NASA TECHNICAL MEMORANDUM

NASA TM X-53183

DECEMBER 16, 1964

N65-24989 (ACCESSION NUMBER)	(THRU)
36 (PAGES)	1 (CODE)
TMX 53183 (NASA CR OR TMX OR AD NUMBER)	15 (CATEGORY)

FACILITY FORM 602

NASA TM X-53183

STATUS REPORT ON LIQUID OXYGEN SEAL INVESTIGATION

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GPO PRICE $ ______

OTS PRICE(S) $ ______

Hard copy (HC) 2.00

Microfiche (MF) .50

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ABSTRACT

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The purpose of this integrated internal and contracted program is to develop an improved gasket material for liquid oxygen applications. Several proprietary fluorocarbon materials were investigated locally, but no single parameter or relationship could be established as a true index of cryogenic seal performance. Parallel studies by a contractor have resulted in the development of a laminated gasket construction consisting of alternating layers of glass fabric and fluorocarbon film. The material is then compressed and heated to cause partial wetting of the glass fabric by the fluorocarbon resin. The unique properties of these laminates are discussed in detail, and data are presented that indicate an attractive future for these materials as general purpose cryogenic seals.

This program failed completely to establish any margin of superiority on the part of the Allpax 500 product now used for liquid oxygen gasketing over several other products studied.

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By

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MATERIALS DIVISION
PROPULSION AND VEHICLE ENGINEERING LABORATORY

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

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George C. Marshall Space Flight Center

SUMMARY

The only gasket product now approved for liquid oxygen service on the Saturn launch vehicle is an asbestos-filled styrene-butadiene product which is manufactured principally for steam and condensate service. This product can usually be rendered safe for liquid oxygen use by an elaborate process that is conducted here on a batch basis. However, this treatment is costly and time consuming, and the product does not always seal satisfactorily.

In an effort to find a superior material, nine representative fluorocarbon plastics and composites were investigated with respect to their low temperature compression properties, hardness, and creep behavior. These materials included several products considered previously at this Center for liquid oxygen seal applications. The data obtained during this internal program permitted a number of interesting conclusions which indicated that the full potential of fluorocarbon plastic-based composites has not been developed in any material of this type considered previously for this application.

Concurrent with this internal program, a related contract effort oriented toward the same goal has been carried out at the Narmco Research and Development Division of Whittaker Corporation. This program has resulted in the development of a novel laminated gasket concept which provides oriented reinforcement in the direction of cold flow. This lamination process simultaneously confers unique compressive properties on the laminate. Test data are presented to demonstrate the potential of these materials as cryogenic seals.

INTRODUCTION

The development of an improved LOX gasket material suitable for use in existing flat flange designs is being investigated in both internal and contract programs by the Non-Metallic Materials Branch of the Materials Division. The only product now approved for this service is Allpax 500, an asbestos-synthetic rubber composite material that is marketed for other purposes. Since this product is not inherently compatible with liquid oxygen, an elaborate treating process is required to minimize this deficiency (Ref. 1). The implementation of this process is costly and time consuming, and it does not always accomplish the desired goal. In addition, the treated Allpax has definite performance limitations which have been manifested by leakage problems and torque relaxation phenomena.

Both the internal and contracted programs are described below in greater detail. Each program began with a detailed study of the physical properties of the Allpax product which are serving as baseline data for the evaluation of other products and the development of improved materials.

INTERNAL PROGRAM

The materials selected for study during the internal program are tabulated and described in Table I. Some of these products were selected on the basis of tentatively promising previous flange test experience, e.g., Fluorogreen E-600 and Duroid 5600. The other products were principally unfilled fluorocarbons, Teflon TFE, Teflon FEP, and Kel-F, which were tested to obtain some indication of their potential value in filled or reinforced compositions. This investigation was limited to the fluorocarbon plastics, which are chemically the most consistently satisfactory materials for liquid oxygen usage.

There are two limitations of this test program which should be kept in mind. First, the parameters which characterize and determine the performance of a material as a cryogenic seal are not well defined. Only one other research program (Ref. 2) is now known to be in progress that is even partially oriented toward defining these variables, and that program is not devoted specifically to flat gaskets. Consequently, the tests conducted during this program were intuitively selected, within the capabilities of available test equipment, to represent the key physical properties presumed to have some role in the material's gasket performance. Secondly, the physical properties of most of the materials of interest are dependent to an unpredictable extent upon their past thermal and processing history. However, these conditions are seldom specified or even known with certainty by most commercial plastics fabricators. Thus, it was deemed best to accept the materials identified in Table I as being reasonably typical of the categories they represent in spite of these admitted uncertainties.

Hardness Tests

Shore D scale hardness values were measured at room temperature for the materials. The results are shown in Table I. This is a penetration type hardness measurement, and the values obtained by this method should indicate in a relative way the conformability of the materials to flange surface irregularities. A possible advantage is indicated in this one respect for the unreinforced Teflons (TFE and FEP) and some of the reinforced TFE Teflons, but it is doubtful that these differences are great enough to be of practical significance when superimposed upon other parameters.

Compression Tests

Compression tests at room temperature (FIG 1) and liquid nitrogen temperature (FIG 2) were conducted with conventional metallurgical test equipment. These data were obtained on stacked specimens 1/2 x 1/2 x 1/16 inch held between two mating U-shaped jigs. These jigs were assembled in opposition to form a compression cage and attached to different crossheads of a standard tensile tester to permit the compression measurements.

Of the products surveyed to date, Duroid 5600 makes the closest approach to the overall stress-strain properties of Allpax 500 in compression. In fact, Duroid 5600 is consistently closer to the treated Allpax 500 product in this respect than Fluorogreen E-600, which appears more promising on the basis of more exhaustive flange tests. It may be significant that the stress-strain curve of the Fluorogreen product intersects the curve for Allpax at a stress level (2,000 - 2,200 psi) falling within the range of seating stresses generally specified for most asbestos-reinforced synthetic rubber gaskets typified by Allpax 500. (See FIG 1.) If gasket seating stress levels of this general magnitude are being attained in current flange designs, the Fluorogreen and Allpax products, for all practical purposes, would be equivalent with respect to their room temperature compressive behavior due to these fortuitous circumstances.

It is evident from the data of FIG 2 that treated Allpax 500 has the greatest average compressive modulus at -320°F (-183°C) of the nine products investigated. The average modulus of Fluorogreen E-600 is also increased drastically by cooling to liquid nitrogen temperature in comparison to the other materials studied. Intuitively, one would expect a high compressive modulus to be detrimental to good gasket performance. To avoid gross leakage under specific pressure conditions, the flanges must act against the gasket and create a minimum gasket compressive or seating stress. The actual seating stress would be expected to vary from point to point around the flange circumference because of the localized nature of the bolt loads and other stresses that may be induced in service. A low-modulus gasket material would be confined under these conditions at a more constant stress level than would be attained in the case of a high modulus material; that is, the lower the compressive modulus the greater the capacity of the gasket to adjust itself to flange deflections without simultaneously losing a critical proportion of the required seating stress conferred during initial assembly.

Creep Studies

The progressive strain induced by a continuous, uniformly-applied load at room temperature was studied as another basis for comparing these products. A stress level of 3,000 psi was chosen arbitrarily as being probably high enough to accelerate the effects being sought in the case of the high modulus materials. These data are shown in FIG 3 and are characteristic of the type of materials being surveyed. The perceptible deviation of the treated Allpax from the straight line relationship shown by the other materials on the logarithmic plot of FIG 3 is believed to be caused by the synthetic rubber binder used in this product. Materials of this nature are viscoelastic, i.e., subject to both elastic deformation and viscous flow under an applied load. At a constant load, the strain (s) of ideally elastic materials is related to the time (t) as follows (Ref. 3):

$$s = A \log t + B$$

where A and B are functions of the material and the temperature. For viscoelastic materials, the inclusion of a linear time term is necessary to compensate for the viscous flow tendencies:

$$s = A \log t + B + C\,t$$

wherein A, B, and C are constants determined by the nature of the material and the temperature under a constant stress.

Creep in a gasket material is detrimental for our purposes. The persistence of a viscoelastic creep mechanism in the Allpax product, despite its asbestos filler content, indicates that other filled elastomeric materials may share this shortcoming. Creep was not detected with the equipment available for this study in any of the materials at liquid nitrogen temperature.

Stress Relaxation

A different indication of the cold flow tendencies of the nine products surveyed was obtained by compressing suitable specimens to a predetermined initial stress level. The change in this stress level with time was then recorded at room temperature for each of the materials surveyed. The room-temperature results, shown graphically on FIG 4, dramatically demonstrate that the treated Allpax 500 product is the poorest of the nine materials surveyed from this standpoint. In fact, treated Allpax 500 appears considerably inferior to unfilled Teflon TFE, which has acquired a vastly exaggerated reputation for cold flow behavior. These data, as expected, are consistent with the hardness data obtained earlier.

Attempts to conduct this load decay test at cryogenic temperature from a base-line stress imposed during room temperature adjustment of the test assembly encountered difficulty because of the thermal contraction of the Inconel X compression cage assembly. As shown in FIG 5, cooling the assembly from room temperature to liquid nitrogen temperature, -320°F, imposed a higher stress level. The initial stress achieved after cooling to this low temperature was roughly proportional to the cryogenic compressive modulus, with the drastic exception of treated Allpax 500. This product again behaved anomalously by achieving one of the lowest peak stress values after chilling to liquid nitrogen temperature. This is another characteristic of the elastomeric (rubber-like) binder used in this product which will readily undergo elastic deformation during chill-down to absorb thermally induced stresses in the flange assembly until the temperature of the binder attains a value characteristic of the specific binder material in question. At this so-called second-order or glass transition temperature, the rubbery binder loses the extensibility-retractability that characterizes it at higher temperatures and becomes, in effect, an organic glass. This transition is also accompanied by an abrupt change in certain other properties of the binder material. Thus, the anomalous behavior of the Allpax 500 product probably can be explained by any or a combination of several of these factors.

In summary, the only conclusion permitted by the cryogenic stress relaxation data shown on FIG 5 is that stress relaxation probably is not a major problem at low temperatures, even above stress levels that are normally sought when designing with these materials. The additional compression stress imposed here during chill-down is a consequence of the compression test fixture design described previously and cannot be considered as a consistently reproducible feature of actual piping systems.

Thermal Contraction

The thermal contraction behavior of several materials was investigated as another factor potentially capable of influencing seal performance. Generally, the thermal contraction coefficients of plastics are several times greater than those of the alloys favored for flange construction. Thus, differential thermal contraction in the radial plane between the gasket and flange materials could impose shear stresses on the gasket.

It is generally true that the addition of increasing quantities of filler materials decreases the coefficient of contraction of fluorocarbon plastics to an ultimate value approaching that of the pure filler material. However, because these were commercial, proprietary materials, the precise filler nature and proportion used in the filled Teflon materials studied during this program were not known. The values shown on FIG 6 were determined experimentally on two of the filled Teflons representing the two observed extremes in compression behavior. The equipment and techniques utilized in making these measurements are described in a report by the Engineering Physics Branch of this division (Ref. 4).

The experimental data of FIG 6 represent average coefficients of contraction (or expansion) over the indicated temperature ranges. Any attempt to compare them with the data of other investigators (Ref. 5 and 6) for unfilled Teflon TFE is complicated by a transition that the unfilled polymer undergoes in the neighborhood of 20°C (68°F). This transition temperature is accompanied by abrupt changes in specific volume and coefficient of expansion. Uncertainties in the true coefficient values near this transition point, which coincides with one of the temperature extremities studied, make a rigorous comparison difficult. It can only be said that the data obtained for the filled compositions investigated in this program fall within the extremes of the very sparse published data pertaining to materials of specified filler type and level.

ANALYSIS OF DATA

The results obtained during this internal program do not suggest any simple interrelationship between engineering properties and overall cryogenic seal performance. If such a relationship exists, it obviously is not dependent upon any single property studied during this investigation.

The data outlined previously are somewhat contradictory to local performance reports and anticipations. For example, unfilled Teflon TFE has been shunned for most seal applications because of its cold flow behavior. Yet, Teflon TFE did not appear significantly worse than the product now being used on the basis of creep tests, and Teflon TFE actually appears superior from the standpoint of stress relaxation.

It is appropriate to comment here on one other important aspect of the behavior of Teflon TFE that may have enhanced its cold flow reputation. The transition mentioned previously which occurs in the vicinity of room temperature is accompanied by a decrease in volume which would be manifested by an abnormally high apparent stress relaxation as a confined TFE gasket is cooled through this transition temperature. It would be incorrect to assign all of this stress relaxation to cold flow or thermal contraction effects on the part of the gasket material. It should be noted also that Teflon FEP does not undergo any transition of this type at room temperature, and its application as a cryogenic seal would be simplified correspondingly.

It again appears that the only attribute tentatively associated with satisfactory seal performance that was defined by this investigation is the desirability of a low compressive modulus under cryogenic service conditions. This postulate is supported by intuition and also by the results obtained during the parallel contracted study, which are presented below.

CONTRACT PROGRAM

The following paragraphs summarize briefly the progress that has been made to date by the Narmco Research and Development Division of Whittaker Corporation under Contract NAS8-5053. This contract program has been integrated with the internal effort described in the preceding section in an overall attempt to develop an improved liquid oxygen static seal which would preferably function in other cryogenic environments. Although the concept developed under this program is not yet fully proven, the results to date have been very encouraging.

The contractor first investigated the actual gasket performance of conventional filled fluorocarbon materials in a flanged fixture. The specimen chosen for all evaluation testing was in the form of a flat gasket with an O. D. of 2.06 inches and an I. D. of 1.31 inches. This specimen gave a flange contact area of two square inches. Most specimens were from 80-90 mils thick. This particular sample configuration was chosen to mate with a leakage test fixture whose application to this program will be described later; however, this same sample configuration was used in most of the other studies, which are described later. The contractor also developed and utilized the necessary tooling for molding filled fluorocarbon gaskets of known composition and filler level, using bulk resin and special fillers available from various sources. This was necessary to obtain realistic data on filled plastics of known composition. The critical functions performed by fillers and other processing additives have a key influence on the engineering properties of the final filled plastic. Most commercial suppliers of filled fluorocarbon materials are reluctant to reveal the nature, proportion, and/or orientation of fillers used in their product. Therefore, the contractor was directed to formulate known filler-resin combinations which would be utilized to study the effects of filler nature and proportion. In addition, random proprietary fluorocarbon products were studied to insure that the filled materials formulated by the contractor were approaching these commercial products in properties and performance.

Compression Behavior

Candidate materials were evaluated in an initial test which was termed "load decay." This test was designed to establish how well the material was able to maintain its resistance to compression. The test was an exaggerated one, with a very high flange pressure, and was designed to magnify cold flow problems in a gasket material. Specimens which resist cold flow and have sufficient tensile strength to resist material failure performed well in this test. The specimen was loaded to 15,000 psi between two flat flanges in a hydraulic press with tight check valves, which enabled the plotting of the decay of the load or the pressure exerted by the compressed gasket. The load was followed for a period of 30 minutes; typical curves are presented on FIG 7.

The compressibility and compression set are also recorded in this test. The upper curve shown on FIG 7 refers to Fluorolube-treated Allpax 500, which is now used for most Saturn LOX gasketing applications. Materials with poor load decay performance are readily identified by their sharp drop in load, as illustrated by the lower curve on FIG 7. This curve was obtained on an asbestos-filled Viton-A fluorocarbon elastomer specimen. The filler level was 37% by weight. The compression set, i.e., the compression remaining 24 hours after releasing the load, was much higher in the case of this filled elastomer.

The fact that different fillers do not have an equivalent effect at the same level was demonstrated by this technique. A family of curves was obtained with specimens containing various levels of zinc oxide. It was observed that a filler level of 37% provided a fairly good load decay curve. Higher concentrations did not perform as well, apparently because the tensile strength began to decrease rapidly at this high filler level.

Several specimens were prepared by molding Teflon powder with various levels of chopped fiberglass filler. The effect of filler level on the compression properties is shown on FIG 8. Also shown on FIG 8 are curves for three commercial cryogenic gasketing materials of this type. A compression set of about 30% appears typical for these materials. It is also noteworthy that the load decay curves do not approach a constant load until the fiberglass filler level approaches 30%.

Laminated Materials

It became evident at this point that the degree of resistance to cold flow required in this situation would not be attained with any known filled or fiber-reinforced fluorocarbon polymer without seriously compromising other important physical properties. This led to a laminated gasket design consisting of alternating plies of a woven glass fabric and a suitable fluorocarbon film. The resulting laminate has adequate reinforcement, and the woven structure effectively inhibits cold flow. A typical load decay curve for a fluorocarbon polymer - 112 glass fabric laminate is shown in FIG 9.

Table II summarizes the compressibility and compression set data obtained during the load decay testing. Most of the commercial gaskets suffered considerable compression set.

Evaluation of Laminates

During the next series of experiments, the compressive moduli of gasket candidates were obtained at more realistic flange pressures. Furthermore, the gasket specimens were load-cycled 10 times to 3, 000 psi to observe changes in the compression modulus resulting from compression set or flow. Stress-strain curves were obtained during this cycling which were conveniently used to calculate the compressive modulus in each cycle. Because most of the change occurred during the first and second cycles, modulus values were tabulated only for the first, second, and tenth cycle. The modulus was estimated by determining the slope of the stress-strain curve at 1, 000 psi. The non-linearity of these curves requires that the modulus be referenced to a specific point on the curve.

The test equipment that was used consisted of two plates mounted on an Instron testing machine, with the gasket deflection measured by an extensometer driven by an appropriate linkage. For cryogenic testing, the entire fixture was immersed in liquid nitrogen. A number of modulus values for various materials are shown in Table III. The low modulus values obtained for the fluorocarbon polymer - 112 glass laminates appear relatively insensitive to cycling and temperature effects.

A summary of the modulus values for the various types of gaskets is shown in the form of a bar graph on FIG 10. Filled fluorocarbon elastomers have high compressibility at room temperature but become quite hard at -320^{o}F. Conventional glass filler additions decrease the temperature dependence of Teflon's modulus. Laminated fillers are particularly effective in decreasing this modulus variation with temperature.

The dramatic difference between compression behavior of these fluorocarbon laminates and conventional filled Teflons is demonstrated again by the data plotted on FIG 11 and 12. FIG 11 shows a stress hysteresis curve for a 25% glass filled Teflon TFE which is typical of many commercial products. The data plotted on FIG 12 were obtained under identical conditions for a laminated construction of Teflon TFE and #112 glass fabric. The laminate closely follows Hooke's law.

Variables in the Laminating Process

These properties are conferred by certain unique features of the laminating procedure. This procedure involves pressing alternating layers of glass fabric and fluorocarbon polymer film at temperatures sufficient to produce some flow but not high enough to give complete saturation of the fiber bundle. This process yields a material with a springlike compressibility which is not subject to drastic changes in modulus with decreasing temperature.

This difference in bundle wetting at different laminating pressures was demonstrated by placing polished edges of a series of Teflon laminates which were prepared at temperatures from 500°F-700°F in a dye penetrant solution for 20 minutes. At the end of this time, the laminates were removed from the solution and wiped dry. The extent of lateral dye penetration into the laminate was measured and found to be a function of the laminating temperature. Lesser penetration was observed at 700°F because of the lower resin viscosity and the resin's greater ability to wet the binder.

Each fluorocarbon plastic has a range of temperatures and laminating pressures that is applicable to a given glass fabric. For example, Teflon FEP will form laminates if pressed at 100 psi and temperatures between 500-700°F. Rigid plastics, like the Teflons, can be alternated in the layup with uncured Viton-type fluoroelastomer films. The time and temperature combinations required to cause flow of the rigid plastic usually are adequate to vulcanize the elastomeric constituent. This makes it possible to attain a very wide range of laminate properties.

Sealing Characteristics

The actual sealing characteristics of materials were also studied. Two aspects of the sealing ability were investigated. The first object was to establish the flange pressure required to maintain a seal against an internal gas pressure. The gasket was loaded to 1500 psi flange pressure; then, the small volume inside the gasket was pressurized to 200 psi. The flange pressure was gradually decreased until a leak was observed on a pressure monitoring gauge. A small leak, due to the small volume inside the gasket, was detected readily. It was noted that almost all gaskets were similar in performance at -320°F. The minimum flange pressure required to prevent a leak was between 200 psi and 250 psi for all materials, irrespective of the nature, level, and distribution of their filler content. Since materials known to be vastly different in gasket performance gave essentially the same results by this test, another investigation was made to monitor the allowable flange deflection before leakage for each given material. It was believed that this would indicate the response of the gasket material to variations in gasket seating stress which would accompany any flange deflection or deformation. Some very striking differences were revealed by these measurements. It was possible to obtain a coefficient that appears to provide an index of the gasket material's ability to retain a seal during these environmental or service extremes which cause localized decreases in the original gasket seating stress. This coefficient, termed the flange deflection to leak, is simply the maximum flange deflection permitted prior to the onset of gross leakage. This deflection is measured perpendicular to the gasket plane and is expressed per unit of original thickness.

Table IV summarizes flange deflection coefficients for the material types considered during this study. As expected, the filled elastomers have the highest coefficients at room temperature, but their values at liquid nitrogen temperature are among the lowest of the materials studied. Flange deflection values for glass fabric-fluorocarbon plastic laminates are relatively independent of temperature and are higher than the values for the other materials at -320°F. Intuitively, one would expect this flange deflection coefficient and the compressive modulus to be related. The lower the modulus, the smaller will be the stress decrease induced by a given flange deflection. This deduction is supported by the earlier observation (FIG 2) that treated Allpax has the highest cryogenic compressive modulus of any material considered and, also, has the lowest flange deflection coefficient (Table V). In this respect, Allpax 500 is a very poor gasket; its success over properly reinforced fluorocarbon plastics cannot be explained on the basis of this work.

CONCLUSIONS

These separate but integrated efforts have established quantitatively the importance of a few of the basic properties of a material which contribute to its cryogenic seal performance. The interrelationship of these materials has not been defined completely. More work in this area is required and will be undertaken.

The cryogenic sealing concept developed by the Narmco Research and Development Division of Whittaker Corporation under Contract NAS8-5053 appears particularly promising, and the unique properties of these laminates may recommend them for other applications. It is definitely possible to regulate the properties of these laminates within very wide limits by combining fluorocarbon elastomers with plastics. Time, temperature, and pressure relationships during the pressing operations also govern the final laminate properties, and work is underway now to establish the combination of manufacturing parameters that will yield materials having optimum sealing properties.

Because of the unusual promise demonstrated by the fluorocarbon laminates, future program resources will be devoted exclusively to their optimization and continued development. It is hoped ultimately to provide not only a drastically improved seal material based upon this concept but also an analytical expression that will permit estimation of required gasket dimensions in terms of the environmental parameters and the mechanical properties of the seal material alone.

TABLE I
MATERIALS INVESTIGATED FOR GASKET PERFORMANCE

Product Trade Name	Description	Shore D Hardness
Allpax 500, Fluorolube-Treated per MS-750.0B Manufacturing Specification for Non-Metallic (Asbestos) Gaskets, Manufacturing Engineering Laboratory, George C. Marshall Space Flight Center	Asbestos fiber, styrene butadiene rubber binder	66
Duroid 5600	Ceramic-filled Teflons, Rogers Corporation	64
Duroid 5650	Rogers, Connecticut	66
Teflon TFE*	Polytetrafluoroethylene $\left[CF_2 - CF_2\right]_N$ DuPont Company	56
Teflon FEP*	Copolymer of tetrafluoroethylene and hexafluoropropylene $\left[CF_2\text{-}CF_2\right]_X\left[CF_2 - \underset{\vert}{\overset{CF_3}{}}CF\right]_Y$ DuPont Company	58
Fluorogreen E-600	Filled Teflon, John L. Doré Company	55
Fluorogold	Filled Teflon, Fluorocarbon Company	56
Halon TVS-270	A modified polytrifluorochloroethylene, Allied Chemical Corporation	75
"Lox Grade" Kel-F	Polytrifluorochloroethylene processed by the Fluorocarbon Company	76

* The trade name "Teflon," when used alone, always denotes polytetrafluoroethylene, or Teflon TFE. However, Teflon FEP is a different material and is usually differentiated by the FEP designation or by Teflon 100X, an older DuPont tradename.

TABLE II
SUMMARY OF COMPRESSION-COMPRESSION SET DATA ON GASKET MATERIALS

MATERIAL	COMPRESSIBILITY	COMPRESSION SET
Treated Allpax 500	20%	12%
Fluorogreen E-600	47%	30%
Fluorogold	52%	24%
CG-12 Gasket*	48%	36%
Taskline Gasket*	34%	22%
Fiberglass Filled Teflon (40% Fiberglass)	50%	40%
CG-24 Gasket*	44%	30%
Zinc Oxide (65%) Filled Viton A	46%	4%
Teflon-112 Glass Fabric Laminate	12%	2%

[1] A Teflon-encapsulated gasket submitted by the Fluorocarbon Company.

[2] A Teflon-encapsulated perforated metal gasket by the Duriron Company.

[3] An unfilled fluorocarbon plastic by the Fluorocarbon Company.

TABLE III

COMPRESSIVE MODULUS OF VARIOUS TYPES OF GASKETS

MATERIAL	RT MODULUS			-320°F		
	1st Cycle	2nd Cycle	10th Cycle	1st Cycle	2nd Cycle	10th Cycle
Filled (3% ZnO) Viton A	10,000	10,000	10,000	167,000	163,000	163,000
Glass-Filled Teflon Compositions						
20% Glass	57,600	68,900	71,400	143,000	175,000	173,000
30% Glass	57,100	72,100	72,100	140,000	154,000	154,000
40% Glass	61,300	83,000	87,000	140,000	151,000	150,000
Flurogreen E-600	55,500	62,700	67,100	95,000	123,000	126,000
Fluorogold	51,500	60,800	66,000	132,000	136,000	130,000
HS-10[1]	50,000	63,000	70,100	113,000	113,000	118,000
Fluorolube Treated Allpax 500	35,000	54,000	60,000	175,000	180,000	190,000
Teflon-Asbestos Laminate	52,100	63,900	67,700	87,600	89,600	93,300
Aclar 33C[2]- 112 Glass Fabric Laminate	69,200	76,600	78,300	72,800	73,900	74,500

[1] A fiberglass-filled Teflon marketed by the DuPont Company. Filler level approximately 25%.

[2] A fluorohalocarbon film product of Allied Chemical Corporation, General Chemical Division.

TABLE IV
ALLOWABLE FLANGE DEFLECTION BEFORE LEAKAGE

	Flange Deflection Per Unit thickness of Gasket	
	RT	-320°F
Treated Allpax 500	0.079	0.014
Filled Viton A Elastomer	0.5	0.020
CG-24 Fluorocarbon	0.051	0.023
Teflon	0.064	0.026
CG-12 Gaskets	0.035	0.021
Fluorogreen E-600	0.056	0.025
Fluorogold	0.064	0.018
HS-10	0.059	0.023
Fiberglass (25%)-Teflon	0.068	0.022
Aclar-112 Glass Laminate	0.062	0.041
Teflon 112-Glass Laminate	0.041	0.034

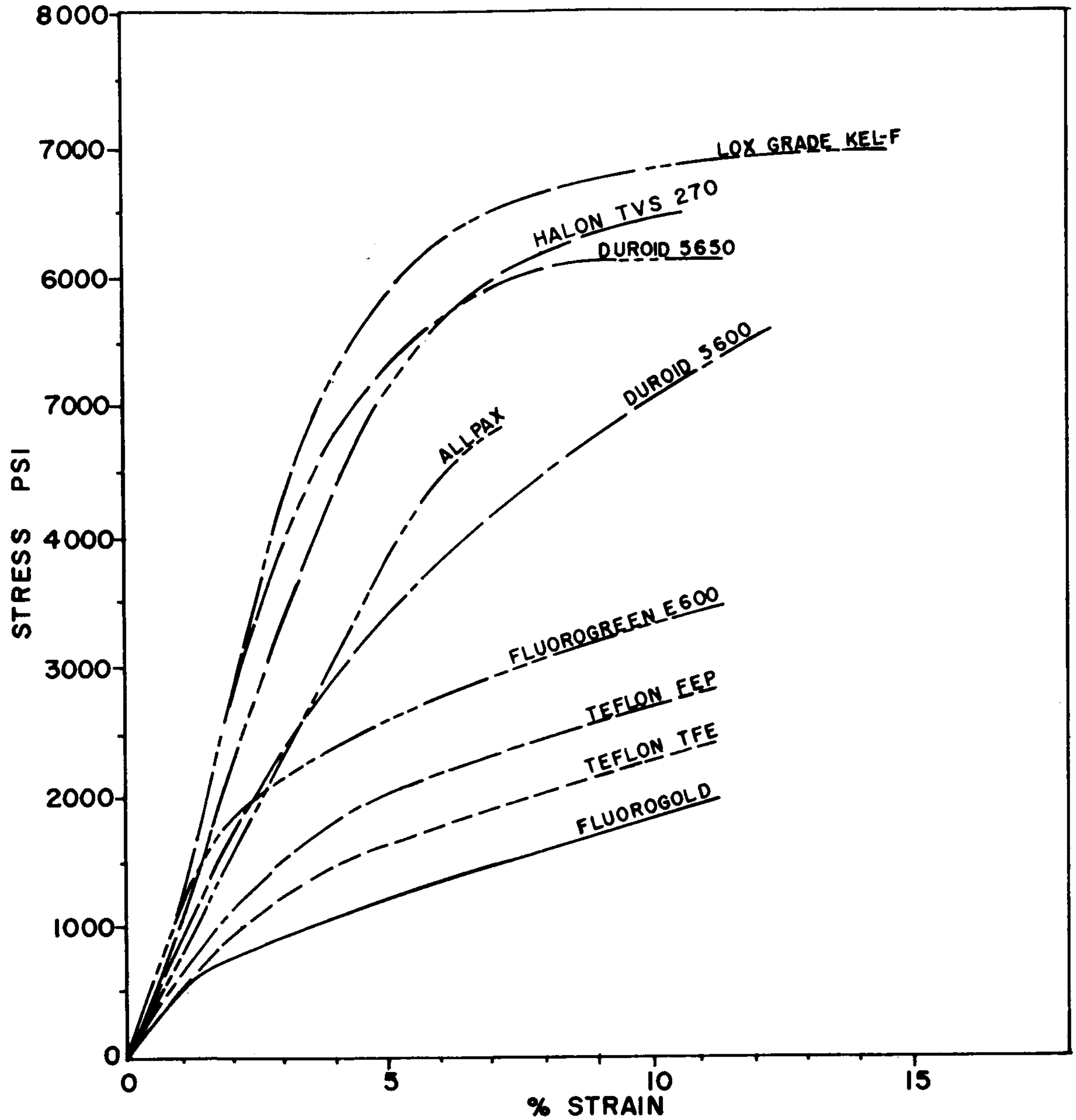


FIGURE 1. COMPRESSION TESTS OF VARIOUS GASKET MATERIALS AT ROOM TEMPERATURE

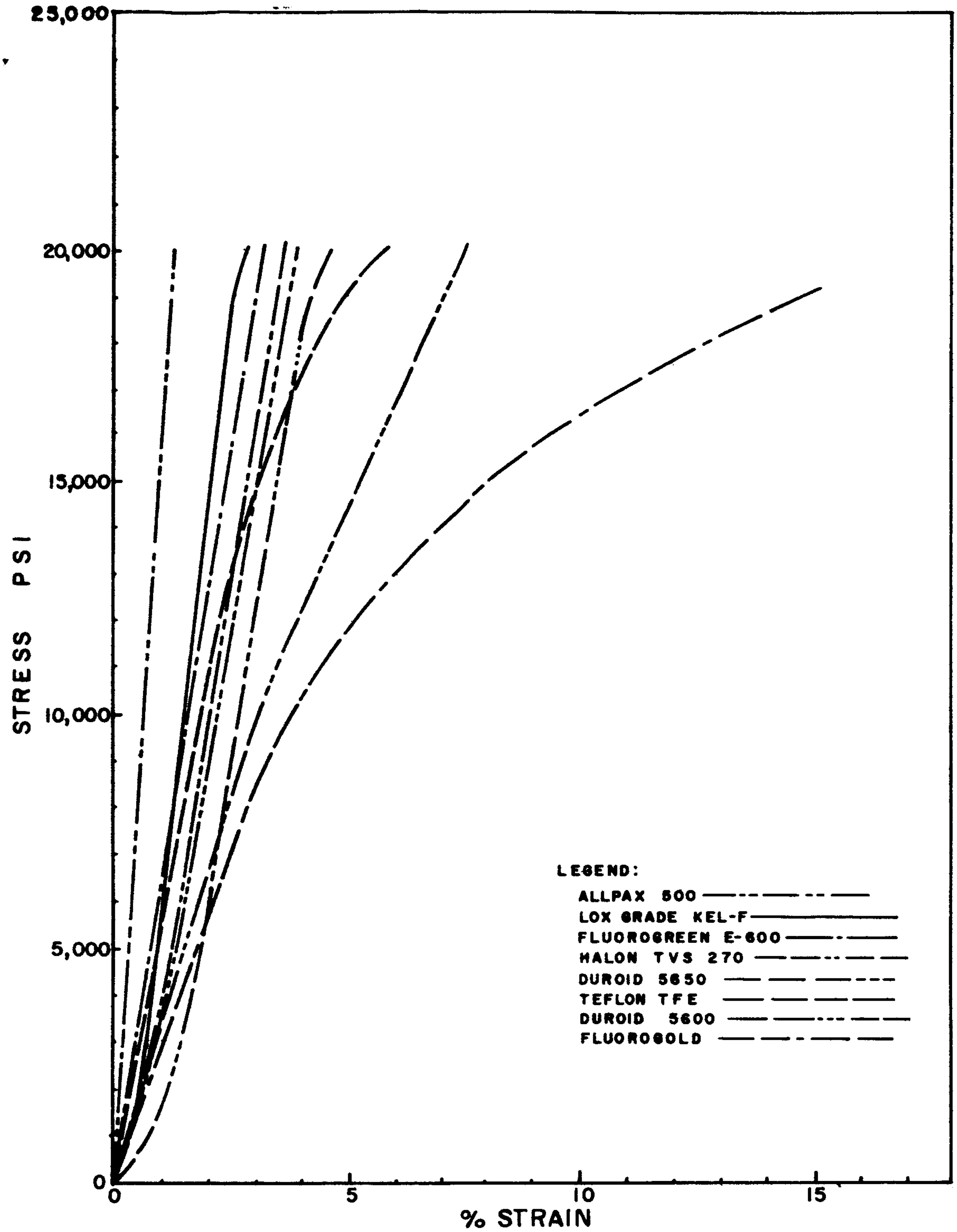


FIGURE 2. COMPRESSION TESTS OF VARIOUS GASKET MATERIALS AT -320° F (-196° C)

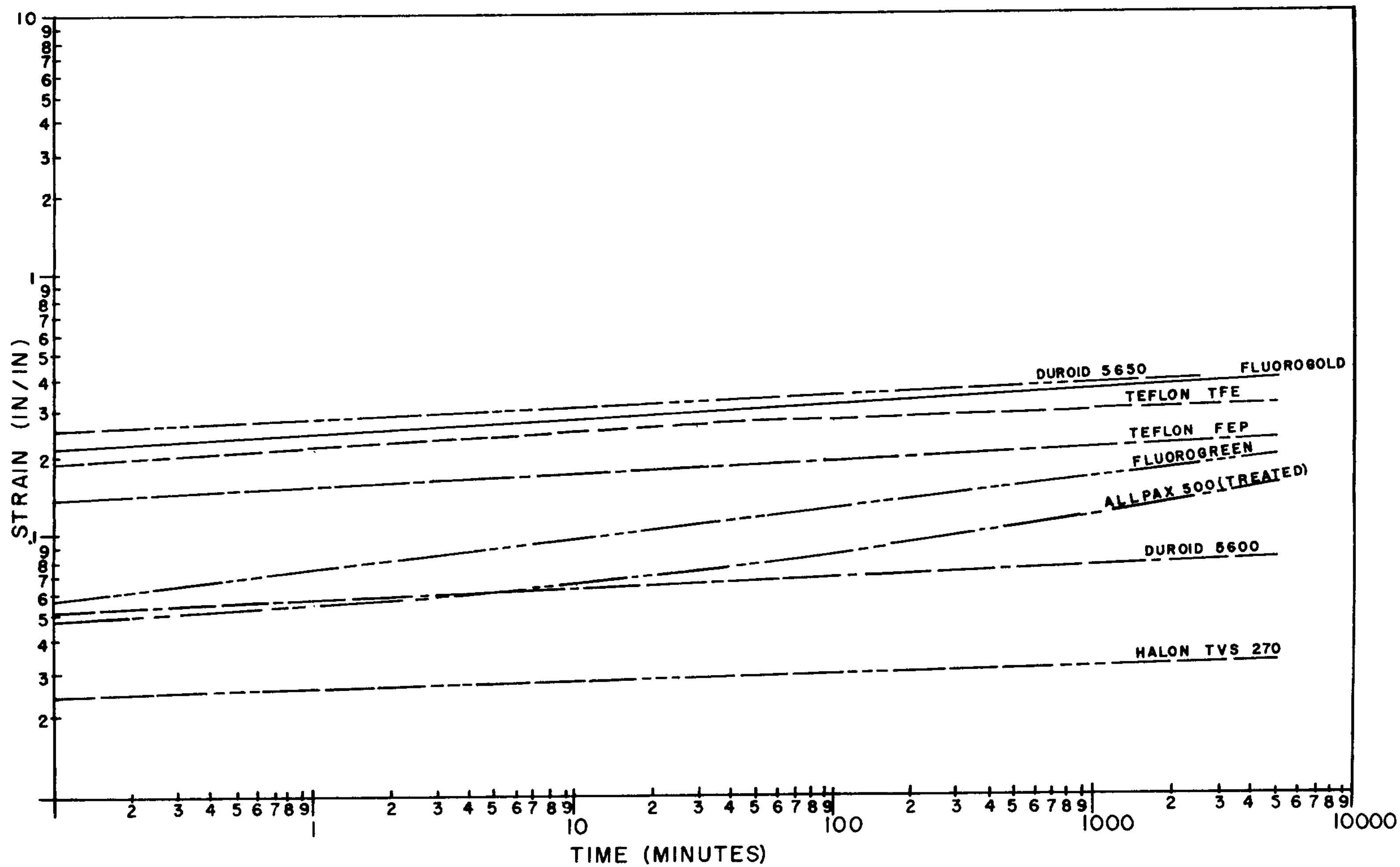


FIGURE 3. CREEP DATA FOR VARIOUS GASKET MATERIALS AMBIENT TEMPERATURE 3000 PSI STRESS

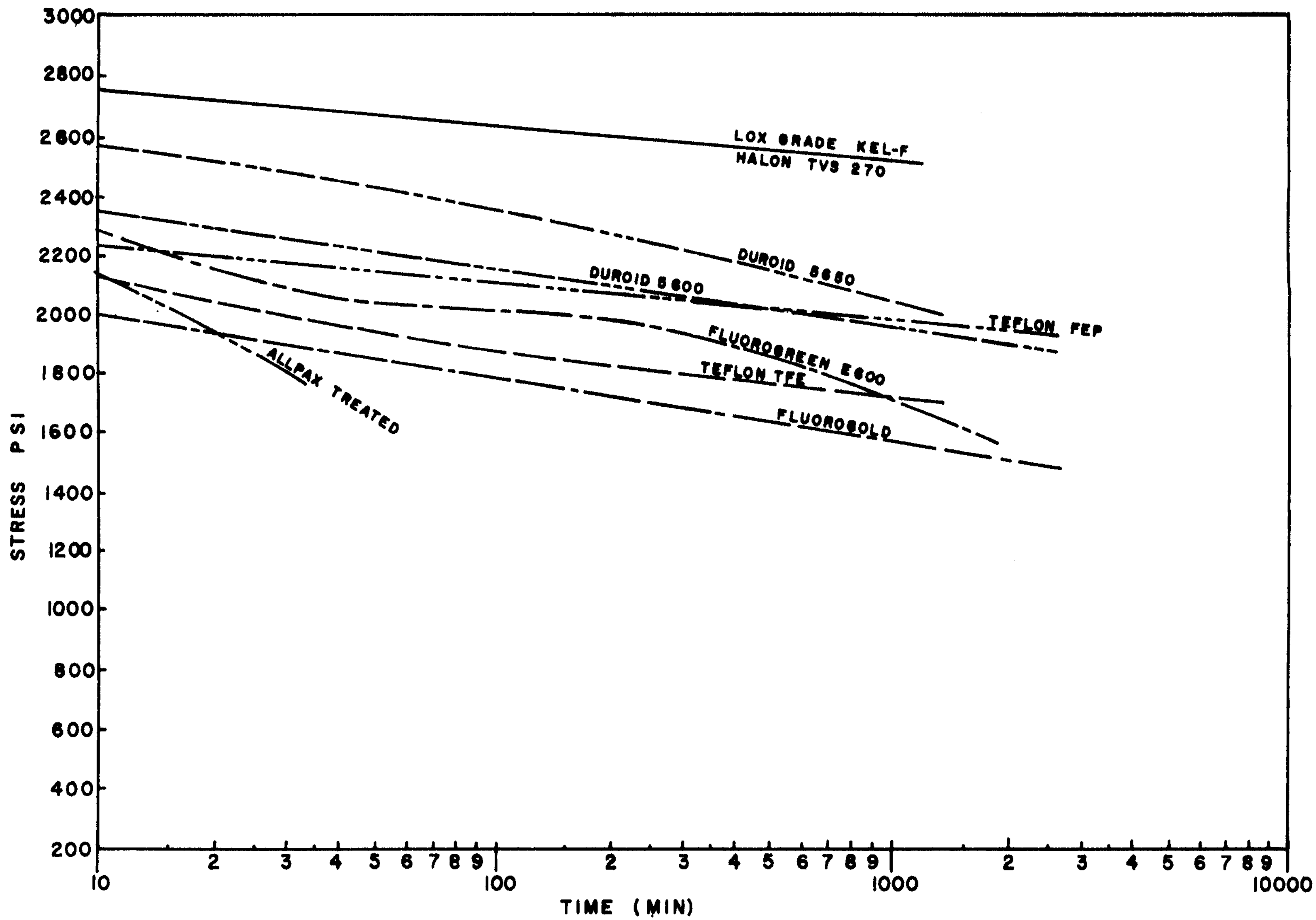


FIGURE 4. ROOM TEMPERATURE STRESS RELAXATION DATA

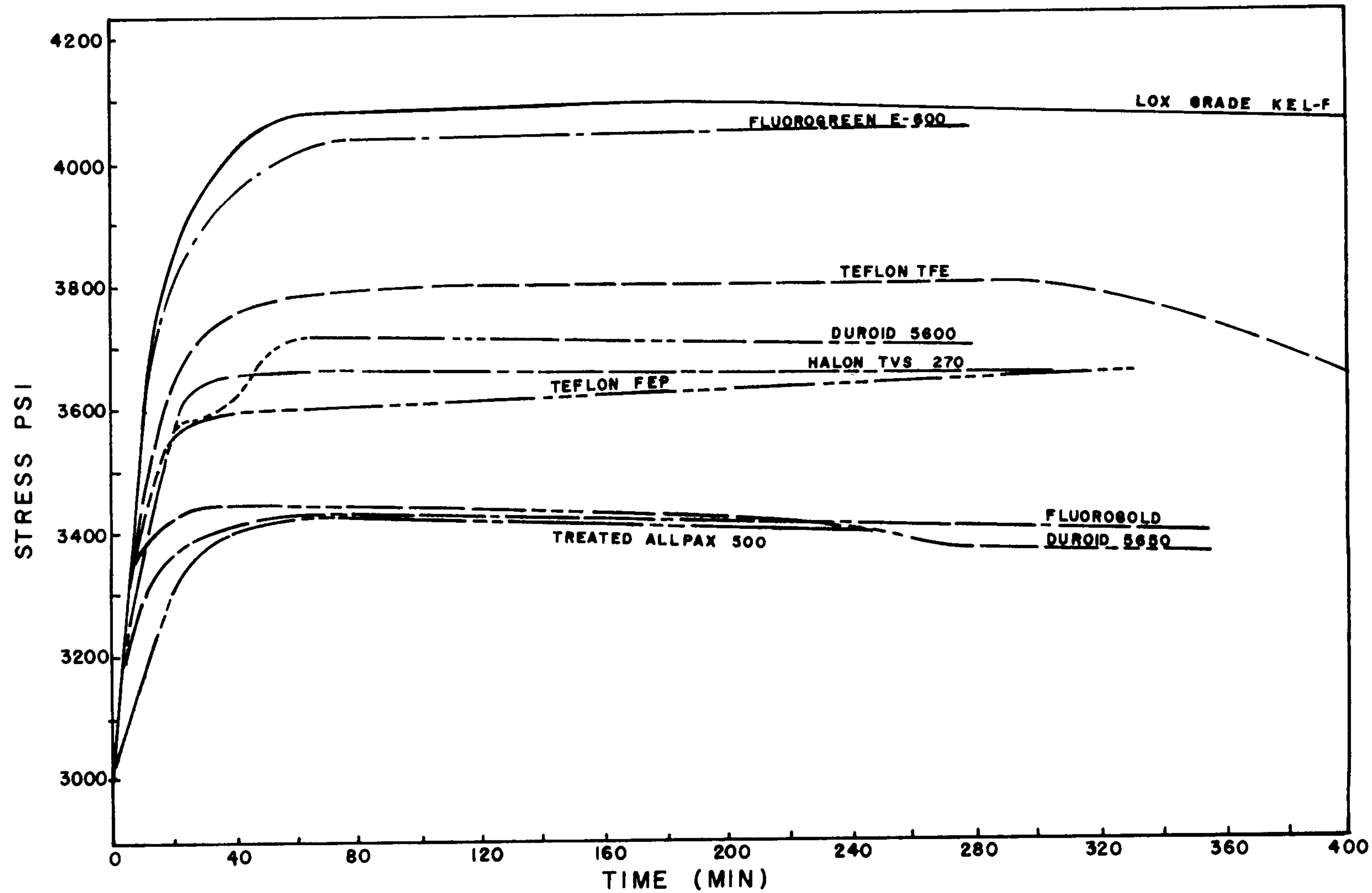
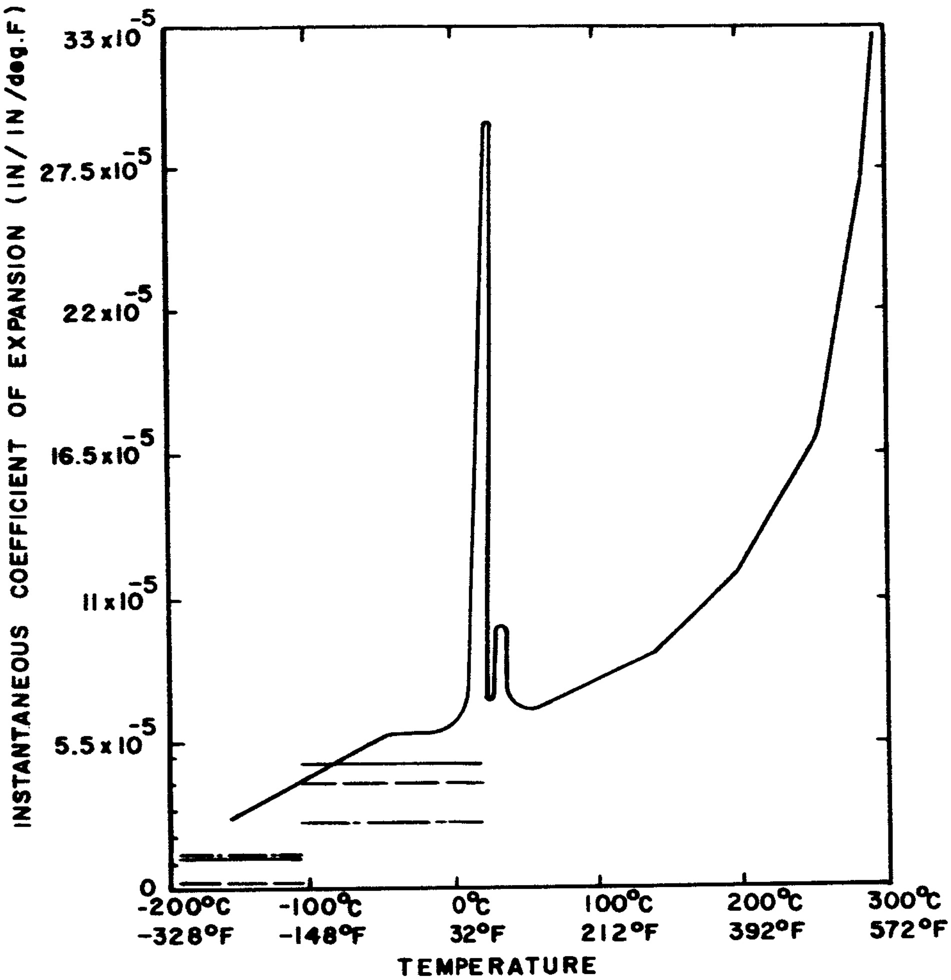


FIGURE 5. STRESS RELAXATION DATA FOR -320°F (-196°C)



SOLID LINE: INSTANTANEOUS THERMAL EXPANSION COEFFICIENT OF TEFLON TFE FROM REF. 5 HORIZONTAL LINES SHOW AVERAGE OF MEASUREMENTS OVER INDICATED TEMPERATURE RANGES MADE DURING THIS INVESTIGATION ON THE FOLLOWING MATERIALS DURING BOTH HEATING AND COOLING CYCLES.

——— FLUOROGREEN E 600

— — — FLUOROGOLD

—·— LOX GRADE KEL-F

FIGURE 6. THERMAL EXPANSION AND CONTRACTION BEHAVIOR OF FLUOROCARBON PLASTICS

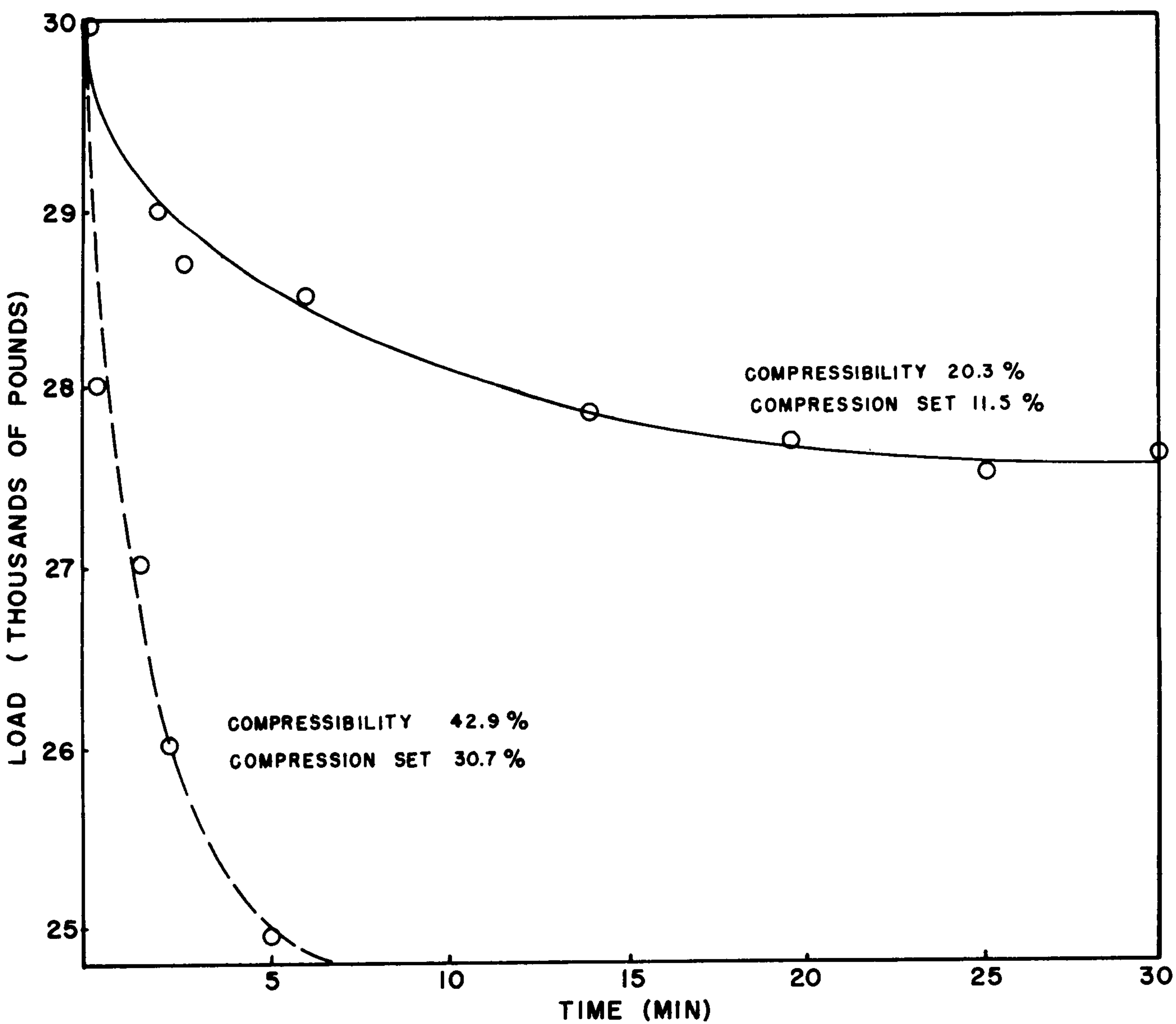


FIGURE 7. LOAD DECAY CURVES FOR TREATED ALLPAX 500 AND ASBESTOS-FILLED VITON A ELASTOMERS

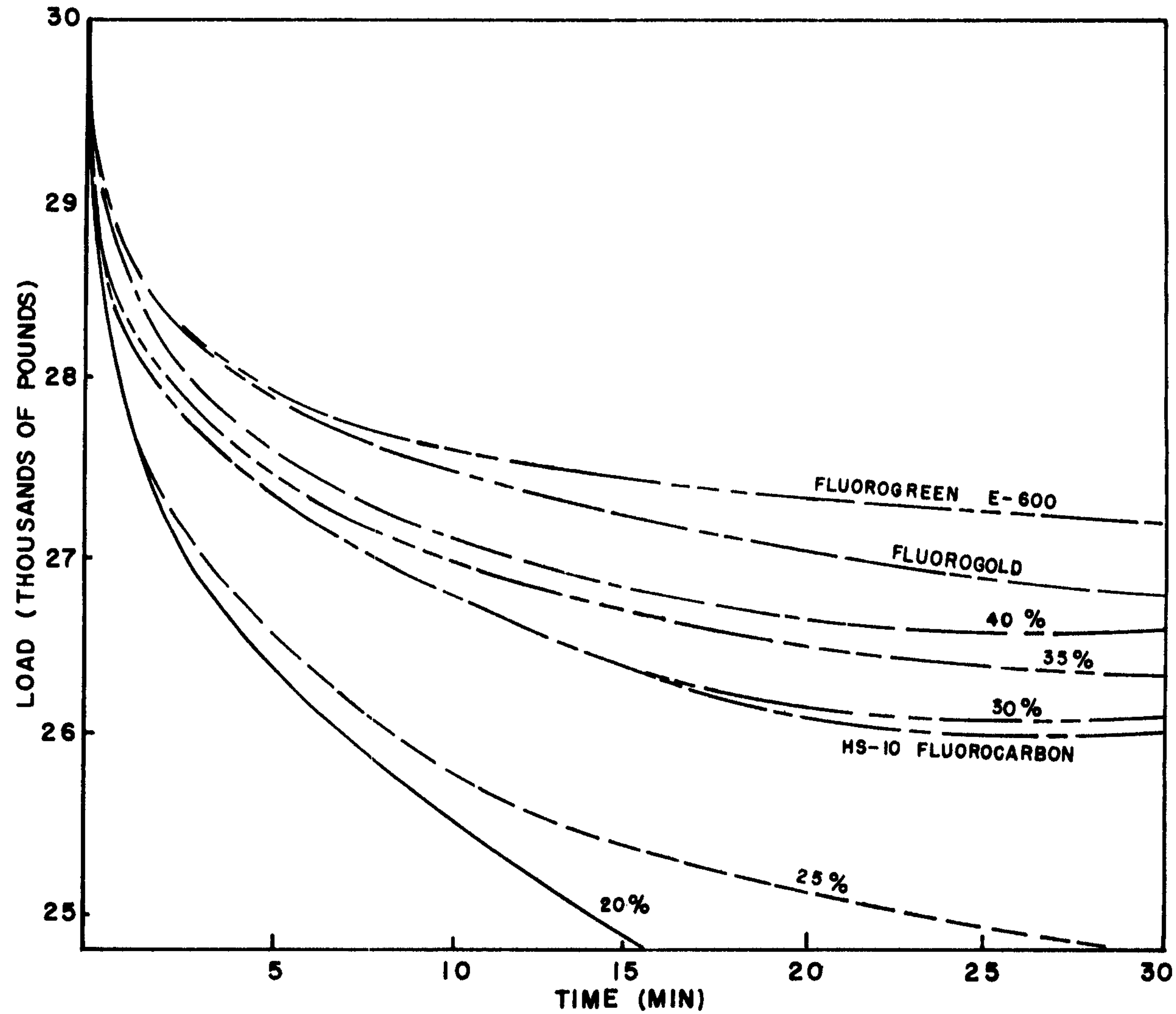


FIGURE 8. LOAD DECAY CURVES FOR VARIOUS FILLER LEVELS OF FIBERGLASS-TEFLON GASKETS

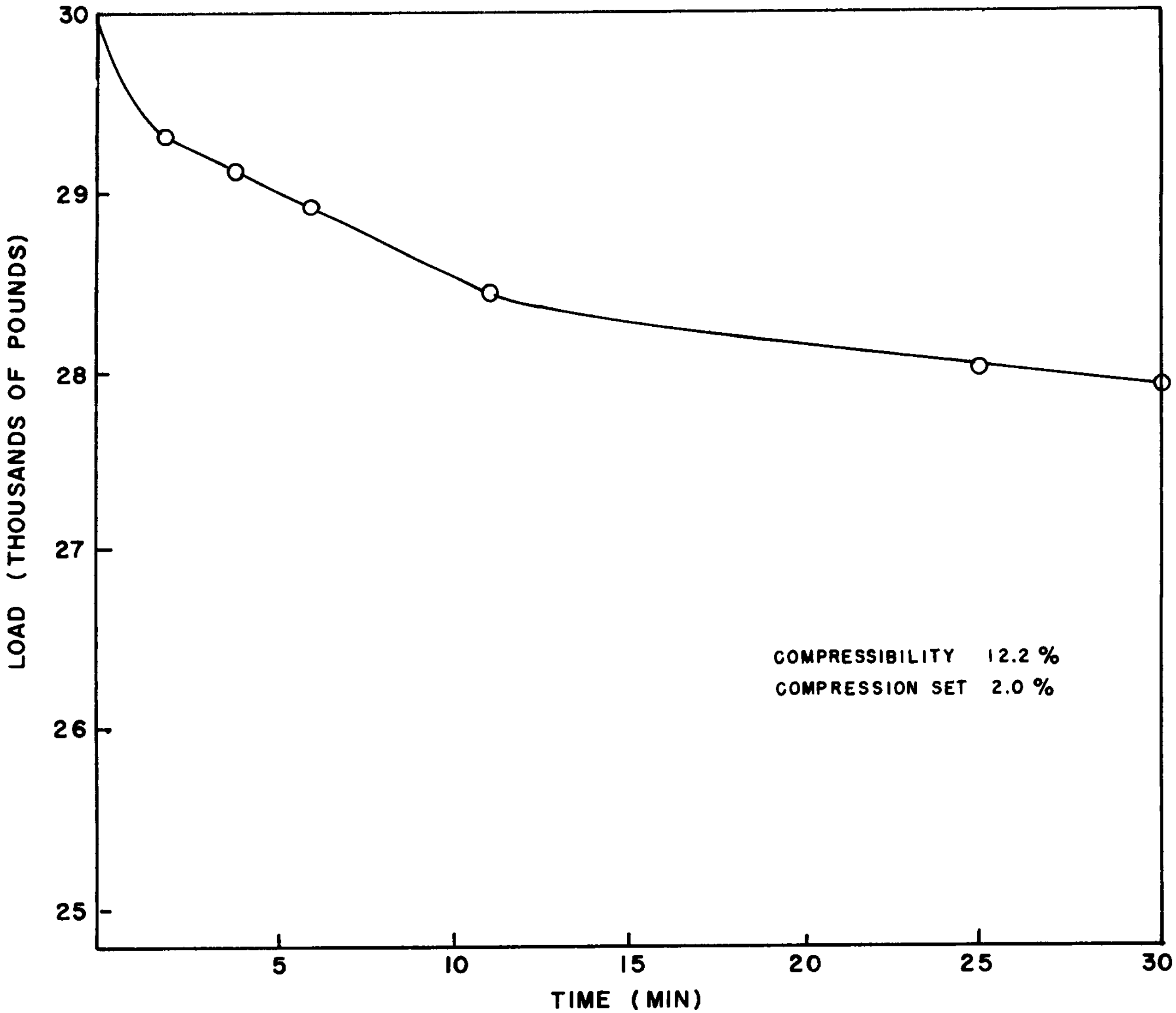


FIGURE 9. LOAD DECAY CURVE OF TEFLON AND 112 GLASS FABRIC LAMINATE

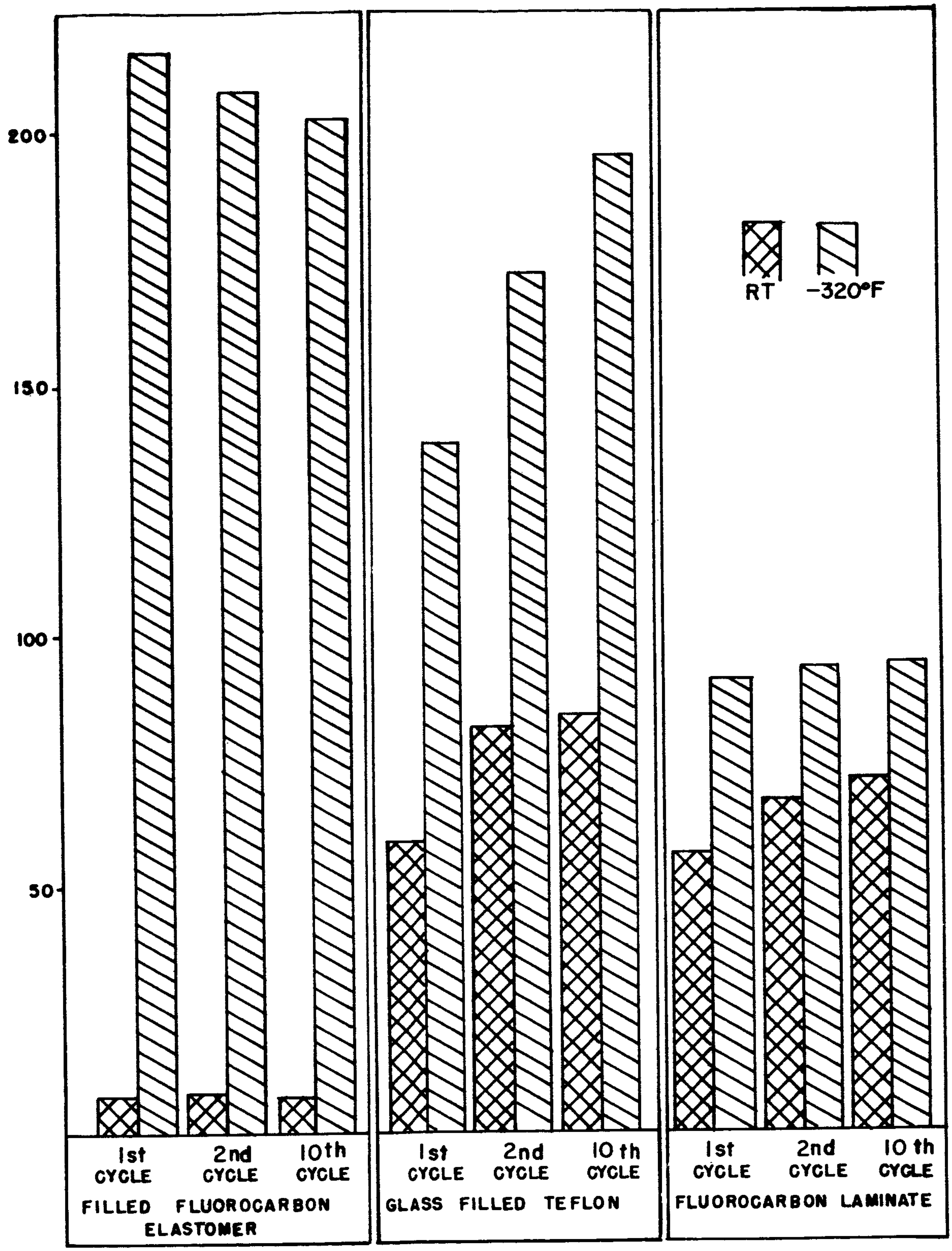


FIGURE 10. COMPARATIVE COMPRESSION MODULI OF THREE TYPES OF FLUOROCARBON COMPOSITES AFTER CYCLING AT ROOM TEMPERATURE AND -320°F (-196°C)

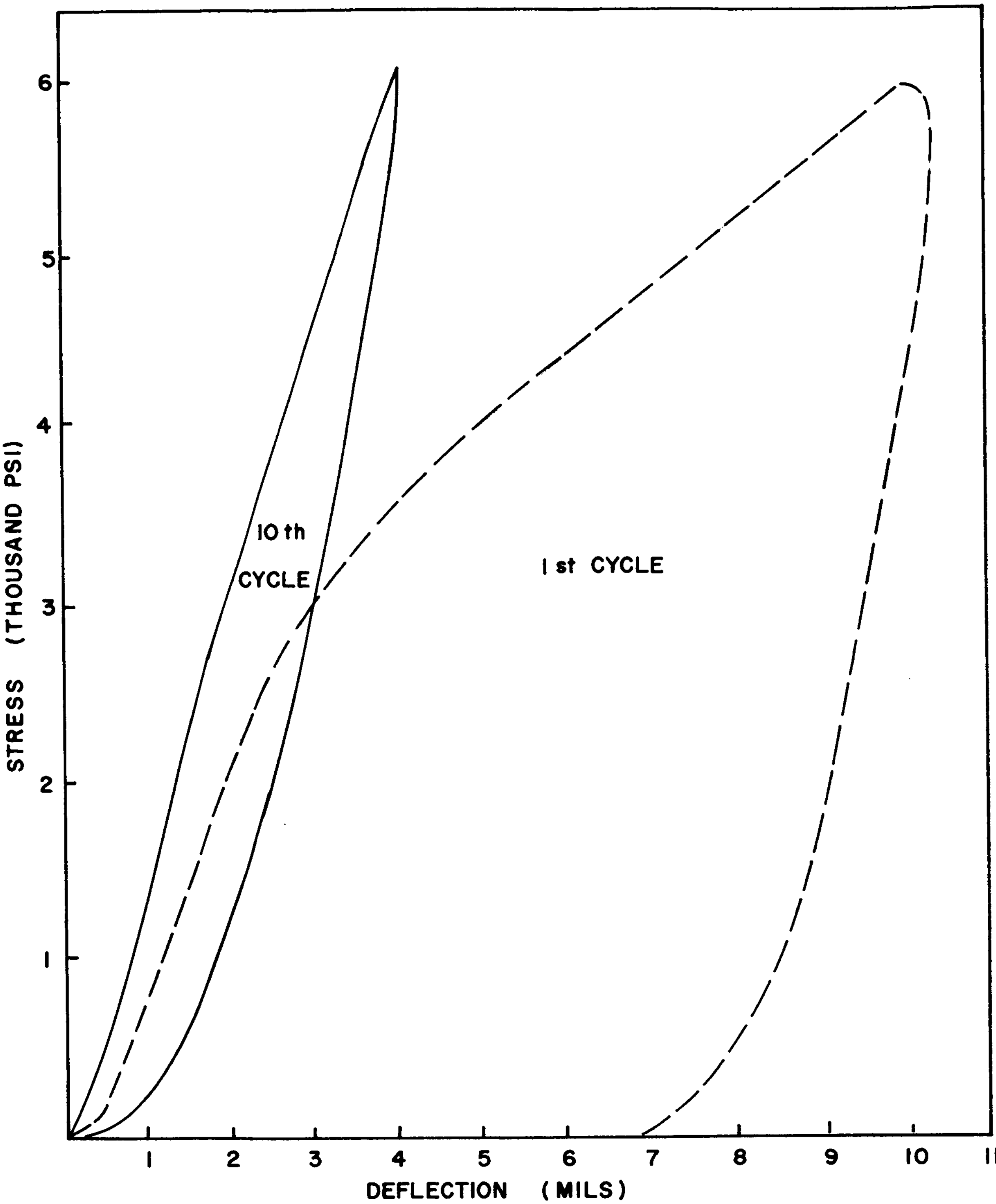


FIGURE 11. COMPRESSIVE HYSTERESIS CURVES FOR 25% GLASS FILLED TEFLON AT ROOM TEMPERATURE

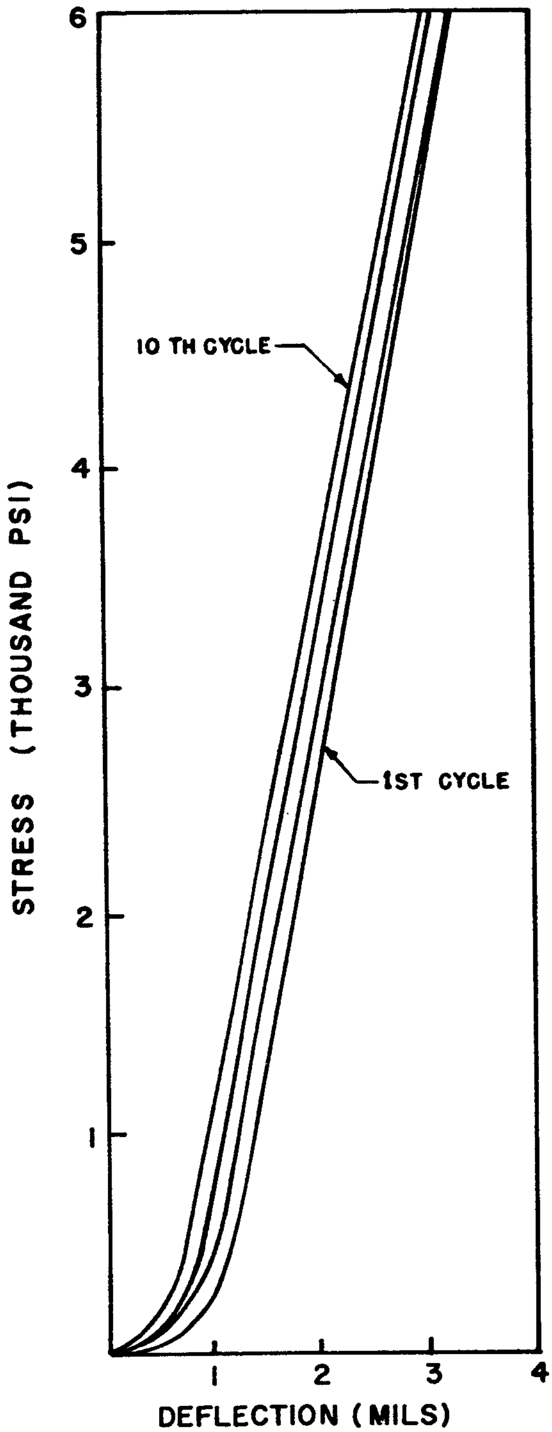


FIGURE 12. COMPRESSIVE HYSTERESIS CURVES FOR TEFLON - 112 GLASS LAMINATE AT ROOM TEMPERATURE

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December 16, 1964 APPROVAL NASA TM X 53183

STATUS REPORT ON LIQUID OXYGEN
SEAL INVESTIGATION

By James E. Curry

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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