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AN EXPERIMENTAL INVESTIGATION OF THE MECHANICAL PROPERTIES OF A SELECTED GROUP OF PLASTIC MATERIALS

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Department of Mechanical Engineering
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Pittsburgh, Pennsylvania

for

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SUMMARY

There is abundant information in the general literature and manufacturers' data concerning the properties and behavior of plastic materials. However, much of this information is in such form that the fundamental mechanical properties cannot be conveniently ascertained. Therefore, a selected group of plastics was subjected to static and dynamic tests to determine the behavior of their mechanical properties. The materials selected were those which, it was believed, would exhibit reasonably linear elastic properties. Stress-strain curves and associated information were obtained from conventional tensile tests according to ASTM Standards. Dynamic behavior was investigated over a range of temperatures and frequencies by observing the vibration characteristics of cantilever beam specimens. The dynamic tests also provided information on the log-decrement damping characteristics of the materials.

INTRODUCTION

Although abundant and detailed information is available concerning chemical and environmental properties of plastics, there is scant meaningful quantitative data available concerning the mechanical properties of these materials. Consequently, a testing program was originated to measure the mechanical properties of a selected group of plastics. The materials selected represent eleven different chemical families of thermoplastics. The following properties were selected for investigation: static stress-strain relationships, dynamic modulus of elasticity versus frequency, and log-decrement damping characteristics. The behavior of these properties are reported in graphical and tabular form. Appendix A is a list of materials tested listing trade names, chemical compositions, and the manufacturers.

MATERIAL SPECIMENS

Samples of the twelve materials tested were selected on a random "as available" basis from a local manufacturer of plastic models and mechanisms. All tensile test and beam specimens conform to ASTM Designation D 638-61T(1)* and were dumb-bell shaped 8 inches long by 3/4 inch wide, with a nominal working section 2 inches long by 1/2 inch wide by 1/4 inch thick. By actual measurement, specimen dimensions varied ± .001 inches from nominal. Each specimen was measured to determine cross-sectional

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*Parenthetical references placed superior to the line of text refer to the bibliography.

area for stress calculations. All beam specimens were 15 inches long by 1/4 inch wide by 1/5 inch deep, with a tolerance of ± .001 for individual pieces. With some exceptions, each different material was represented by four tensile test specimens and three beam specimens fabricated from the same "batch" of material. Figure 1 shows typical tensile and beam specimens.

TEST APPARATUS

Static Tests

Dumb-bell tensile test specimens were tested on a Tinius Olsen HL-400-2 Tensile Test Machine, utilizing a Tinius Olsen Strain Gage Extensometer with Counterbalance. This last item is specifically designed for plastic materials exhibiting excessive strain characteristics. The Tinius Olsen machine permits variable strain rates and provides a direct plot of load versus strain. Figures 2a and 2b show the Tinius Olsen machine and a close-up of the Strain Gage Extensometer mounted on a tensile specimen. Figure 5 is a typical load versus strain curve provided by the Tinius Olsen machine.

Dynamic Test Equipment

For the dynamic measurements, beam specimens were clamped as cantilever beams in a relatively massive support. S. Sterling AF-7 bonded wire strain gages were cemented to the beams with Eastman 910 Adhesive and excited electronic recording equipment to provide a strain versus time history of the freely oscillating beam.

The strain-gages were mounted adjacent to the clamped end and were sufficiently light in weight so as to cause no measurable effect on the vibration characteristics of the beam as indicated by preliminary measurements.

The clamped beam assembly was mounted in an insulated box containing a heating element for temperature control. Heating controls were manual, and temperatures were maintained at ± 2°F.

Ambient temperatures in the vicinity of the beam were measured. The placement of thermcouples on the beam itself was rejected because of the likelihood that even such small additional mass would affect the vibration characteristics. Sufficient warm-up time was allowed to bring the material specimen up to the required temperature as was indicated by preliminary measurements.

Electronic recording equipment included a Sanborn Recorder with appropriate strain gage bridge and balancing equipment, together with an oscilloscope upon which was mounted a Polaroid Camera. Figures 3a and 3b show the beam clamping device and the environmental enclosure. Figure 3c shows the electronic recording equipment. Figures 4a and 4b show typical Sanborn and Oscilloscope traces.

TEST PROCEDURE

Static Test Procedure

For each different material tested, three or four tensile specimens were subjected to tensile loading as prescribed by ASTM Standards(1) at a strain rate of .175 inches/inch/minute. All tests were performed at room temperature, which was maintained at a nominal value of 75^{o}F by means of the thermostatic control on the laboratory radiator system. No special temperature control was maintained for static tests. Each static run provided a direct plot of load versus strain. Figure 5 is a typical load-strain curve produced by the Tinius Olsen machine.

Dynamic Test Procedure

All materials tested were represented by two or three beam specimens as described. The beams were excited into free oscillation by a slight impulse at the free end. The dynamic tests were originated with the full length of the beam in a cantilever configuration. The beam length was then successively shortened to obtain higher natural frequencies. The cantilever beam specimens were mounted in an insulated chamber containing a heating element. Successive runs on the same beam with different lengths were performed at room temperature and at 122^{o}F and 158^{o}F. Room temperature varied from day to day and is noted in the results.

The elevated temperature values were maintained within $\pm$ 2^{o}F. Data from the dynamic tests were either as oscillograph records of strain versus time on the Sanborn Recorder chart or as a polaroid photograph of an oscilloscope screen. The Sanborn equipment was used only for frequencies below 100 cps. Figures 4a and 4b show typical Sanborn and Oscillograph records.

Data for the calculation of log-decrement decay were taken from selected oscillograph records. Log-decrement decay data were measured for two different frequencies for each material sample.

DATA REDUCTION

Raw data from the static tests were presented in the form of load in pounds versus stain in inches/inch. The load was converted to stress by the familiar relation

$$\sigma = \frac{F}{A} \tag{1}$$

where σ = Stress, psi
F = Load, pounds
A = Cross-sectional area, square inches

The static modulus of elasticity was calculated by graphically constructing a straight line tangent to the load-strain curve at the origin and calculating the slope. Thus, the expression for static-tangent modulus of elasticity, as defined in ASTM Standards,(1) is

$$E = \frac{F}{A \epsilon} \tag{2}$$

where E = Modulus of elasticity, psi
F = Load, pounds
A = Cross-sectional area, square inches
ϵ = Strain corresponding to F, inches/inch

Values for ultimate strength, proportional limit, per cent of elongation, and yield point(1) were observed from the load versus strain curves and expressed in the proper dimensions by the preceding formulas.

The calculations for dynamic modulus were performed assuming accepted theory for vibrating beams.(2) For a cantilever beam, the frequency equation for the first mode may be rearranged to

$$E = \left(\frac{2\pi}{3.515}\right)^2 \left(\frac{A \gamma L^4 f^2}{Ig}\right) \tag{3}$$

where E = Modulus of elasticity, psi
A = Cross-sectional area, square inches
γ = Weight density, pounds/cubic inches
L = Beam length, inches
f = Natural frequency, cps
I = Moment of inertia of cross-section, inches^4
g = Acceleration of gravity, inches/square seconds

The natural frequency, f, was obtained from the oscillograph records by measuring the number of cycles in a given length of chart (representing the time axis). Thus,

$$f = \frac{\text{(number of cycles)} \times \text{(paper speed)}}{\text{(length of record)}} \tag{4}$$

A similar calculation was made to calculate the natural frequency, f, from the Polaroid photographs of the oscilloscope trace.

Log-decrement decay curves were constructed by measuring the displacement amplitude in millimeters from the oscillograph records and plotting them versus the corresponding number of cycles that had occurred. Data for the log-decrement decay calculations were taken from the Sanborn Oscillograph records only.

The curves of amplitude versus number of cycles provide quantitative information concerning the damping characteristics of the material. It can be shown(2) that

$$\frac{d(\ln X)}{dn} = -2\pi\xi \tag{5}$$

where ξ = C/C_c, dimensionless
C = Equivalent viscous damping coefficient, pounds-second/feet
C_c = Equivalent viscous critical damping coefficient
n = Number of cycles
X = Amplitude of vibration, mm

Precision of Measurement and Propagation of Error

The following tolerances are estimated for the variables and parameters involved in the calculations:

Quantity		Tolerance
F	Load, pounds	± 1.0%
A	Cross-sectional area, square inches	± .6%
ϵ	Strain, inches/inches	± 1%
n	Number of cycles on oscillograph records	± 0%
S	Chart speed or sweep on oscillograph records, mm/sec.	± .01%
d	Length of record on oscillograph records, mm	± 1%
h	Depth of beam, inches	± .5%
L	Length of Beam, inches	± .02%

Quantity		Tolerance
	- Specific gravity of material, dimensionless	± .5%
X	- Amplitude of oscillation, mm	± 5.0%

Considering Equations (1), (2), (3), (4), and (5), it can be seen that the following precision is maintained on calculated quantities:

σ	- Stress, psi	± 1.6%
E_s	- Static Modulus of Elasticity, psi	± 2.6%
E_d	- Dynamic Modulus of Elasticity, psi	± 3.6%

The propagation of error in the log-decrement damping coefficient calculation varies inversely with the difference of the natural logarithms of two amplitude values. For these calculations, this difference may be a relatively small number, depending on the amplitude values involved. For this reason, the error in calculated values for ξ may be as high as ± 15% in some cases.

These estimates are based strictly on the characteristics of the recording devices used in the experimental apparatus and from actual measurements of test specimens. The actual precision of results may reasonably be expected to lie between the minimal values listed and a maximum of ± 5%, with the exception of the log-decrement damping calculations as noted above.

RESULTS

The results of the previously described tests are presented in tabular and graphical form. Appendix A lists the materials tested by trade name, chemical composition, and manufacturer. Some of the materials tested are manufactured by a variety of companies under numerous trade names. The specific materials tested are identified in Appendix A, although they may be referred to in the report by either trade name or composition.

Appendix C, Tables 1 through 12 summarize the mechanical properties, with the exception of the log-decrement damping characteristics, which are listed in Table 13. Each material tested was represented by one "batch" of material from which were fabricated tensile and dynamic test specimens. The "specimen numbers" referred to in Tables 1 through 12 should be interpreted as indicating distinct dynamic and static test specimens and from the same "batch." The specific gravity did not vary from specimen to specimen for each batch, and values are reported at the bottom of Tables 1 through 12. In Tables 1 through 12, values of modulus of elasticity are tangent modulus of elasticity, as described in ASTM Standards.(1) Values of dynamic modulus are the maximum and minimum values calculated by Equation (3) in the section, "Data Reduction." The remaining physical properties are consistent with ASTM Standards.(1)

Table 13 lists the log-decrement damping factors calculated from selected oscillograph records. The damping factor ξ is defined in Equation (5) in the section, "Data Reduction." Particular dynamic runs for these calculations were selected arbitrarily at two different temperatures and two different frequencies, as shown. Data for these properties were taken from Sanborn Oscillograph records only.

Appendix D, Figures 6 through 17, are typical stress-strain curves for the various materials. These curves were traced from actual data curves as produced on the Tinius Olsen machine and illustrated in Figure 5. Those curves were traced which seemed to be most representative of the material tested.

Appendix D, Figures 18 through 28, are values of dynamic modulus of elasticity, as defined in Equation (3) in the section, "Data Reduction." Values are reported for several temperatures, as indicated.

Appendix D, Figures 29 through 39, are semi-log plots of amplitude versus number of cycles for selected oscillograph records for the dynamic specimens. Log-decrement damping data were obtained only from Sanborn Oscillograph records, thereby limiting the range in frequencies which could be considered. Values for the damping factor calculations (See Appendix C, Table 13) were taken from these curves and calculated from Equation (5) in the section, "Data Reduction."

Discussion of Results

Static Tests. - Scrutiny of the tables in Appendix C and the static stress-strain curves, Figures 6 through 17 in Appendix D, shows that many of the materials tested exhibit reasonably linear characteristics. These curves are tracings of selected curves taken directly from the Tinius Olsen machine. The abrupt termination of a curve indicates failure of the specimen. Figure 5 is a typical record from which the curves of Figures 6 through 17 were traced. The curve for Tenite II, Figure 6, is particularly interesting because of its similarity to that of Steel. This curve is also similar, both quantitatively and qualitatively, to that reported by Racke.(3) Figure 6 is also remarkably similar to a stress-strain curve reported by the Dow Chemical Company(6) for compression molded Styron 475. Figure 12 is the curve for the Styron sample tested in this investigation. This sample failed at about the elastic limit and can not be compared with the curve for Styron 475, as reported by the Dow Chemical Company.(6) The static curve for Plexiglas, Figure 15, compares favorably with a curve provided by Rohm and Haas Company.* Also, modulus of elasticity values measured for Plexiglas, as reported in Table 10, compare favorably with those listed by the Rohm and Haas Company for Plexiglas I-A and II-UVA.

The materials tested for this report were represented by only three or four samples, and the curves in Figures 6 through 17 represent only one run for one sample. Since any given material may be obtained in a variety of nominal properties, these curves should be interpreted as indicating the general behavior of a particular class of materials. It is recommended that, in specific applications, samples of the specific material involved should be tested. These or similar samples should be retained so that the properties may be re-evaluated from time to time for aging effects.

Dynamic Tests. - The dynamic tests, as indicated in the curves of Figures 18 through 28 exhibit unexpectedly consistent results, with the exception of Teflon, which was so flexible that significant dynamic data could not be obtained. One of the problems involved in the vibration of cantilever beams is the elastic and damping effect of the support at the built-in end. This is particularly troublesome when the support and the beam are of the same material. However, in these tests, the support material (steel) was considerably heavier and stiffer than the plastic beam specimens. Thus, it was assumed that there was sufficient impedence mismatch between beam and support that the beam specimens could be considered as truly cantilever beams. This assumption was justified experimentally by the behavior of the test data and the fact that dynamic modulus values are consistently higher than static values. The minimum values of dynamic modulus listed in Tables 1 through 12 are the lowest values actually calculated. An examination of Figures 18 through 28 shows that an extrapolated value, as frequency approaches zero, compares favorably with static values. The dynamic curves for Tenite II and Plexiglas compare favorably with those reported by Sankey.(4)

Figures 29 through 39 are plots of amplitude versus number of cycles for dynamic runs selected arbitrarily from the dynamic data. Data for these curves was taken from Sanborn Oscillograph records only. The slopes of these curves were calculated as described in Equation (5) and are presented in Table 13. These numbers are the ratio of damping coefficient to critical damping coefficient, as defined in the section, "Data Reduction." An interpretation of the significance of the log-decrement decay characteristics of the vibrating beam specimens is beyond the scope of this investigation. This data is reported in the hope that it will be of use to investigations specifically directed along the subject of internal damping behavior of materials.

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*Letter and attachments from R. K. Marple, Jr., to William M. Laird dated October 7, 1964.

CONCLUSIONS

Most of the thermo-plastic materials tested in this investigation exhibit reasonable elastic properties, provided stress levels are kept to reasonable values. An arbitrary evaluation of the relative merits of the materials tested is difficult, but four materials exhibiting excellent behavior are Tenite II, Boltaron 6200, Boltaron 7200, and Styron. The remaining materials are quite favorable by comparison, except Teflon, which is obviously inadequate insofar as elastic properties are concerned. Note that Nylon is remarkably well-behaved. All materials except Teflon exhibit fairly consistent linear dynamic response. The general behavior of the experimental data is considered to be highly satisfactory. The linearity of the semi-log plots justifies confidence in the results and in the assumption of truly exponential damping characteristics.

Finally, it is concluded that many thermo-plastic materials are suitable for structural or model applications. The preceding results may serve as a guide to select appropriate materials for specific applications. It is recommended that, in any application, represented samples be tested to determine specific values of each "batch" of material used. It is also recommended that sufficient test specimens be retained so that aging effects can be evaluated at appropriate intervals.

From experience gained in preparing test specimens, it is also concluded that there exists no insurmountable machining difficulties. Acceptable tolerances can be maintained if reasonable procedures are followed. Pre-determined dimensions may be difficult to attain, but approximate dimensions may be held to close relative tolerances. Machining difficulties arise, in general, from temperature effects and are well understood by skilled machinists experienced in working with thermo-plastics.

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APPENDIX A

MATERIALS TESTED BY TRADE NAME AND MANUFACTURERS

Tenite II --- Cellulose Acetate Butyrate - Eastman Chemical Products, Inc., Subsidiary of Eastman Kodak Company, Kingsport, Tennessee.

Lucite --- Methyl Methacrylate Resin - E. I. DuPont de Nemours Company, Inc., 1700 Market Street, Wilmington, Delaware.

Alathon Type III --- Hi-Density Polyethylene* - E. I. DuPont de Nemours Company, Inc., 1700 Market St., Wilmington, Delaware.

Boltaron 6200 --- Polyvinyl Chloride - General Tire and Rubber Company, 1708 Englewood Avenue, Akron 9, Ohio.

Boltaron 7200 --- Polyvinyl Chloride - General Tire and Rubber Company, 1708 Englewood Avenue, Akron 9, Ohio.

Polypropylene --- Dow Chemical Company, Plastics Department, Midland, Michigan. (Also other manufacturers.)

Styron --- Polystyrene - Dow Chemical Company, Plastics Department, Midland, Michigan.

Teflon --- Tetrafluoroethylene - E. I. DuPont de Nemours Company, Inc., 1700 Market Street, Wilmington, Delaware.

Lexan --- Polycarbonate Resin - General Electric Corporation, Chemical Materials Department, Pittsfield, Massachusetts.

Plexiglas --- Acrylate and Methacrylate Resin - Rohm and Haas Company, Washington Square, Philadelphia 5, Pennsylvania.

Nylon 101 --- Polyamides - Many manufacturers; exact source unknown.

Delrin --- Acetal Resin - E. I. DuPont de Nemours Company, Inc., 1700 Market Street, Wilmington, Delaware.

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*Hi-Density: Specific Gravity $>$ .940
Lo-Density: Specific Gravity $<$ .940 (See reference 5.)

APPENDIX B

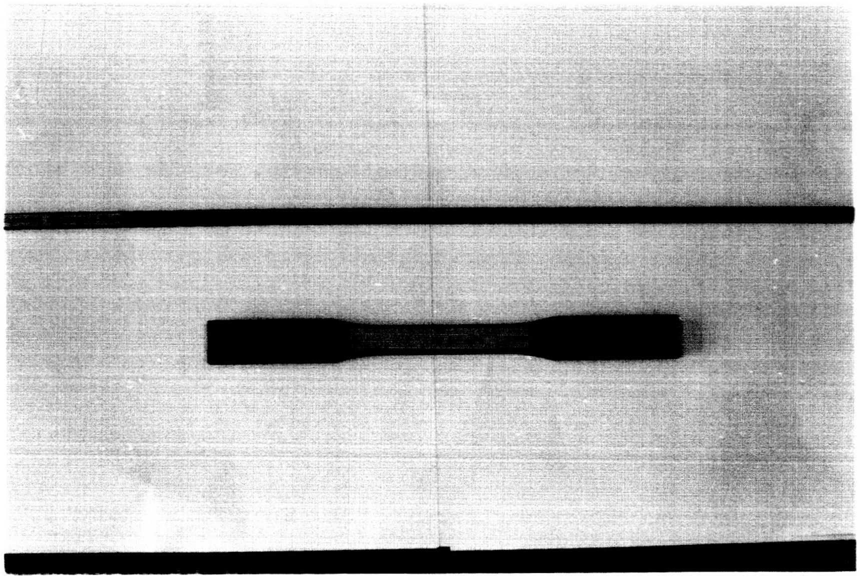


Figure 1

BEAM AND STATIC TEST SECTIONS

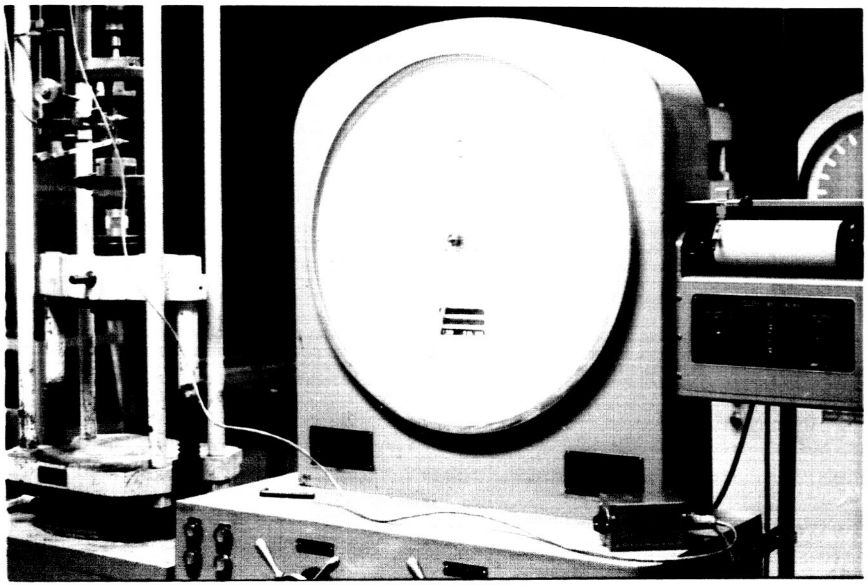


Figure 2a

TINIUS OLSEN TESTING MACHINE AND RECORDER

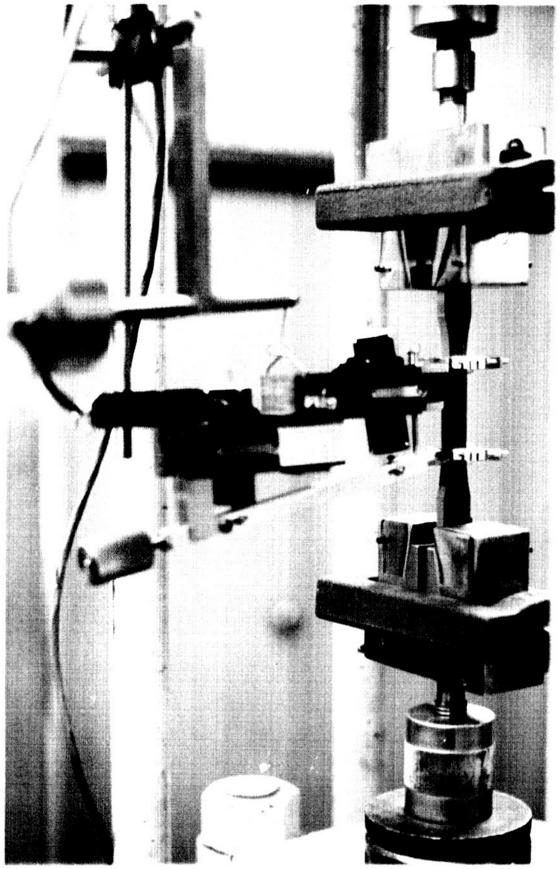


Figure 2b

TINIUS OLSEN STRAIN GAGE EXTENSOMETER

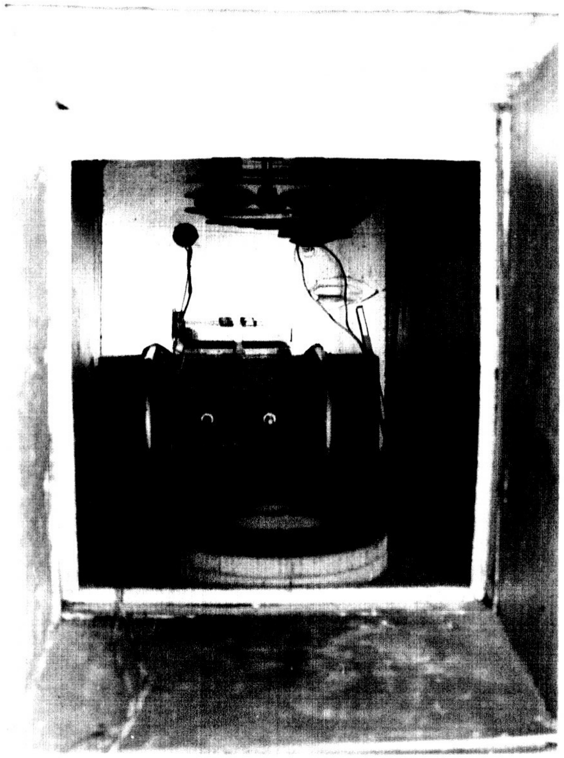


Figure 3a

BEAM SPECIMEN CLAMPING SYSTEM AND

ENVIRONMENTAL ENCLOSURE

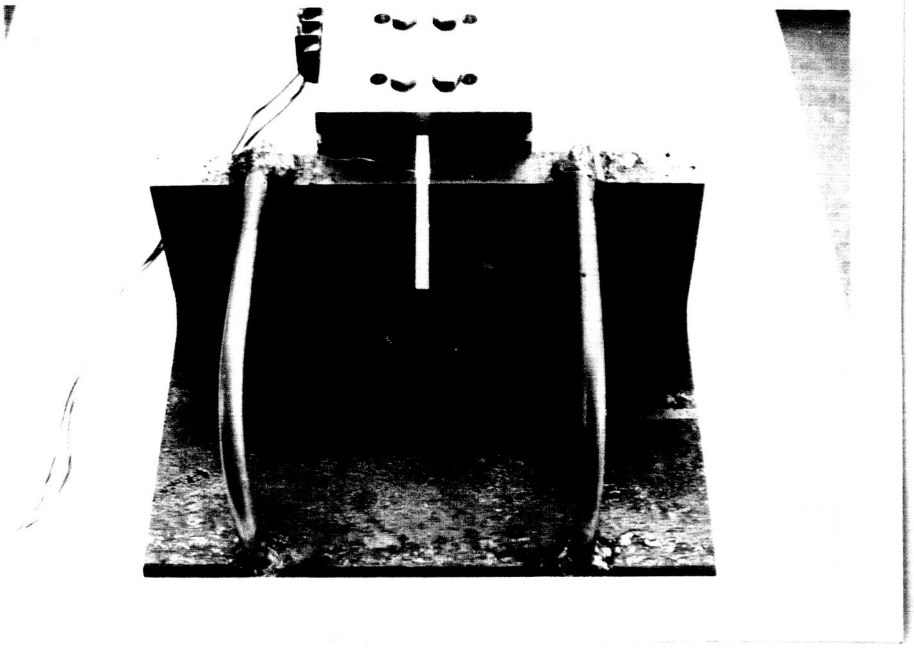


Figure 3b

DETAIL OF BEAM CLAMPING SYSTEM

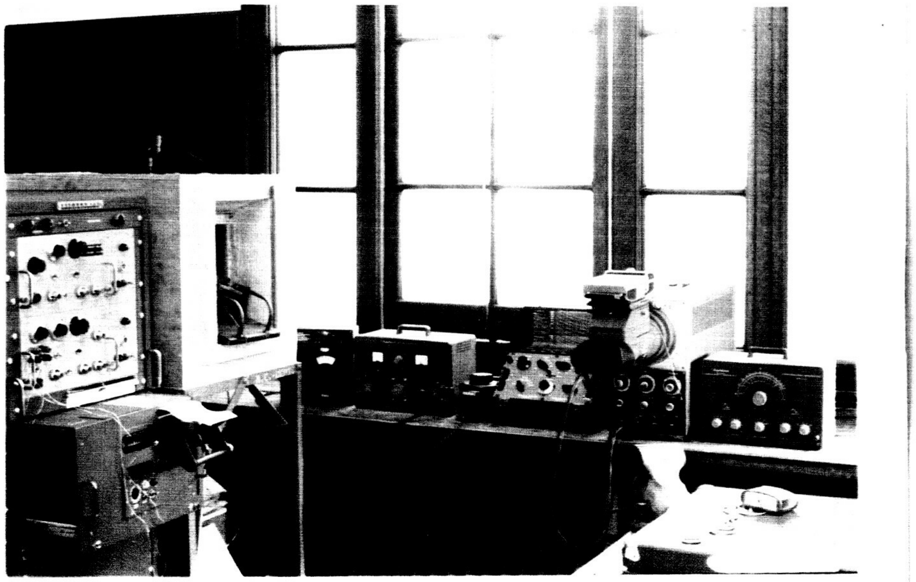


Figure 3c

ELECTRONIC INSTRUMENTATION

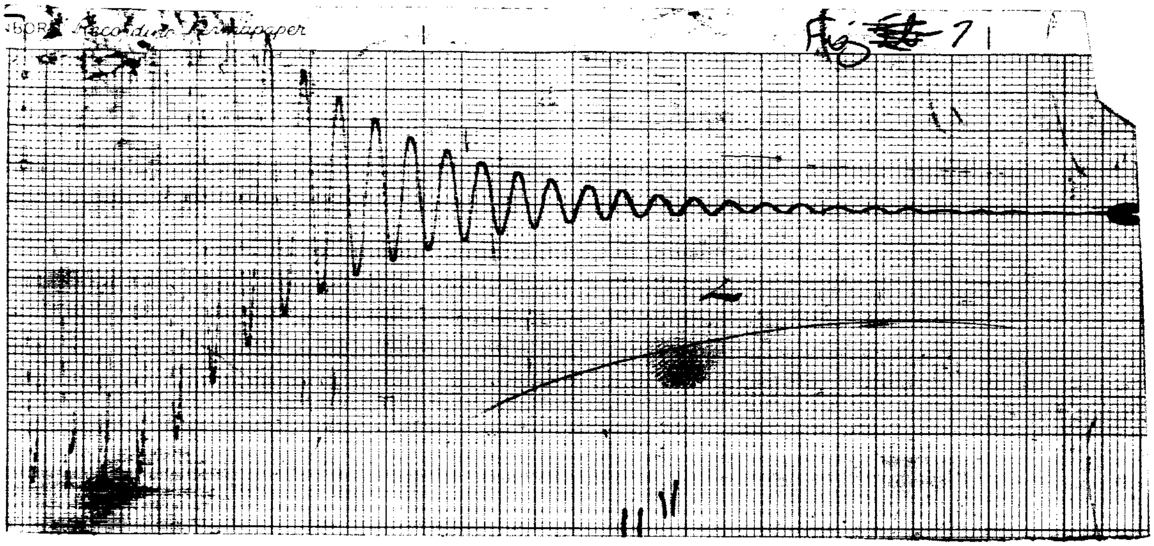


Figure 4a

TYPICAL SANBORN OSCILLOGRAPH RECORDING

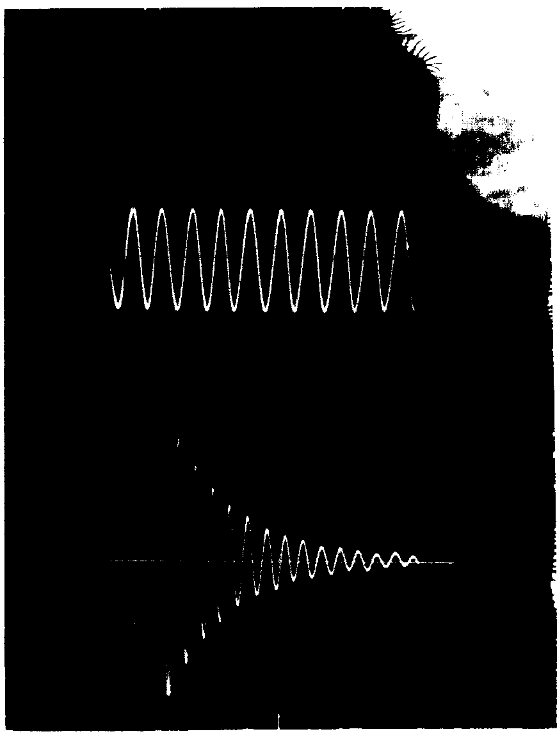


Figure 4b

TYPICAL PHOTOGRAPH OF OSCILLOSCOPE TRACE

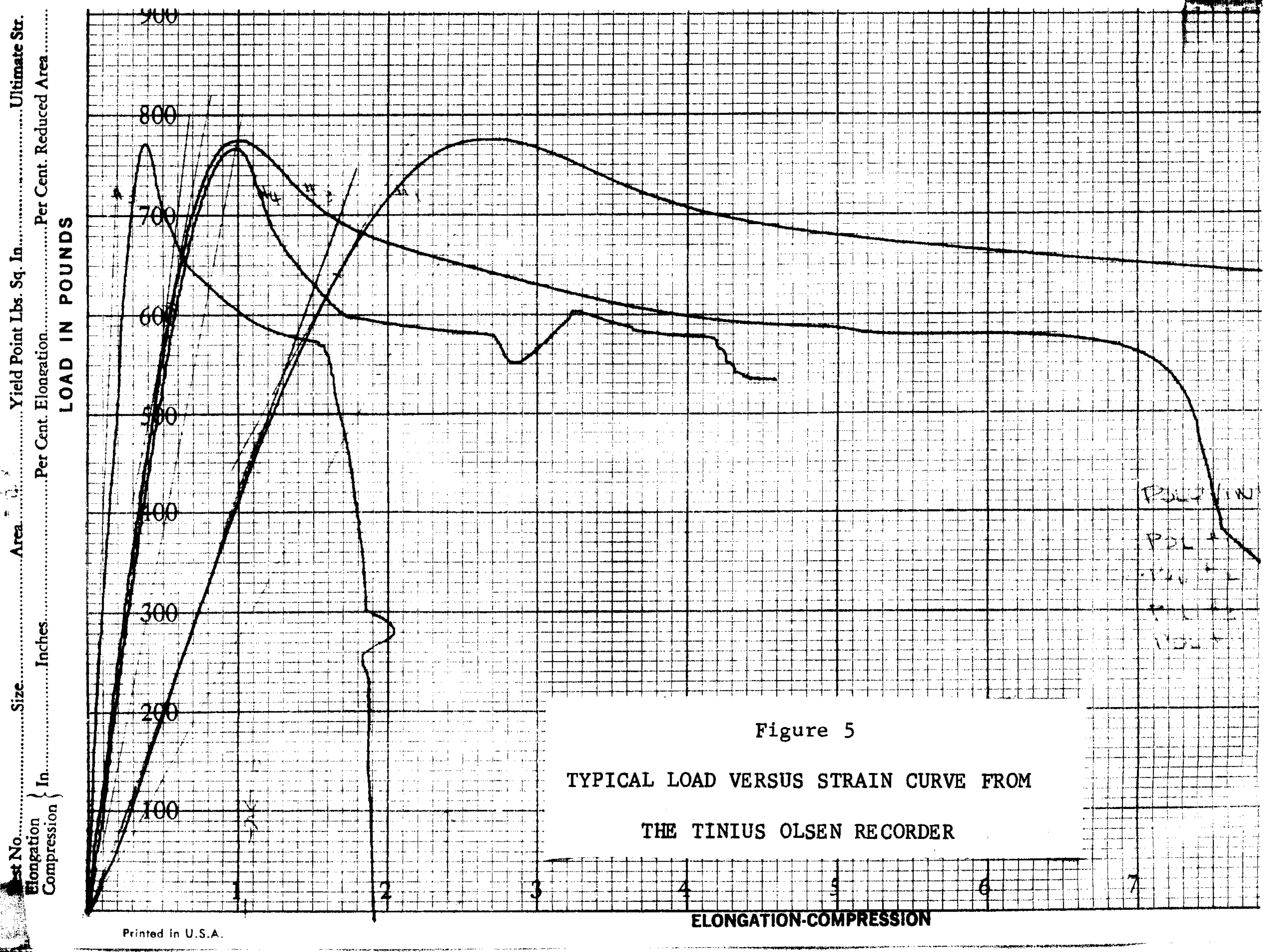


Figure 5

TYPICAL LOAD VERSUS STRAIN CURVE FROM

THE TINIUS OLSEN RECORDER

APPENDIX C

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4
Static E (psi)		207 000	220 000	228 000	228 000
Dynamic E (psi)	80°F	245 000 ↓ 302 000	242 000 ↓ 321 000		
	122°F				
	158°F				149 000 ↓ 214 000
Ultimate Strength (psi)			4960	4570	5040
Proportional Limit (psi)		2560			
% Elongation		Off Scale At 10 ↑	75	66	69
Yield Point (psi)		4000	3880	3970	4160

Specific Gravity - 1.19

Table 1

MECHANICAL PROPERTIES

TENITE II

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4	Specimen #5
Static E (psi)		343 000	413 000		413 000	427 000*
Dynamic E (psi)	83°F	565 000 ↓ 639 000	561 000 ↓ 646 000			
	122°F			478 000 ↓ 637 000		
	158°F				374 000 ↓ 440 000	
Ultimate Strength (psi)		9200	7600		9280	
Proportional Limit (psi)		6320	5190		5190	
% Elongation		4.7	5.6		6.6	
Yield Point (psi)						

Specific Gravity - 1.19

* Re-Run Using Dynamic Beam Specimen - Average Value Used to Eliminate Influence of Bending

Table 2

MECHANICAL PROPERTIES

LUCITE

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4
Static E (psi)		137 000	152 000	140 000	
Dynamic E (psi)	76°F	331 000 ↓ 401 000	331 000 ↓ 359 000		
	122°F			198 000 ↓ 204 000	
	158°F				125 000 ↓ 164 000
Ultimate Strength (psi)		Off Scale At 2000↓	Off Scale At 1880↓		
Proportional Limit (psi)		1040			
% Elongation			Off Scale At 100↑	Off Scale At 100↑	
Yield Point (psi)			3200	3160	

Specific Gravity - .950

Table 3

MECHANICAL PROPERTIES

ALATHON TYPE III

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4
Static E (psi)		473 000	473 000	473 000	473 000
Dynamic E (psi)	76°F	506 000 ↓ 530 000	518 000 ↓ 561 000		
	122°F			440 000 ↓ 452 000	
	158°F				241 000 ↓ 309 000
Ultimate Strength (psi)			6280		6400
Proportional Limit (psi)		7160	7160	7160	7160
% Elongation			7.9		8.8
Yield Point (psi)		9070	9070	9070	9070

Specific Gravity - 1.43

Table 4

MECHANICAL PROPERTIES

BOLTARON 6200

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4
Static E (psi)		335 000	308 000	373 000	373 000
Dynamic E (psi)	76°F	391 000 ↓ 419 000	393 000 ↓ 419 000		
	122°F			349 000 ↓ 366 000	
	158°F				254 000 ↓ 258 000
Ultimate Strength (psi)			4560	4630	4800
Proportional Limit (psi)		5120		4900	4900
% Elongation		Off Scale At 10 ↓	16	12.3	4.3
Yield Point (psi)		6200	6160	6200	6120

Specific Gravity - 1.35

Table 5

MECHANICAL PROPERTIES

BOLTARON 7200

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4
Static E (psi)		270 000	299 000	296 000	296 000
Dynamic E (psi)	83°F	359 000 ↓ 388 000	344 000 ↓ 397 000		
	122°F			233 000 ↓ 256 000	
	158°F				153 000 ↓ 179 000
Ultimate Strength (psi)		5080	5360	5120	5240
Proportional Limit (psi)		2000	2040	1960	2160
% Elongation		4.4	2.4	2.4	2.4
Yield Point (psi)					

Specific Gravity - .902

Table 6

MECHANICAL PROPERTIES

POLYPROPYLENE

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4
Static E (psi)		503 000	448 000	448 000	527 000
Dynamic E (psi)	83°F	492 000 ↓ 510 000	485 000 ↓ 509 000		
	122°F			428 000 ↓ 455 000	
	158°F				412 000 ↓ 423 000
Ultimate Strength (psi)		6480	6000	6160	6400
Proportional Limit (psi)		6040			6040
% Elongation		1.7	1.4	1.5	1.6
Yield Point (psi)		6480			6400

Specific Gravity - 1.05

Table 7

MECHANICAL PROPERTIES

STYRON

Material Property		Specimen #1	Specimen #2
Static E (psi)		561 000	572 000
Dynamic E	Room		
	122°F		
	158°F		
Ultimate Strength (psi)		Off Scale At 1600 ↑	Off Scale At 1600 ↑
Proportional Limit (psi)		384	472
% Elongation		Off Scale At 100 ↑	Off Scale At 100 ↑
Yield Point (psi)			

Specific Gravity - 2.18

Table 8

MECHANICAL PROPERTIES

TEFLON

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4	Specimen #5
Static E (psi)		337 000	337 000	341 000	341 000	
Dynamic E (psi)	83°F	360 000 ↓ 387 000	355 000 ↓ 365 000			
	122°F			322 000 ↓ 345 000		
	158°F				312 000 ↓ 340 000	
Ultimate Strength (psi)					9200	9040
Proportional Limit (psi)		5360	5360	5760	5760	
% Elongation					8	7.6
Yield Point (psi)		9440	9440	9440	9440	

Specific Gravity - 1.20

Table 9

MECHANICAL PROPERTIES

LEXAN

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4
Static E (psi)		447 000	452 000	467 000	468 000
Dynamic E (psi)	76°F	617 000 ↓ 653 000	601 000 ↓ 649 000		
	122°F				
	158°F				335 000 ↓ 404 000
Ultimate Strength (psi)		10 000		11 200	10 800
Proportional Limit (psi)		6440	6470	6600	6520
% Elongation		3.8	Off Scale At 5 ↑	4.6	4.8
Yield Point (psi)					

Specific Gravity - 1.19

Table 10

MECHANICAL PROPERTIES

PLEXIGLAS

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4	Specimen #5
Static E (psi)		493 000	480 000	640 000	480 000*	415 000**
Dynamic E (psi)	83°F	436 000 ↓ 485 000	428 000 ↓ 445 000			
	122°F			227 000 ↓ 363 000		
	158°F				147 000 ↓ 242 000	
Ultimate Strength (psi)		8000	8800			
Proportional Limit (psi)		6760				
% Elongation		9.5				
Yield Point (psi)						

Specific Gravity - 1.12

* Re-Run Using Standard Tensile Specimen 5/12/65

** Re-Run Using Dynamic Beam Specimen - Average Value Used to Eliminate Influence of Bending 5/12/65

Table 11

MECHANICAL PROPERTIES

NYLON

Material Property		Specimen #1	Specimen #2	Specimen #3	Specimen #4	Specimen #5
Static E (psi)		674 000	674 000	657 000	657 000	589 000*
Dynamic E (psi)	76°F		561 000 567 000			
	83°F	587 000 605 000				
	122°F			350 000 457 000		
	158°F				359 000 410 000	
Ultimate Strength (psi)		10 800	11 200	10 800		
Proportional Limit (psi)		5 000	5 000	4 150	4 150	
% Elongation		4.5	4.6	9.6		
Yield Point (psi)						

Specific Gravity - 1.43

* Re-Run Using Dynamic Beam Specimen - Average Values Used to Eliminate Influence of Bending, 5/12/65

Table 12

MECHANICAL PROPERTIES

DELRIN

MATERIAL	TEMPERATURE	FREQUENCY	DAMPING RATIO
Tenite II	80°F	21.3 cps	-.029
	80°F	6.0 cps	-.022
	158°F	10.1 cps	-.032
	158°F	4.6 cps	-.032
Lucite	83°F	31.2 cps	-.036
	83°F	10.3 cps	-.042
	158°F	20.2 cps	-.048
	158°F	8.7 cps	-.047
Alathon Type III	76°F	32.3 cps	-.018
	76°F	11.5 cps	-.024
	158°F	11.0 cps	-.072
	158°F	6.4 cps	-.072
Boltaron 6200	76°F	33.4 cps	-.0065
	76°F	10.9 cps	-.0063
	158°F	23.4 cps	-.047
	158°F	12.9 cps	-.059
Boltaron 7200	76°F	13.3 cps	-.0080
	76°F	8.3 cps	-.0065
	158°F	18.4 cps	-.057
	158°F	6.6 cps	-.029
Polypropylene	83°F	12.0 cps	-.022
	83°F	3.2 cps	-.025
	158°F	23.5 cps	-.023
	158°F	9.3 cps	-.021
Styron	83°F	3.6 cps	-.0083
	83°F	1.3 cps	-.0085
	158°F	33.3 cps	-.016
	158°F	12.5 cps	-.018
Lexan	85°F	27.2 cps	-.0046
	85°F	10.4 cps	-.0046
	158°F	10.5 cps	-.0070
	158°F	2.5 cps	-.0086
Plexiglas	80°F	70.0 cps	-.035
	80°F	15.1 cps	-.037
	158°F	79.4 cps	-.057
	158°F	11.9 cps	-.053
Nylon 101	83°F	21.8 cps	-.015
	83°F	10.0 cps	-.013
	158°F	21.7 cps	-.047
	158°F	9.7 cps	-.047
Delrin	83°F	27.8 cps	-.0057
	83°F	10.0 cps	-.0060
	158°F	28.6 cps	-.0069
	158°F	9.1 cps	-.0074

Table 13--LOG-DECREMENT DAMPING CHARACTERISTICS

APPENDIX D

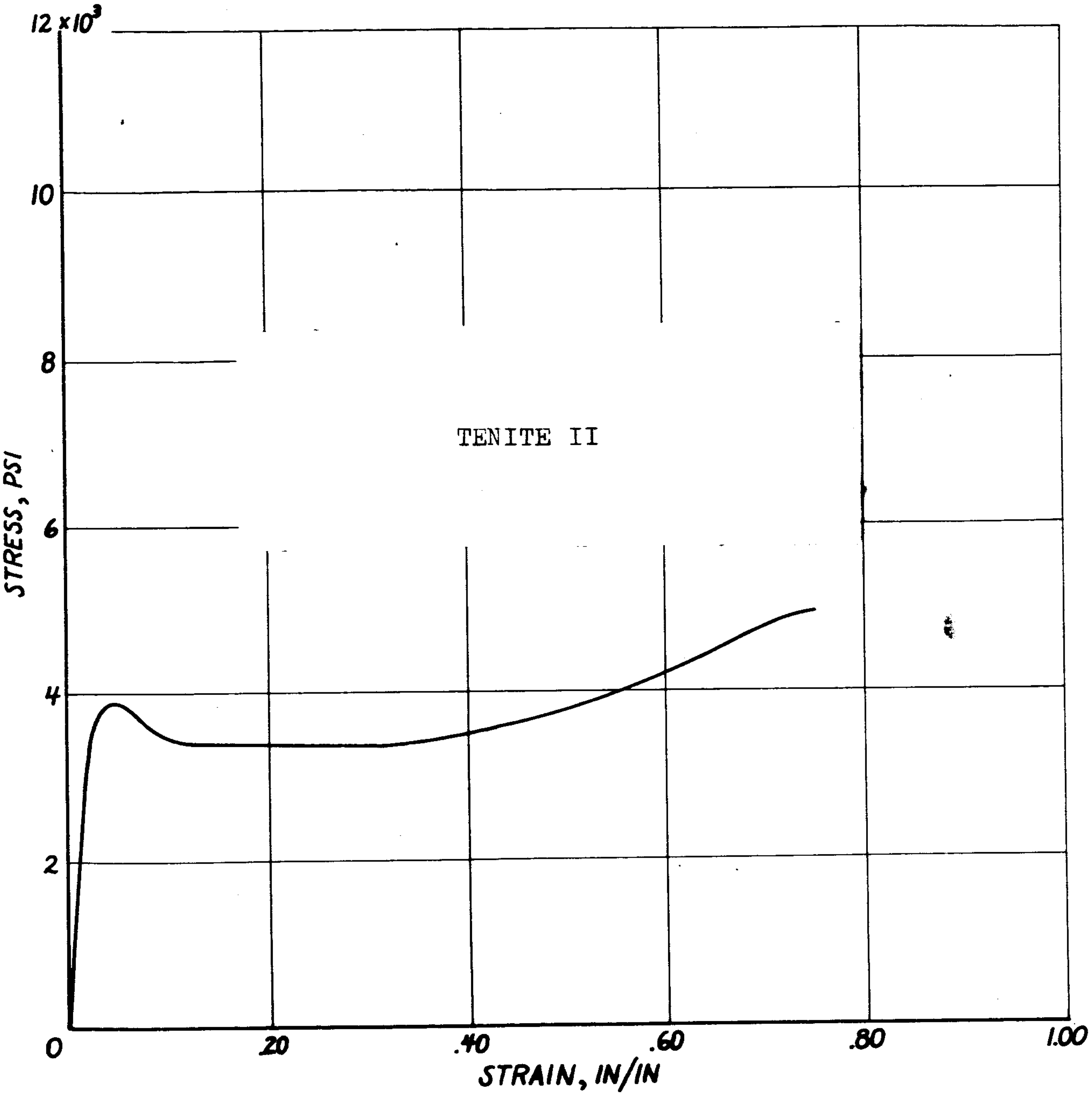


FIGURE 6

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

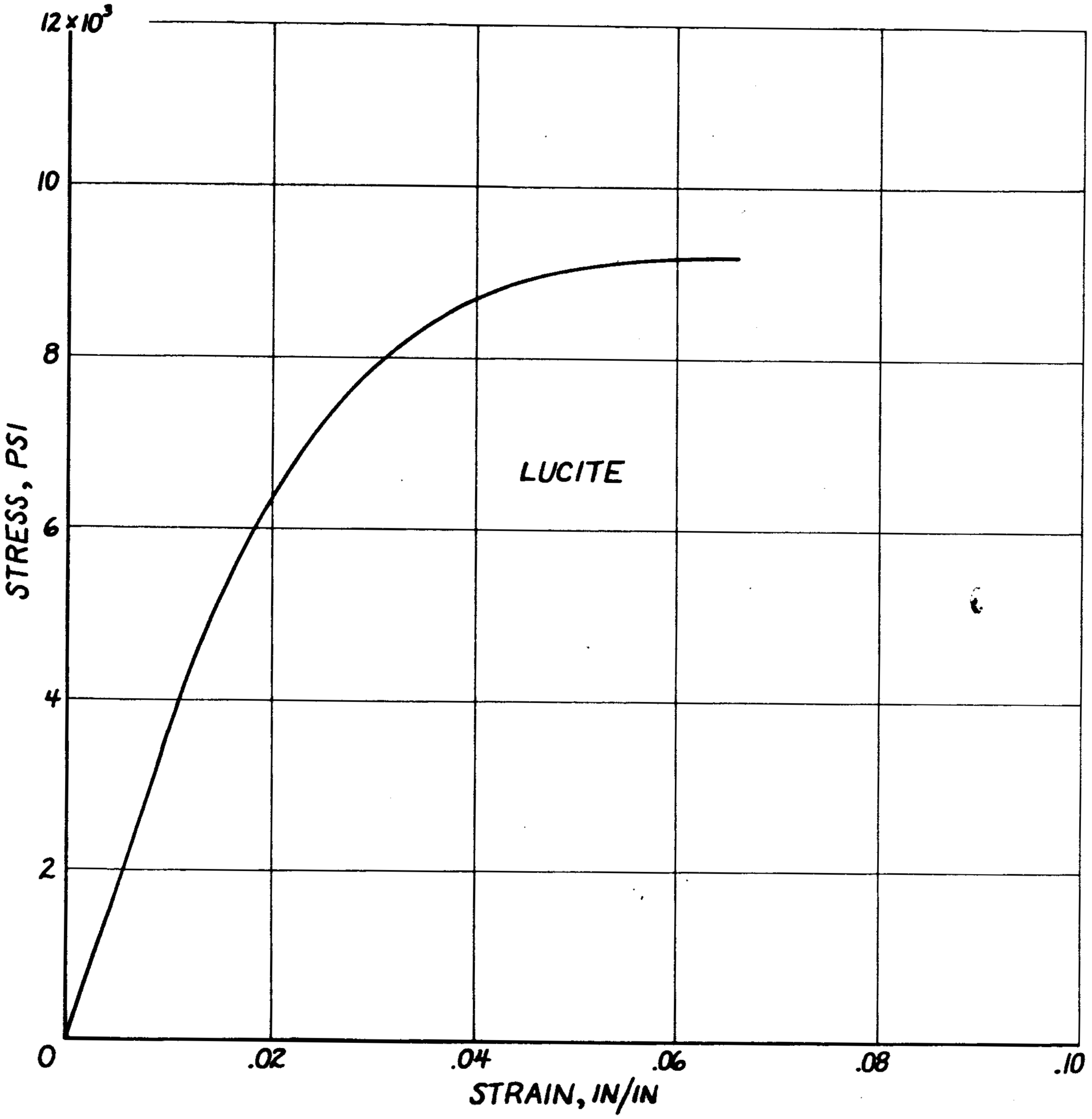


FIGURE 7

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

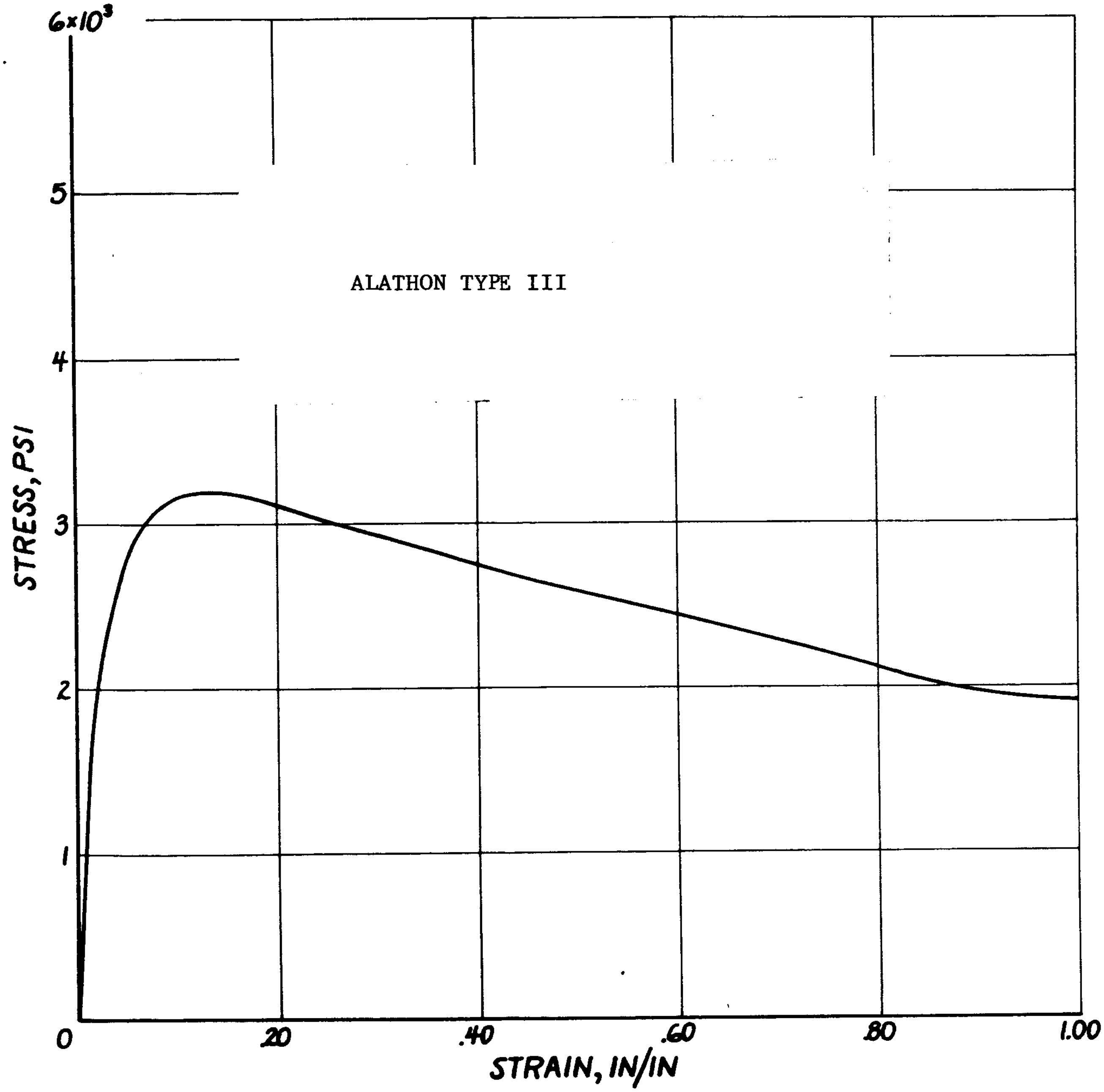


FIGURE 8

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

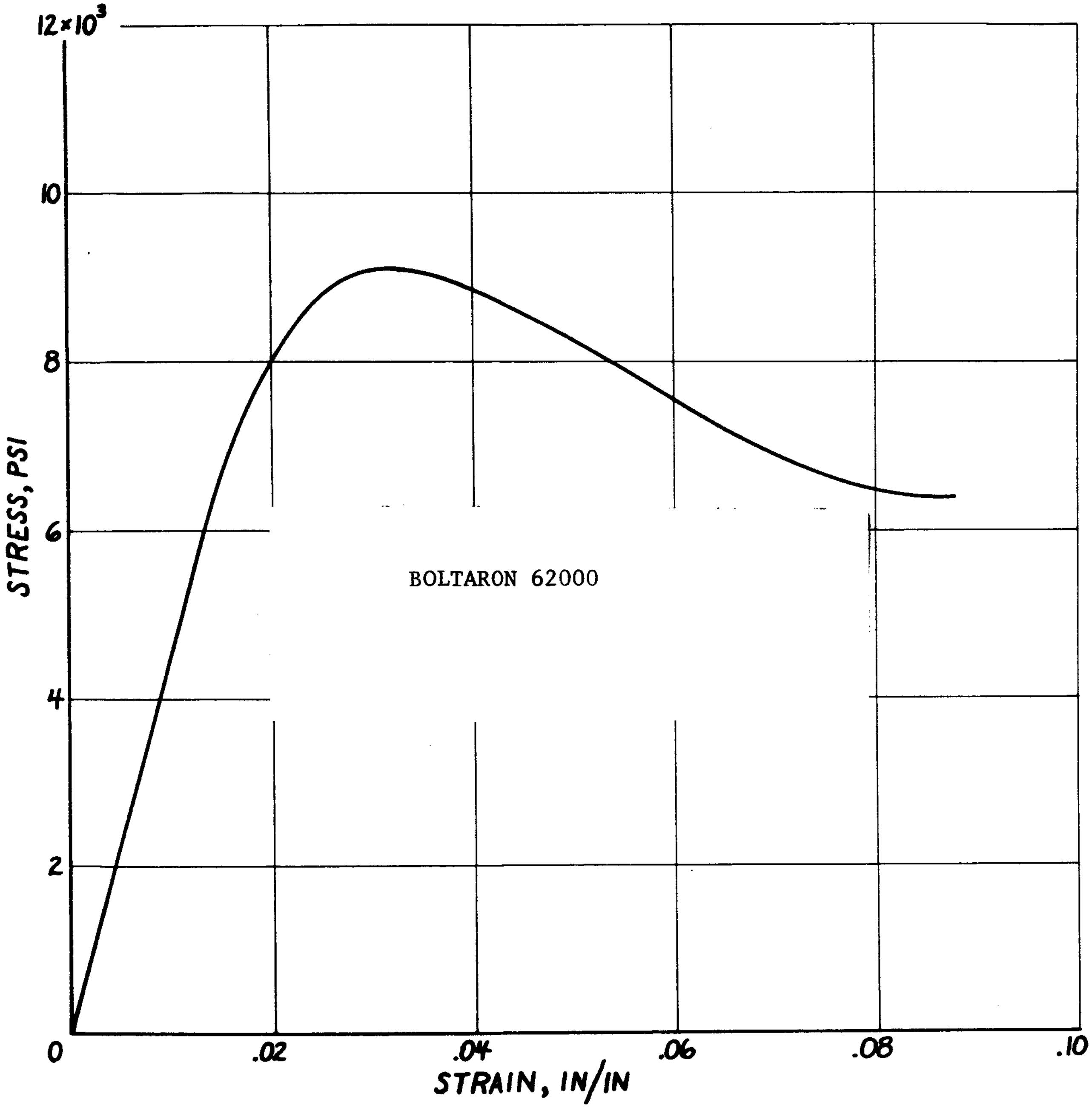


FIGURE 9

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

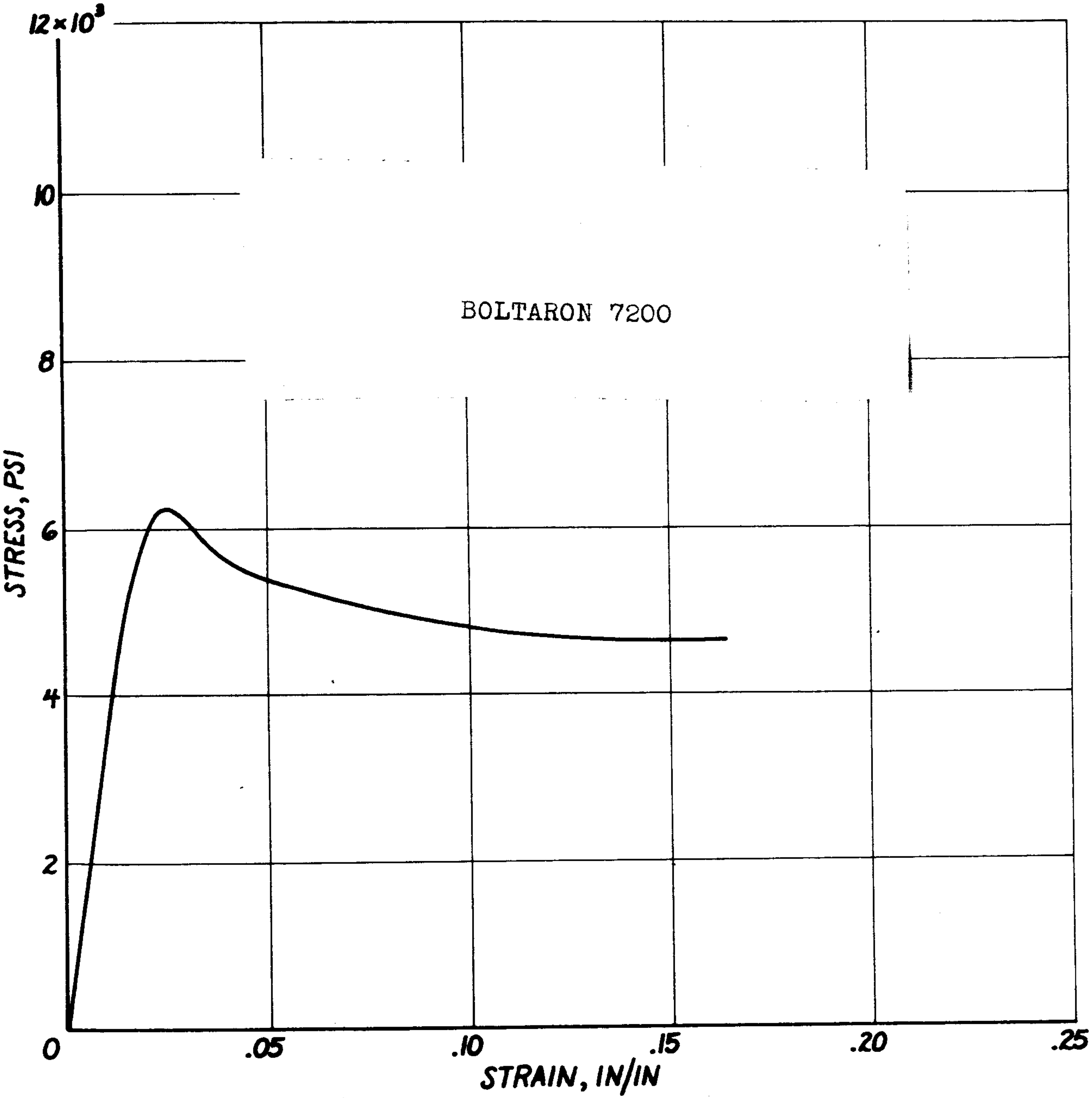


FIGURE 10

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

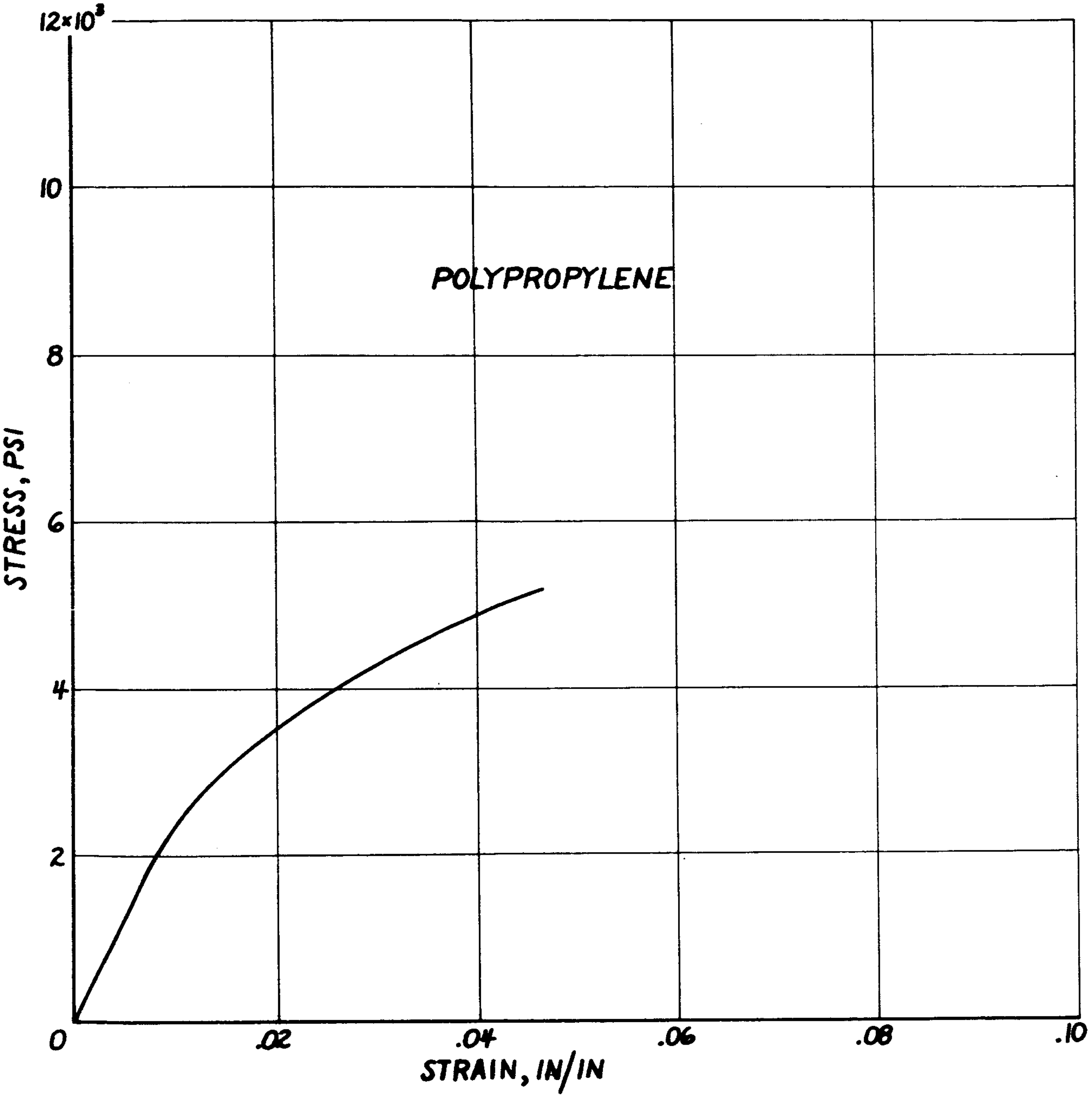


FIGURE 11

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

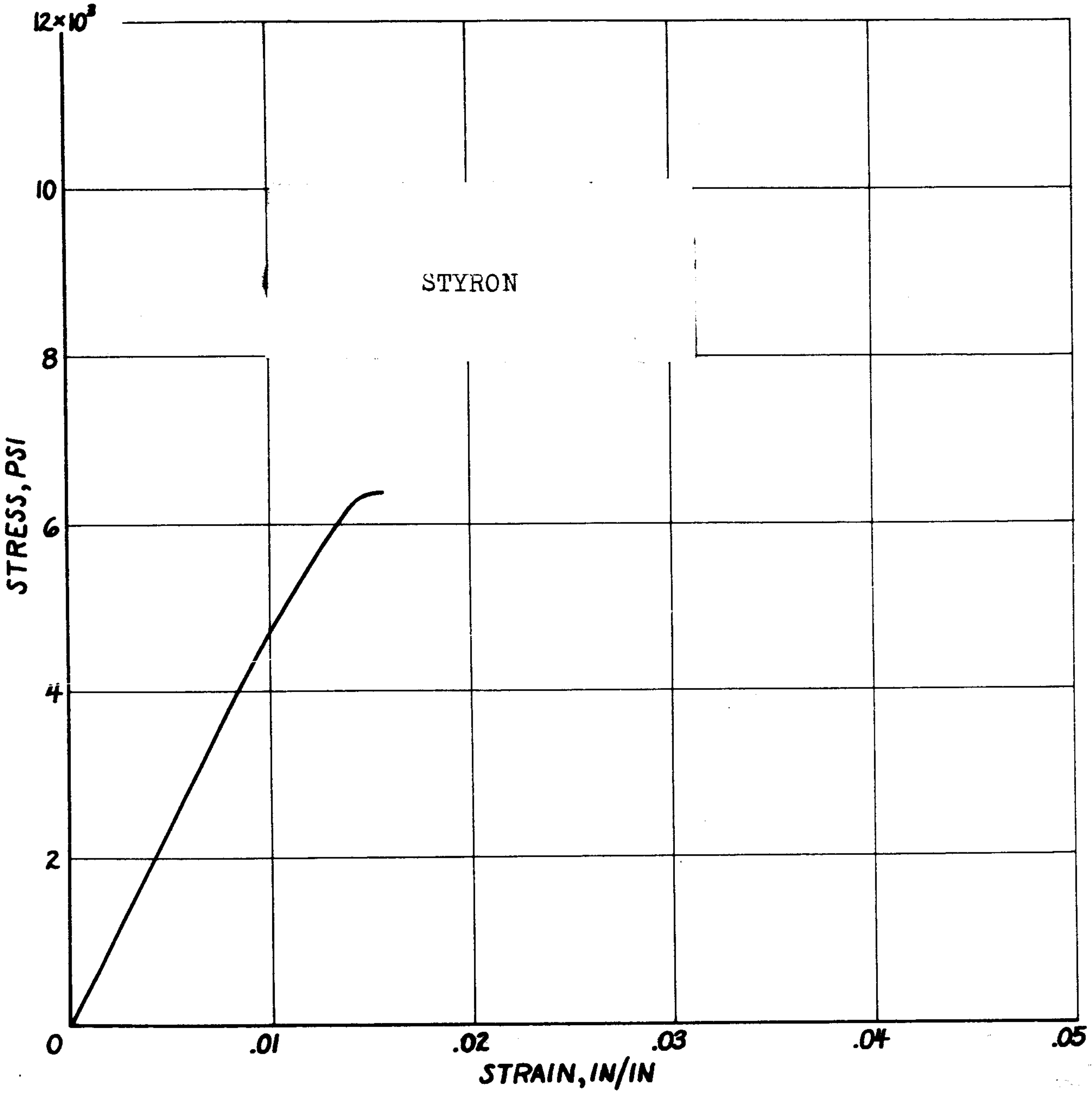


FIGURE 12

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

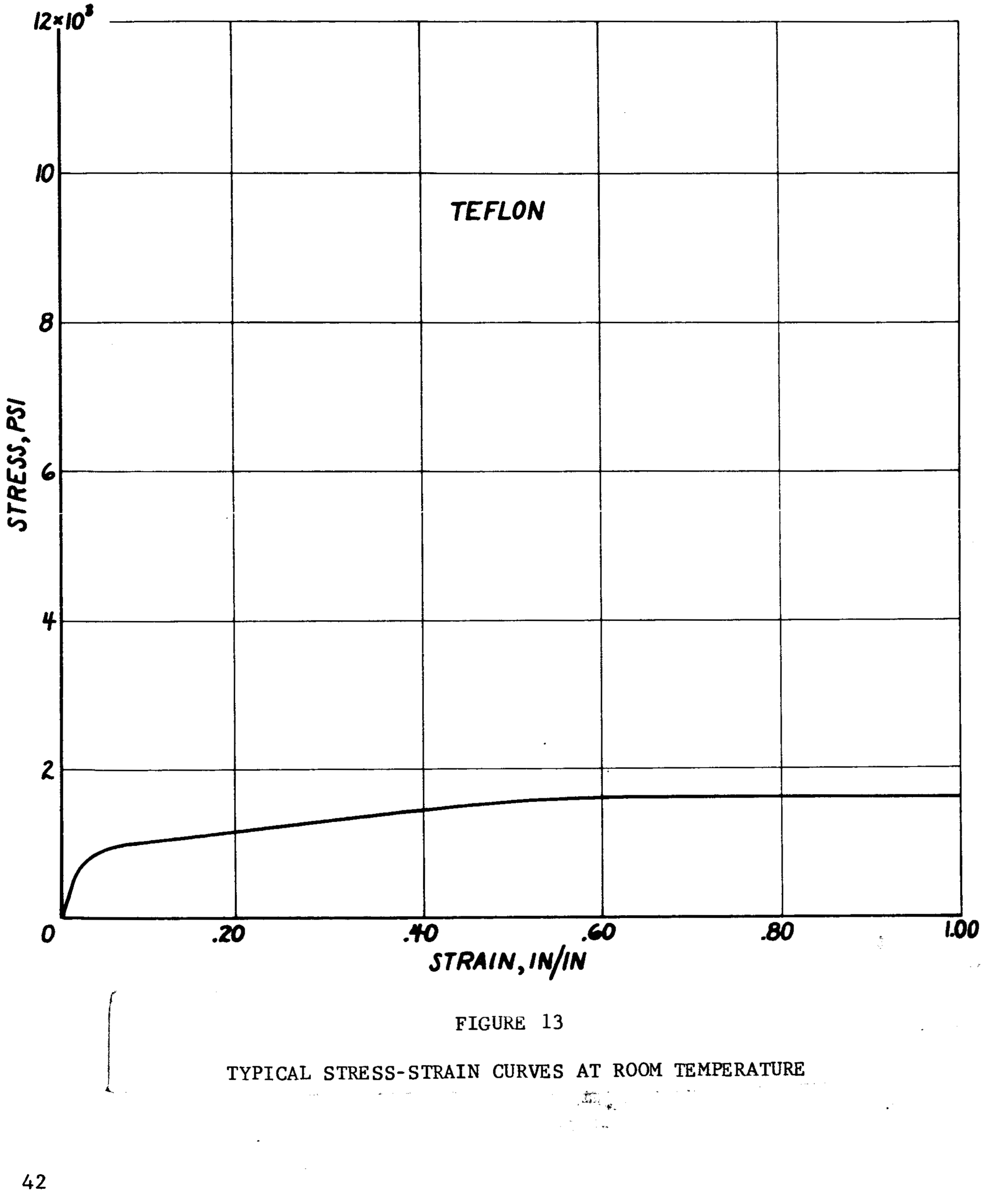


FIGURE 13

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

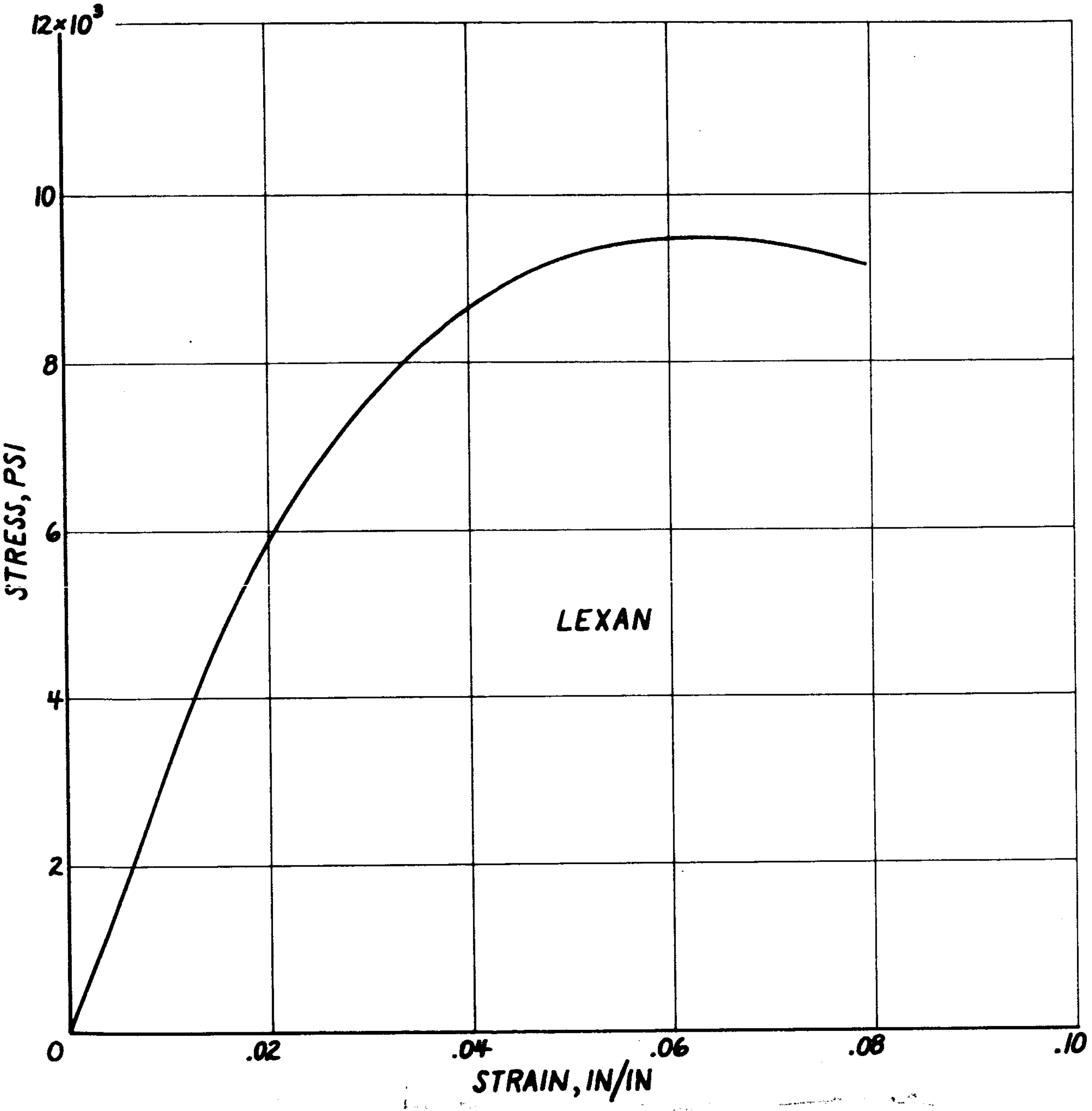


FIGURE 14

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

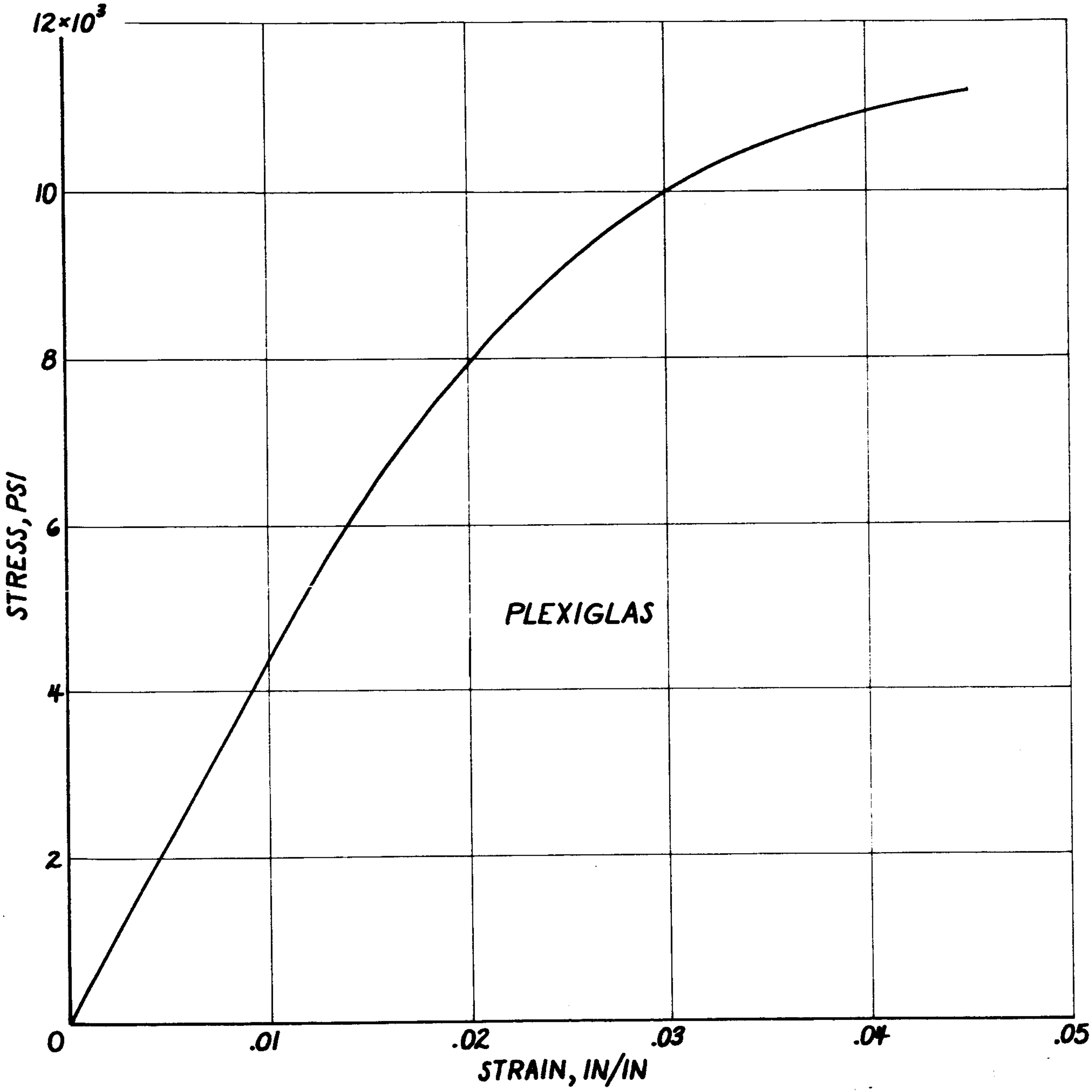


FIGURE 15

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

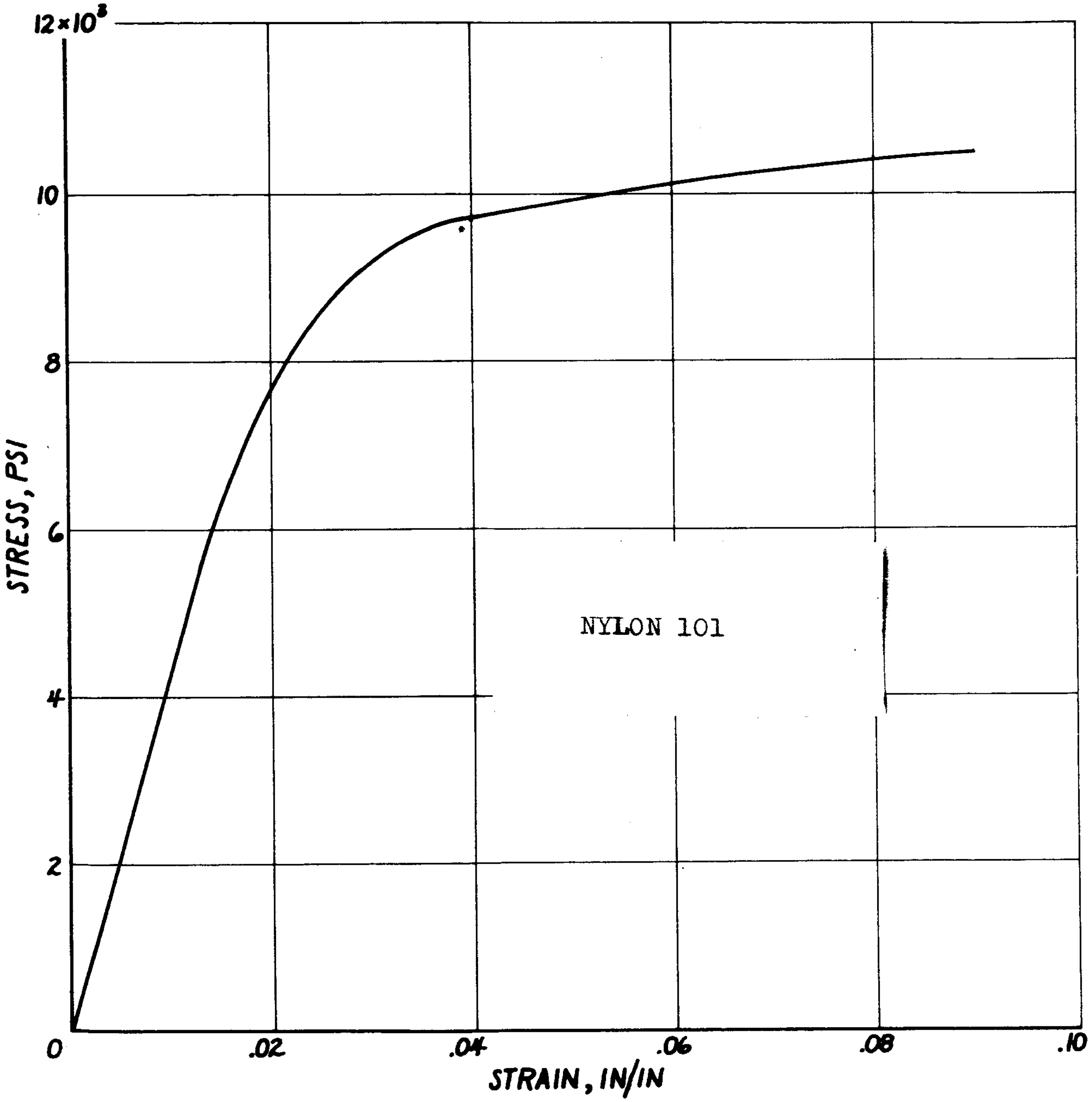


FIGURE 16

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

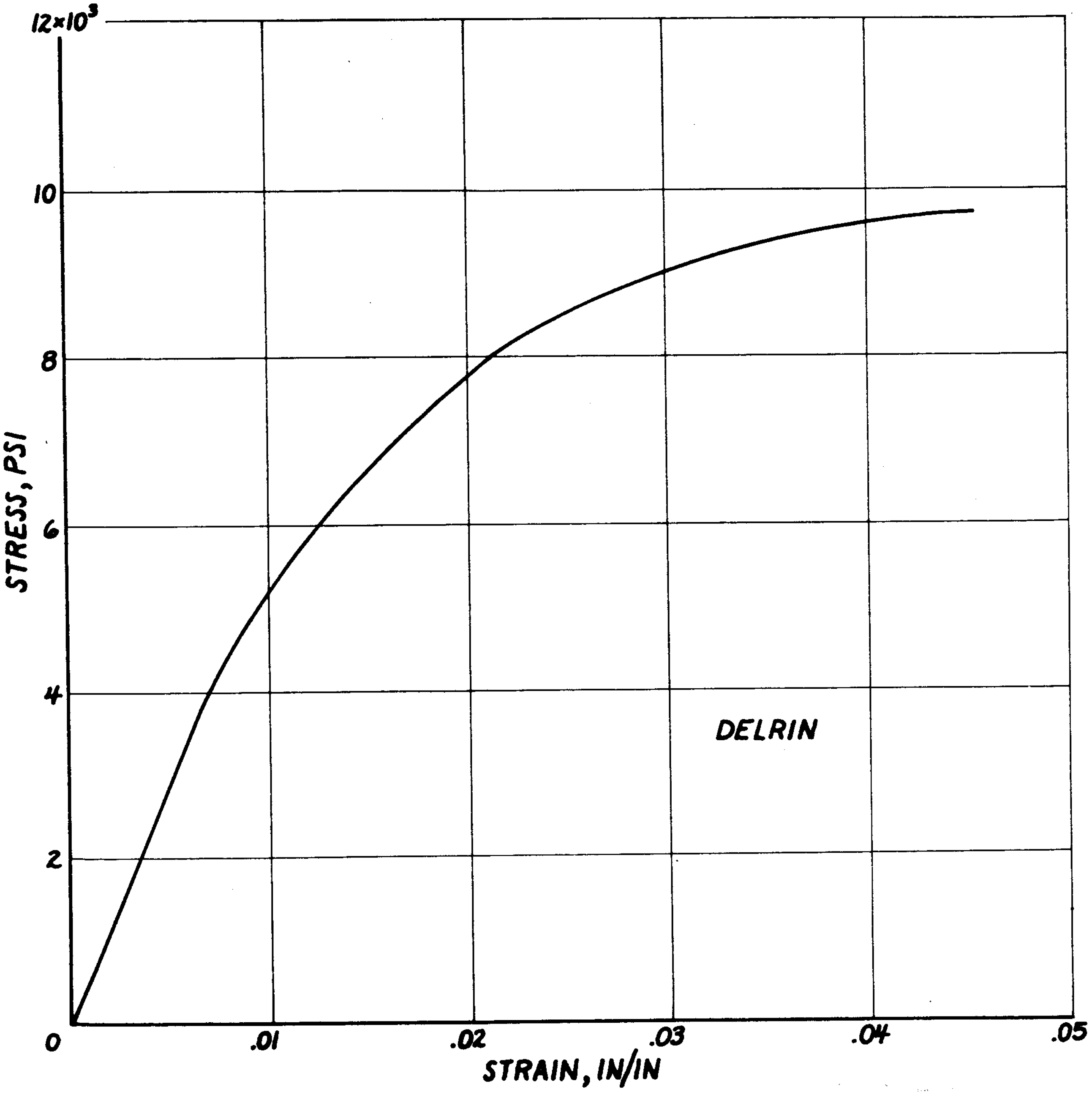


FIGURE 17

TYPICAL STRESS-STRAIN CURVES AT ROOM TEMPERATURE

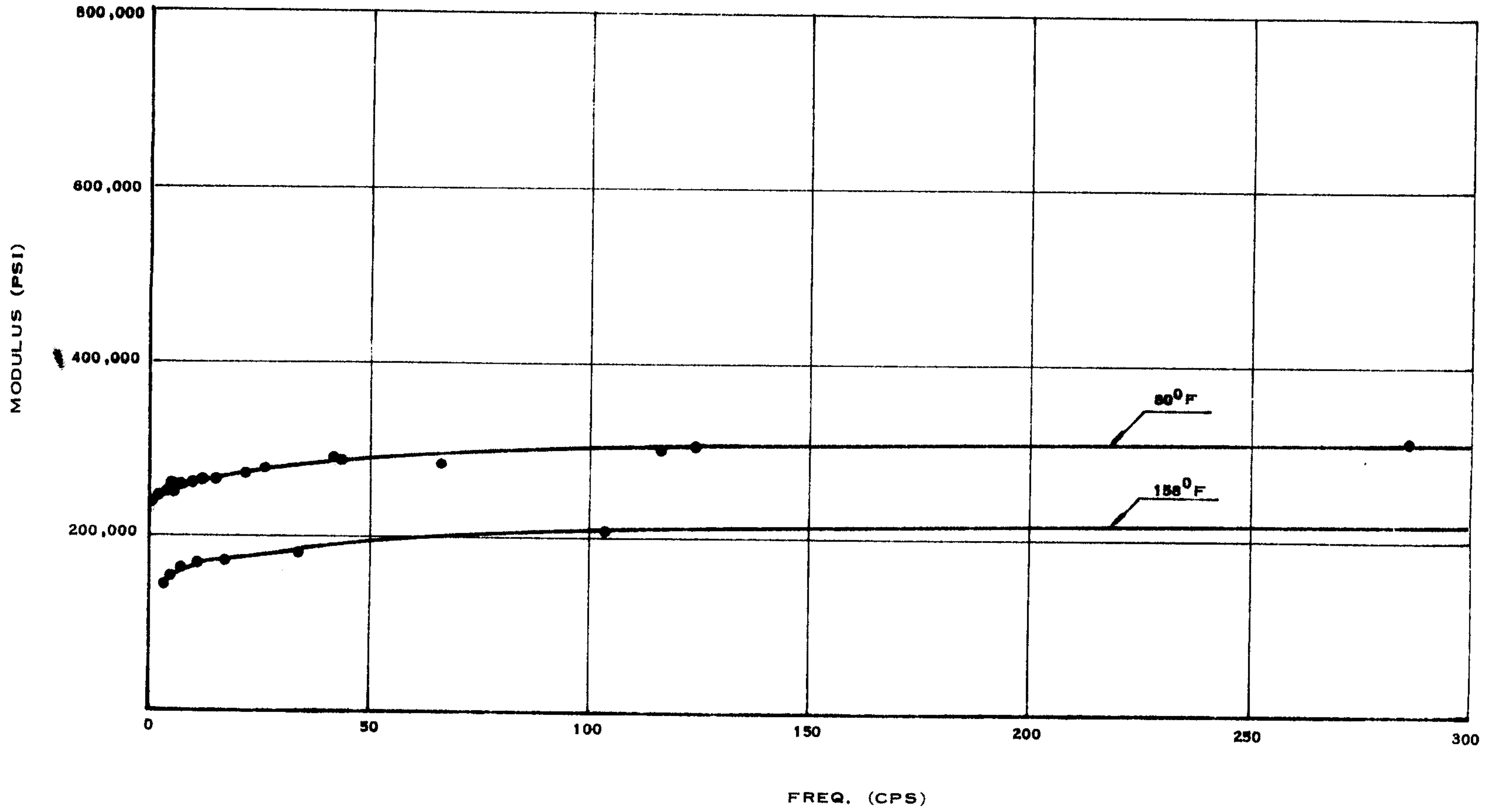


FIG. 18
DYNAMIC MODULUS VS FREQUENCY
TENITE II

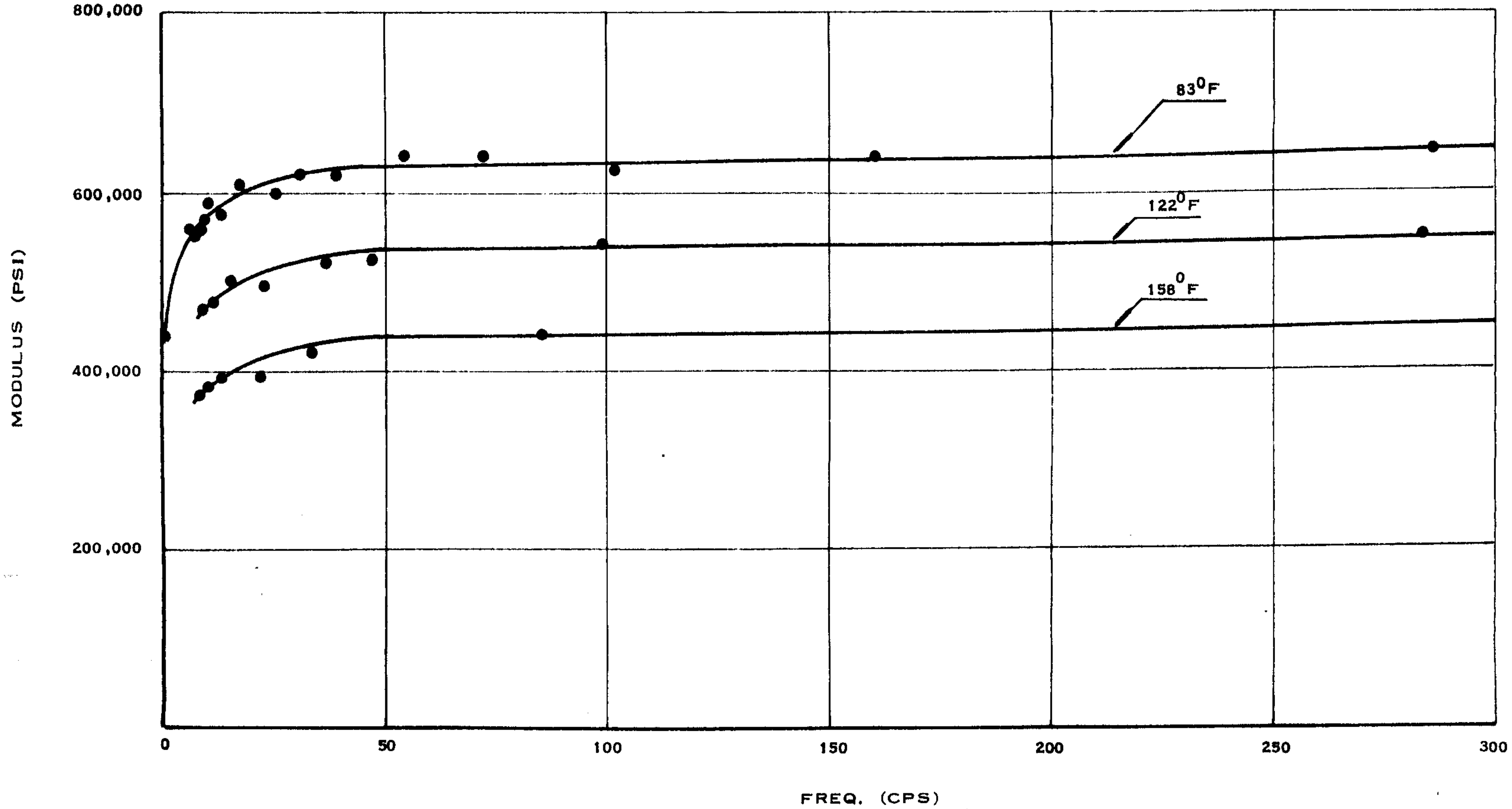


FIG. 19
DYNAMIC MODULUS VS FREQUENCY
LUCITE

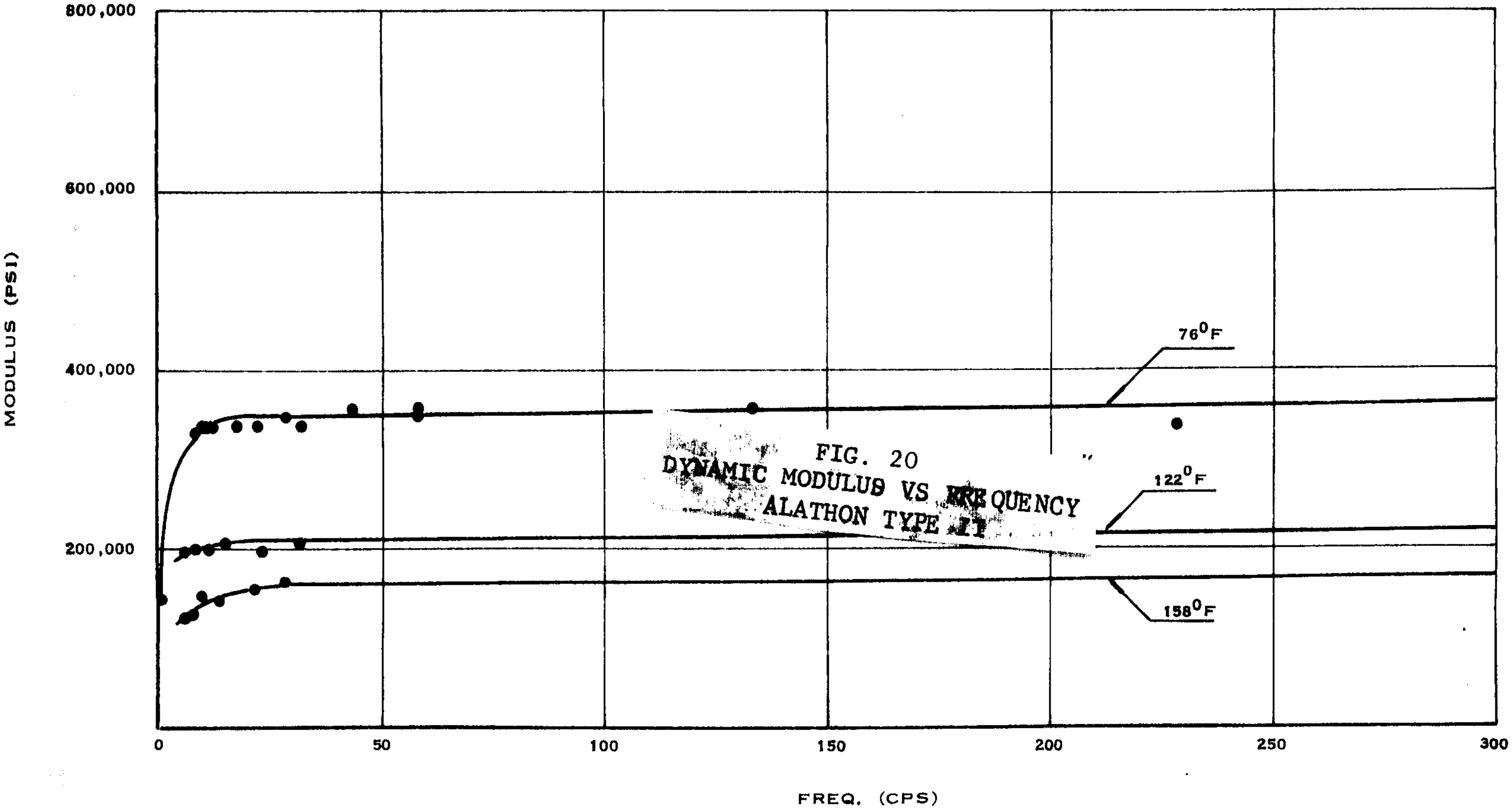
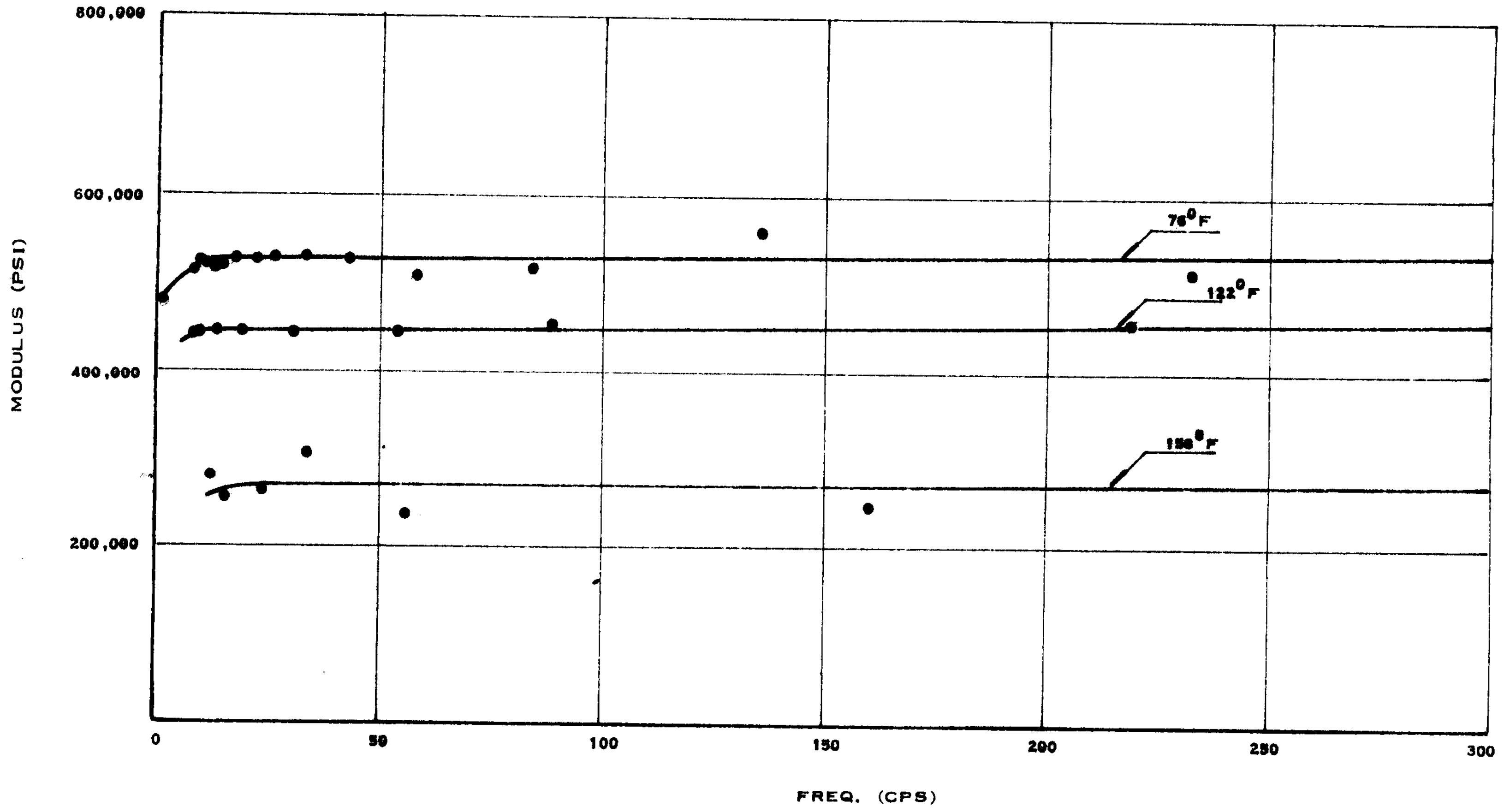


FIG. 20
DYNAMIC MODULUS VS FREQUENCY
ALATHON TYPE II


800,000
600,000
400,000
200,000
MODULUS (PSI)
76°F
122°F
158°F
0
50
100
150
200
250
300
FREQ. (CPS)

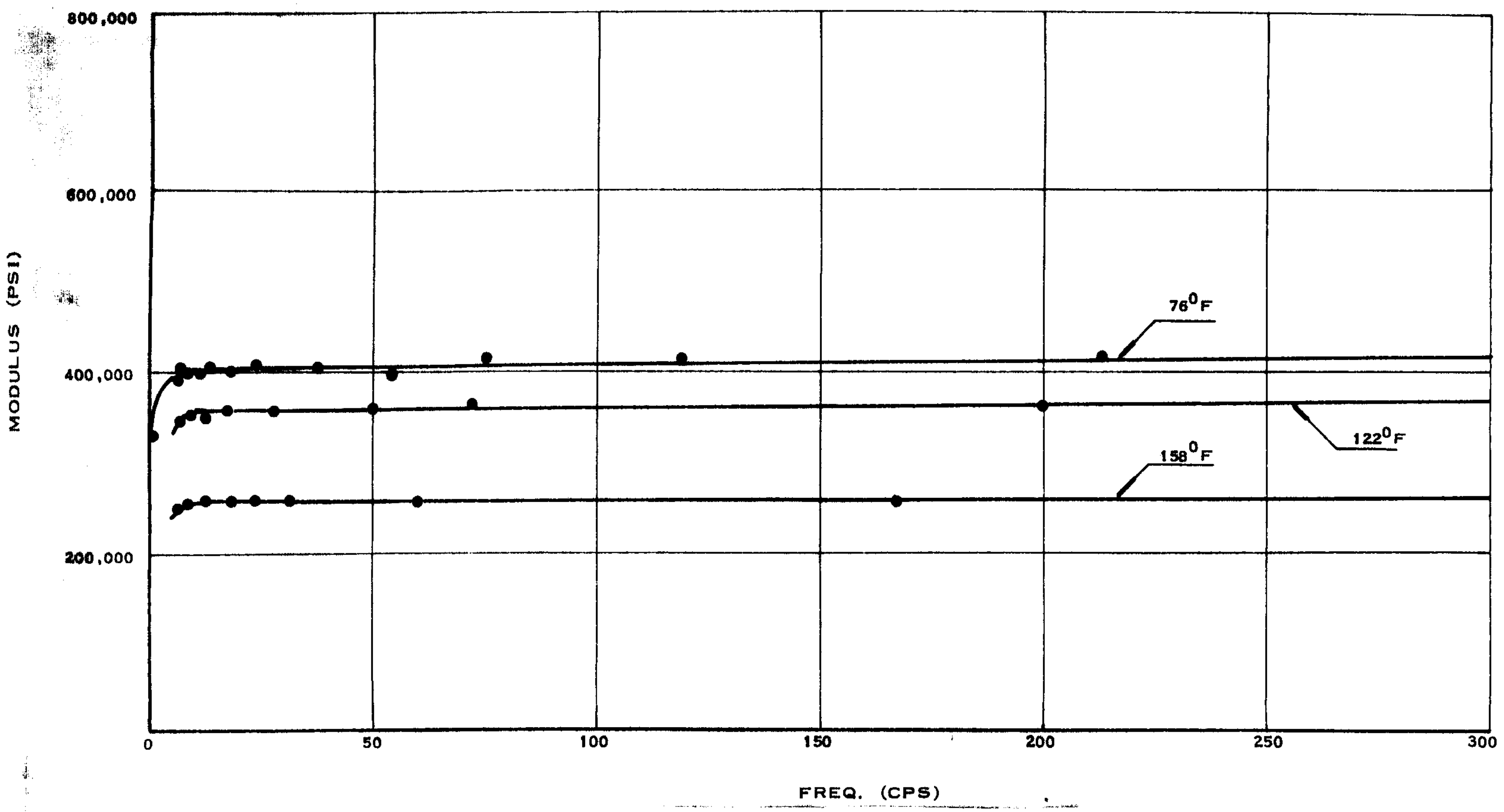


FIG. 22
DYNAMIC MODULUS VS FREQUENCY
BOLTARON 7200

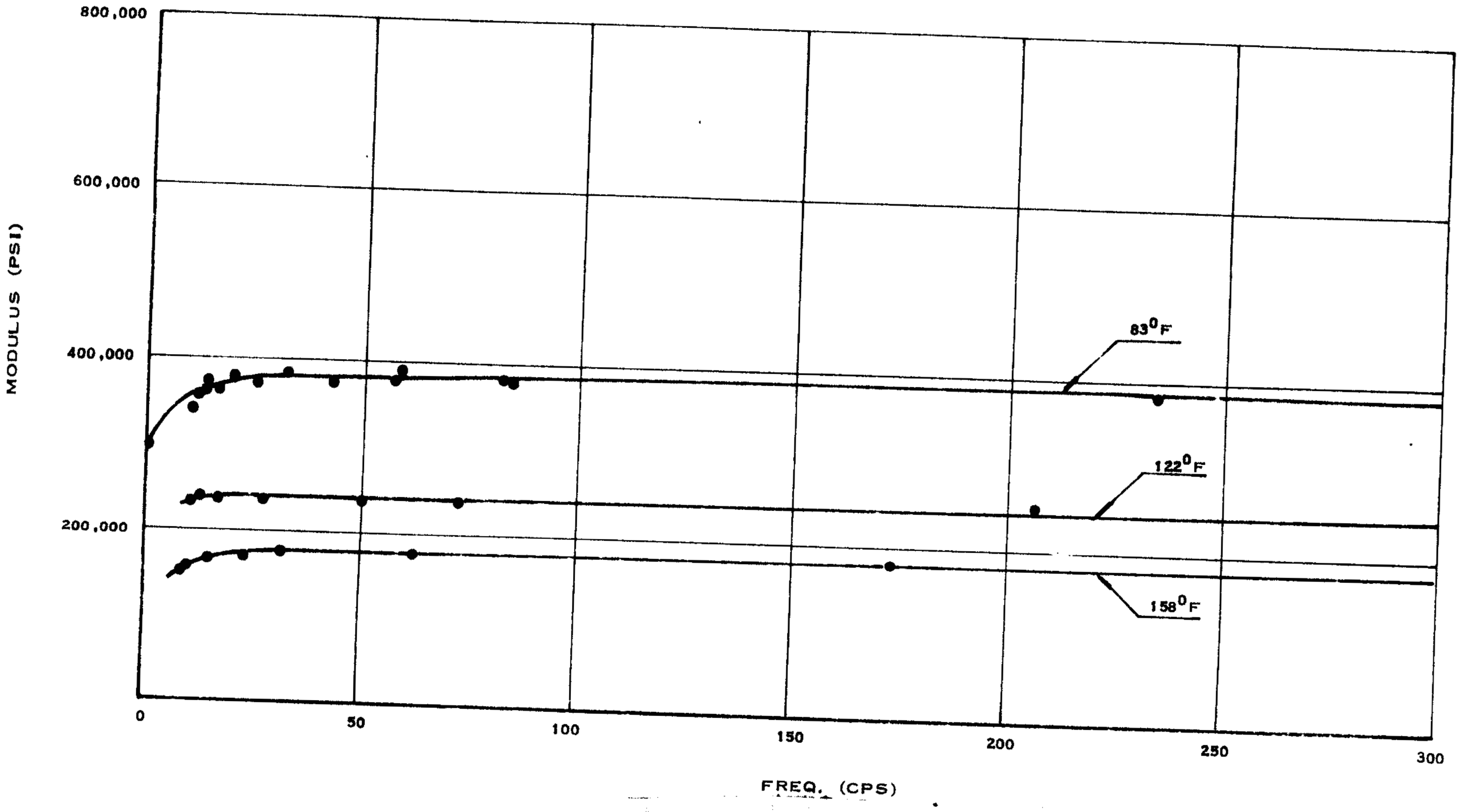


FIG. 23
DYNAMIC MODULUS VS FREQUENCY
POLYPROPYLENE

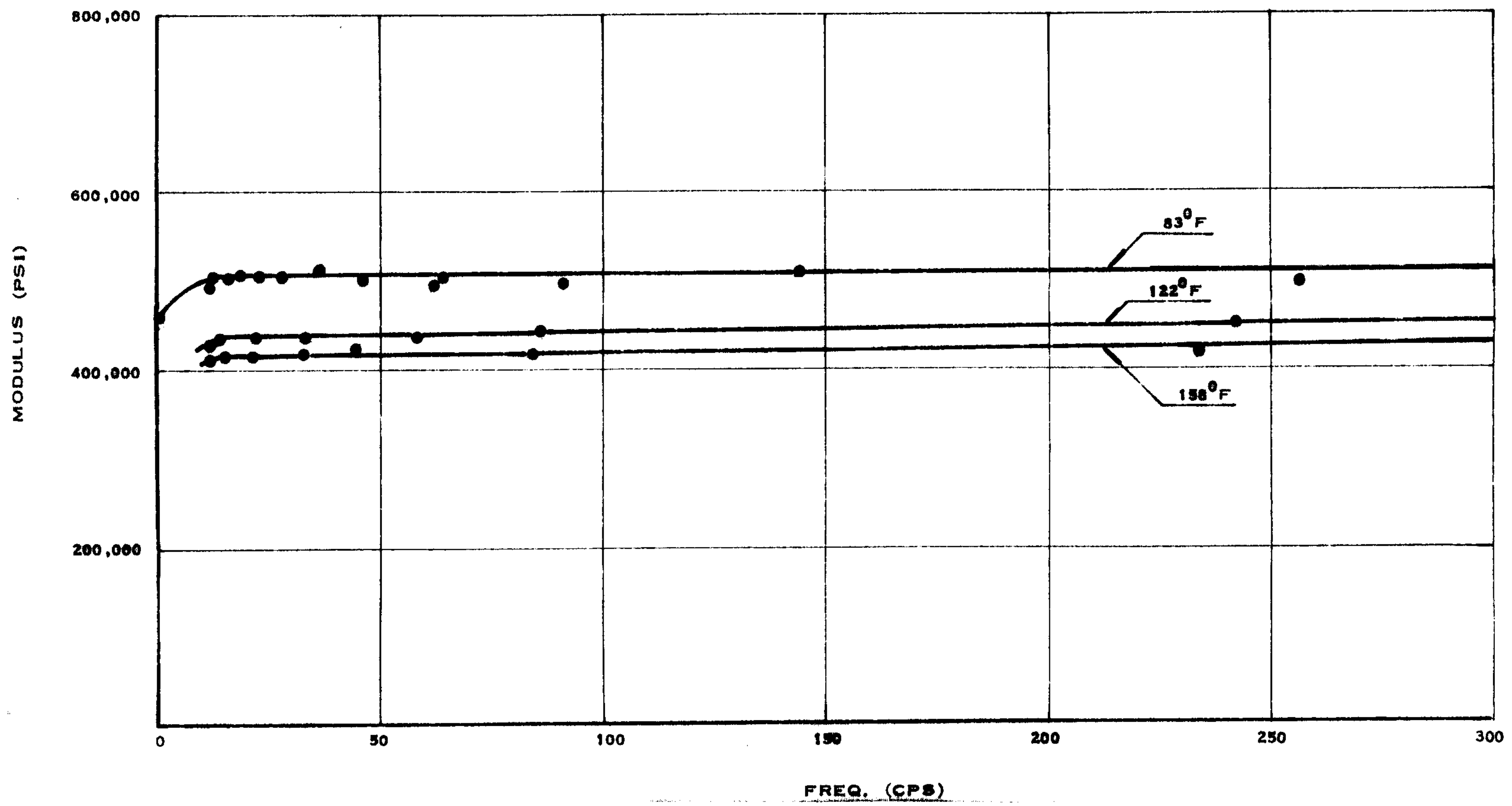


FIG. 24
DYNAMIC MODULUS VS FREQUENCY
STYRON

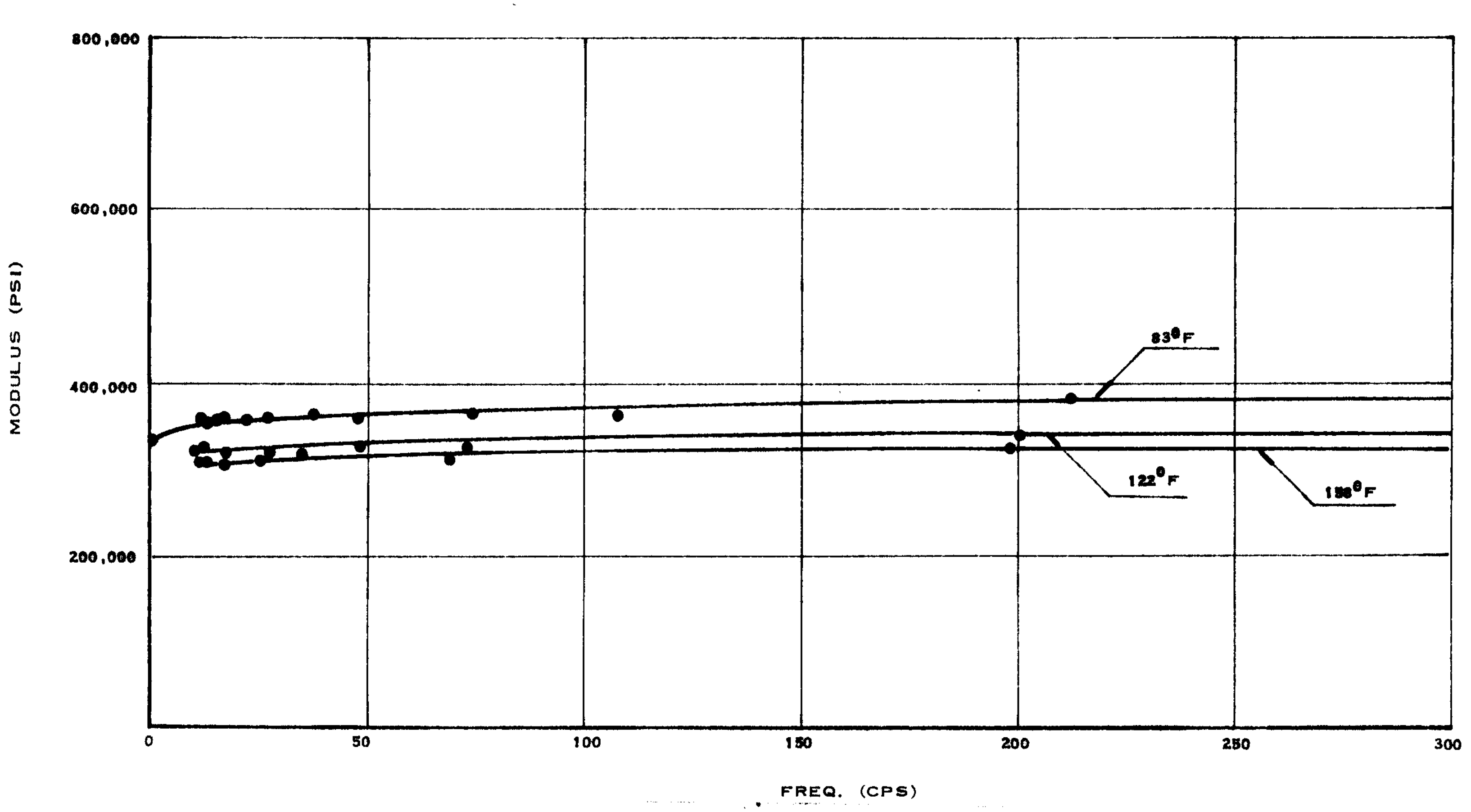


FIG. 25
DYNAMIC MODULUS VS FREQUENCY
LEXAN

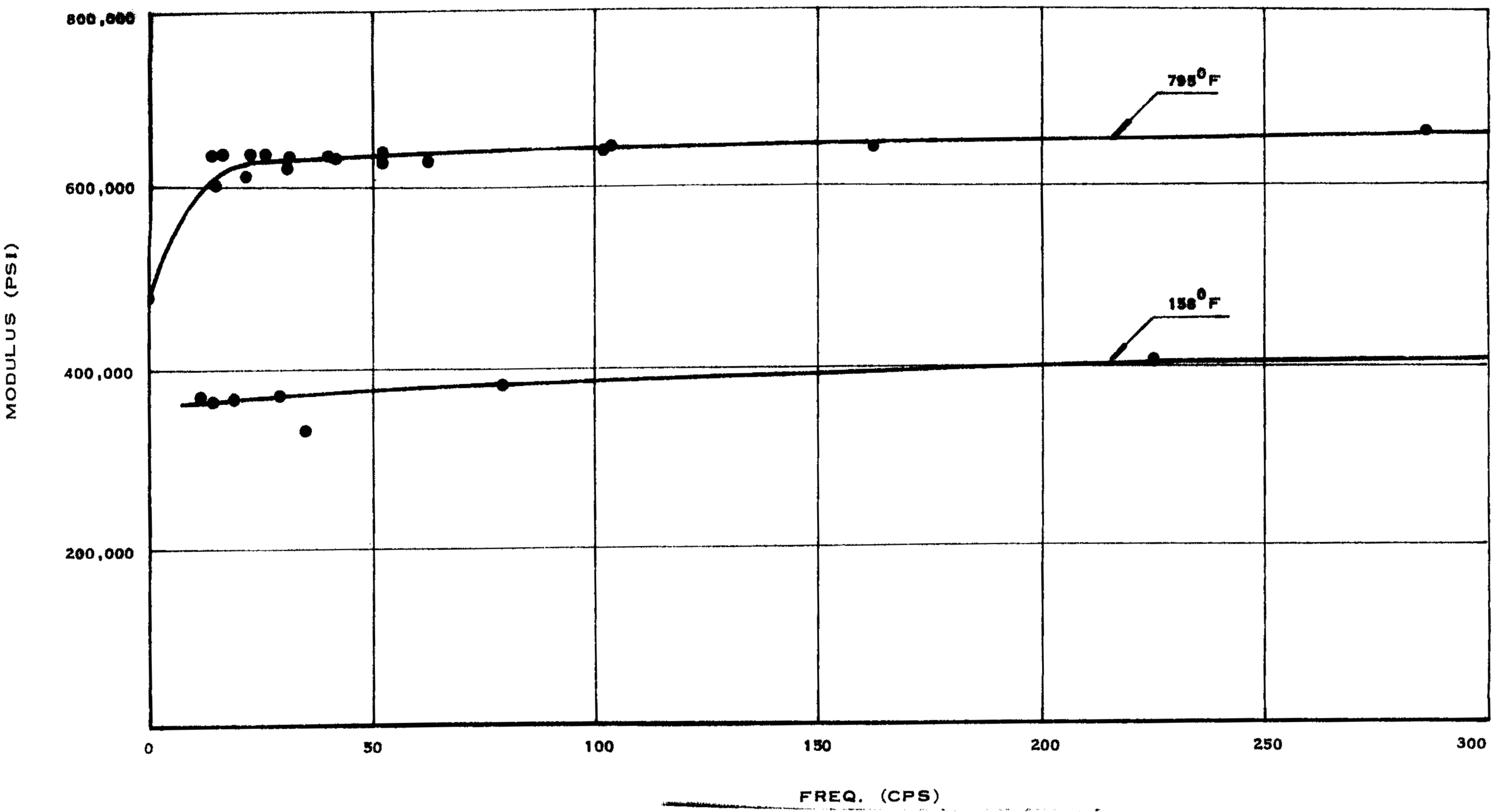


FIG. 26
DYNAMIC MODULUS VS FREQUENCY
PLEXIGLAS

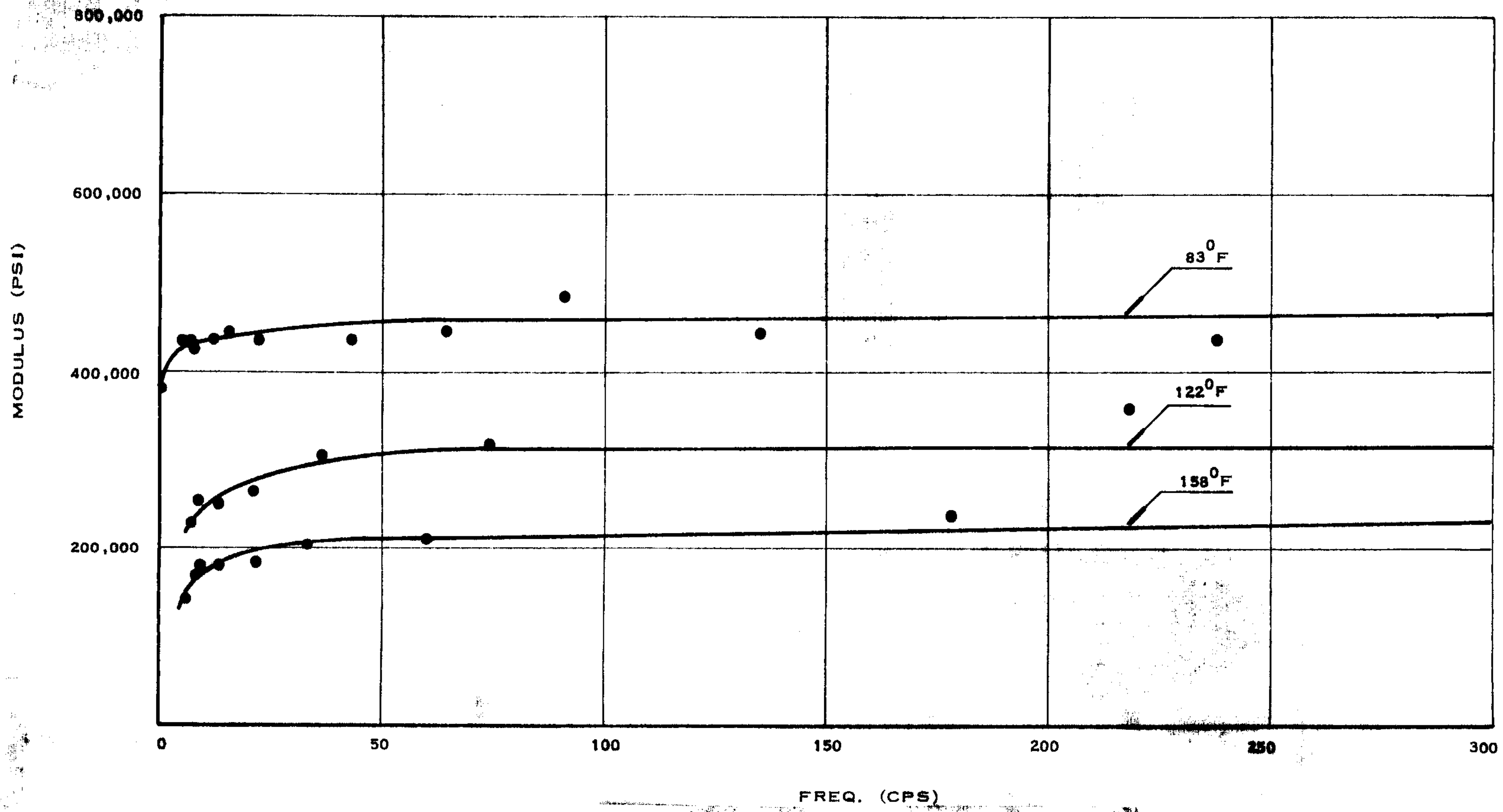


FIG. 27
DYNAMIC MODULUS VS FREQUENCY
NYLON -101

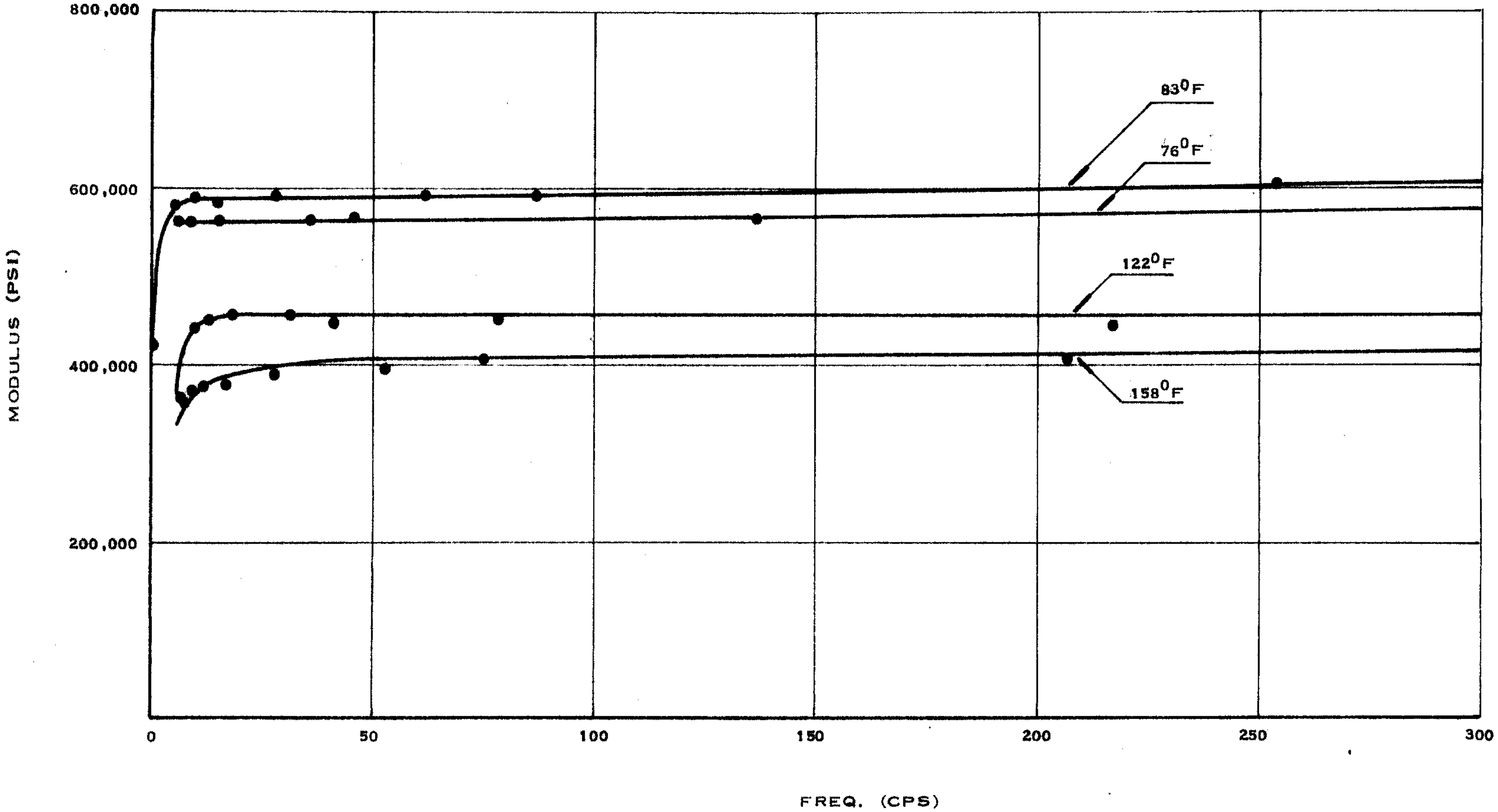


FIG. 28
DYNAMIC MODULUS VS FREQUENCY
DELRIN

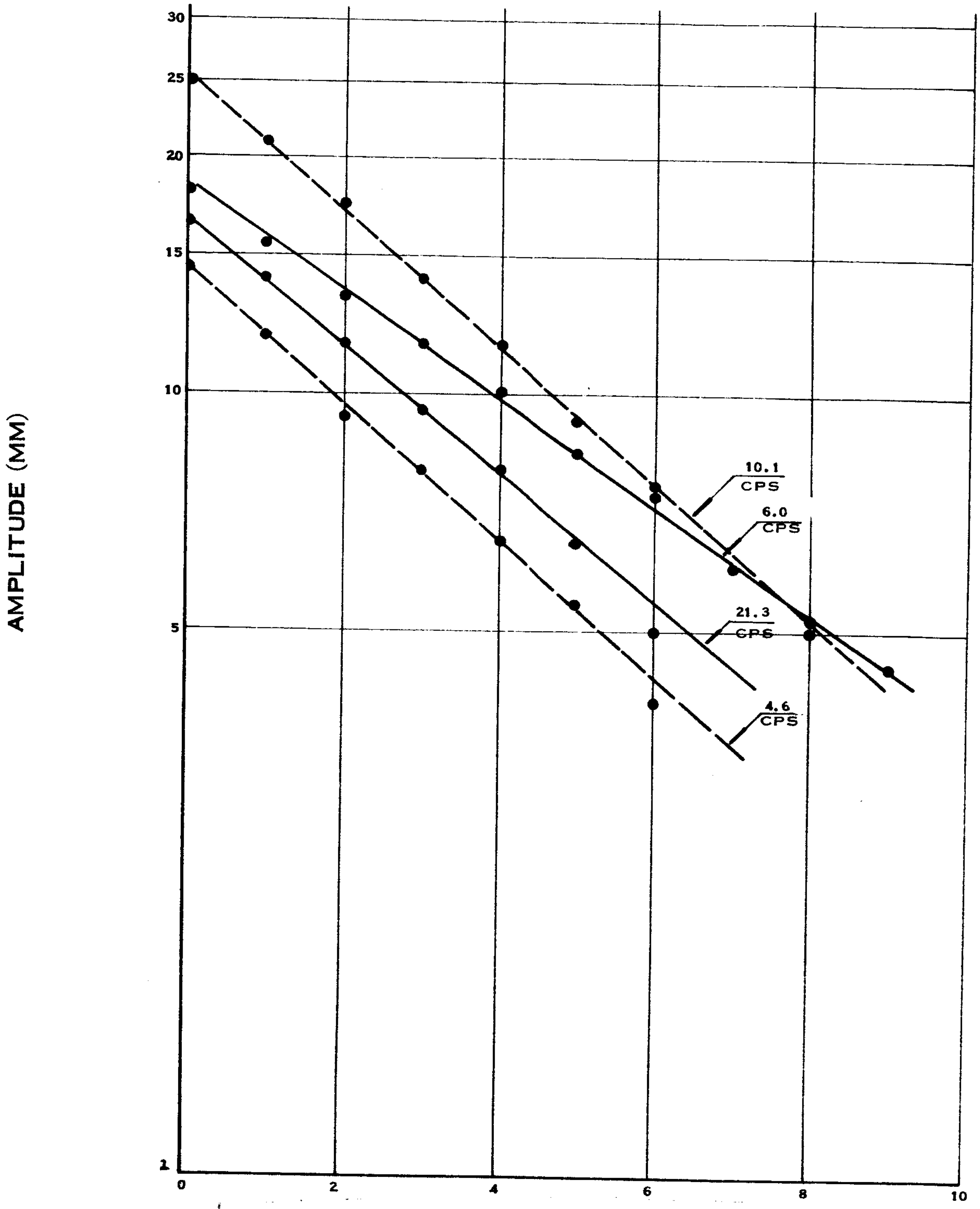


FIG. 29
LOG - DECREMENT DECAY
AMPLITUDE VS. NUMBER OF CYCLES

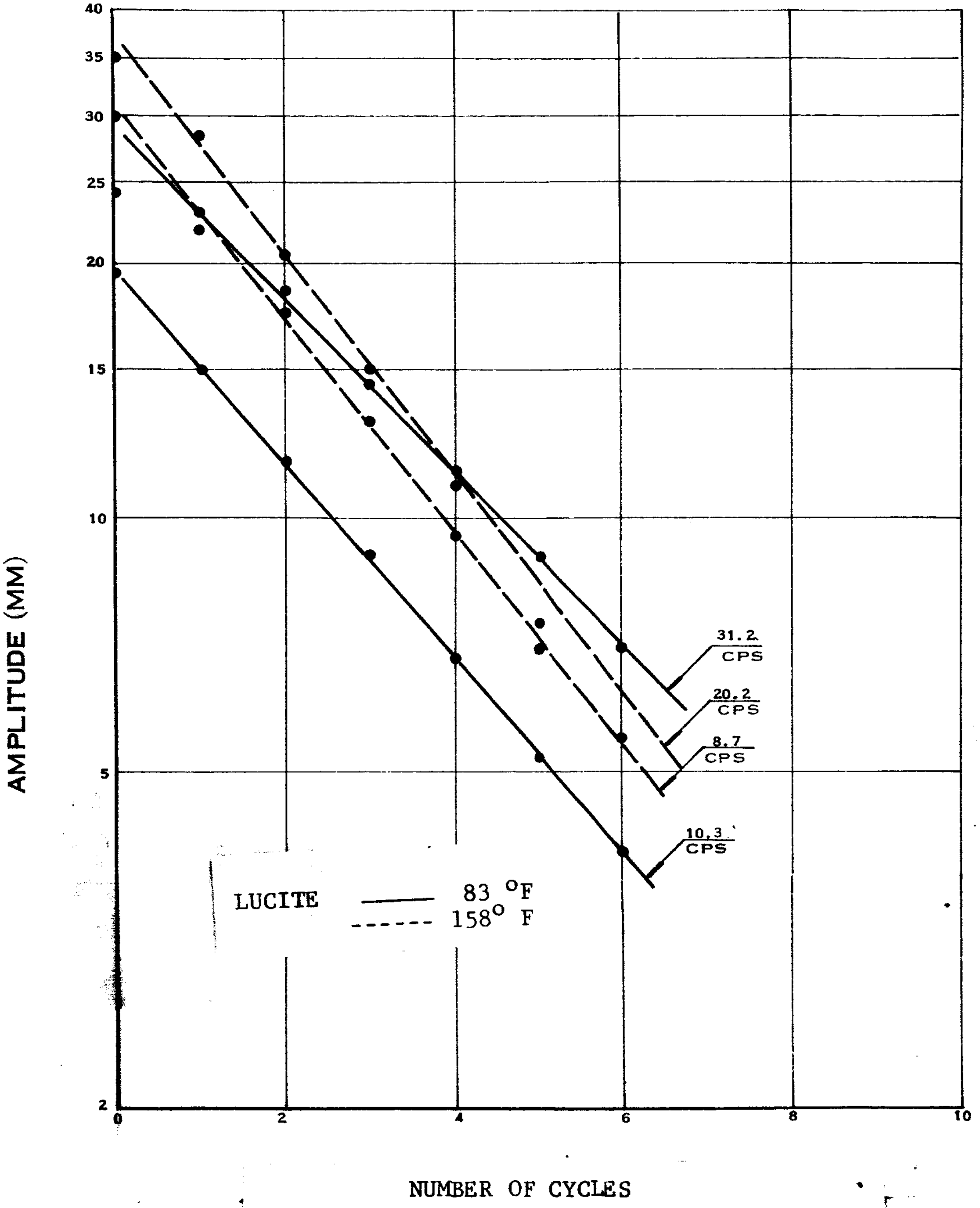


FIG. 30
LOG - DECREMENT DECAY
AMPLITUDE VS. NUMBER OF CYCLES

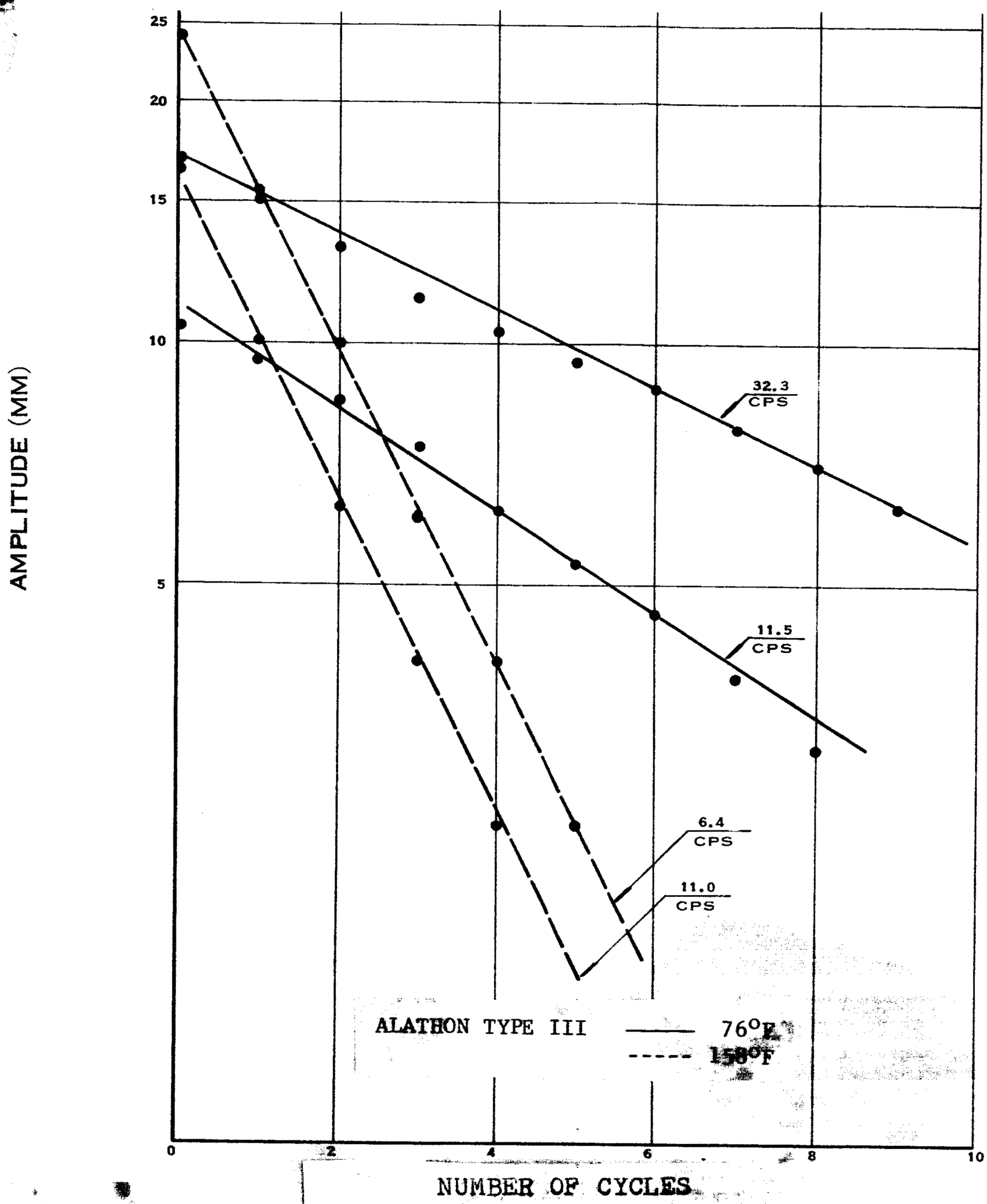


FIG. 31
LOG- DECREMENT DECAY
AMPLITUDE VS NUMBER OF CYCLES

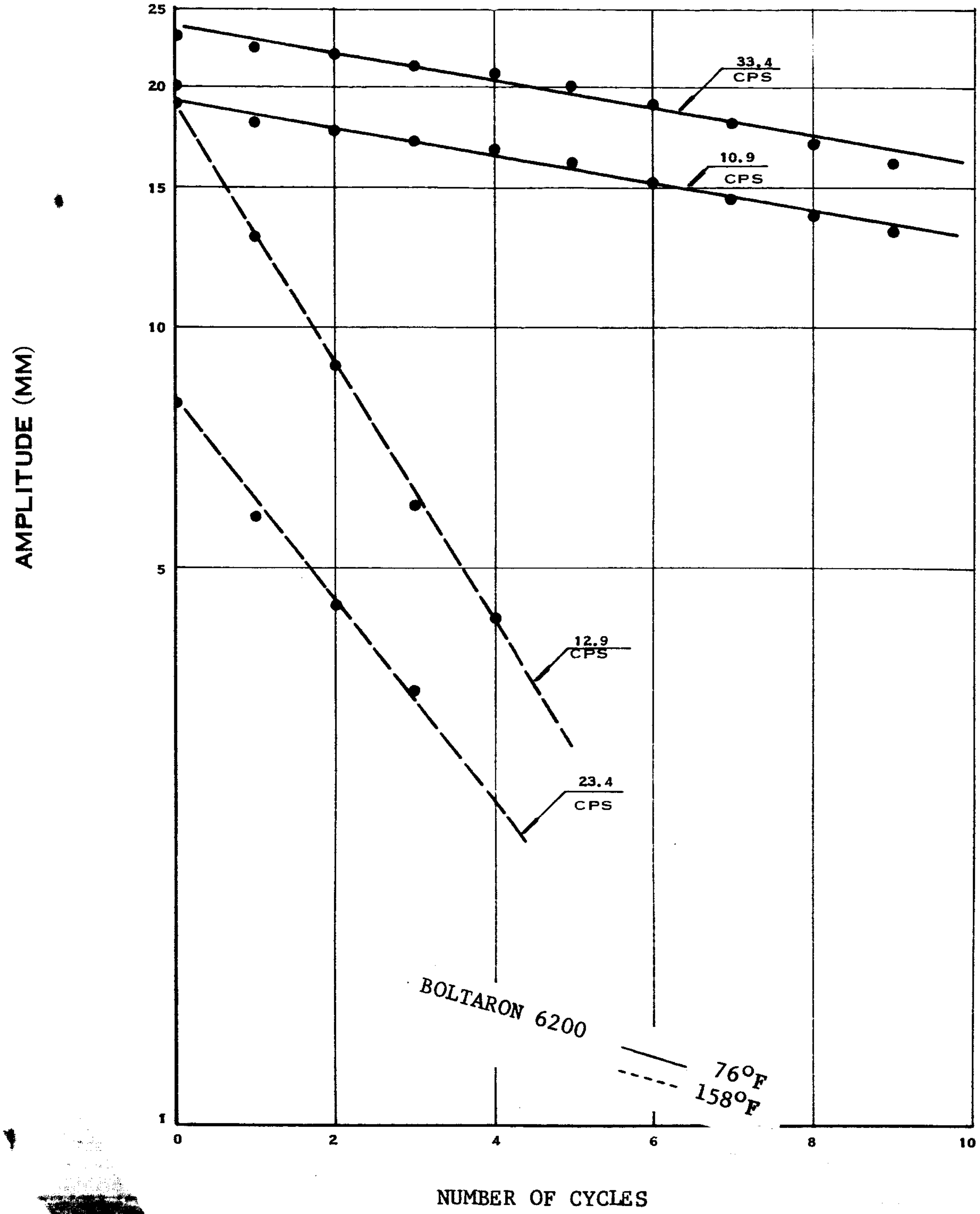


FIG. 32
LOG - DECREMENT DECAY
AMPLITUDE VS. NUMBER OF CYCLES

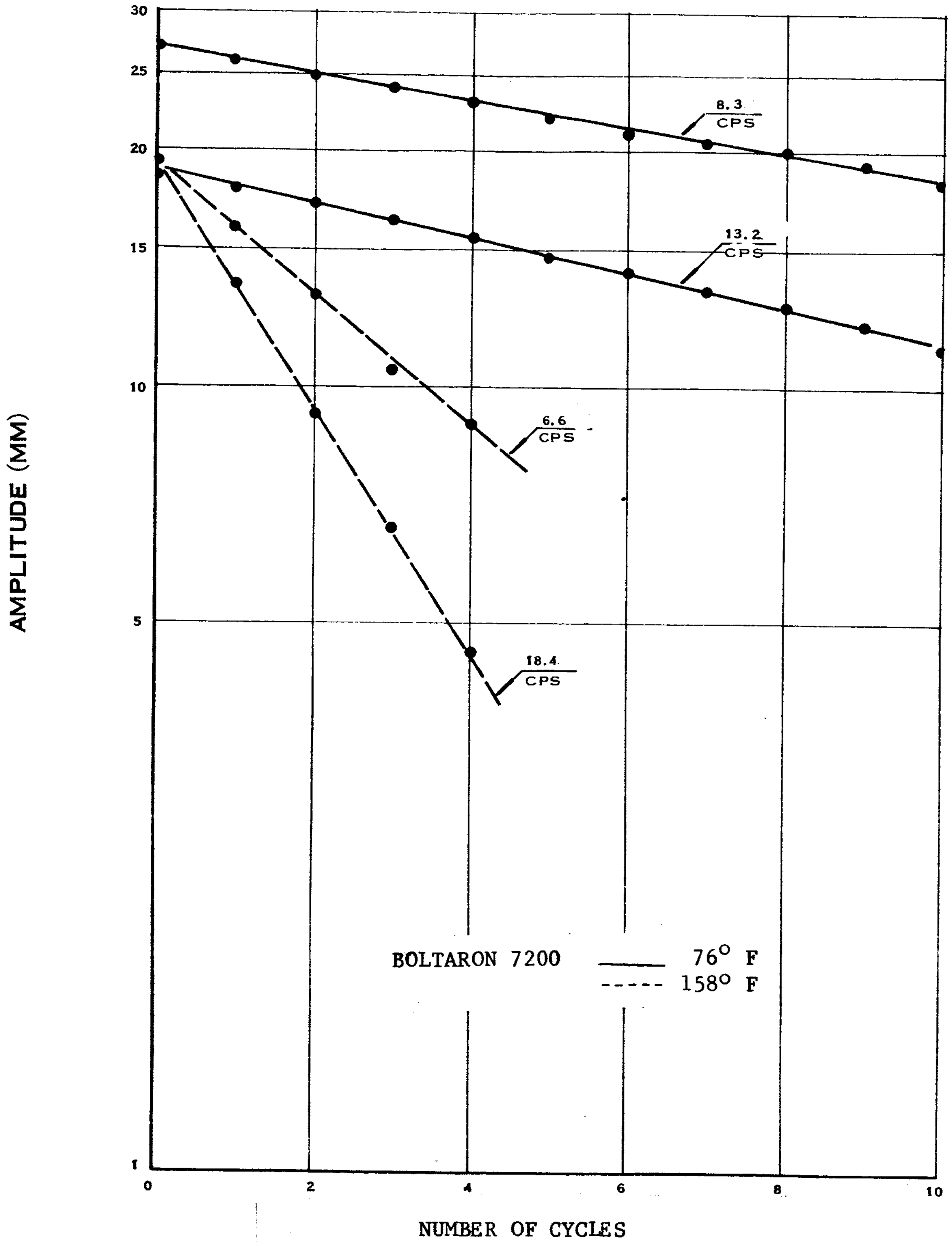


FIG. 33
LOG - DECREMENT DECAY
AMPLITUDE VS. NUMBER OF CYCLES

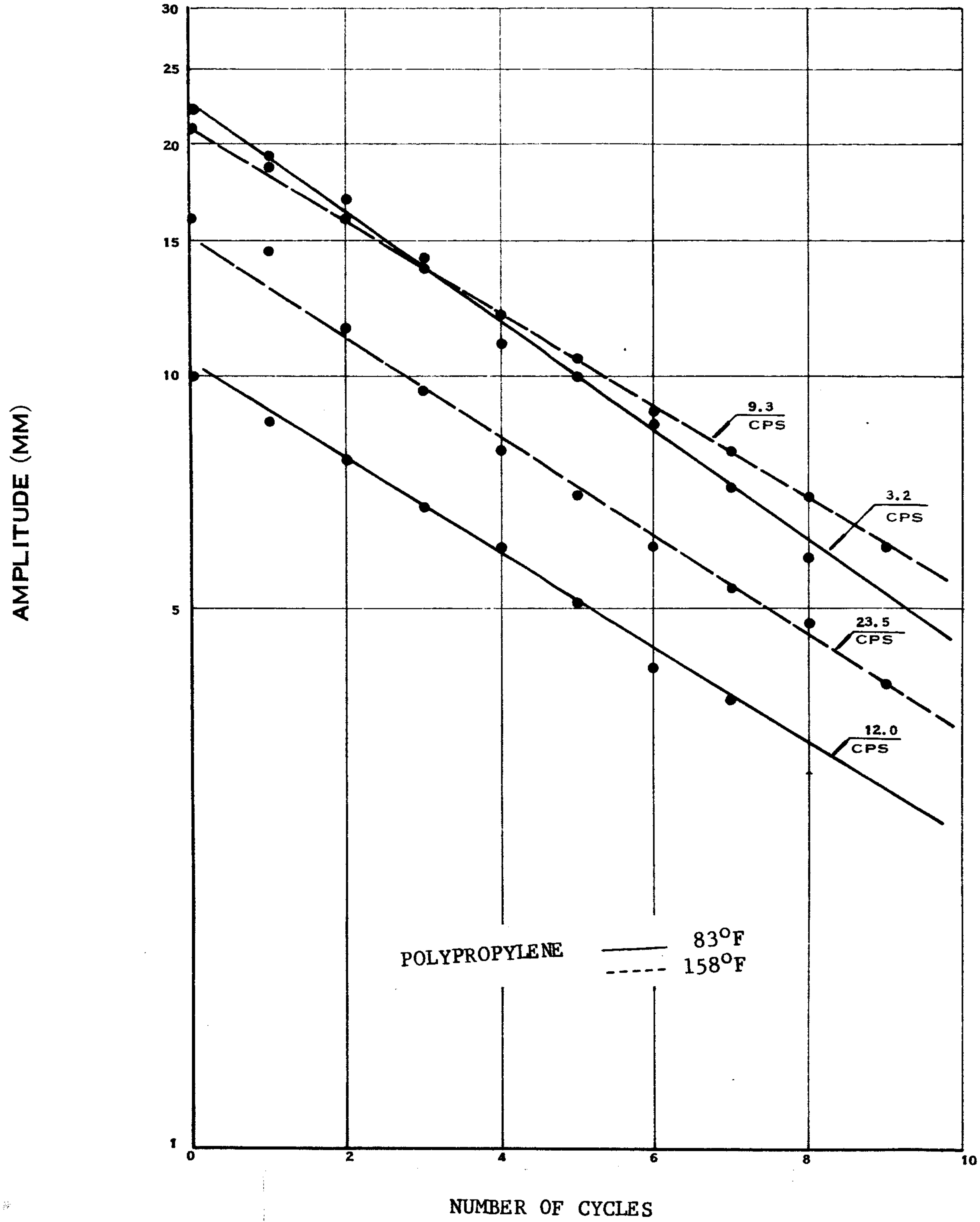


FIG. 34
LOG - DECREMENT DECAY
AMPLITUDE VS. NUMBER OF CYCLES

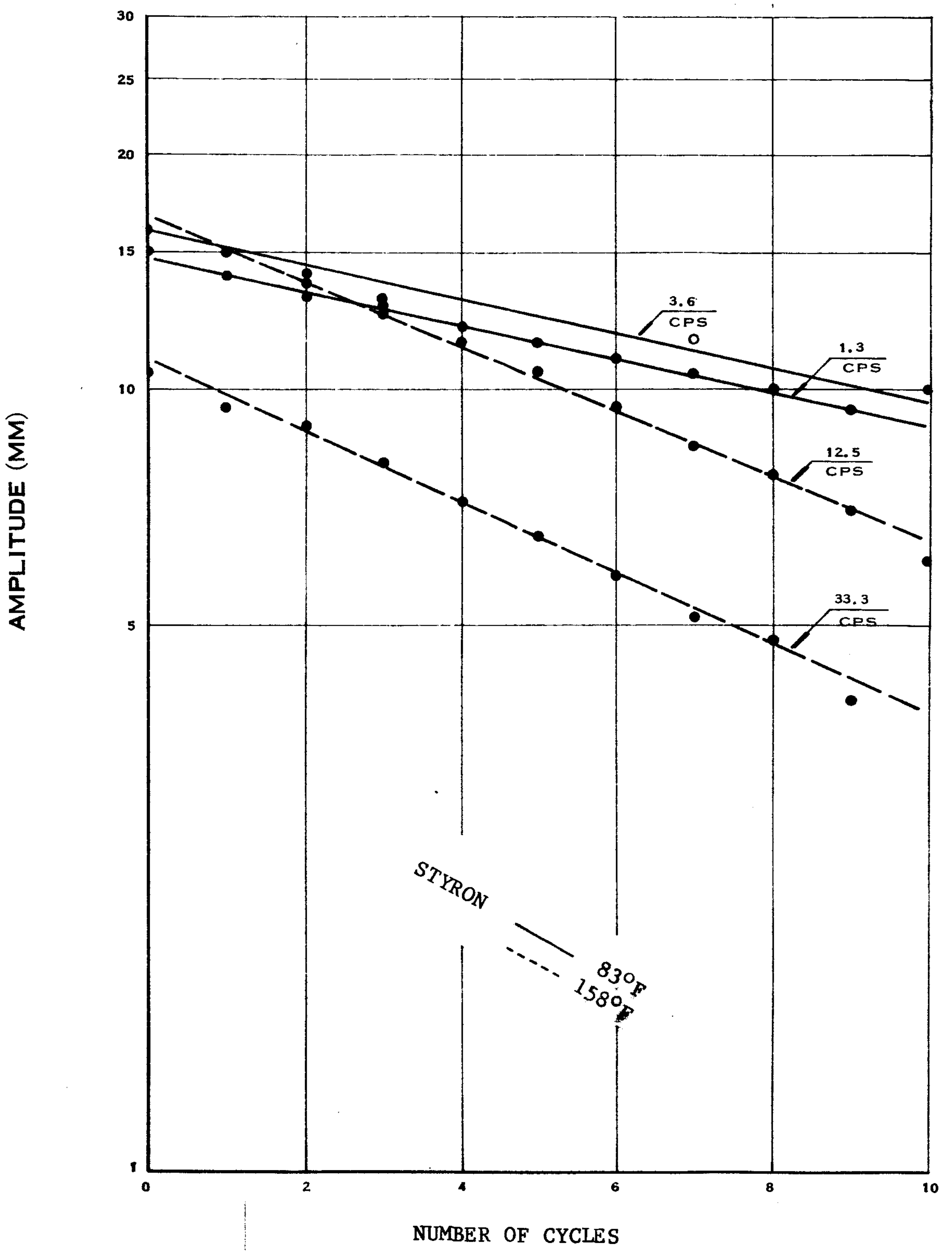
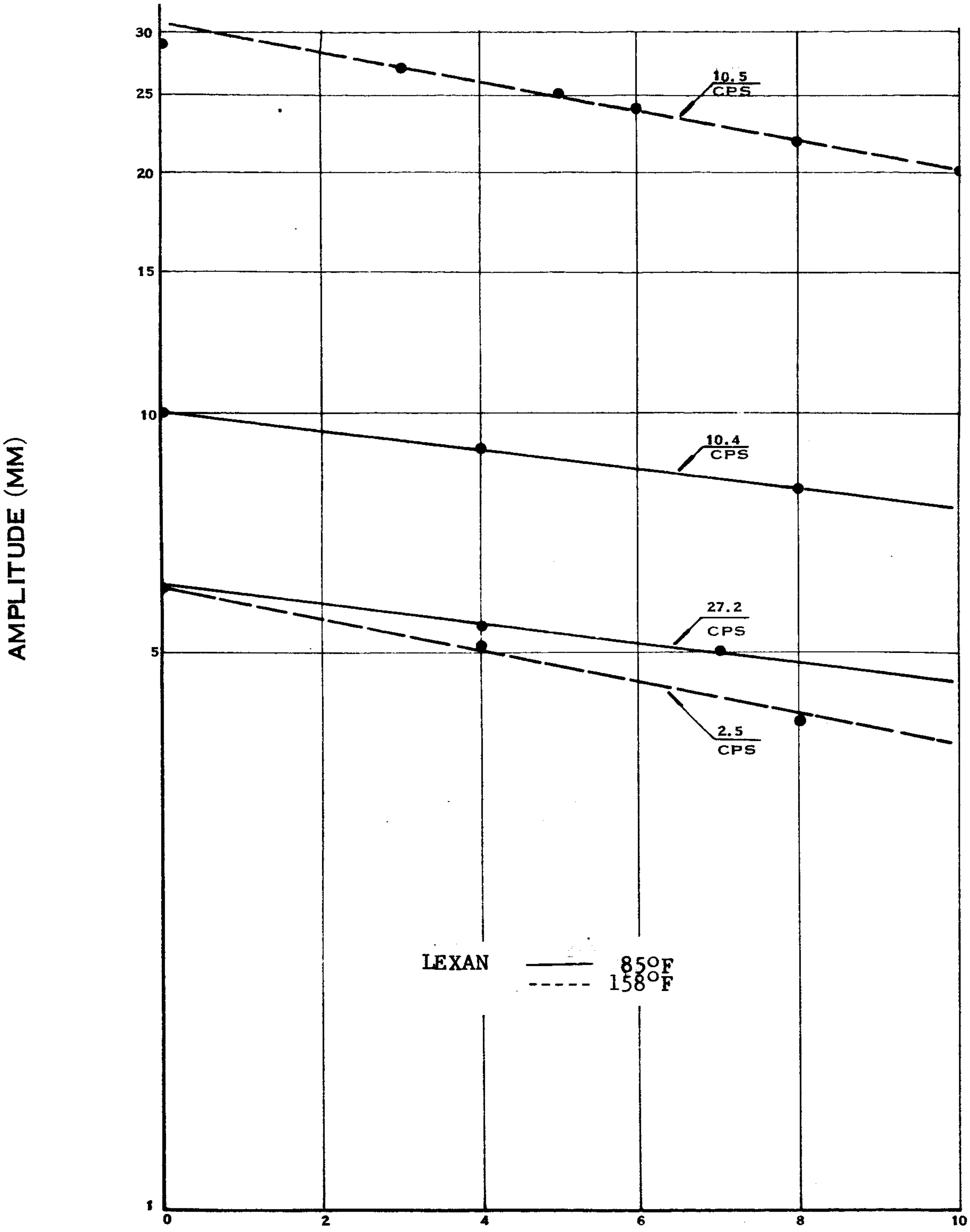


FIG. 35
LOG - DECREMENT DECAY
AMPLITUDE VS. NUMBER OF CYCLES



NUMBER OF CYCLES
FIG. 36
LOG - DECREMENT DECAY
AMPLITUDE VS. NUMBER OF CYCLES

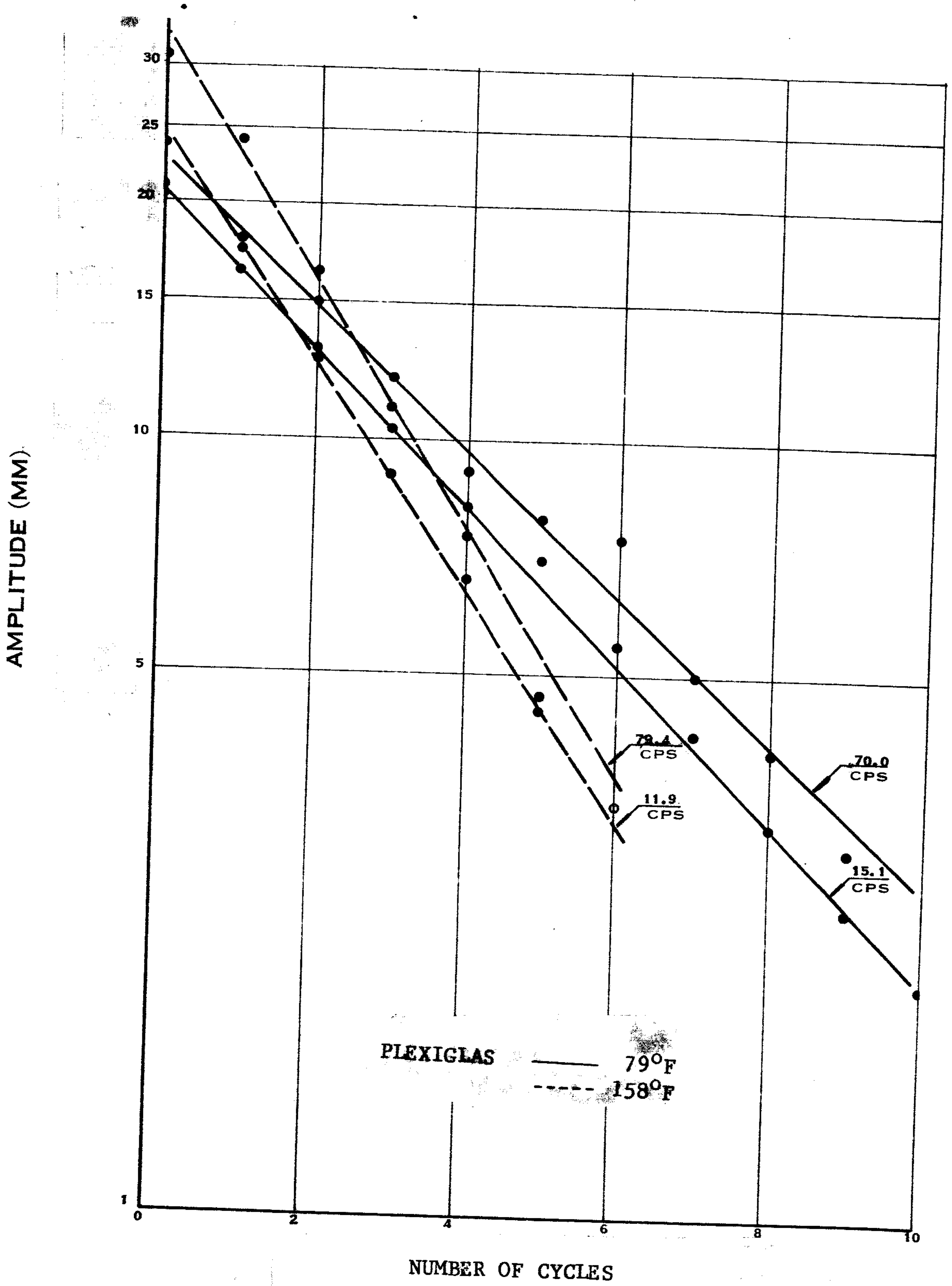


FIG. 37
LOG - DECREMENT DECAY
AMPLITUDE VS. NUMBER OF CYCLES

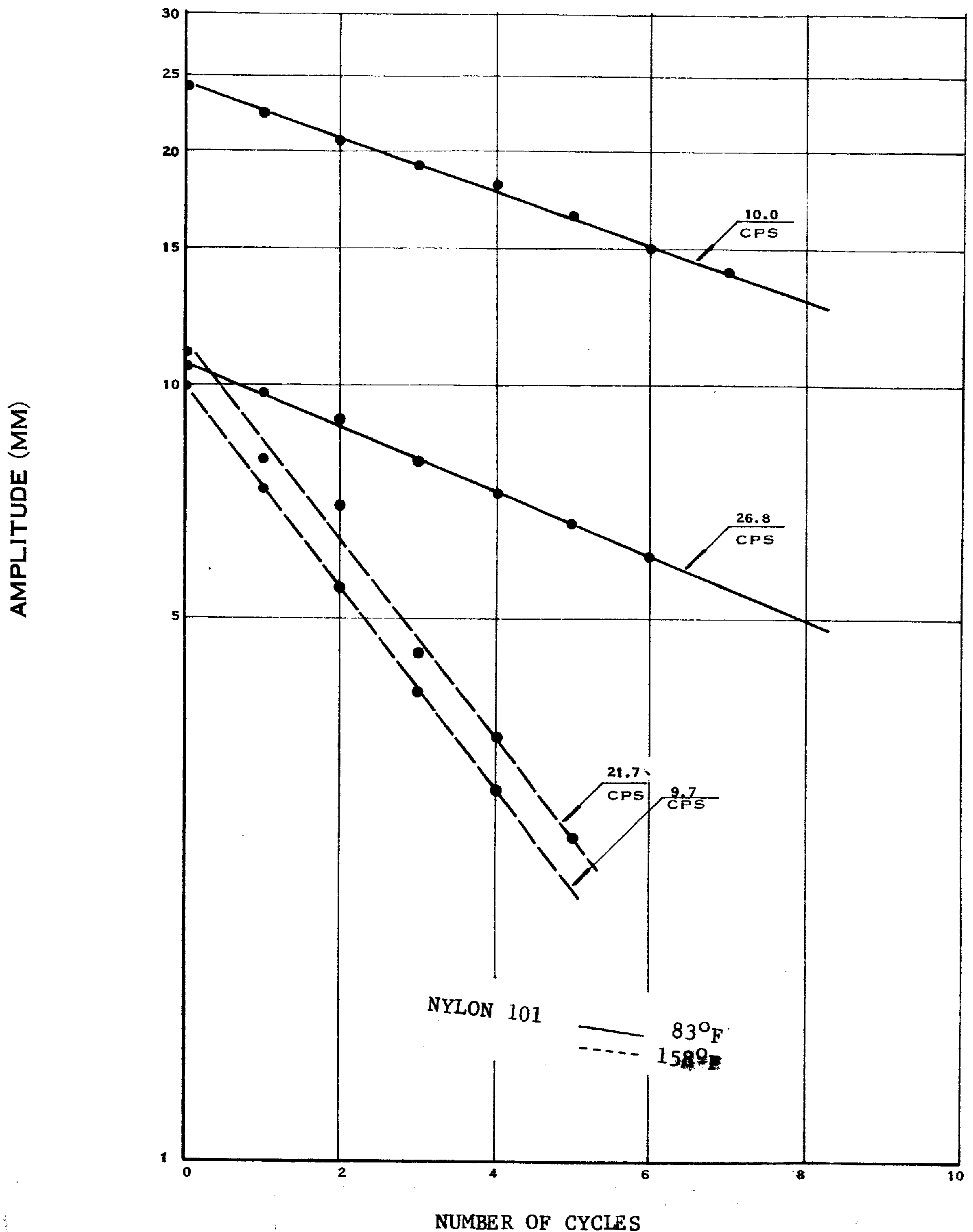
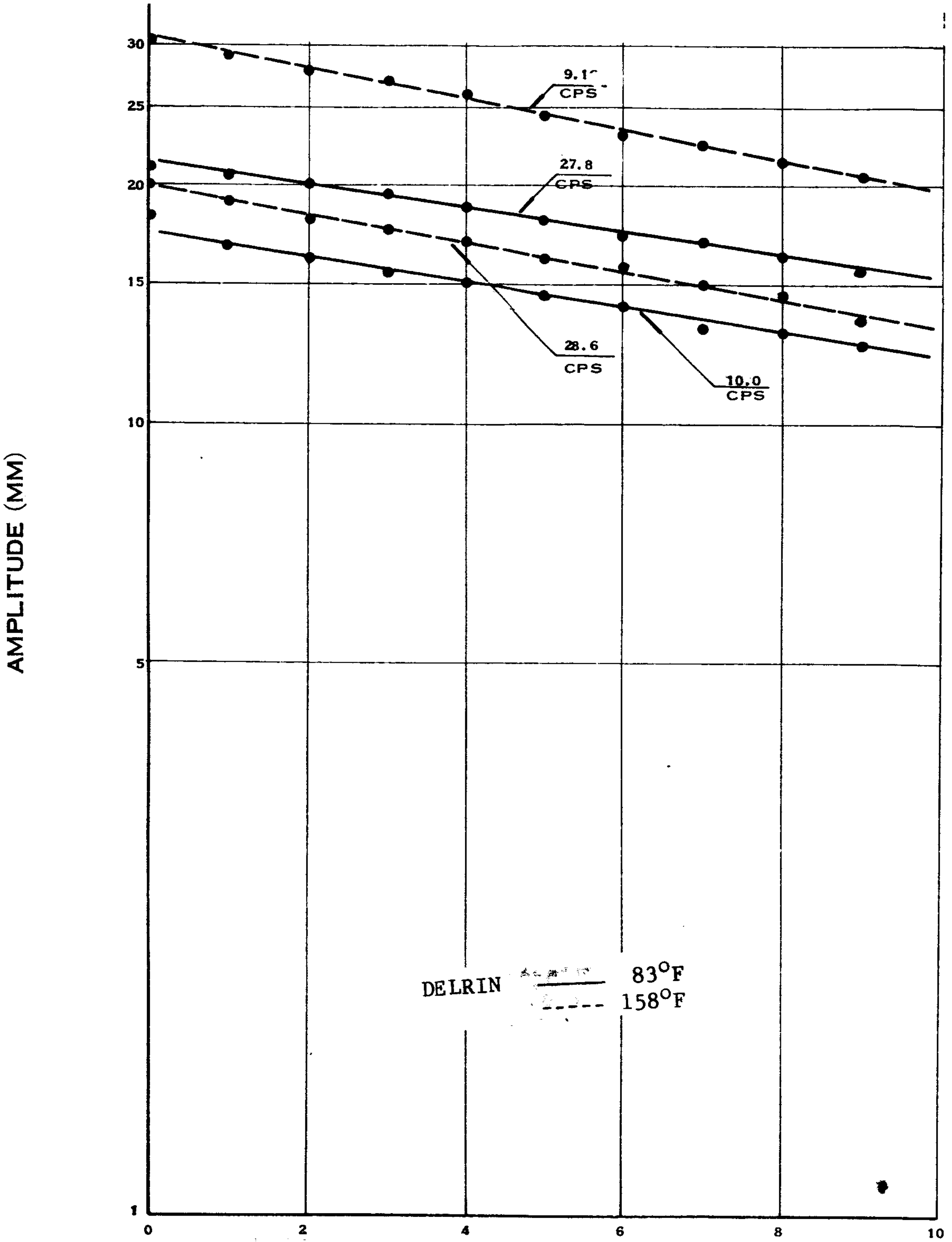


FIG. 38
LOG - DECREMENT DECAY
AMPLITUDE VS. NUMBER OF CYCLES



NUMBER OF CYCLES

FIG. 39

LOG - DECREMENT DECAY

AMPLITUDE VA. NUMBER OF CYCLES