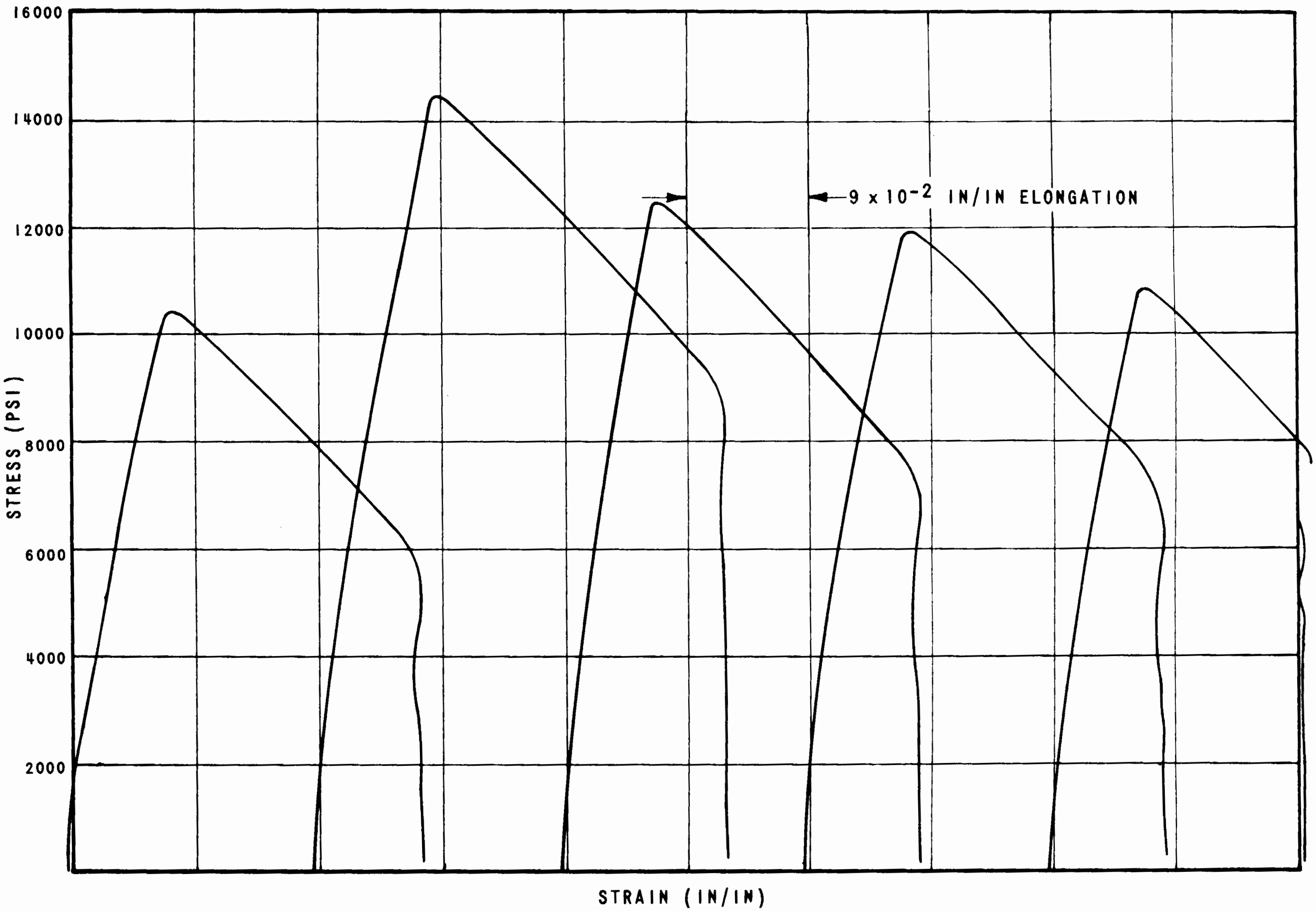


FIGURE 18.3 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C, 12 WEEKS

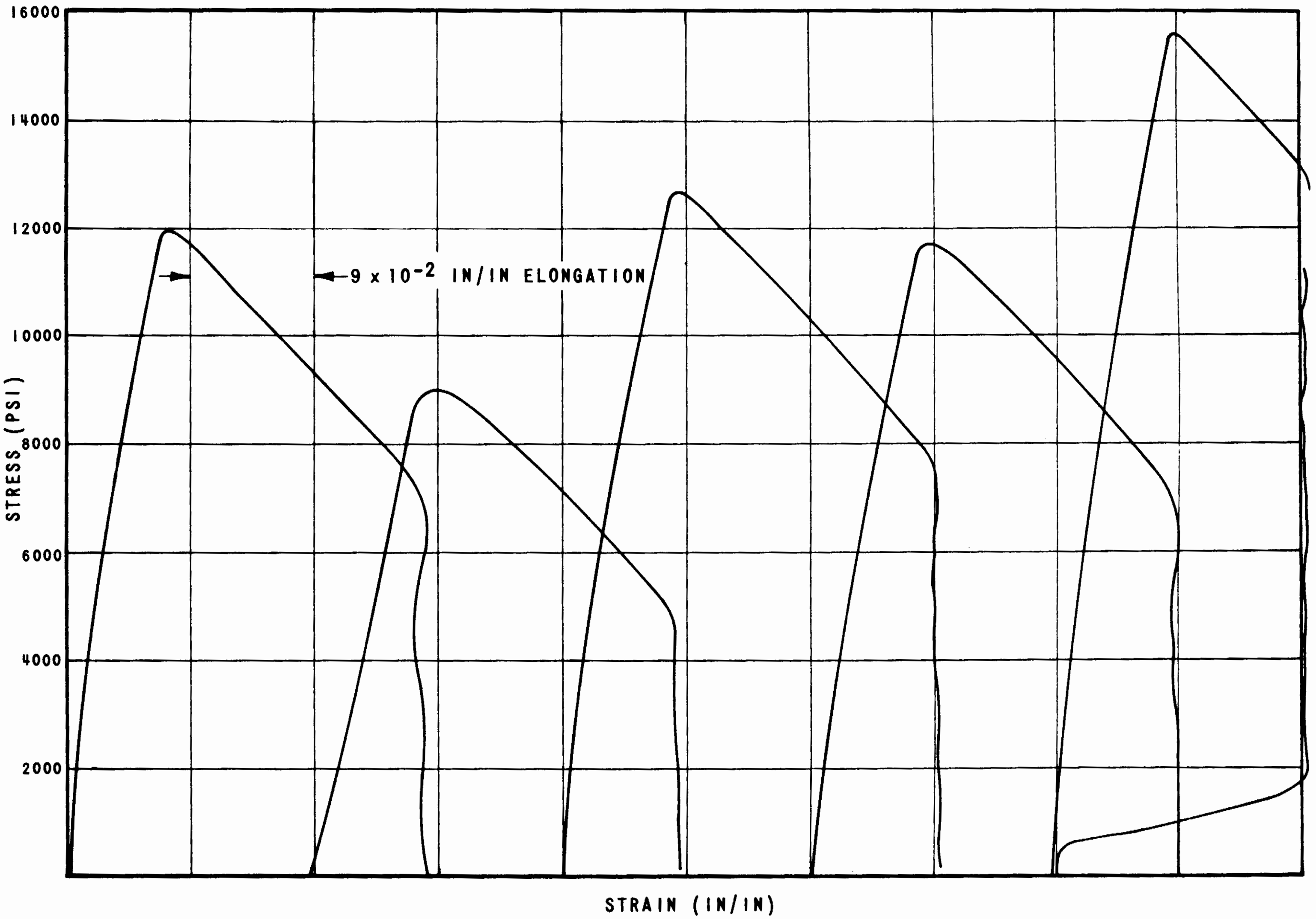


FIGURE 18.4 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C, 24 WEEKS

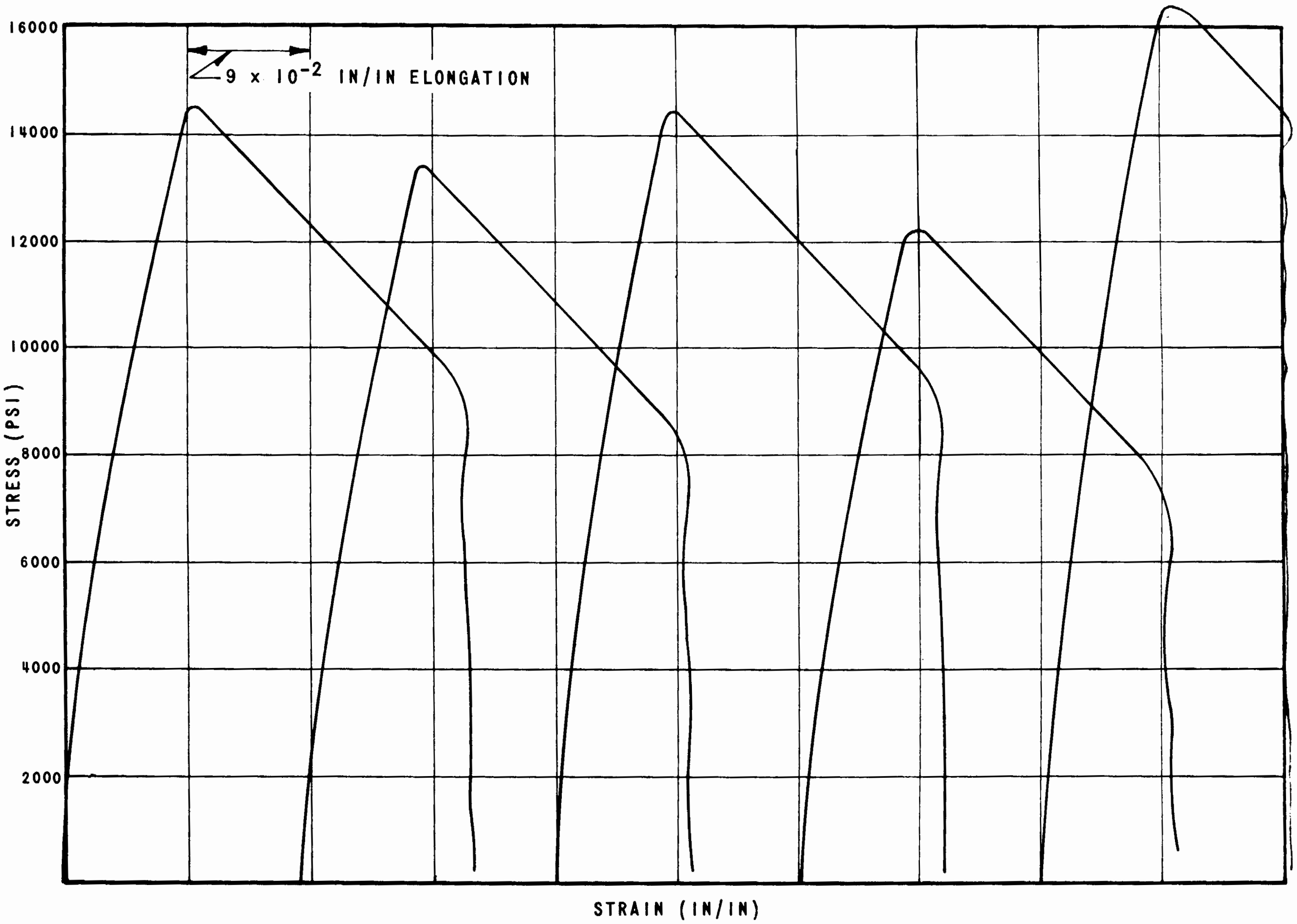


FIGURE 18.5 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C IN FYRQUEL VAPOR, ONE WEEK

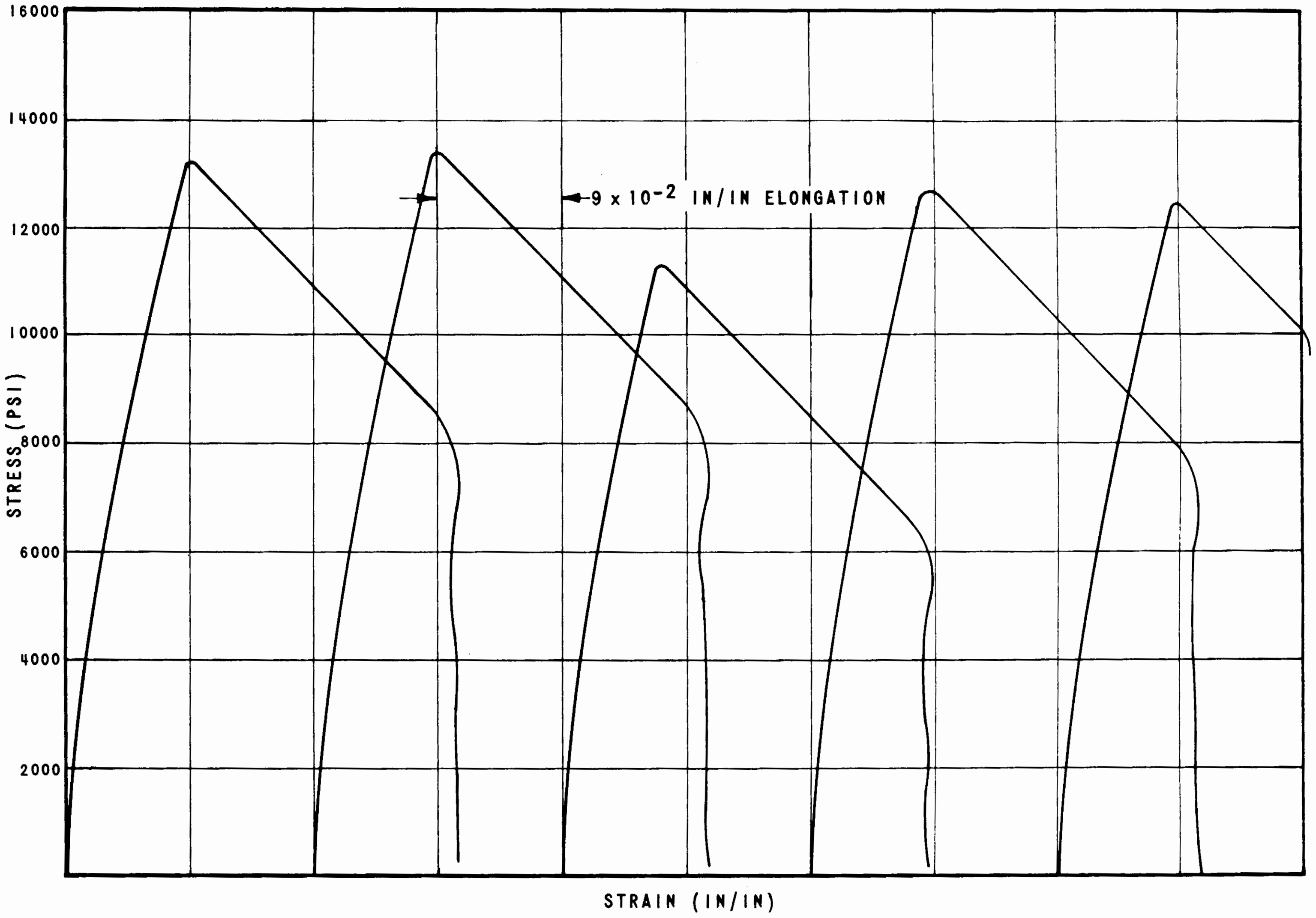


FIGURE 18.6 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C IN FYRQUEL VAPOR, 4 WEEKS

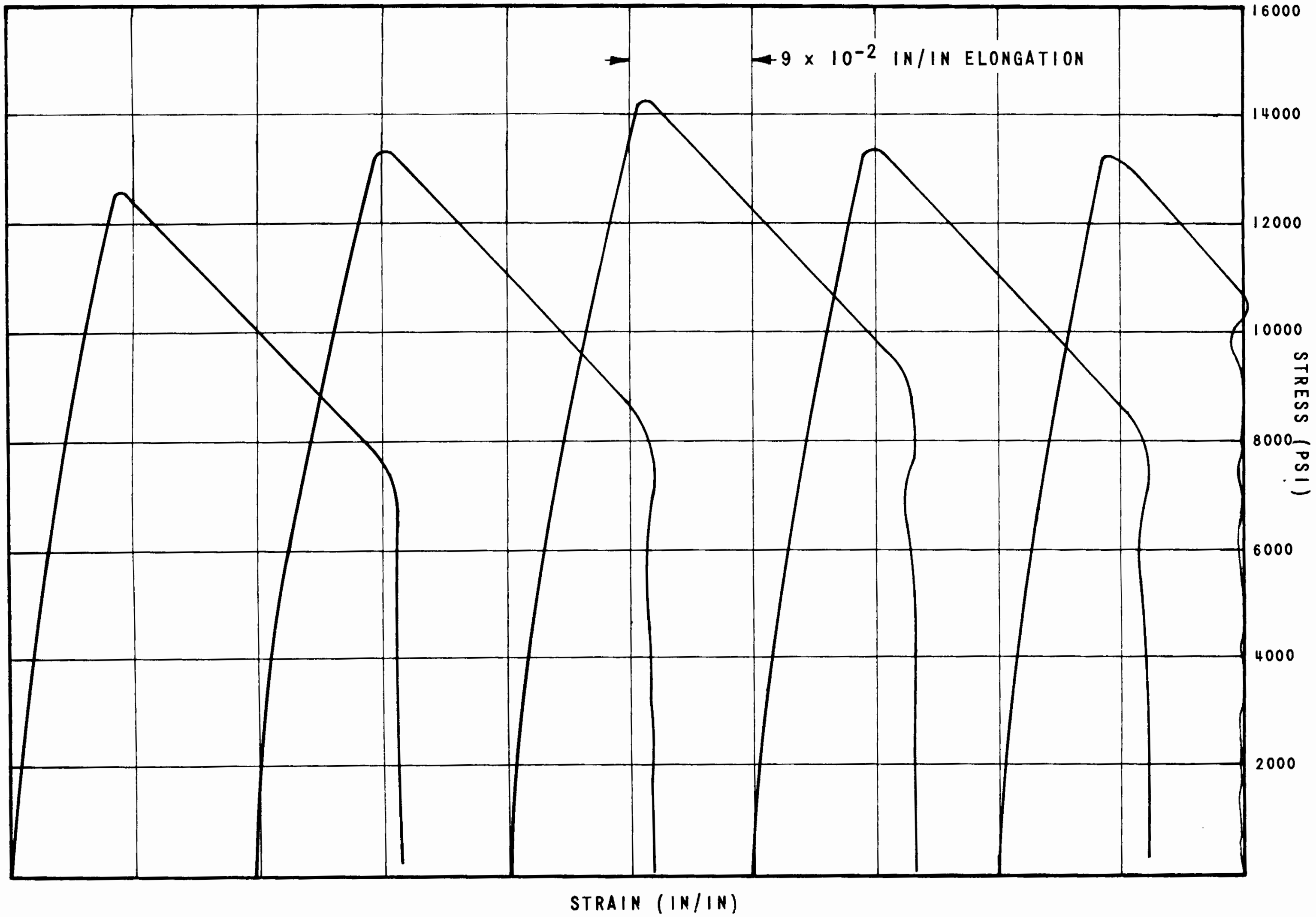


FIGURE 18.7 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C, IN FYRQUEL VAPOR, 12 WEEKS

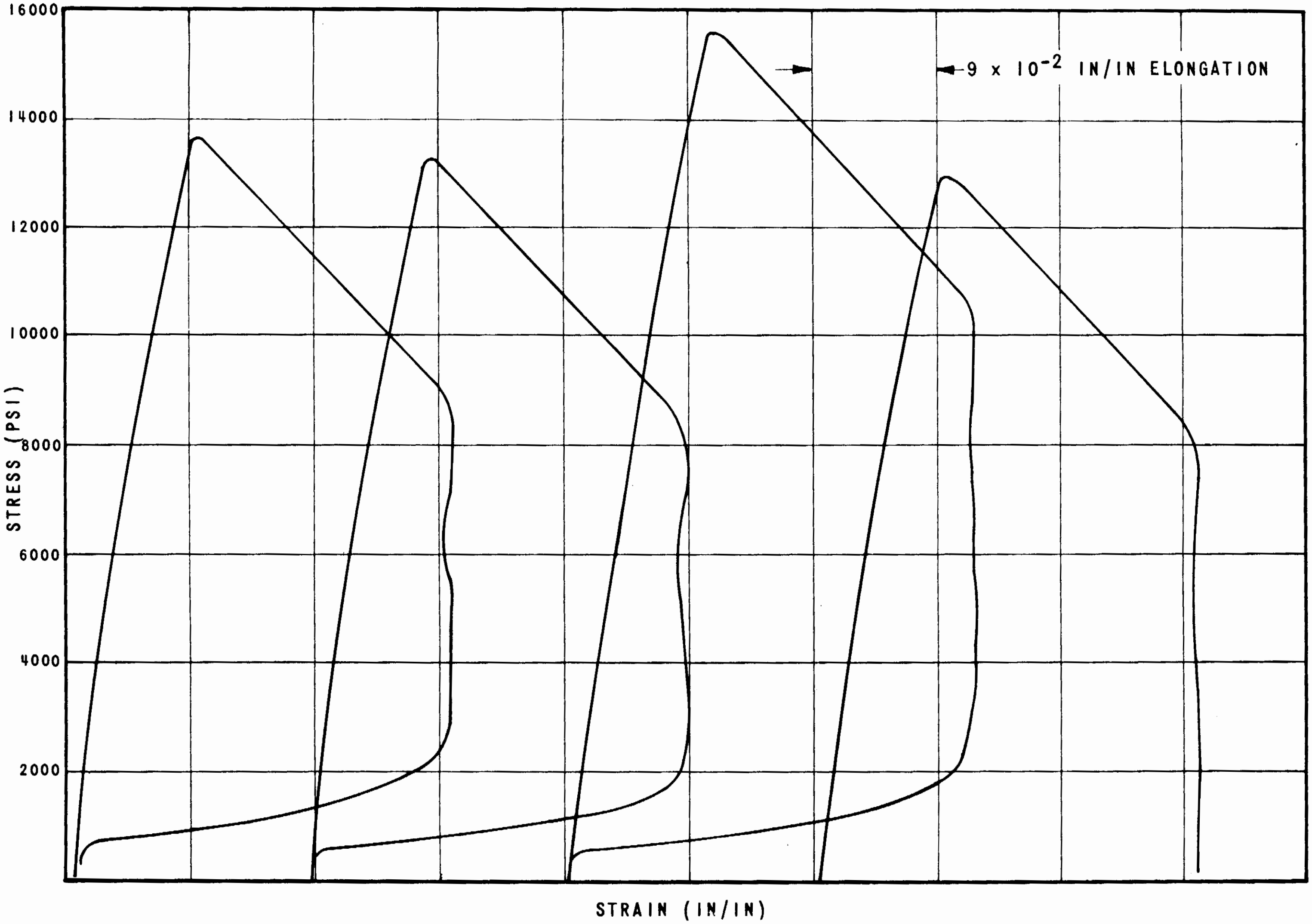


FIGURE 18.8 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C IN FYRQUEL VAPOR, 24 WEEKS

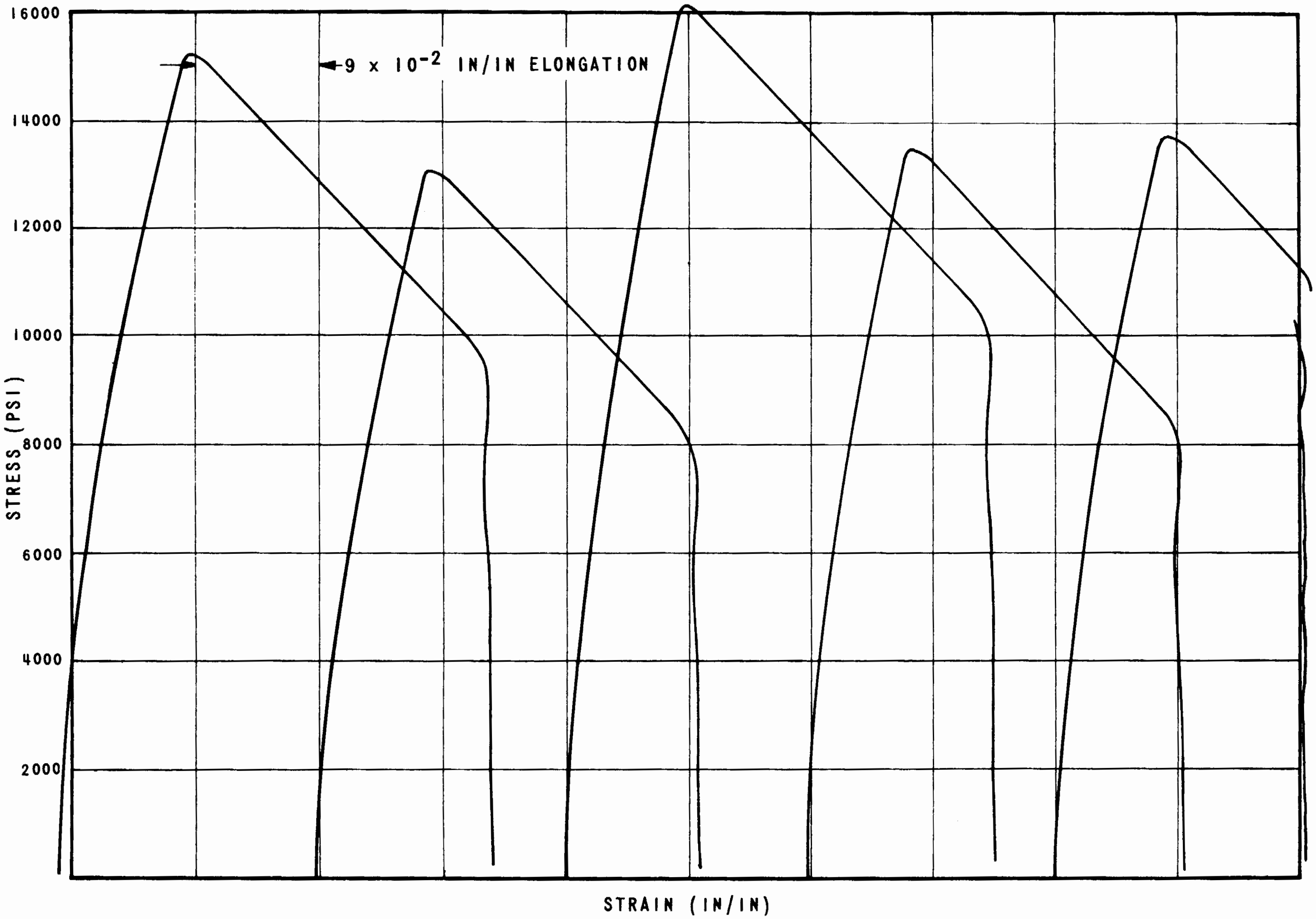


FIGURE 18.9 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER NEMA GPO–1, AGED 135°C IN FYRQUEL LIQUID, 4 WEEKS

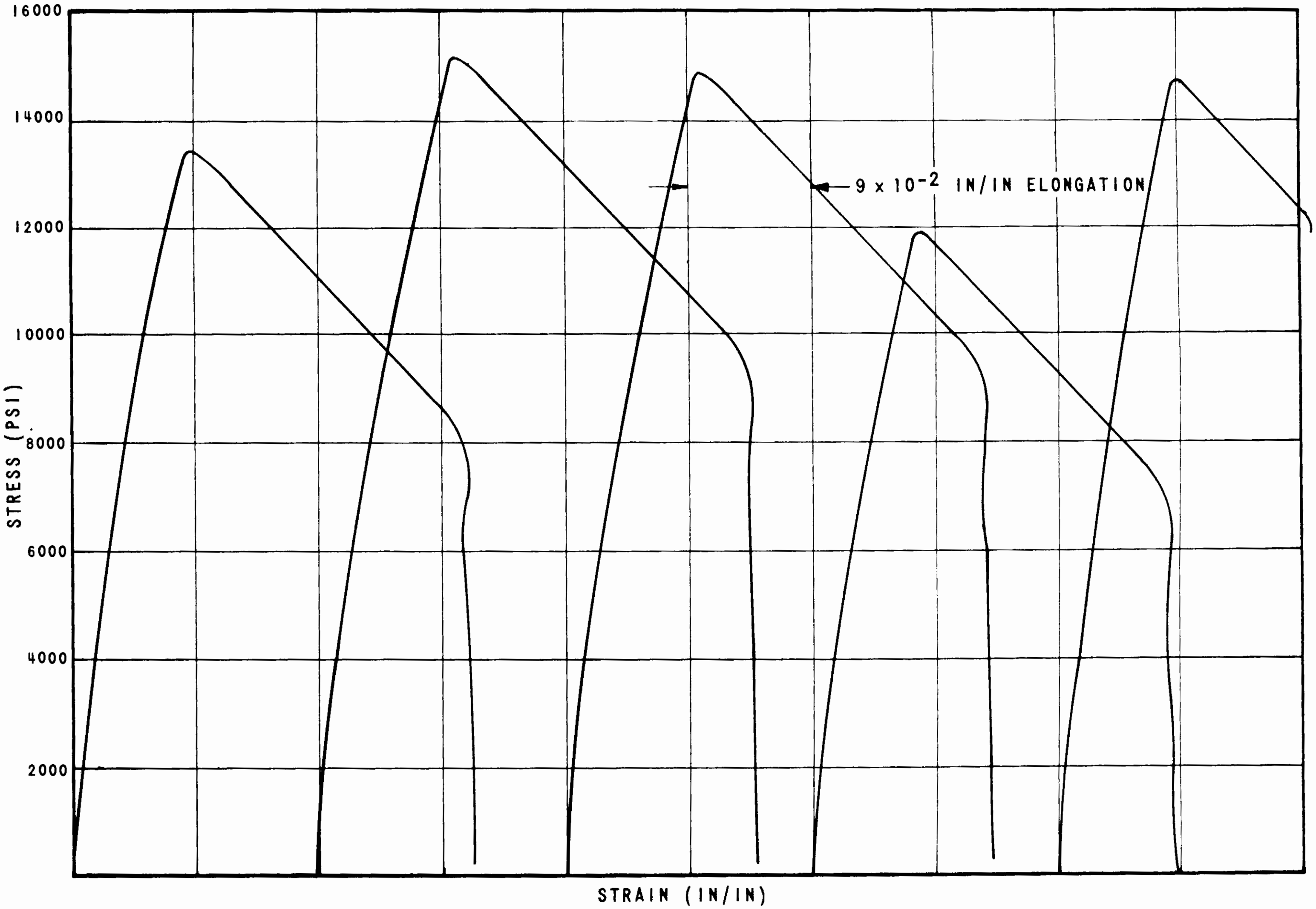


FIGURE 18.10 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C IN FYRQUEL LIQUID, 12 WEEKS

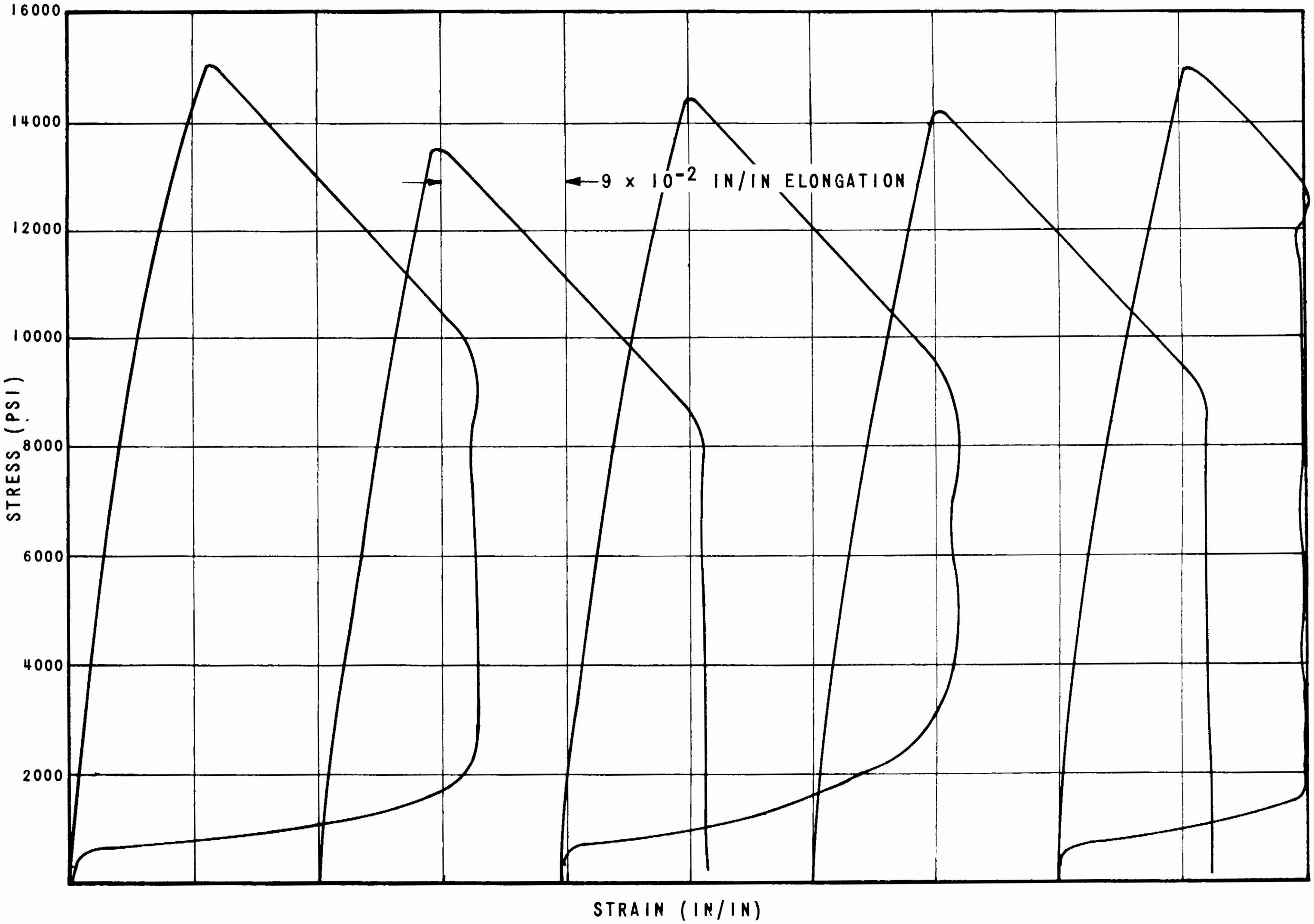


FIGURE 18.11 TENSILE STRESS–STRAIN, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C IN FYRQUEL LIQUID, 24 WEEKS

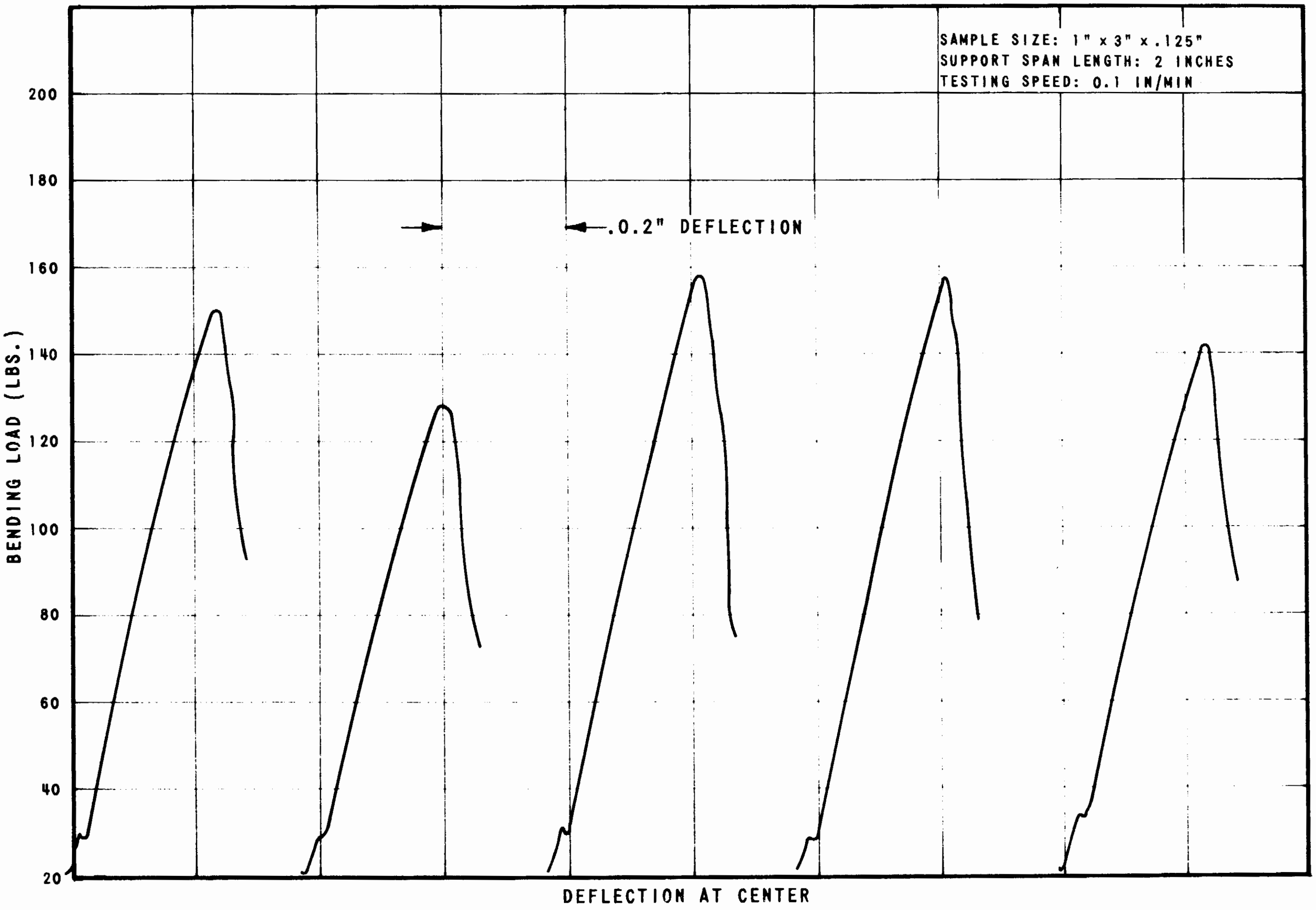


FIGURE 18.12 3–POINT FLEXURE, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C, 24 WEEKS

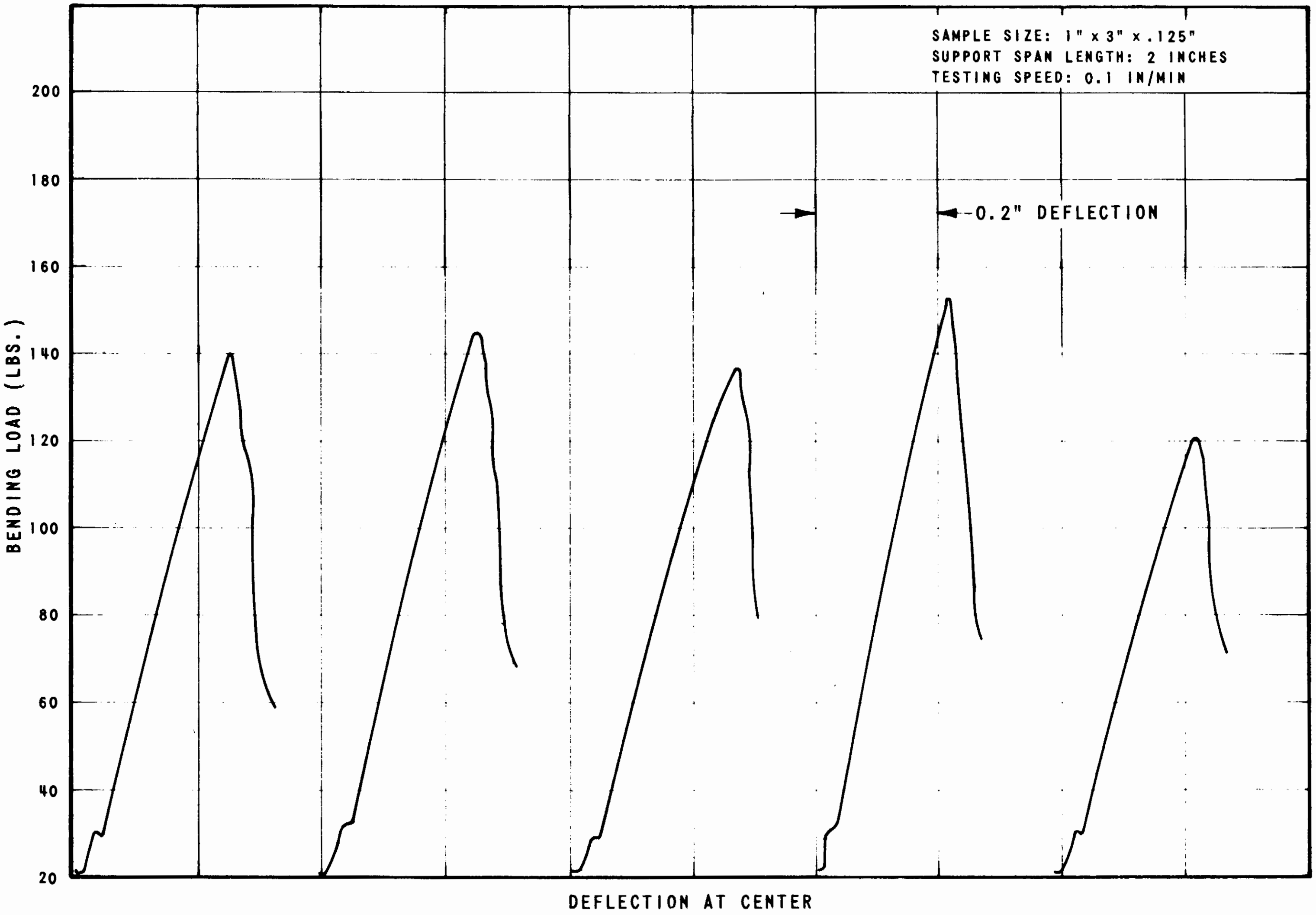


FIGURE 18.13 3–POINT FLEXURE, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C IN FYRQUEL VAPOR, 24 WEEKS

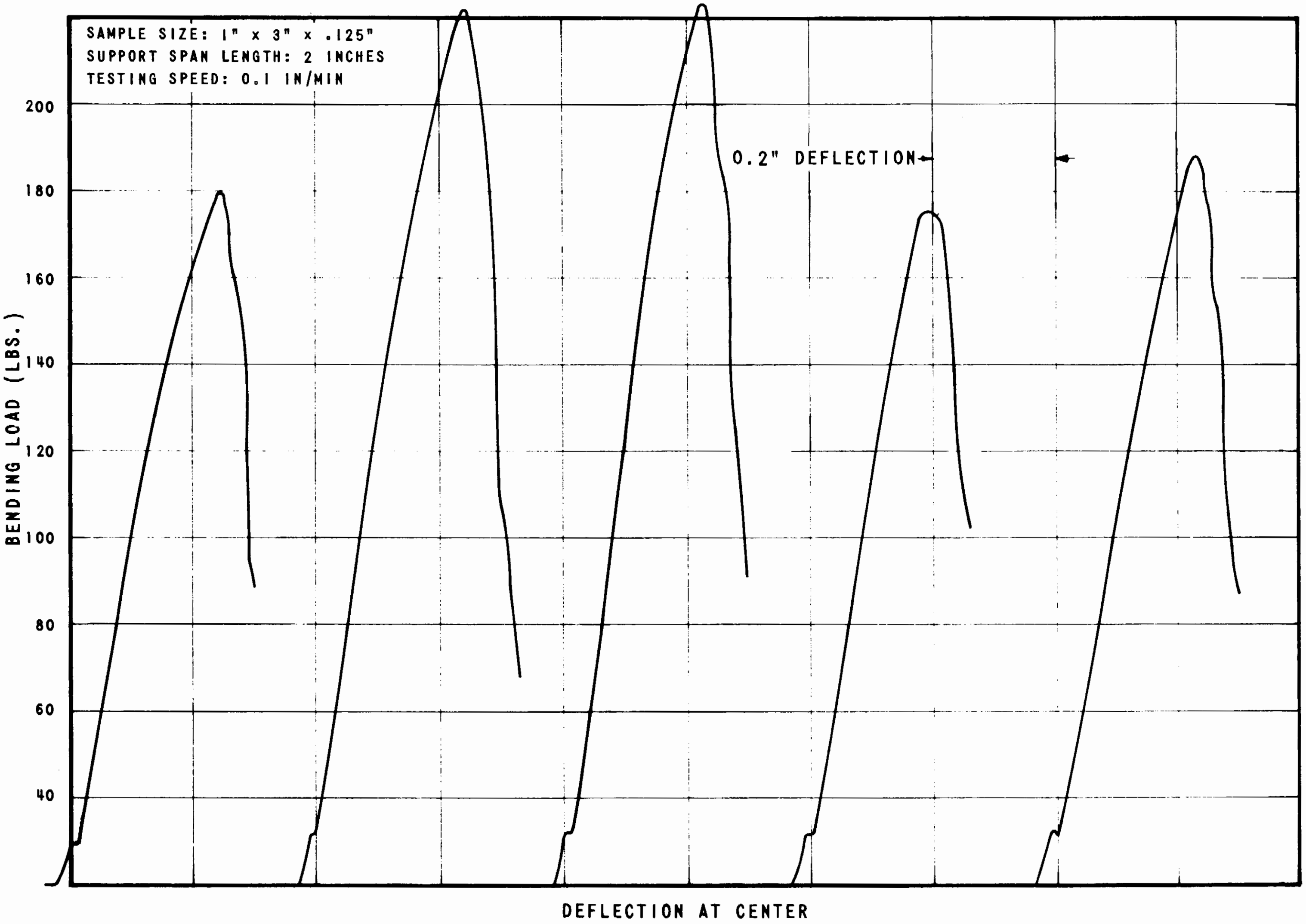


FIGURE 18.14 3–POINT FLEXURE, GLASS MAT POLYESTER LAMINATE NEMA GPO–1, AGED 135°C IN FRYQUEL LIQUID, 24 WEEKS

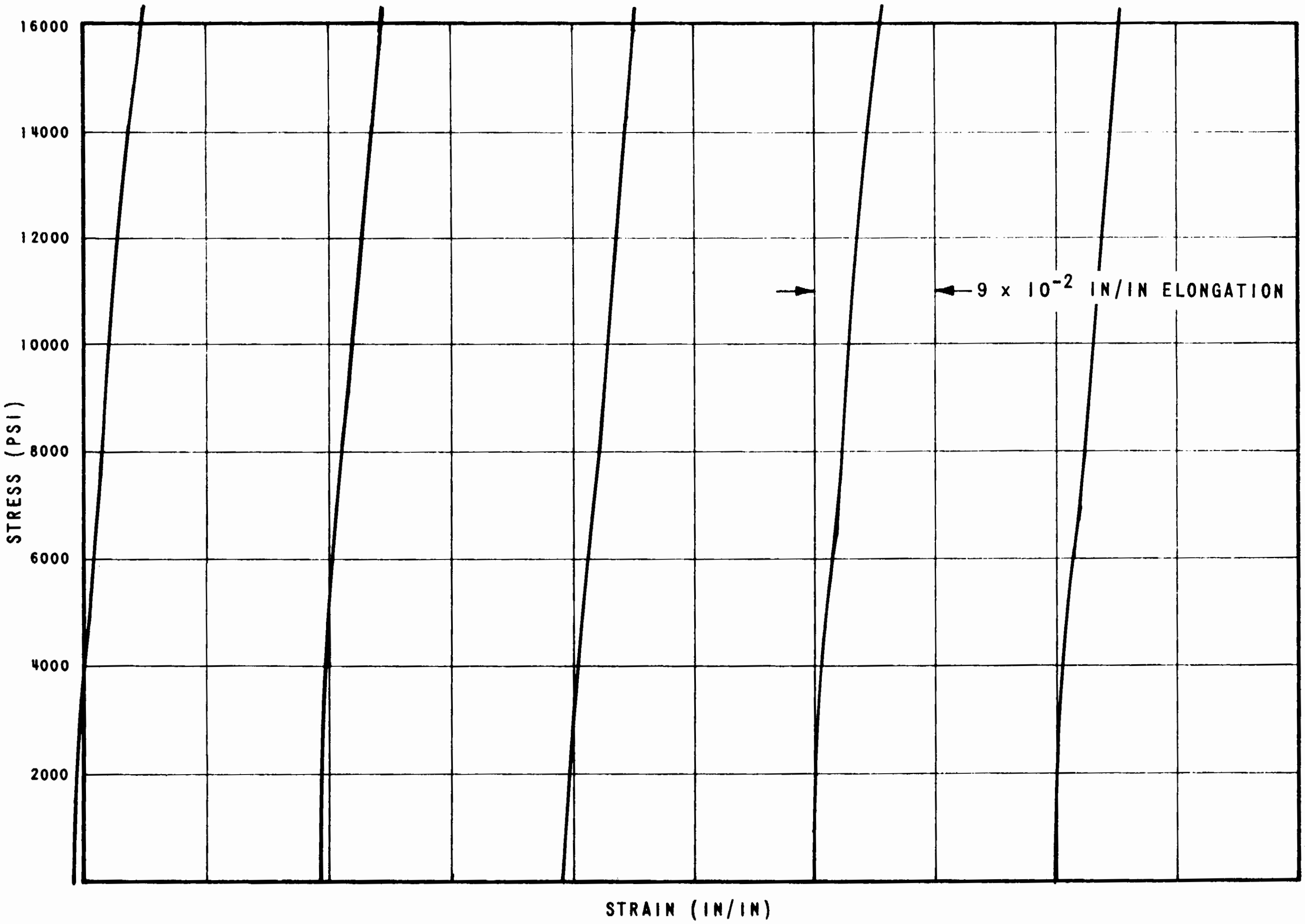


FIGURE 18.15 TENSILE STRESS–STRAIN GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C ONE WEEK

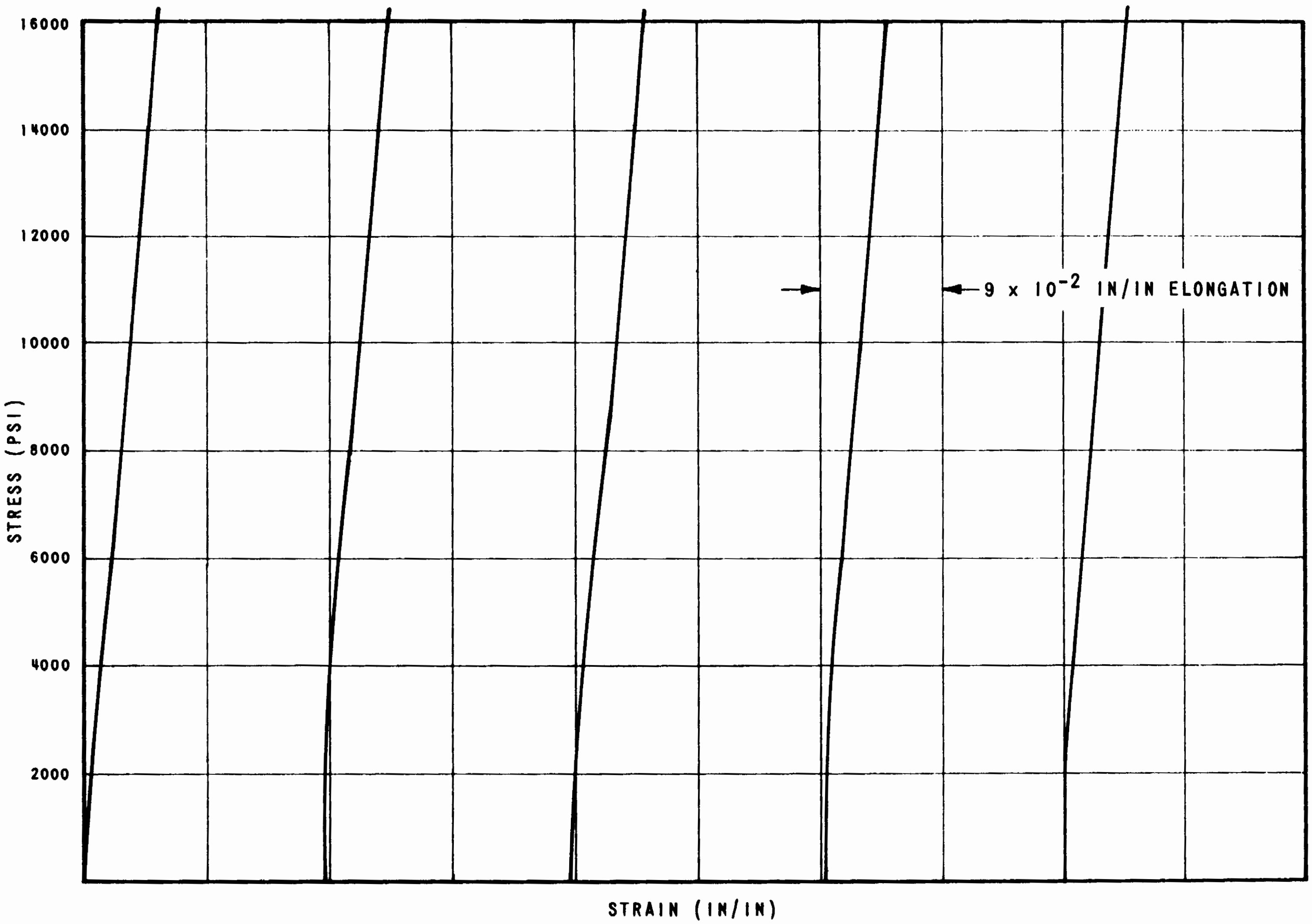


FIGURE 18.16 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C FOUR WEEKS

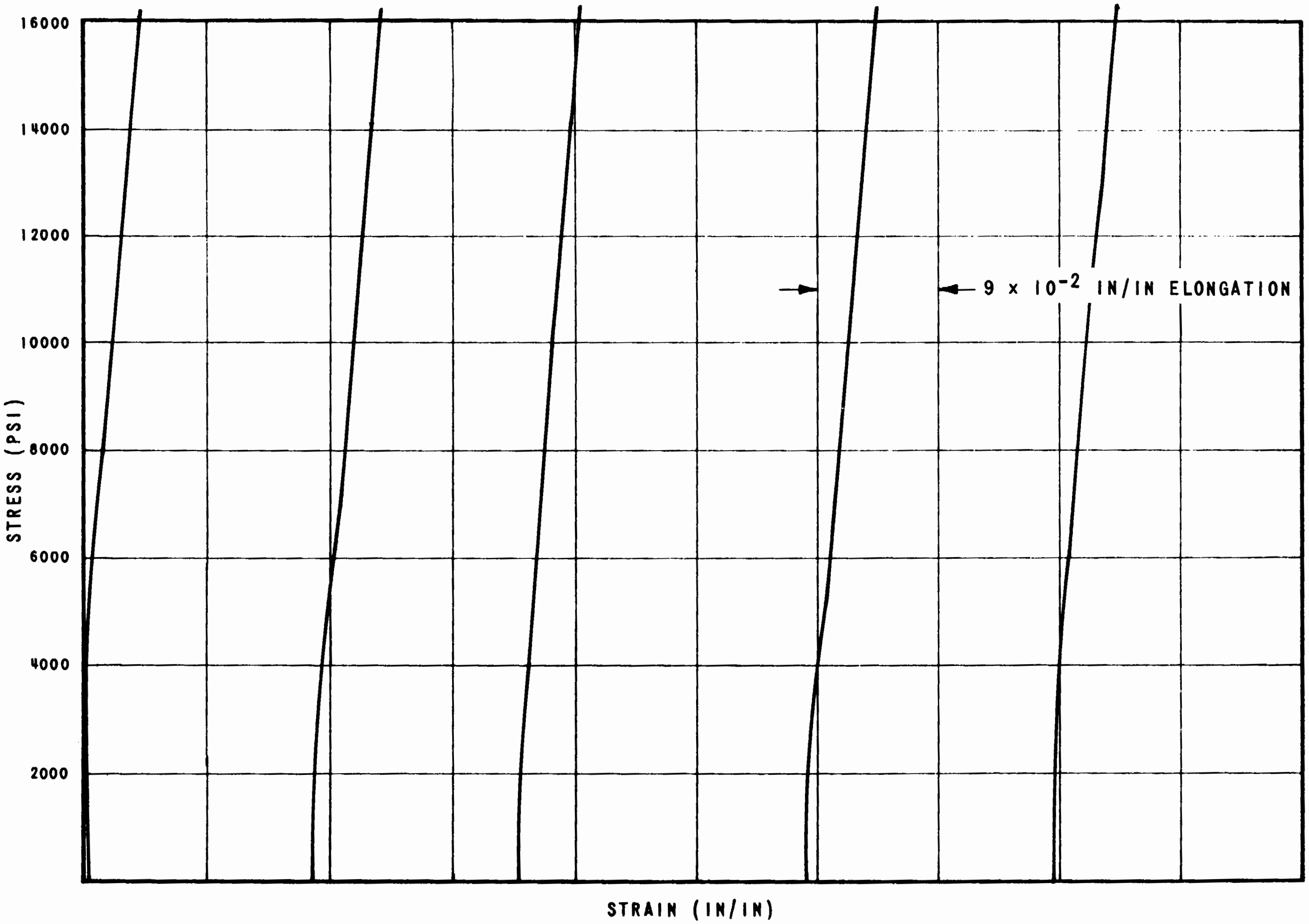


FIGURE 18.17 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C 12 WEEKS

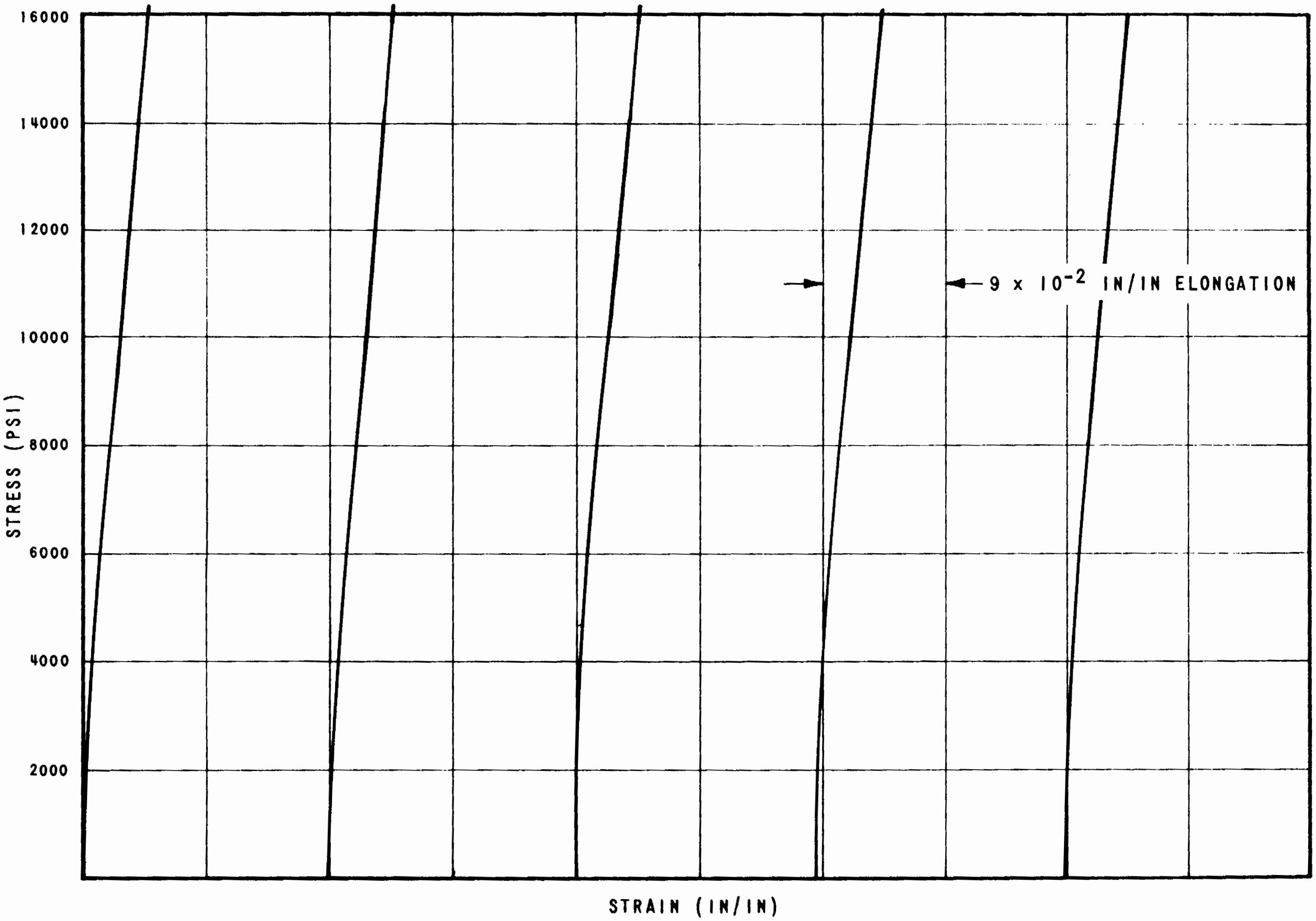


FIGURE 18.18 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C 24 WEEKS

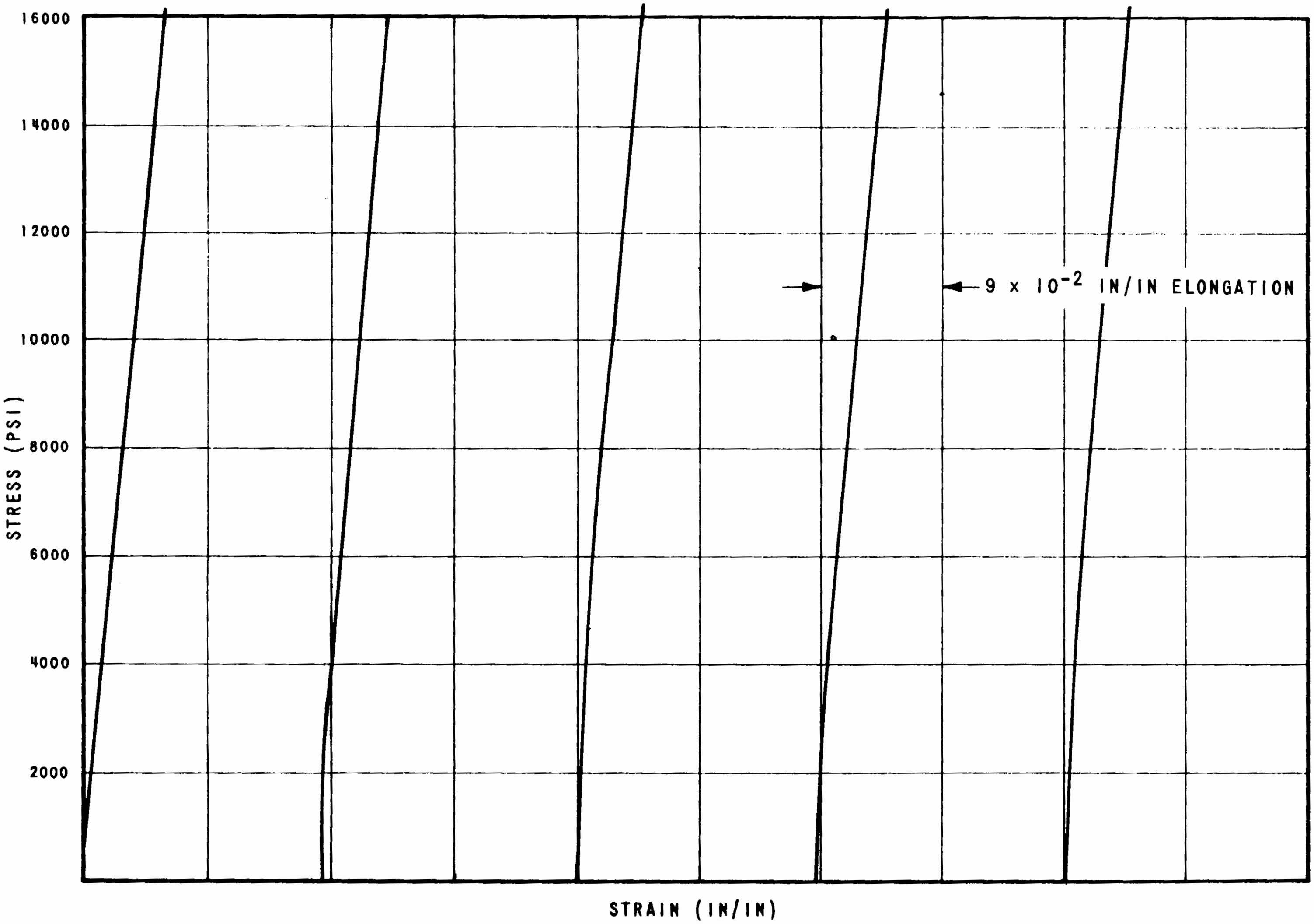


FIGURE 18.19 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C IN FYRQUEL VAPOR ONE WEEK

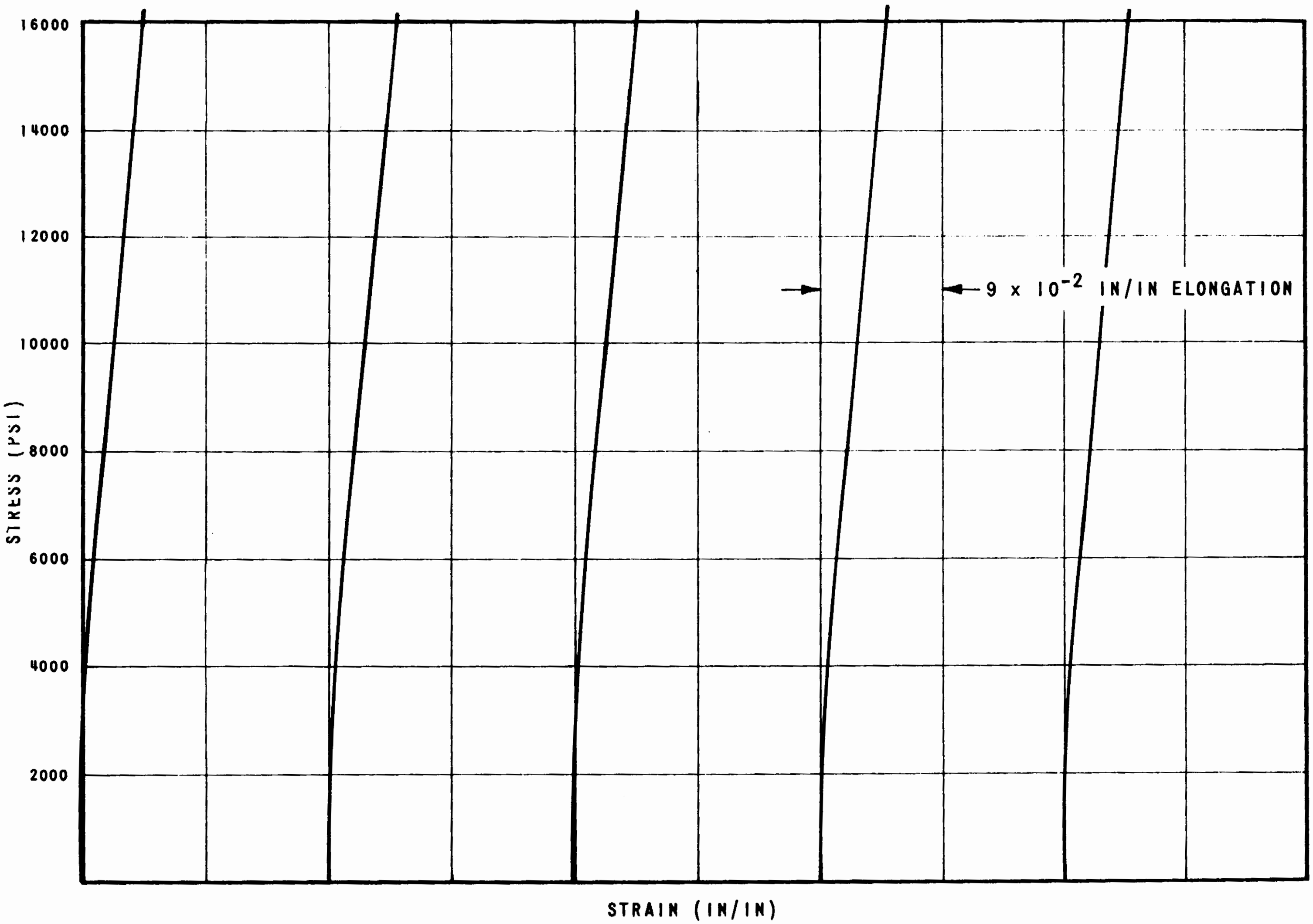


FIGURE 18.20 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C IN FYRQUEL VAPOR FOUR WEEKS

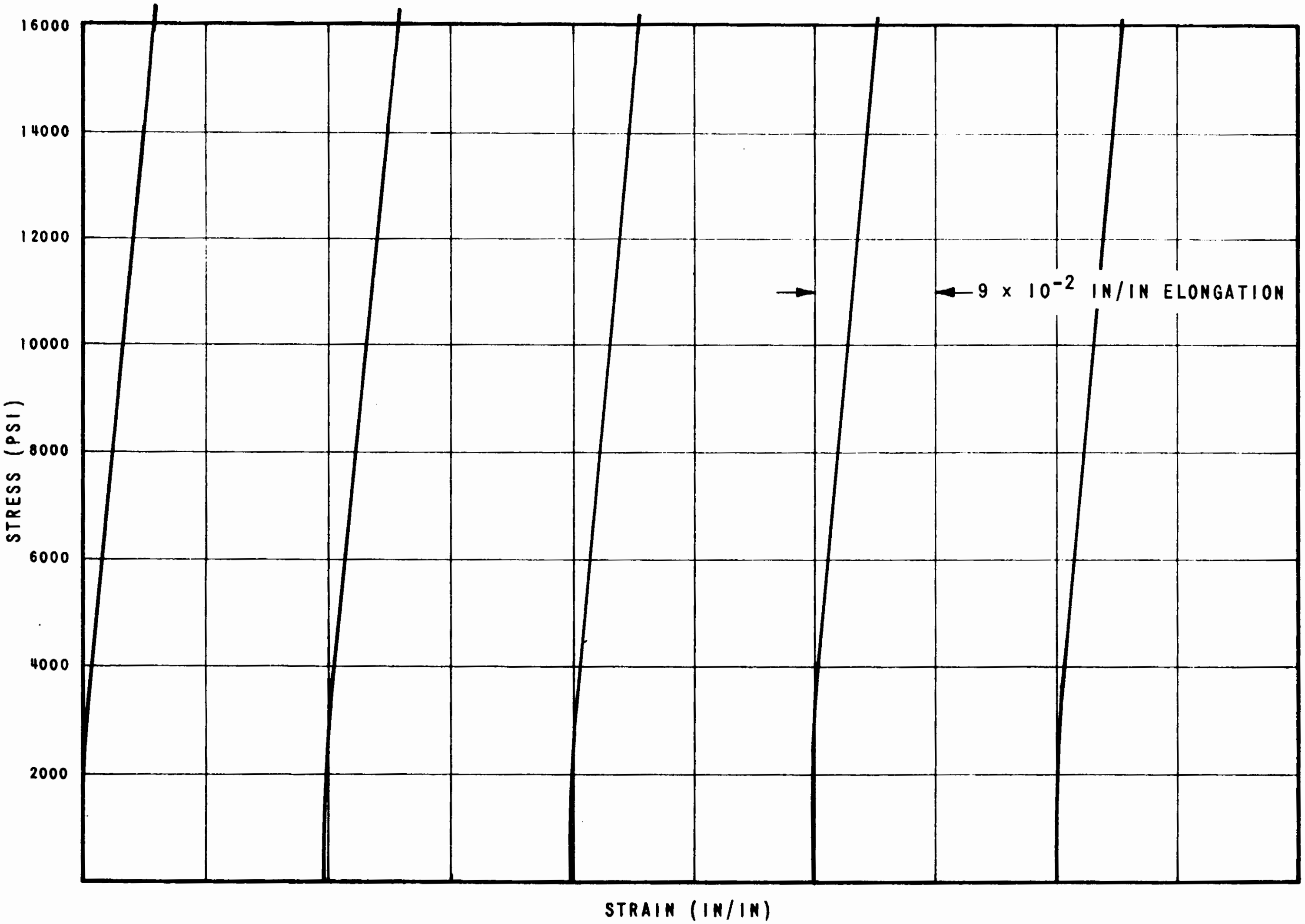


FIGURE 18.21 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C IN FYRQUEL VAPOR 12 WEEKS

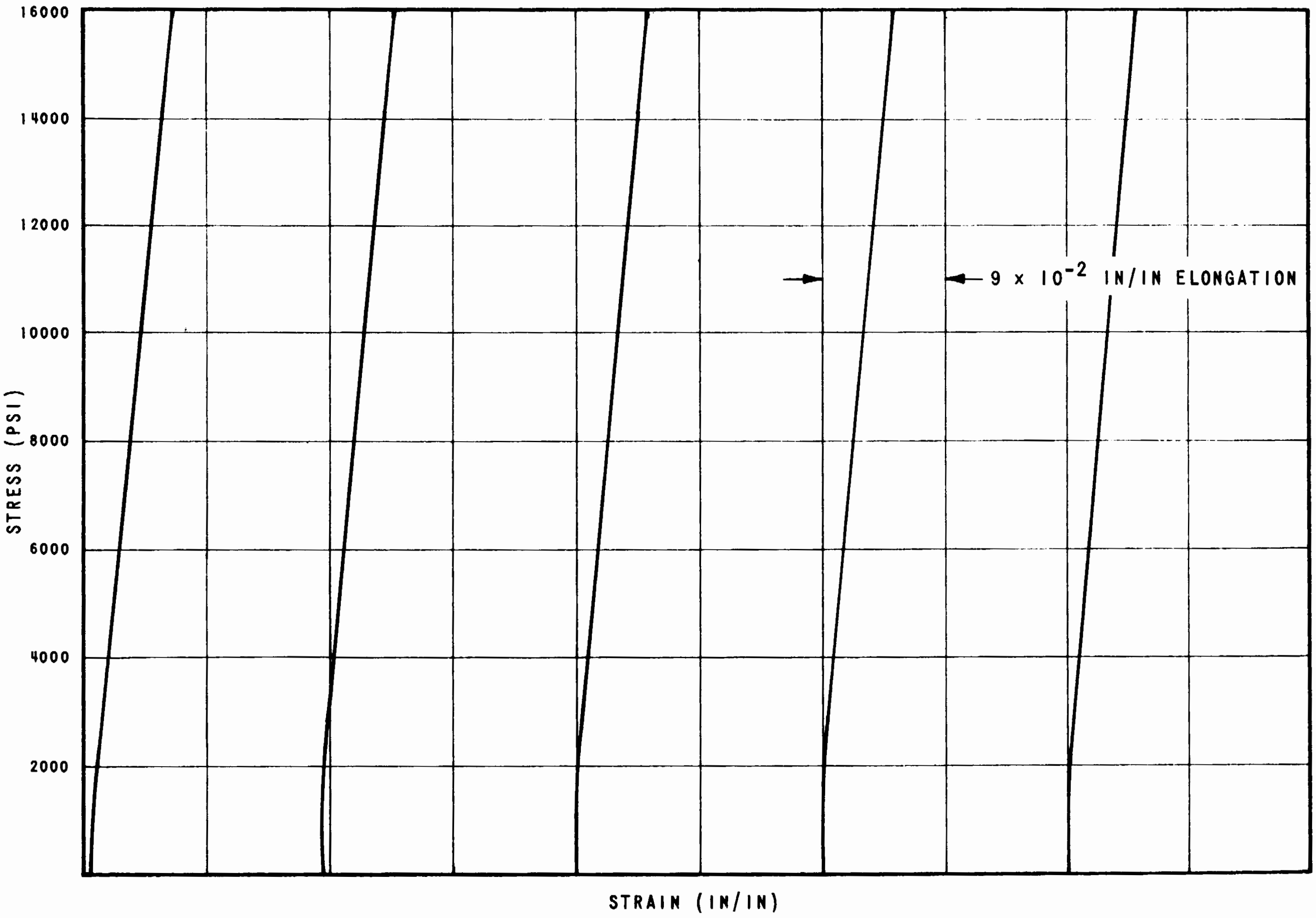


FIGURE 18.22 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C IN FYRQUEL VAPOR 24 WEEKS

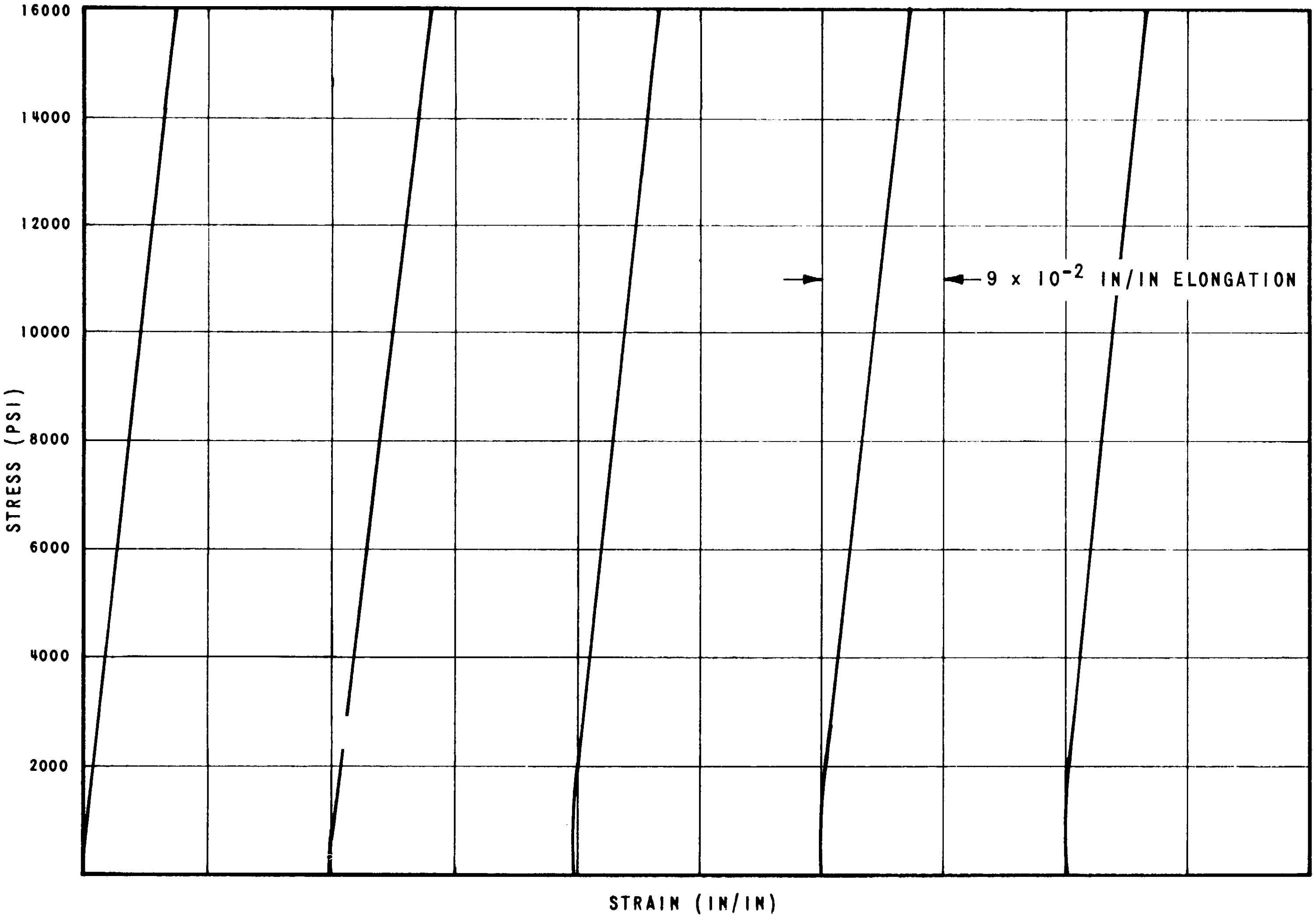


FIGURE 18.23 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135° IN FYRQUEL LIQUID ONE WEEK

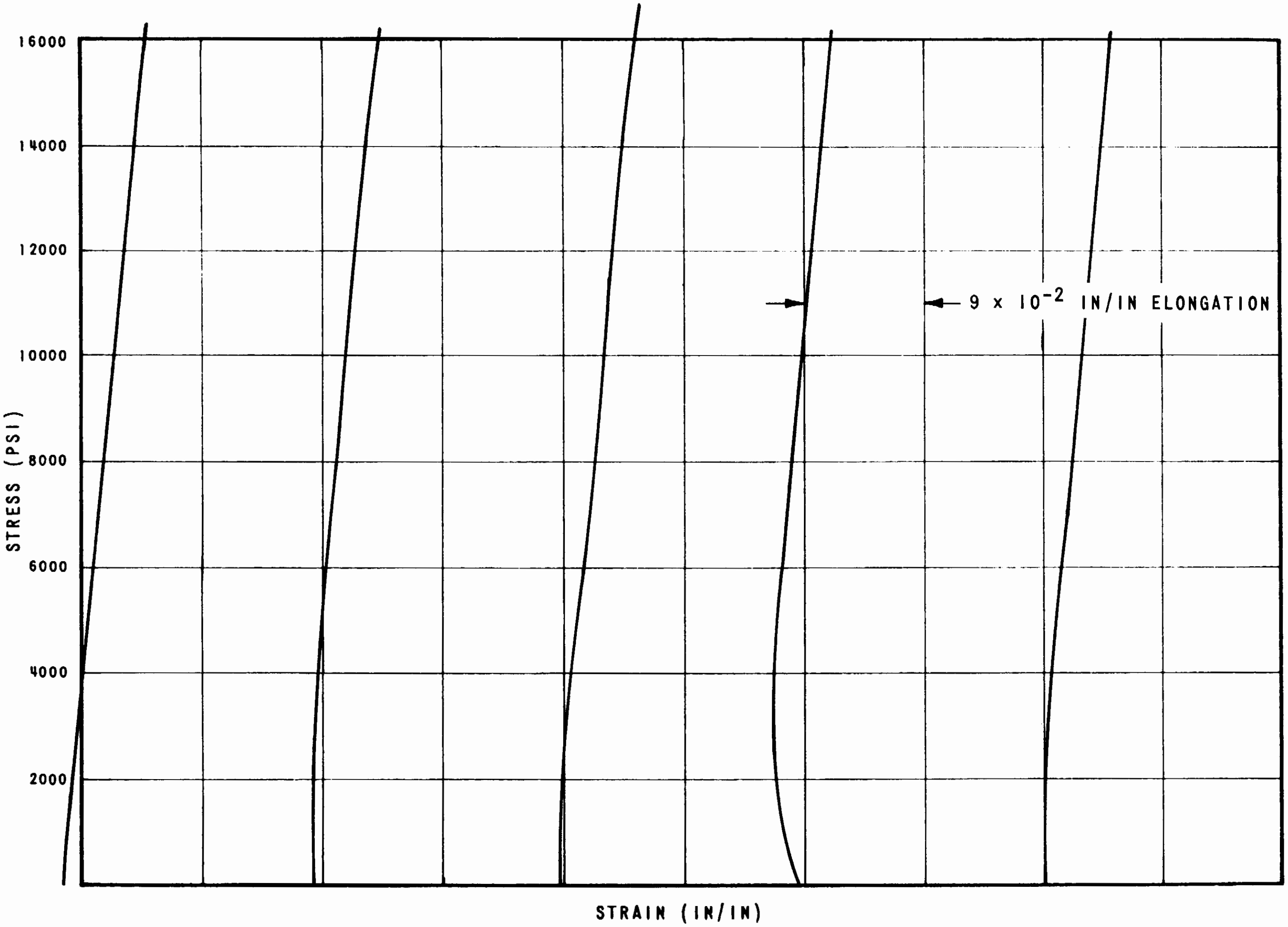


FIGURE 18.24 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C IN FYRQUEL LIQUID 4 WEEKS

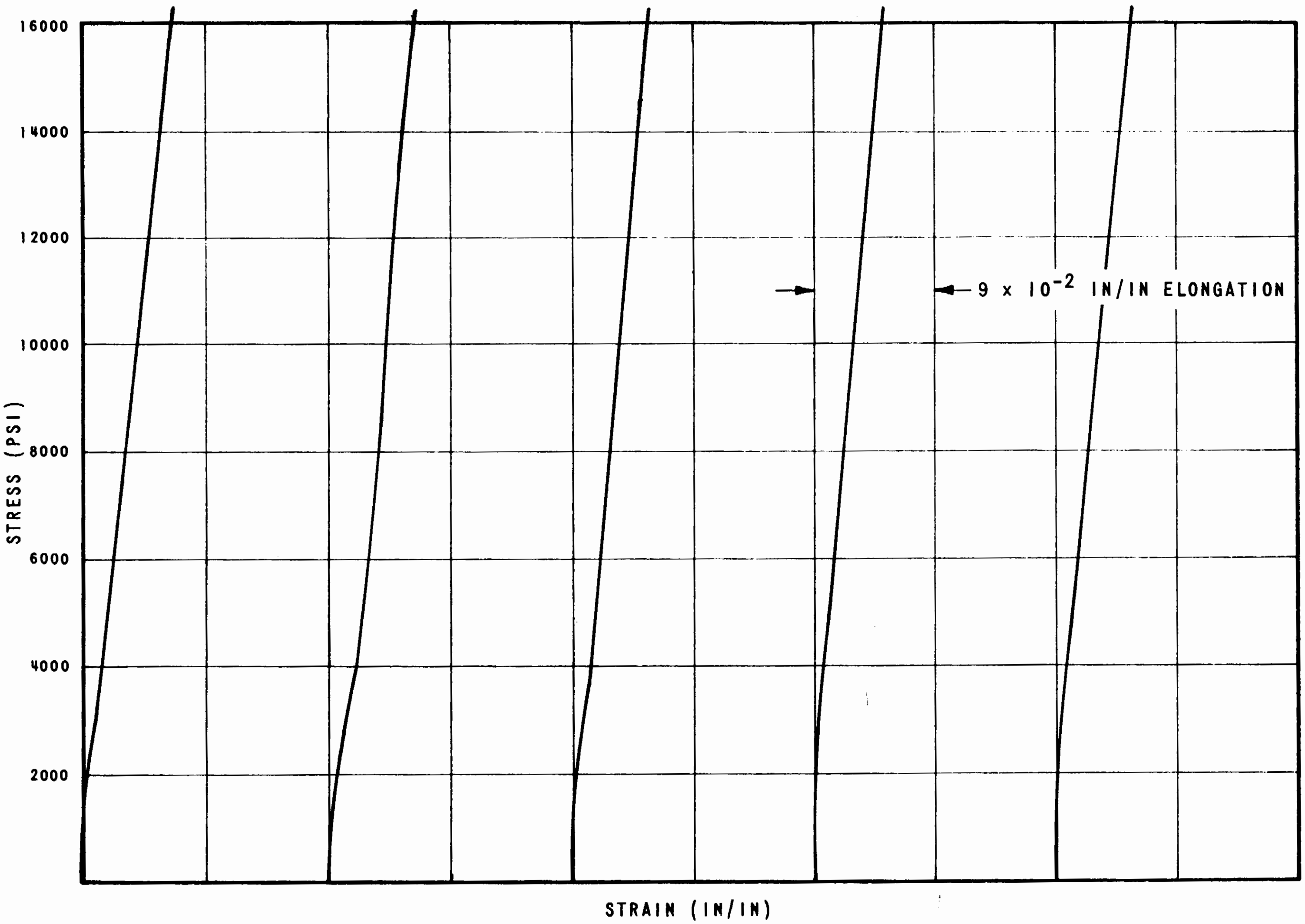


FIGURE 18.25 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C IN FYRQUEL LIQUID 12 WEEKS

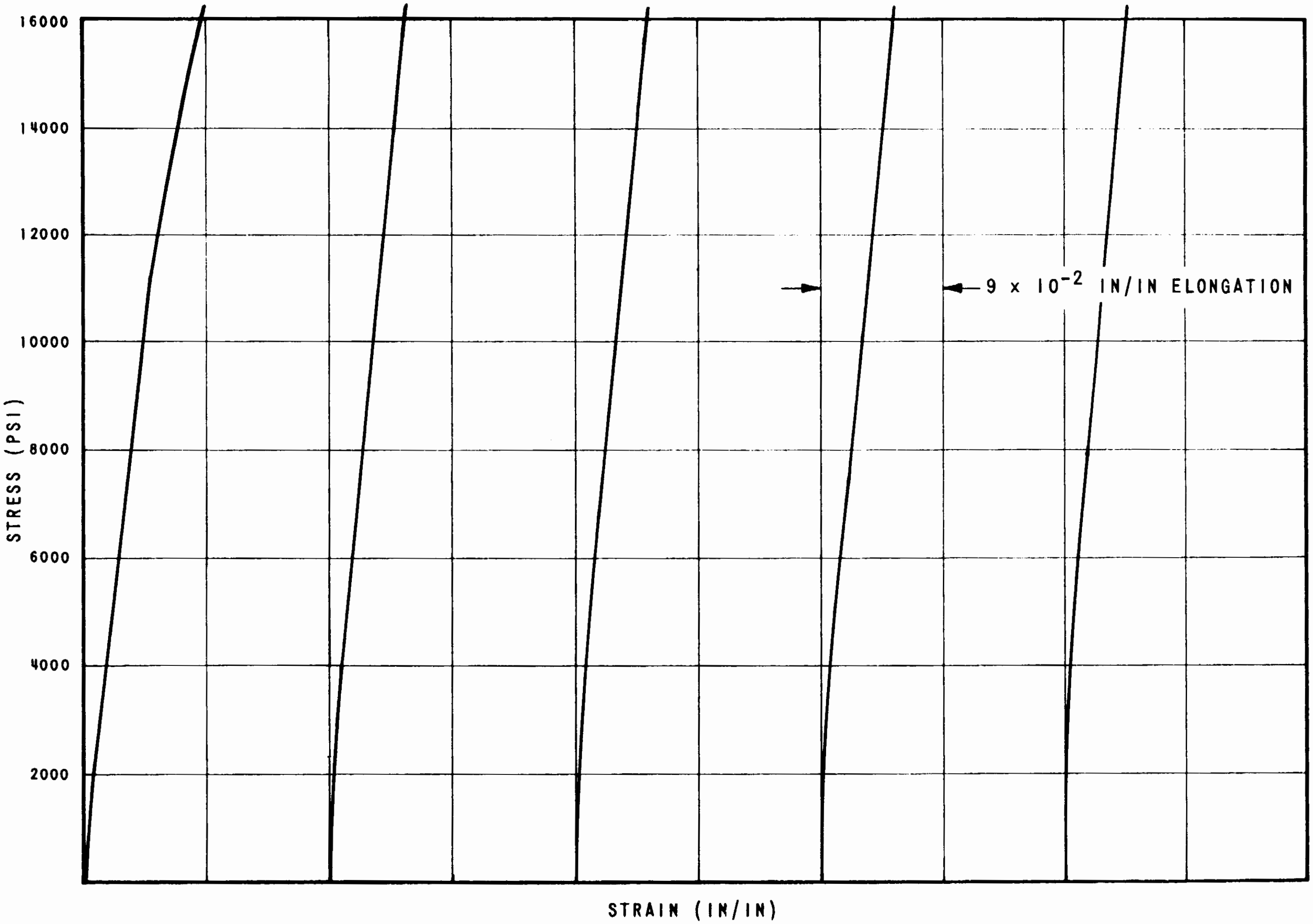


FIGURE 18.26 TENSILE STRESS–STRAIN, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C IN FYRQUEL LIQUID 24 WEEKS

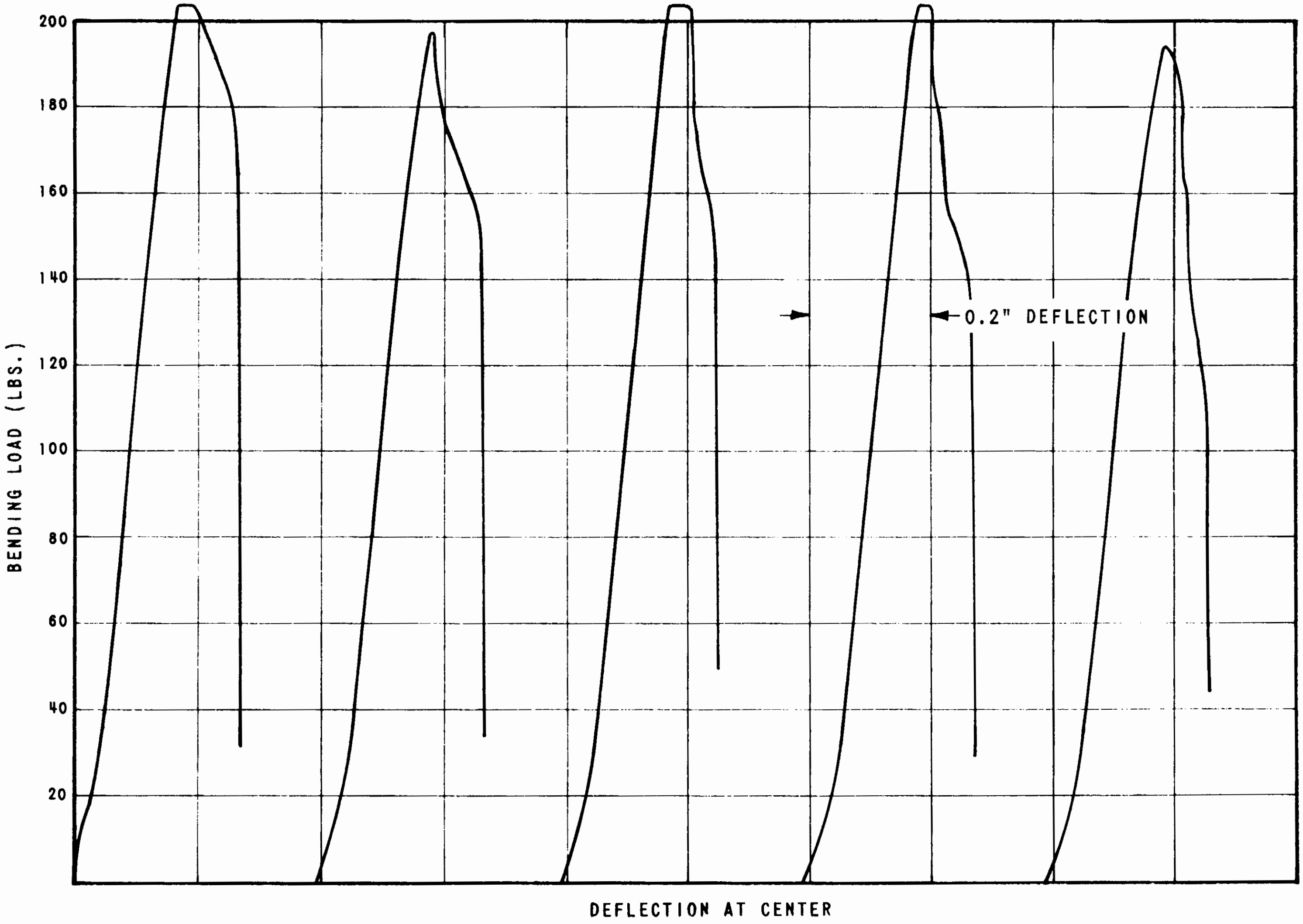


FIGURE 18.27 THREE–POINT FLEXURE, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C 24 WEEKS

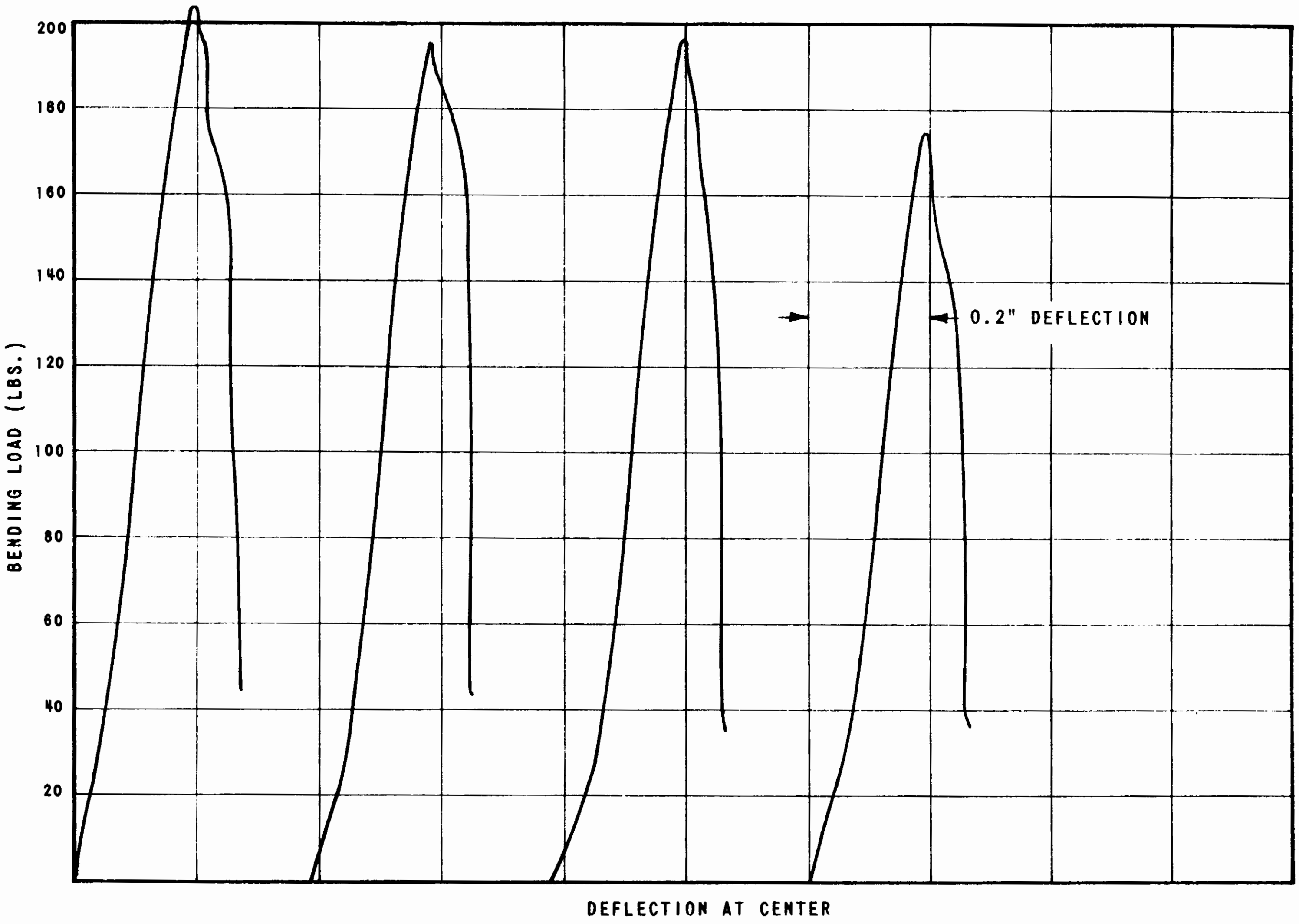


FIGURE 18.28 THREE–POINT FLEXURE, GLASS MELAMINE LAMINATE NEMA G–9, AGED 135°C IN FYRQUEL VAPOR 24 WEEKS

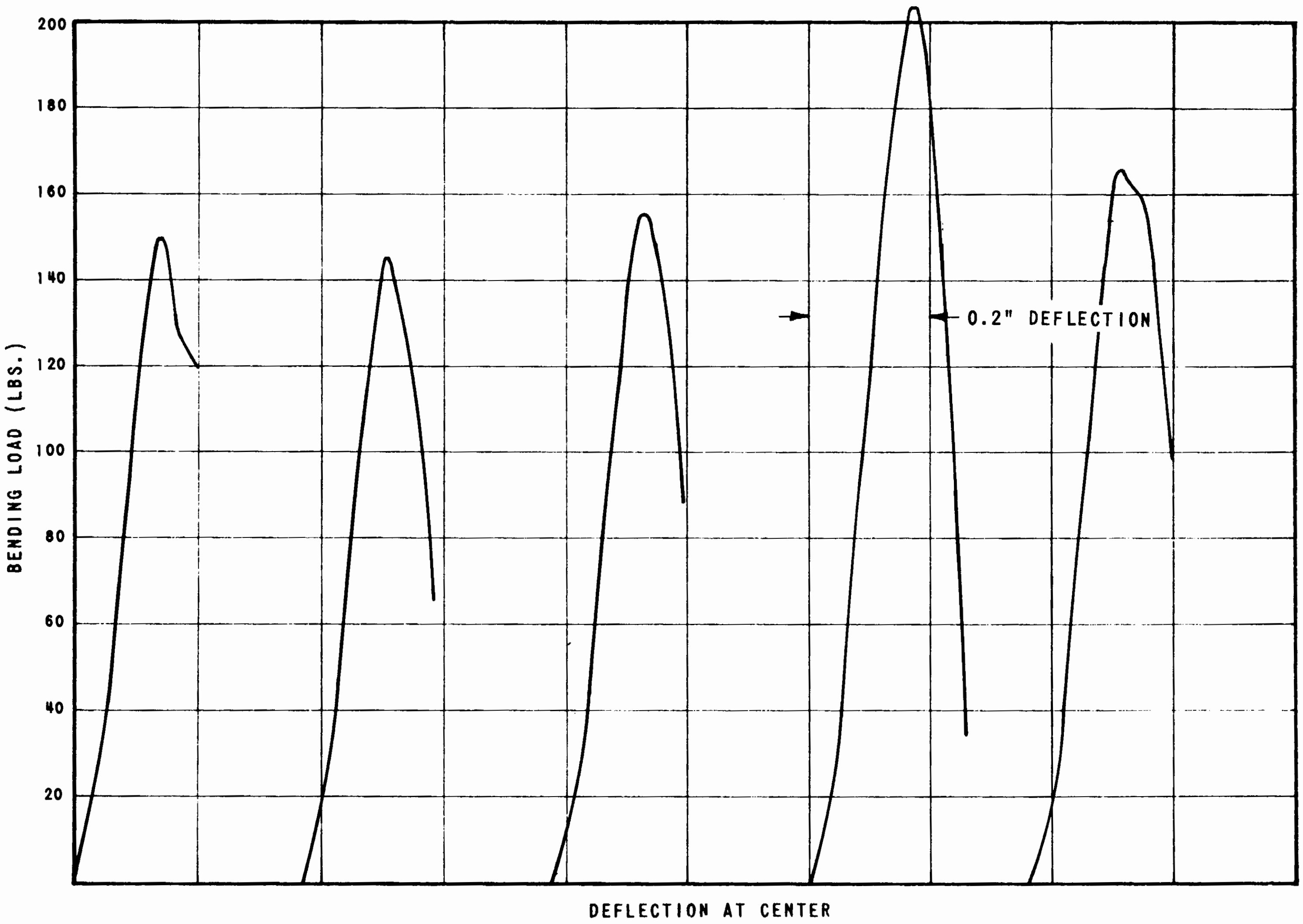


FIGURE 18.29 THREE–POINT FLEXURE, GLASS MELAMINE LAMINATE NEMA G–9, IN FYRQUEL LIQUID 24 WEEKS

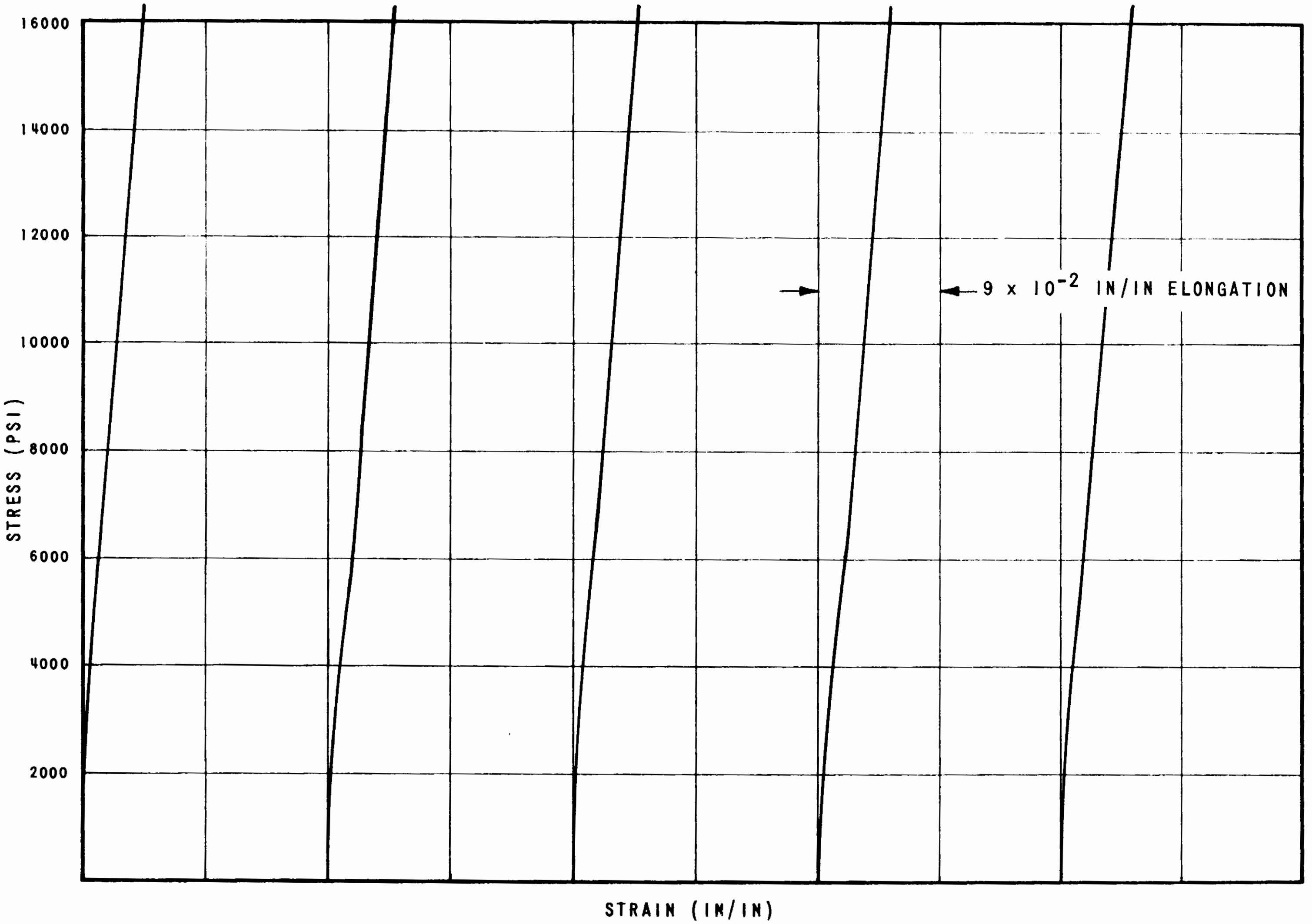


FIGURE 18.30 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C ONE WEEK

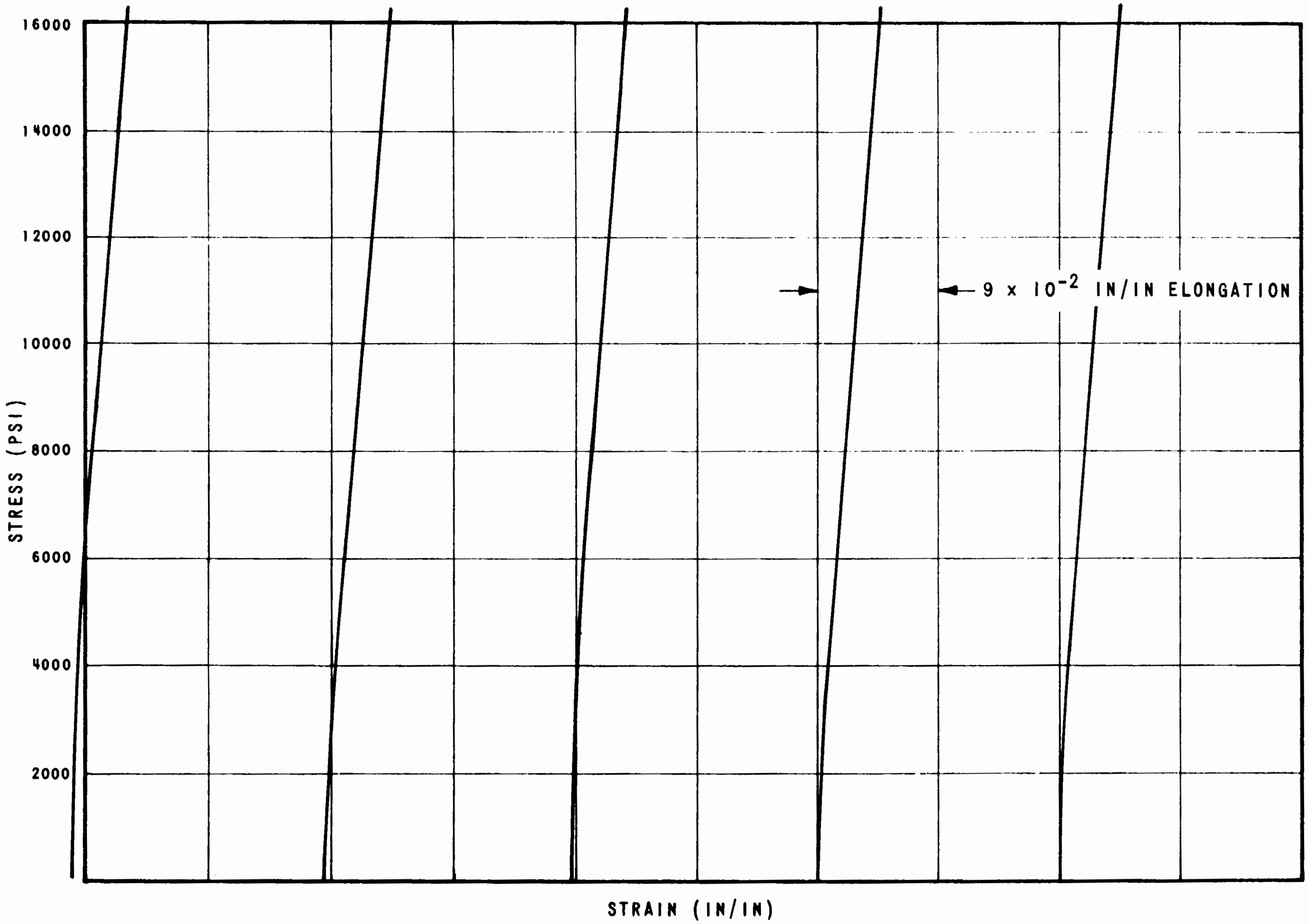


FIGURE 18.31 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–1, AGED 135°C FOUR WEEKS

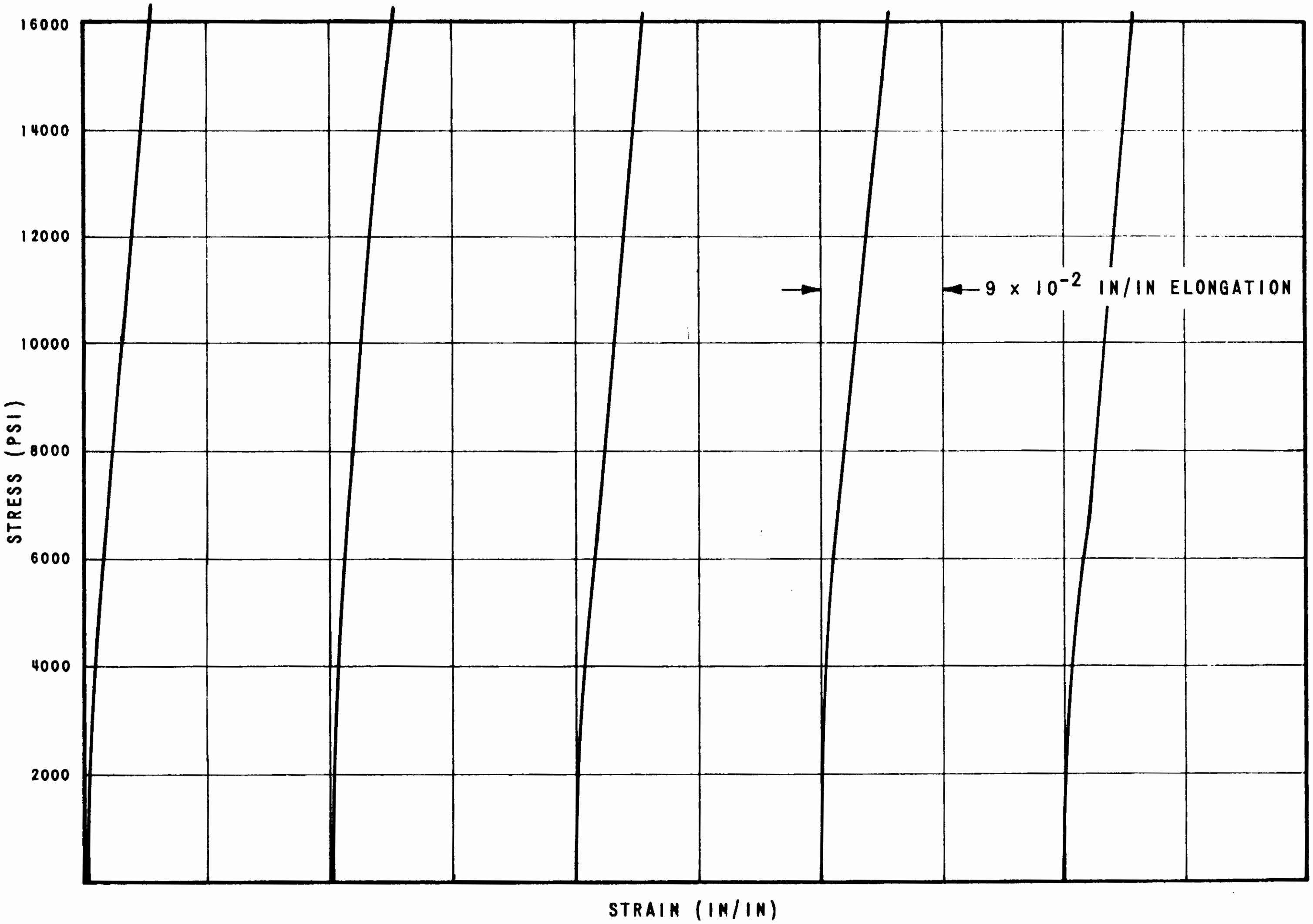


FIGURE 18.32 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C 12 WEEKS

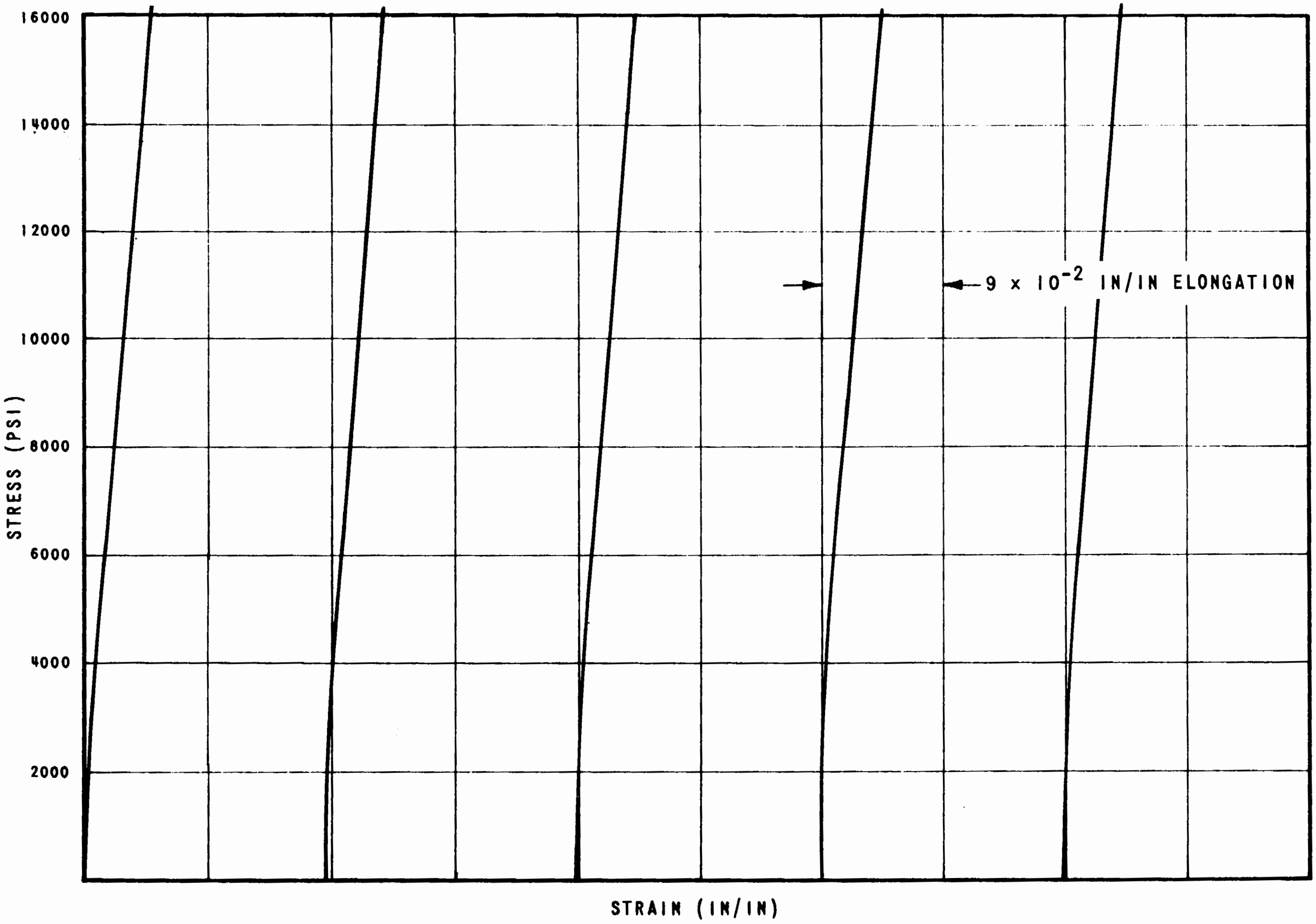


FIGURE 18.33 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C 24 WEEKS

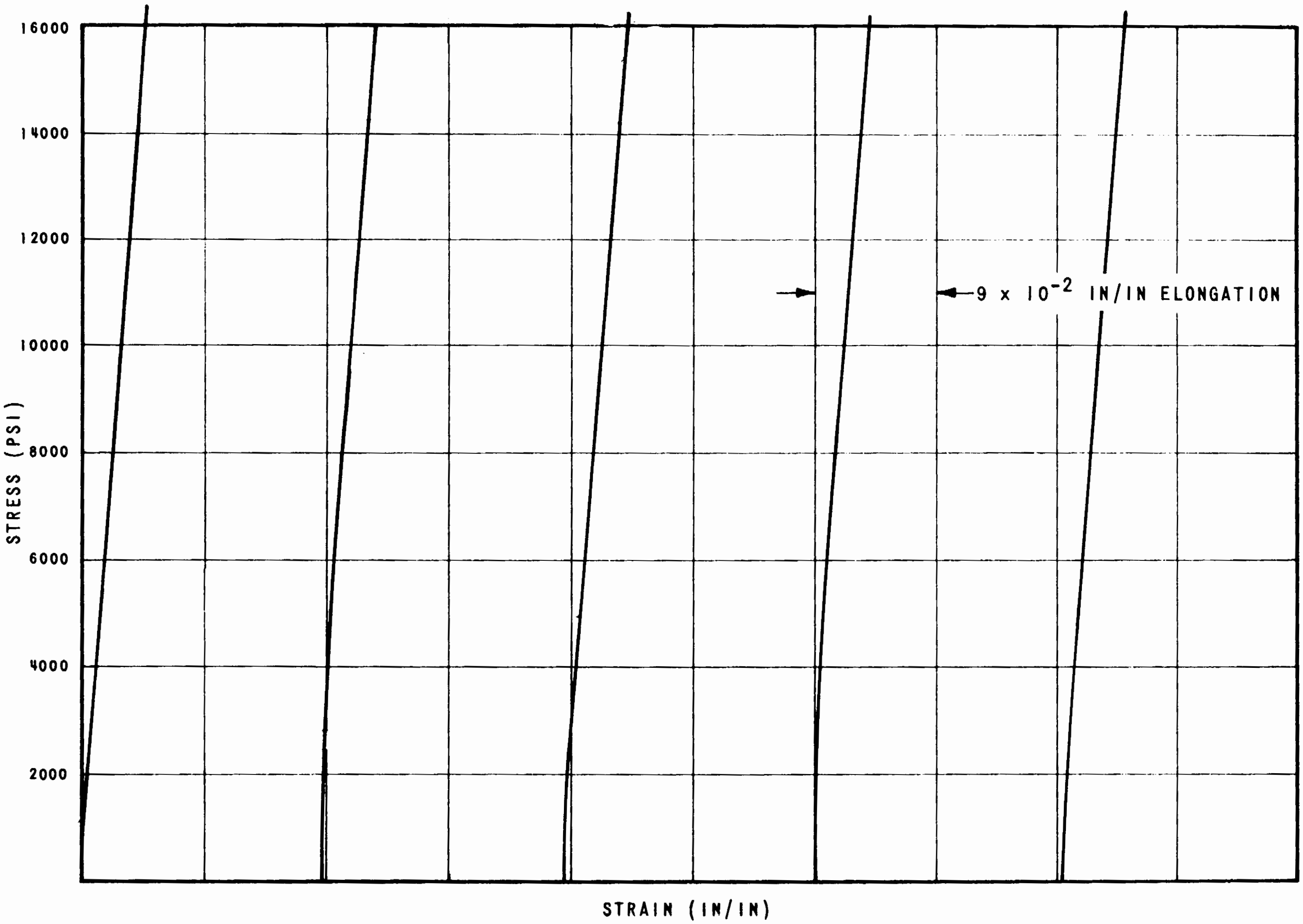


FIGURE 18.34 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C IN FYRQUEL VAPOR ONE WEEK

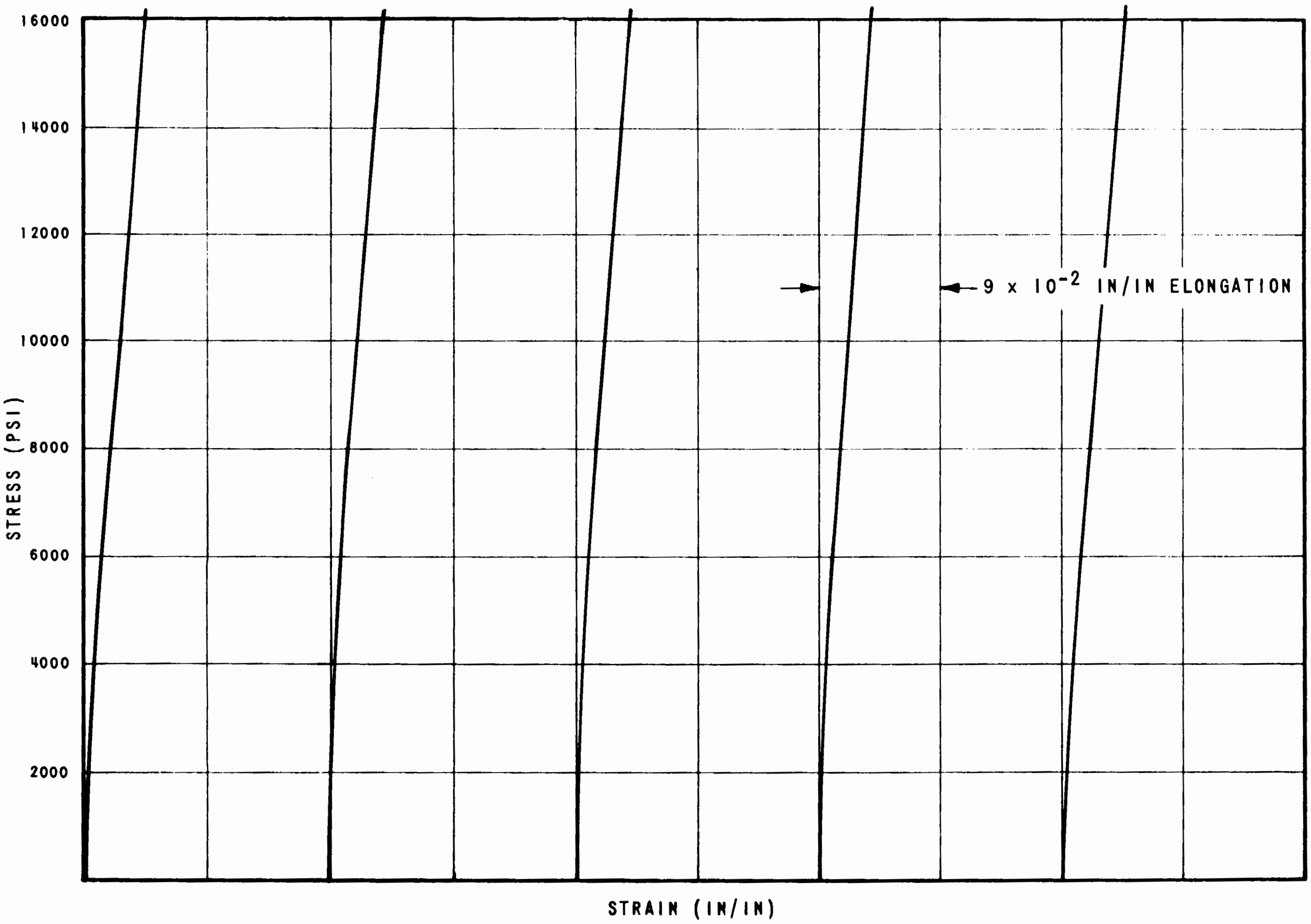


FIGURE 18.35 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C IN FYRQUEL VAPOR FOUR WEEKS

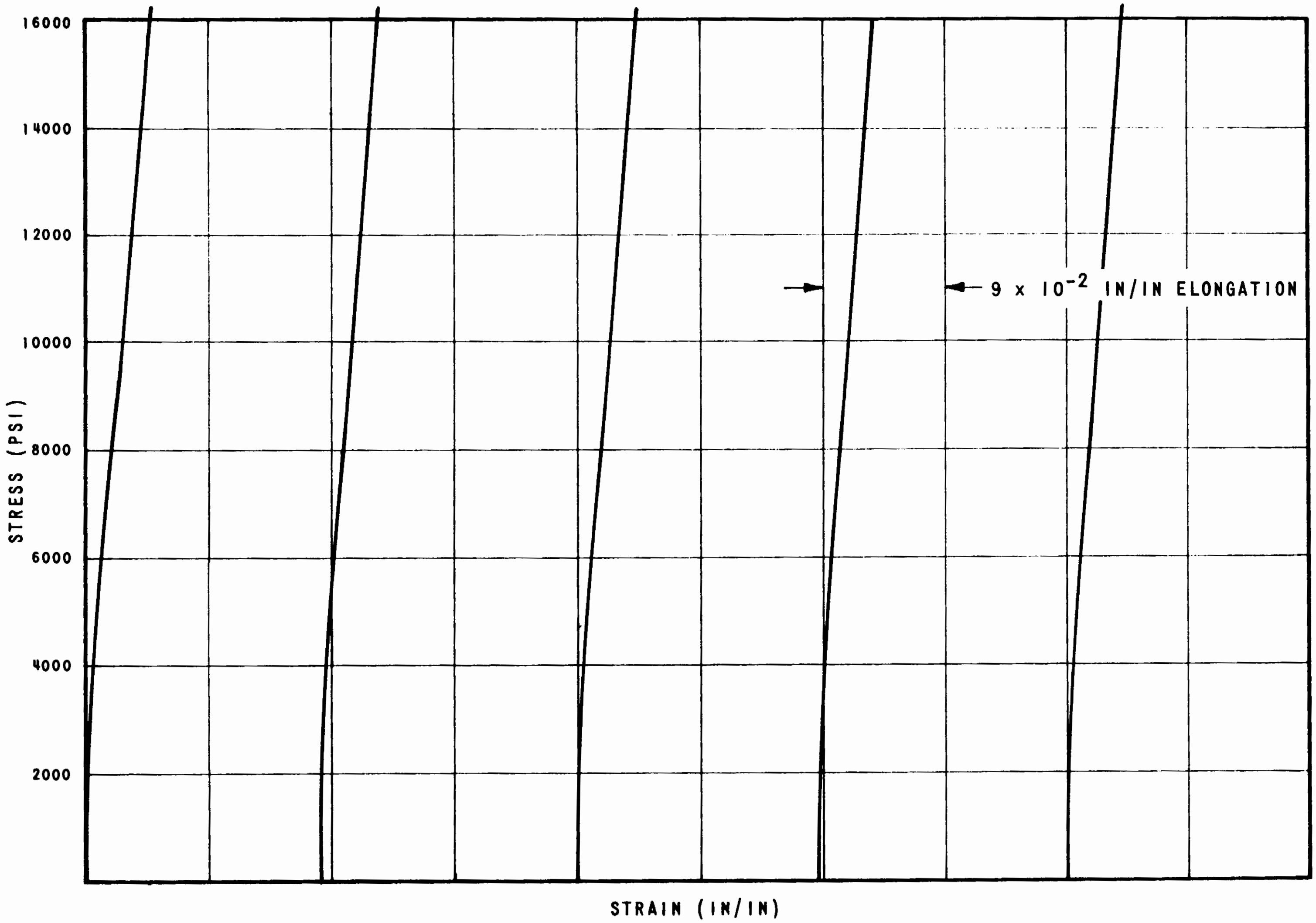


FIGURE 18.36 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C IN FYRQUEL VAPOR 12 WEEKS

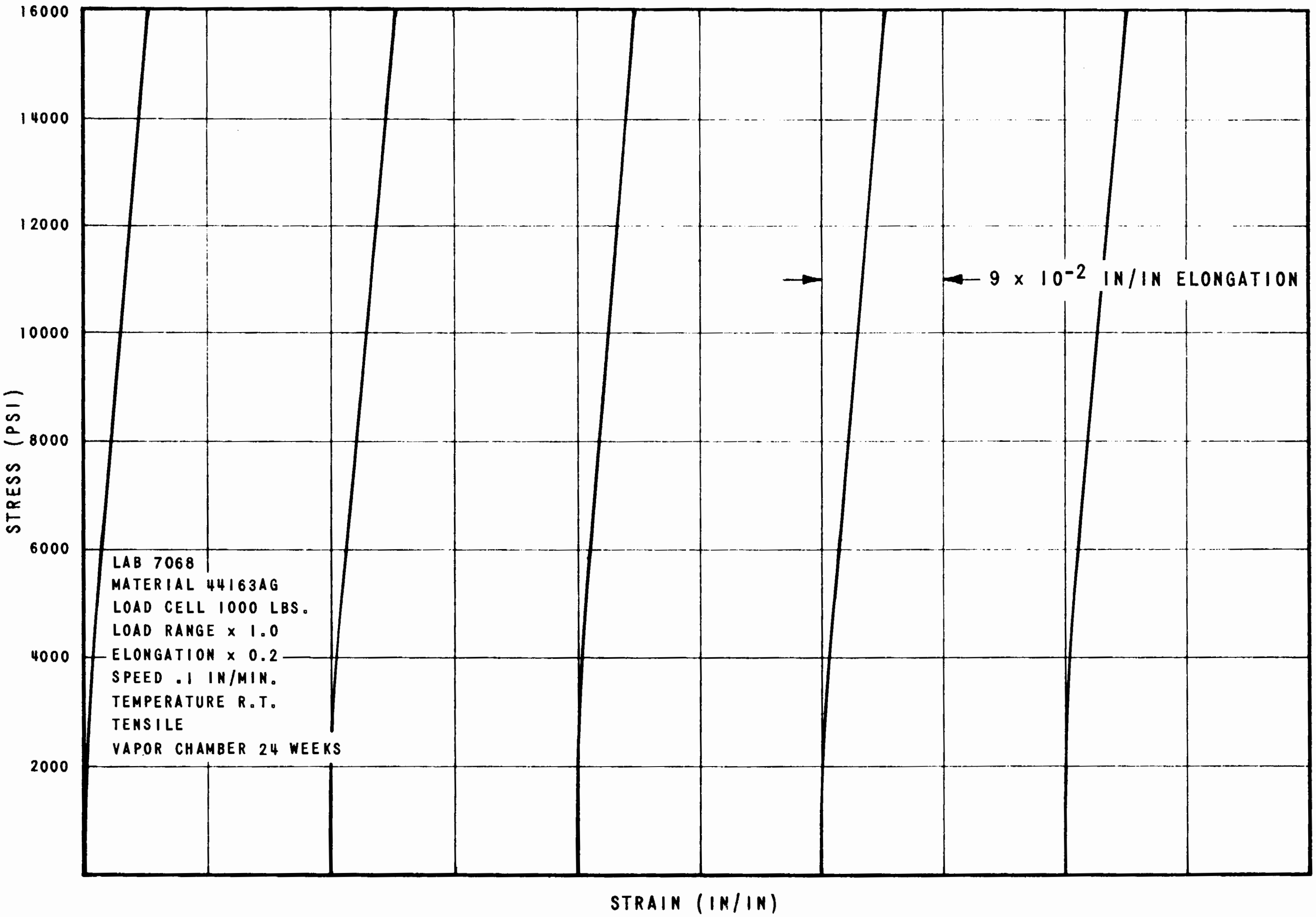


FIGURE 18.37 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C IN FYRQUEL VAPOR 24 WEEKS

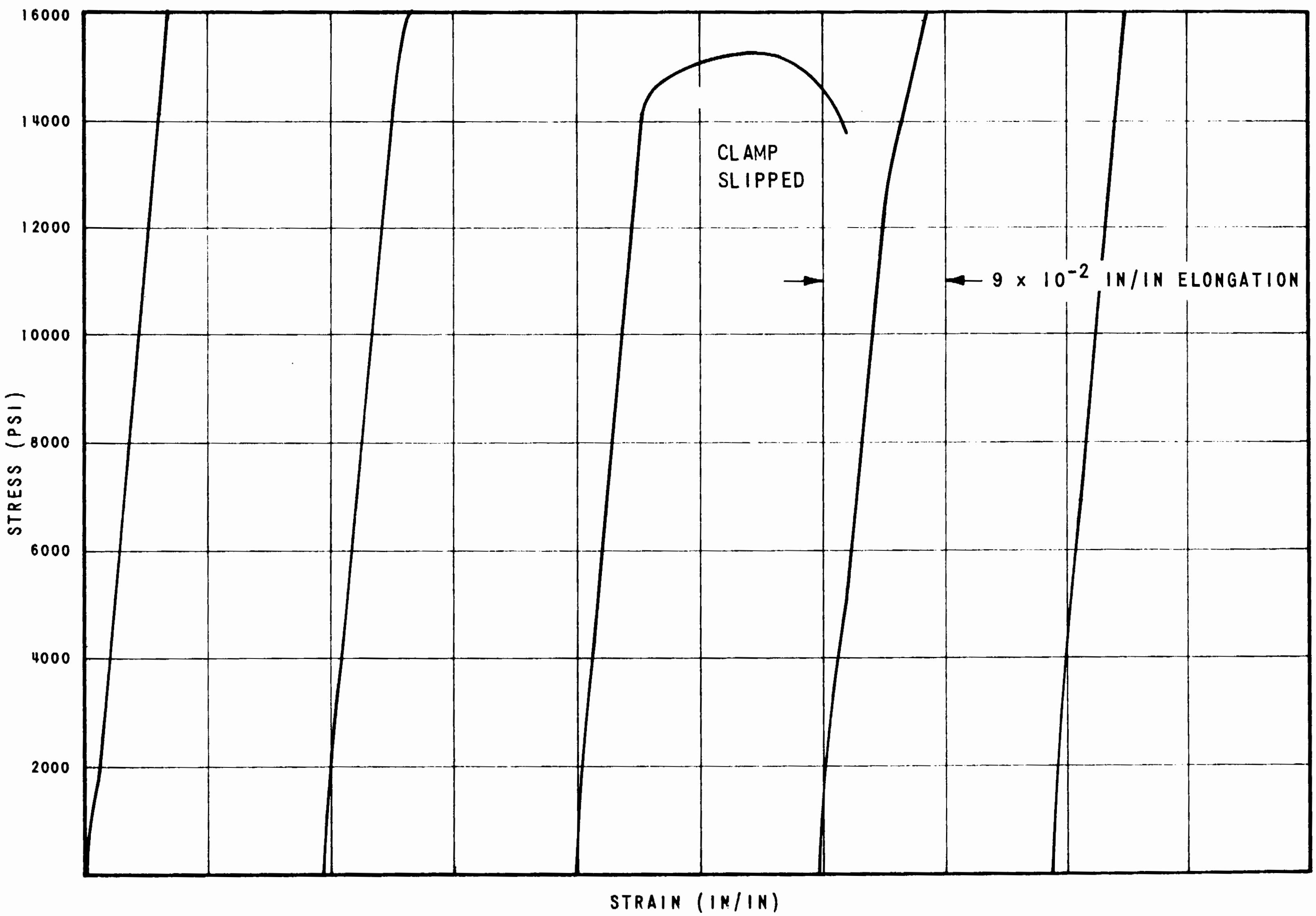


FIGURE 18.38 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C IN FYRQUEL LIQUID ONE WEEK

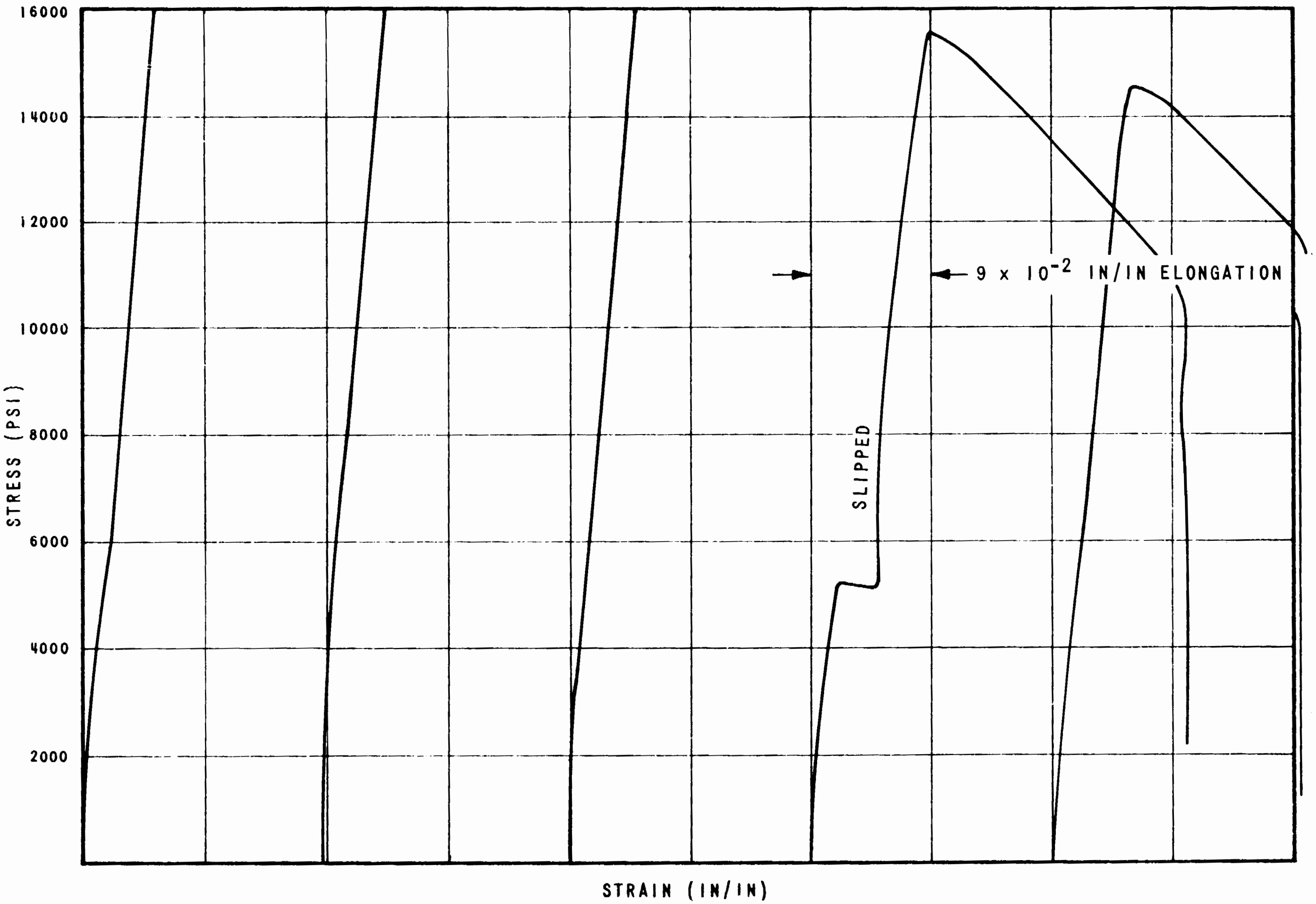


FIGURE 18.39 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C IN FYRQUEL LIQUID FOUR WEEKS

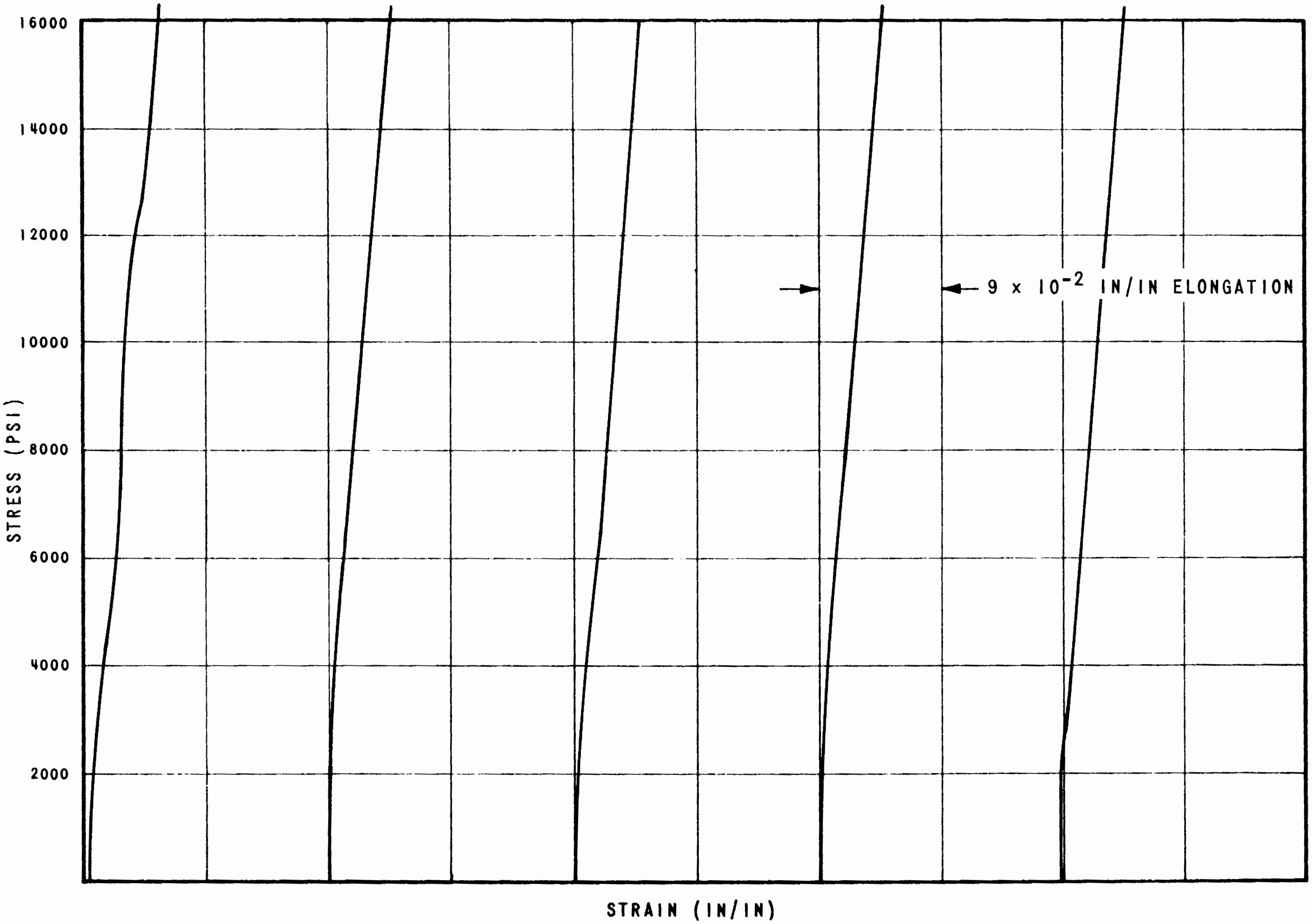


FIGURE 18.40 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C IN FYRQUEL LIQUID 12 WEEKS

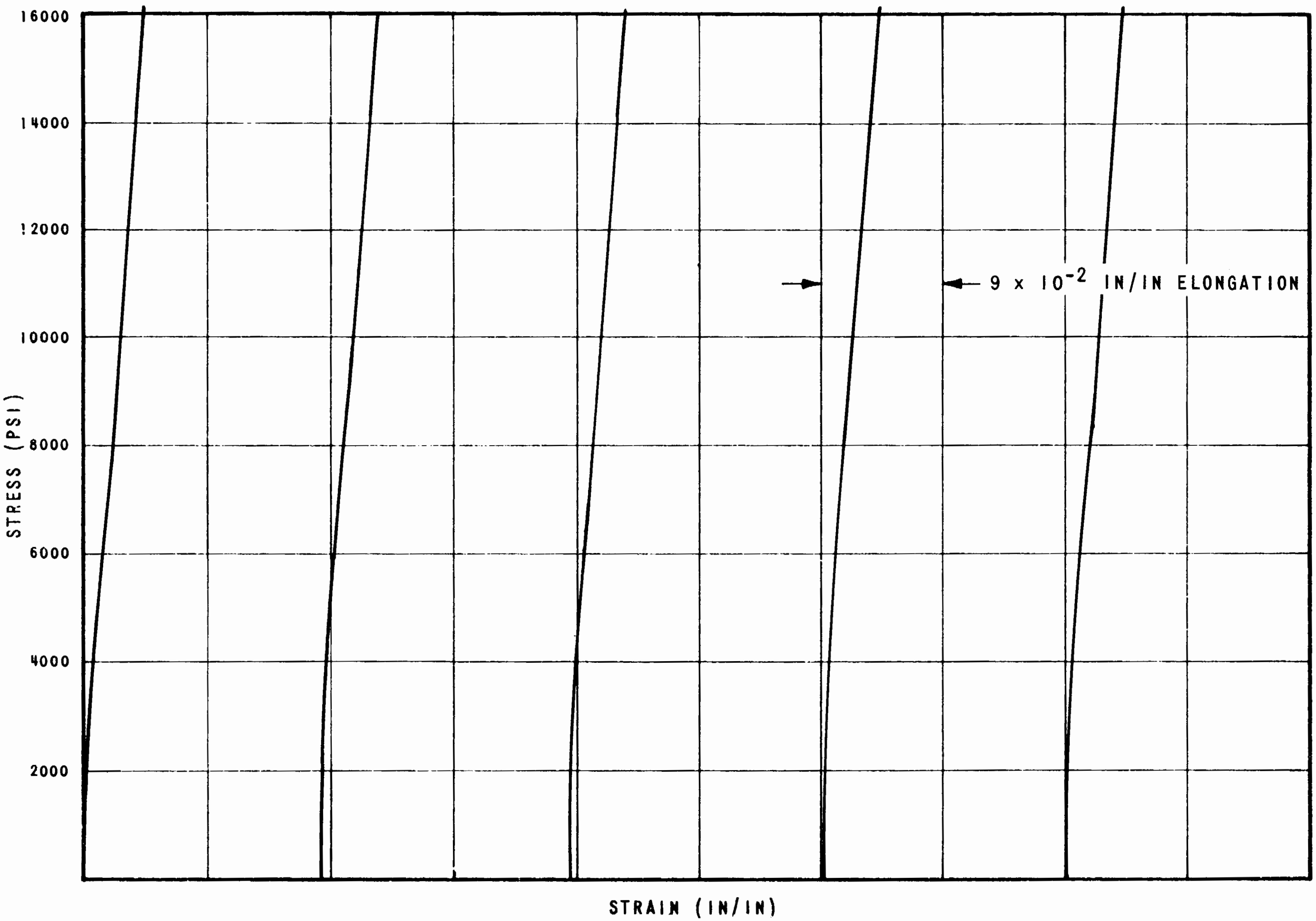


FIGURE 18.41 TENSILE STRESS–STRAIN, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C IN FYRQUEL LIQUID 24 WEEKS

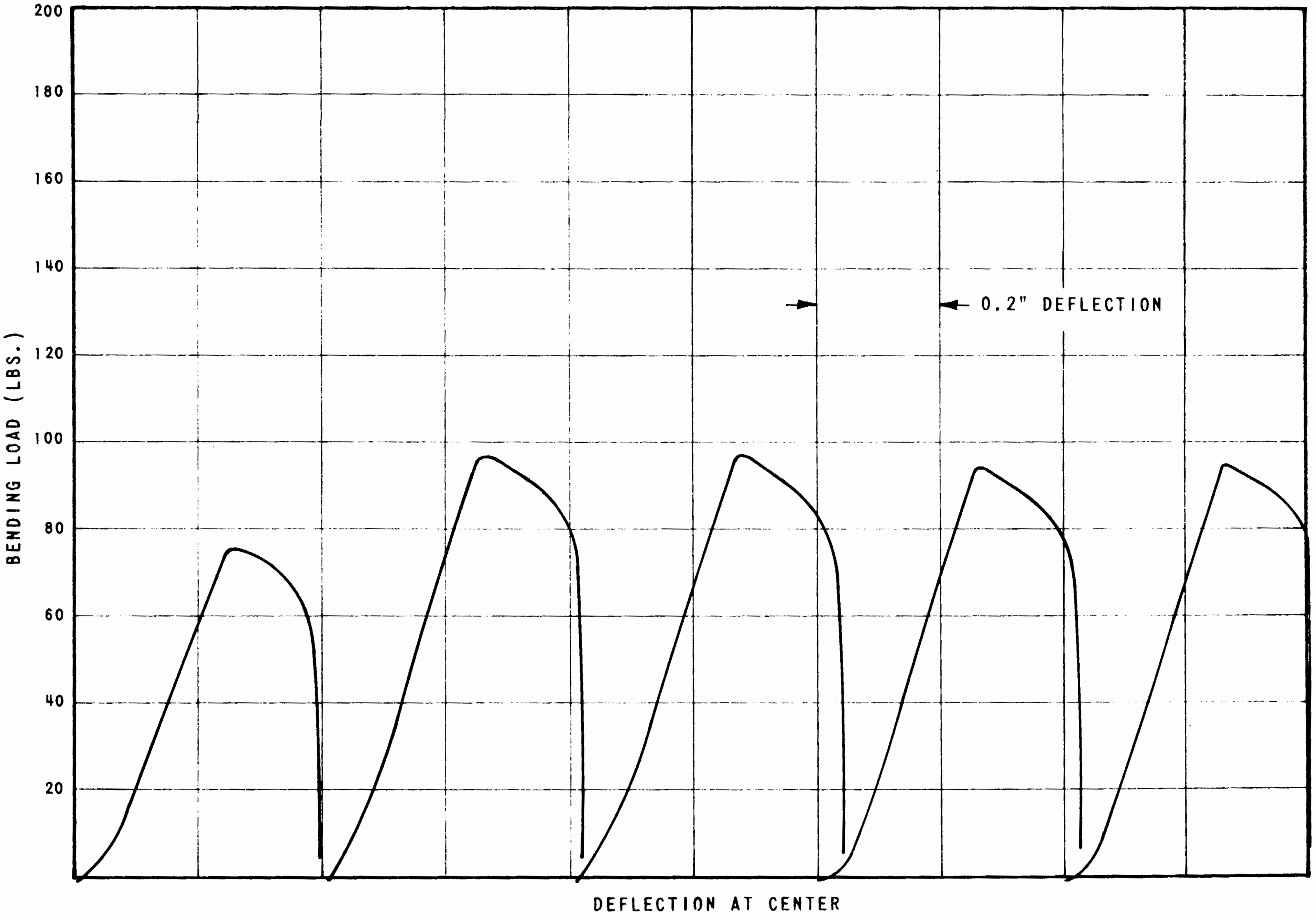


FIGURE 18.42 THREE–POINT FLEXURE, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C 24 WEEKS

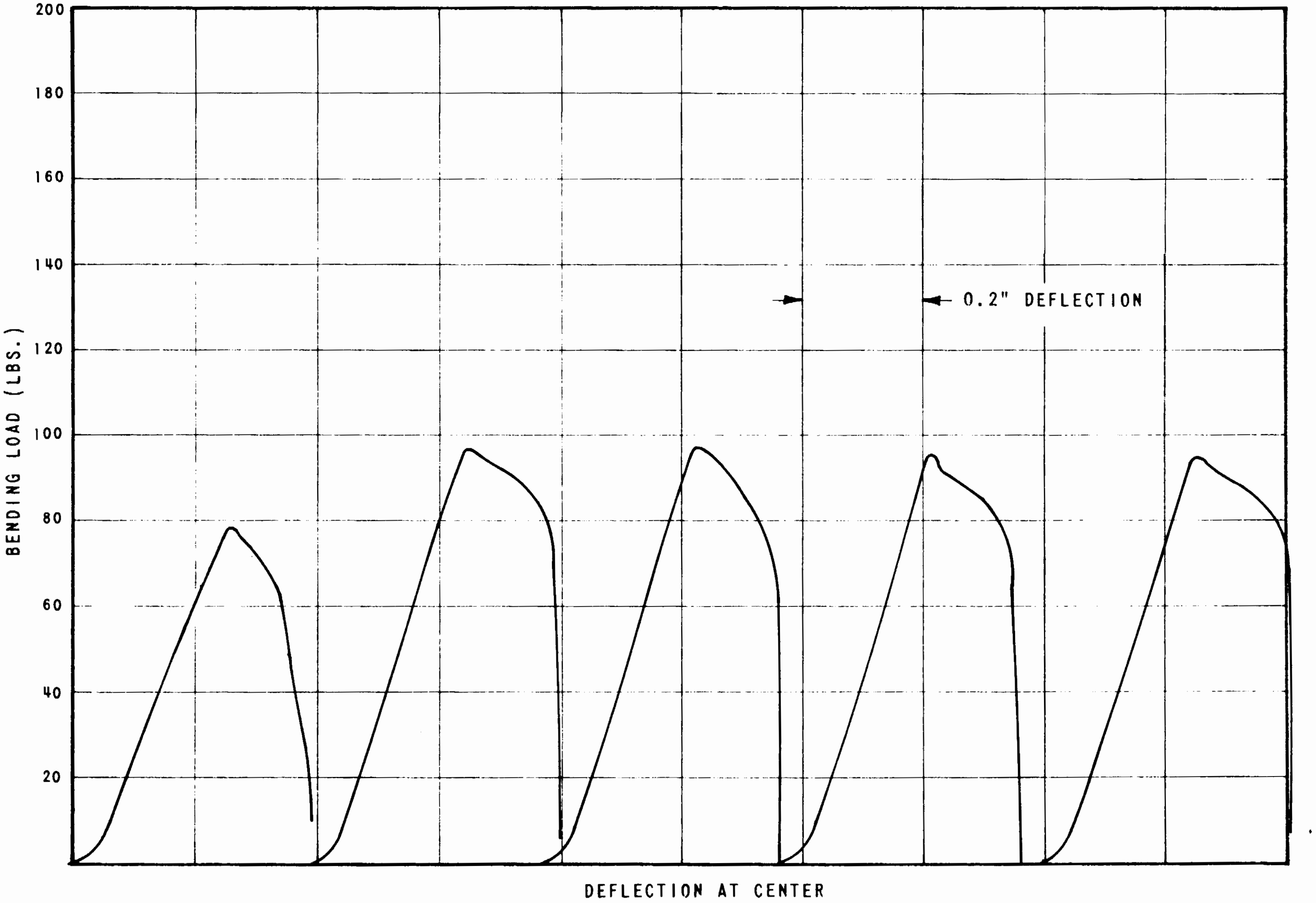


FIGURE 18.43 THREE–POINT FLEXURE, GLASS EPOXY LAMINATE NEMA G–11, AGED 135°C IN FYRQUEL VAPOR 24 WEEKS

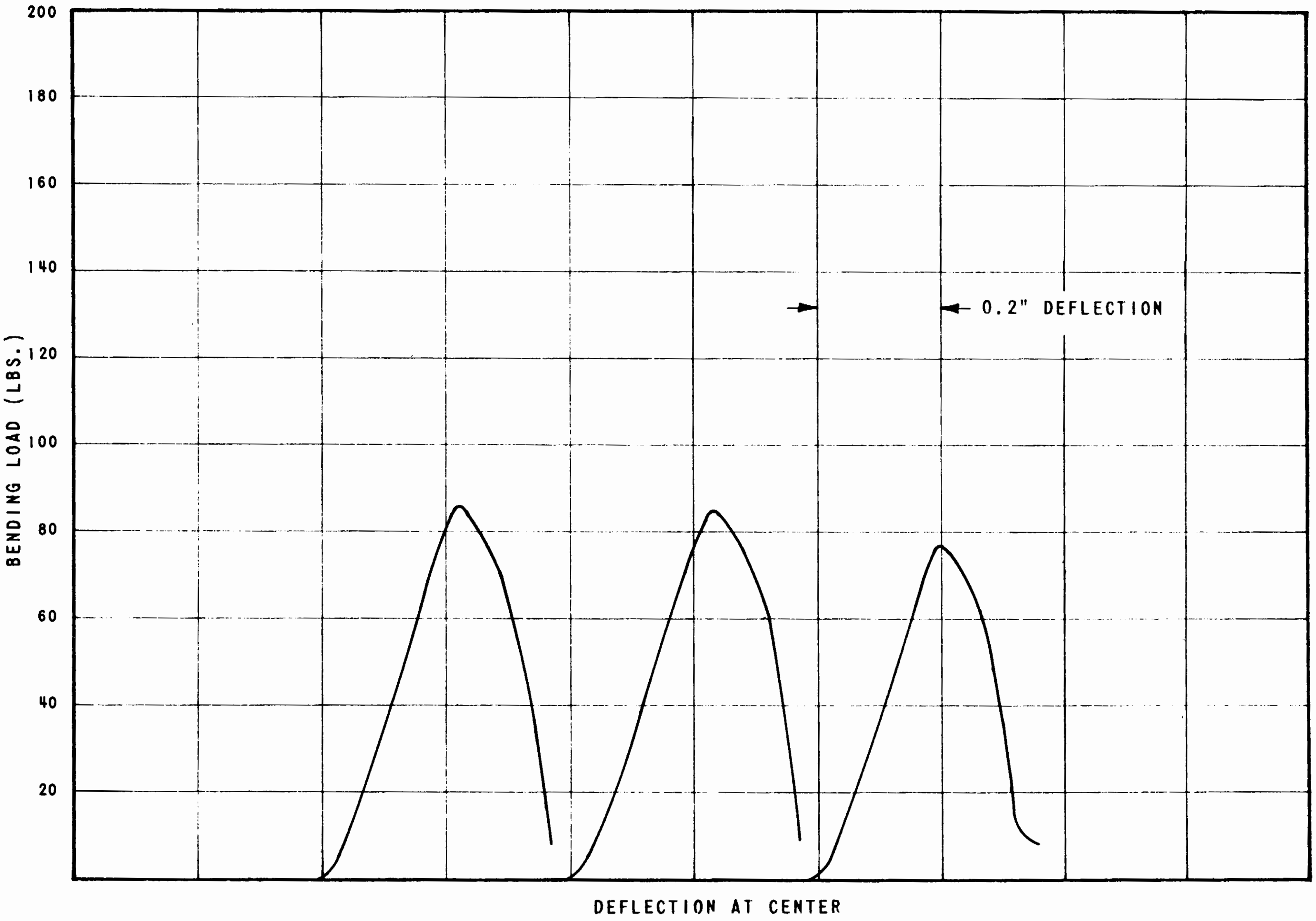


FIGURE 18.44 THREE–POINT FLEXURE, GLASS EPOXY LAMINATE

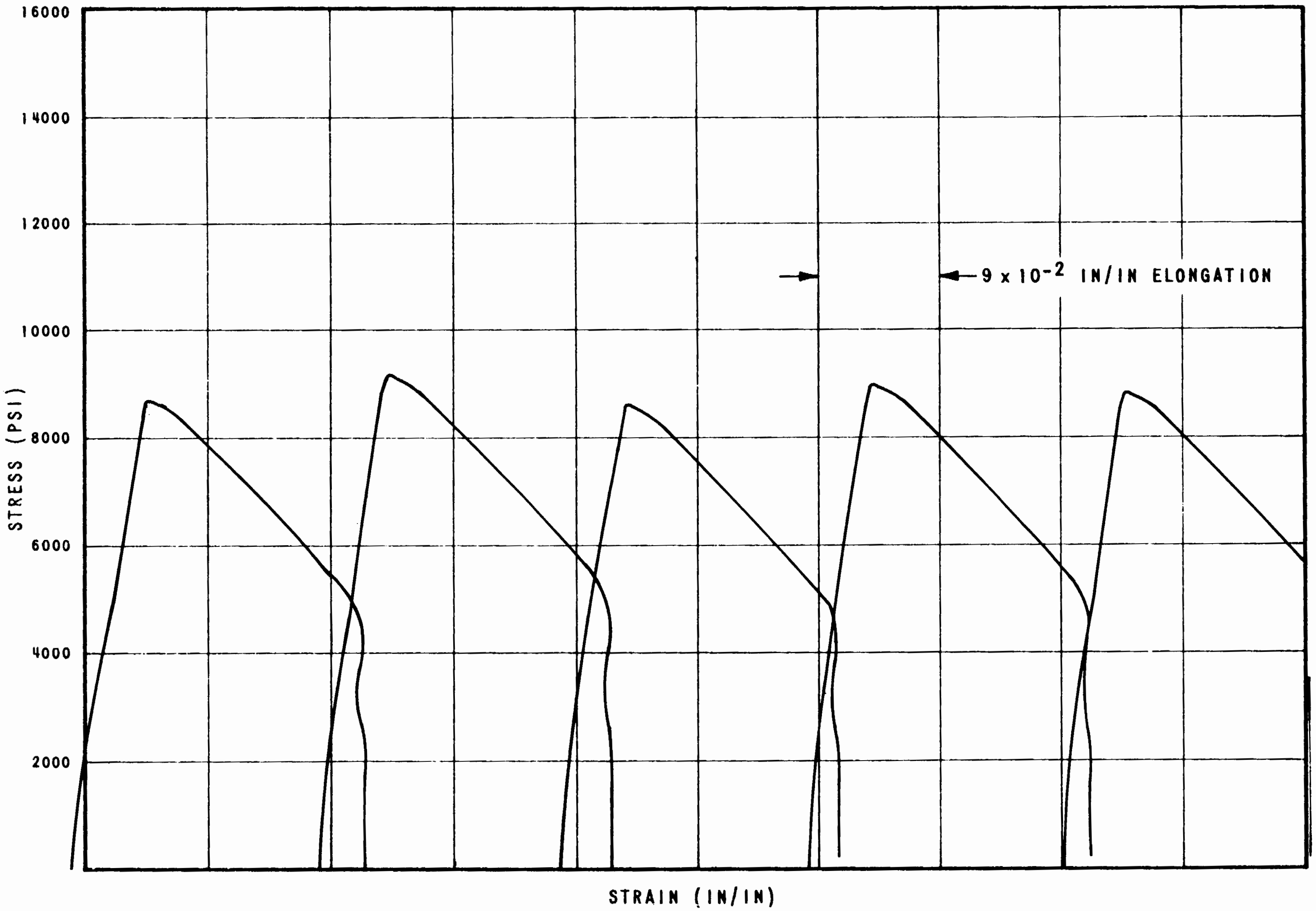


FIGURE 18.45 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C 1 WEEK

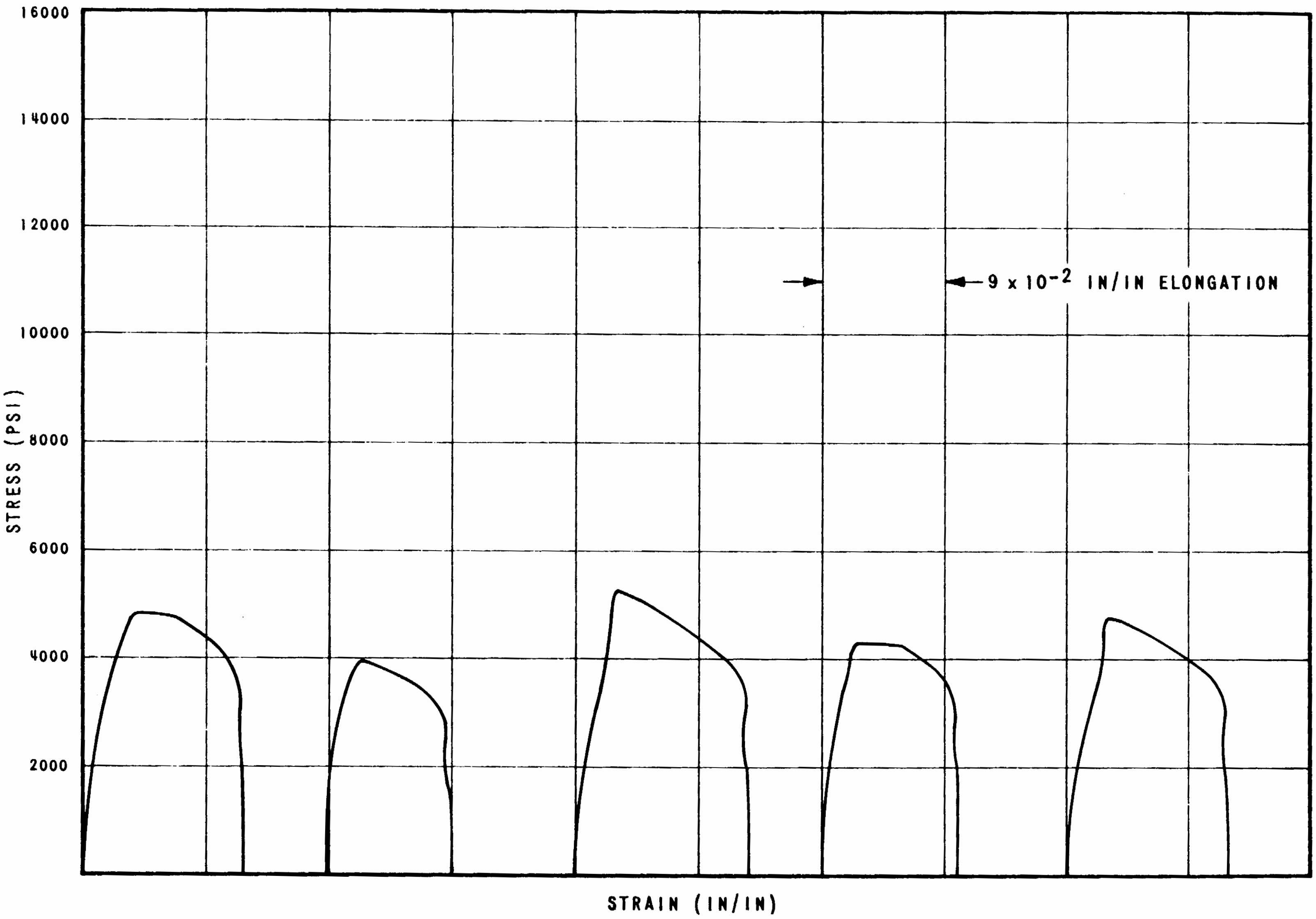


FIGURE 18.46 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C FOUR WEEKS

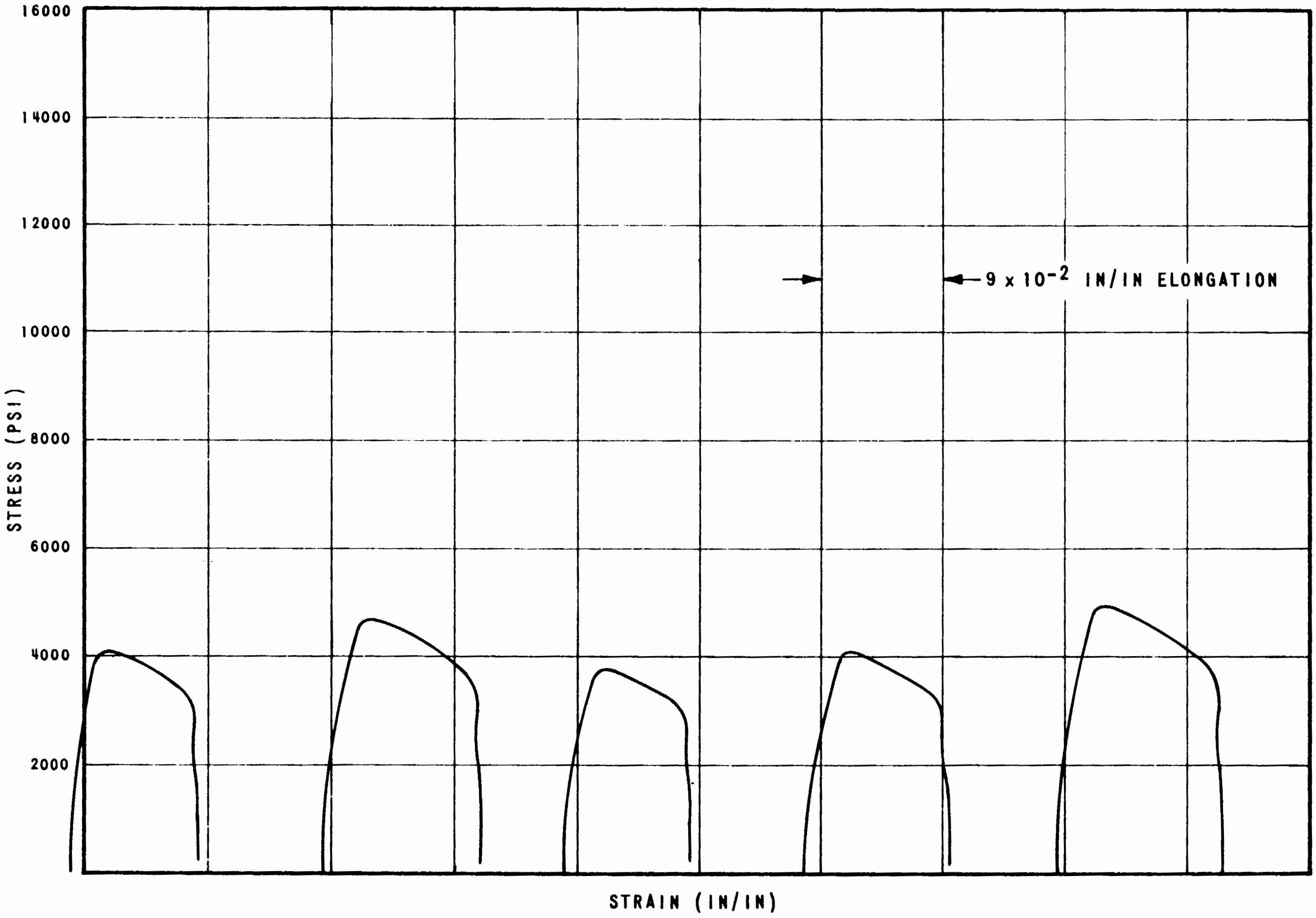


FIGURE 18.47 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C 12 WEEKS

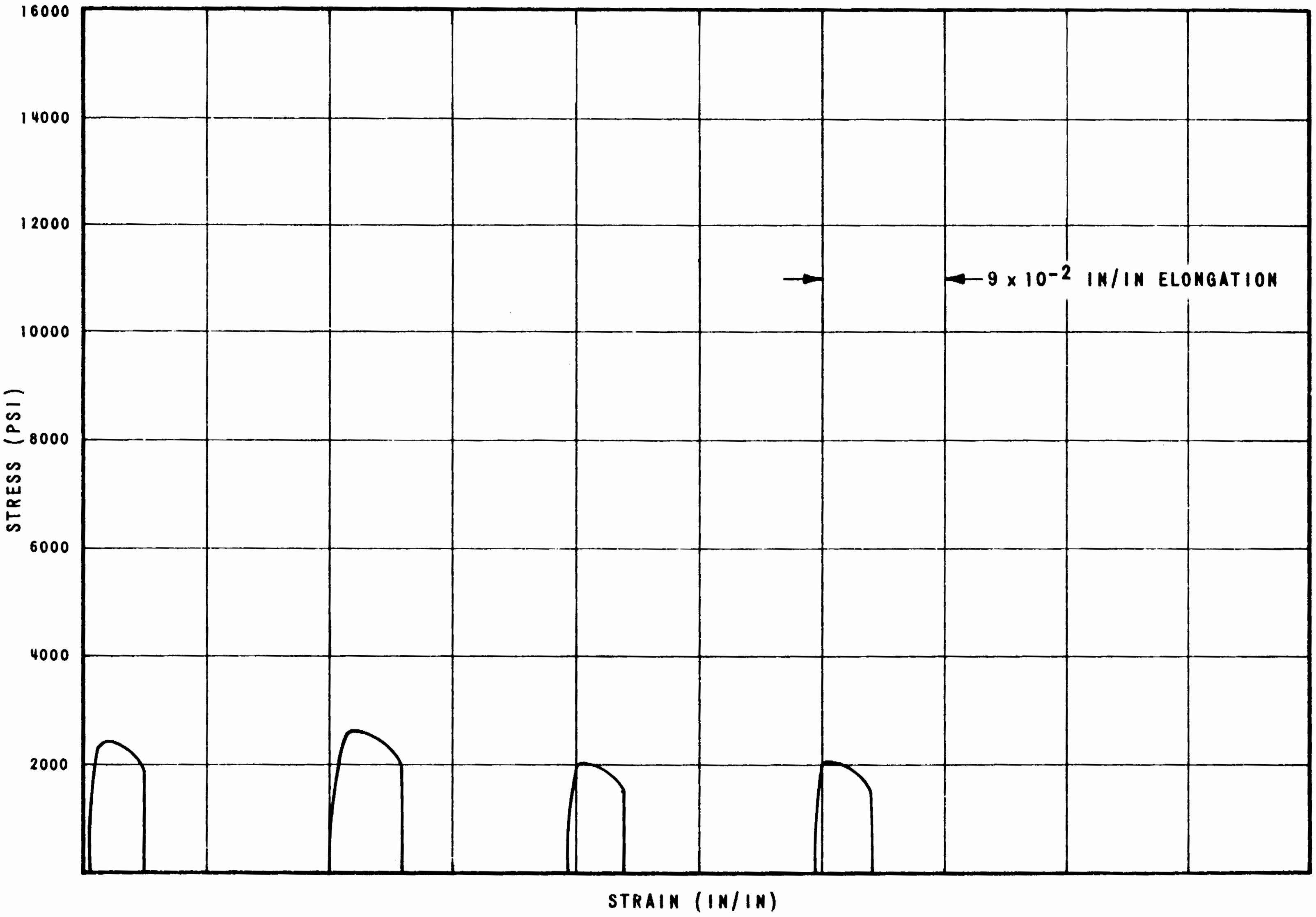


FIGURE 18.48 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C 24 WEEKS

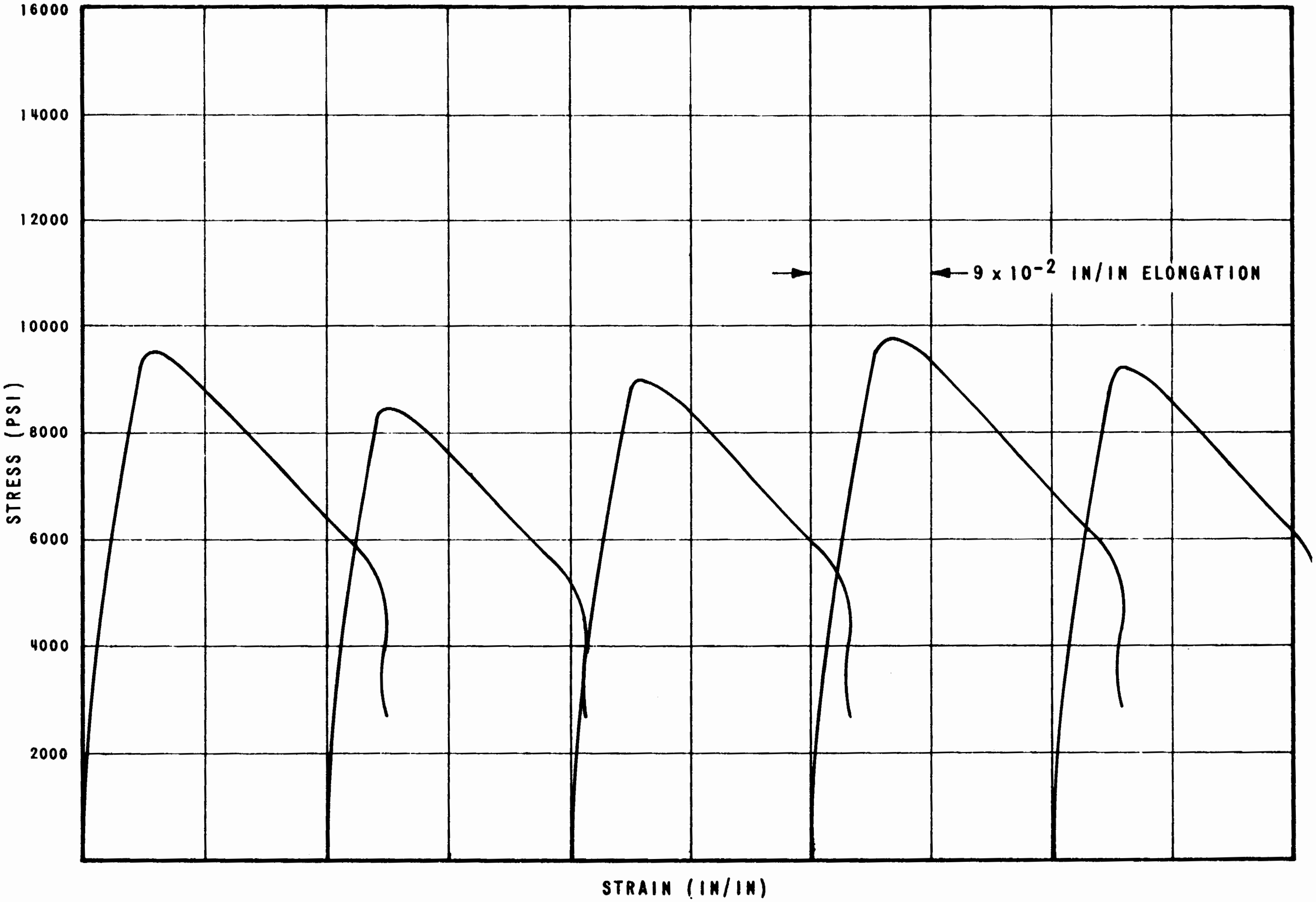


FIGURE 18.49 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135 °C IN FYRQUEL VAPOR ONE WEEK

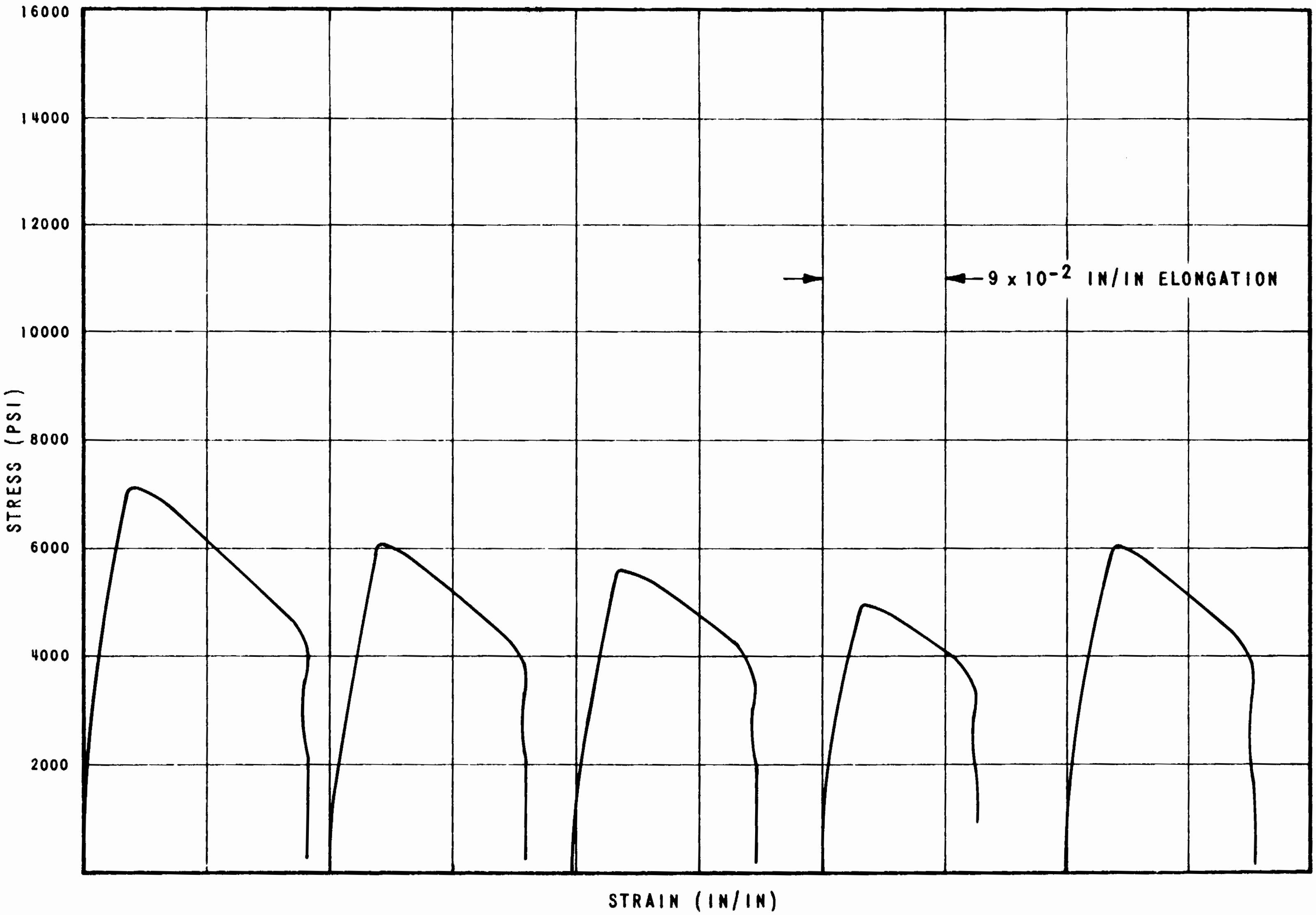


FIGURE 18.50 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C IN FYRQUEL VAPOR FOUR WEEKS

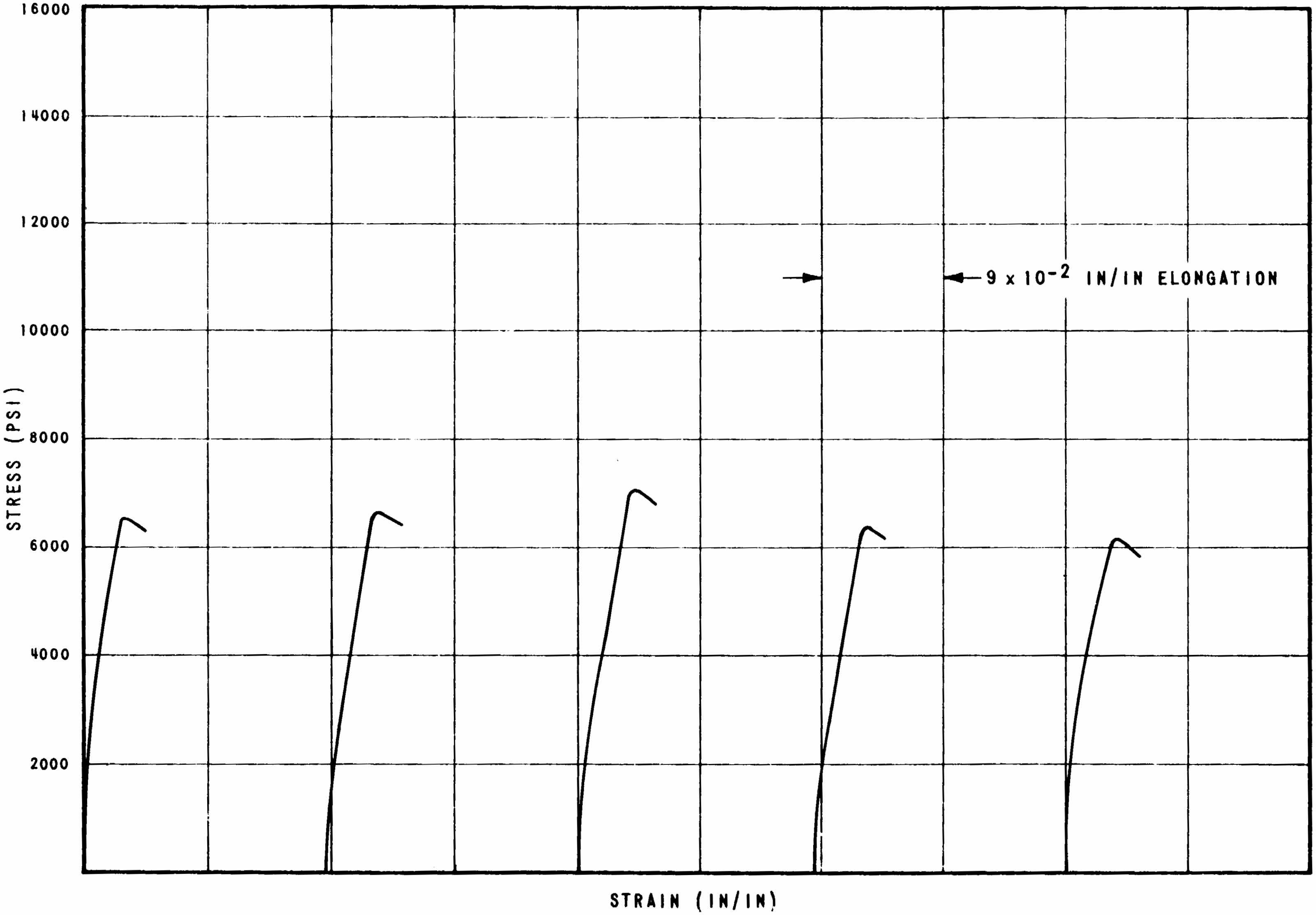


FIGURE 18.51 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C IN FYRQUEL VAPOR 12 WEEKS

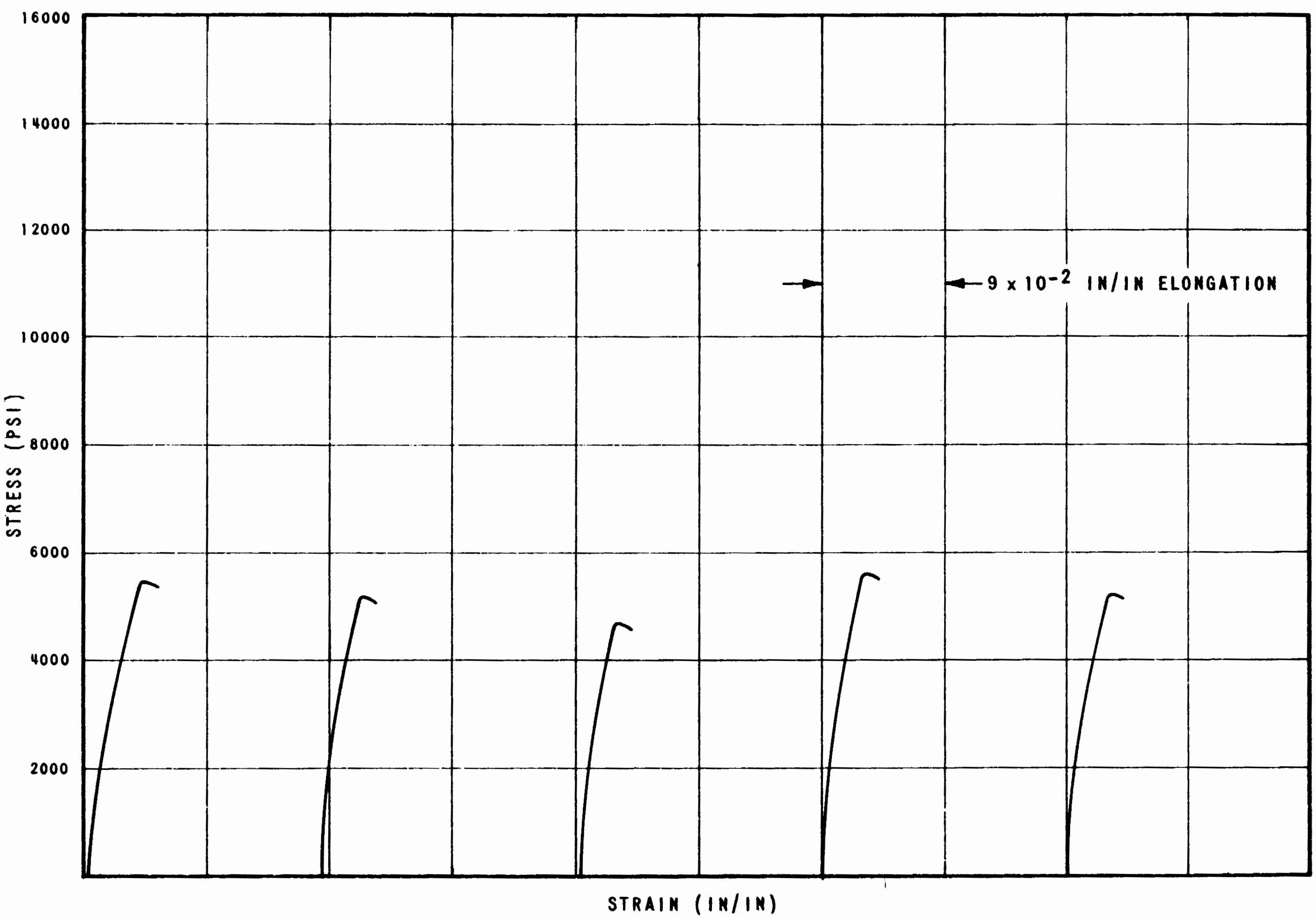


FIGURE 18.52 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C IN FYRQUEL VAPOR 24 WEEKS

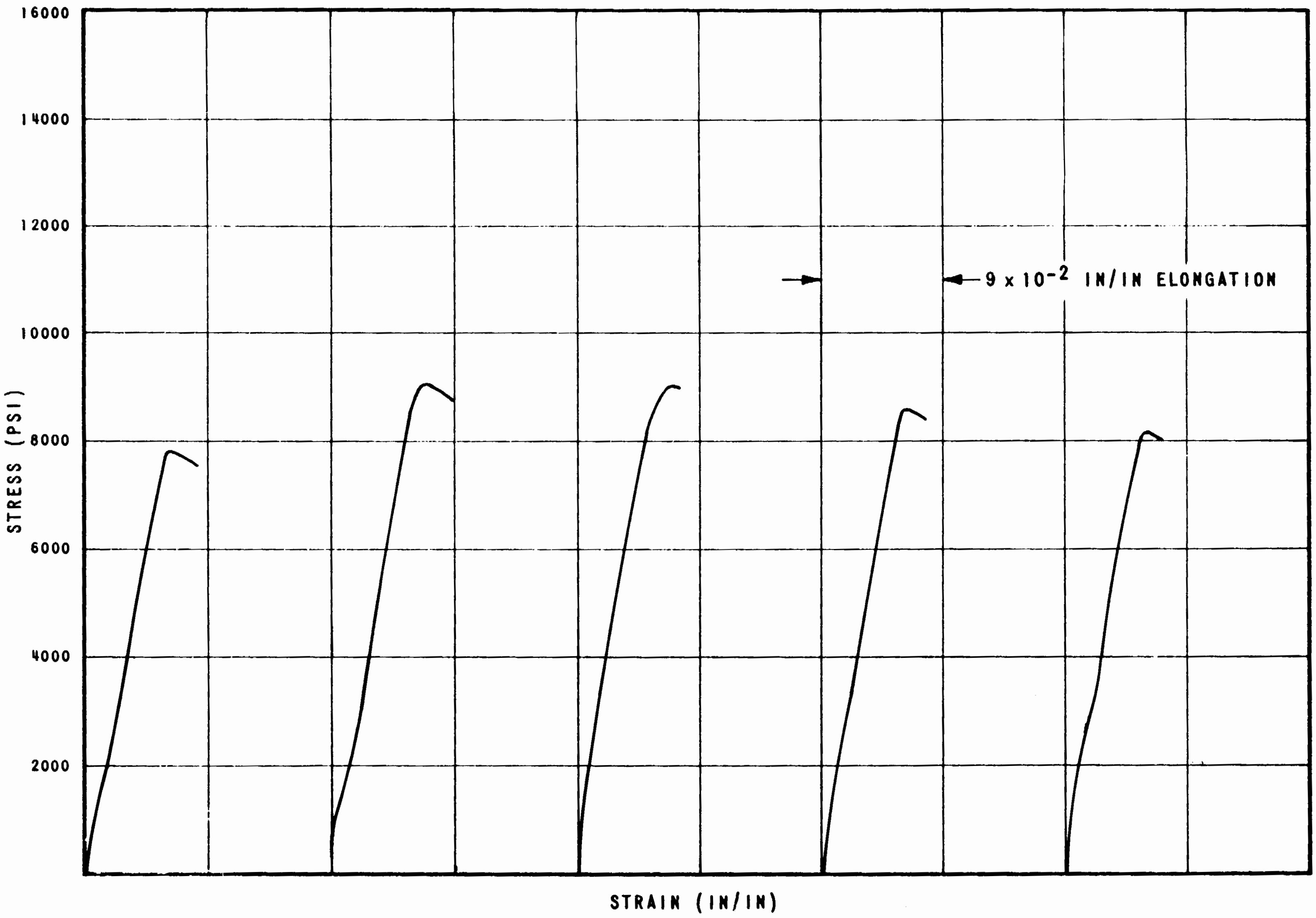


FIGURE 18.53 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C IN FYRQUEL LIQUID ONE WEEK

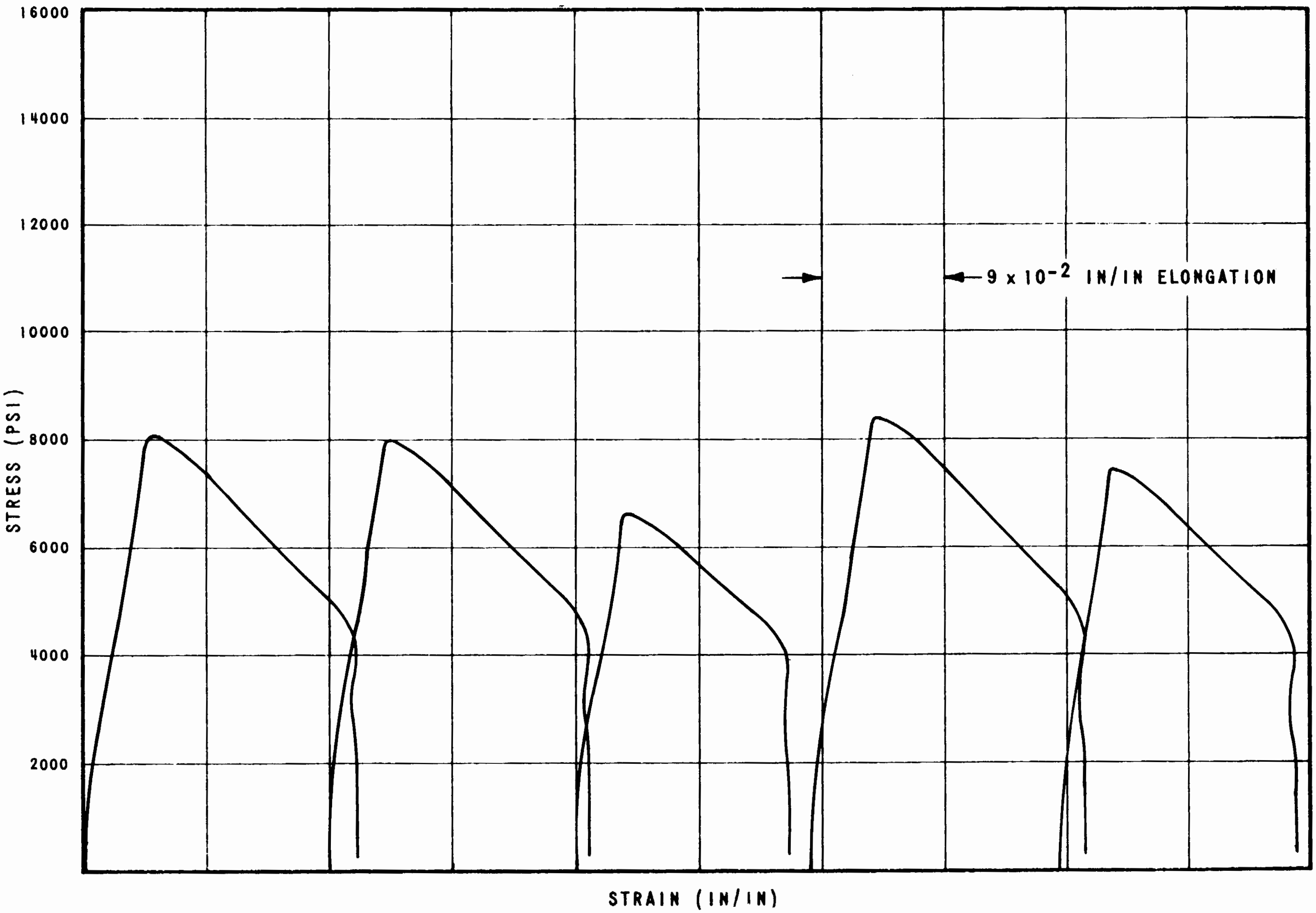


FIGURE 18.54 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE GRADE C, AGED 135°C IN FYRQUEL LIQUID FOUR WEEKS

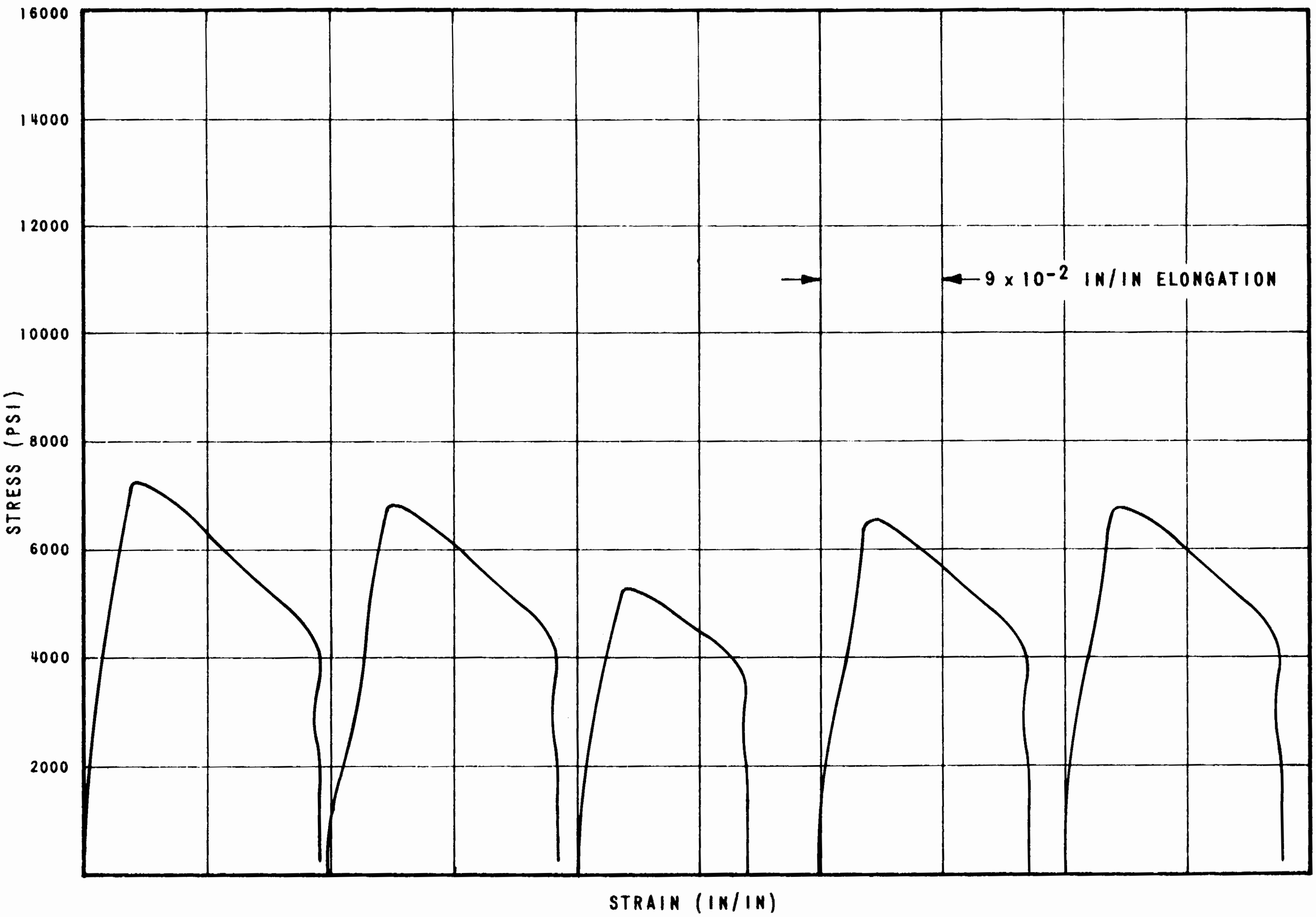


FIGURE 18.55 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C IN FYRQUEL LIQUID 12 WEEKS

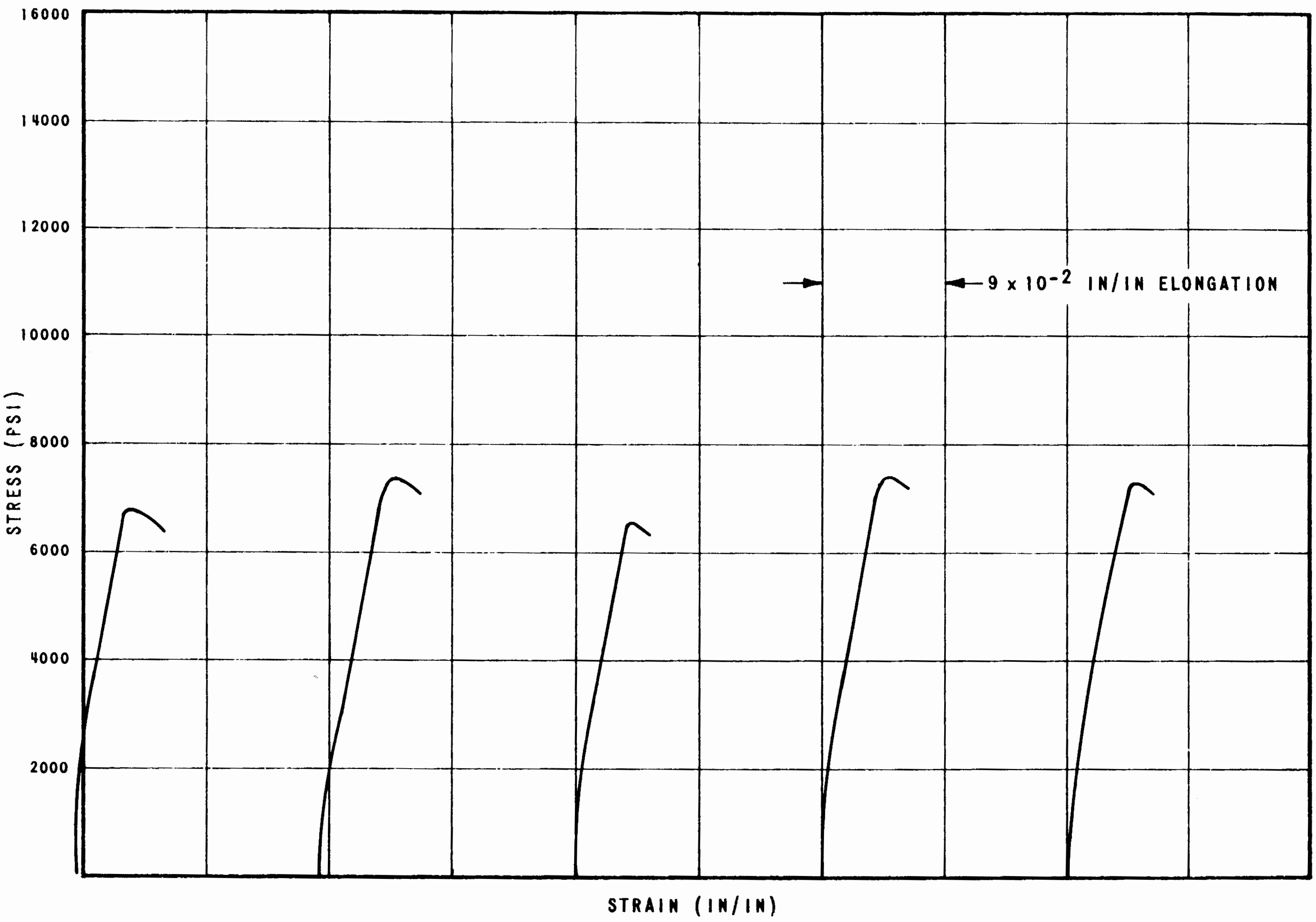


FIGURE 18.56 TENSILE STRESS–STRAIN, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C IN FYRQUEL LIQUID 24 WEEKS

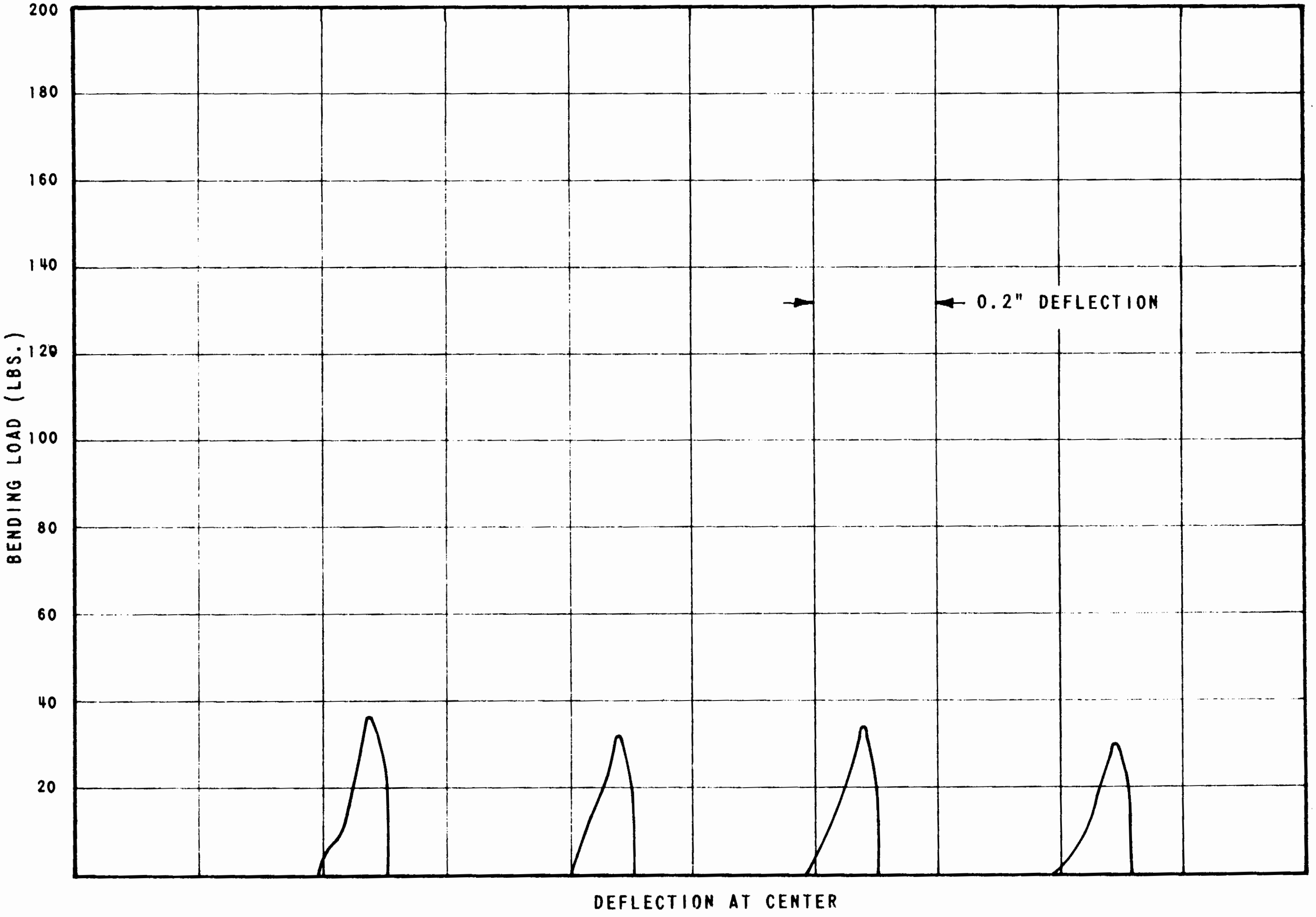


FIGURE 18.57 THREE–POINT FLEXURE, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C 24 WEEKS

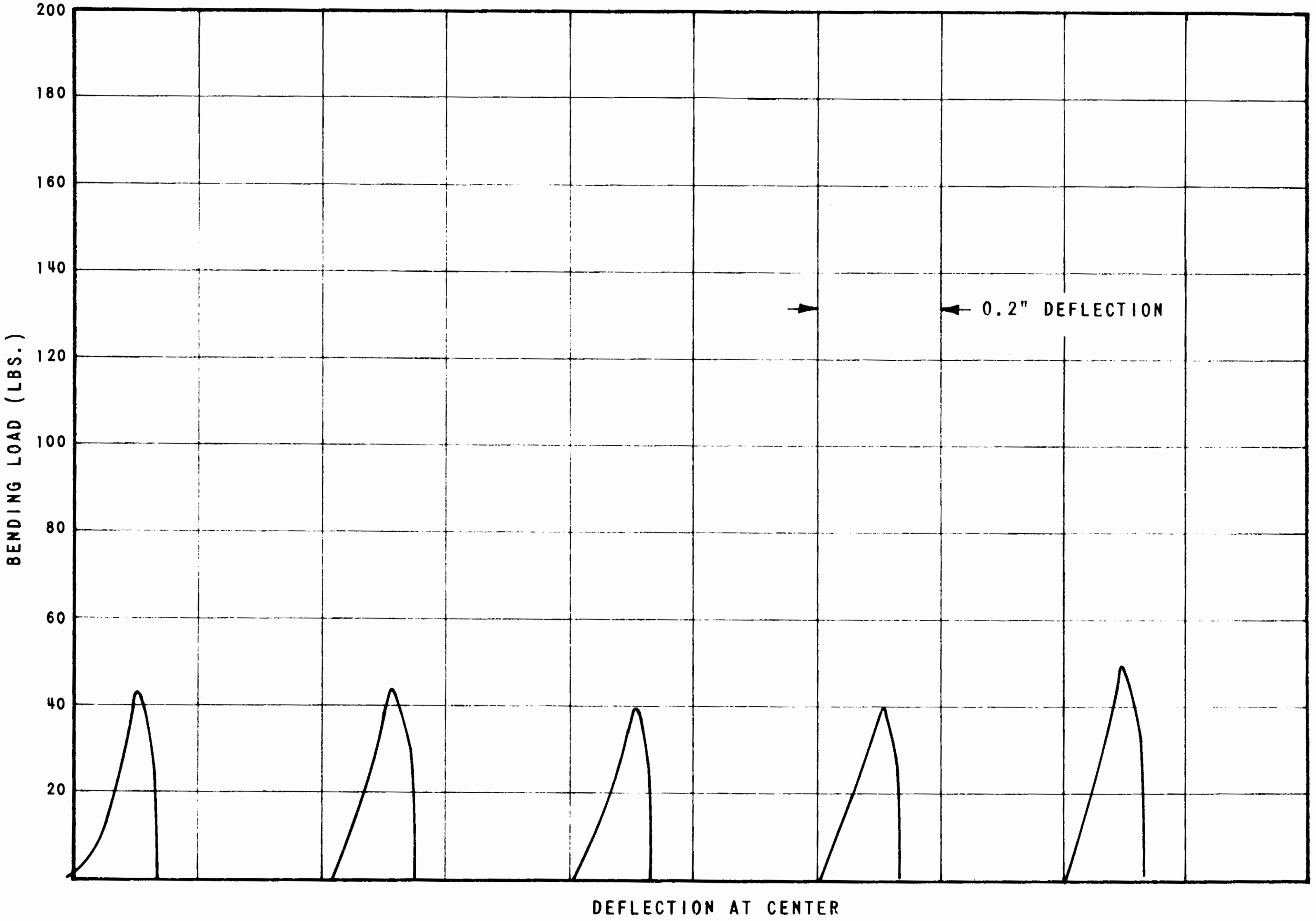


FIGURE 18.58 THREE–POINT FLEXURE, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C IN FYRQUEL VAPOR 24 WEEKS

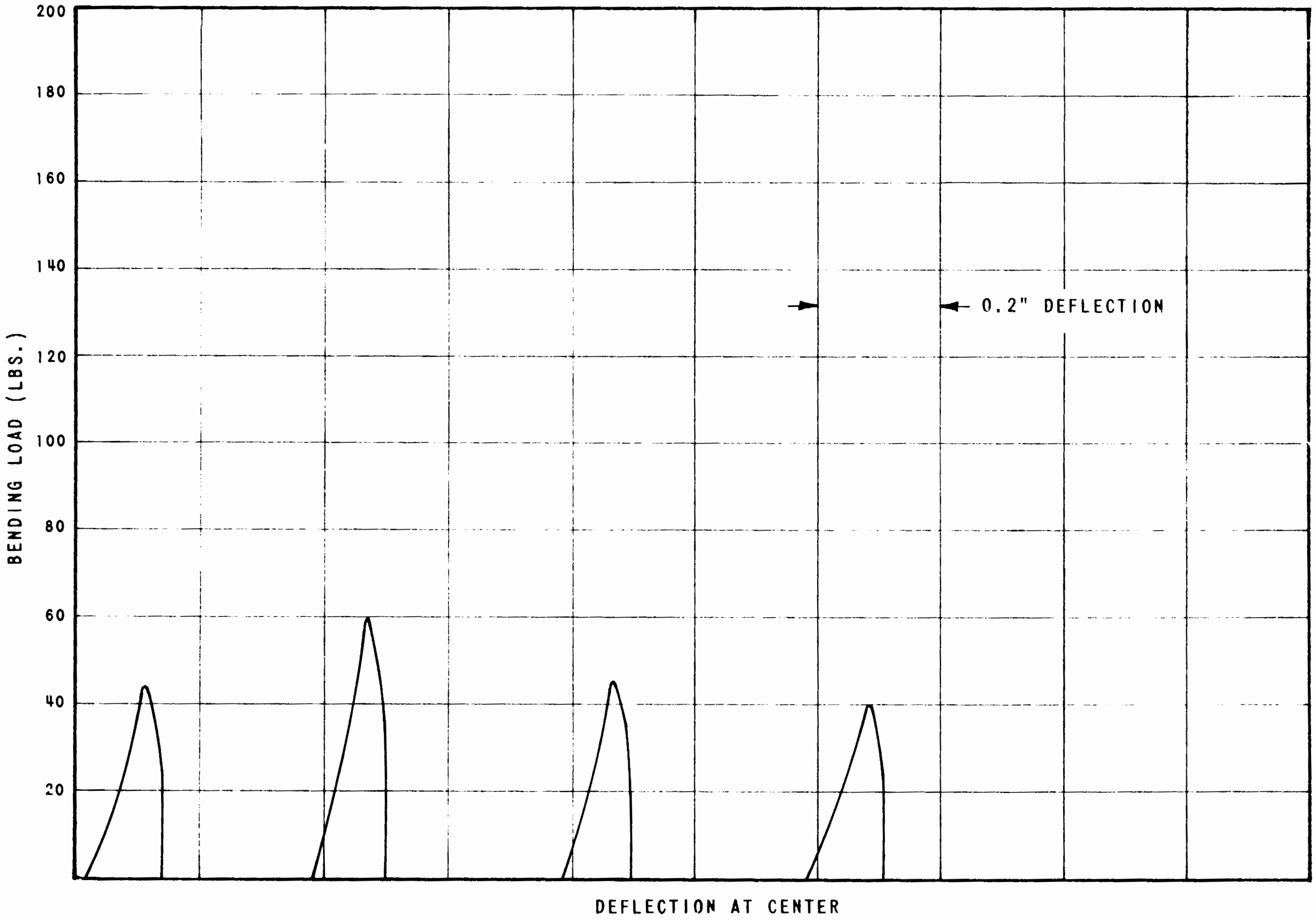


FIGURE 18.59 THREE–POINT FLEXURE, COTTON PHENOLIC LAMINATE NEMA GRADE C, AGED 135°C IN FYRQUEL LIQUID 24 WEEKS

SECTION 19.0

ADDITIONAL TESTING OF INSULATION COMPONENTS

19.0 ADDITIONAL TESTING OF INSULATION COMPONENTS

19.1 COMPATIBILITY TESTING USING FYRQUEL RCP

The evaluation of the compatibility of stator winding insulation and stator winding bracing components with Fyrquel GT lubricant was made using a formulation of the lubricant containing an acidic rust inhibitor. Subsequently the rust inhibitor was changed to a neutral composition, and another change ensued which removed the rust inhibitor completely and replaced it with a stability additive package. These fluid reformulations caused some concern as to whether compatibility with organic components was influenced to a degree that would invalidate conclusions derived using the earlier formulation.

To resolve the uncertainty, a retesting of several components was initiated using the current Fyrquel RCP formulation. Representative components previously tested were selected to be exposed to the heated vapor of the modified Fyrquel fluid, following the same testing procedure as originally employed. Two ground wall systems were retested; a mica paper wrapper insulation impregnated in a vinyl modified epoxy resin, and mica paper end turn taping brushed during application with an amine activated epoxy resin. Two stress grading procedures were retested: an unprotected silicon carbide film applied over impregnated cured mica insulation, and the same coating protected with two overcoats of epoxy varnish.

Figure 19.1 superimposes dissipation factor data of bars immersed in hot Fyrquel RCP onto the original data. An effect on dissipation factor comparable to that observed with the initial testing is noted. Figure 19.2 similarly compares the dissipation factors of bars exposed to the vapors of the initial and the current formulations. The effects are identical, the predominating influence being that of the thermal aging resulting in an improvement of the dissipation factor characteristics.

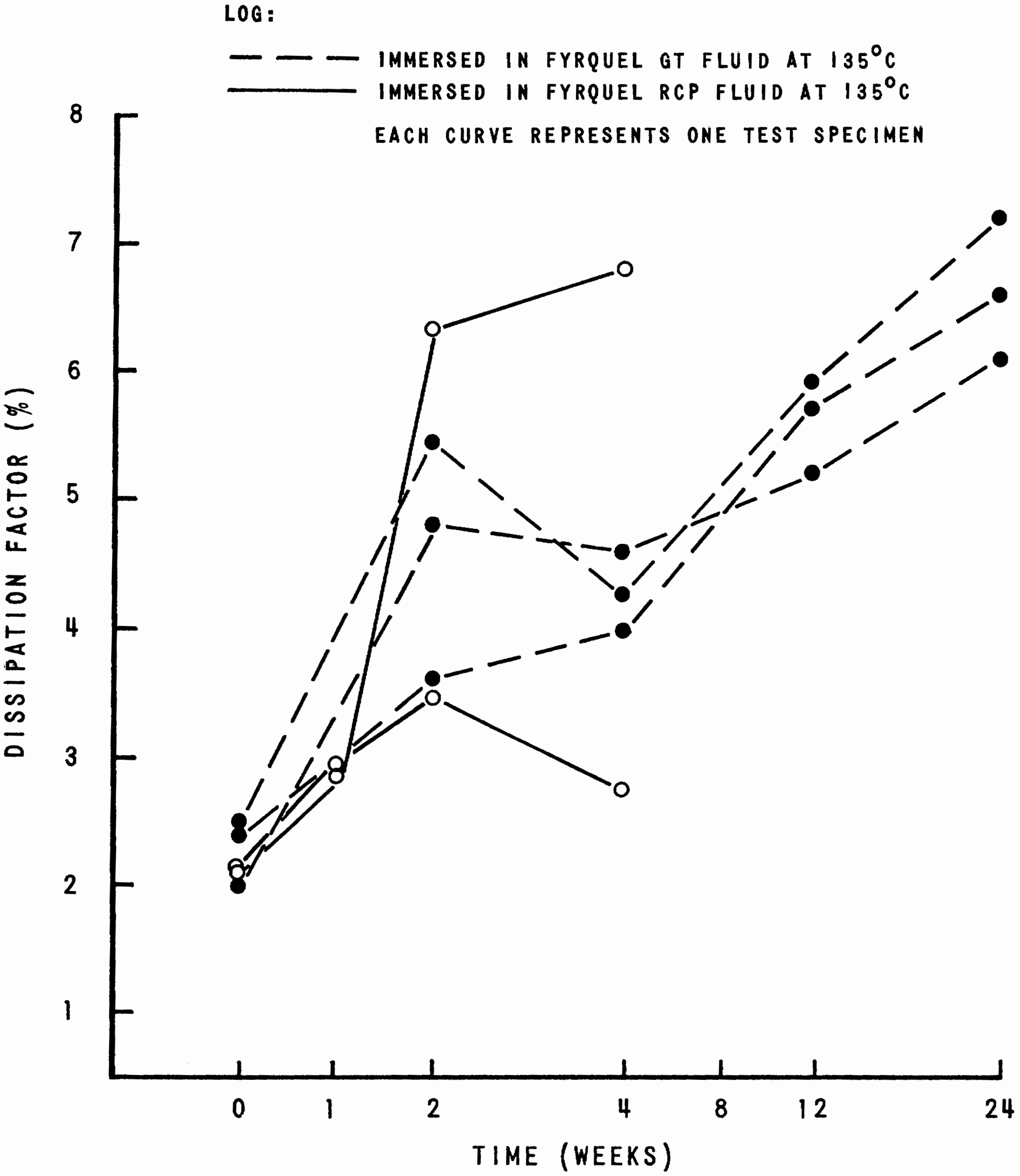


FIGURE 19.1 COMPARISON OF THE EFFECTS ON DISSIPATION FACTOR OF MICA PAPER WRAPPER INSULATION IMPREGNATED IN VINYL MONOMER MODIFIED EPOXY RESIN AFTER IMMERSION IN HOT FYRQUEL GT AND FYRQUEL RCP FLUIDS

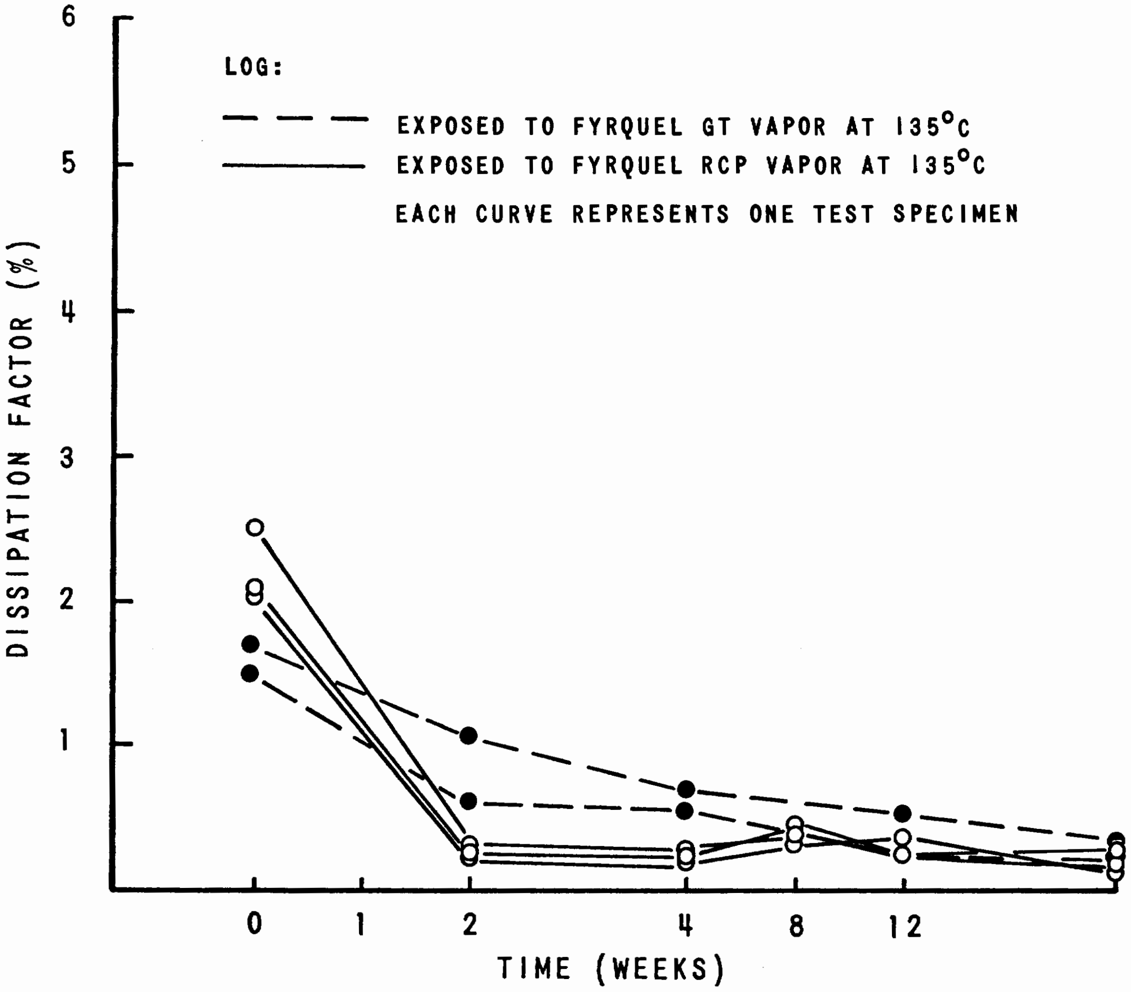


FIGURE 19.2 COMPARISON OF THE EFFECTS ON DISSIPATION FACTOR OF MICA PAPER WRAPPER INSULATION IMPREGNATED IN VINYL MONOMER MODIFIED EPOXY RESIN AFTER EXPOSURE TO HOT FYRQUEL GT AND FYRQUEL RCP VAPORS

Figure 19.3 compares the dissipation factor curves of identical end turn insulation exposed to the original and to the current formulations. Again, the data from the latest modification show no deviation from the original data. This insulation simulated hand taping of connections with resin brushed in. Therefore, its imperviousness to moisture (and other contaminants) does not approach that of vacuum and pressure impregnated insulation as represented by Figure 19.2. The initial high values of dissipation factor of Figure 19.3 are indicative of atmospheric moisture being absorbed by the relatively porous insulation over months of storage at ambient conditions.

Tables 19.1 and 19.2 compare the resistance values of stress grading paint subjected to the hot vapors of the initial and the current modification. No changes beyond sample deviation are noted.

From the data of the rerun of the two insulations and the two stress grading films, good correlation exists. There is no evidence of greater sensitivity with the one formulation as opposed to the other.

19.2 COMPATIBILITY TESTING OF INSULATING MATERIALS FROM OTHER MANUFACTURERS

Several materials suggested by Allis Chalmers were checked for compatibility with Fyrquel RCP. One was a semi-conducting coating, GE-9921 GLYPTAL, described in the manufacturer's product data sheet as a "green conducting paint designed for equalizing voltage stress on electrical insulation surfaces of cables, transformers, and rotating equipment to prevent or decrease corona damage."

The data in Table 19.3 shows results similar to the other semiconducting systems tested. The fluid vapors tended initially to increase the resistance of the coating. Subsequently the resistance dropped progressively with additional exposure, as the effects of the thermal aging dominated. When two coats of a protective epoxy varnish were used, the data shown in Table 19.4 resulted. From these data, it is obvious that there was incompatibility between the semiconducting coating and the protective varnish. Exposure to

TABLE 19.1

COMPARISON OF THE EFFECTS OF FYRQUEL GT AND FYRQUEL RCP FLUID VAPORS ON STRESS GRADING COATING APPLIED OVER IMPREGNATED INSULATION

	Specimen Iden.	MEGOHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 2 Weeks	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	3975	3925		3525	3450	1750
	2	3525	3825				1900
	3	3600	3825		3525	3225	2900
Exposed To Vapors In Chamber Maintained At 135C. (FYRQUEL GT)	7	4125	4750		4425	4425	3775
	8	3825	4425		4425	4525	3825
	9	3525	4425		4350	4125	3150
Exposed To Vapors In Chamber Maintained At 135C. (FYRQUEL RCP)	10	4425	3925	3975	4425	4275	3925
	11	4750	4750	4900	5225	4425	4600
	12	4425	4125	4750	4425	4125	3975

TABLE 19.2

COMPARISON OF THE EFFECTS OF FYRQUEL GT AND FYRQUEL RCP VAPORS ON STRESS GRADING COATING APPLIED OVER IMPREGNATED INSULATION, OVERCOATED WITH EPOXY VARNISH

	Specimen Iden.	MEGOHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 2 Weeks	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	3125	2475		2600	2675	1900
	2	2900	2450		2600	2600	1900
	3	2675	2300		2525	2600	1875
Exposed To Vapors In Chamber Maintained At 135C. (FYRQUEL GT)	7	2900	2525		2750	2900	2900
	8	2900	2850		2675	2825	2075
	9	3050	2825		2675	2825	2900
Exposed To Vapors In Chamber Maintained At 135C. (FYRQUEL RCP)	10	3225	3675	3525	3600	3050	2600
	11	2900	3225	2975	2900	3050	3225
	12	2975	3675	3225	3525	3375	3225

TABLE 19.3

EFFECT OF FYRQUEL RCP VAPOR ON SEMI-CONDUCTING COATING APPLIED OVER IMPREGNATED INSULATION (GE 9921 GLYPTAL SEMI-CONDUCTING PAINT)

	Specimen Iden.	KILOHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 2 Weeks	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	33	40	20	19		12
	2	57	49	32	29		40
	3	23	38	35	33		10
Exposed To Vapors In Chamber Maintained At 135C.	4	10	34	15	55	31	11
	5	12	634	10	71	61	30
	6	36	80	27	60	36	11

TABLE 19.4

EFFECT OF FYRQUEL RCP VAPOR ON SEMI-CONDUCTING COATING APPLIED OVER IMPREGNATED INSULATION, OVERCOATED WITH EPOXY VARNISH (GE 9921 GLYPTAL SEMI-CONDUCTING PAINT)

	Specimen Iden.	KILOHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 2 Weeks	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	3600	1540	720	470	210	110
	2	800	350	220	160	90	50
	3	2670	970	600	400	200	90
Exposed To Vapors In Chamber Maintained At 135C.	4	2560	1040	720	500	230	200
	5	30,400	15,200	1900	1980	1450	920
	6	22,000	930	550	370	200	170

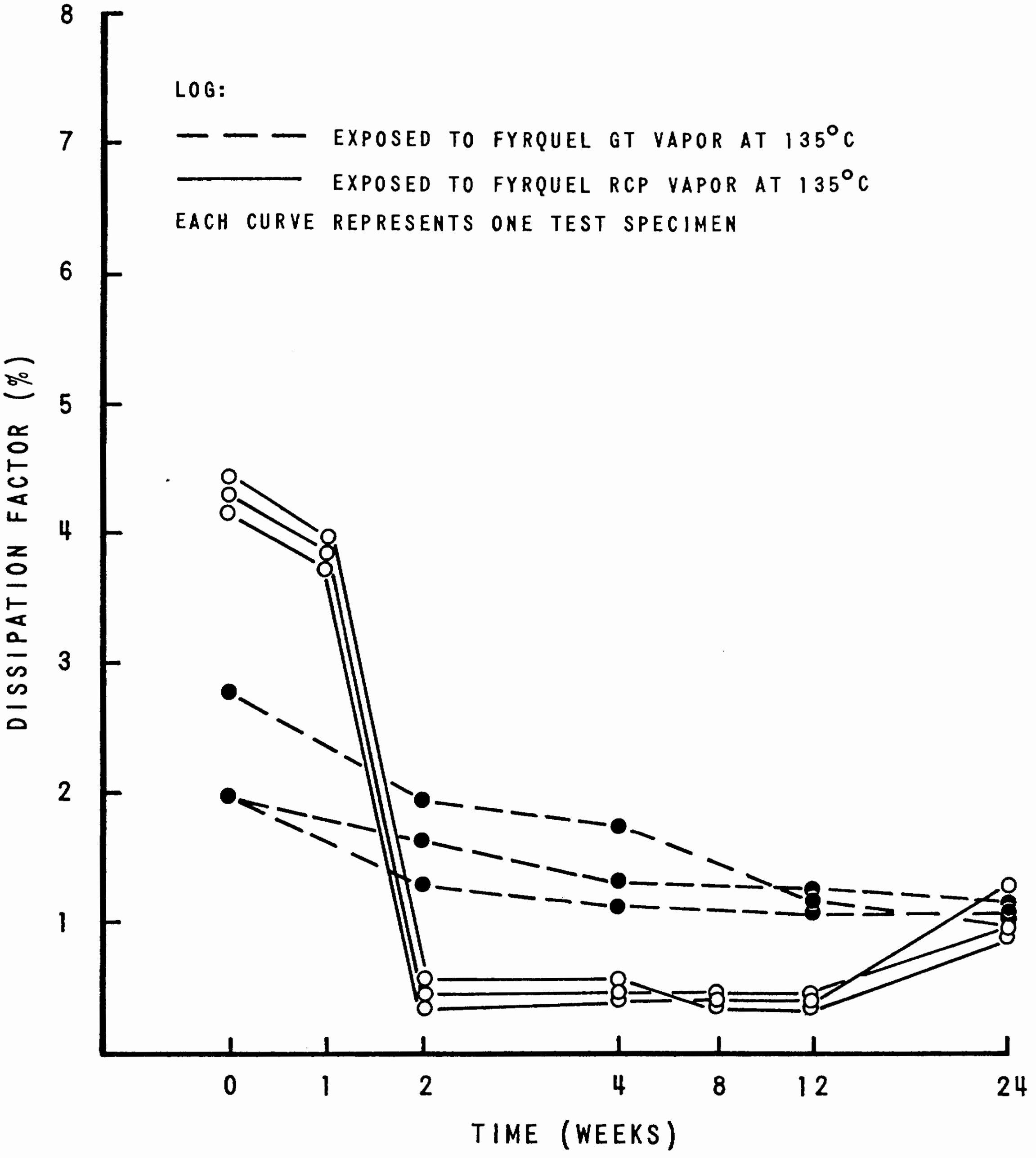


FIGURE 19.3 COMPARISON OF THE EFFECTS ON DISSIPATION FACTOR OF MICA PAPER END TAPING BRUSHED WITH AMINE ACTIVATED EPOXY RESIN AFTER EXPOSURE TO HOT FYRQUEL GT AND FYRQUEL RCP VAPORS

the fluid vapors did not result in further deterioration, and, in fact, the resistivity decreased as if in response to the thermal aging.

Another material tested was an asbestos tape used for stress grading. The material is Atlas Textile Co. 4-11-A1, 1-1/4" x .010" 2548-13.

The asbestos tape maintained exceptional integrity even under the severest exposure to Fyrquel RCP. No significant changes were noted in specimens exposed to vapors at 135°C compared to specimens thermally aged at 135°C. Only moderate changes were noted under the very severe conditions of immersion in the fluid at 135°C. In contrast to the effect of immersion in the lubricant which is to increase the resistance of organic coatings, the effect of immersion on the asbestos tape was a modest decrease in resistance, possibly the result of the tendency of the lubricant to separate the fibers. These data are shown in Table 19.5.

A short coil section, approximately 1-1/2 feet long, from AEG (Kleiber & Schulz, Inc.) was received for evaluation. The section consisted of a portion of the coil straight part and a portion of the end turn. The straight part was coated with a semiconducting treatment; asbestos tape on the diamond served as the stress grading medium. Secured to the coil diamond were two resin saturated lugs which functioned as bracing between adjacent coil diamonds. (See Figure 19.4 for photographs of the coil section.)

One coil sample was received. In order to acquire maximum data, it was decided to subject the coil to lubricant vapor at high temperature and monitor the following:

- Change in dissipation factor of the ground wall on the straight part of the coil.
- Change in conductivity of the semiconducting coating on the coil straight parts.
- Change in conductivity of the stress grading tape.
- Change in hardness of the diamond bracing lugs.

TABLE 19.5
EFFECT OF FYRQUEL RCP LUBRICANT AND VAPOR ON ASBESTOS TAPE USED FOR STRESS GRADING

	Specimen Iden.	MEGOHMS PER SQUARE					
		Initial	Aged 1 Week	Aged 2 Weeks	Aged 4 Weeks	Aged 12 Weeks	Aged 24 Weeks
Control Specimens - Aged At 135C.	1	5150	4000	4500	4000	4575	4125
	2	4825	3925	4825	4000	3500	3325
	3	5000	4000	3825	3325	4000	3750
Immersed in Lubricant Maintained At 135C.	4	5325	3750	3825	3575		
	5	5000	2925	3675	3325		
	6	5000	3500	4128	3825		
Exposed To Vapors In Chamber Maintained At 135C.	7	5500	5825	5150	5325	5250	4575
	8	5150	5825	5000	5825	4400	3575
	9	4825	5675	5325	4500	4000	4225

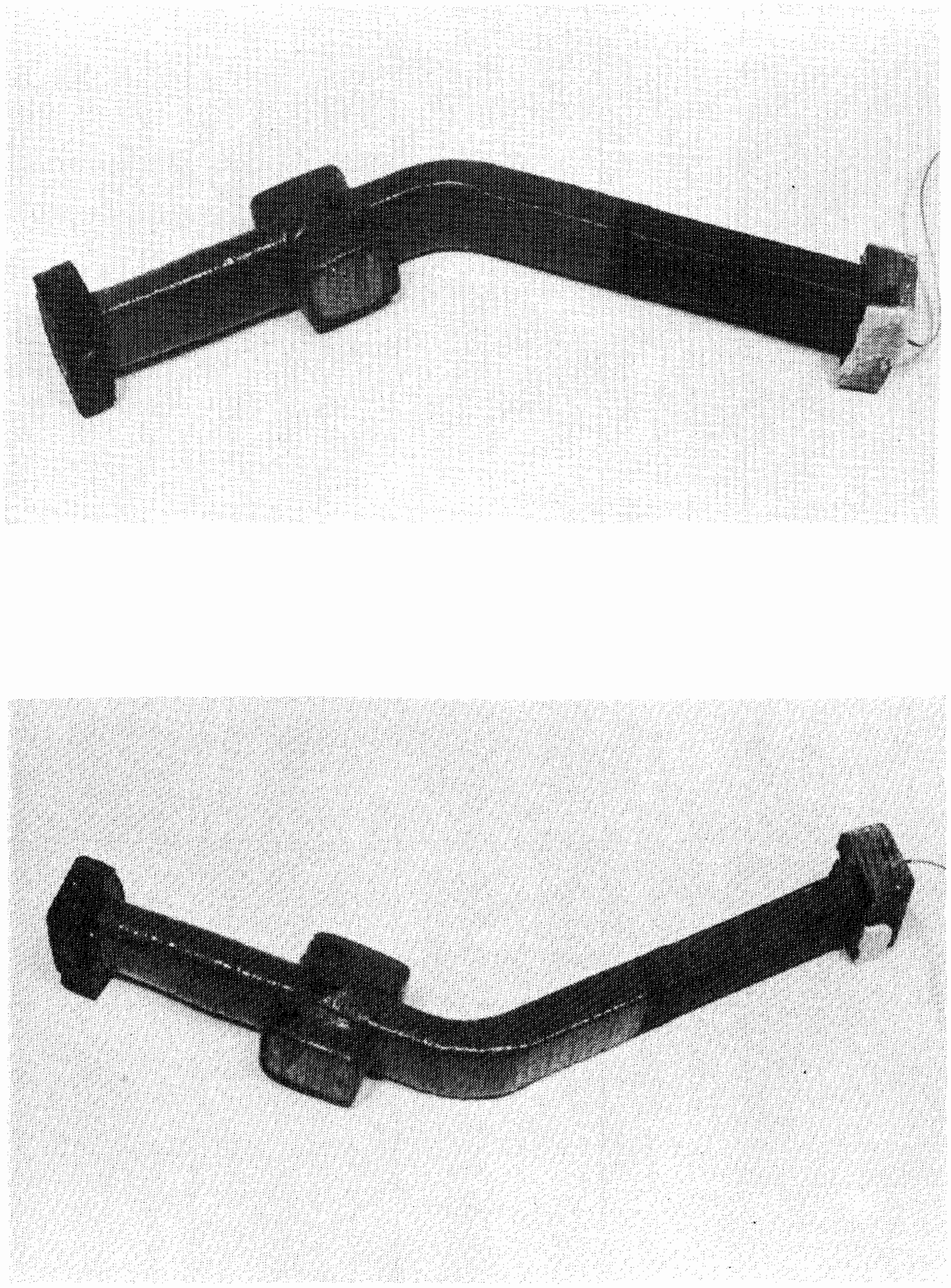


FIGURE 19.4 AEG COIL SECTION EVALUATED FOR COMPATIBILITY WITH FYRQUEL GT LUBRICANT

The coil section was prepared for testing. A half inch length of the conducting binder was trimmed off the end of the straight part of the coil to increase the creepage from the conducting binder to the copper of the coil during dissipation factor measurements. Both open ends of the coil were potted in a silica filled epoxy compound in order to prevent ingress of the fluid through the exposed cross section of the insulation laminae. Potting on the end of the straight part was kept as shallow as possible in order to utilize the maximum length of the straight part of the coil for testing.

The following measurements were made initially:

- The dc resistance of the center 3 inch length of the conducting surface was measured.
- The resistance of the voltage gradient tape was determined by applying two bands of thin copper wire around the coil, separated by 3/8". A dc voltage of 3000 volts was applied across the 3/8" width, and the current flow was measured.
- Dissipation factor was measured.
- Hardness measurements were made on the bracing lugs on both faces and all four sides.

The coil section was then placed in an environmental chamber and exposed to vapor from Fyrquel RCP at 135^{o}C. Periodically, the coil section was removed and the above measurements repeated. Data are given in Tables 19.6 and 19.7 and Figure 19.5. Since only one sample was available, results must be compared in a general way to previous experience:

- Measurements of the resistance of the semiconducting coating did not indicate that it was being attacked in a significant manner by the lubricant vapor. The decrease of resistance with time followed the anticipated reaction of semiconducting coatings to thermal aging.
- Resistance of the gradient tape did not change with increasing exposure. This agrees with previous experience on measurements of asbestos tape.

TABLE 19.6 EXPOSURE OF AEG COIL SECTION TO FYRQUEL GT VAPOR AT 135°C

DC RESISTANCE OF COIL CONDUCTING SURFACE (OHMS)

Initial	Aged 1 Wk	Aged 2 Wks	Aged 4 Wks	Aged 8 Wks	Aged 16 Wks	Aged 24 Wks
34000		15000	3100	1700	1200	2500

RESISTANCE OF STRESS GRADING (MEASURE AS CURRENT FLOW (µA) AT 3 KV ACROSS 3/8" BAND)

Initial	Aged 1 Wk	Aged 2 Wks	Aged 4 Wks	Aged 8 Wks	Aged 16 Wks	Aged 24 Wks
.1	.1	.1	.1	.1	.1	

TABLE 19.7 EXPOSURE OF AEG COIL SECTION TO FYRQUEL GT VAPOR AT 135°C

CHANGE IN HARDNESS OF DIAMOND SPACING LUGS (TYPE D DUROMETER)

Surface #	Initial	Aged 1 Wk	Aged 2 Wks	Aged 4 Wks	Aged 8 Wks	Aged 16 Wks	Aged 24 Wks
1	68	75	75	72	69	76	76
2	64	71	65	71	78	74	72
3	67	72	75	73	77	82	84
4	61	75	63	79	66	75	75
5	75	65	68	69	76	73	79
6	65	77	60	72	76	80	87
7	66	71	71	80	76	78	83
8	64	76	67	71	90	92	92
9	75	72	76	81	70	84	76
Av.	69	73	69	74	75	79	81

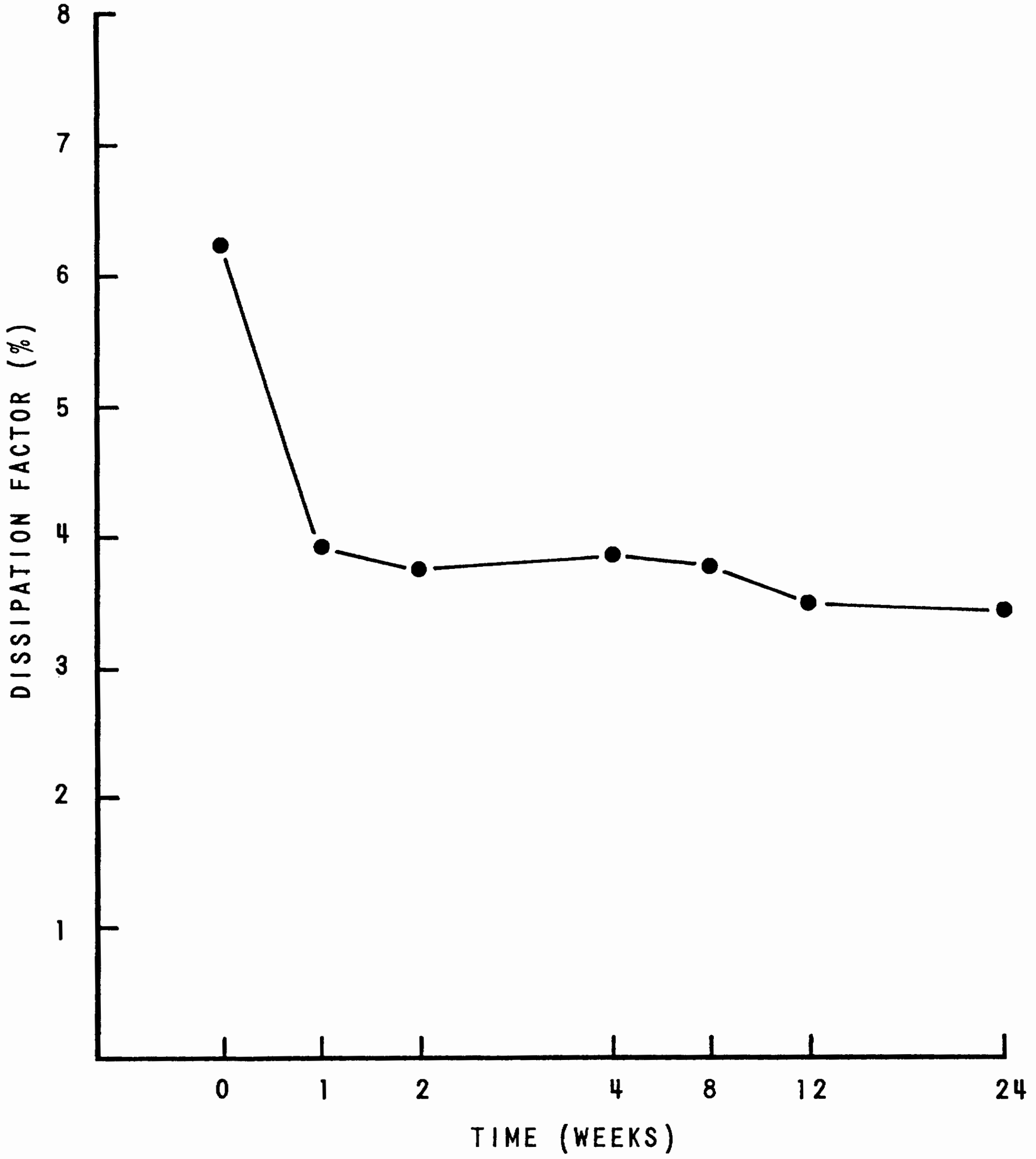


FIGURE 19.5 DISSIPATION FACTOR, WHEN EXPOSED TO FYRQUEL RCP VAPOR AT 135°C, OF GROUND WALL OF AEG COIL SECTION

- Hardness of the bracing lugs appeared to be increasing. There is no previous specific background, but the assumption is that the thermal aging is furthering their cure. Attack by the lubricant would be expected to be exhibited by a softening of the lugs.

- Dissipation factor data (Figure 18.5) do not indicate significant attack on the insulation body by the lubricant vapor. The initial high dissipation factor reading can be assumed to be related to the degree of cure of the insulation, with dissipation factor improving because of the post cure provided by the initial phase of the thermal aging.

- The AEG sample gave no indication that the components in the coil would present concern when used in an environment influenced by Fyrquel GT lubricant.

SECTION 20.0

COMPATIBILITY TESTING OF PAINTS AND ELASTOMERS

20.0 COMPATIBILITY TESTING OF PAINTS AND ELASTOMERS

20.1 GENERAL DISCUSSION

In general, phosphate esters are excellent paint removers; so care must be exercised in painting surfaces which may come into contact with the phosphate ester fluid. On a reactor coolant pump motor, the interiors of the oil pots and the exterior of the motor are typically painted to prevent the formation of rust.

In addition, the phosphate esters agressively attack elastomers that are commonly used for gaskets and O-rings in the manufacture of motors.

20.2 PAINTS

Two paints were tested for compatibility with the various candidate fluids. The paints were Dimetcote Steel Primer #2, used on the external surfaces of the motor, and a red primer (Celanese Chromate Primer 553, Sherwin Williams Cinoxide Primer C-14829, or Westinghouse Primer B-5-609) used on the interior of the oil pots. The Dimetcote Primer #2 withstood the petroleum oil, the diester fluid, the silicone fluid and the phosphate ester fluids. After 1000 hours in the fluids at 130°C no discoloration and little loss of adhesion were observed. Since this paint contains a finely divided organic zinc powder, the fluids were ashed, and an emission spectrum was run to compare the zinc content of the virgin oils with the tested oils. Table 20.1 shows the percentage of ash for each fluid along with the emission spectrum results for the zinc in the ash.

The red primer did not withstand the attack of the phosphate ester fluids. The test panels became discolored (dark brown) with the paint lifting and blistering. With petroleum oil, the effect was less severe although the panels did discolor and blister. However, the paint did not lift off the panel.

With the reformulation of Fyrquel GT, further testing was required. Samples suggested by Allis Chalmers and already scheduled for testing were delayed to be tested using Fyrquel RCP. In addition three other paint systems were tested. These paints were:

1. Keeler and Long paint system using #7107 epoxy white primer with top coat of #E-1-7475 epoxy enamel. (Allis Chalmers)
2. Bearing housing oil reservoir paint (Allis Chalmers):
   a) W. C. Richards Company E-4183 Yellow Oxide Casting Sealer.
   b) Zummach Paint Corporation Buff Primer U-3001.
3. Motor exterior paint system using Dimetcote Steel Primer #2 with top coat of Amercote #66.
4. Paint system qualified under MIL-P-24441 consisting of a first coat using Formula 150, a second coat using Formula 151 and a top coat using a formula chosen from Formulas 152 to 157. (Formula 156 will be tested.) These panels were obtained from Mobil.
5. An Ameron Protective Coatings paint that was indicated by the Stauffer brochure to be compatible.

There was no blistering nor softening of the paint at the end of the 1000 hour exposure at 130^{O}C to either petroleum oil or Fyrquel RCP.

The panels painted with the Keeler and Long paint system did exhibit a loss of adhesion when exposed to either fluid (Figures 20.1 and 20.2). An apparent loss of adhesion was also shown when Amercoat 85 was exposed to both petroleum oil and Fyrquel RCP (Figure 20.3). However, further inspection revealed that a baked-on oil layer could be removed to reveal the paint surface. A retest of the panels showed that there was a real loss of adhesion on both panels. The remaining paints showed no loss of adhesion.

20.2 ELASTOMERS

The test methods chosen to evaluate the effect of the phosphate ester on the commonly used elastomers are standard ASTM tests, including:

ASTM-D-395: Compression Set of Vulcanized Rubber.

ASTM-D-471: Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids.

ASTM-D-1415: Test for International Standard Hardness of Vulcanized Rubbers.

ASTM-D-952: Bond or Cohesive Strength of Sheet Plastics and Electrical Insulating Materials.

These ASTM tests measure the comparative ability of the tested material to withstand the chemical attack of the fluid. The material must not be affected by the fluid in such a way as to alter either operational characteristics or resonable life expectancy. Normally a good indiction of the deterioration of the material would be a gross change in the material's properties such as: volume swell or shrinkage, decrease or increase in hardness, extreme change in tensile strength or elongation. However the results of any standard test must be interpreted in terms of the actual end use of the material.

The elastomers commonly used in the fabrication of a reactor coolant pump motor are shown in Table 20.2. The standard tests conducted on each elastomer are also shown in Table 20.2. The physical properties were measured before and after complete immersion in the fluid for times of 22, 70, 166 and 670 hours at temperatures of 23°C, 50°C and 100°C. Complete immersion may be much more severe than the actual application where fluid contact with the elastomer is limited through design.

Volume changes in an elastomer exposed to a fluid are almost always accompanied by a decrease in hardness. For static O-ring applications, a volume swell of as much as 5 % can usually be tolerated while materials which swell much more (in excess of 100%) can be tolerated in designs where there is a controlled confinement of the elastomer which results in a limited fluid contact. Swell may aid a seal, but this has not been proved in all cases. For instance swell may compensate for compressive set.

The various elastomers were exposed to the fluid, and their weight gain and dimensional changes were measured. The results are shown in Tables 20.3 (thickness) and 20.4 (weight) as well as in Figures 20.4 through 20.13.

Because the elastomers tested showed a large dimensional increase (except for Viton 90), it could be expected that their hardness would also show a large decrease, as confirmed by test. Low values of Shore A hardness indicate that an elastomer will have less resistance to pressure and will, as a result, be expected to flow into the micro fine grooves of mating parts. Conversely, a high hardness reading indicates a greater resistance to flow and, in an O-ring, will indicate a reduced tendency to be extruded beyond the O-ring groove. Based upon the particular application, a compromise is reached, and a particular elastomer is selected. The hardness values of the elastomers tested are shown in Table 20.5. Normally hardness is reported in increments of 10 as shown in parentheses in Table 20.5 due to rubber batch variations and reading variations.

Compression set is the last test which was performed on most of the elastomers. It is generally determined in air and is the percentage by which the elastomer fails to recover after having been compressed for a fixed time under specified load and temperature. It is always desirable to have a low compression set, but it is not as critical as it might appear because of actual service variables. One group of compression set tests was performed under constant load, and another group of such tests was performed under constant deflection. Both groups of tests used a load applied for 22 hours at 70^{o}C after exposure to the phosphate ester fluid. The results of tests using a constant load of 400 pounds are shown in Table 20.6. The results of another test for which there was a constant deflection to 0.375" (which is 75% of the original unexposed thickness) are shown in Table 20.7. Comparison of Table 20.3 with Tables 20.6 and 20.7 confirms that the swelling of the elastomer when exposed to the phosphate ester fluid reduces the compression set. For the asbestos sheet the chemical attack of the fluid resulted in fractured specimens when compressed to 0.375" after the fluid exposure. Several cork neoprene specimens from the two compression set tests exhibited a similar result from fluid exposure. Tests were conducted on a polyester resin adhesive, Locktite #84. The test data for this adhesive are shown in Table 20.8.

The data presented in this section must be assessed on a case by case basis as an elastomer may work satisfactorily in one application but not in another.

TABLE 20.1

ANALYSIS OF ASH AND ZINC CONTENT OF DIMETCOTE NO. 2 PRIMER PAINT

	% Ash		Zinc Constituent of Ash	
Fluid	Virgin Fluid	Tested Fluid	Virgin Fluid	Tested Fluid
Teresstic 46	0.032	0.067	Major (1–10%)	Principle (10–100%)
Fyrquel GT	0.10	0.85	Major (.3–3%)	Principle (10–100%)
Turbinol 1122	0.12	1.95	––	Major (1–10%)
SF # 1147	4.02	3.82	––	––
Anderol 495	0.005	0.049	Major (.3–3%)	Major (3–30%)

TABLE 20.2

TYPES OF TESTS PERFORMED ON VARIOUS ELASTOMERS

		Type of Test		
Elastomer	Dimension	Weight	Hardness	Compression
Asbestos Sheet Packing	X	X	X	X
Cork Neoprene Seal	X	X	X	X
Neoprene Sheet Gasket	X	X	X	X
Viton 90	X	X	X	X
Buna N (ASA16)	X	X		

TABLE 20.3

ELASTOMER THICKNESS CHANGES WHEN EXPOSED TO FYRQUEL GT

Elastomer	Time (Hrs.) of Exposure to Fluid	Increase in Thickness (%) Fluid Temperature 23°C	50°C	100°C
Asbestos Sheet	22	3.7	15.2	25.1
	70	9.7	19.2	27.3
	166	17.7	21.4	30.1
	670	18.2	23.9	41.0
Cork Neoprene	22	2.2	2.2	8.5
	70	1.1	6.0	10.1
	166	1.1	6.6	11.8
	670	4.9	13.2	35.0
Neoprene Sheet	22	4.5	8.9	7.3
	70	5.2	8.8	11.6
	166	8.3	9.8	24.8
	670	20.1	22.8	Dissolved
Viton 90	22	1.8	0.8	1.3
	70	3.1	2.5	4.0
	166	0	0.3	1.8
	670	1.0	3.3	9.3
Buna N (ASA 16)	22	4.0	7.3	22.2
	70	3.2	11.3	25.8
	166	6.2	21.6	29.9
	670	11.8	29.3	50.3

TABLE 20.4
ELASTOMER WEIGHT CHANGE WHEN EXPOSED TO FYRQUEL GT

		Weight Gain (%)		
		Fluid Temperature		
Elastomer	Time (Hrs) of Exposure to Fluid	23°C	50°C	100°C
Asbestos Sheet	22	11.9	25.2	31.4
	70	17.2	26.7	33.4
	166	21.2	27.8	37.2
	670	25.9	27.7	45.8
Cork Neoprene	22	7.5	24.1	50.2
	70	10.8	40.0	80.1
	166	16.1	57.6	110.7
	670	27.9	79.3	177.0
Neoprene	22	9.7	43.6	85.1
	70	16.3	58.6	156.0
	166	29.8	62.5	240.0
	670	55.8	72.2	Dissolved
Viton 90	22	0.4	0.8	2.9
	70	0.7	1.2	4.8
	166	0.8	1.5	7.0
	670	0.7	2.5	11.1
Buna N (ASA-16)	22	4.6	21.0	85.8
	70	10.0	44.6	114.5
	166	16.6	77.7	122.0
	670	41.2	111.0	215.0

TABLE 20.5

ELASTOMER HARDNESS CHANGE WHEN EXPOSED TO FYRQUEL GT

		Hardness (Share A)*		
		Fluid Temperature		
Elastomer	Time (Hrs.) of Exposure to Fluid	23°C	50°C	100°C
Asbestos Sheet	22	83 (80)	85 (90)	86 (90)
(90 hardness specified)	70	85 (90)	87 (90)	87 (90)
All unexposed specimens	166	85 (90)	86 (90)	85 (90)
measured 90	670	88 (90)	85 (90)	79 (80)
Cork Neoprene	22	71 (70)	64 (60)	56 (60)
(60-75 hardness	70	72 (70)	65 (70)	55 (60)
specified)	166	68 (70)	56 (60)	48 (50)
All unexposed specimens	670	65 (70)	57 (60)	43 (40)
measured 70				
Neoprene	22	53 (50)	41 (40)	29 (30)
(60 hardness specified)	70	54 (50)	42 (40)	29 (30)
All unexposed specimens	166	48 (50)	41 (40)	18 (20)
measured 60	670	40 (40)	36 (40)	Dissolved
Viton 90	22	71 (70)	73 (70)	68 (70)
All unexposed specimens	70	70 (70)	68 (70)	64 (60)
measured 70	166	73 (70)	63 (60)	68 (70)
	670	72 (70)	68 (70)	61 (60)

* Plain figures are measured. Figures in parentheses show test figures rounded off to nearest multiple of 10, per normal practice used for rubber.

TABLE 20.6

COMPRESSION SET DUE TO CONSTANT LOAD OF 400 POUNDS FOR 22 HOURS AT 70°C AFTER EXPOSURE TO FYRQUEL GT

Elastomer	Time (Hrs.) of Exposure to Fluid	Compression Set (% of Original Thickness) Fluid Temperature 23°C	50°C	100°C
Asbestos Sheet	22	7.2	1.2	–2.6
(12.2% as received)	70	2.0	2.2	–4.6
	166	5.9	0.2	–4.2
	670	2.2	–3.4	–6.1
Cork Neoprene	22	26.1	18.3	18.1
(30.4% as received)	70	23.5	13.6	*
	166	20.8	18.1	*
	670	25.2	*	*
Neoprene Sheet	22	6.4	–6.3	–7.3
(17.4% as received)	70	2.7	–––	–19.6
	166	–2.5	–16.9	–––
	670	–13.0	–15.6	Dissolved
Viton 90	22	14.0	13.7	9.0
(13.3% as received)	70	13.1	13.2	9.9
	166	15.1	11.8	9.1
	670	13.5	10.7	4.4

* Fractured when loaded to 400 pounds after specified exposure to Fyrquel GT

TABLE 20.7

COMPRESSION SET DUE TO CONSTANT DEFLECTION TO 75% OF NOMINAL THICKNESS (TO 0.375 INCH) FOR 22 HOURS AT 70°C AFTER EXPOSURE TO FYRQUEL GT

Elastomer	Time (Hrs.) of Exposure to Fluid	Compression Set (% of Original Deflection *)		
		Fluid Temperature		
		23°C	50°C	100°C
Asbestos Sheet	22	75.6△	61.2△	26.4△
(74.2% as received)	70	72.1△	45.0△	−1.6△
	166	68.4△	45.4△	24.2△
	670	50.0△	12.1△	−26.8△
Cork Neoprene	22	67.2	42.3	25.7
(73.9% as received)	70	55.5	33.9	24.0
	166	57.3	30.8	16.7
	670	47.1	40.8	△
Neoprene Sheet	22	21.2	—	—
(31.9% as received)	70		Unable to measure	
	166		due to softness	
	670	—	—	Dissolved
Viton 90	22	34.4	36.1	23.5
(28.5% as received)	70	28.6	27.3	16.0
	166	29.9	26.7	9.4
	670	28.3	23.6	1.3

* Original deflection is unexposed thickness minus 0.375"

△ Fractured when loaded to 0.375" thickness after specified exposure to Fyrquel GT.

TABLE 20.8

ADHESIVE STRENGTH OF LOCKTITE NO. 84 AFTER EXPOSURE TO FYRQUEL GT

Time (Hrs.) of Exposure to Fluid	Fluid Temperature (^{o}C)	Coated Area As % of Total Area	Strength (PSI) Based on Total Area	Strength (PSI) Extrapolated to 100% Coating
As recieved	––	90	178	197
22	23	90	328	364
	50	100	138	138
	100	90	50	56
70	23	90	565	628
	50	90	73	81
	100	90	58	64
166	23	75	445	593
	50	50	278	555
	100	90	60	67
670	23	75	310	413
	50	100	1500	1500
	100	25	75	300

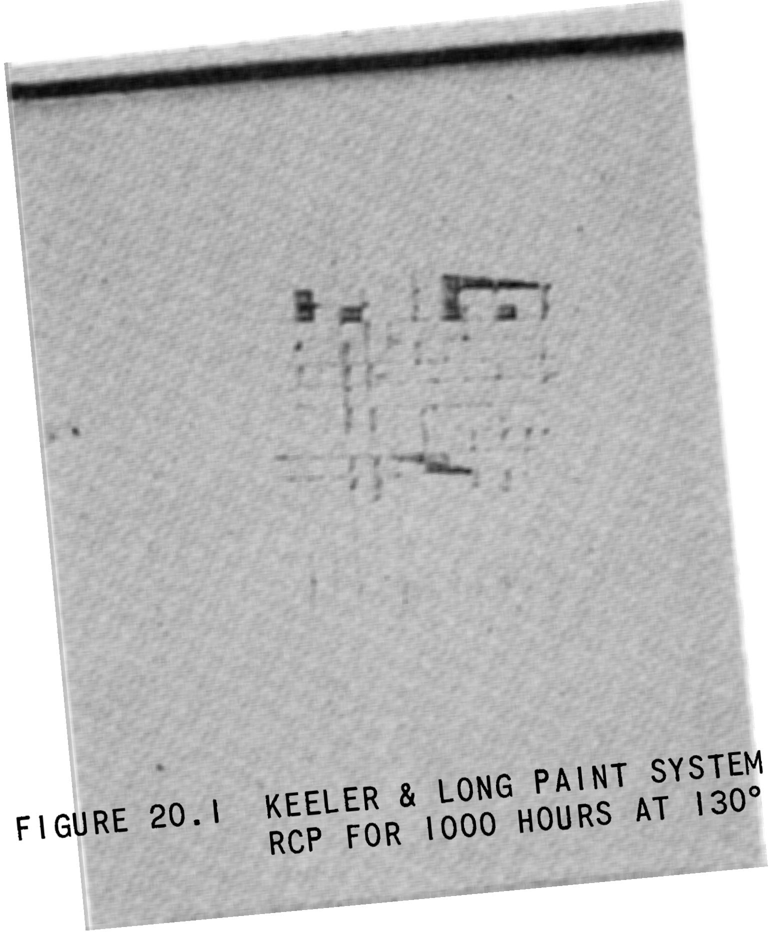


FIGURE 20.1 KEELER & LONG PAINT SYSTEM AFTER EXPOSURE TO FYRQUEL RCP FOR 1000 HOURS AT 130°C SHOWING LOSS OF ADHESION

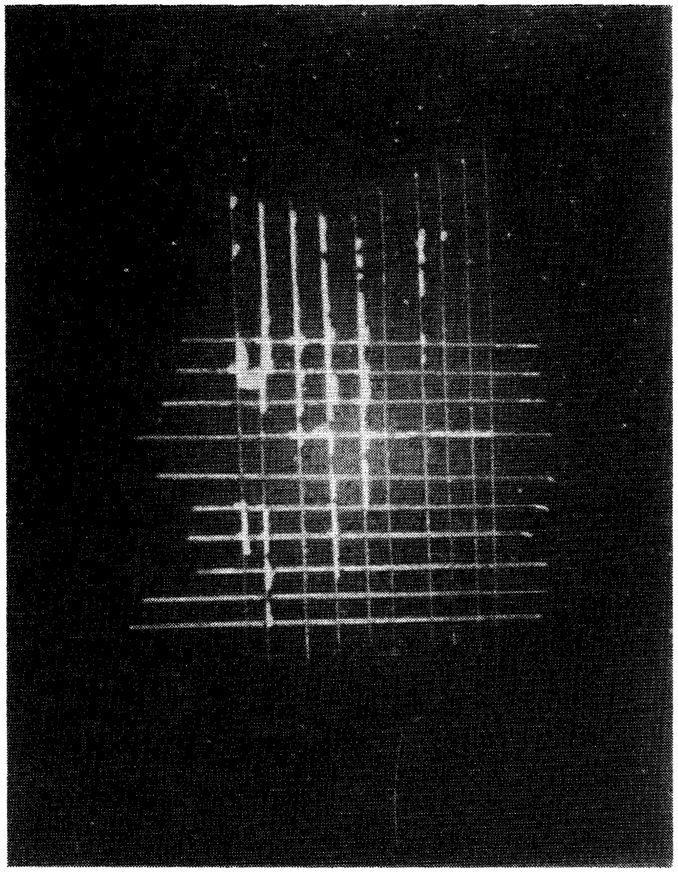
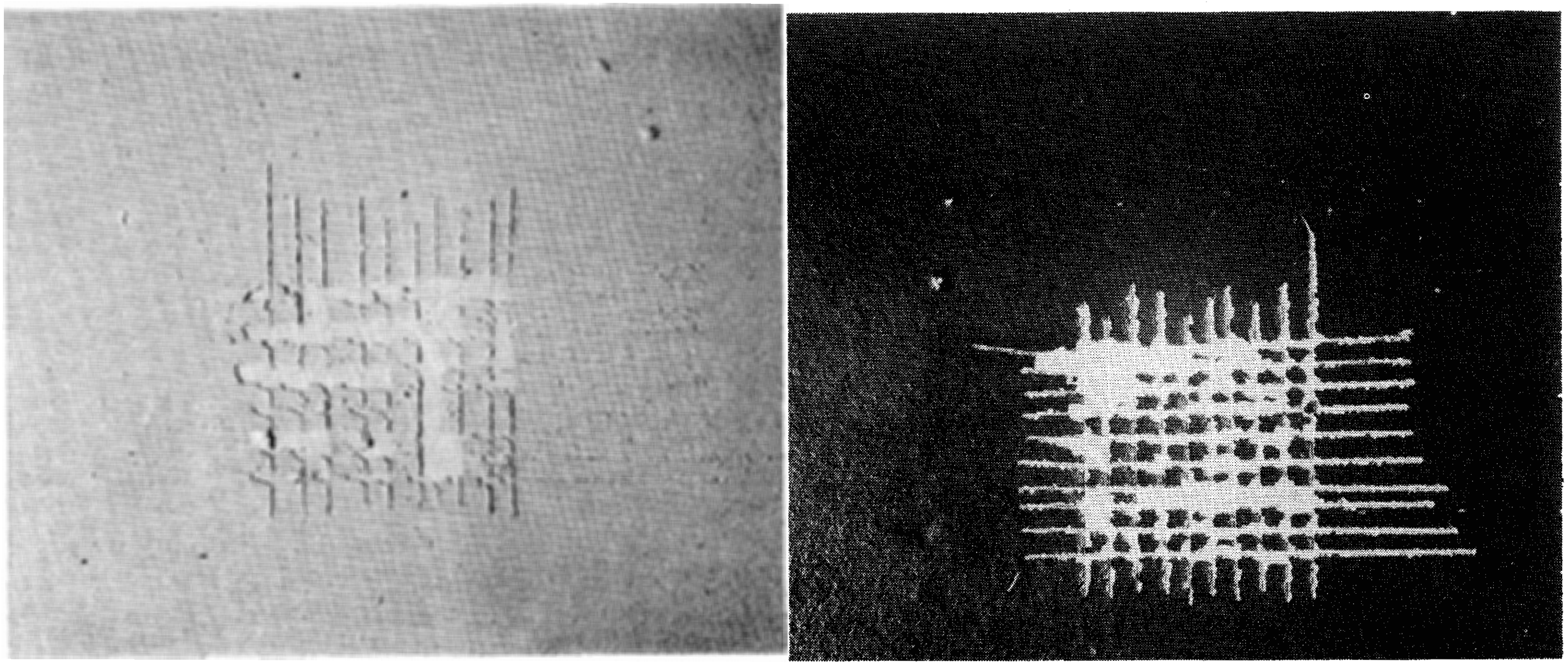


FIGURE 20.2 KEELER & LONG PAINT SYSTEM AFTER EXPOSURE TO PETROLEUM OIL FOR 1000 HOURS AT 130°C SHOWING LOSS TO ADHESION



a) FYRQUEL RCP

b) PETROLEUM OIL

FIGURE 20.3 ADHESION OF A BAKED ON OIL FILM TO THE AMERCOAT 85 PAINT FOLLOWING TEST AT 130°C FOR 1000 HOURS

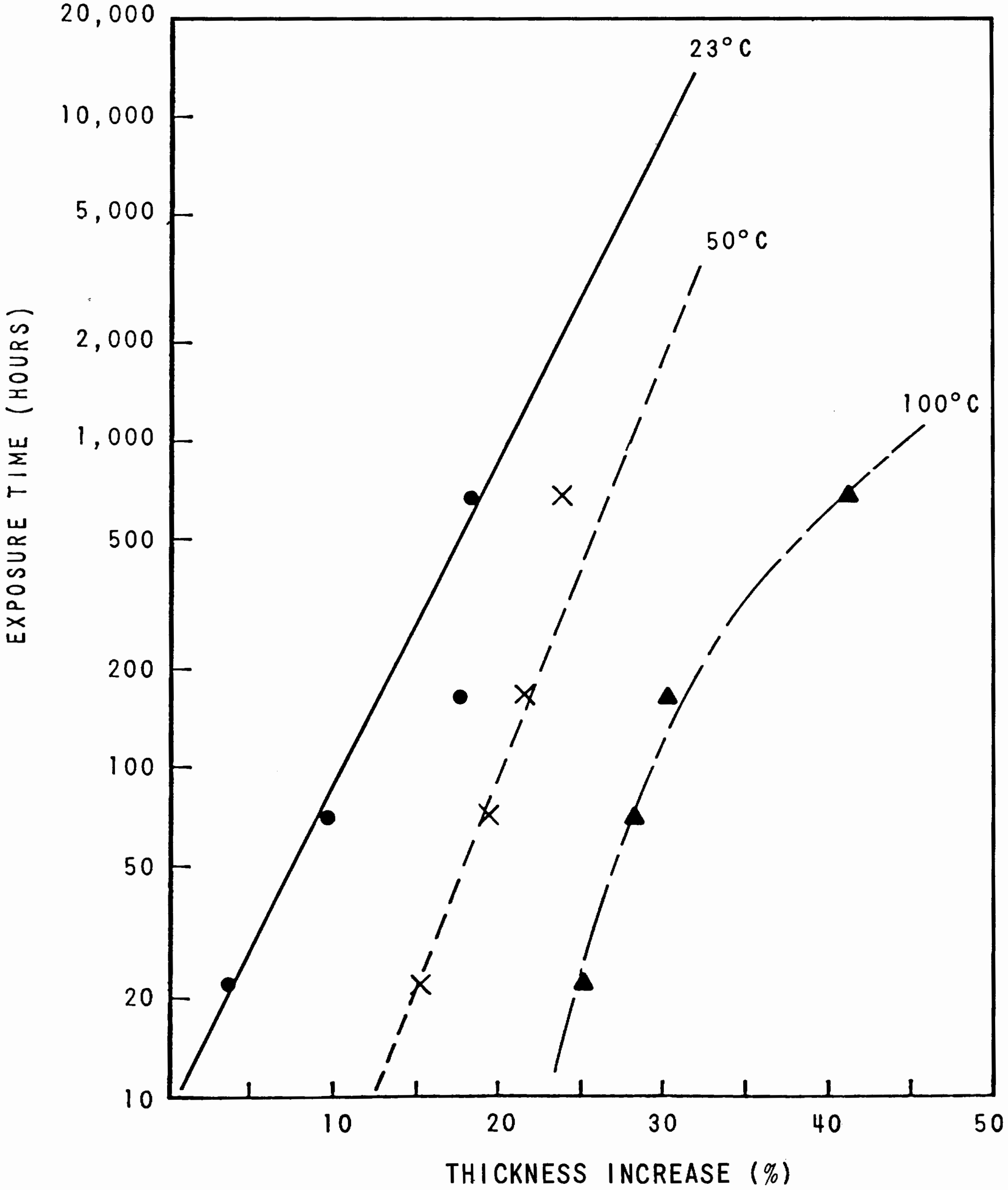


FIGURE 20.4 ASBESTOS SHEET THICKNESS INCREASE WHEN EXPOSED TO FYRQUEL GT

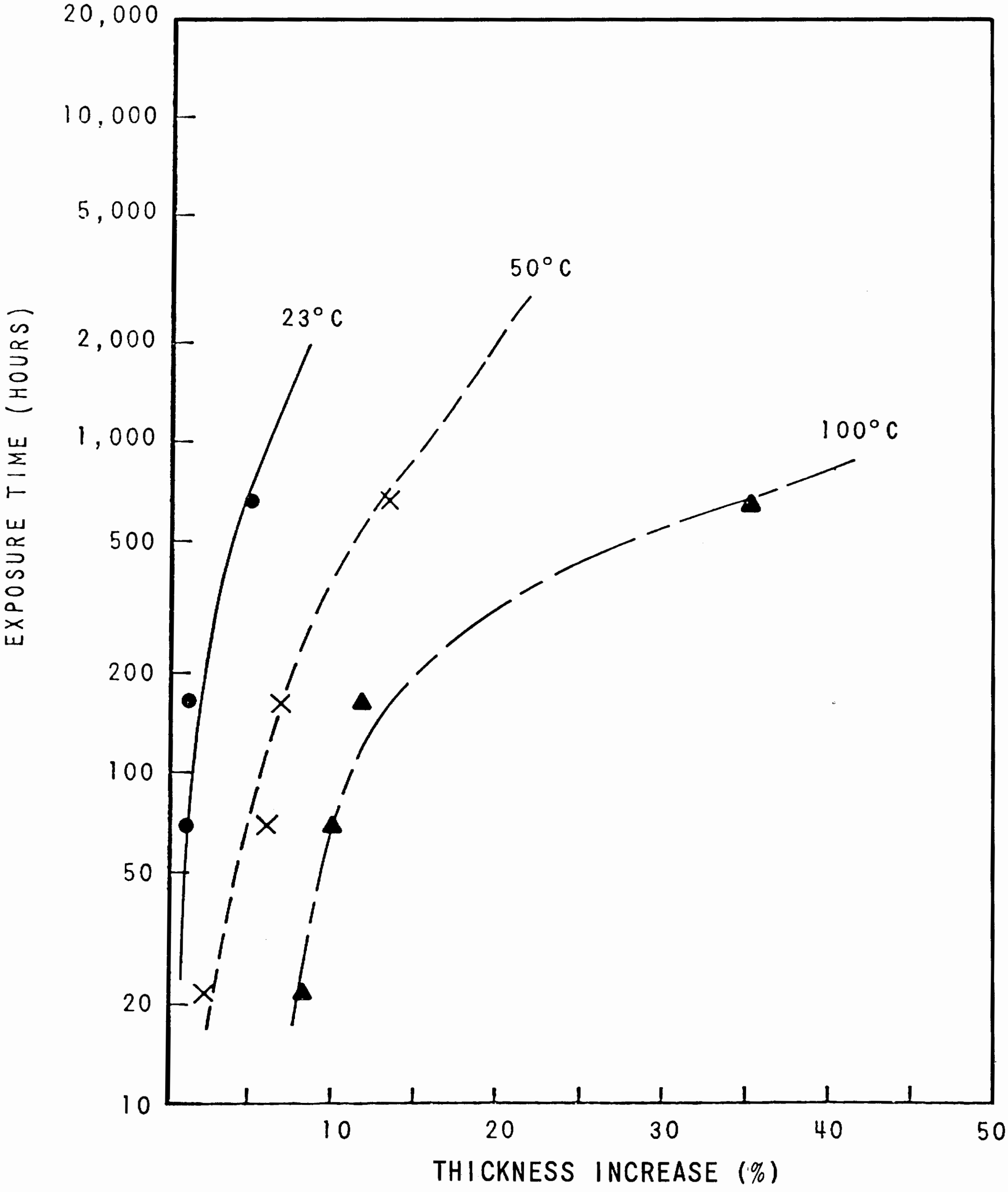


FIGURE 20.5 CORK NEOPRENE SHEET THICKNESS INCREASE WHEN EXPOSED TO FYRQUEL GT

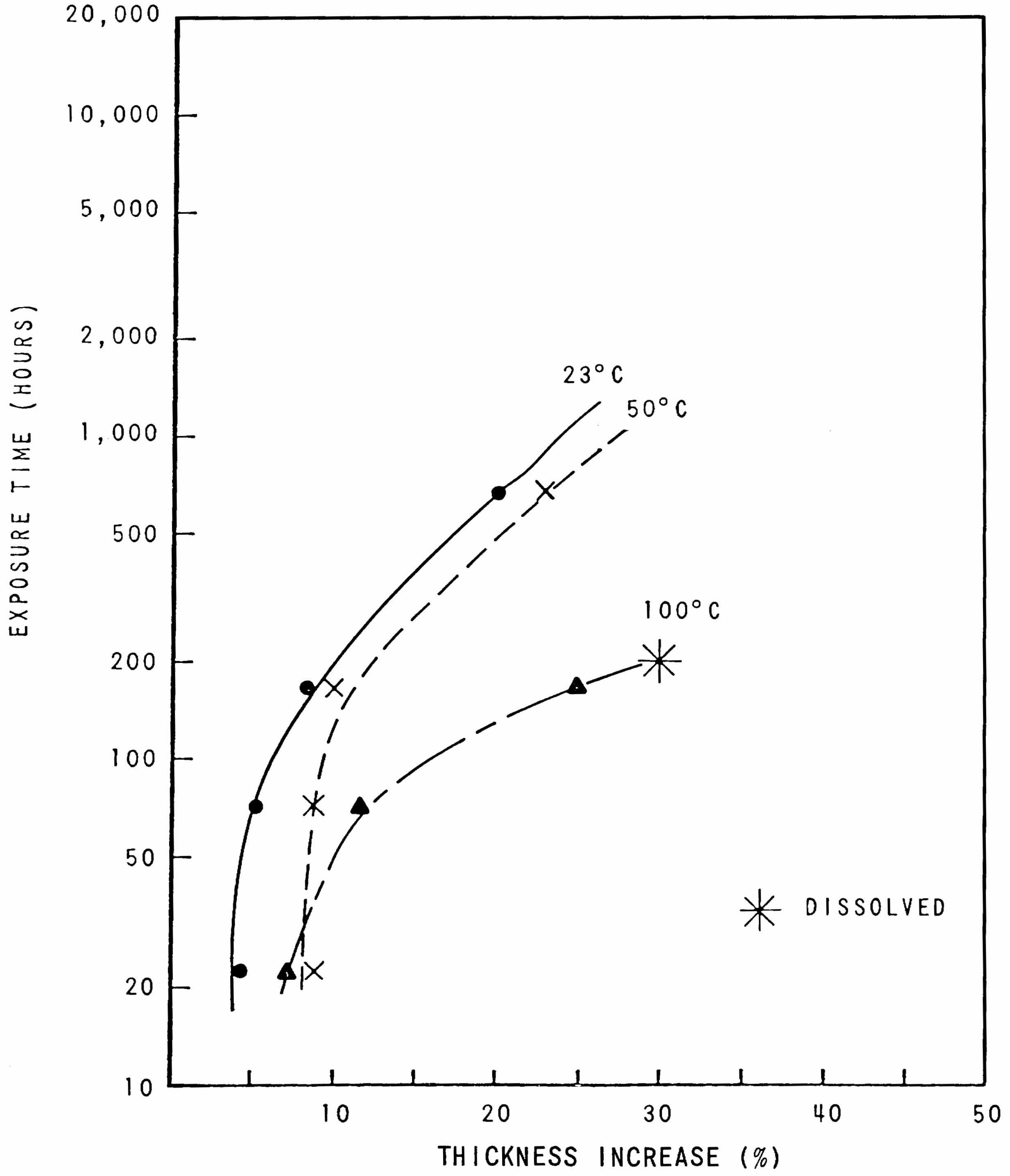


FIGURE 20.6 NEOPRENE SHEET THICKNESS INCREASE WHEN EXPOSED TO FYRQUEL GT

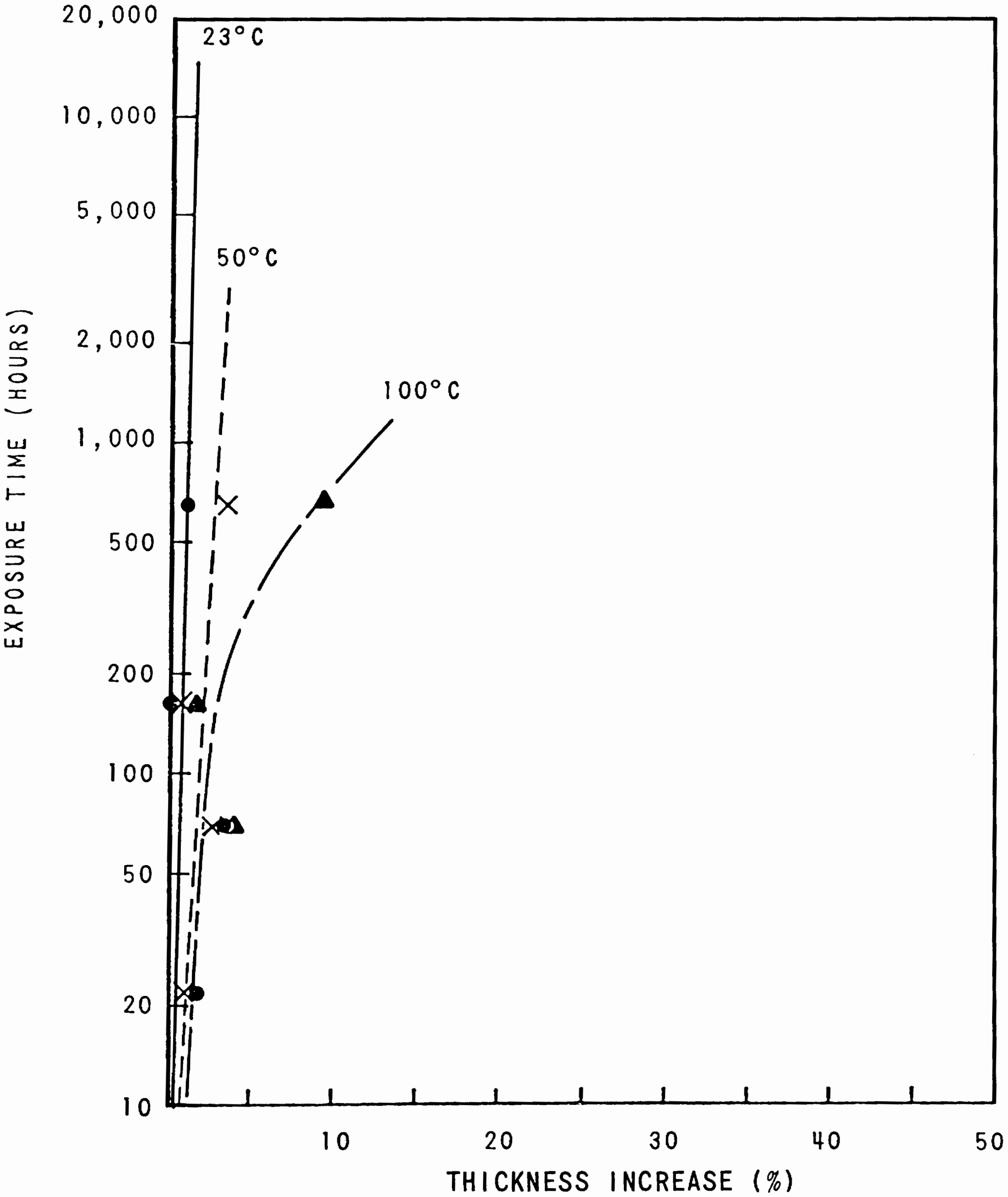


FIGURE 20.7 VITRON 90 THICKNESS INCREASE WHEN EXPOSED TO FYRQUEL GT

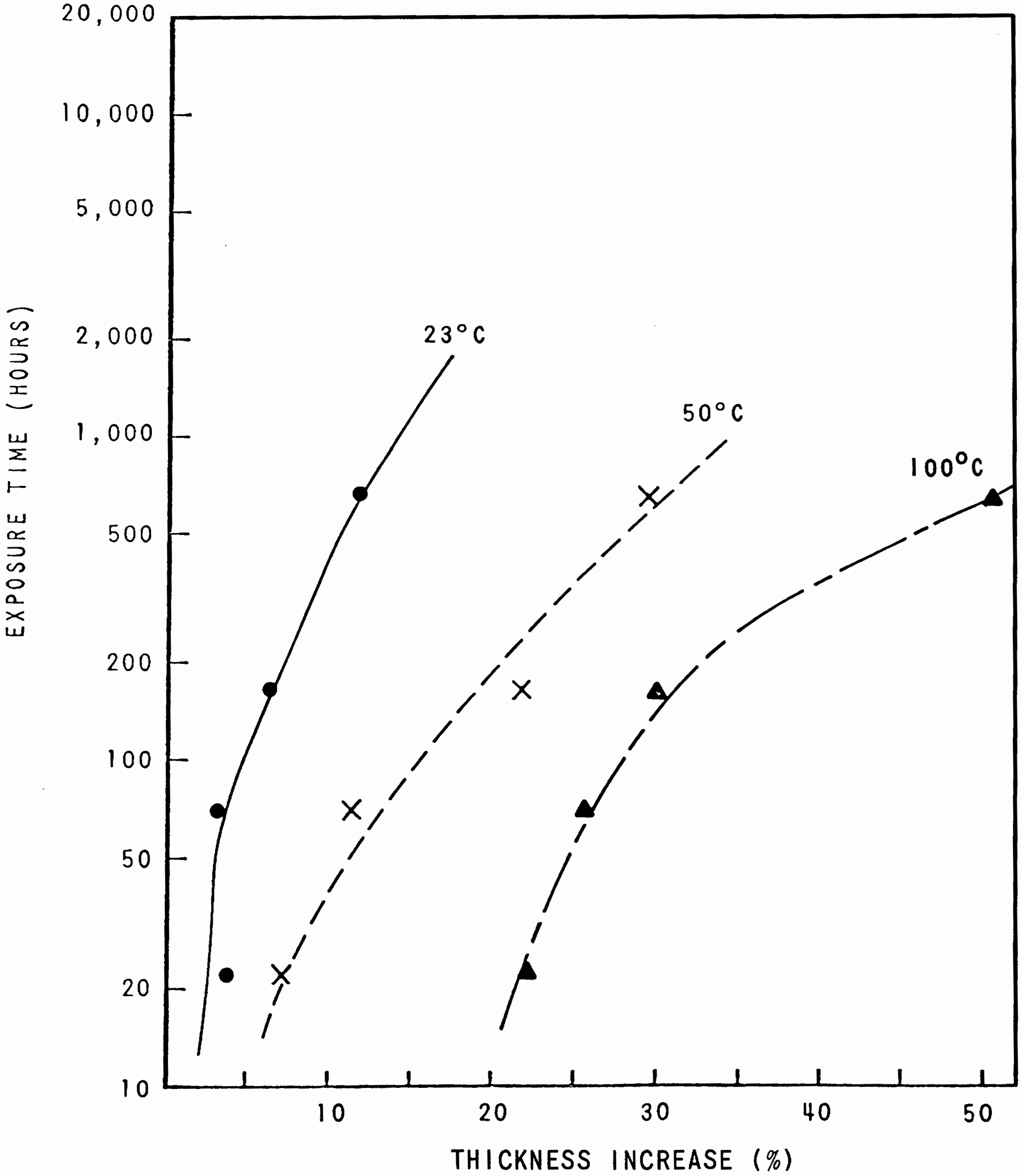


FIGURE 20.8 BUNA N THICKNESS INCREASE WHEN EXPOSED TO FYRQUEL GT

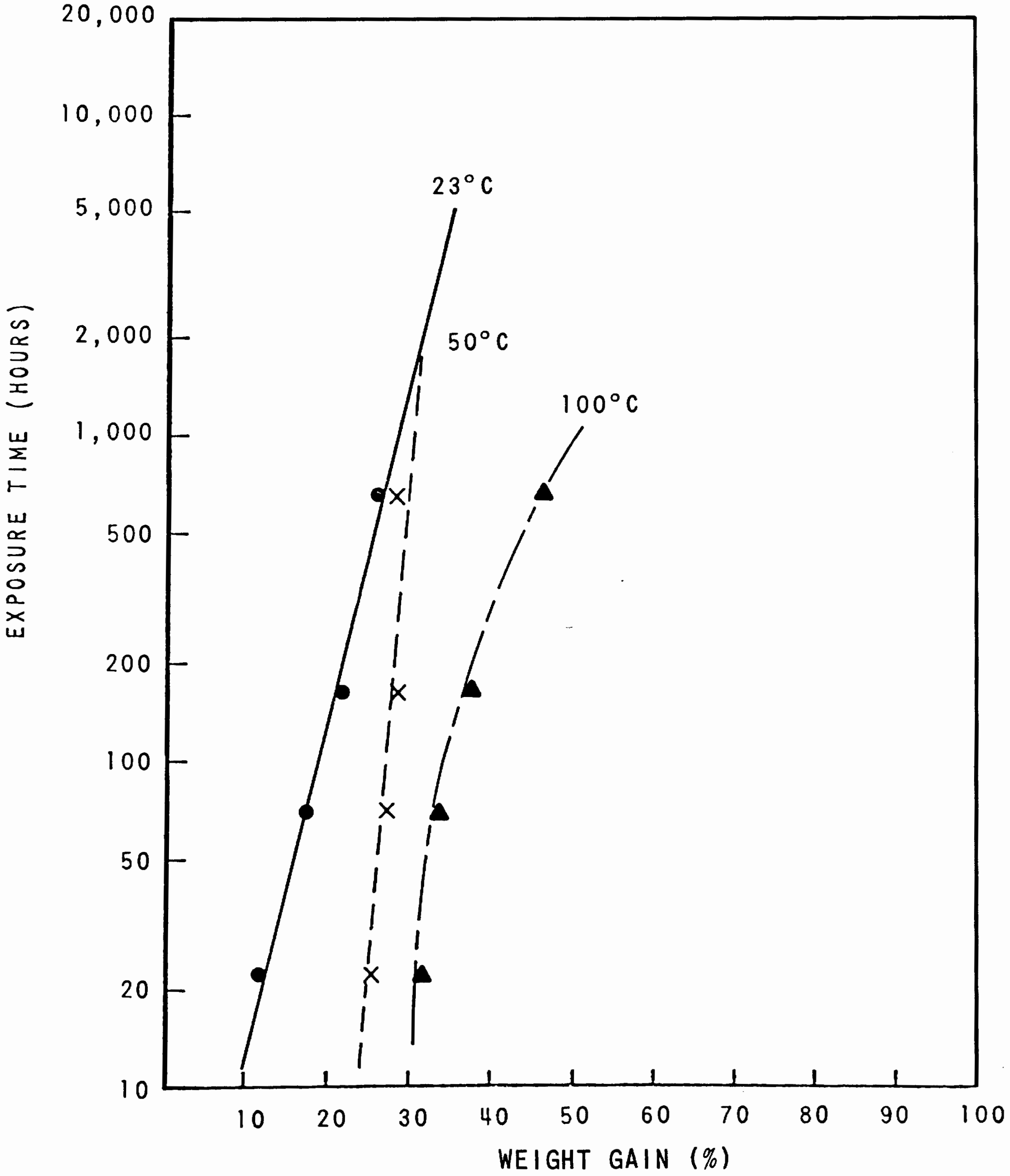


FIGURE 20.9 ASBESTOS SHEET WEIGHT GAIN WHEN EXPOSED TO FYRQUEL GT

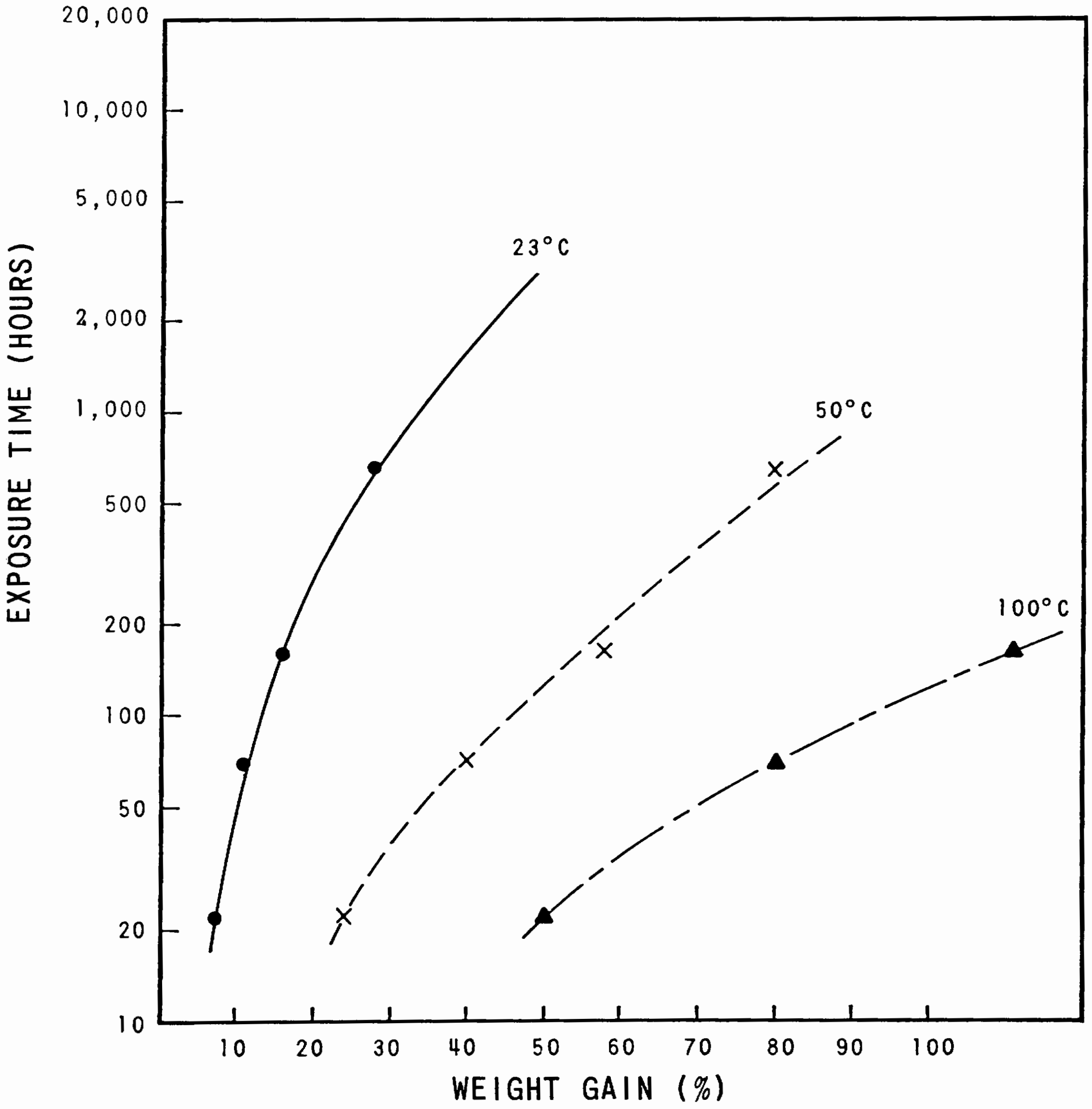


FIGURE 20.10 CORK NEOPRENE SHEET WEIGHT GAIN WHEN EXPOSED TO FYRQUEL GT

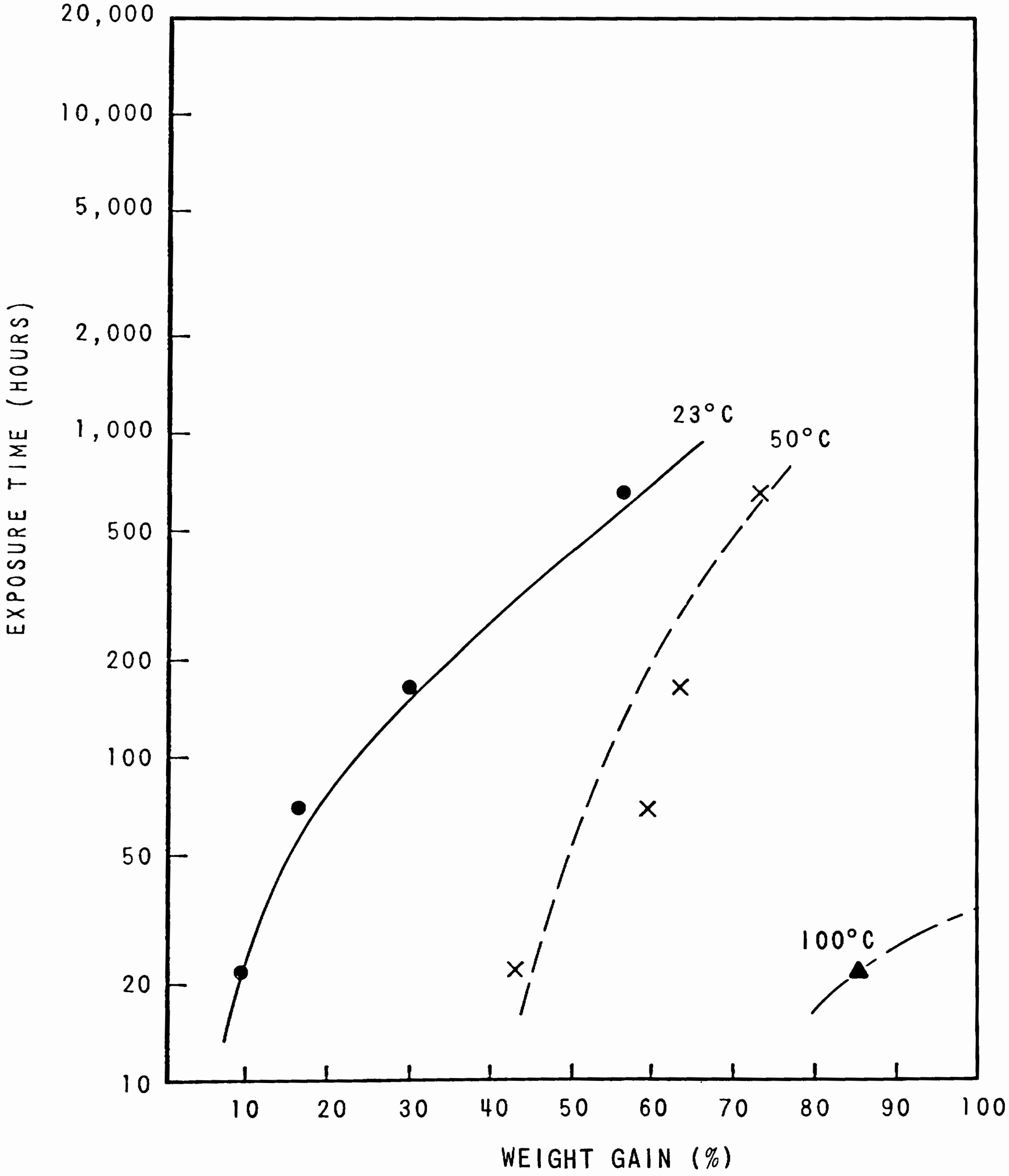


FIGURE 20.11 NEOPRENE SHEET WEIGHT GAIN WHEN EXPOSED TO FYRQUEL GT

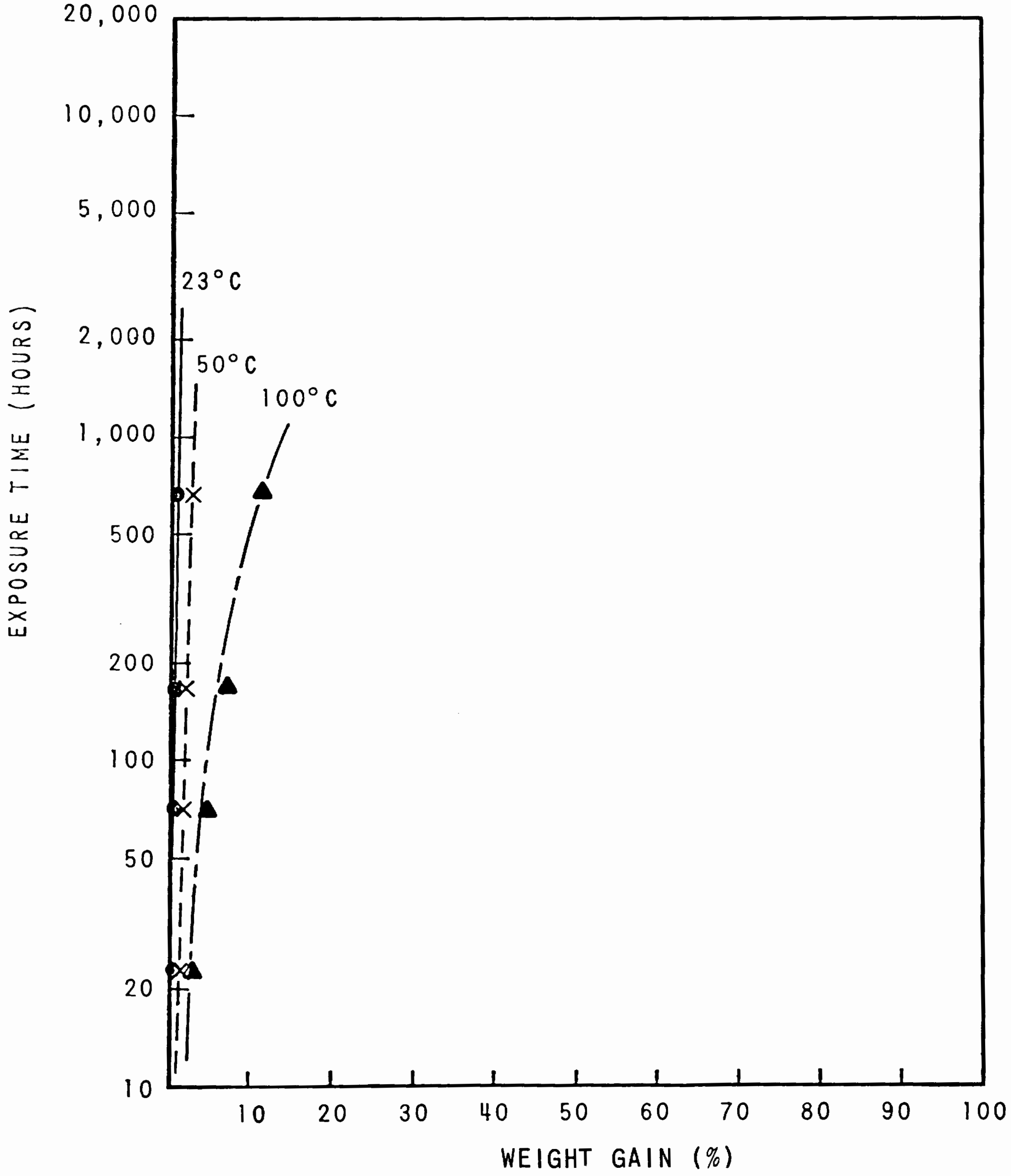


FIGURE 20.12 VITRON 90 WEIGHT GAIN WHEN EXPOSED TO FYRQUEL GT

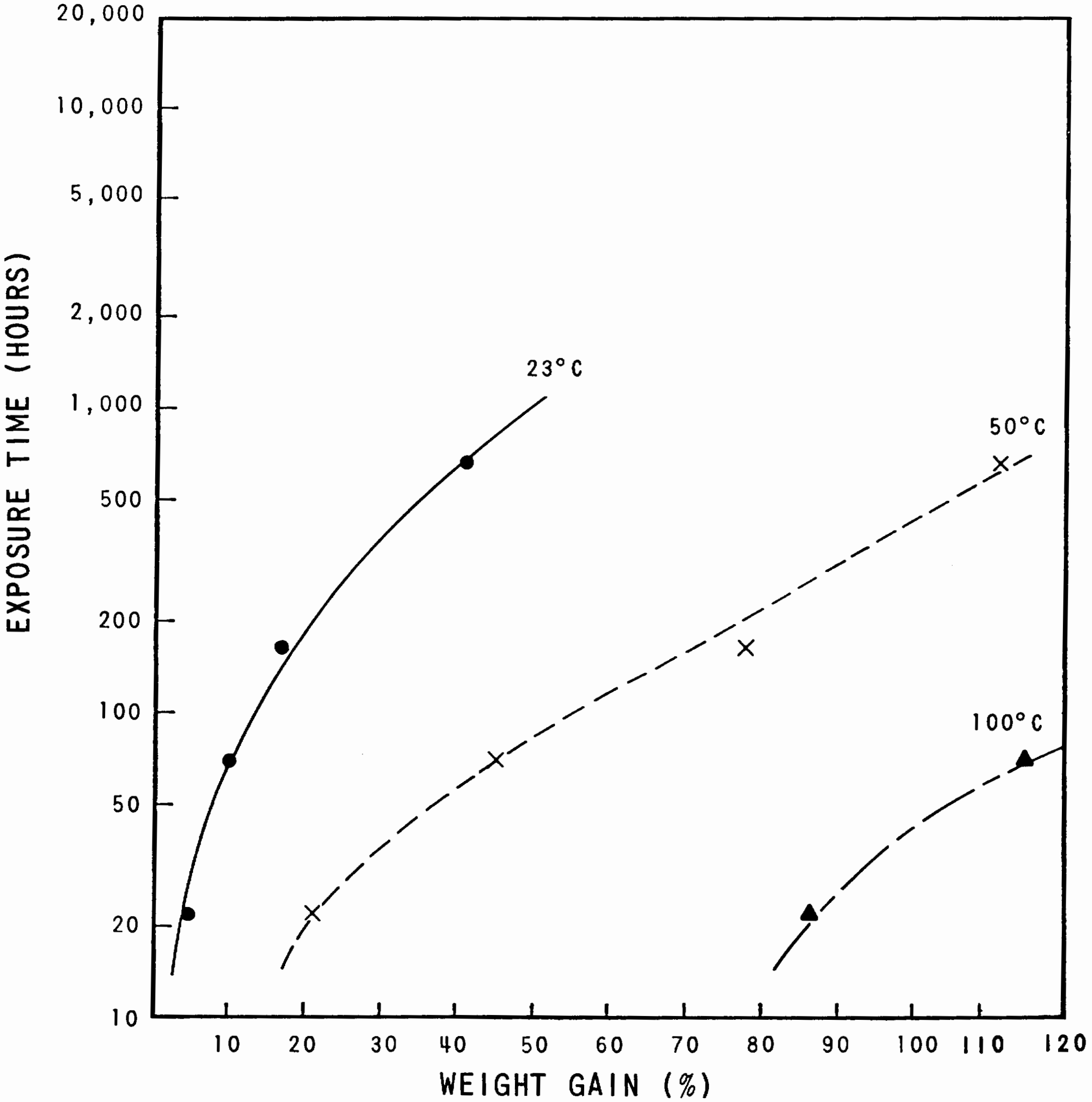


FIGURE 20.13 BUNA N WEIGHT GAIN WHEN EXPOSED TO FYRQUEL GT

SECTION 21.0

DISCUSSION AND RECOMMENDATIONS

21.0 DISCUSSION AND RECOMMENDATIONS

21.1 DISCUSSION*

Evaluation and testing of fire resistant fluid lubricants have been completed successfully, and a suitable fluid has been identified. Recommendations for further testing, leading to their eventual application, are in Section 21.2.

This project was directed entirely toward the use of a fire resistant lubricant in coolant pump motors for nuclear reactors. The fluid identified also has potential application in the balance of the nuclear plant where it is desirable to reduce the fire hazard associated with oil reservoirs and fluid transportation.

The scope of the project included a consideration of the following fluid properties:

- Chemical
- Physical
- Lubrication
- Radiation resistance
- Fire
- Thermal and oxidative stability
- Hydrolytic stability
- Material compatibility

*NOTE: Sections 21.1 and 21.2 are the same as Sections 12.1 and 12.2 in Volume One. They are presented in both volumes for the convenience of the reader.

The results of this study, while favorable, indicate several long-term stability problems requiring further study prior to the application of fire resistant fluid lubricants within nuclear containment. These are:

- Maintenance of fluid cleanliness
- Acidity control
- Hydrolytic decontamination

21.2 RECOMMENDATIONS

Before a fire resistant fluid lubricant can be used in a reactor coolant pump motor inside nuclear containment, a practical method for remotely monitoring the extent of degradation of the lubricant must be developed. This will require the demonstration of the feasibility of one or more monitoring schemes and the development of the selected scheme into a rugged and reliable device suitable for use in a nuclear power plant.

A study of monitoring techniques was undertaken in the last half of 1979 after the investigations discussed in the body of this report were completed. This recent study showed the need for the following recommended additional investigations:

1. Demonstration of the hydrolytic stability of static (unstirred) fluid at a temperature of 100^{o}F which is considered typical of the fluid temperature existing during an extended portion of a shutdown of an RCP motor.

   This test is necessary because in recent tests made at 212^{o}F, considered to be near the bearing operating temperature, hydrolytic degradation occurred much more rapidly when the fluid was not stirred.

2. Demonstration of the change, if any, in the rate of hydrolytic degradation of the lubricant resulting from its use in a lubrication system containing mechanical filtration and/or reconditioning equipment to reduce the acid number of the lubricant.

   A recent literature search revealed that these types of fluid-conditioning devices can alter or remove certain additives which provide desirable characteristics in fresh lubricants.

To provide this information, a test loop is being proposed, as an extension of the monitoring study, to simulate a lubrication system. The loop would contain one or more operating bearings and all critical materials of the lubrication system of an RCP motor. This test facility would help determine the need for auxiliary equipment that may be required in an actual RCP motor application. By-pass piping and valves would be included to permit the inclusion or exclusion of any piece of equipment. Auxiliary devices for use in the test loop would include:

- Mechanical equipment to remove particulates.
- Reconditioning equipment containing fuller's earth or activated alumina to reduce the fluid acid number.
- Other equipment (possibly a vapor extractor) that may be required to assure the proper functioning of the monitoring device selected.
- One or more monitoring devices.

For this demonstration, the above loop test is recommended over making the test using a motor in service because the motor in service would not be readily available to Westinghouse investigators.

It is recommended that Fyrquel lubricant not be demonstrated or used on RCP motors until the proposed tests are completed, conclusions reached and final operating and maintenance instructions become available.

A unique soaked cube fire test has been developed. This should be proposed to ASTM, ANSI, ISO, etc. for inclusion as a standard test. This test will be useful in further defining fire hazards within power plants.

A specification has been proposed for the fire resistant fluid lubricant. This should be pursued through the standardizing bodies involved.

One manufacturer now has an acceptable fire resistant fluid lubricant. Other manufacturers should be encouraged to qualify their fluids.

21.3 QUESTIONS AND COMMENTS DURING FINAL MEETING OF DESIGN REVIEW COMMITTEE

At the final meeting of the Design Review Committee on June 6, 1979, the following questions and comments resulted from the committee's review of the May 1, 1979, draft of this final report:

1. Question: How would Fyrquel lubricant perform in a reactor coolant pump motor under high radiation exposure such as occurred at Three Mile Island?

   Reply:

   - Testing under this program was limited to a rate of 0.23 X 10^6 Rads/hour for 60 hours and to a total exposure of 1.4 X 10^7 Rads. (See Volume I, Table 3.6.)
   - Fyrquel acid number increased from 0.34 at 1.4 X 10^6 Rads to 4.56 at 1.4 X 10^7 Rads. (See Volume I, Table 3.8.)
   - Viscosity increased only 18% during this exposure. (See Volume I, Table 3.7.)
   - The maximum corrosion observed experimentally was for electrolytic tough pitch copper in Fyrquel GT for a 23 week exposure. For this exposure, the weight loss was 10 mg/cm^2, which is equivalent to a reduction of approximately 0.0005 inch in thickness. The acid number increased to 10 during this exposure. (See Figure 14.1 in Volume Two of this revised final report.)
   - The conclusion is that failure of a reactor coolant pump motor due to changes in Fyrquel lubricant during a 23 week emergency period of operation seems improbable. This result and this conclusion are applicable only to the extent that they are analogous to the experiment referenced. The result would probably be improved by the use of Fyrquel RCP (now marketed as Fyrquel VPF) and by filtration of the lubricant.

2. Comment: It was noted that a correction was required in Table 4.3 of the draft: The chlorine content of the fluids should have been 5 ppm. instead of 50 ppm. (This has been corrected in this reissue of the report.)

3. Comment: The Stauffer Chemical Company's commercial representatives stated that henceforth Fyrquel GT would be the designation of what had formerly been designated as Fyrquel RCP and that the single formulation would include the additives included at that time in Fyrquel RCP. This later formulation was adopted by Stauffer because of its improved acid number stability and hydrolytic stability. (See Volume One, Section 2.4 also for a later name change by Stauffer.)

4. Question: What is the Westinghouse position with respect to supplying and/or warranting a motor suitable for operation with Fyrquel GT as a lubricant?

   Reply: The answer, which was promised at the meeting follows:

   a. As a result of the Fire Resistant Fluid Lubricant Project, large motors, such as those used for the coolant pumps of nuclear reactors, can be designed for operation with Fyrquel VPF as the lubricant. (Refer to Volume One Section 2.4 for a discussion of various designations for Fyrquel.)

   b. Design changes are required in the motor using materials and paint that are compatible with Fyrquel.

   c. The initial study of monitoring in the last half of 1979 recommends a "loop test" for a complete Fyrquel lubrication system, containing at least the following features:

      - One or more operating bearings.
      - All critical materials expected to exist in a Fyrquel lubrication system of an RCP motor.
      - Mechanical filters to remove particulates from the lubricant.
      - Reconditioning equipment, using fuller's earth or activated alumina, to reduce the acid number of the lubricant.
      - One or more types of monitoring equipment to detect remotely the degradation (increased acid number) of the lubricant.
      - Any other auxiliary equipment which may be found necessary for the proper functioning of the monitoring equipment. (This may be a vapor extractor if changes in the water content of the lubricant are found to affect the monitoring process adversely.)

d. The proposed tests will provide the information necessary to develop suitable operating and maintenance instructions for the motor and for the components of its Fyrquel lubrication system. These instructions will state whether mechanical filtration and/or fluid reconditioning should be periodic or continuous.

e. When this demonstration phase has been completed successfully, the Westinghouse Generator Systems Department will be able to offer and warrant reactor coolant pump motors which can be operated with Fyrquel VPF as a lubricant.

5. Question: What is the EPRI position with respect to sharing risk on a motor test using Fyrquel GT?

   Reply: Mr. Roy Swanson, EPRI Project Manager, will consider alternatives based upon the results of the remote monitoring project and a Westinghouse position that, based upon present knowledge, a motor can be built by Westinghouse which will operate properly when using a phosphate ester equivalent to the present petroleum oil.

6. Question: Are other lubricant products (other than what Stauffer Chemical Company had called Fyrquel RCP) ruled out?

   Reply: Other lubricant manufacturers are encouraged to qualify their products.