WADC TECHNICAL REPORT 55-412

ELEVATED- AND ROOM-TEMPERATURE PROPERTIES OF SIERRACIN 611, PMACA, AND PLEXIGLAS 55 TRANSPARENT PLASTIC SHEET MATERIALS

JOHN A. VANECHO

GALE R. REMELY

WARD F. SIMMONS

BATTELLE MEMORIAL INSTITUTE

DECEMBER 1955

MATERIALS LABORATORY

CONTRACT No. AF 33(038)-10818

PROJECT No. 7340

TASK No. 73400

WRIGHT AIR DEVELOPMENT CENTER

AIR RESEARCH AND DEVELOPMENT COMMAND

UNITED STATES AIR FORCE

WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield,O.
300 - April 1956

FOREWORD

This report was prepared by the Battelle Memorial Institute under USAF Contract No. AF 33(038)-10818. The contract was initiated under Project No. 7340, "Rubber, Plastics, and Composite Materials", Task No. 73400, "Structural Plastics", and RDO No. 614-12, "Structural Plastics", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with D. H. Cartolano acting as project engineer.

The work covered by this report was performed during the period July 1 to November 1, 1954.

ABSTRACT

Creep and creep-rupture, short-time tensile, and deterioration properties of two transparent plastic sheet materials, Sierracin 611, a polyester, and PMACA, an acrylate, were determined over a temperature range of 80 to 300 F. Some creep and creep-rupture and tensile data were also obtained on Plexiglas 55, an acrylic transparent, for comparison with the strength properties of an experimental acrylic, 5105XP.

The PMACA sheet material displays, in general, at least 50 per cent greater creep, creep-rupture, and short-time tensile strength and elastic-modulus properties than do Sierracin 611 and Plexiglas 55. This PMACA material compares almost equally as favorably with other transparent plastics previously tested under this evaluation program, such as acrylates Polymer K, 5105XP, Lucite HC-202, and Plexiglas II and the polyester resin Selectron 44.

The deterioration losses determined for PMACA and Sierracin 611 remained relatively low for temperatures as high as 250 F. Of the three transparents tested, crazing was shown to occur in the PMACA and Plexiglas 55 materials.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(Continued)

SUMMARY

Creep, creep-rupture, short-time tensile, and deterioration tests were made on two transparent plastics — Sierracin 611, a polyester, and PMACA, an acrylate, at temperatures ranging from 80 to 300 F. A few similar check tests were also made on Plexiglas 55, an acrylate with an ultraviolet-light absorber added, for comparison with an experimental acrylic transparent, 5105XP. The results of these tests are briefly summarized as follows:

(1) The PMACA plastic sheet has, for the most part, a much greater creep and creep-rupture strength than any other transparent plastic tested under this program. The 100-hour rupture strength of this material ranges from about 9300 psi at room temperature to 2100 psi at 250 F.

(2) The short-time tensile strength and modulus of elasticity of PMACA are also much superior to those of other plastics tested. The tensile strength ranges from 15,700 psi at room temperature to 4700 psi at 250 F. The elastic modulus ranges from 920,000 psi at 80 F to 370,000 psi at 250 F.

(3) Of the three transparents tested, only PMACA and Plexiglas 55 crazed under tensile and creep testing.

(4) Neither PMACA nor Sierracin 611 showed excessive losses at temperatures of 160, 200, or 250 F in deterioration tests. At 300 F, both materials deteriorate appreciably, with PMACA apparently decomposing after about 24 hours.

(5) The creep, creep-rupture, and short-time tensile strength of Plexiglas 55 are the same as that of 5105XP, assuming normal material and test-procedure variations.

(6) Although tests were limited, a variation in test-temperature-holding time from 0 to 45 minutes did not seem to result in any variation in the tensile strength of PMACA at 250 F.

INTRODUCTION

The work discussed in this report was accomplished under Contract No. AF 33(038)-10818, Research and Development Order No. 614-12. It is a continuation of our evaluation of elevated- and room-temperature properties of plastics and plastic-glass laminates. This report contains data on three transparent plastics: Sierracin 611, a polyester; PMACA, an acrylate; and Plexiglas 55, also an acrylate. Several other transparent and reinforced plastics were evaluated previously under this contract and others are to be evaluated.

SPECIFICATIONS, PREPARATION, AND HEAT TREATMENT OF TEST MATERIALS

Material specifications of the three transparent plastics evaluated under this program are as follows.

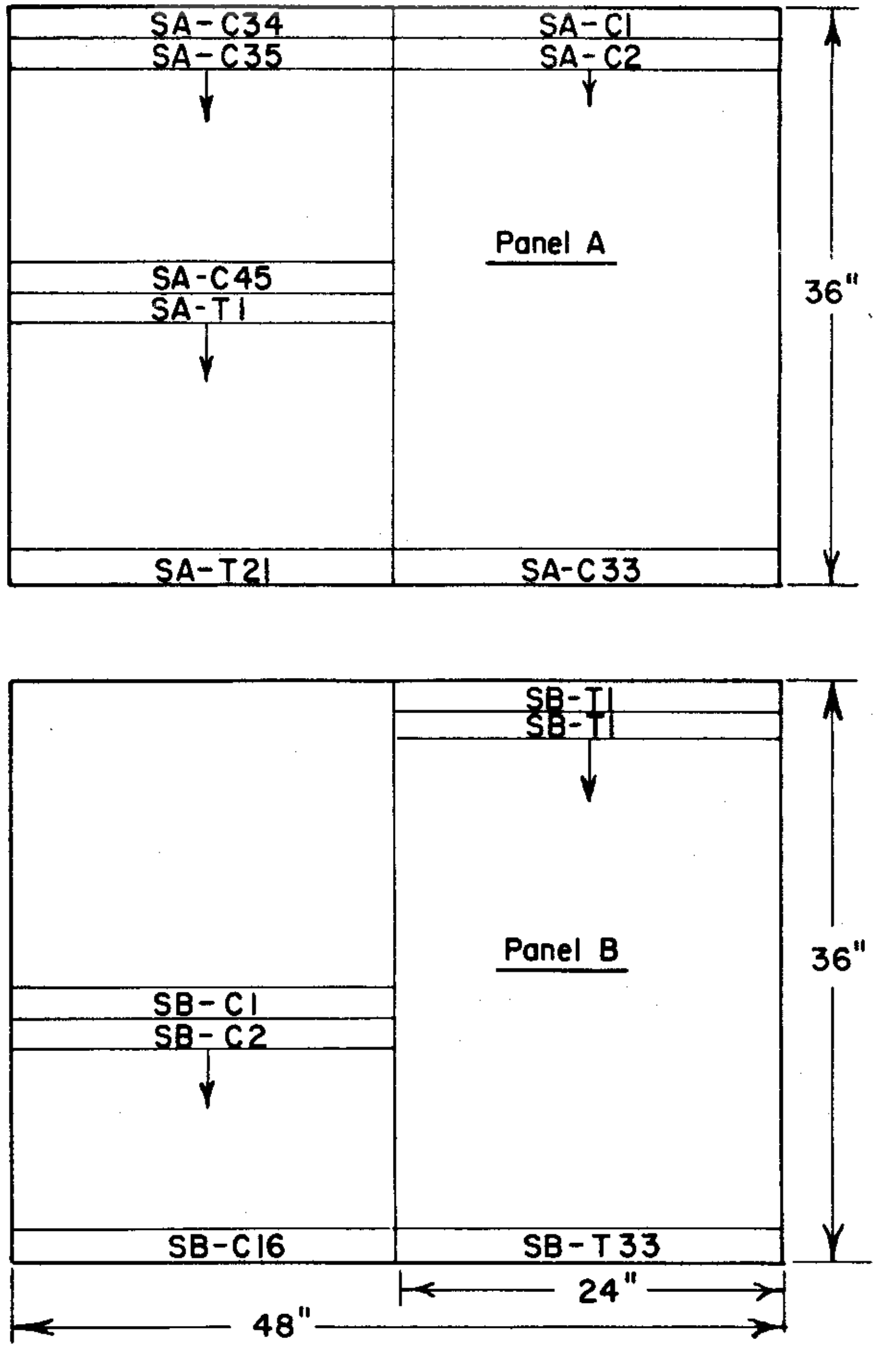
Sierracin 611

Supplier: The Sierracin Corporation
Resin: polyester
Panels
- Number: two
- Size: 36 x 48 x 1/4 inch
- Batch: 41554
- Test report: 5-1826

Heat treatment: specimens laid flat in a forced-air furnace at 200 F for 16 hours and furnace cooled in 2 to 2-1/2 hours
Location of specimens in panels: see Figure 1.

Polymethyl-Alpha-Chloroacrylate (PMACA)

Supplier: obtained through WADC
Resin: acrylate
Panels
- Number: four
  - (1) TM 1184 (General Aniline No. 669)
  - (2) TM 1186 (General Aniline No. 668)
  - (3) TM 1187 (General Aniline No. 670)
  - (4) TM 1188 (General Aniline No. 674)



S — Indicates material (Sierracin 611)
A and B — Indicate panel
C — Creep specimens
T — Tensile specimens
Panel thickness — 1/4 inch

FIGURE 1. LOCATION OF TEST SPECIMENS IN TRANSPARENT SIERRACIN 611 PANELS

A-14951

Size: 24 x 24 x 1/4 inch

Heat treatment: panels laid flat in a forced-air furnace at 320 F for 30 minutes and furnace cooled to 150-200 F in 1-1/2 to 2 hours.

Location of specimens in panels: see Figure 2.

Plexiglas 55

Supplier: Rohm and Haas Company

Resin: acrylate

Panels

Number: two (MIL-P-8184, Finish A)

Size: 36 x 48 x 1/4 inch

Heat treatment: specimens suspended in a forced-air furnace at 311 F (155 C) for 30 minutes and furnace cooled to room temperature in 2 to 2-1/2 hours

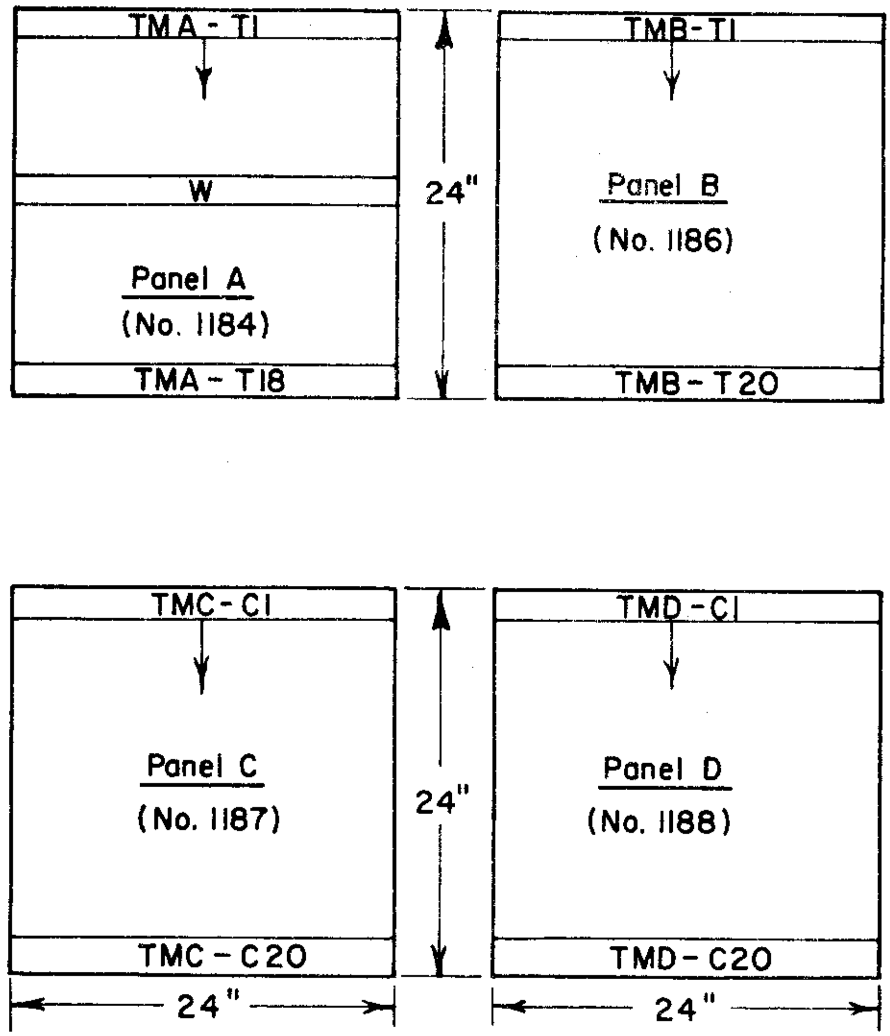
Location of specimens in panels: unknown.

Plexiglas 55 is the identification given to the experimental polymer 5105XP by Rohm and Haas when an ultraviolet-light absorber is added.

The test material and specimens were handled carefully prior to testing so that the surface was not damaged. It was necessary, however, to remove the protective paper in most cases, so as to prevent slippage during the machining operation. No lubricant or coolant was used during machining. Some cooling was accomplished by blowing dry air across the cutter. This also helped to remove the chips. The cutter speed was maintained quite low, so that very little cooling actually was needed.

All three transparents were typical of such materials obtained in production. Of these three materials tested, PMACA and Plexiglas 55 were tested in the as-machined condition. Sierracin 611 was polished in the gaged section prior to testing. The polishing was done on a buffing wheel using rouge as an abrasive.

All test specimens were kept in a room maintained at 78 to 80 F and a relative humidity of about 40 to 60 per cent. The room-temperature creep and creep-rupture tests were also conducted in a room maintained under these conditions.



TM – Indicates material (polymethyl alpha choroacrylate)

A, B, C, and D – Indicate panel

T – Tensile specimens

C – Creep specimens

W – Section used for weight-loss specimens

Panel thickness – 1/4 inch

FIGURE 2. LOCATION OF TEST SPECIMENS IN TRANSPARENT PMACA PANELS

A-14952

TEST PROCEDURE

A complete description of the procedure used in making both the creep and the creep-rupture and short-time tensile tests has already been given in a previous report.[1] Nevertheless, a brief description of the test procedures will be presented at this time, since there have been some modifications.

Creep and Creep-Rupture Tests

These tests were made in standard Battelle creep-testing frames and furnaces. Each testing unit is equipped with a chromium-plated copper or steel shell furnace 6 inches in diameter and about 18 inches long, wound with 14-gage Chromel-A wire, and insulated with Sil-O-Cel. Small windows are provided at both the front and the back of the furnace for measuring the deformation of the specimens by optical means.

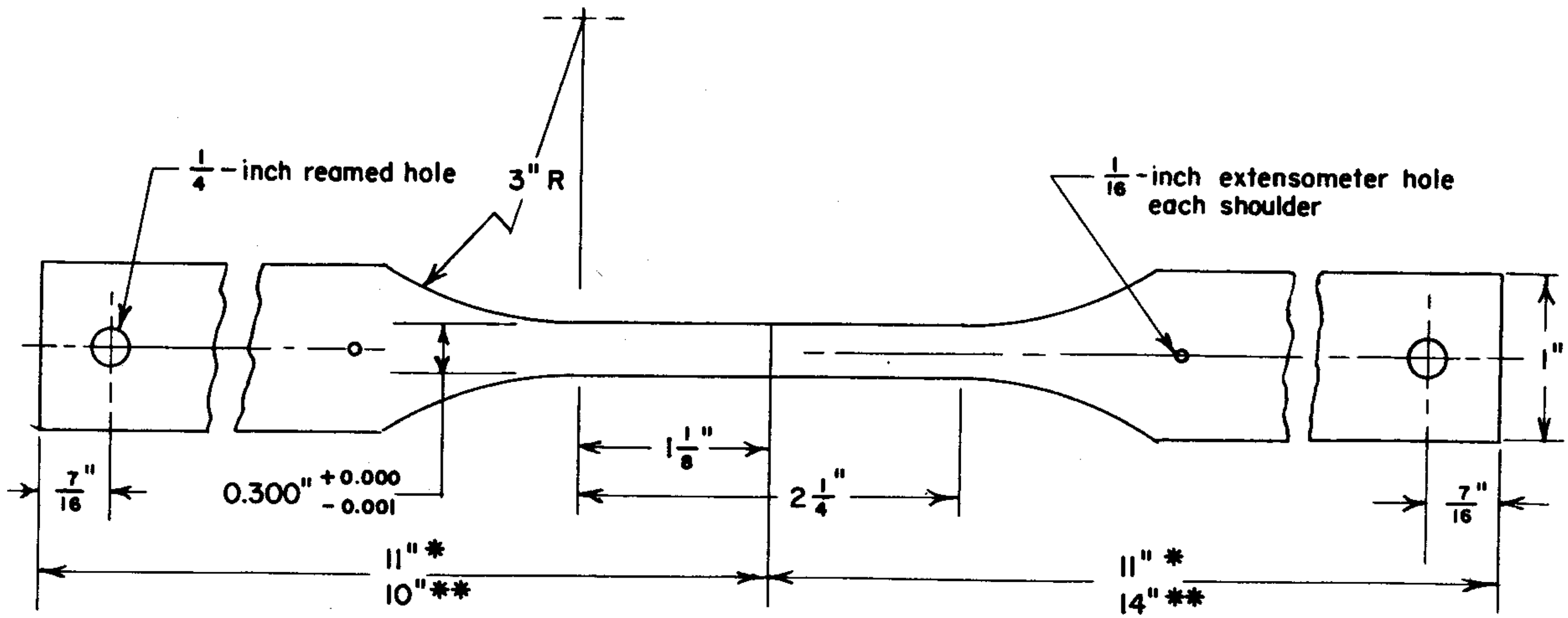
The test temperature of each furnace was maintained by means of (1) a Tag Celectray indicating controller equipped with a throttling mechanism for closer control or (2) a Foxboro controller to which an anticipating device has been added to improve the temperature control. The temperature of the creep and creep-rupture tests was held to an accuracy of about ±2 F.

The specimens were 22 inches long with a 2.25-inch by 0.300-inch gage section in the center of the specimen, as shown in Figure 3. All materials tested were 1/4 inch thick. The stress was applied to the specimens either by means of a 9:1-ratio lever-arm arrangement or by direct loading with a dead weight after the specimen had reached test temperature.

The deformation of the test specimens was measured by means of a platinum-strip extensometer attached to the gage length as shown in Figure 4. The extensometer consists of two strips, one of which slides within the folded-over edges of the other. The surfaces of the strip are polished and a series of very fine marks scribed on them. Two cross marks, one on each strip, are chosen as reference marks, and the distance between them is measured periodically with a filar microscope. The change in length or creep of the specimen is determined by measuring the change in distance between the reference marks.

The microscope has an eyepiece fitted with a filar micrometer and is mounted on a graduated screw. The smallest division on the eyepiece is 0.00005 inch, which, on a 2-1/4-inch gage length, would be equal to 0.0022 per cent.

The deformation readings are usually made daily by two observers. Extensometers are generally attached to both the front and back of the test specimen to obtain greater accuracy and to check on axial loading. The optical deformation readings are converted to percentages and plotted as curves of time versus deformation on rectangular coordinates. The readings of both observers on both the front and the back of the specimen are

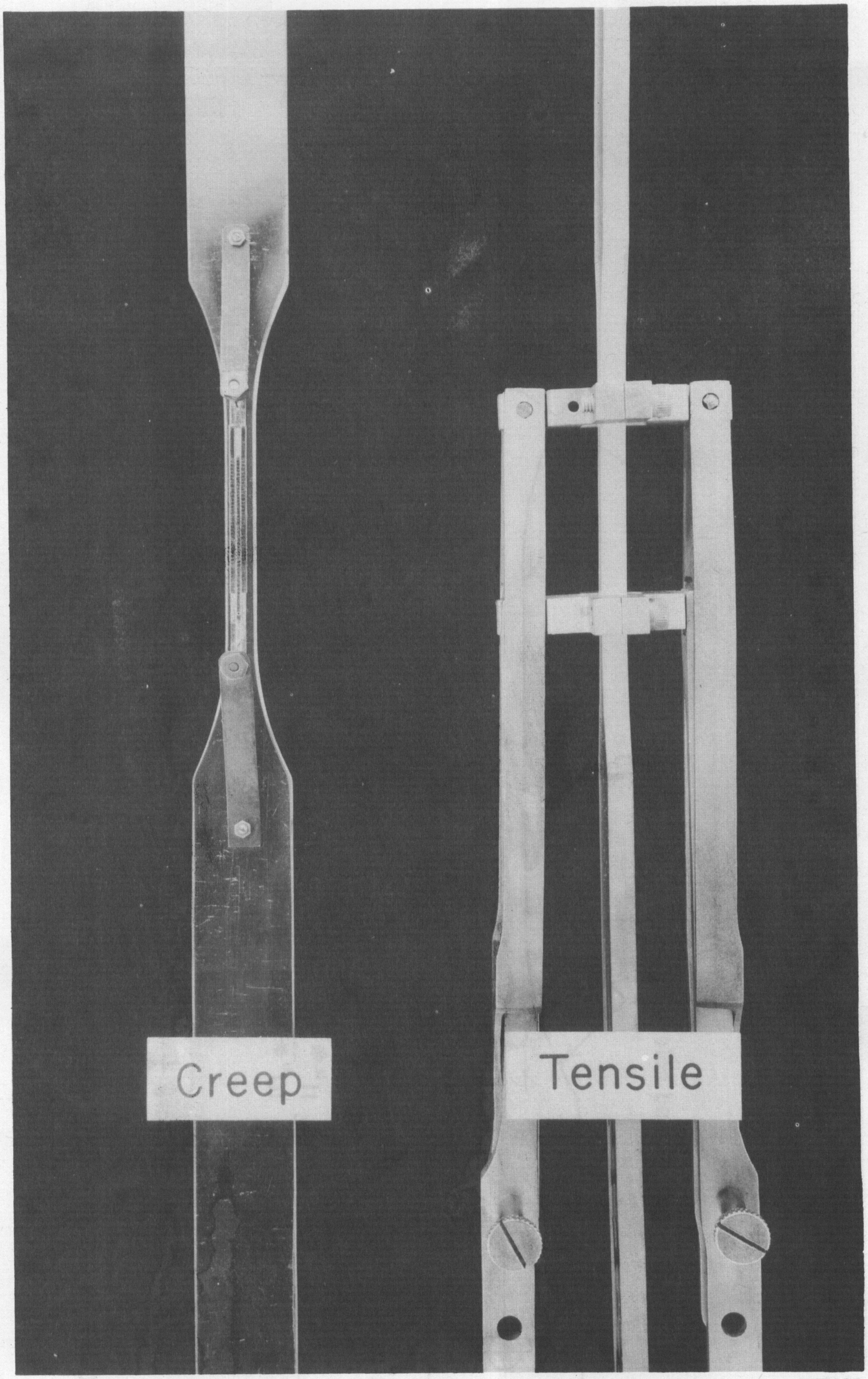


Note: Specimens are 1/4-inch thick.

* Creep and creep-rupture specimen
** Tensile specimen

FIGURE 3. CREEP AND CREEP-RUPTURE AND TENSILE SPECIMENS USED FOR TESTING SIERRACIN 611, PMACA, AND PLEXIGLAS 55 TRANSPARENT PLASTICS AT ALL TEST TEMPERATURES

A-15000



N22465

FIGURE 4. CREEP SPECIMEN WITH PLATINUM-STRIP EXTENSOMETER AND TENSILE SPECIMEN WITH EXTENSOMETER GRIPS ATTACHED

averaged to produce the curves. All the data shown in Tables 1, 2, and 3 were taken from these time-deformation curves. The design curves shown in Figures 5 through 13 were, in turn, constructed principally from the data in the tables. However, some of the design-curve data were taken directly from the time-deformation curves.

Short-Time Tensile Tests

The short-time tensile tests were made in a Baldwin-Southwark hydraulic machine. An electric-resistance-heated furnace 7 inches in diameter and 12-1/2 inches long was used to make the elevated-temperature tests. Two Chromel-Alumel thermocouples were used on each test specimen to measure and control the temperature. Approximately 1/2 hour was needed to heat the specimens to the test temperature and the specimens were held at test temperature another 1/2 hour prior to testing. The desired test temperature was maintained by means of a Foxboro controller to an accuracy of about ±5 F.

The tensile specimens were 24 inches long with a 2.25 by 0.300-inch gage section slightly offset from the center, as shown in Figure 3. The offset allows the specimens to extend a greater distance from the bottom end of the furnace, and thereby, the specimen grips do not interfere with the extensometer.

If the material was found to be sensitive to the extensometer grips, the ultimate strength was determined without the use of the grips. For determining the modulus, the Templin stress-strain recorder was employed with the recorder mechanism attached to the extensometer by means of a selsyn motor. The extensometer is shown attached to the test specimen, as shown in Figure 4.

Deterioration Tests

One-inch-square by 1/4-inch-thick specimens were used in determining the stability or deterioration properties of the transparent plastics caused by exposures to temperature for 1/2 to 1000 hours. The exposures were made at 160, 200, 250, and 300 F in most cases. The following procedure was used in making these tests.

(1) The specimens were cut, machined, and placed in a desiccator.

(2) Prior to starting a test at the desired temperature, the original weight of the samples was determined on an ordinary chemical balance.

TABLE 1. CREEP AND CREEP-RUPTURE DATA ON TRANSPARENT SIERRACIN 611 AT 80, 160, AND 200 F

Specimen	Temperature, F	Stress, psi	Rupture Time, hours	Minimum Creep Rate, %/hour	Initial Deformation, %	Final Deformation[a], %	Hours, to Produce Total Deformation of: 1.0%	2.0%	3.0%	5.0%	7.0%	10.0%
SA-C3	80	8,000	0.4	--	2.58	5.32	--	--	0.05	0.26	--	--
SA-C5	80	8,000	3 minutes	--	6.27	9.20	--	--	--	--	--	--
SA-C1	80	7,000	1.4	--	2.23	4.53	--	--	0.13	--	--	--
SA-C8	80	7,000	0.2	--	3.69	8.96	--	--	--	--	0.15	--
SA-C10	80	6,000	2.3	--	2.63	8.78	--	--	0.1	0.6	1.3	--
SA-C4	80	6,000	13.9	0.320	2.17	5.20	--	--	0.5	6.3	--	--
SB-C3[b]	80	6,000	21.1	0.155	2.35	3.98	--	--	1.0	--	--	--
SA-C27	80	5,500	5.8	0.137	2.00	3.09	--	--	2.5	--	--	--
SA-C33	80	5,500	7.9	0.110	3.07	4.45	--	--	--	--	--	--
SA-C18	80	5,000	71.7	0.132	1.94	7.51	--	--	1.1	8.2	23.6	--
SA-C6	80	5,000	158.2	0.0215	1.55	6.34	--	0.7	5.5	83.0	--	--
SB-C4[b]	80	5,000	174.6	0.0103	1.43	4.45	--	1.9	33.5	--	--	--
SA-C34	80	4,500	122.2	0.0087	1.30	3.25	--	7.3	75.0	--	--	--
SA-C20	80	4,200	605.1	0.0054	1.16	7.13	--	5.8	30.5	176.0	550.0	--
SA-C17	80	4,000	684.7	0.00497	1.22	7.04	--	2.0	40.0	238.0	--	--
SA-C35	80	3,800	1005.7[c]	0.00216	0.906	4.36	0.2	109.0	450.0	--	--	--
SA-C16	160	4,000	1 minute	--	--	--	--	--	--	--	--	--
SA-C19	160	3,000	0.1	--	7.70	--	--	--	--	--	--	--
SA-C7	160	3,000	2 minutes	--	3.52	--	--	--	--	--	--	--
SA-C14	160	2,500	1.5	--	3.59	13.7	--	--	--	--	0.1	0.5
SA-C23	160	2,000	2.0	--	2.88	9.9	--	--	--	--	0.25	--
SA-C9	160	2,000	5.3	1.27	1.67	5.62	--	--	0.1	--	--	--
SA-C21	160	1,750	17.9	0.53	1.92	8.15	--	--	--	0.8	2.0	--
SB-C7[b]	160	1,750	32.4	0.18	0.93	10.2	--	0.04	0.06	0.55	2.5	17.5
SA-C28	160	1,600	28.6	0.058	2.60	9.90	--	--	0.04	0.4	2.7	--
SA-C11	160	1,500	859.7	0.0024	1.42	10.39	--	0.1	0.4	5.0	35.0	635.0
SB-C5[b]	160	1,500	162.9	0.0114	1.75	7.56	--	0.05	0.77	15.5	90.0	--
SA-C15	160	1,000	1004.9[c]	0.00104	1.15	5.08	--	2.0	22.0	900.0	--	--

Table 1. (Continued)

Specimen	Temperature, F	Stress, psi	Rupture Time, hours	Minimum Creep Rate, %/hour	Initial Deformation, %	Final Deformation[a], %	Hours, to Produce Total Deformation of: 1.0%	2.0%	3.0%	5.0%	7.0%	10.0%
SA-C12	200	1500	4 minutes	--	4.27	--	--	--	--	--	--	--
SA-C22	200	1000	0.1[d]	--	3.56	--	--	--	--	--	--	--
SA-C24	200	1000	0.4	--	2.53	4.93	--	--	0.03	--	--	--
SA-C25	200	800	0.7	--	2.00	5.34	--	--	0.11	0.5	--	--
SA-C32	200	800	0.4	--	2.65	6.04	--	--	0.015	0.1	--	--
SA-C13	200	500	21.9	--	1.05	3.92	--	0.3	1.6	--	--	--

(a) This final deformation indicates the last reading obtained before failure or discontinuation of test.
(b) Indicates specimens with unpolished gaged sections; balance of specimens were polished.
(c) Test discontinued.
(d) Failure occurred outside gaged section.

TABLE 2. CREEP AND CREEP-RUPTURE DATA ON

Specimen	Temperature, F	Stress, psi	Rupture Time, hours	Minimum Creep Rate, %/hour	Initial Deformation, %	Final Deformation[a], %
TMC-C5	80	16,000	1 minute	--	4.97	--
TMC-C6	80	15,000	Outside gage	--	--	--
TMC-C8	80	14,000	0.4	--	3.28	4.82
TMC-C9	80	13,400	0.8	1.29	2.64	3.99
TMD-C19	80	11,500	12.9	0.069	2.19	3.56
TMC-C10	80	10,000	48.3	0.0078	1.67	3.00
TMD-C20	80	9,000	146.1	0.0030	1.59	2.75
TMC-C7	80	7,600	1006.8[b]	0.00022	1.11	2.32
TMC-C11	160	12,000	On loading	--	--	--
TMC-C15	160	11,000	15 seconds	--	4.46	--
TMC-C17	160	10,000	1 minute	--	3.40	--
TMD-C12	160	9,000	0.9	--	2.84	4.86
TMD-C11	160	8,500	4.0	--	--	--
TMC-C20	160	8,000	2.4	--	2.65	--
TMD-C13	160	7,500	23.6	0.112	2.66	5.73
TMD-C17	160	7,250	13.2	1.30	2.40	4.23
TMD-C3	160	7,000	384.6	0.000136	1.36	2.99
TMD-C16	160	7,000	100.9	0.0118	1.08	2.85
TMD-C5	160	6,500	1005.0[b]	0.0010	1.86	5.39
TMC-C12	200	8,000	3 minutes	--	2.08	--
TMD-C4	200	6,500	0.4	--	2.66	--
TMC-C16	200	6,000	2.1	2.30	1.59	2.84
TMC-C14	200	5,500	12.8	1.05	1.74	3.35
TMC-C13	200	5,000	69.5	0.055	2.05	7.58
TMC-C18	200	5,000	128.6	0.035	1.23	7.20
TMD-C6	200	4,500	1005.1[b]	0.00154	1.13	4.92
TMC-C19	250	4,000	0.1	--	1.65	--
TMD-C1	250	3,000	0.7	--	1.07	--
TMD-C8	250	3,000	4.5	--	1.11	10.62
TMD-C2	250	2,500	44.0[c]	--	0.924	1.60
TMD-C9	250	2,500	10.1[c]	--	0.670	3.05
TMD-C10	250	2,000	127.6[c]	0.457	0.716	18.15
TMD-C18	250	1,750	223.9[c]	0.34	0.50	6.0
TMD-C15	250	1,500	669.7[c]	0.154	0.658	25.32

(a) This final deformation indicates the last reading obtained before failure or discontinuation of test.

(b) Test discontinued.

(c) Test discontinued; specimen elongated to limit of testing machine.

TRANSPARENT PMACA AT 80, 160, 200, AND 250 F

Hours, to Produce Total Deformation of:						Start of Crazing,	
2.0%	2.5%	3.0%	5.0%	7.0%	10.0%	hours	Remarks
--	--	--	--	--	--	--	
--	--	--	--	--	--	--	Lightly crazed
--	--	--	--	--	--	--	Heavily crazed
--	--	--	--	--	--	0.2	Medium crazed
--	0.1	1.2	--	--	--	0.1	Heavily crazed
0.5	10.0	42.0	--	--	--	0.2	Heavily crazed
2.5	61.5	--	--	--	--	--	Heavily crazed
230.0	--	--	--	--	--	--	Medium crazed
--	--	--	--	--	--	--	Heavily crazed
--	--	--	--	--	--	--	Heavily crazed
--	--	--	--	--	--	--	Heavily crazed
--	--	--	0.45	--	--	--	Heavily crazed
--	--	--	--	--	--	--	Heavily crazed
--	--	--	--	--	--	--	Heavily crazed
--	--	0.15	10.8	--	--	--	Heavily crazed
--	--	0.35	--	--	--	--	Heavily crazed
23.0	50.0	--	--	--	--	--	Heavily crazed
22.0	47.5	--	--	--	--	--	Heavily crazed
0.2	2.0	12.5	615.0	--	--	--	Heavily crazed
--	--	--	--	--	--	--	Heavily crazed
--	--	--	--	--	--	--	Heavily crazed
--	0.24	--	--	--	--	--	Heavily crazed
--	0.40	0.87	--	--	--	--	Heavily crazed
--	0.5	1.5	11.5	42.0	--	--	Heavily crazed
1.1	2.0	7.5	40.0	107.0	--	--	Heavily crazed
5.0	10.0	30.0	--	--	--	--	Heavily crazed
--	--	--	--	--	--	--	Heavily crazed
--	--	--	--	--	--	--	Heavily crazed
0.17	0.21	0.31	0.62	0.72	0.95	--	Medium crazed
--	--	--	--	--	--	--	Heavily crazed
--	--	--	--	--	--	--	Medium crazed
0.4	0.6	1.0	2.3	4.1	8.9	--	Lightly crazed
1.8	2.5	3.3	9.1	--	--	--	Lightly crazed
6.0	10.0	14.0	50.0	165.0	350.0	--	Lightly crazed

TABLE 3. CREEP AND CREEP-RUPTURE CHECK TEST DATA ON TRANSPARENT PLEXIGLAS 55 AT 80, 160, AND 200 F

Specimen	Temperature, F	Stress, psi	Rupture Time, hours	Minimum Creep Rate, %/hour	Initial Deformation, %	Hours, to Produce Total Deformation of: 0.5%	1.0%	2.0%	3.0%	5.0%	7.0%	10.0%	Start of Third-Stage Creep: Time, hours	Deformation, %	Remarks
P55A-C1	80	8000	2.2	--	3.03	--	--	--	--	0.25	1.7	--	--	--	(a)
P55A-C2	80	7500	22.2	0.160	3.17	--	--	--	--	0.9	7.0	--	--	--	(a)
P55A-C5	80	7000	79.4	0.061	2.43	--	--	--	0.2	6.7	26.0	--	--	--	(a)
P55A-C3	160	4500	0.5	--	2.57	--	--	--	--	0.23	--	--	--	--	(a)
P55A-C6	160	4000	6.4	1.7	2.21	--	--	--	0.13	0.85	1.5	--	1.2	5.6	(a)
P55A-C8	160	3500	184.1	0.070	1.51	--	--	0.5	0.7	8.00	15.0	55.0	115.0	15.0	(a)
P55A-C4	200	3000	<0.1 (b)	--	2.87	--	--	--	--	--	--	--	--	--	(a)
P55A-C7	200	2000	20.0	3.85	2.14	--	--	--	0.1	0.45	1.0	--	--	--	(a)
P55A-C9	200	1500	1007.5 (c)	0.0016	0.81	--	1.0	2.0	4.0	5.0	15.0	85.0	--	--	--

(a) Heavy crazing observed in specimen.
(b) Specimen elongated to limit of testing machine without failing.
(c) Test discontinued.

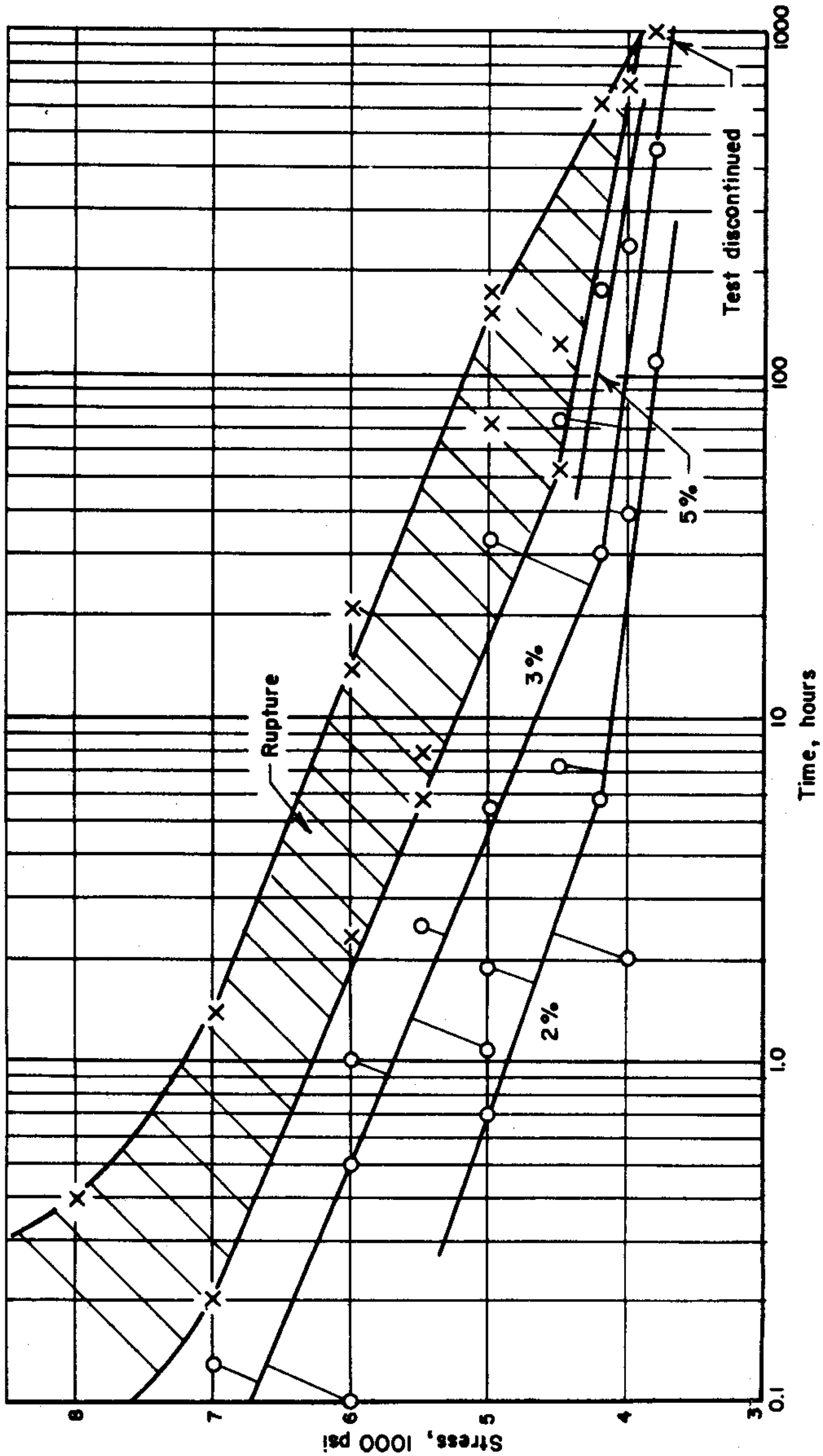


FIGURE 5. DESIGN CURVES FOR TRANSPARENT SIERRACIN 611 AT 80 F

A-14953

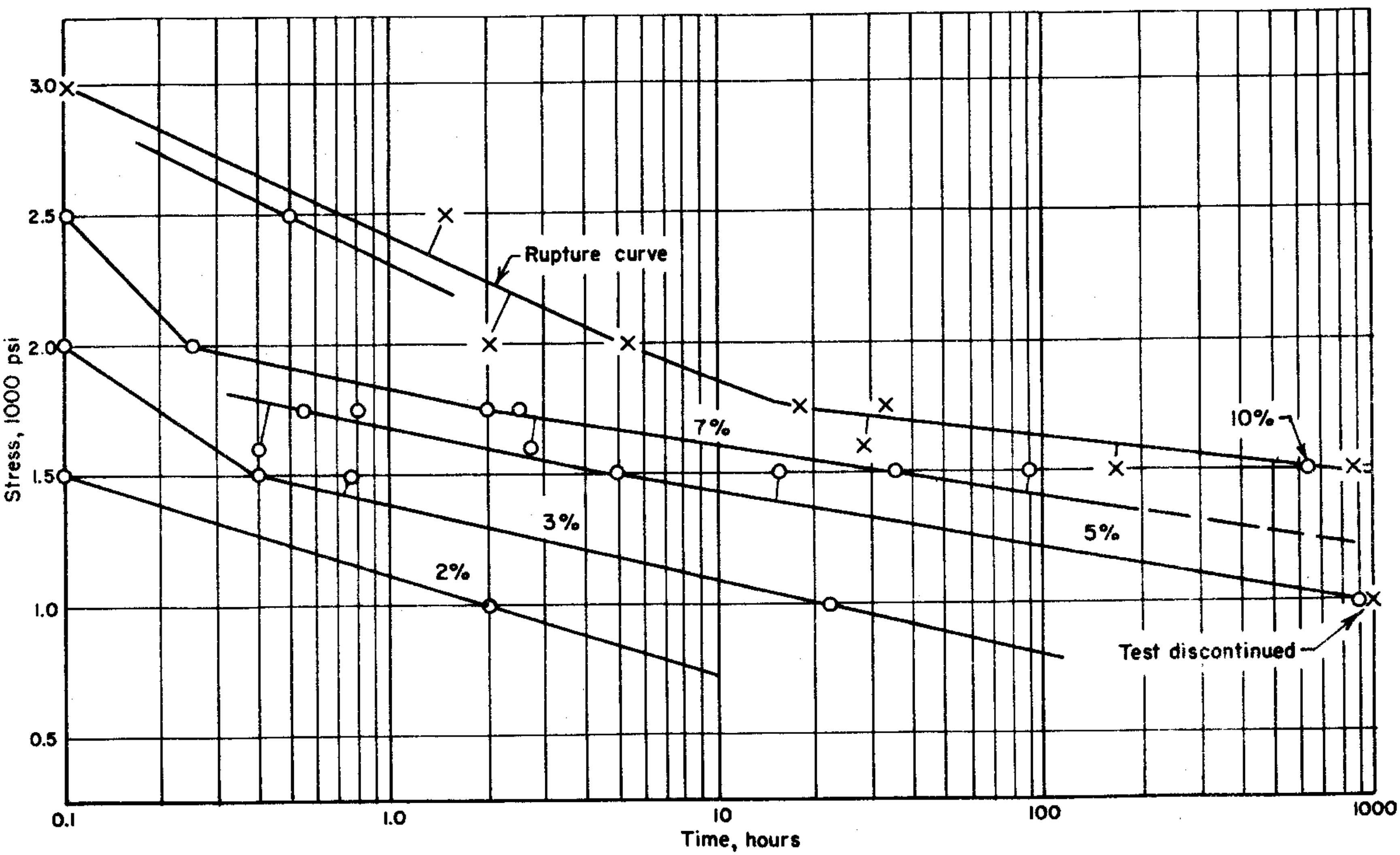


FIGURE 6. DESIGN CURVES FOR TRANSPARENT SIERRACIN 611 AT 160 F

A-14954

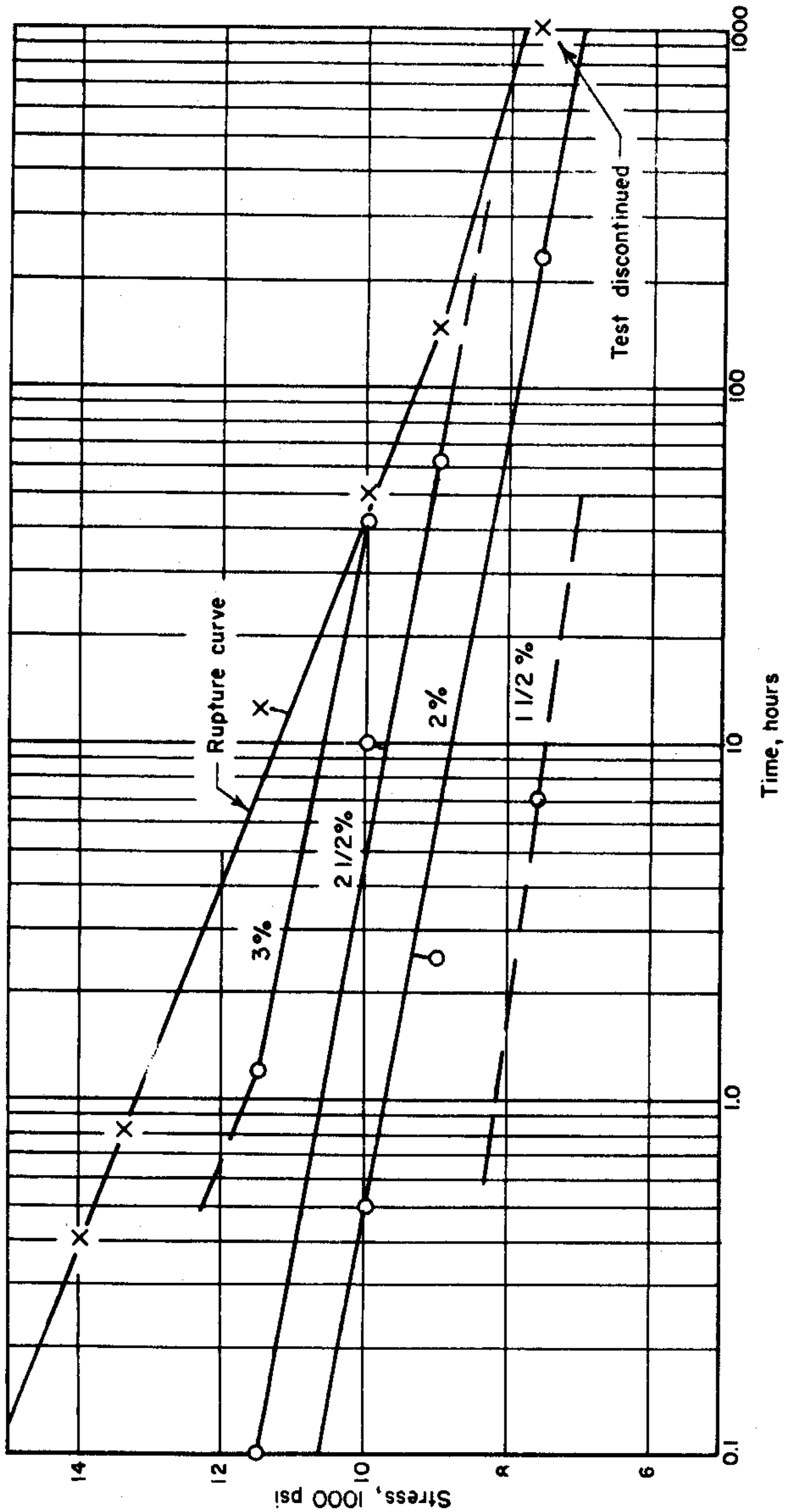


FIGURE 7. DESIGN CURVES FOR TRANSPARENT PMACA AT 80 F

A-14955

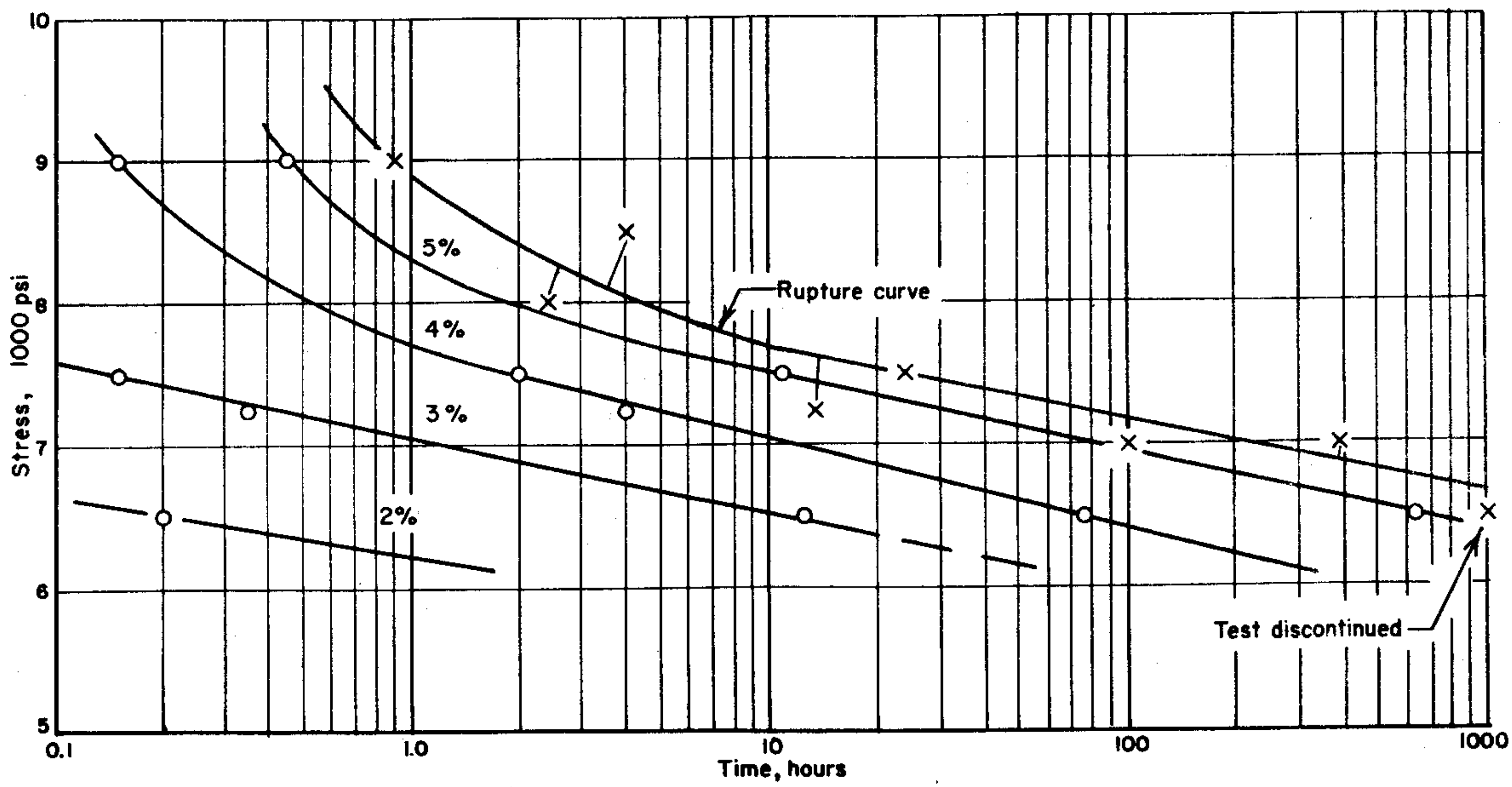


FIGURE 8. DESIGN CURVES FOR TRANSPARENT PMACA AT 160 F

A-14956

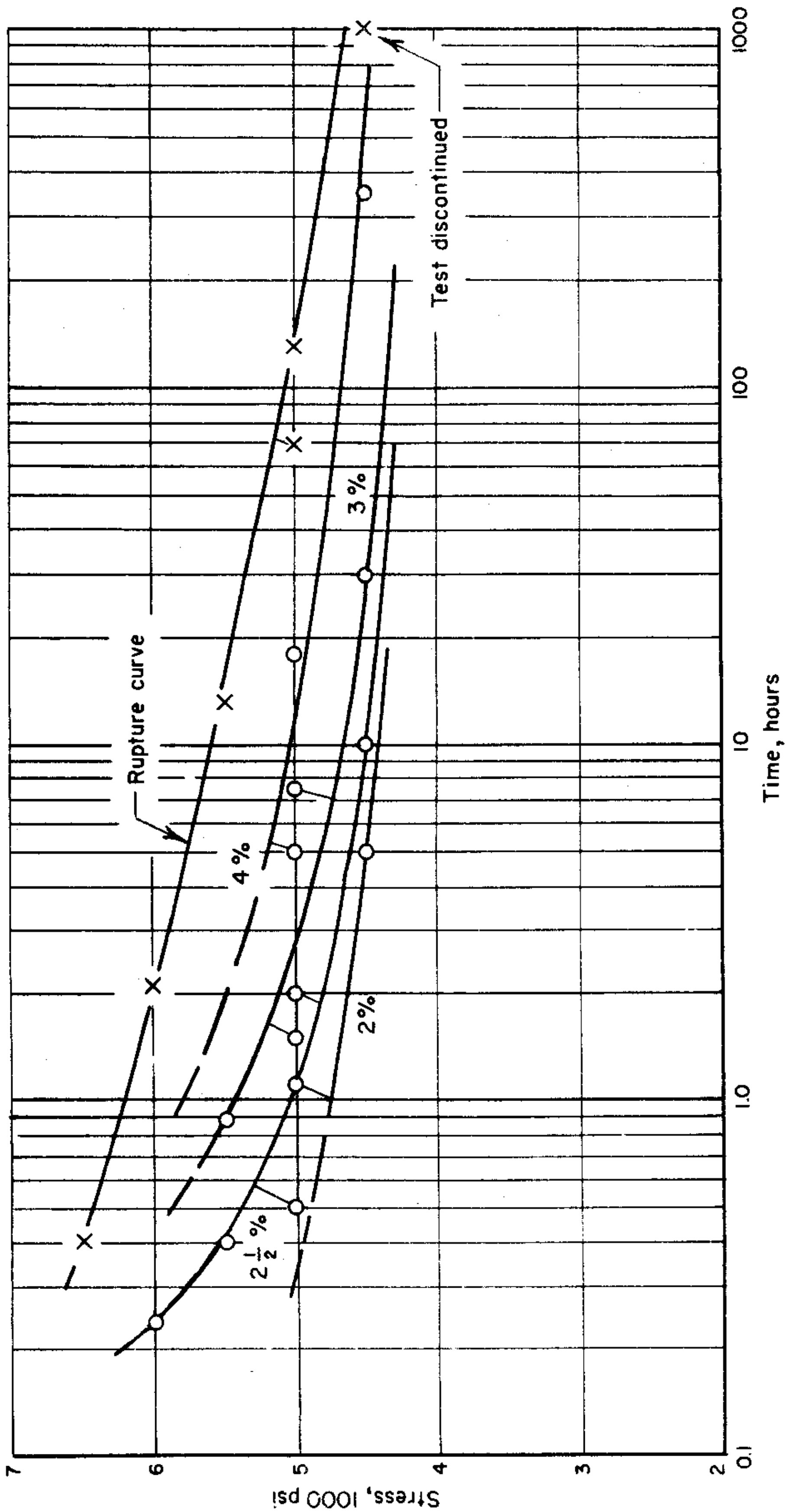


FIGURE 9. DESIGN CURVES FOR TRANSPARENT PMACA AT 200 F

A-14957

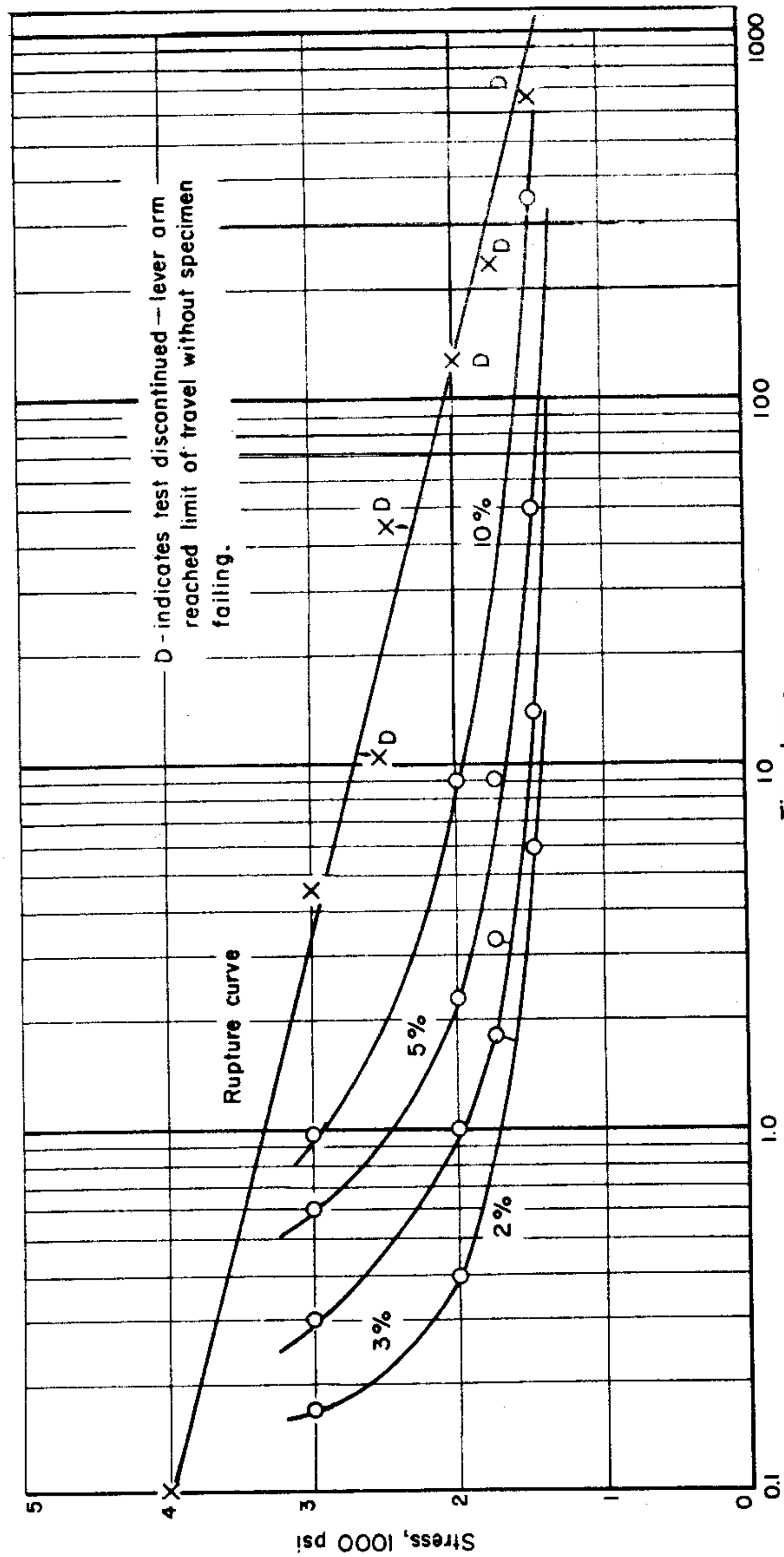


FIGURE 10. DESIGN CURVES FOR TRANSPARENT PMACA AT 250 F

A-14958

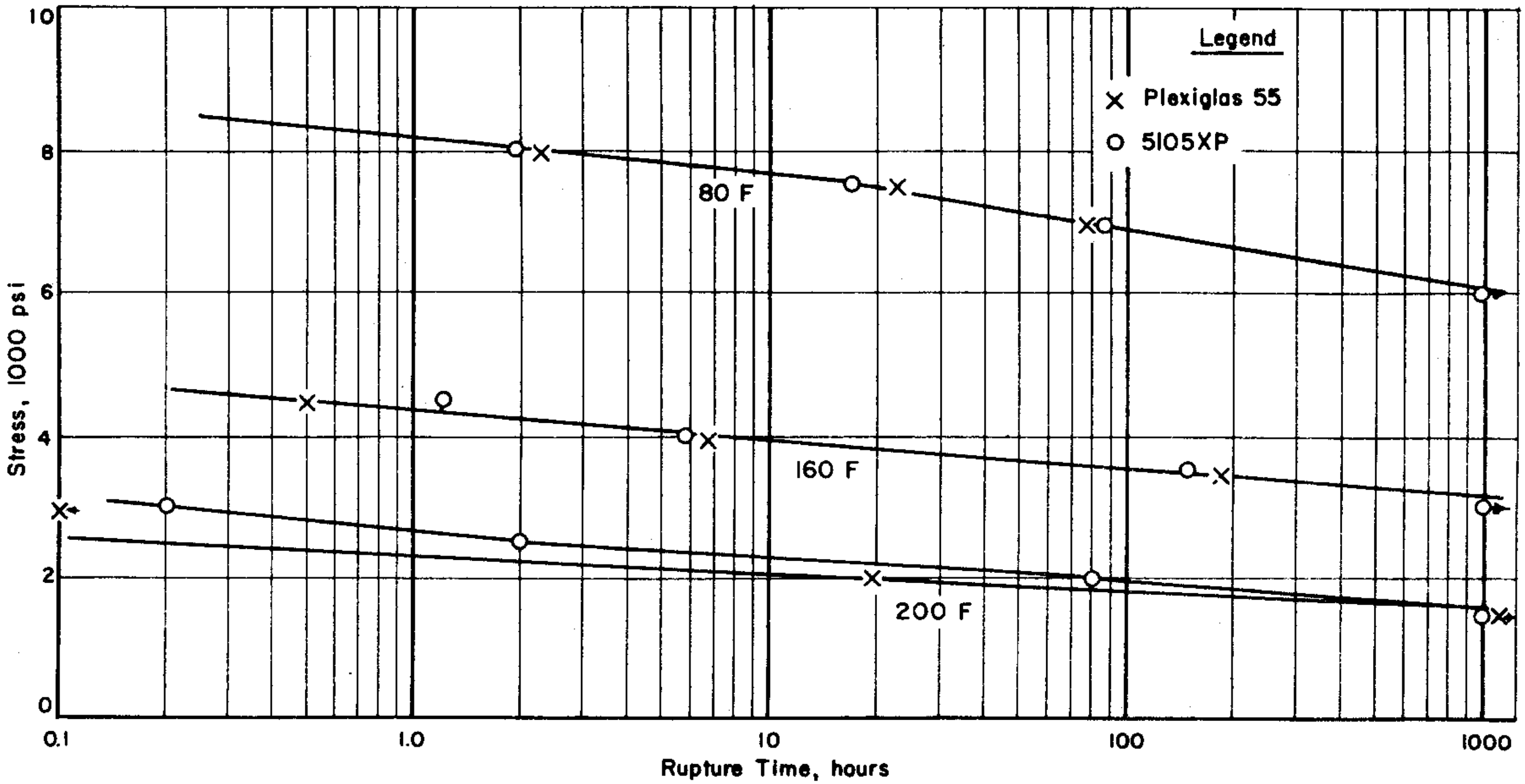


FIGURE 11. STRESS VERSUS RUPTURE-TIME CURVES FOR PLEXIGLAS 55 TRANSPARENT AT 80, 160, AND 200 F AS COMPARED WITH THE 5105XP TRANSPARENT PLASTIC

A-14959

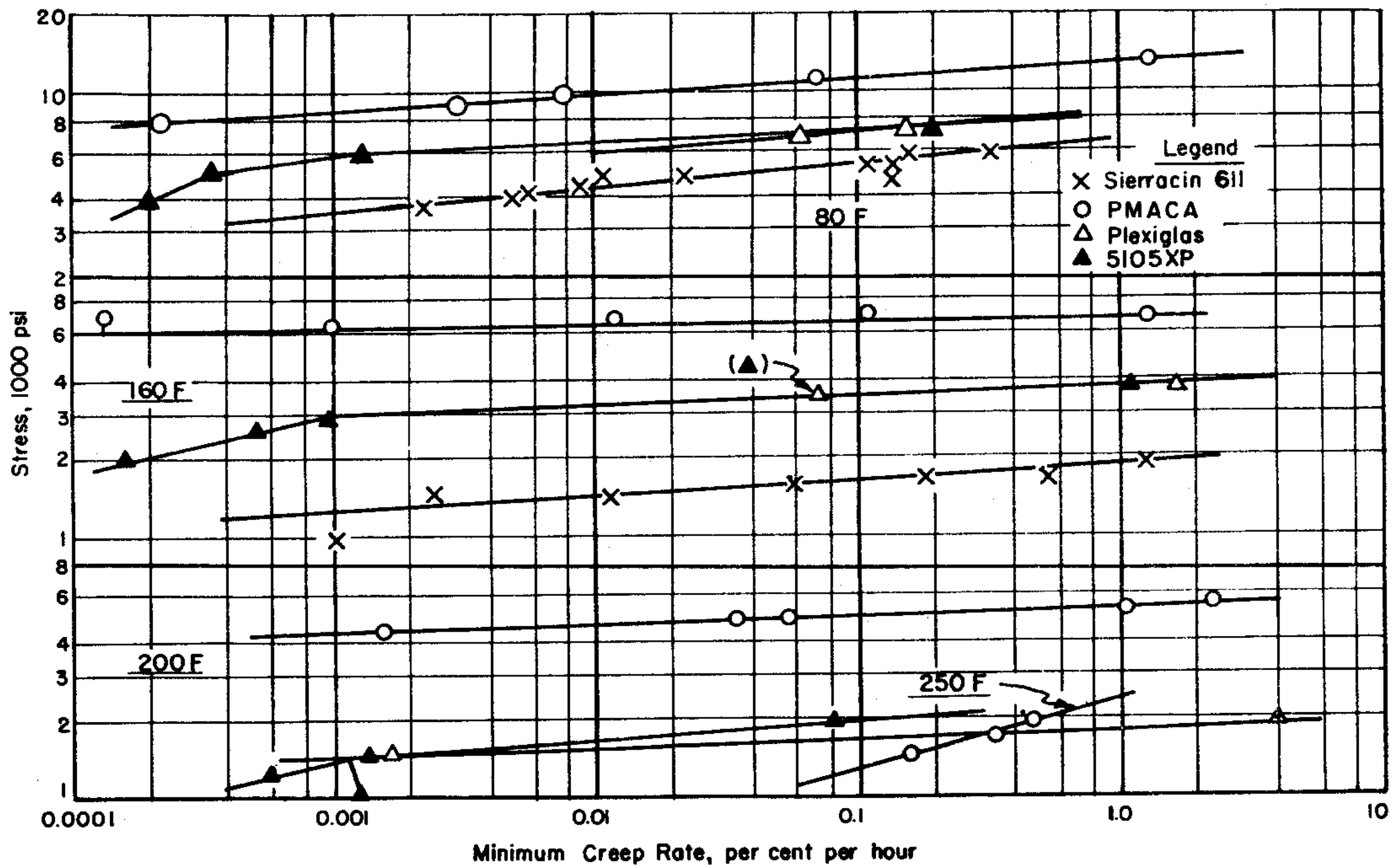


FIGURE 12. STRESS VERSUS CREEP-RATE CURVES FOR SIERRACIN 611, PMACA, 5105XP, AND PLEXIGLAS 55 AT 80, 160, 200, AND 250 F

A-14960

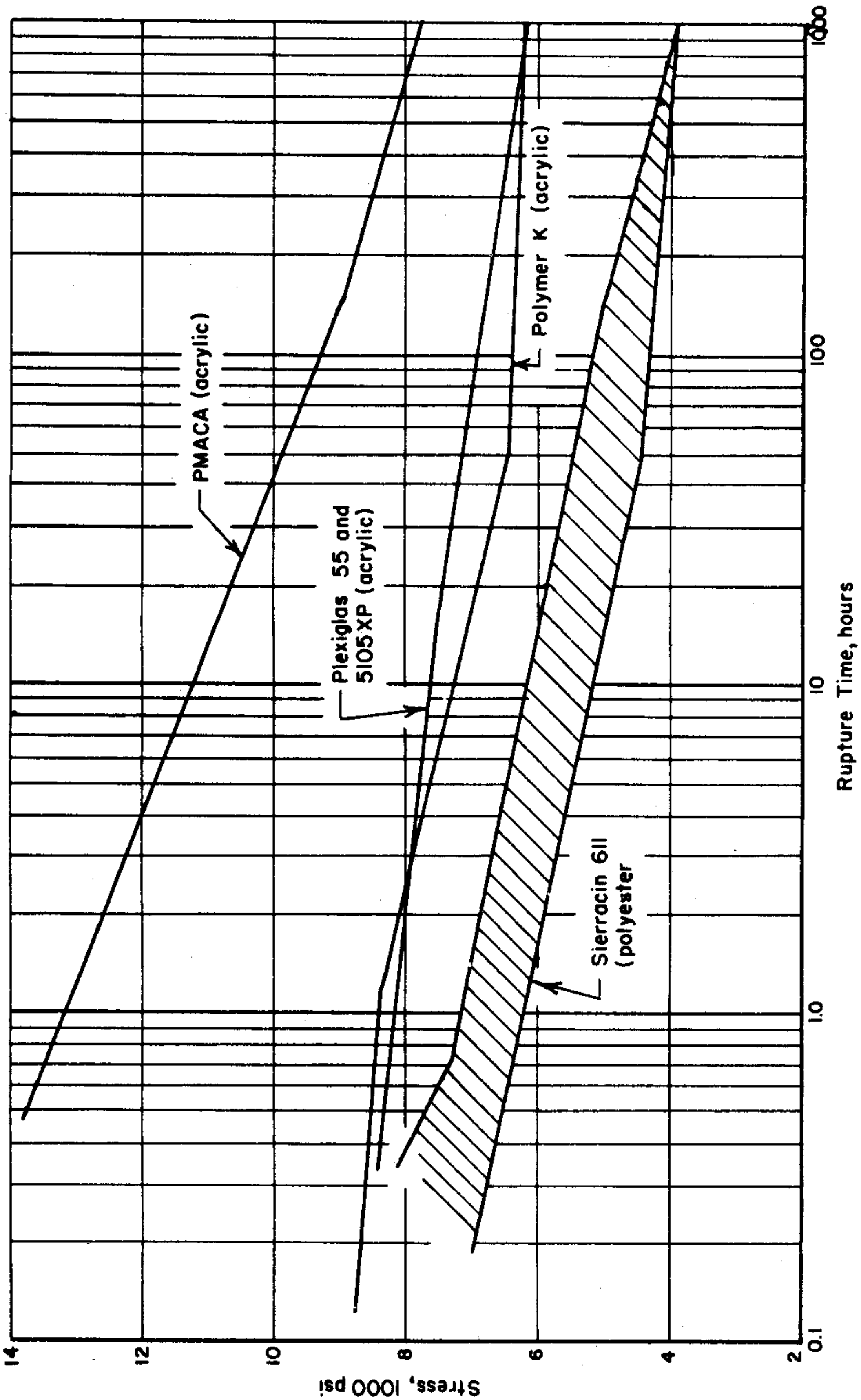


FIGURE 13. STRESS-RUPTURE STRENGTH PROPERTIES OF SEVERAL TRANSPARENT PLASTIC SHEET MATERIALS AT ROOM TEMPERATURE (80 F)

A-14961

(3) After the first exposure in a tube furnace, the specimens were returned to a desiccator to cool and then were weighed.

(4) The specimens were exposed for additional times as desired and were cooled in a desiccator. The weight of sample was determined after each exposure until each specimen was exposed for 1000 hours.

(5) The various per cent weight losses were then calculated, on the basis of the original weight of specimen.

RESULTS AND DISCUSSION

Creep and Creep-Rupture Tests

A series of creep and creep-rupture tests was made on the polyester-resin transparent plastic Sierracin 611, and the acrylates PMACA and Plexiglas 55. The series of tests included creep-rupture tests with rupture times between about 0.1 and 1000 hours, as well as some creep tests that did not fail in 1000 hours. By mutual agreement with WADC, no tests were made at stresses below 500 psi.

Sierracin 611 was tested at 80, 160, and 200 F, and PMACA, at 80, 160, 200, and 250 F. Since Plexiglas 55 is the same material as 5105XP, with an ultraviolet-light absorber added, only three check tests were made on Plexiglas 55 at each of three temperatures — 80, 160, and 200 F. The 5105XP acrylic-resin transparent was previously tested in this evaluation program(2). Extensometers were attached to all test specimens so that creep, as well as rupture data, if failure occurred, could be obtained.

All the creep and creep-rupture data obtained on Sierracin 611, PMACA, and Plexiglas 55, are shown in Tables 1, 2, and 3. These data consist of (1) rupture time or maximum time, if the test is discontinued, (2) minimum creep rate, (3) initial deformation, (4) final deformation reading obtained before failure, (5) time to produce certain designated percentages of deformation, and (6) other pertinent data, if available, such as crazing characteristics and start of third-stage creep.

Some of the data shown in Tables 1, 2, and 3 were then reproduced graphically on semilog coordinates as design curves. The stress was plotted as the ordinate and the log of the rupture time and time to attain certain designated percentages of deformation as the abscissa. Design curves for Sierracin 611 plastic are shown in Figures 5 and 6 for temperatures of 80 and

160 F, respectively. The design curves for the PMACA transparent material are shown in Figures 7, 8, 9, and 10 for temperatures of 80, 160, 200, and 250 F, respectively. Since only a few check tests were made on Plexiglas 55, only the rupture times were plotted, as shown in Figure 11. The stress-rupture strength of the acrylic-resin transparent 5105XP is also shown in Figure 11 for comparison with Plexiglas 55.

Figure 12 shows a log-log plot of the stress versus the minimum creep rate for the three test materials — Sierracin 611, PMACA, and Plexiglas 55. A separate plot is shown for each temperature of 80, 160, and 200 F. A curve for the PMACA material for 250 F is shown in the 200 F plot. As in Figure 11, some creep data on the 5105XP transparent are also shown in Figure 12 for comparison with Plexiglas 55.

As a summary, and also for purposes of relating the strength properties of the various materials, the curves of stress versus rupture time shown in Figures 13, 14, and 15 were prepared. These data are plotted on semilog coordinates similar to the design curves (Figures 5 to 10). Also shown with these curves (Figures 13, 14, and 15) are some stress-rupture data for the acrylic transparents, 5105XP(2) and Polymer K(3), previously tested under this evaluation program. A summary of the rupture-strength properties of the three materials, Sierracin 611, PMACA, and Plexiglas 55, together with Polymer K and 5105XP transparents, is also exhibited below for ease in comparison and evaulation.

Material	Stress, psi, for Hours to Failure: 1	10	100	1000
		80 F		
PMACA	13,200	11,300	9300	7800
Polymer K	8,430	7,310	6440	6300
5105XP	8,210	7,570	6900	6250
Plexiglas 55	8,210	7,570	6900	6250
Sierracin 611	{7,200	6,200	5200	3900
	{6,200	5,200	4300	
		160 F		
PMACA	8900	7700	7200	6650
Polymer K	5360	4400	4050	3700
5105XP	4440	4000	3550	3100
Plexiglas 55	4440	4000	3550	3100
Sierracin 611	2420	1900	1600	1420
		200 F		
PMACA	6220	5620	5080	4630
Polymer K	3850	3450	3220	3000
5105XP	2640	2250	1920	1600

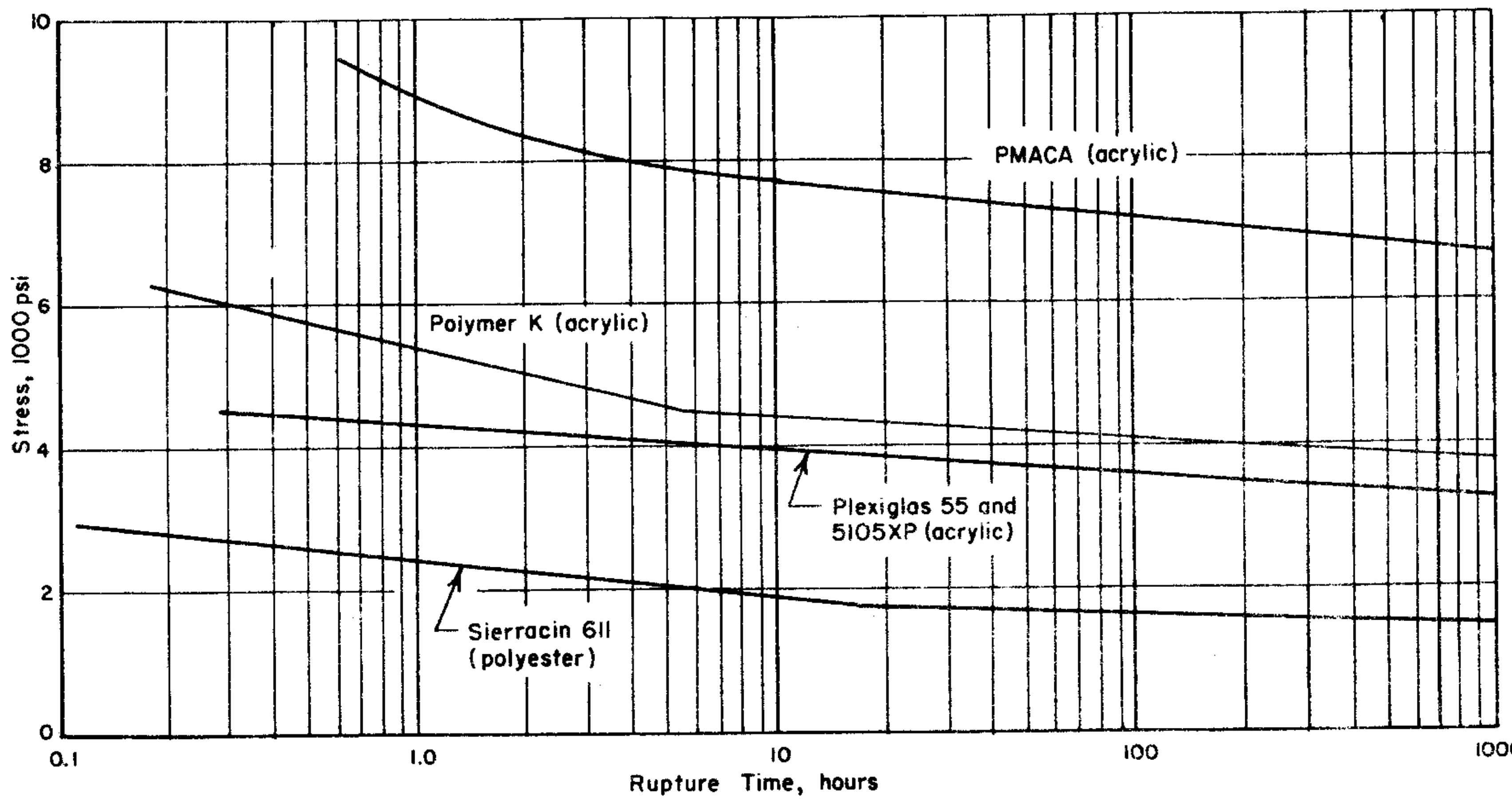


FIGURE 14. STRESS-RUPTURE STRENGTH PROPERTIES OF SEVERAL TRANSPARENT PLASTIC SHEET MATERIALS AT 160 F

A-14962

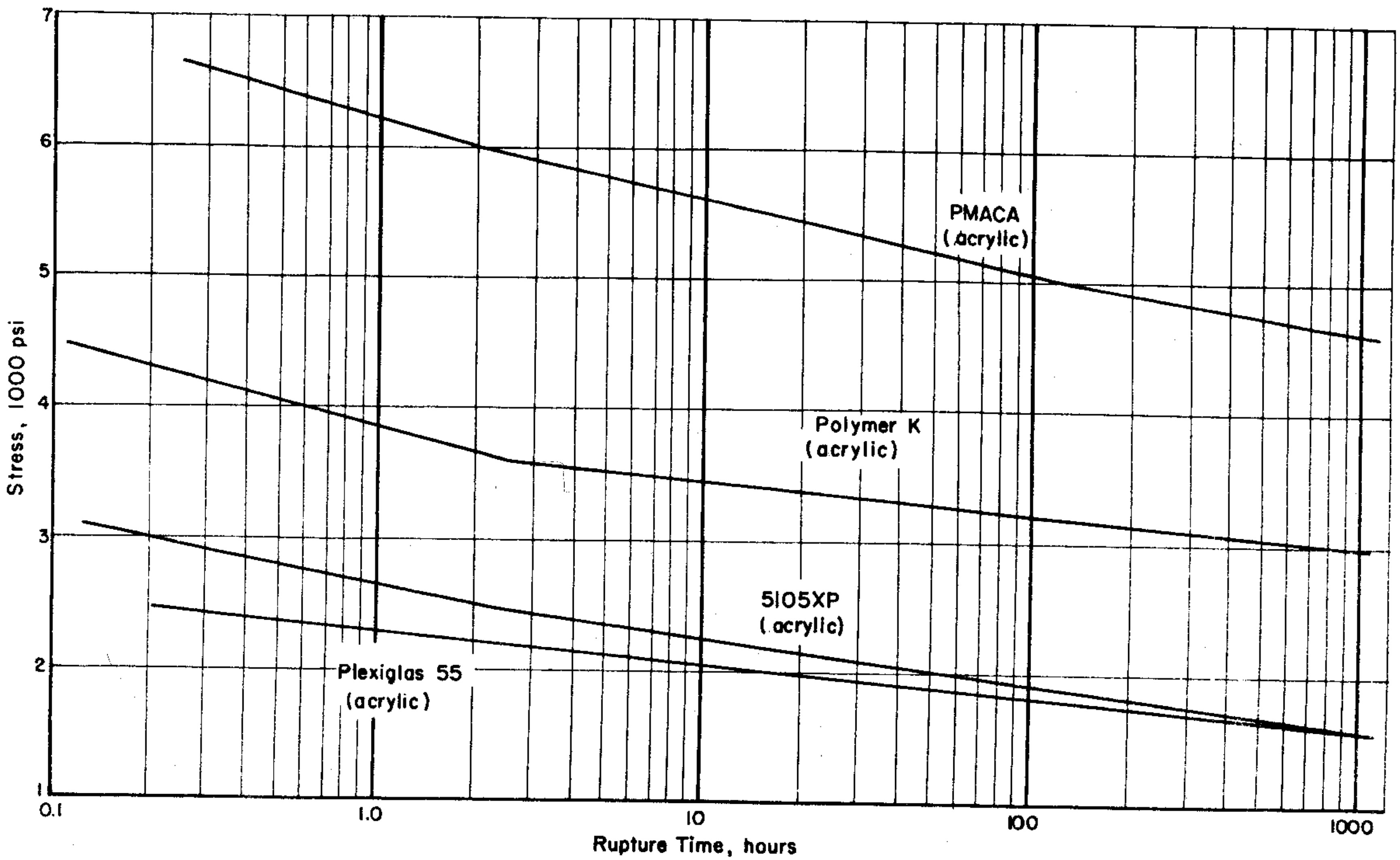


FIGURE 15. STRESS-RUPTURE STRENGTH PROPERTIES OF SEVERAL TRANSPARENT PLASTIC SHEET MATERIALS AT 200 F

A-14963

200 F

Plexiglas 55	2300	2070	1820	1600
Sierracin 611	770	560	350, est.	--

250 F

PMACA	3350	2700	2080	1430
Polymer K	1900	1750	1610	1590

The strength superiority of the polymethyl-alpha-chloroacrylate (PMACA) material over the other transparents is readily apparent from Figures 13, 14, and 15, and the above tabulation. Only at 250 F, after 1000 hours in test, is the strength of PMACA exceeded by that of Polymer K. Since only these two materials were tested at 250 F, no stress-rupture curves were prepared for this temperature.

It is pointed out, as indicated in Figure 10, that most of the tests made on PMACA at 250 F did not actually fail. The specimens were so ductile at this temperature that they elongated to the maximum extent allowed by the testing machine without failing. This maximum amount of deformation was in excess of about 25 per cent but was not measurable because the extensometers became inoperative with such large deformations.

Examination of Figures 5 and 13 shows Sierracin 611 to have a considerable amount of scatter in test results at room temperature. In view of this, a larger number of tests than are usually made at one temperature were conducted on this material. All tests, except two, were made with specimens cut from one panel and, therefore, the scatter cannot be attributed to variations in different panels. Nearly all of these specimens were polished, using rouge and a buffing wheel, and it is possible that nonuniform polishing of the various specimens may have caused the scatter. There seems to be less scatter at the higher temperature of 160 F, which, in turn, may be due to the annealing effect at this temperature.

The Sierracin 611, a polyester-resin material, displays a relatively good creep and creep-rupture strength at room temperature, which is about one-half that of PMACA and nearly equal to that of Plexiglas 55 for the shorter time periods. Sierracin 611 loses its strength quite rapidly with an increase in temperature, having only about one-fourth the strength of PMACA at 160 F and less than one-eighth at 200 F. Very few tests were made at 200 F because of its extremely low strength. A test at 500 psi failed in 21.9 hours, and no additional lower stress tests were then made. The strength of the Sierracin 611 material is very similar to that of Selectron 44, another polyester-resin transparent sheet material.(2)

The few check tests on Plexiglas 55 indicate that this material has creep and creep-rupture strength at 80 and 160 F identical to that of the 5105XP transparent, as shown in Figures 11 through 14 and in the preceding tabulation. As previously mentioned, Plexiglas 55 is 5105XP plastic with an ultraviolet-light absorber added. At 200 F, Plexiglas 55 appears to be slightly weaker than 5105XP (Figures 11 and 12). Since this difference is very slight, it could be attributed to testing scatter or normal variations in properties from panel to panel, rather than to an effect of the ultraviolet-light absorber.

Of the three materials tested, PMACA and Plexiglas 55 crazed during the creep and creep-rupture testing. The time at which crazing started was not determined, however. The specimens were examined after completion of the test, and Tables 2 and 3 indicate whether light, medium, or heavy crazing was observed.

Short-Time Tensile Tests

Short-time tensile tests were conducted on all three test materials — Sierracin 611, PMACA, and Plexiglas 55 — at 80, 160, 200, and 250 F. Two tests were also made on PMACA at 300 F. The results of these tensile tests are displayed in Tables 4, 5, and 6, and also graphically in Figure 16. Load-strain curves for the three materials are shown in Figures 17, 18, and 19.

Unless indicated otherwise, all tensile tests were pulled at a strain rate of 0.05 inch per minute whenever an extensometer was attached to the specimens for recording deformation. When the extensometer was not in use, the strain rate was changed to 0.20 inch per minute.

Because of the possible notching effect of the extensometer clamps and consequent early failure, tests were made both with and without extensometers. In nearly all cases, tests made without the extensometers showed the materials to have a higher tensile strength. Also, extensometers were not used at some of the higher temperatures when the materials were too soft to hold the extensometer rigidly enough to function properly.

Examination of Figure 16 shows the polymethyl-alpha-chloroacrylate (PMACA) material to have a minimum of 50 per cent greater tensile strength than any of the other materials tested. The tensile strength of the PMACA plastic ranges from about 15,700 psi at room temperature to 4700 psi at 250 F. The tests at 300 F showed this material to have a tensile strength of only about 275 psi at this temperature.

Some supplementary tests were made on PMACA plastic at 250 F to determine the effect of holding time prior to testing. Test specimens were held 0, 15, 30, and 45 minutes before pulling. The results of these tests are shown in Table 5. Only a limited number of tests were conducted because of a shortage of material. It should also be mentioned that all other tests were maintained at test temperature about 1/2 hour prior to actual testing. The single test made with no holding time showed the highest tensile

TABLE 4. SHORT-TIME TENSILE DATA ON TRANSPARENT SIERRACIN 611 AT TEMPERATURES RANGING FROM 80 TO 250 F

Specimen	Temperature, F	Area, inch^2	Tensile Strength, psi	Elastic Modulus, 10^6 psi	Rate of Pull, inch/minute
SA-T1	80	0.0745	9,700	0.60	0.06
SA-T2	80	0.0742	9,500	0.54	0.06
SA-T3	80	0.0728	8,700	0.48	0.06
SA-T6	80	0.0742	9,800	0.47	0.06
SA-T4	80	0.0735	8,800	0.48	0.02
SA-T5	80	0.0731	9,700	(a)	0.20
Average	--	--	9,330	0.51	
SA-T9	80	0.0749	10,500	(b)	0.06
SA-T20	80	0.0738	10,100	(b)	0.06
SB-T13	80	0.0748	10,700	(b)	0.20
SB-T4	80	0.0752	11,000	(b)	0.20
Average	--	--	10,580		
SB-T2	160	0.0756	3,070	(a)	0.05 and 0.20
SB-T3	160	0.0758	2,930	0.066	0.05 and 0.20
SB-T5	160	0.0750	4,140	0.213	0.05 and 0.20
Average	--	--	3,380	0.140	
SB-T1	160	0.0753	3,560	(b)	0.20
SB-T4	160	0.0752	4,070	(b)	0.20
Average	--	--	3,820		
SB-T6	200	0.0755	795	0.075	0.05 and 0.20
SB-T8	200	0.0755	927	0.039	0.05 and 0.20
SB-T11	200	0.0750	613	0.027	0.05 and 0.20
Average	--	--	780	0.047	
SB-T7	200	0.0759	1,850	(b)	0.20
SB-T10	200	0.0755	2,130	(b)	0.20
Average	--	--	1,990		
SB-T15	250	0.0750	786	(b)	0.20
SB-T16	250	0.0742	849	(b)	0.20
SB-T17	250	0.0745	698	(b)	0.20
Average	--	--	780		

Note: This material showed no crazing after test.

(a) Extensometer slipped during test.

(b) No extensometer was used.

TABLE 5. SHORT-TIME TENSILE DATA ON TRANSPARENT PMACA AT TEMPERATURES RANGING FROM 80 TO 300 F

Specimen	Temperature, F	Area, inch^2	Tensile Strength, psi	Elastic Modulus, 10^6 psi	Remarks
TMB-T4	80	0.0741	13,500	1.01	Lightly crazed
TMB-T5	80	0.0734	11,200	0.82	Lightly crazed
TMB-T14	80	0.0727	17,300	1.06	Lightly crazed
TMB-T15	80	0.0742	17,500	0.81	Lightly crazed
Average	--	--	14,900	0.92	
TMA-T4	80	0.0724	17,100	(b)	Lightly crazed
TMA-T5	80	0.0719	17,200	(b)	Lightly crazed
TMA-T6[a]	80	0.0716	14,800	(b)	Lightly crazed
TMA-T7[a]	80	0.0716	13,800	(b)	Lightly crazed
Average	--	--	15,700		
TMA-T8	160	0.0716	11,700	0.56	Medium crazed
TMA-T9	160	0.0718	12,000	0.63	Medium crazed
TMA-T12	160	0.0724	11,300	0.62	Medium crazed
Average	--	--	11,700	0.60	
TMA-T11	160	0.0718	12,000	(b)	Medium crazed
TMA-T13	160	0.0730	12,700	(b)	Medium crazed
TMA-T15	160	0.0742	12,300	(b)	Medium crazed
TMA-C2[a]	160	0.0794	10,900	(b)	Medium crazed
Average	--	--	12,000		
TMA-T14	200	0.0733	8,900	0.44	Heavily crazed
TMA-T16	200	0.0738	9,700	0.60	Heavily crazed
TMA-T18	200	0.0754	8,100	0.40	Heavily crazed
Average	--	--	8,900	0.48	
TMA-T17	200	0.0744	9,000	(b)	Heavily crazed
TMB-T1	200	0.0751	9,700	(b)	Heavily crazed
TMB-T2	200	0.0728	8,900	(b)	Heavily crazed
TMC-C1	200	0.0792	6,700	(b)	Heavily crazed
Average	--	--	8,600		
TMA-T10	250	0.0724	4,000	0.35	Heavily crazed
TMB-T6	250	0.0732	5,700	0.38	Heavily crazed
TMB-T7	250	0.0719	4,300	Gage slipped	Heavily crazed
Average	--	--	4,700	0.37	
		Specimens Tested Upon Reaching Test Temperature			
TMC-C4	250	0.0722	6,000	(b)	Heavily crazed
		Held 15 Minutes at Test Temperature Before Testing			
TMB-T19	250	0.0744	4,800	(b)	Heavily crazed
TMB-T17	250	0.0743	4,400	(b)	Heavily crazed
Average	--	--	4,600		
		Held 30 Minutes at Test Temperature Before Testing			
TMB-T8	250	0.0727	5,800	(b)	Heavily crazed
TMB-T9	250	0.0715	5,900	(b)	Heavily crazed
TMB-T10	250	0.0710	5,800	(b)	Heavily crazed
TMB-T20	250	0.0741	4,300	(b)	Heavily crazed
TMB-T18	250	0.0742	4,300	(b)	Heavily crazed
Average	--	--	5,220		
		Held 45 Minutes at Test Temperature Before Testing			
TMB-T16	250	0.0729	5,200	(b)	Heavily crazed
TMB-T11	300	0.0727	275	(b)	Heavily crazed
TMB-T12	300	0.0728	275	(b)	Heavily crazed
Average	--	--	275		

Note: When stress-strain curves were being recorded, the rate of pull was 0.05 inch per minute. After the extensometer was removed, the rate of pull was increased to 0.20 inch per minute. When no extensometer was used, the rate of pull was 0.20 inch per minute throughout the test.

(a) Specimens were annealed after machining.
(b) No extensometer was used.

TABLE 6. SHORT-TIME TENSILE DATA ON TRANSPARENT PLEXIGLAS 55 AT TEMPERATURES RANGING FROM 80 TO 250 F

Specimen	Temperature, F	Area, inch^2	Tensile Strength, psi	Elastic Modulus, 10^6 psi
P55A-T1	80	0.0761	10,000	0.52
P55A-T3	80	0.0759	10,100	(a)
P55A-T4	80	0.0739	10,400	0.47
Average	--	--	10,170	0.49
P55A-T9	160	0.0736	5,500	0.29
P55A-T10	160	0.0722	5,600	0.30
P55A-T14	160	0.0732	6,200	(a)
P55A-T11	160	0.0736	5,700	(b)
P55A-T13	160	0.0716	5,600	(b)
Average	--	--	5,720	0.29
P55A-T17	200	0.0758	2,970	0.22
P55A-T18	200	0.0756	3,660	0.24
P55A-T8	200	0.0741	3,520	(b)
P55A-T15	200	0.0750	3,670	(b)
Average	--	--	3,600	0.23
P55A-T5	250	0.0756	502	(a)
P55A-T19	250	0.0748	374	0.013
P55A-T6	250	0.0747	510	(b)
P55A-T7	250	0.0750	506	(b)
Average	--	--	470	0.013

Notes: 1. Specimens with extensometer attached were pulled at 0.05 inch per minute to obtain stress-strain curve and increased to 0.20 inch per minute after the extensometer was removed. Tests with no extensometer were pulled at 0.20 inch per minute.

2. Medium to heavy crazing was exhibited by most of the tests.

(a) Extensometer slipped during test.

(b) No extensometer was used.

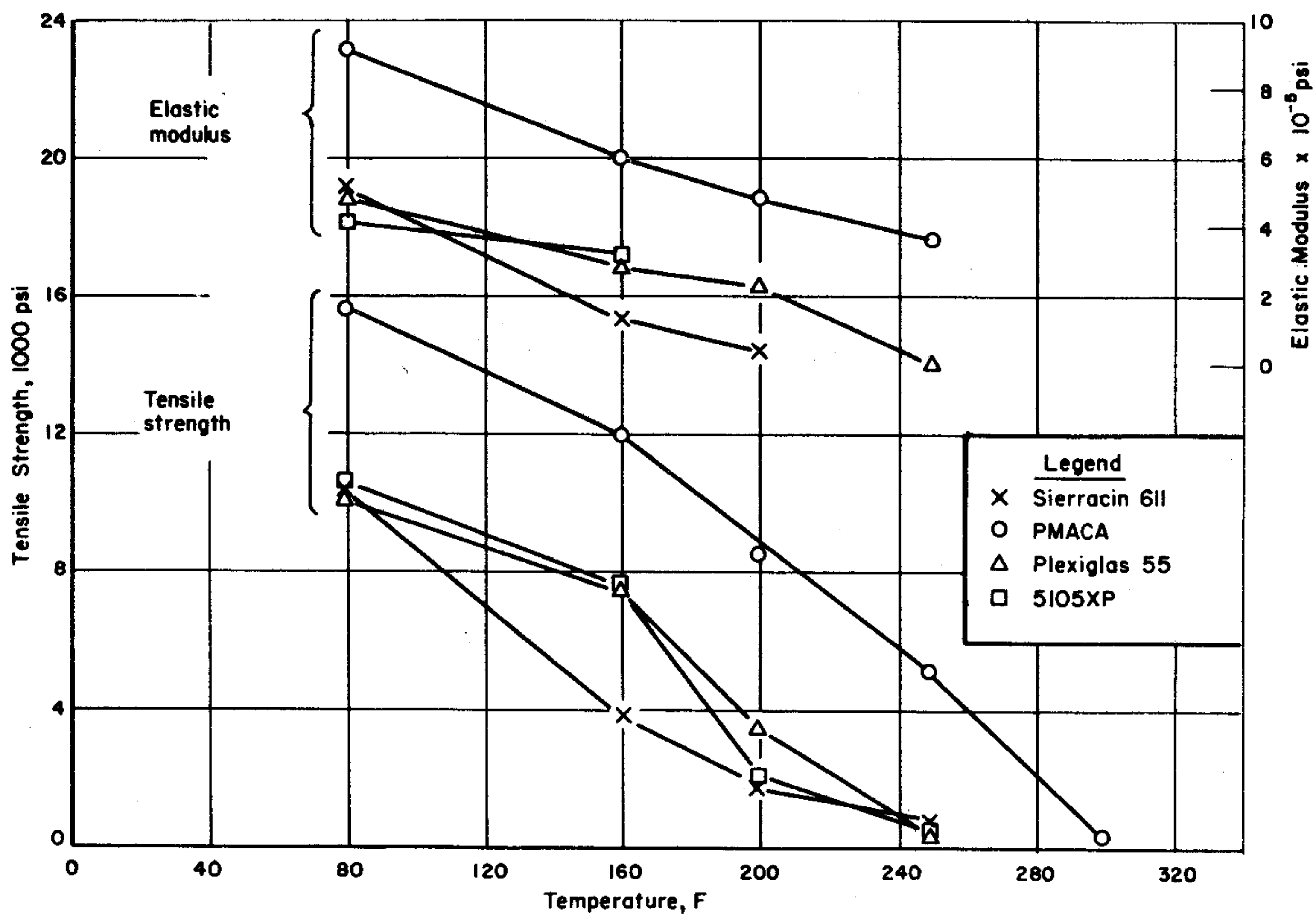


FIGURE 16. SHORT-TIME TENSILE PROPERTIES OF SEVERAL TRANSPARENT PLASTIC SHEET MATERIALS AT TEMPERATURES RANGING FROM 80 TO 300 F

A-14964

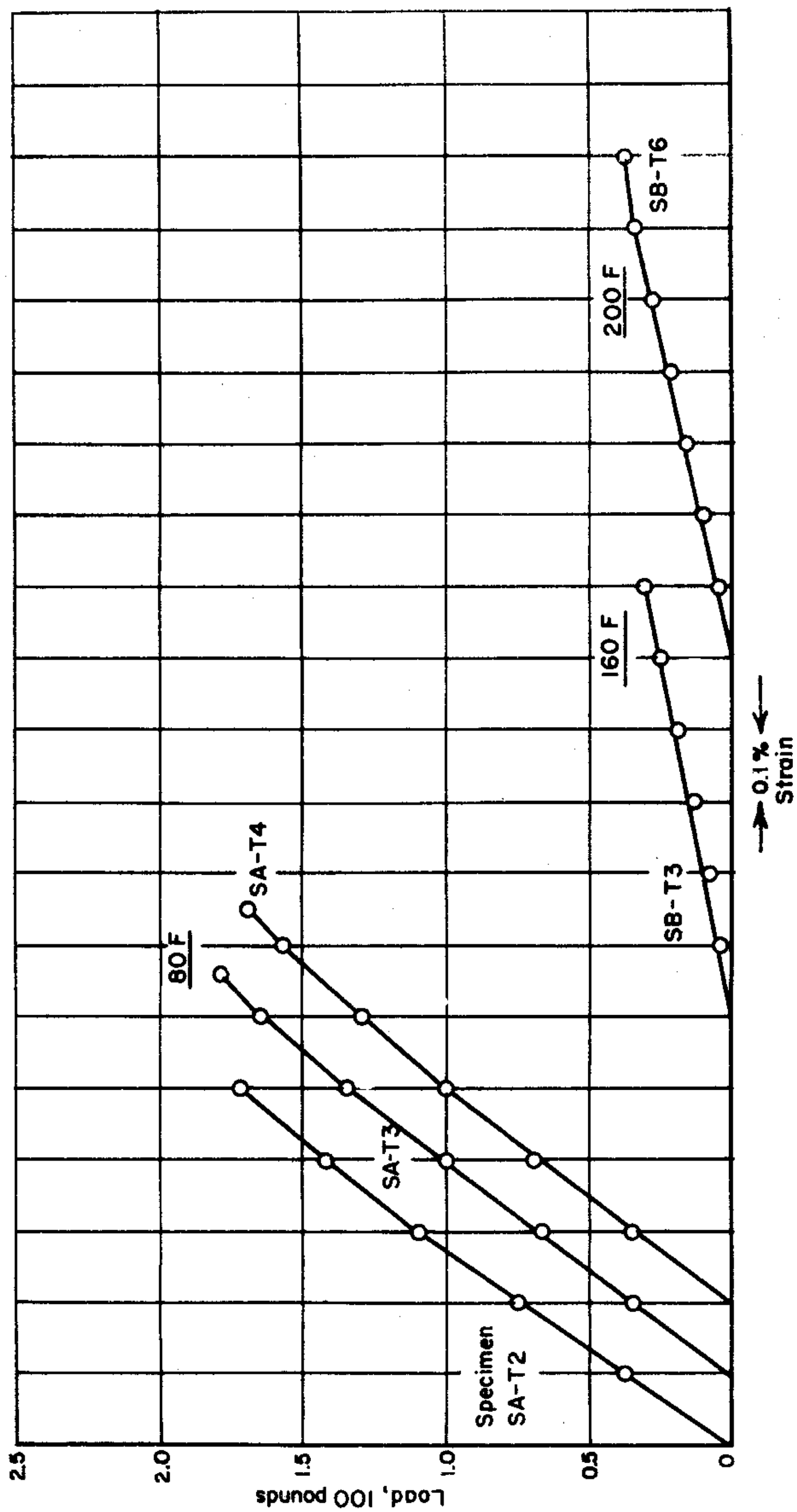


FIGURE 17. LOAD-STRAIN CURVES FOR TRANSPARENT SIERRACIN 611 AT 80, 160, AND 200 F

A-14965

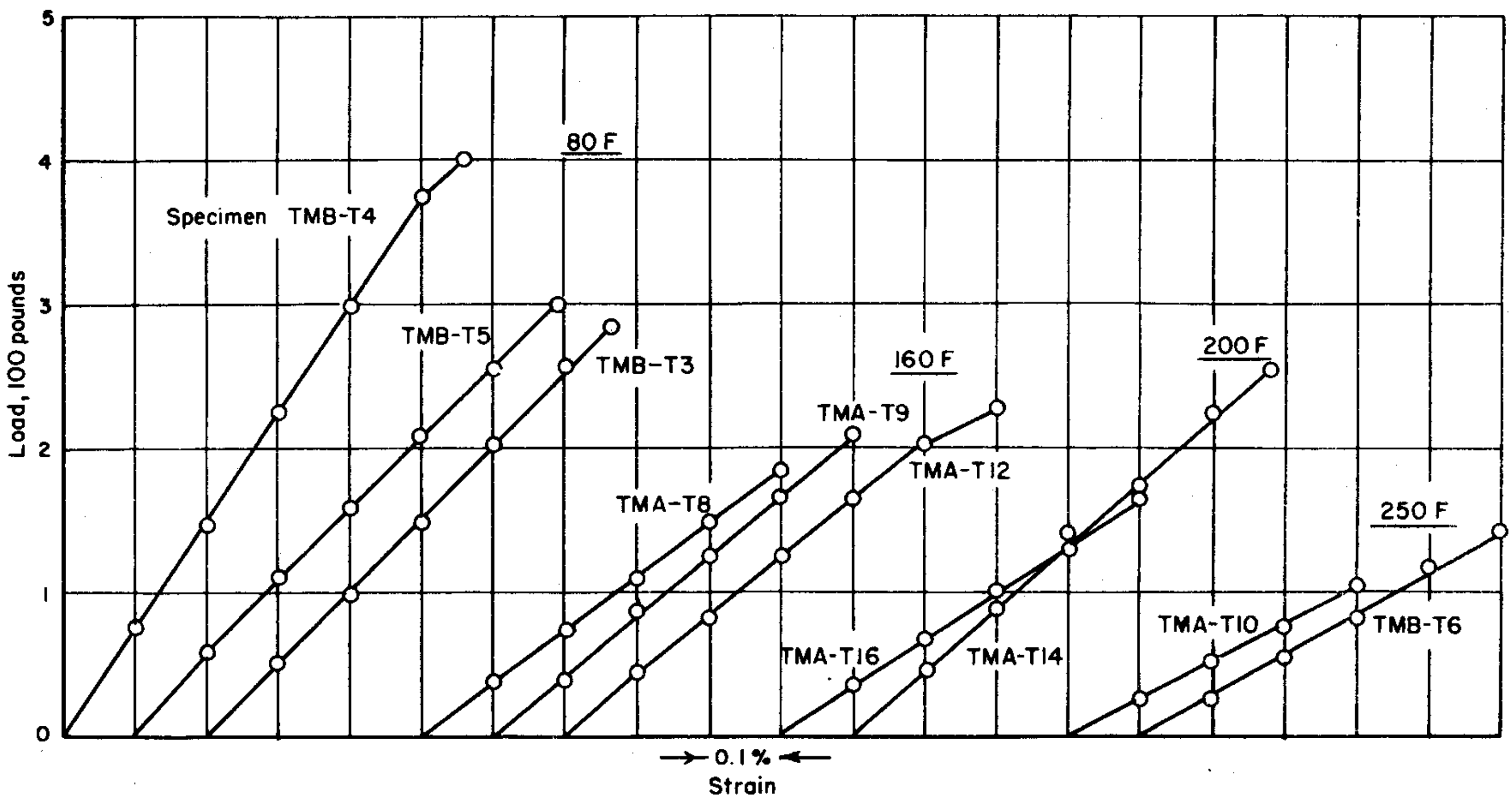


FIGURE 18. LOAD-STRAIN CURVES FOR TRANSPARENT PMACA AT 80, 160, 200, AND 250 F

A-14966

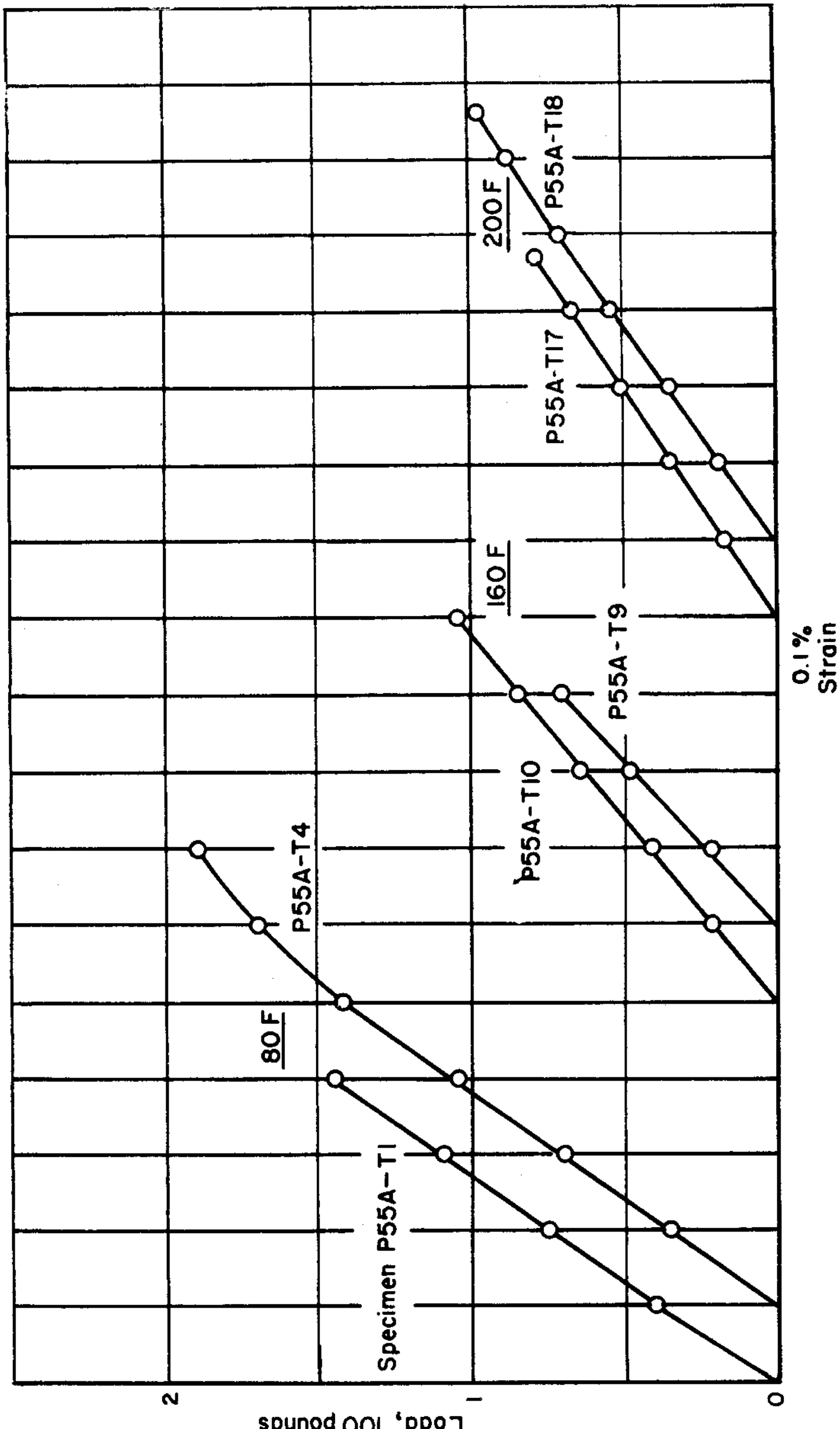


FIGURE 19. LOAD-STRAIN CURVES FOR TRANSPARENT PLEXIGLAS 55 AT 80, 160, AND 200 F

A-14967

strength — 6000 psi. The lowest tensile strength, 4600 psi, was displayed by the 15-minute-holding-time tests. The longest holding-time tests, 30 and 45 minutes, exhibited the intermediate tensile strengths of about 5200 psi. Thus, the tensile strength of PMACA varies from 4600 to 6000 psi, for a total variation of 1400 psi. It is doubtful, however, that this variation can be attributed to a difference in holding time, since there is a scatter of 1600 psi (from 4300 to 5900 psi) for the 30-minute holding time alone. The regular tensile tests on PMACA at 200 F displayed a scatter of 2300 psi, ranging from 6700 to 9000 psi. Therefore, because of (1) insufficient tests and (2) an apparent large scatter in existing test results, it is not known definitely whether holding time has affected the tensile strength of PMACA. From the data available, it does not seem likely that it does.

The elastic modulus of the PMACA transparent ranges from about 920,000 psi at room temperature to 370,000 psi at 250 F. The material was too soft and weak at 300 F for an extensometer to be attached to the specimen. The elastic modulus of PMACA is at least 50 per cent greater than it is for any other transparent plastic tested under this program at all test temperatures (Figure 16).

PMACA and Plexiglas 55 displayed a tendency to craze when tensile tested. The PMACA material displayed a light craze at room temperature, medium craze at 160 F, and a heavy craze at 200, 250, and 300 F. Plexiglas 55, generally, showed medium to heavy crazing characteristics at all test temperatures.

Plexiglass 55 has a tensile strength and modulus of elasticity very similar to those for 5105XP, as expected. There are some small differences in properties of these two materials that probably can be attributed to variations in material and testing procedure.

Sierracin 611 has tensile-strength properties at 80 and 250 F about the same as those for Plexiglas 55 and 5105XP transparents. At the intermediate test temperatures of 160 and 200 F, Sierracin 611 appears to be inferior to these two materials in both elastic modulus and tensile strength. Different rates of extension were used on the specimens of Sierracin 611 at room temperature in order to determine whether there was any effect on the tensile strength. Although the number of tests was limited, a variation in rate of extension from 0.02 to 0.20 inch per minute did not show any appreciable change in the tensile-strength properties.

Deterioration Tests

Deterioration or exposure tests were made on only the Sierracin 611 and PMACA transparents. Since Plexiglas 55 is nearly the same as 5105XP transparent, which was previously tested for deterioration, no such tests were made on it. The results of these deterioration tests are shown in Table 7 and Figure 20. Also shown in Figure 20 are deterioration data for

TABLE 7. DETERIORATION LOSSES IN TRANSPARENTS SIERRACIN 611 AND PMACA AT TEMPERATURES OF 160, 200, 250, AND 300 F

Material	Temperature, F	Weight Loss, per cent, After Indicated Exposure						
		1/2 Hour	3 Hours	10 Hours	24 Hours	100 Hours	200 Hours	1000 Hours
Sierracin 611	160	--	--	--	0.04	0.12	0.19	0.30
PMACA	160	--	--	--	0.02	0.07	0.10	0.18
Sierracin 611	200	--	--	--	0.14	0.31	0.34	0.51
PMACA	200	--	--	--	0.05	0.12	0.18	0.29
Sierracin 611	250	--	--	--	0.34	0.59	0.68	1.09
PMACA	250	--	--	--	0.10	0.18	0.22	0.29
Sierracin 611	300	0.33	0.67	1.05	1.24	2.17	2.46	4.41
PMACA	300	0.08	0.17	0.29	0.62	1.72(a)	(b)	(b)

Note: Data are averages of two tests on each material.

(a) Weight loss after 42 hours rather than 100.

(b) No tests were made beyond 42 hours' exposure time because of decomposition of the material.

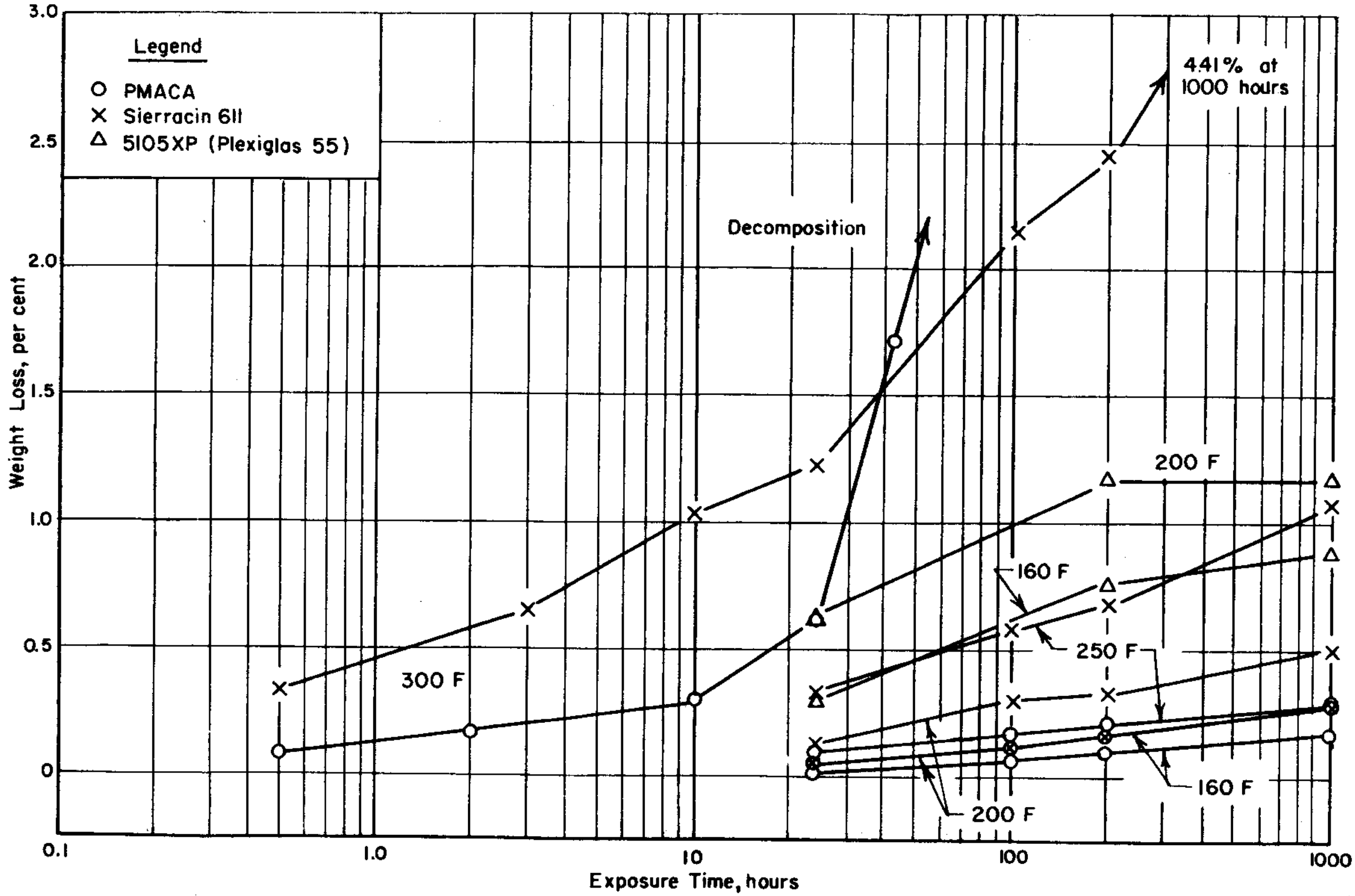


FIGURE 20. WEIGHT LOSS VERSUS EXPOSURE-TIME CURVES FOR TRANSPARENT SIERRACIN 611, PMACA, AND 5105XP (PLEXIGLAS 55) AT TEMPERATURES RANGING FROM 160 TO 300 F

A-14968

the 5105XP transparent taken from a previous report[2], in place of data on Plexiglas 55, which were not obtained.

Deterioration losses for Sierracin 611 and PMACA are relatively low at 160, 200, and 250 F. Sierracin 611 shows a maximum of 1.09 per cent reduction in weight after 1000 hours at 250 F, and PMACA shows only 0.29 per cent weight loss after a similar exposure. As shown in Figure 20, the deterioration losses for 5105XP transparent, which was tested at 160 and 200 F only, are much greater than they are for the other two materials after identical exposures.

Both Sierracin 611 and PMACA exhibit rather large increases in weight loss after exposure at 300 F, as compared with losses at the lower temperatures. Sierracin 611 deteriorated 0.33 per cent after only 1/2 hour at 300 F and 4.41 per cent after 1000 hours. PMACA showed only 0.08 per cent loss in weight after 1/2 hour at 300 F, which increased to 1.72 per cent after 42 hours' exposure. Some gas pockets were noticed in the PMACA samples after 24-hour exposure indicating some sort of decomposition. These samples were therefore examined and weighed again after only 18 additional hours (42 hours total). The weighing showed that the specimens had deteriorated from 0.62 per cent after 24-hours' exposure to 1.72 per cent after 42 hours (Figure 20). Visual inspection of the test samples at this time showed them to be filled with gas bubbles, causing the specimens to be enlarged. In analyzing this reaction, one possible explanation is that the polymethyl-alpha-chloroacrylate (PMACA) material depolymerizes, with the monomer gasifying and forming the gas bubbles. In view of this reaction taking place, no further exposures were made of PMACA beyond 42 hours.

REFERENCES

(1) WADC Technical Report 52-38, February, 1952, entitled "Elevated- and Room-Temperature Properties of Transparent Acrylic Sheet Materials".

(2) WADC Technical Report 52-292, November, 1952, entitled "Elevated- and Room-Temperature Properties of Selectron 44 and 5105XP Transparent Plastic Sheet Materials".

(3) WADC Technical Report 54-429, October, 1954, entitled "Elevated- and Room-Temperature Properties of Polymer K Transparent Plastic Sheet Material".

JAV:GRR:WFS/lla