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ELEVATED- AND ROOM- TEMPERATURE PROPERTIES OF TRANSPARENT ACRYLIC SHEET MATERIALS

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ELEVATED- AND ROOM- TEMPERATURE PROPERTIES OF TRANSPARENT ACRYLIC SHEET MATERIALS

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Battelle Memorial Institute

February 1952

Materials Laboratory
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Wright-Patterson Air Force Base, Ohio

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FOREWORD

This report was prepared by Battelle Memorial Institute under Air Force Contract Number AF 33(038)-10818, Research and Development Order No. R-604-303, Aircraft Structural Plastic Laminates. The work was administered under the direction of the Materials Laboratory, Research Division, Wright Air Development Center. Captain D. Rosato acted as project engineer.

ABSTRACT

Two regular grades of transparent acrylic sheet, Plexiglas Ia and Lucite HC-201, and two heat-resistant grades, Lucite HC-202 and Plexiglas II, were tested in tensile creep and creep rupture, crazing, short-time tensile, and deterioration at room temperature, 160°, and 200°F.

The creep and creep-rupture tests indicated that the heat-resistant variety was considerably stronger than the regular grade, even at room temperature. At 160° and 200°F the superiority of the heat-resistant grade was much greater. At 200°F the regular acrylate sheet did not have any practical load-carrying ability.

The heat-resistant material was also much superior to the regular acrylate sheet in resistance to crazing at elevated temperatures. A linear relationship exists between temperature and stress for incipient crazing in the heat-resistant acrylate over the temperature range of this investigation. The stress to produce crazing decreased about 15 psi for each degree increase in temperature.

PUBLICATION REVIEW

Manuscript Copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Research Division

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SUMMARY

Tensile creep and creep-rupture, crazing, short-time tensile, and deterioration tests were made on two regular (Plexiglas Ia and Lucite HC-201) and two heat-resistant (Lucite HC-202 and Plexiglas II) grades of acrylate sheet at room temperature, 160°, and 200°F.

In general, the data obtained were within the normal scatter band for materials of this type. The following tabulation summarizes the rupture data for the materials tested:

Material	Temperature, °F	Stress, psi, to Produce Rupture in 10 Hours	100 Hours	1000 Hours
Plexiglas Ia	80	5,750	5,050	4,400
Lucite HC-201	80	5,200	4,550	3,900
Lucite HC-202	80	7,400	7,000	6,300
Plexiglas II	80	7,400	6,800	6,100 Est.
Plexiglas Ia	160	1,750	1,300	1,050
Lucite HC-201	160	1,350	1,250	1,200
Lucite HC-202	160	3,320	3,050	2,770 Est.
Plexiglas II	160	3,290	3,000	2,700
Lucite HC-202	200	2,050	1,700	1,300
Plexiglas II	200	1,700	1,350	1,000

Note: Complete series of tests were made on Plexiglas Ia and Lucite HC-202, and check tests on Lucite HC-201 and Plexiglas II.

At 200°F, the regular acrylate sheet did not have any practical load-carrying ability.

The heat-resistant material was much superior to the regular variety in resistance to crazing at elevated temperatures. The following tabulation is a summary of the crazing data:

Material	Temperature, °F	Estimated Stress, psi, to Produce Crazing in 10 Hours	100 Hours	1000 Hours
Plexiglas Ia	80	2,850	2,500	2,100
Lucite HC-202	80	3,450	2,800	2,500
Plexiglas Ia	160	700	450	200
Lucite HC-202	160	2,250	1,750	1,300
Lucite HC-202	200	1,650	1,200	700

The short-time tensile strength of the regular material ranged from 8240 psi at room temperature to 150 psi at 200°F. The heat-resistant material varied from 9980 psi at room temperature to 2660 psi at 200°F.

All of the materials were quite stable, as shown by the deterioration tests. None of the materials lost more than 0.69 per cent of its weight after exposure at 200°F for 1000 hours.

INTRODUCTION

This report covers work done under Contract Number AF 33(038)-10818 and is concerned with four acrylic materials:

A. Two regular acrylates
   1. Plexiglas Ia
   2. Lucite HC-201

B. Two heat-resistant acrylates
   1. Lucite HC-202
   2. Plexiglas II

Tensile creep and creep-rupture, crazing, short-time tensile, and deterioration tests were conducted on each of the above materials. Temperatures of interest were between room temperature (80°F) and 200°F.

The short-time tensile tests were made in a Baldwin-Southwark Universal Testing Machine. Deformations were measured, wherever possible, with a microformer extensometer. The creep, creep-rupture, and crazing tests were made in standard Battelle creep frames and furnaces. Test procedures are described briefly in Appendix I.

The platinum-strip type of extensometer was used to measure deformation in the creep and creep-rupture tests.

SPECIFICATIONS OF MATERIALS TESTED

The four acrylate materials tested under this program were obtained according to specifications given in the contract. The specifications and sheet identification were as follows:

Plexiglas Ia (regular)
- Supplier and manufacturer: Rohm and Haas Company
- Specification number: AN-P-44a
- Size panel: 3 x 4 feet x 1/4 inch thick
- Mix number: W525-21

Lucite HC-201 (regular)
- Supplier and manufacturer: E. I. du Pont de Nemours and Company, Inc.
- Specification number: AN-P-44a
- Size panel: 3 x 4 feet x 1/4 inch thick
- Sheet number: 13733

Lucite HC-202 (heat resistant)
- Supplier and manufacturer: E. I. du Pont de Nemours and Company, Inc.
- Specification number: MIL-P-5425
- Size panel: 3 x 4 feet x 1/4 inch thick
- Sheet number: 2533

Plexiglas II (heat resistant)
- Supplier and manufacturer: Rohm and Haas Company
- Specification number: MIL-P-5425
- Size panel: 3 x 4 feet x 1/4 inch thick
- Mix number: WLK569-33

This evaluation program was carried out to determine the level of properties of the regular and the heat-resistant grades of acrylate sheet, and the differences between them. It is emphasized that the data included in this report were obtained on specimens from only one lot of each of the materials. Tests of other lots of the materials would probably give slightly different values. Therefore, minor variations in the properties of material in the same grade are not necessarily significant and should not be used to rate the materials according to strength characteristics.

PREPARATION AND HEAT TREATMENT OF TEST SPECIMENS

The test materials were handled with extreme care during the machining operations. The protective paper covering had to be removed from the specimen material before machining because the cutting tool tended to remove it and it was difficult to keep the specimens from slipping under the paper. No lubricant was used during the machining operation and care was taken that the specimens did not overheat. No undercutting was noticed at the fillets.

The machined specimens were annealed (stress relieved) prior to testing. The regular acrylates (Plexiglas Ia and Lucite HC-201) were heated for 30 minutes at 125°C (257°F). The heat-resistant acrylates (Lucite HC-202 and Plexiglas II) were heated for 30 minutes at 145°C (293°F). The specimens were suspended from one end during the annealing operation. All materials were allowed to cool to room temperature in about 1-1/2 to 2 hours.

TENSILE CREEP AND CREEP-RUPTURE, AND CRAZING TESTS

Tensile creep and creep-rupture tests were made on two regular and two heat-resistant grades of acrylate sheet. The regular acrylates were tested at 80° and 160°F and the heat-resistant materials at 80°, 160°, and 200°F. A few tests were also conducted at 145° and 185°F. These latter tests were made unintentionally because of a failure in the temperature control equipment. The results of these tests are reported herein but very little comment will be made regarding them.

The creep-rupture tests covered rupture times from about one to 1000 hours. Some lower stress creep tests were made to obtain creep-rate data and also the low deformation points for the design curves. A description of the test procedure is given in Appendix I.

It was agreed with representatives of the Materials Laboratory that only one of the regular and one of the heat-resistant materials would be completely tested in creep and creep rupture. It was assumed that the materials would be closely comparable, and check tests would be made to determine this similarity. Subsequent check tests proved the assumption to be correct as shown by the test data obtained. Therefore, a complete series of tests was made on Plexiglas Ia and Lucite HC-202 and check tests were made on Lucite HC-201 and Plexiglas II. It was also agreed that no tests would be made at stresses below 500 psi.

Start of crazing was readily noticeable in the room-temperature creep and creep-rupture tests; these data are shown in the figures containing the design curves. At temperatures above room temperature, however, it was not possible to observe whether crazing had started while the test was in progress because the specimen was enclosed in the furnace. In this case, the specimens were observed after the tests were discontinued and it was noted whether or not crazing had taken place. These tests were generally of about 1000 hours' duration. Thus the stress for start of crazing at 1000 hours could be estimated from these tests.

In order to obtain another point on the crazing curves, several tests lasting 75 hours were made on each material at various stresses. After 75 hours, the specimens were removed from the furnace and inspected for crazing. From these tests, the stress to start crazing at 75 hours could be estimated. The crazing curves were then plotted from these two estimated points as shown in the design curves and in Figure 11 comparing the crazing properties of the materials tested.

The creep laboratory, in which the creep, creep-rupture, and crazing tests were made, was temperature controlled at 80°F. Relative humidity was not controlled and varied between 38 and 59 per cent.

Regular Acrylates

All creep, creep-rupture, and crazing data obtained on the regular acrylates, Plexiglas Ia and Lucite HC-201, are given in Table 1. These data are shown as design curves in Figures 1 and 2 and as stress versus creep-rate curves in Figure 3.

A complete series of tests was made on Plexiglas Ia at 80°and 160°F, but only a few check tests were conducted on Lucite HC-201 at the same temperatures. No tests were made on these materials at 200°F because of their extremely low strength. A trial test on Plexiglas Ia at 200°F resulted in about 75 per cent elongation immediately upon application of a 350 psi stress.

As shown in Figure 1, Plexiglas Ia has about 500 psi higher creep-rupture strength at 80°F than does Lucite HC-201. The creep rates for these two materials at 80°F appear to be about the same (Figure 3).

At 160°F, Plexiglas Ia shows the higher creep-rupture strength, but only at the higher stresses. A test at 1200 psi shows Lucite HC-201 to have the higher strength (Figure 2). The stress versus creep-rate curves of Figure 3 show that Plexiglas Ia at 160°F also has the higher creep strength at the higher stresses. At the lower stresses, Lucite HC-201 appears to be the stronger of the two materials.

The room-temperature creep and creep-rupture tests were observed from time to time to determine start of crazing. This was done only on Plexiglas Ia, the material on which the complete series of tests was made. It appears from the design curves of Figure 1, that crazing in Plexiglas Ia

TABLE 1. CREEP, CREEP-RUPTURE, AND CRAZING DATA FOR PLEXIGLAS Ia AND LUCITE HC-201 AT 80, 145, AND 160°F

Material	Specimen Number	Temp, 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
Plexiglas Ia	Pla-2	80	5000	153.2	0.026	1.5	–	–	1.0	15.0	84.0	133.0	–	84	5.0	–
	Pla-3	80	7725	0.1	–	–	–	–	–	–	–	–	–	–	–	–
	Pla-6	80	6000	4.1	1.00	2.15	–	–	–	0.5	2.0 est.	–	–	–	–	–
	Pla-7	80	4750	215.6	0.028	1.40	–	–	1.0	22.5	110.0	190.0	–	100	4.9	–
	Pla-9	80	4000	1008.0(a)	0.00056	1.10	–	0.1 est.	75.0	875.0	–	–	–	–	–	–
	Pla-14	80	4500	749.6	0.0044	1.40	–	–	10.0	75.0	495.0	–	–	4.5	4.8	–
	Pla-15	80	4500	108.3	0.041	1.50	–	–	0.5	6.0	51.0	89.0	–	51	5.0	–
	Pla-16	80	2500	1010.0(a)	0.00010	0.65	–	1200 est.	–	–	–	–	–	–	–	Started to craze, 95 hours
	Pla-17	80	1500	1030.0(a)	0.00007	0.49	–	–	–	–	–	–	–	–	–	No crazing
	Pla-20	80	3000	1036.0(a)	Nil	0.85	–	13.0	–	–	–	–	–	–	–	Started to craze, 4 hours
Lucite HC-201	HC-201-2	80	6000	0.8	3.000	2.10	–	–	–	0.2	0.7	–	–	0.7	5.0	–
	HC-201-3	80	5500	3.0	0.33	0.50	–	0.3	1.0	1.9	–	–	–	–	–	–
	HC-201-4	80	4500	132.7	0.025	1.45	–	–	10.0	27.0	103.0	–	–	102	4.8	–
Plexiglas Ia	Pla-18	145	500	1009.7(a)	0.00018	0.46	2.5	–	–	–	–	–	–	–	–	–
Lucite HC-201	HC-201-8	145	1400	637.0	–	0.50	–	2.0	14.0	43.0	110.0	216.0	370.0	90	4.0	–
	HC-201-9	145	1500	450.0	–	0.60	–	0.7	8.0	16.0	24.0	40.0	94.0	188	14.0	–
Plexiglas Ia	Pla-8	160	2000	2.3	1.800	0.65	–	0.1	0.4	1.0	1.1	1.2	1.4	1.1	5.0	–
	Pla-11	160	1500	34.0	0.500	0.65	–	0.8	2.4	4.2	–	–	–	–	–	–
	Pla-12	160	1000	1200(a)	0.043	0.50	–	1.0	2.5	5.0	16.0	29.0	62.0	123	13.5	–
	Pla-13	160	1200	1200.0(a)	0.14	0.55	–	0.5	2.5	6.0	13.0	19.0	35.0	–	–	–
	Pla-19	160	500	1030.0(a)	0.00086	0.40	–	25.0	475.0	–	–	–	–	–	–	Medium crazed
	Pla-25	160	500	75.0(a)	(c)	–	–	–	–	–	–	–	–	–	–	Lightly crazed
	Pla-26	160	750	74.4(a)	(c)	–	–	–	–	–	–	–	–	–	–	Medium to heavy craze
	Pla-27	160	600	75.0(a)	(c)	–	–	–	–	–	–	–	–	–	–	Medium crazed
Lucite HC-201	HC-201-6	160	2000	0.6	4.00	3.10	–	–	–	–	0.3	0.4	0.5	5.0	8.0	–
	HC-201-7	160	1500	1.9	2.30	0.80	–	–	0.5	0.8	1.2	1.4	1.5	55	3.3	–
	HC-201-5	160	1200	610.0(a)	0.0015	0.10	–	50.0	190.0	435.0	–	–	–	–	–	–
	HC-201-10	160	1400	5.4	1.400	0.76	–	0.1	0.6	0.8	1.1	–	–	0.5	1.5	–
	HC-201-11	160	1250	10.4	–	0.70	–	0.1	0.5	–	–	–	–	–	–	–
Plexiglas Ia	Pla-10	200	(b)	–	–	–	–	–	–	–	–	–	–	–	–	[illegible]

(a) Discontinued. (b) Specimen elongated about 75% when 350 psi was applied. Tests were discontinued at this temperature. (c) No extensometer strip was used.

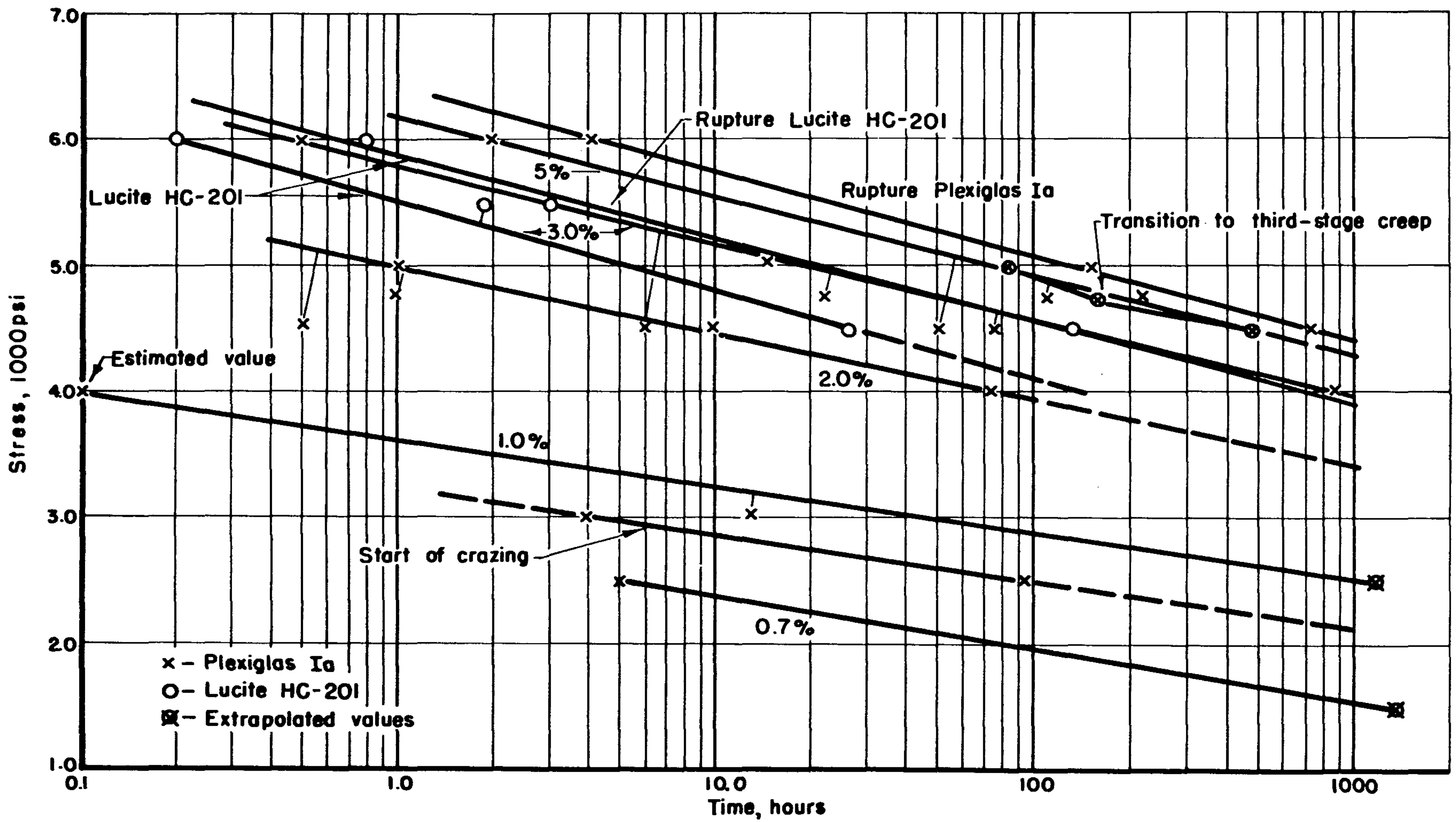

FIGURE I. DESIGN CURVES FOR PLEXIGLAS Ia AT 80°F WITH CHECK POINTS FOR LUCITE HC-201
(Note: Deformations shown are total deformations)

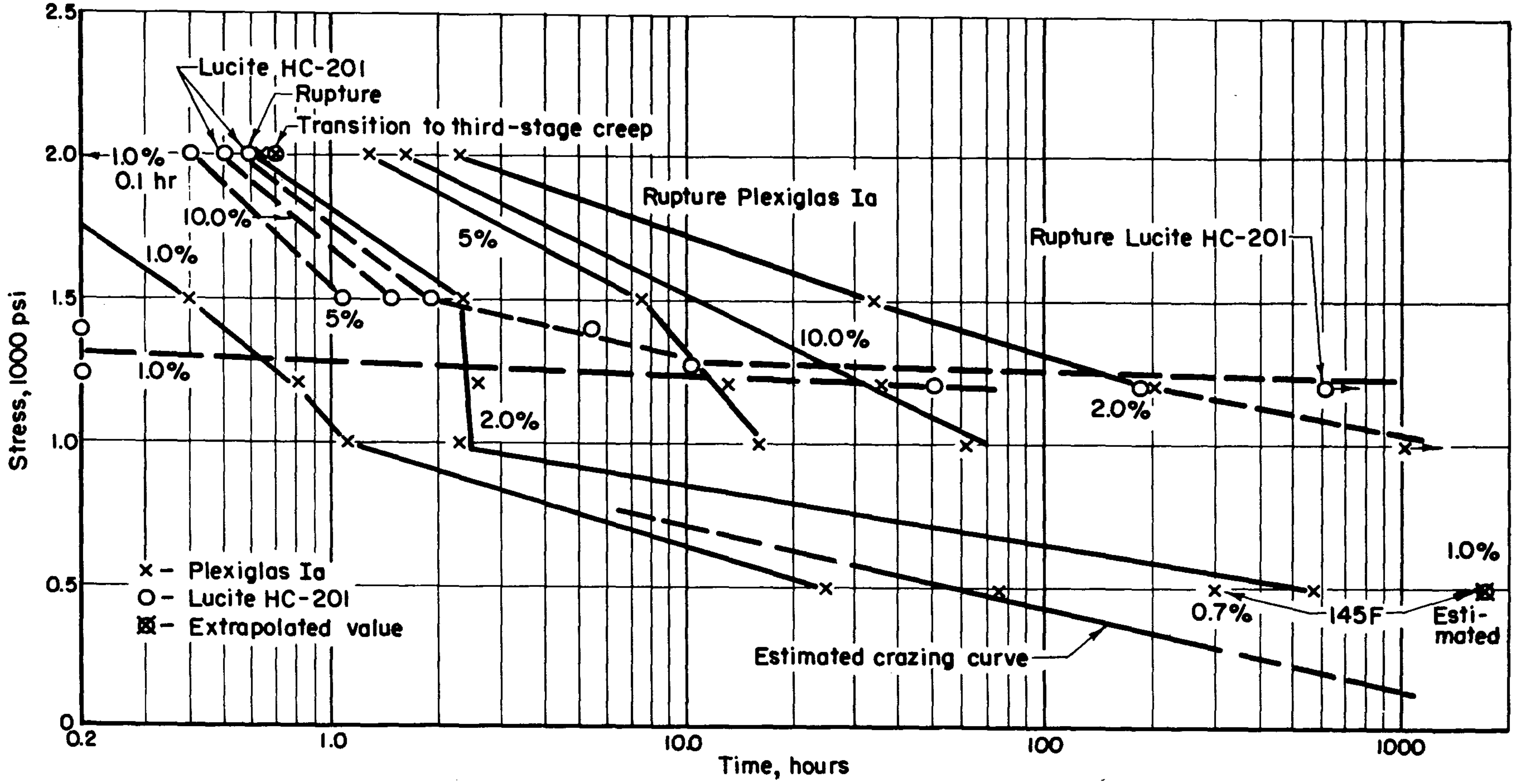

FIGURE 2. DESIGN CURVES FOR PLEXIGLAS Ia AT 160°F WITH CHECK POINTS FOR LUCITE HC-201
(Note: Deformations shown are total deformations)

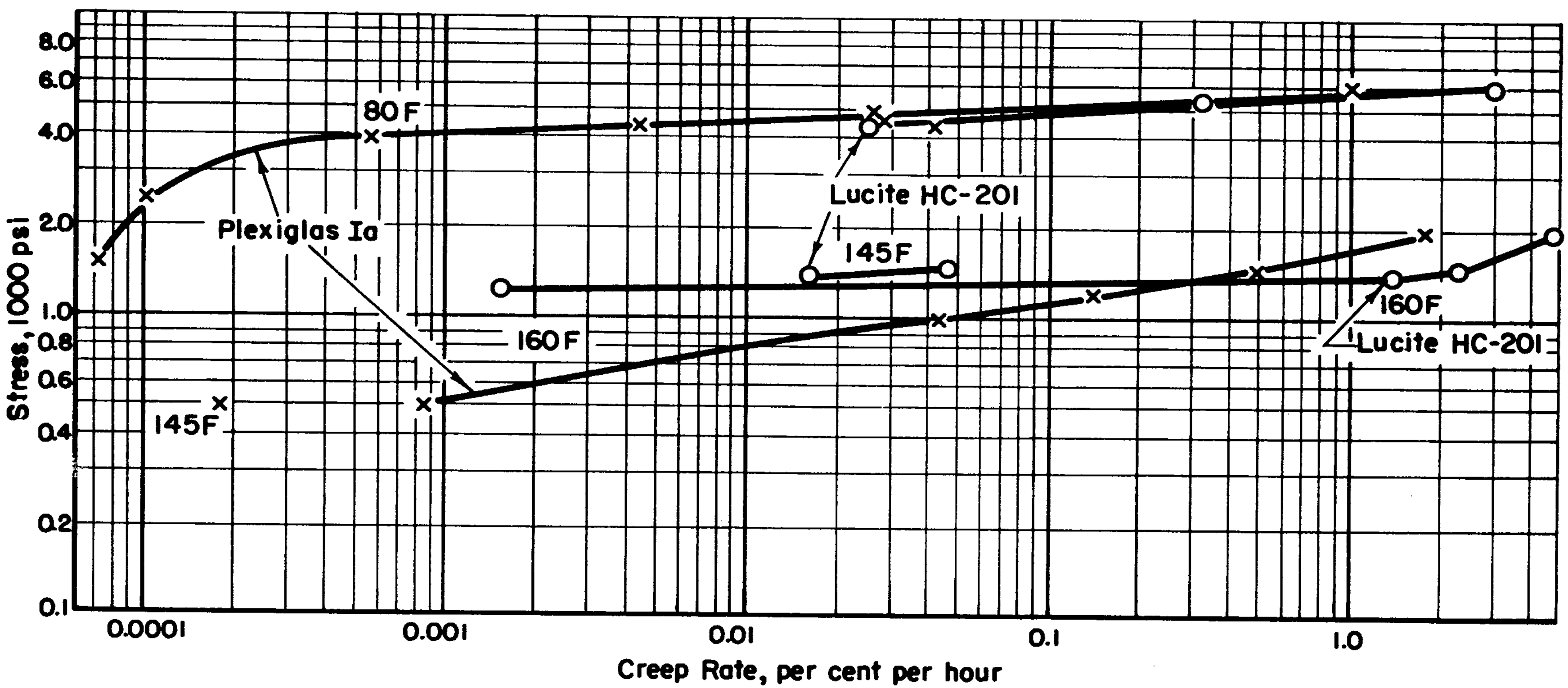

FIGURE 3. STRESS VERSUS CREEP-RATE CURVES AT 80 AND 160°F FOR PLEXIGLAS Ia WITH CHECK POINTS FOR LUCITE HC-201

at room temperature begins between 0.7 and 1.0 per cent deformation under the conditions of these tests.

At 160°F, the estimated crazing curve for Plexiglas Ia falls between the one and the two per cent deformation curves (Figure 2).

Results of the tests conducted on the regular acrylates at 145°F are shown in Table 1 and Figures 2 and 3.

Heat-Resistant Acrylates

The two heat-resistant grades of acrylate, Lucite HC-202 and Plexiglas II, were tested at room temperature, 160°, and 200°F. A complete series of creep and creep-rupture tests was made on Lucite HC-202 and only a few check tests on Plexiglas II. Some special crazing tests were also conducted on Lucite HC-202 at 160° and 200°F.

Results of the creep, creep-rupture, and crazing tests are given in Table 2. The results were plotted as design curves in Figures 4, 5, and 6, and as stress versus creep-rate curves in Figure 7.

Results of the creep and creep-rupture tests on Lucite HC-202 and Plexiglas II at 145 and 185 F are given in Table 2 and Figures 8, 9, and 10.

An inspection of Figures 4 through 7 will show that the creep and creep-rupture strengths of Lucite HC-202 and Plexiglas II at room temperature, 160°, and 200°F are very nearly the same. Lucite HC-202 may show a slightly greater strength, especially at 200°F.

Crazing was observed to start between one and two per cent deformation in Lucite HC-202 at room temperature (Figure 4). At 160°F (Figure 5), it appears that this material starts to craze between about 1 and 3 per cent deformation. At 200°F, the amount of deformation at which crazing starts may be more dependent upon the strain rate. The crazing tests at 75 hours' duration indicated that, between 1200 and 1300 psi, crazing did not start until 10 per cent deformation had been exceeded. However, at 1000 psi, crazing had started in less than 1200 hours before 3 per cent deformation had been reached. (See Figure 6 and Table 2, Specimen HC-202-3.)

Figure 11 is a plot of the stress versus start-of-crazing time for Plexiglas Ia and Lucite HC-202 at 80°, 160°, and 200°F. After 100 hours at 80°F, the regular variety had about 90 per cent as much resistance to crazing as the heat-resistant variety. However, at 160°F, the superiority of the heat-resistant variety is very significant. The regular variety having

TABLE 2. CREEP, CREEP-RUPTURE, AND CRAZING DATA FOR LUCITE HC-202 AND PLEXIGLAS II AT 80°, 145°, 160°, 185°, AND 200°F

Material	Specimen Number	Temp, 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
Plexiglas II	PII-9	80	7000	49.5	–	1.70	–	–	1.0	3.0	–	–	–	–	–	Crazed on loading
	PII-11	80	8000	2.0	2.20	3.00	–	–	–	–	–	–	–	–	–	Crazed on loading
	PII-12	80	6500	222.9	0.0093	1.90	–	–	2.5	4.5	1.38	–	–	138	5.0	Crazed on loading
	PII-22	80	6000	290.0[a]	0.010	1.70	–	–	3.0	7.0	42.0	225.0	–	–	–	Not crazed
Lucite HC-202	HC-202-6	80	6000	1012.0[a]	0.00072	3.10	–	–	–	–	500.0	–	–	–	–	Started to craze, 0.3 hour
	HC-202-11	80	8000	0.5	1.1 est.	0.55	–	–	–	–	–	–	–	–	–	Crazed on loading
	HC-202-15	80	7000	107.0	0.0188	1.70	–	–	0.5	2.0	66.0	–	–	–	–	Crazed on loading
	HC-202-19	80	3000	1005.0[a]	0.000082	1.04	–	0.25	–	–	–	–	–	–	–	Started to craze, 24 hours
	HC-202-20	80	4000	1003.0[a]	0.00017	1.00	–	1.0	3600 est.	–	–	–	–	–	–	–
	HC-202-23	80	2500	1010.0[a]	0.00026	0.61	–	487.0	–	–	–	–	–	–	–	Not crazed
	HC-202-32	80	5000	1060.8	0.00075	1.37	–	–	2.0	24.0	582.0	–	–	–	–	Started to craze, 0.5 hour
Plexiglas II	PII-17	145	3130	1150.0[a]	0.00040	0.80	–	0.5	200.0	–	–	–	–	–	–	Crazed
	PII-19	145	4500	18.4	–	2.50	–	–	–	0.3	3.0	5.5	–	–	–	Crazed
	PII-21	145	5000	0.4	–	5.50	–	–	–	–	–	0.1	–	–	–	Crazed
Lucite HC-202	HC-202-8	145	2500	1080.0[a]	0.00016	0.75	–	45.0	–	–	–	–	–	–	–	Crazed
	HC-202-12	145	5000	6.2	0.80	1.90	–	–	–	0.1	–	–	–	–	–	Crazed
	HC-202-18	145	3500	985.0[a]	0.00065	1.10	–	–	45.0	950.0	–	–	–	–	–	Crazed
	HC-202-21	145	4500	1.1	–	3.30	–	–	–	–	–	0.1	0.6	0.6	10.0	Crazed
Plexiglas II	PII-23	160	4000	0.8	10.00	2.16	–	–	–	–	0.3	0.4	0.6	–	–	Crazed
	PII-24	160	4000	0.5	16.00	2.60	–	–	–	–	0.1	0.2	0.4	–	–	Crazed
	PII-25	160	3500	2.2	4.50	2.16	–	–	–	0.1	0.5	0.9	–	–	–	Crazed
	PII-28	160	2500	1040.0[a]	0.0026	1.00	–	–	3.0	5.0	53.0	265.0	–	–	–	Heavily crazed
Lucite HC-202	HC-202-2	160	1500	1674.0[a]	0.00009	0.47	–	–	–	–	–	–	–	–	–	Light craze
	HC-202-27	160	4000	0.3	–	2.42	–	–	–	–	–	0.1	–	–	–	–
	HC-202-24	160	1000	1077.0[a]	0.00011	0.40	–	355.0	–	–	–	–	–	–	–	Not crazed
	HC-202-30	160	3000	175.0	0.036	1.15	–	–	1.0	8.0	30.0	63.0	87.0	90	10	Crazed
	HC-202-31	160	3500	2.4	3.600	1.52	–	–	–	0.2	0.9	–	–	–	–	Crazed
	HC-202-33	160	2000	1151.0[a]	0.0024	1.02	–	–	20.0	90.0	550.0	–	–	–	–	Heavily crazed

TABLE 2. (Continued)

Material	Specimen Number	Temp, 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	Start of Third Stage Creep, Deformation, %	Remarks
Lucite HC-202	HC-202-35	160	1500	75.0	(c)	–	–	–	–	–	–	–	–	–	–	Not crazed
	HC-202-38	160	1400	75.0	(c)	–	–	–	–	–	–	–	–	–	–	Not crazed
	HC-202-40	160	1600	74.2	(c)	–	–	–	–	–	–	–	–	–	–	Not crazed
	HC-202-41	160	2000	75.0	(c)	–	–	–	–	–	–	–	–	–	–	Lightly crazed
	HC-202-42	160	2300	75.9	(c)	–	–	–	–	–	–	–	–	–	–	Lightly crazed
Plexiglas II	PII-13	185	3000	3.6	1.250	1.27	–	–	0.8	1.4	2.6	–	–	2.5	4.5	Crazed
	PII-15	185	3000	1.8	2.350	1.40	–	–	0.3	0.6	1.3	1.7	–	1.6	6.4	Crazed
	PII-14	185	2500	46.0	1.150	1.10	–	–	2.5	6.0	–	–	–	24	3.1	Crazed
	PII-16	185	2200	131.3	0.069	0.92	–	0.1	2.5	11.0	37.0	64.0	–	92	9.5	Crazed
	PII-18	185	1800	955.0[a]	0.0048	1.20	–	0.6	22.0	80.0	410.0	810.0	–	813	7.2	Crazed
Lucite HC-202	HC-202-16	185	3000	9.9	0.480	1.22	–	–	0.6	2.5	6.3	–	–	5.6	4.5	Crazed
	HC-202-9	185	2500	257.0	0.021	0.45	–	1.2	14.0	35.0	115.0	190.0	240.0	0.17	6.2	Crazed
	HC-202-17	185	2200	1206.7	0.0038	0.75	–	0.5	26.0	130.0	620.0	1020.0	–	590	4.8	Crazed
	HC-202-5	185	1500	1028.0[a]	0.00020	0.46	–	36.0	–	–	–	–	–	–	–	Crazed
Plexiglas II	PII-27	200	2000	1.6	0.900	0.95	–	0.2	0.8	1.3	–	–	–	0.5	1.3	Crazed
	PII-26	200	1500	40.0	0.600	0.65	–	0.4	1.0	2.1	4.1	6.0	–	–	–	Crazed
	PII-29	200	1000	1027.0[a]	0.0014	0.10	2.0	5.0	10.0	15.0	38.0	110.0	160.0	–	–	Medium crazed
Lucite HC-202	HC-202-1	200	500	1100.0[a]	0.00022	0.12	35.0	800.0	–	–	–	–	–	–	–	Not crazed
	HC-202-3	200	1000	1204.0[a]	0.0010	0.40	0.8	23.0	355.0	–	–	–	–	–	–	Crazed
	HC-202-28	200	3000	1 min	–	–	–	–	–	–	–	–	–	–	–	Crazed
	HC-202-25	200	2000	13.4	0.68	0.96	–	0.5	1.2	2.1	3.0	6.0	–	0.6	1.3	Crazed
	HC-202-26	200	1500	18.1	2.80	0.30	–	0.1	0.5	0.8	1.5	2.0	–	0.3	1.8	Crazed
	HC-202-29	200	1200	1034.0[a]	0.0082	0.60	–	1.0	2.0	2.5	4.0	7.5	12.0	–	–	Crazed
	HC-202-34	200	900	75.0[a]	(c)	–	–	–	–	–	–	–	–	–	–	Not crazed
	HC-202-37	200	1400	75.0[a]	(c)	–	–	–	–	–	–	–	–	–	–	Heavily crazed
	HC-202-36	200	1200	75.0[a]	(c)	–	–	–	–	–	–	–	–	–	–	Not crazed
	HC-202-39	200	1300	74.5[a]	(c)	–	–	–	–	–	–	–	–	–	–	Medium to heavy craze

(a) Discontinued.
(c) No extensometer strip was used.

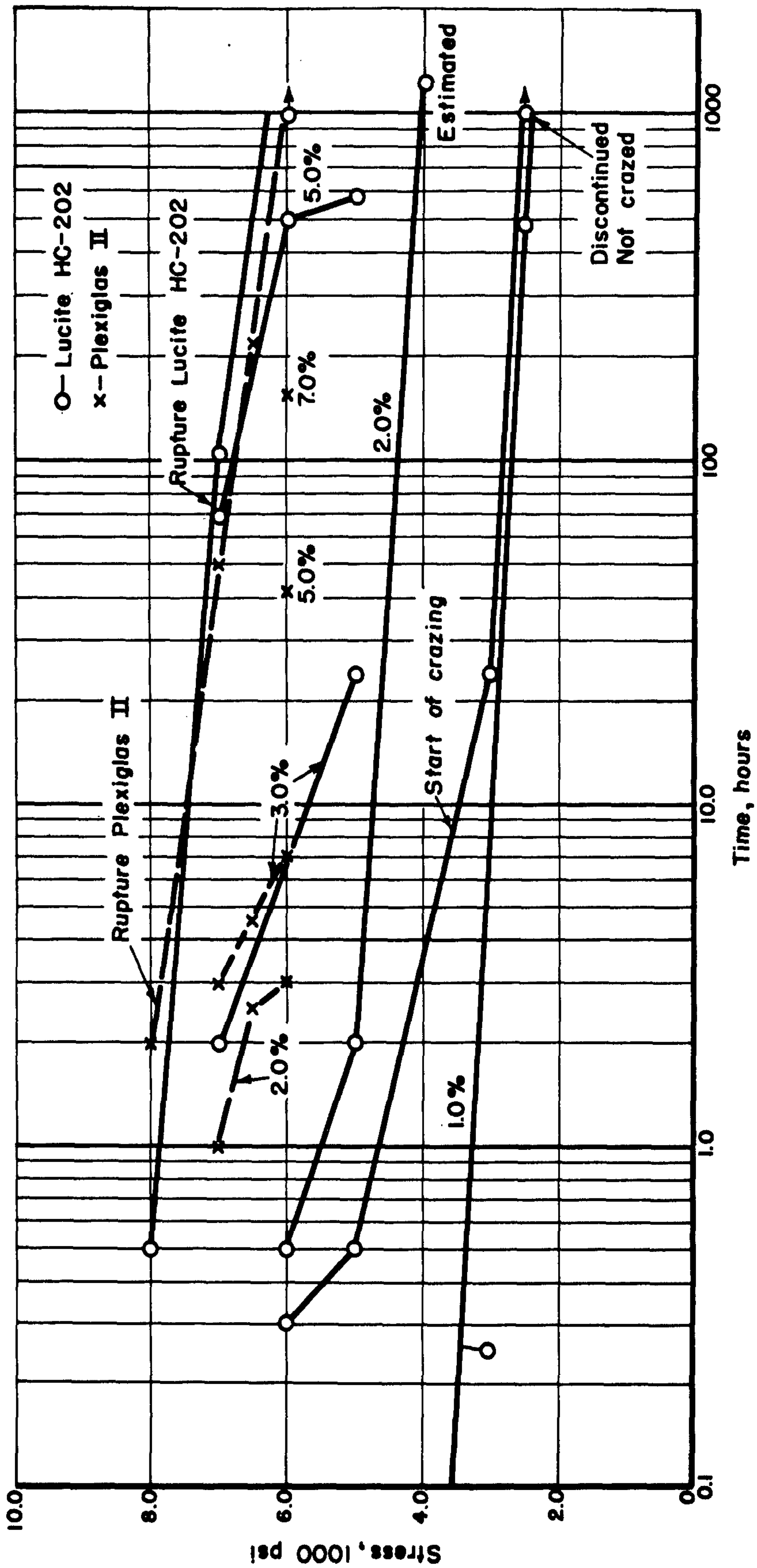

FIGURE 4. DESIGN CURVES FOR LUCITE HC-202 AT 80°F WITH CHECK POINTS FOR PLEXIGLAS II
(Note: Deformations shown are total deformations)

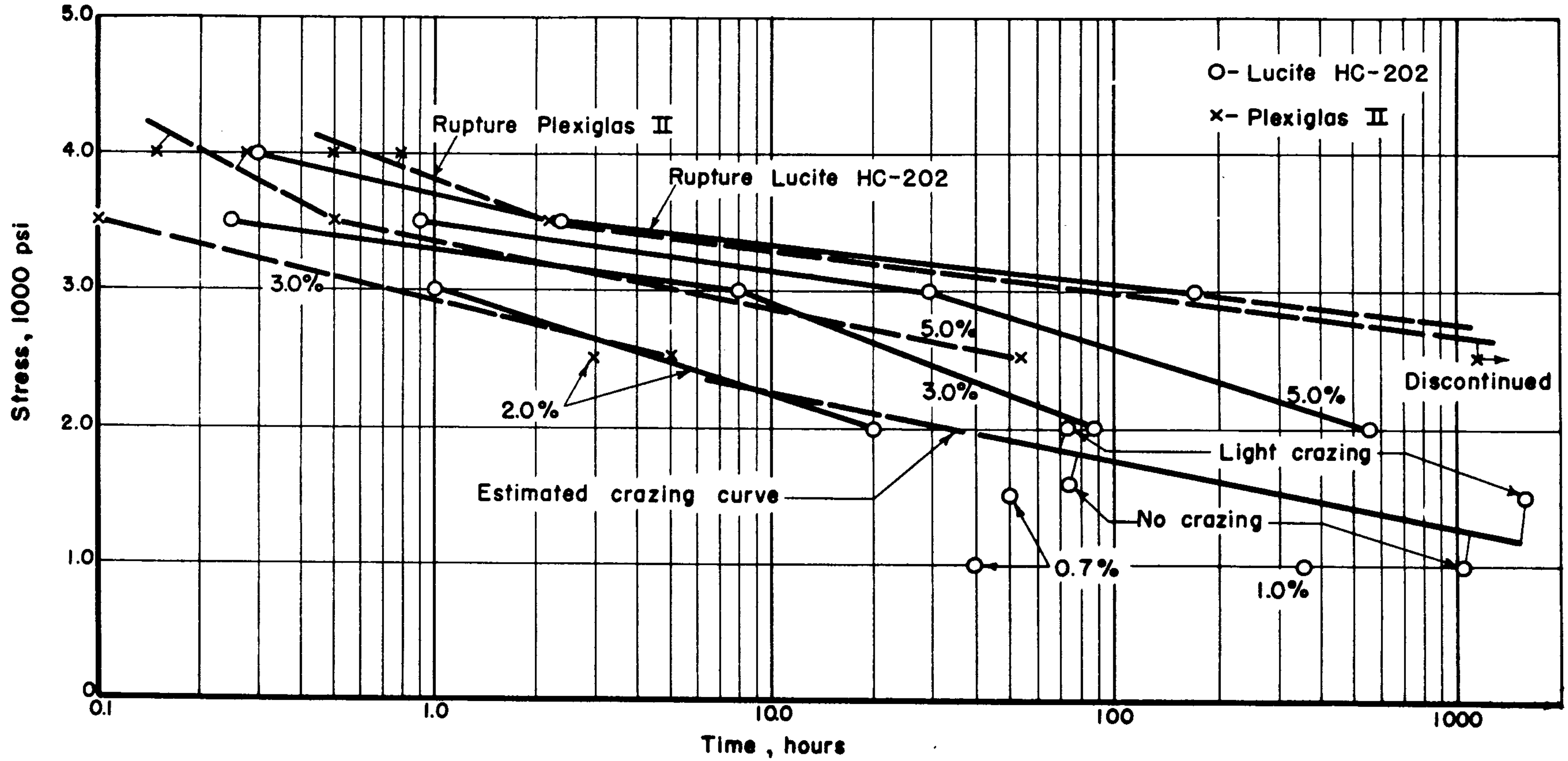

FIGURE 5. DESIGN CURVES FOR LUCITE HC-202 AT 160°F WITH CHECK POINTS FOR PLEXIGLAS II
(Note: Deformations shown are total deformations)

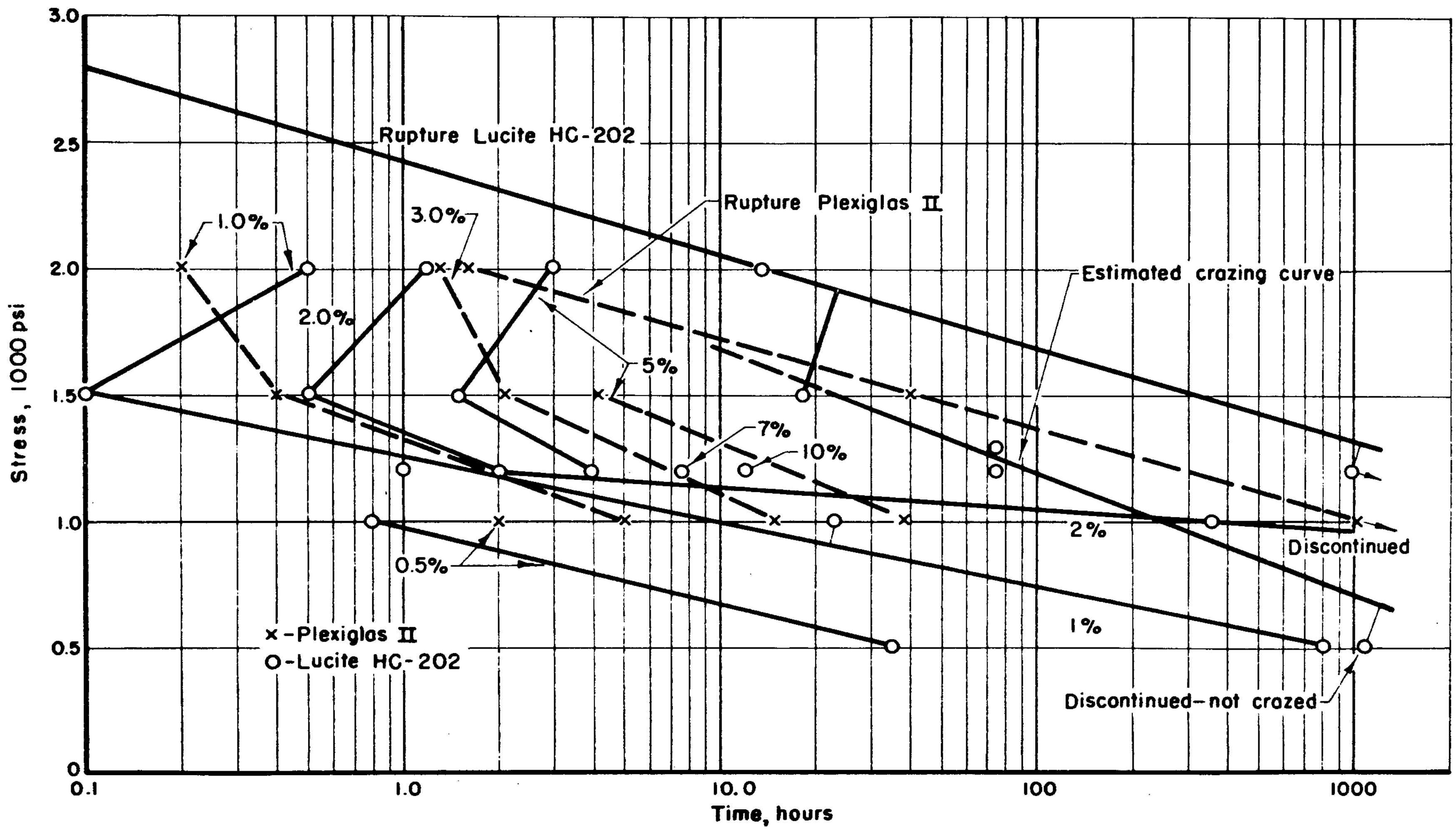

FIGURE 6. DESIGN CURVES FOR LUCITE HC-202 AT 200°F WITH CHECK POINTS FOR PLEXIGLAS II
(Note: Deformations shown are total deformations)

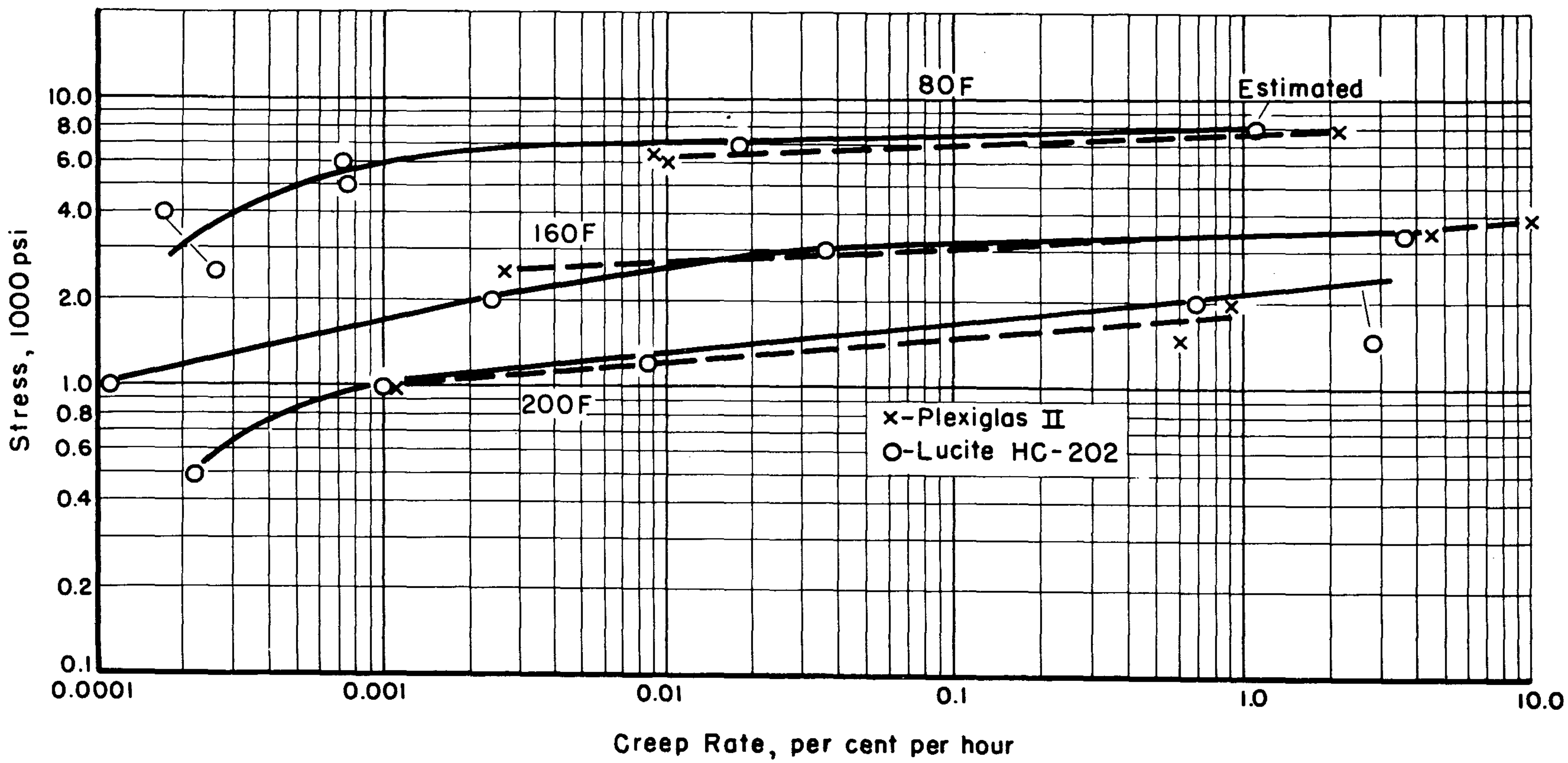

FIGURE 7. STRESS VERSUS CREEP-RATE CURVES FOR LUCITE HC-202 AT 80°, 160°, AND 200°F WITH CHECK POINTS FOR PLEXIGLAS II

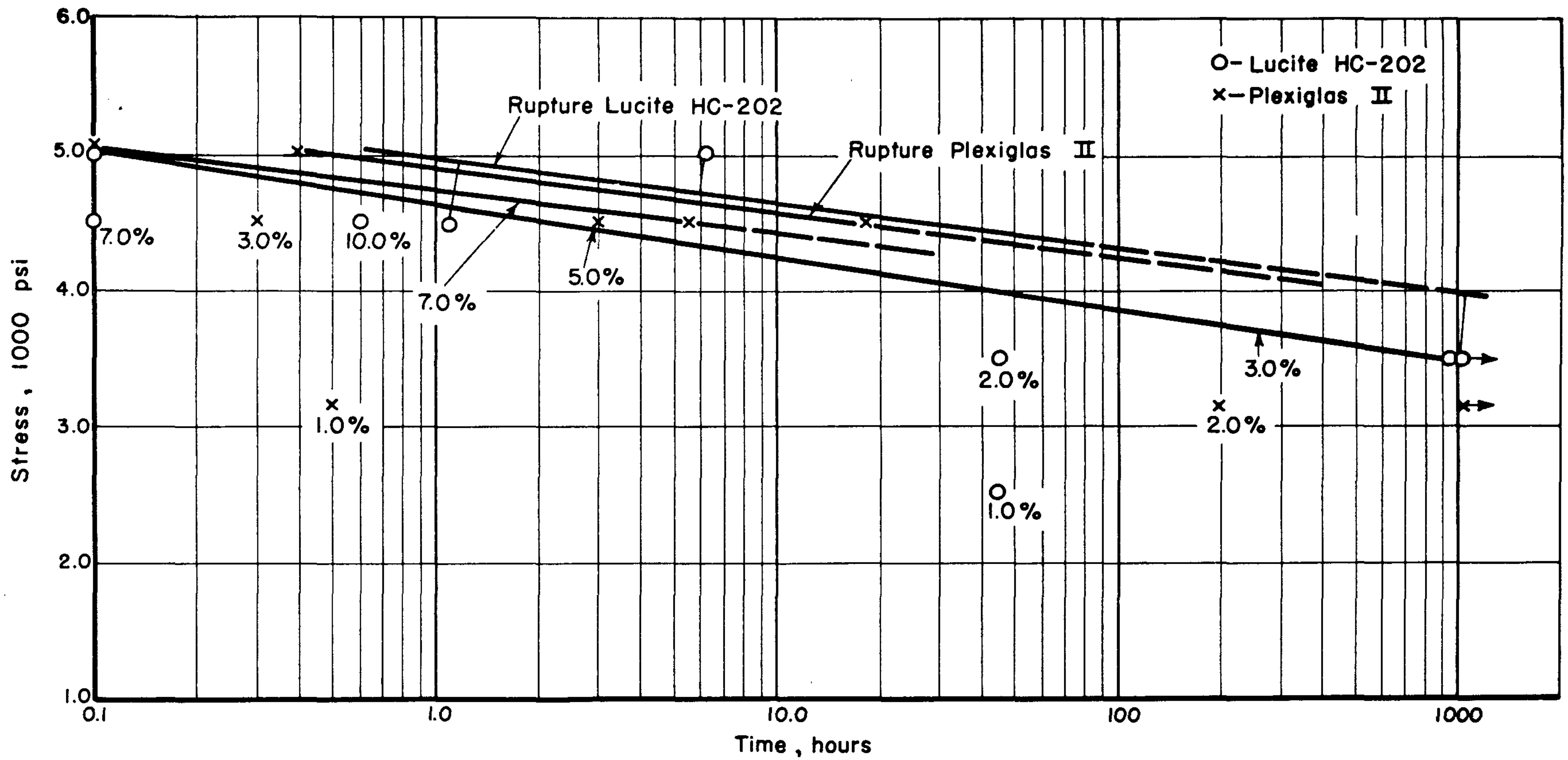

FIGURE 8. DESIGN CURVES FOR LUCITE HC-202 AT 145°F WITH CHECK POINTS FOR PLEXIGLAS II (Note: Deformations shown are total deformations)

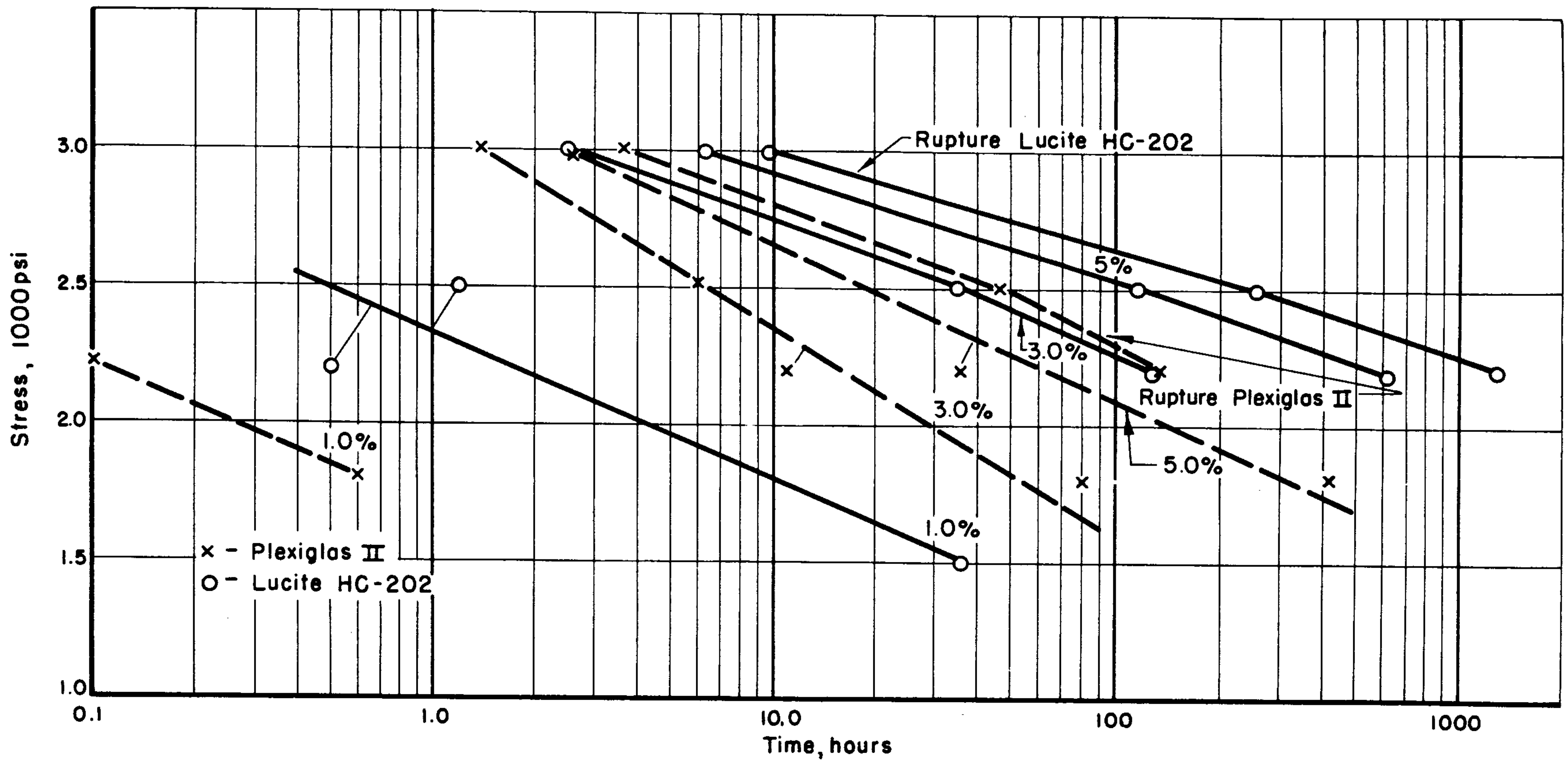

FIGURE 9. DESIGN CURVES FOR LUCITE HC-202 AT 185°F WITH CHECK POINTS FOR PLEXIGLAS II
(Note: Deformations shown are total deformations)

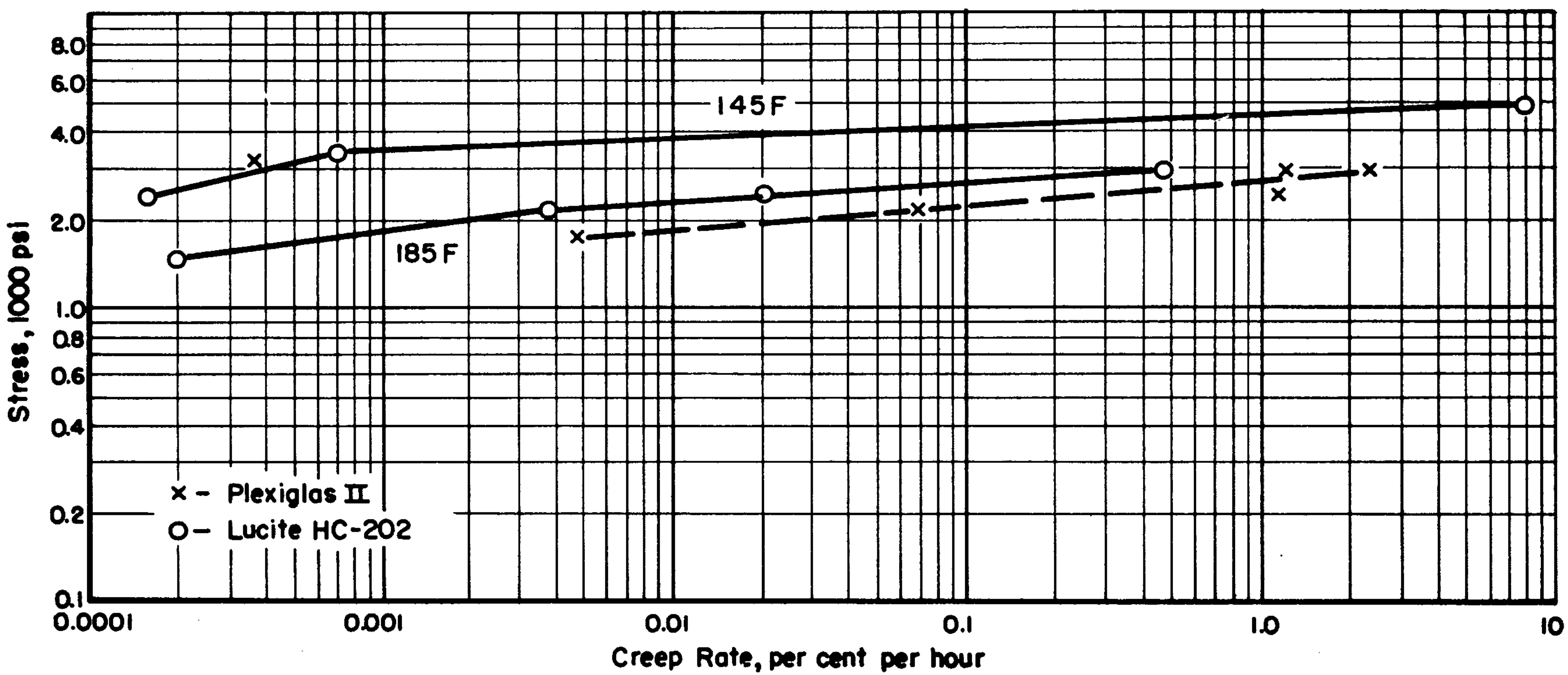

FIGURE 10. STRESS VERSUS CREEP-RATE CURVES FOR LUCITE HC-202 AND PLEXIGLAS II AT 145° AND 185°F

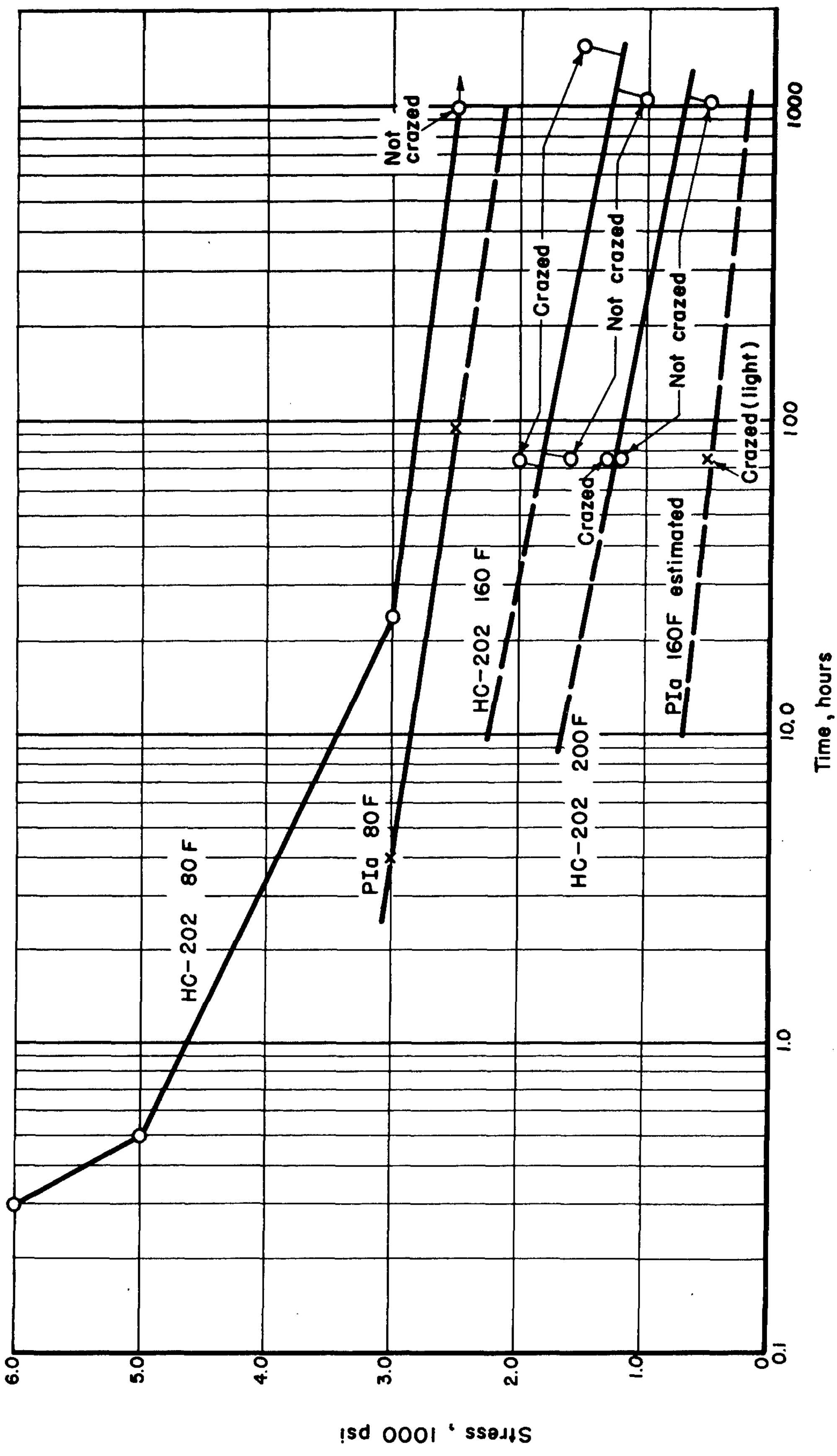

FIGURE 11. STRESS VERSUS START-OF-CRAZING CURVES FOR PLEXIGLAS Ia AND LUCITE HC-202 AT 80°, 160°, AND 200°F

only about 25 per cent as much resistance to crazing as the heat-resistant variety at 100 hours.

When the temperature was increased from 160°to 200°F, the stress for incipient crazing in 100 hours decreased from 1750 psi to 1200 psi for the heat-resistant acrylate sheet. This is a decrease of about 31 per cent. When the crazing data for the heat-resistant acrylate sheet are examined, it is found that there is a linear relation between temperature and stress for incipient crazing. In the testing temperature range 80°to 200°F, the stress to produce crazing in 10, 100, or 1000 hours decreased approximately 15 psi for each degree increase in temperature.

SHORT-TIME TENSILE TESTS

Short-time tensile tests were made on all four of the materials at room temperature, 160°, and 200°F. Only at room temperature, however, was it possible to obtain yield strength, proportional limit, and elastic modulus values. A microformer type of extensometer was attached to the room-temperature tensile test specimens in order to obtain these values (Appendix I). At 160°and 200°F, all four materials soften too rapidly to allow an extensometer to be attached to the specimens. Results of these short-time tensile tests are shown in Table 3 and Figure 12. Figure 13 shows the load-strain curves from which the yield strength (0.1 and 0.2 per cent offset), proportional limit, and elastic modulus data were obtained.

The tensile properties of the heat-resistant acrylate sheet were superior to those for the regular grade, even at room temperature. At 200 F°, the superiority of the heat-resistant grade was very significant.

The short-time tensile strength of the regular material ranged from 8240 psi at room temperature to 150 psi at 200°F. The heat-resistant material varied from 9980 psi at room temperature to 2660 psi at 200°F.

DETERIORATION TESTS

A series of deterioration tests (time at temperature versus weight loss) was made in duplicate on the four acrylic materials at 160°and 200°F. This was done in order to find what effect exposure for 24, 200, and 1000 hours at these two temperatures would have on the stability of Plexiglas Ia and II and Lucite HC-201 and HC-202. The results, in per cent weight loss for each exposure, are shown in Table 4. The samples used for the tests were one inch square by 1/4 inch in thickness.

TABLE 3. SHORT-TIME TENSILE DATA FOR LUCITE HC-201 AND HC-202 AND PLEXIGLAS Ia AND II AT 80°, 160°, AND 200°F

Rate of Pull - 0.06 Inch Per Minute

Material	Specimen Number	Temp, F	Area, sq in.	Tensile Strength, psi	Average Tensile Strength, psi	Yield Strength, psi 0.1% Offset	Yield Strength, psi 0.2% Offset	Elastic Modulus, psi	Proportional Limit, psi
Plexiglas Ia	PIa-1	Room Temp	0.1260	8260	-	4250	5040	318,000	1980
	PIa-2	Room Temp	0.1250	8220	8240	4240	5040	352,000	1760
	PIa-3	160	0.1254	2550	-	-	-	-	-
	PIa-4	160	0.1269	2480	2510	-	-	-	-
	PIa-5	200	0.1273	150	150	-	-	-	-
Lucite HC-201	HC-201-1	Room Temp	0.1165	7120	-	4070	4970	352,000	1840
	HC-201-2	Room Temp	0.1153	6970	7040	4290	5060	347,000	1730
	HC-201-3	160	0.1172	2560	-	-	-	-	-
	HC-201-5	160	0.1210	2070	2260	-	-	-	-
	HC-201-6	200	0.1184	170	170	-	-	-	-
Plexiglas II	PII-1	Room Temp	0.1183	9850	-	4440	5530	397,000	1730
	PII-2	Room Temp	0.1208	9960	9900	4350	5390	385,000	1450
	PII-3	160	0.1204	5150	-	-	-	-	-
	PII-4	160	0.1165	5020	5080	-	-	-	-
	PII-5	200	0.1242	2410	-	-	-	-	-
	PII-6	200	0.1232	1870	-	-	-	-	-
	PII-7	200	0.1175	3210	-	-	-	-	-
	PII-8	200	0.1212	2920	-	-	-	-	-
	PII-26	200	0.1288	2640	-	-	-	-	-
	PII-27	200	0.1323	2640	-	-	-	-	-
	PII-28	200	0.1293	2940	-	-	-	-	-
	PII-29	200	0.1348	2670	2660	-	-	-	-
Lucite HC-202	HC-202-1	Room Temp	0.1303	9890	-	4710	5640	399,000	2070
	HC-202-2	Room Temp	0.1265	10080	9980	5020	6050	379,000	2450
	HC-202-3	160	0.1262	5780	-	-	-	-	-
	HC-202-4	160	0.1267	5520	5650	-	-	-	-
	HC-202-5	200	0.1262	4000	-	-	-	-	-
	HC-202-6	200	0.1260	4600	-	-	-	-	-
	HC-202-7	200	0.1257	2410	-	-	-	-	-
	HC-202-13	200	0.1185	4680	-	-	-	-	-
	HC-202-X	200	0.1197	4340	-	-	-	-	-
	HC-202-26	200	0.1294	3820	-	-	-	-	-
	HC-202-27	200	0.1254	3310	-	-	-	-	-
	HC-202-28	200	0.1258	3740	-	-	-	-	-
	HC-202-29	200	0.1240	3270	3800	-	-	-	-

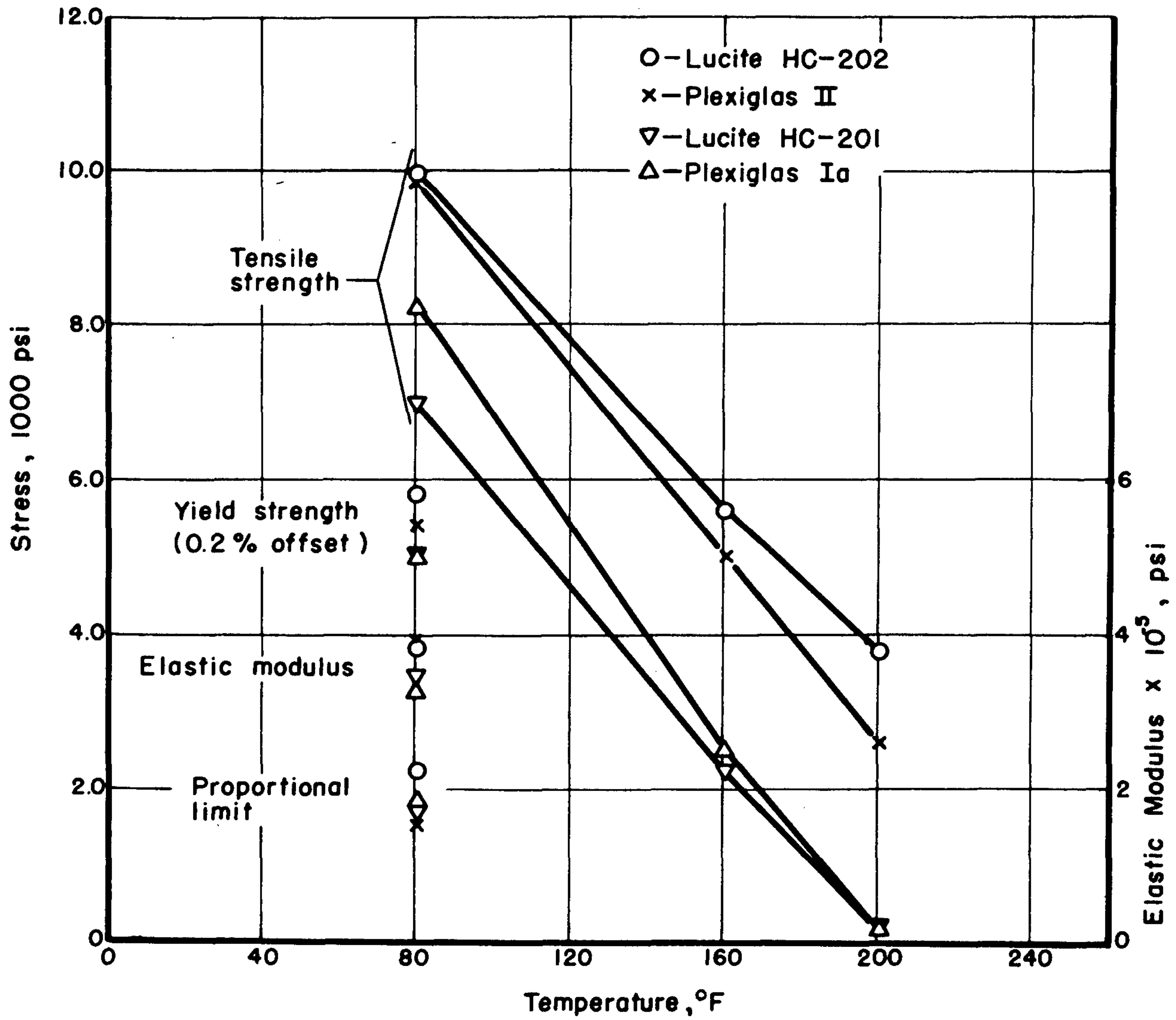

FIGURE 12. SHORT-TIME TENSILE PROPERTIES OF LUCITE HC-201, HC-202, AND PLEXIGLAS Ia AND II AT 80°, 160°, AND 200°F

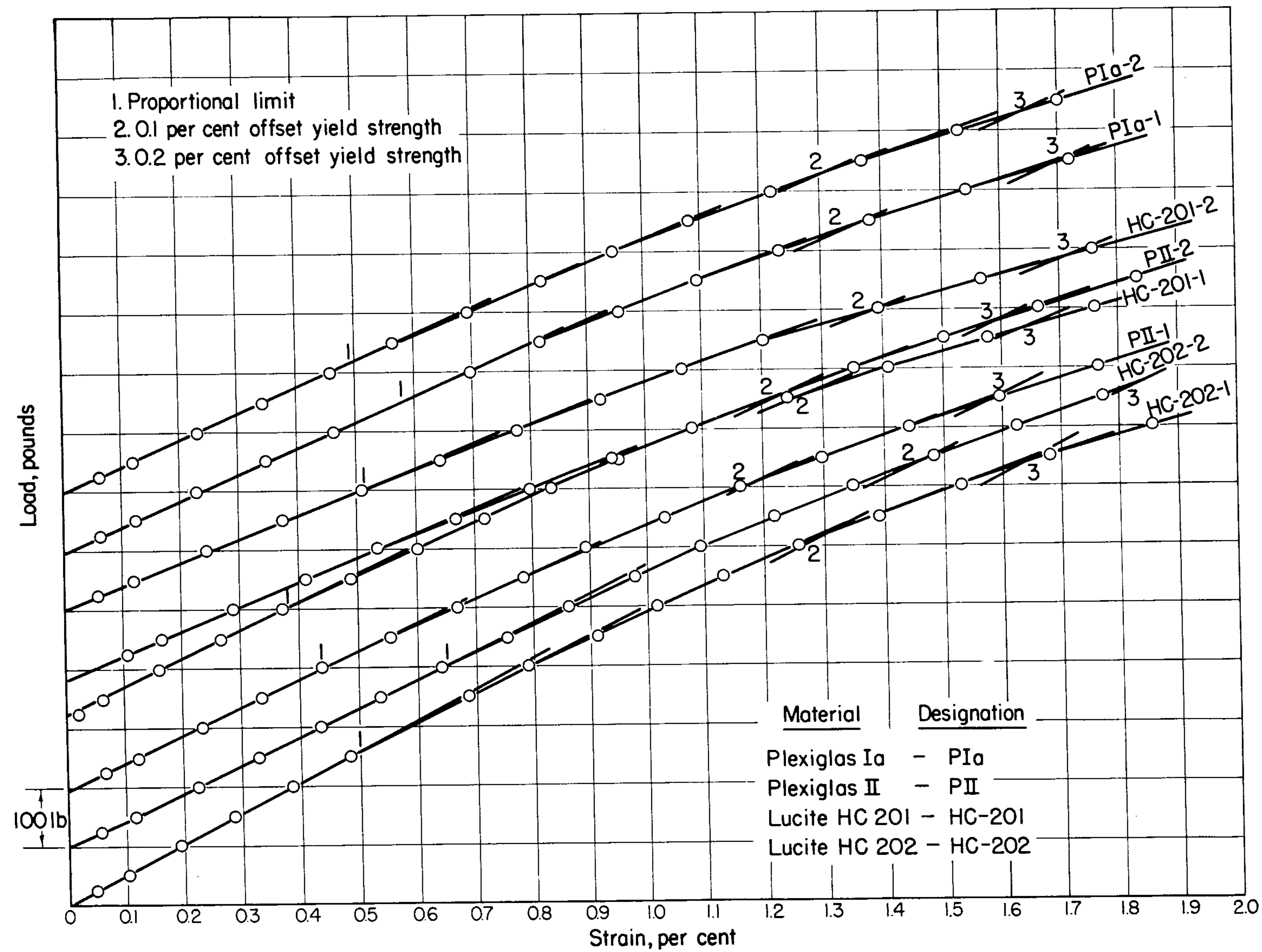

FIGURE 13. TENSILE LOAD-STRAIN CURVES FOR LUCITE HC-201 AND HC-202, AND PLEXIGLAS Ia AND II AT ROOM TEMPERATURE
(Note: Cross-sectional areas of test specimens are given in Table 3)

TABLE 4. DETERIORATION DATA ON PLEXIGLAS Ia AND II AND LUCITE HC-201 AND HC-202 AT 160°AND 200°F

Specimen Number[a]	Temp, °F	Per Cent Weight Loss, After Exposure of 24 Hours	200 Hours	1000 Hours
PIa-A	160	0.20	0.48	0.53
PIa-B	160	0.24	0.48	0.52
HC-201-A	160	0.18	0.34	0.36
HC-201-B	160	0.17	0.32	0.36
PIa-C	200	0.47	0.58	0.69
PIa-D	200	0.49	0.55	0.65
HC-201-C	200	0.33	0.38	0.44
HC-201-D	200	0.30	0.35	0.38
PII-A	160	0.18	0.37	0.40
PII-B	160	0.16	0.35	0.40
HC-202-A	160	0.14	0.35	0.43
HC-202-B	160	0.17	0.34	0.42
PII-C	200	0.23	0.38	0.41
PII-D	200	0.24	0.42	0.42
HC-202-C	200	0.24	0.43	0.46
HC-202-D	200	0.23	0.43	0.45

(a) Specimen identity

PIa - Plexiglas Ia

PII - Plexiglas II

HC-201 - Lucite HC-201

HC-202 - Lucite HC-202

The two heat-resistant acrylates, Plexiglas II and Lucite HC-202, had very similar weight losses after each treatment. Of the two regular acrylates, Lucite HC-201 had the lower weight loss.

A comparison among all four materials indicates that there is probably no significant difference between them, although Plexiglas Ia showed slightly greater weight loss than the others. It is possible that most of the loss in weight of the specimens was caused by the elimination of moisture.

APPENDIX I

Test Procedures

Short-Time Tensile Tests

The short-time tensile tests were made in a Baldwin Southwark Hydraulic Testing Machine. The elevated-temperature tests were made in an electric resistance-heated furnace 7 inches in diameter and 12-1/2 inches long. The furnace was fitted with a copper liner to help maintain a uniform temperature in the gage section of the specimens.

Two chromel-alumel thermocouples were used on each test to measure and control the temperature. The specimens were heated to the test temperature in about 1/2 hour and then held at this temperature for approximately 1/2 hour prior to loading. A Foxboro controller maintained the desired temperature to an accuracy of about ± 5°F.

The tensile specimens were 24 inches long with a 2-1/4-inch-long by 1/2-inch-wide gage section. All four materials tested were 1/4 inch thick. The machining specifications for these specimens are shown in Figure 14.

Microformer-type extensometers with a sensitivity of 5 microinches were used to measure strain at room temperature. The method of attachment is shown in Figure 15. Strain at elevated temperatures could not be measured because the extensometer clamps cut too deeply into the softened materials. The specimens were pulled at a head speed of 0.06 inch per minute which is equal to about 0.0026 inch per inch per minute in the gage length of the specimens.

Tensile Creep and Creep-Rupture Tests

The tensile creep and creep-rupture tests were made in standard Battelle creep-testing units and furnaces. Figure 16 shows a group of four such units. Although these units are shown in the process of testing metal specimens, a similar arrangement was used for testing the acrylates.

Each testing unit is equipped with a chromium-plated copper or steel shell furnace 6 inches in diameter and 18 inches long, wound with 14-gage Chromel A wire and insulated with Sil-O-Cel. A small window is provided at both front and back of the furnace for measuring the deformation of the specimen by optical means. These furnaces also had a copper lining to improve the temperature uniformity along the gage section of the specimens.

The test temperature of each furnace was maintained by a Tag Celectroy Indicating Controller equipped with a throttling mechanism for

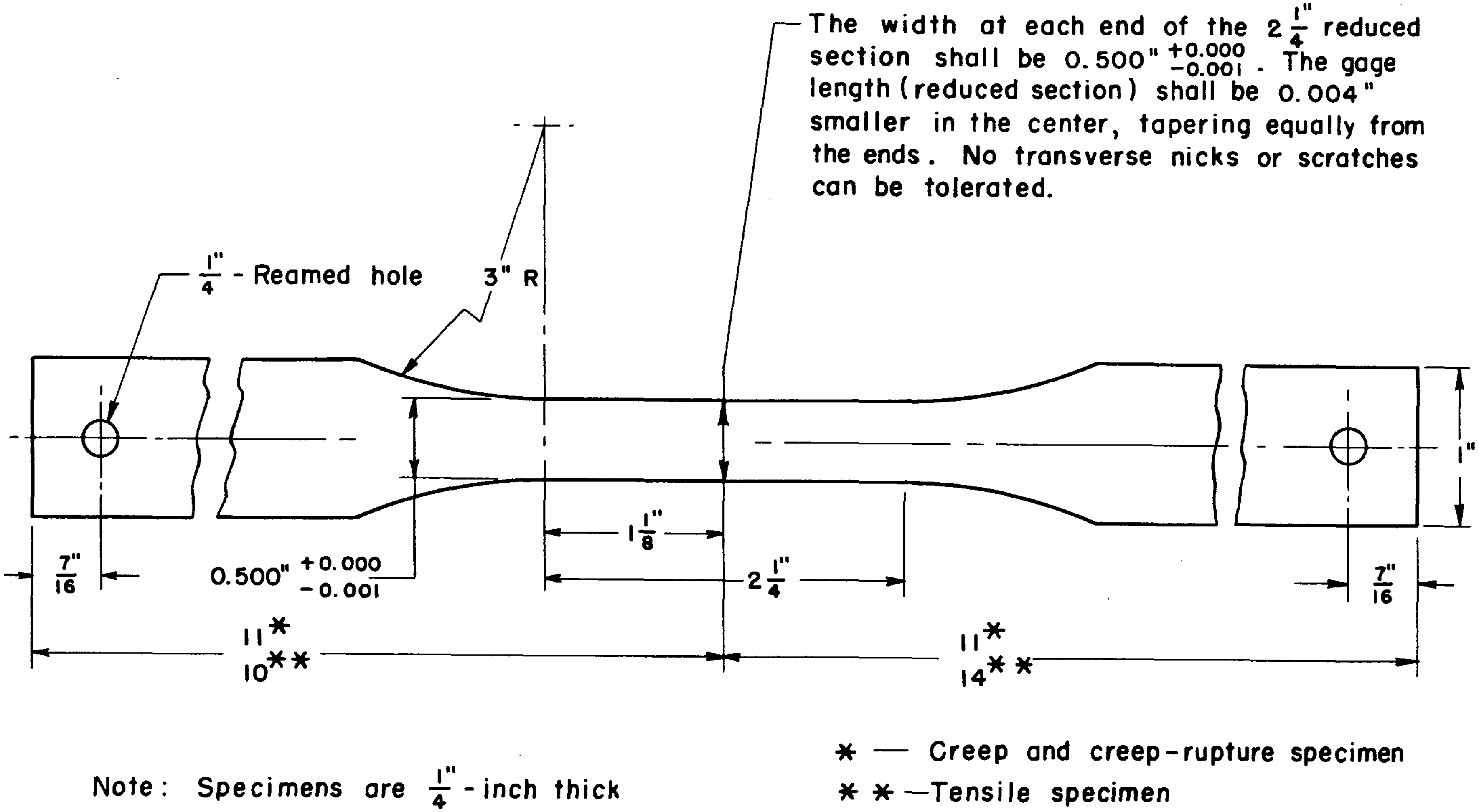

FIGURE 14. CREEP, CREEP-RUPTURE, CRAZING, AND TENSILE SPECIMEN USED FOR TESTING TRANSPARENT PLEXIGLAS Ia AND II AND LUCITE HC-201 AND HC-202 AT ALL TEST TEMPERATURES

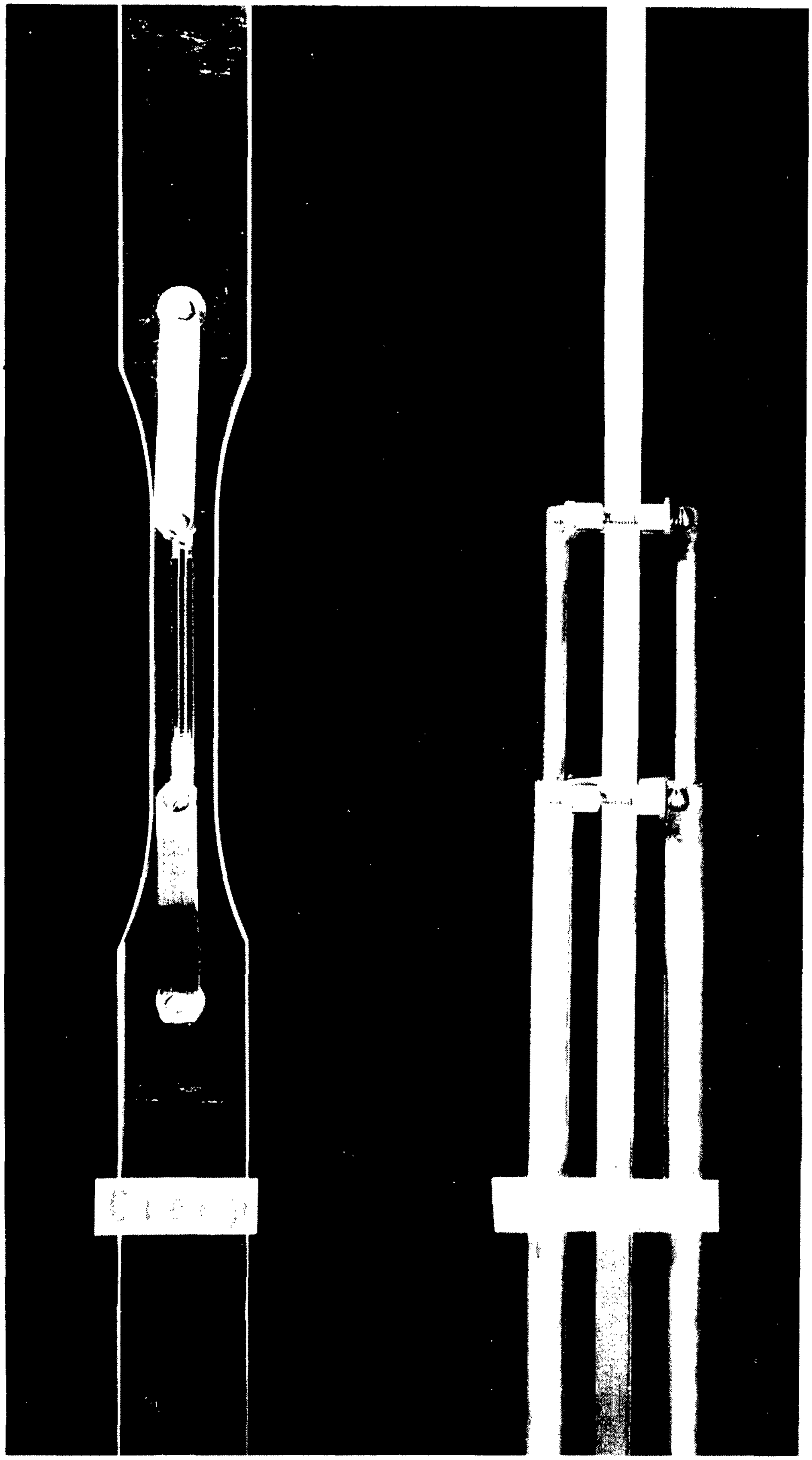

FIGURE 15. CREEP SPECIMEN WITH PLATINUM-STRIP EXTENSOMETER AND TENSILE SPECIMEN WITH MICROFORMER EXTENSOMETER

Note: Front view of the creep specimen and edge view of the tensile specimen are shown

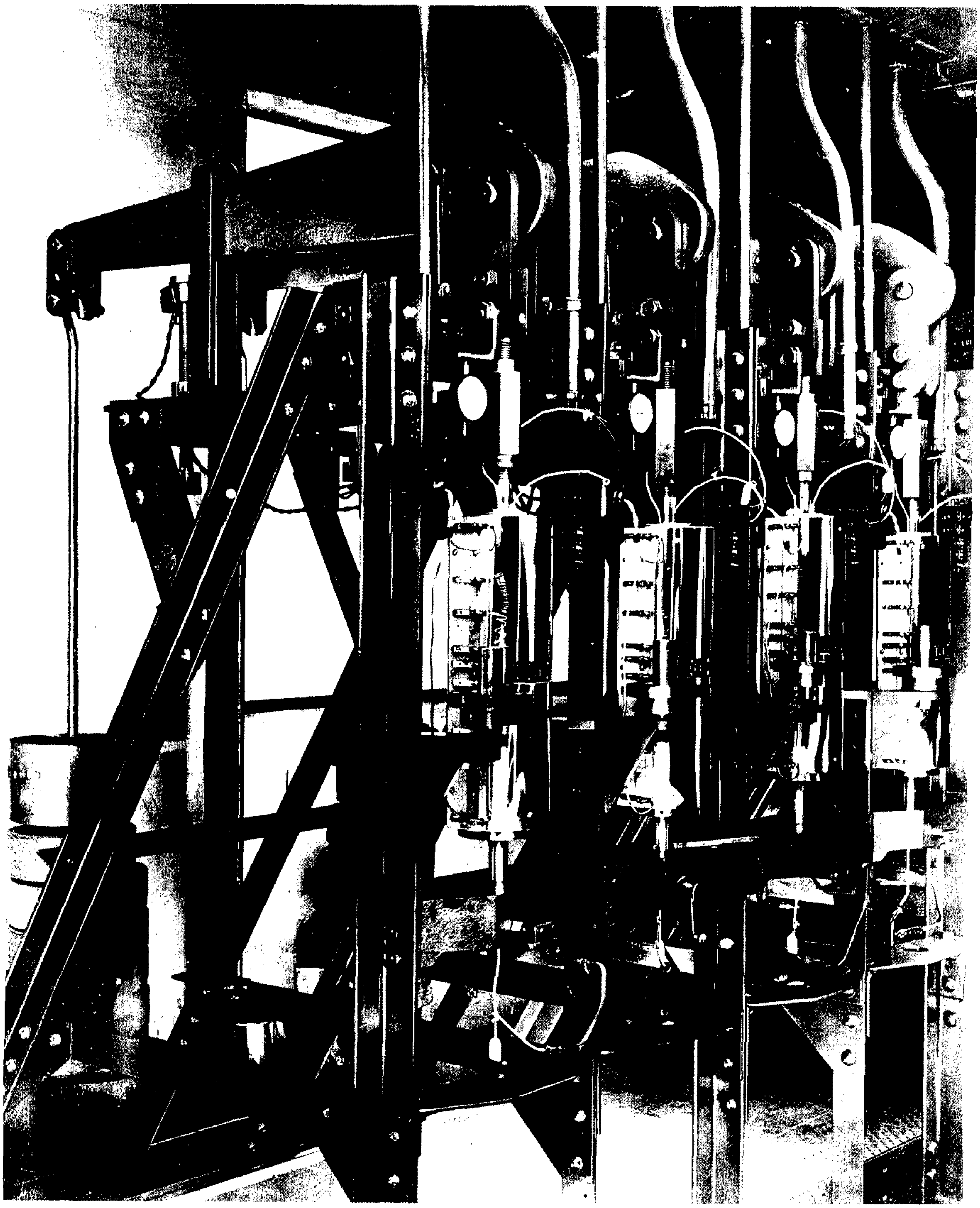

FIGURE 16. STANDARD BATTELLE CREEP AND CREEP-RUPTURE TESTING UNITS

closer control, or by a Foxboro controller to which an anticipating device had 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 stress was applied to the test specimen either by means of a 9 to 1 lever arm ratio or by direct loading with a dead weight after the specimen had reached the test temperature.

The tensile creep and creep-rupture specimen was 22 inches long and had the same gage-length dimensions as the short-time tensile specimen as shown in Figure 14.

The deformation of the test specimens was measured by means of a platinum-strip extensometer attached to the gage length of the specimens. The extensometer and the method of attachment are shown in Figure 15. The platinum extensometers consist of two strips, one of which slides within the folded-over edges of the other. The surfaces of the strips are polished and a series of very fine cross 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 test specimen is determined by measuring the change in the distance between the reference marks.

The microscope with which the deformation readings were made 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-inch gage length, would be equal to 0.0025 per cent.

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 readings are converted to percentages and plotted as time-deformation curves as shown in Figure 17. The deformation readings in both the front and back of the specimen of both observers are averaged to produce these curves.

In all the creep and creep-rupture tests, the no-load, at-temperature condition of the test is represented by the zero or starting point of the time-deformation curves. These curves show all deformations except thermal expansion that occur during the heating of the specimen.

When the load is applied, the specimen deforms an initial amount, which is generally all elastic deformation unless the proportional limit has been exceeded. This is shown by point "a" in each of the curves of Figure 17. (The subscripts indicate the number of the test specimen in each case.) Actual creep of the specimen starts at this point. The part of the time-deformation curves from a to b is called primary creep and is characterized

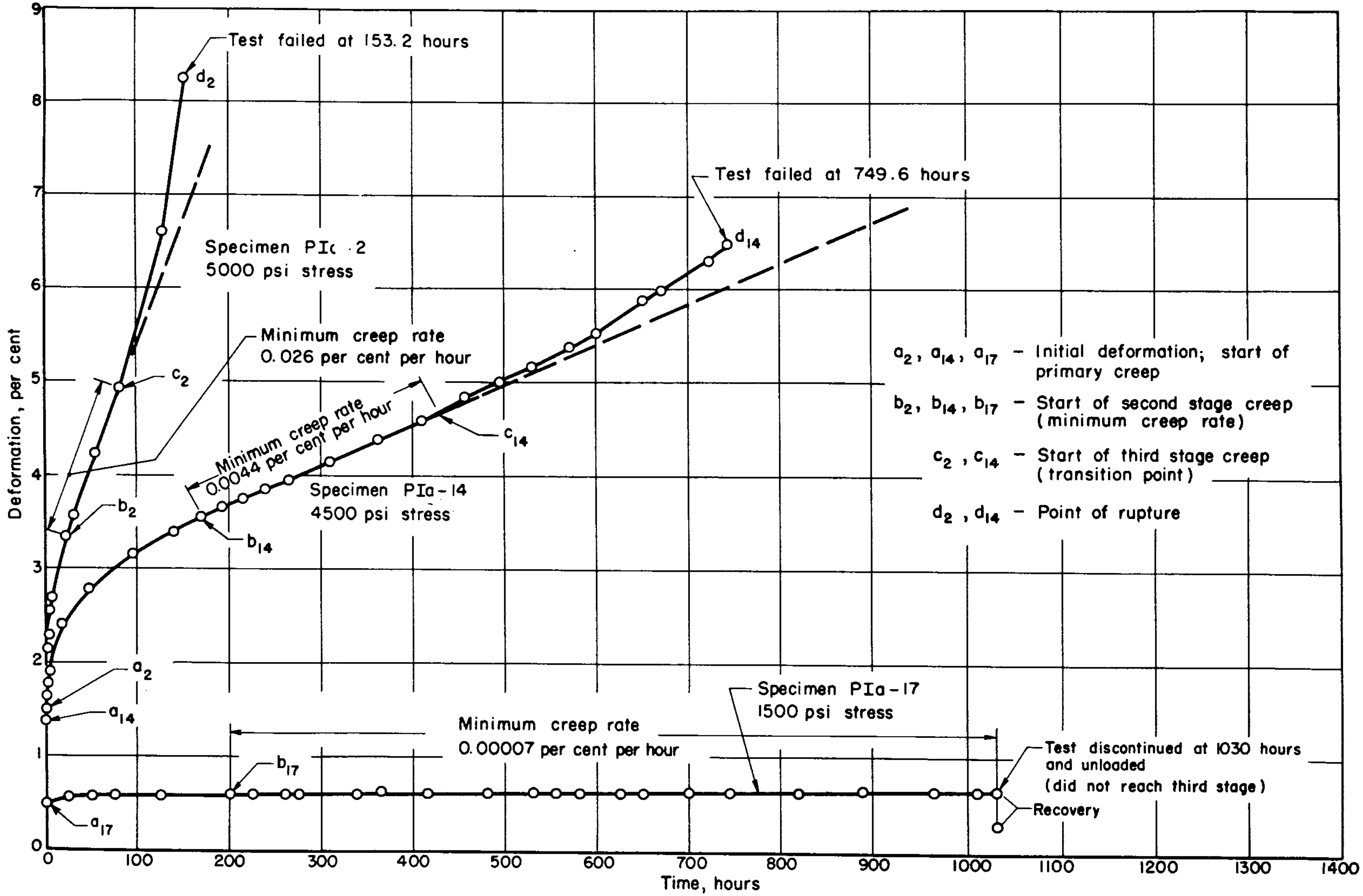

FIGURE 17. TYPICAL CREEP AND CREEP-RUPTURE CURVES FOR PLEXIGLAS Ia AT ROOM TEMPERATURE (Note: These are also typical creep and creep-rupture curves for Lucite HC-201 and HC-202 and Plexiglas Ia and II at all test temperatures

by a decreasing creep rate. Secondary creep begins at point b and ends at point c. This part of the time-deformation curve is characterized by (1) an approximately uniform creep rate and (2) the lowest creep rate of the entire test. It is generally the most important part of the creep curve and is identified as a certain minimum creep rate in per cent per hour. Point c on the curves indicates the start of third-stage creep and it is characterized by an increasing creep rate until failure occurs at point d. Point c is also identified as the transition point.

Specimen PIa-17 was tested in creep and it was discontinued while still in the second stage. This test, therefore, does not show the transition or rupture points. When discontinued, the load was removed from the specimen resulting in the recovery of the elastic portion of the initial deformation as shown in Figure 17.

The deformation above point "a" in each curve is defined as the total creep strain. The total deformation, on the other hand, is the deformation above the abscissa or base line. In other words, initial strain plus creep strain is equal to total deformation.

In order to present these creep data in a more concise and useful form, design curves were prepared from the time-deformation curves. The times to produce total deformations ranging from 0.5 to 10 per cent were taken from the variously stressed tests and assembled in table form as shown in Tables 1 and 2 of the text. Also taken from the time-deformation curves and included in these tables were rupture times or, if discontinued, maximum time of test, minimum creep rates, start of crazing, initial deformation, and time and amount of deformation at the start of third-stage creep. It is not generally possible to obtain all of these data from a single test but a family of as many as ten tests was required to produce a set of design curves on each material at any one temperature. These data were then plotted as design curves (stress versus log of time) and stress versus creep-rate curves as shown in the text. It is emphasized that all deformations are total deformations and include all strain except thermal expansion.