NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3752

TENSILE PROPERTIES OF AZ31A-0 MAGNESIUM-ALLOY SHEET UNDER RAPID-HEATING AND CONSTANT-TEMPERATURE CONDITIONS

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SUMMARY

Specimens of AZ31A-O magnesium-alloy sheet were heated to rupture at nominal rates of 0.2° F to 100° F per second under constant tensile load conditions. The data are presented and compared with the results of conventional tensile stress-strain tests at elevated temperatures after 1/2-hour exposure. A temperature-rate parameter was used to construct master curves from which stresses and temperatures for yield and rupture can be predicted under rapid-heating conditions. A comparison of the elevated-temperature tensile properties of AZ31A-O and HK31XA-H24 magnesium-alloy sheet under both constant-temperature and rapid-heating conditions is included.

INTRODUCTION

Aerodynamic heating of aircraft and missiles has led to considerable research on the strength of materials at elevated temperatures. Recent investigations have shown that materials exhibit greater tensile strength when heated at rapid temperature rates than under conventional constant-temperature test conditions. A number of reports on the effects of rapid heating of materials at high temperature rates have been published by the U. S. Naval Ordnance Test Station at China Lake, California (for example, ref. 1). At the Langley Aeronautical Laboratory of the National Advisory Committee for Aeronautics, tensile properties have been determined under rapid-heating conditions for 7075-T6 and 2024-T3 aluminum alloy, Inconel, RS-120 titanium alloy, and HK31XA-H24 magnesium-alloy sheet (refs. 2 to 4).

The present paper gives the results of rapid-heating tests of AZ31A-O magnesium-alloy sheet heated to failure at nominal temperature rates of 0.2° F to 100° F per second under constant tensile load conditions. These results are compared with conventional tensile stress-strain test data at constant elevated temperatures. The usefulness of a temperature-rate parameter for the prediction of yield and rupture temperatures is investigated. A brief comparison of the elevated-temperature properties of AZ31A-O and HK31XA-H24 magnesium-alloy sheet is also included.

MATERIAL AND SPECIMENS

The test specimens were made from a single 0.126-inch-thick sheet of AZ31A magnesium alloy in the annealed condition. The nominal chemical composition is given in table 1, and typical and minimum tensile properties (ref. 5), in table 2. The alloy and temper designation of the American Society for Testing Materials for this sheet is AZ31A-O; the commercial designations are FS1-O and AMC51S-O.

The specimens for both rapid-heating and stress-strain tests were cut from the sheet with the longitudinal axes of the specimens parallel to the rolling direction. The dimensions of the specimens are given in figure 1.

TEST PROCEDURE

Stress-Strain Tests

Conventional tensile stress-strain tests were performed at room and elevated temperatures to determine the change in Young's modulus with temperature and to compare yield and ultimate stresses with the results from rapid-heating tests. The equipment and procedures were the same as described in reference 6. The specimens were exposed to the test temperature for 1/2 hour and then loaded to failure at a strain rate of 0.002 per minute. The stress-strain curves were recorded autographically, simultaneously with a strain-time curve used to control the strain rate during the test. The temperature variations during the exposure period were within ±10° F and, during the test, within ±5° F of the desired test temperature. The yield stresses were determined with an accuracy of ±2 percent and the ultimate stresses within ±0.5 percent.

Rapid-Heating Tests

The equipment and procedure for rapid-heating tests were essentially the same as described in references 2 and 3. The specimens were loaded at room temperature to the desired stress level by a dead-weight loading system and were then heated to failure at a constant temperature rate. Arbitrary stress levels of 5, 9, 12, 14, and 15 ksi were used. Heating was achieved by passing an electric current directly through the specimen. Strains were measured over a 1-inch gage length by two linear variable differential transformer gages connected to the specimen through lever arms and gage frames. The thermocouples were spotwelded to the specimens with a commercial controlled-condenser-discharge spotwelder designed for that purpose. In rapid-heating tests the accuracy of strain measurements was ±2 percent. Temperatures were measured within ±5° F.

The thermal-expansion characteristics were determined from rapid-heating tests at a stress of 0.6 ksi. The elastic strains due to that stress were negligible.

RESULTS AND DISCUSSION

Stress-Strain Tests

The results of stress-strain tests are given in table 3 and are illustrated in figures 2 to 4.

Typical stress-strain curves for each test temperature are shown in figure 2. The 0.2-percent offset yield is indicated by a tick mark on each curve. The variation of the yield and ultimate stresses with temperature is shown in figure 3 and that of Young's modulus is shown in figure 4.

Rapid-Heating Tests

The results of the rapid-heating tests of the material are given in table 4 and are illustrated in figures 5 to 8. The thermal-expansion curve is illustrated in figure 5 and the average coefficients of thermal expansion determined from that curve are listed in table 5.

The strain-temperature histories at four stress levels for temperature rates from 0.2° F to 107° F per second are shown in figure 5. The families of curves for each stress level are spaced for ease of reading. The strains are total strains which include thermal, elastic, and plastic strains. Until plastic deformation occurs, the experimental curves coincide with the calculated strain curves representing the sum of the thermal and the calculated elastic strain. The elastic strains were calculated by use of the Young's modulus curve in figure 4. Yield temperatures, which are defined as temperatures at which a plastic strain of 0.2 percent occurs, are indicated by tick marks at an offset of 0.2 percent from the calculated strain curve.

In figure 6, yield and rupture temperatures are plotted against the temperature rate on a logarithmic scale. The experimental curves for each stress level are represented by the solid lines. For this material, the relationship between yield and rupture temperatures and the logarithm of the temperature rate is linear at each stress level.

The rapid-heating and tensile stress-strain test results are compared in figures 7 and 8. The solid curves representing the rapid-heating test results for four temperature rates were cross-plotted from the experimental curves of figure 6. The stress-strain results represented by the dashed lines are from figure 3. For temperature rates of about 2° F per second and higher, the material exhibits greater yield strength under rapid-heating conditions than in conventional stress-strain tests (fig. 7). Rupture stresses for the temperature rates covered herein (fig. 8) are all considerably higher than the ultimate stresses from conventional stress-strain tests.

Master curves for yield and rupture (figs. 9 and 10) were obtained by means of linear temperature-rate parameters according to the method described in reference 2. The parameters for the yield temperatures T_y and the rupture temperatures T_r are, respectively,

$$\frac{T_y + 400}{\log h + 15} \tag{1}$$

and

$$T_r - 65.5 \log h \tag{2}$$

in which the temperatures T_y and T_r are in °F and h is the temperature rate in °F per second. The parameter for rupture (2) has a different form from parameter (1) because the experimental curves are parallel instead of convergent at some point (fig. 6).

Except for yield temperatures at stresses of 14 and 15 ksi, the correlation between the data and the master curves is good. Consequently, yield and rupture temperatures or the corresponding stresses can be predicted from the master curves for any temperature rate. The agreement between predicted and experimental yield and rupture temperatures is illustrated in figure 6.

Comparison of AZ31A-O and HK31XA-H24 Magnesium-Alloy Sheet

Comparisons between the stress-strain and rapid-heating results for AZ31A-O and HK31XA-H24 magnesium-alloy sheet are given in figure 11. The data on HK31XA-H24, a new experimental temperature-resistant sheet material, are taken from reference 4. The test conditions and procedures were the same for both materials. The results for HK31XA-H24, however, may not be typical because the material is still in an experimental stage of development.

The comparison in figure 11 definitely indicates that the elevated-temperature properties of HK31XA-H24 are superior to AZ31A-O under both constant-temperature and rapid-heating conditions, particularly with regard to the yield stress.

CONCLUSIONS

From results of rapid-heating tests and of conventional elevated-temperature stress-strain tests of AZ31A-O magnesium-alloy sheet, the following conclusions are indicated.

1. Tensile rapid-heating tests of AZ31A-O magnesium-alloy sheet indicate that for each stress level, yield and rupture temperatures vary linearly with the logarithm of the temperature rate for rates from 0.2° F to 100° F per second. Also, at all stress levels, the yield and rupture temperatures increase with the temperature rate.

2. Yield stresses obtained from rapid-heating tests can be greater or less than the yield stresses obtained from stress-strain tests, depending upon the temperature rate. Rupture stresses for the rapid-heating tests at all temperature rates investigated are appreciably greater than the ultimate tensile stresses from the stress-strain tests.

3. Yield and rupture temperatures or the corresponding stresses can be predicted for any temperature rate by means of master curves and temperature-rate parameters.

4. A comparison of results for AZ31A-O and HK31XA-H24 magnesium-alloy sheet shows that HK31XA-H24 has superior tensile properties for both constant-temperature and rapid-heating conditions than AZ31A-O.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 31, 1956.

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2. Heimerl, George J., and Inge, John E.: Tensile Properties of 7075-T6 and 2024-T3 Aluminum-Alloy Sheet Heated at Uniform Temperature Rates Under Constant Load. NACA TN 3462, 1955.

3. Heimerl, George J., Kurg, Ivo M., and Inge, John E.: Tensile Properties of Inconel and RS-120 Titanium-Alloy Sheet Under Rapid-Heating and Constant-Temperature Conditions. NACA TN 3731, 1956.

4. Gibbs, Thomas W.: Tensile Properties of HK31XA-H24 Magnesium-Alloy Sheet Under Rapid-Heating Conditions and Constant Elevated Temperatures. NACA TN 3742, 1956.

5. Anon.: Magnesium Alloys and Products. The Dow Chemical Co., 1955.

6. Hughes, Philip J., Inge, John E., and Prosser, Stanley B.: Tensile and Compressive Stress-Strain Properties of Some High-Strength Sheet Alloys at Elevated Temperatures. NACA TN 3315, 1954.

TABLE 1

CHEMICAL COMPOSITION OF AZ31A MAGNESIUM ALLOY[1]

[All values in percent]

Aluminum	2.5 to 3.5
Manganese (minimum)	0.20
Zinc	0.7 to 1.3
Calcium (maximum)	0.04
Silicon (maximum)	0.3
Copper (maximum)	0.05
Nickel (maximum)	0.005
Iron (maximum)	0.005
Other impurities (maximum)	0.3
Magnesium	Balance

[1]From reference 5.

TABLE 2

ROOM-TEMPERATURE TENSILE PROPERTIES OF 0.064- TO 0.250-INCH-THICK

AZ31A-O MAGNESIUM-ALLOY SHEET[1]

	Yield stress, ksi	Ultimate stress, ksi	Elongation in 2 inches, percent
Typical	22	37	21
Minimum	15	32	12

[1]From reference 5.

TABLE 3

TENSILE STRESS-STRAIN PROPERTIES FOR 0.126-INCH-THICK AZ31A-O MAGNESIUM-ALLOY SHEET FOR 1/2-HOUR TEMPERATURE EXPOSURE AND A STRAIN RATE OF 0.002 PER MINUTE

Temperature °F	Yield stress, ksi	Ultimate stress, ksi	Young's modulus, psi	Elongation in 2 inches
80	18.1	34.5	6.5×10^6	--
	18.7	35.7	6.4	22
	18.4	35.7	6.2	--
	18.5	34.7	----------	--
	18.3	33.2	6.3	6
200	14.8	24.5	5.8	24
	15.4	24.6	----------	32
300	10.8	15.6	5.2	31
	11.1	16.5	5.2	60
400	8.1	10.1	4.6	53
	-----	-----	4.2[a]	--
500	6.1	6.5	----------	50
	5.8	6.4	----------	43
	-----	-----	3.6[a]	--
	-----	-----	3.4[a]	--
600	3.7	4.1	2.1	56
	3.9	4.2	2.7	77
	-----	-----	2.9[a]	--

[a]Additional tests for Young's modulus.

TABLE 4

TENSILE PROPERTIES FOR AZ31A-O MAGNESIUM-ALLOY SHEET

UNDER RAPID-HEATING CONDITIONS

Stress, ksi	Temperature rate, °F/sec	Yield temperature, °F	Rupture temperature, °F	Elongation in 2 inches, percent
5.0	0.2	(a)	690	42
	0.2	525	(b)	46
	0.6	560	710	54
	2	560	760	76
	6	615	790	72
	20	665	810	---
	50	680	850	---
	107	700	(b)	---
9.0	0.2	345	525	42
	2	380	605	46
	20	430	655	---
	76	475	700	---
	94	485	(b)	---
12.0	0.2	295	460	31
	2	340	535	42
	20	385	595	---
	80	435	(b)	---
14.0	2	(a)	490	31
	26	315	(b)	---
	80	325	595	---
15.0	0.2	250	415	29
	2	260	475	36
	20	(a)	540	71
	20	280	540	---
	78	290	(b)	---

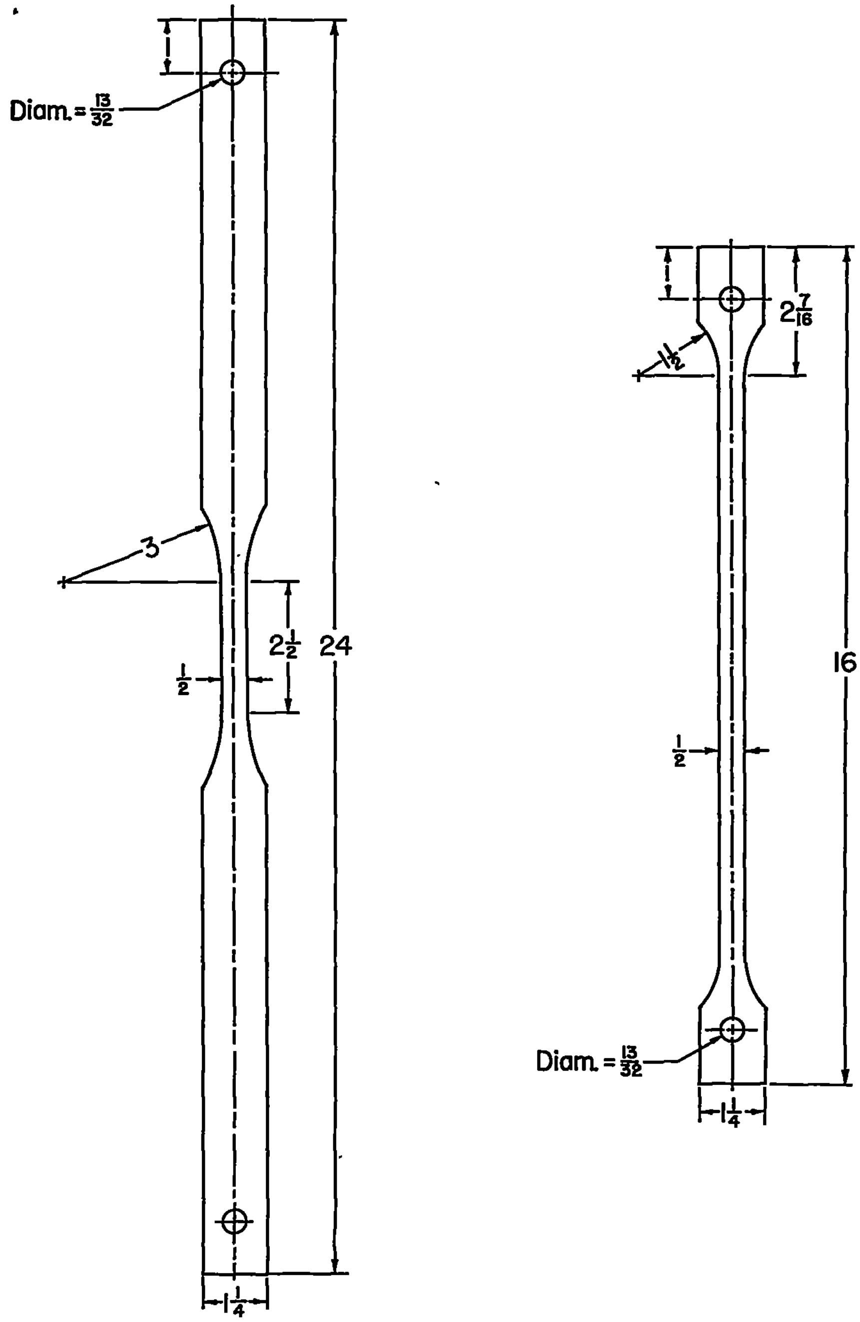
[a]Strain gages inoperative.

[b]Rupture occurred outside of gage length.

TABLE 5

THERMAL EXPANSION OF AZ31A-O MAGNESIUM-ALLOY SHEET

Temperature range, °F	Thermal strain	Coefficient of thermal expansion per °F
80 to 200	0.00165	13.8×10^{-6}
80 to 300	.00320	14.6
80 to 400	.00480	15.0
80 to 500	.00645	15.4
80 to 600	.00820	15.8
80 to 700	.01010	16.3
80 to 800	.01200	16.7



(a) Stress-strain specimen. (b) Rapid-heating specimen.

Figure 1.- Stress-strain and rapid-heating tensile test specimens. All dimensions are in inches. (Edges of reduced sections parallel within ±0.002.)

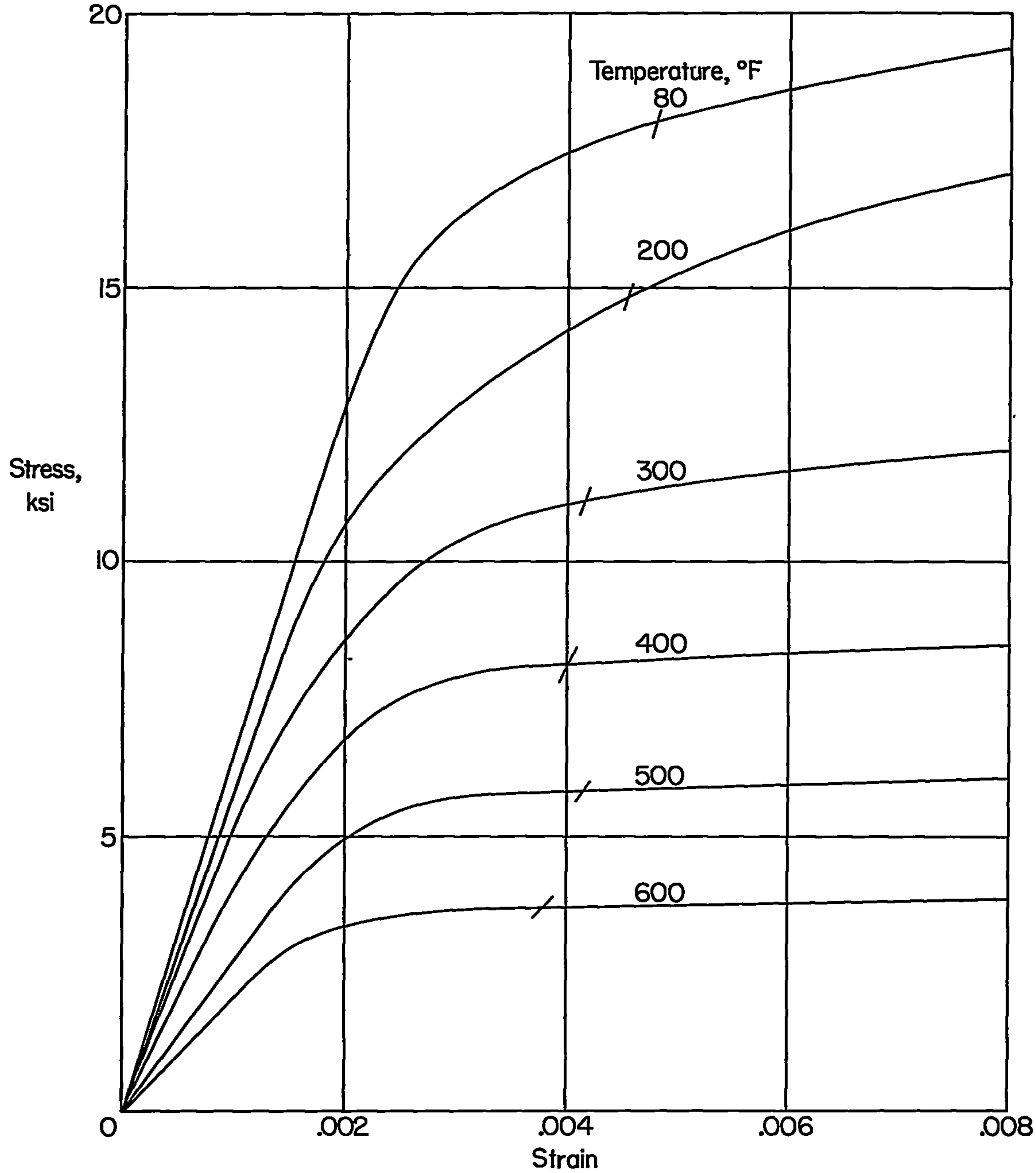


Figure 2.- Tensile stress-strain curves for AZ31A-0 magnesium-alloy sheet after 1/2-hour exposure for a strain rate of 0.002 per minute. The tick marks indicate 0.2-percent-offset yield stresses.

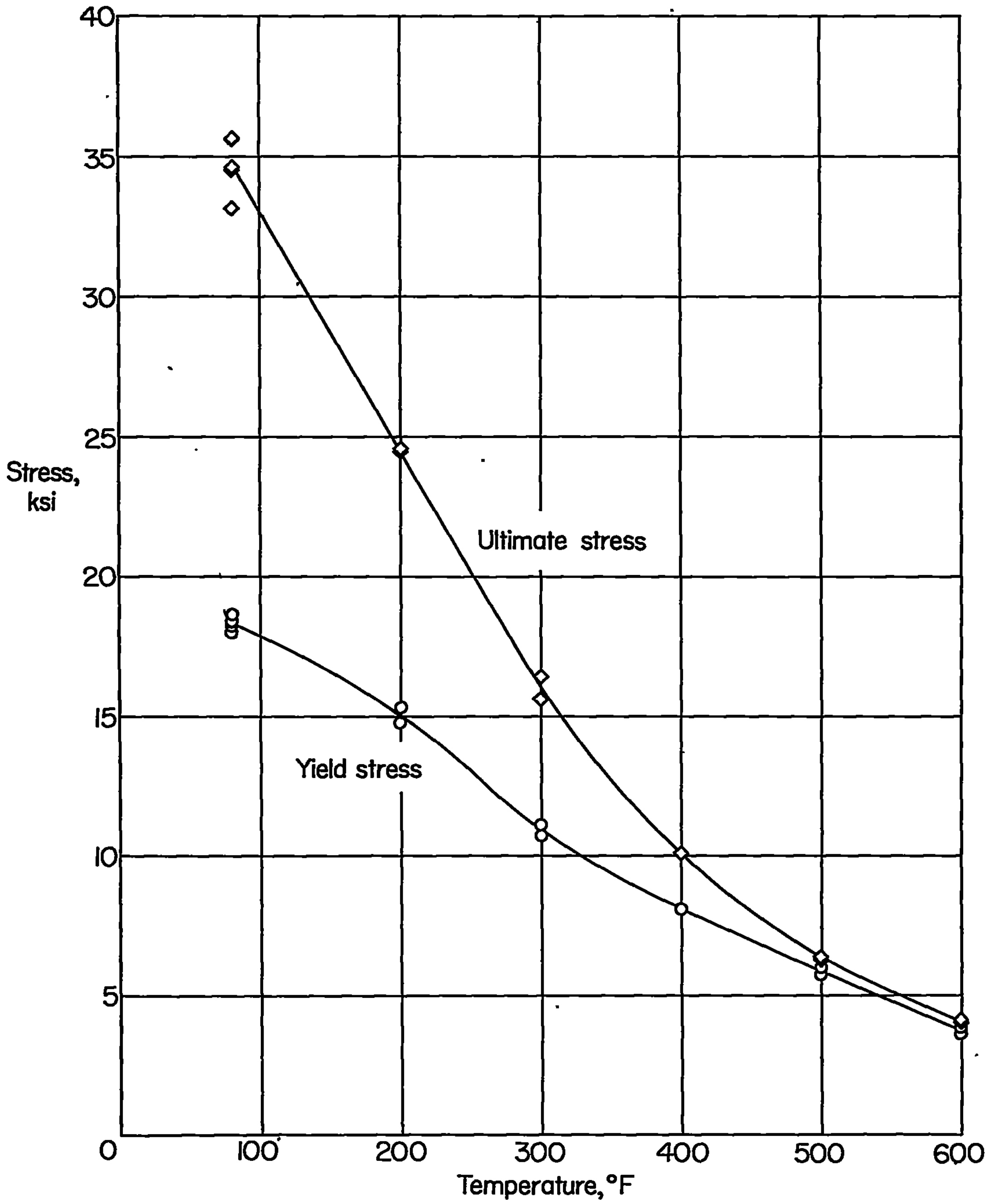


Figure 3.- Tensile yield and ultimate stresses for AZ31A-O magnesium-alloy sheet at elevated temperatures after 1/2-hour exposure for a strain rate of 0.002 per minute. Yield stress is for 0.2-percent offset.

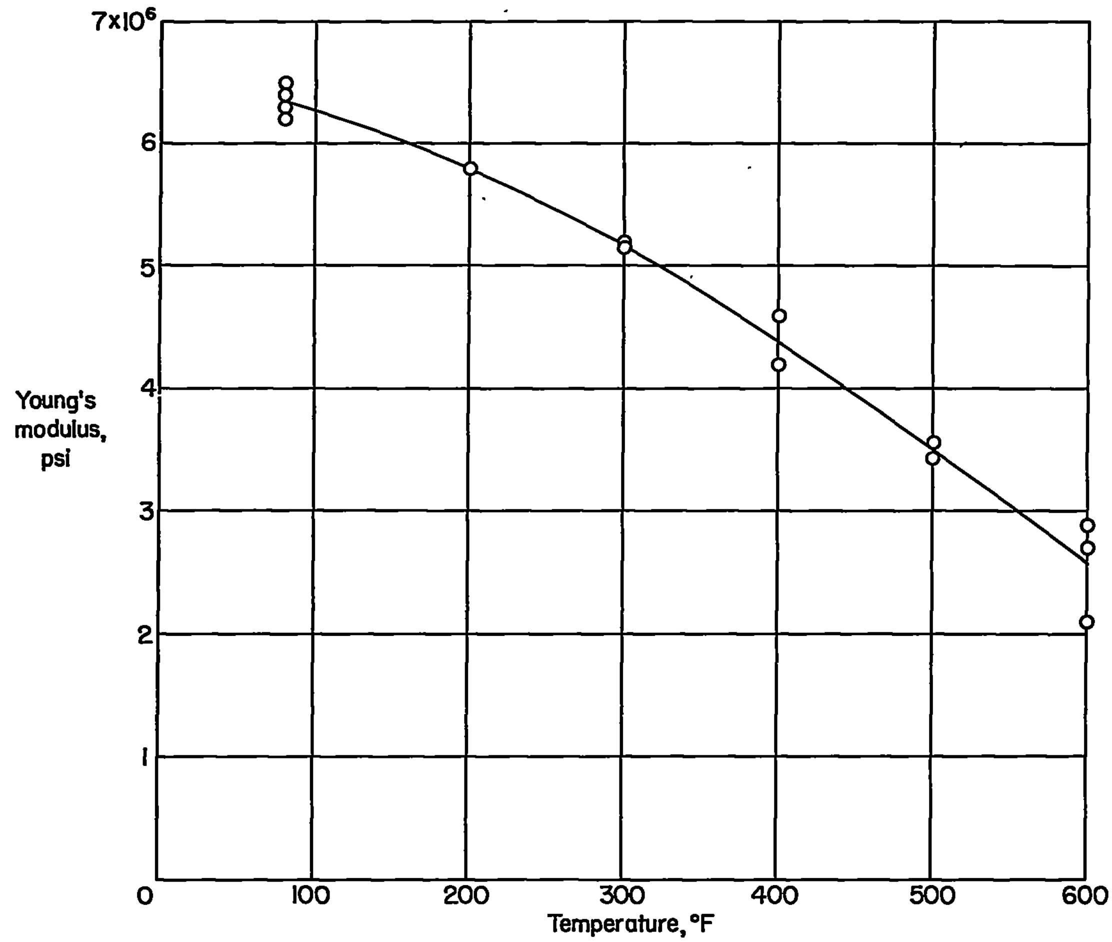


Figure 4.- Young's modulus for AZ31A-0 magnesium-alloy sheet at elevated temperatures after 1/2-hour exposure.

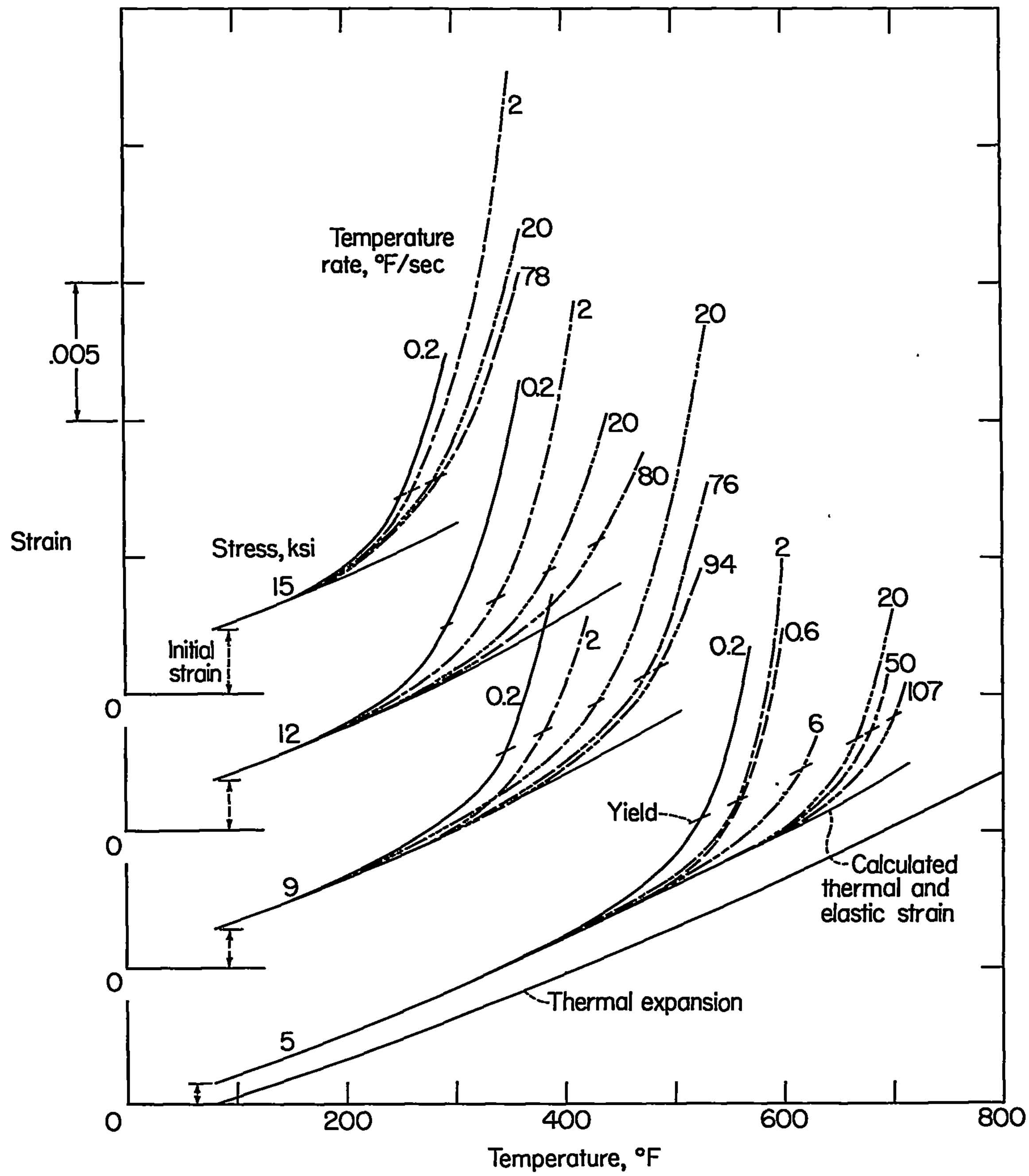


Figure 5.- Strain-temperature curves of AZ31A-0 magnesium-alloy sheet for temperature rates of 0.2° F to 107° F per second for various stresses.

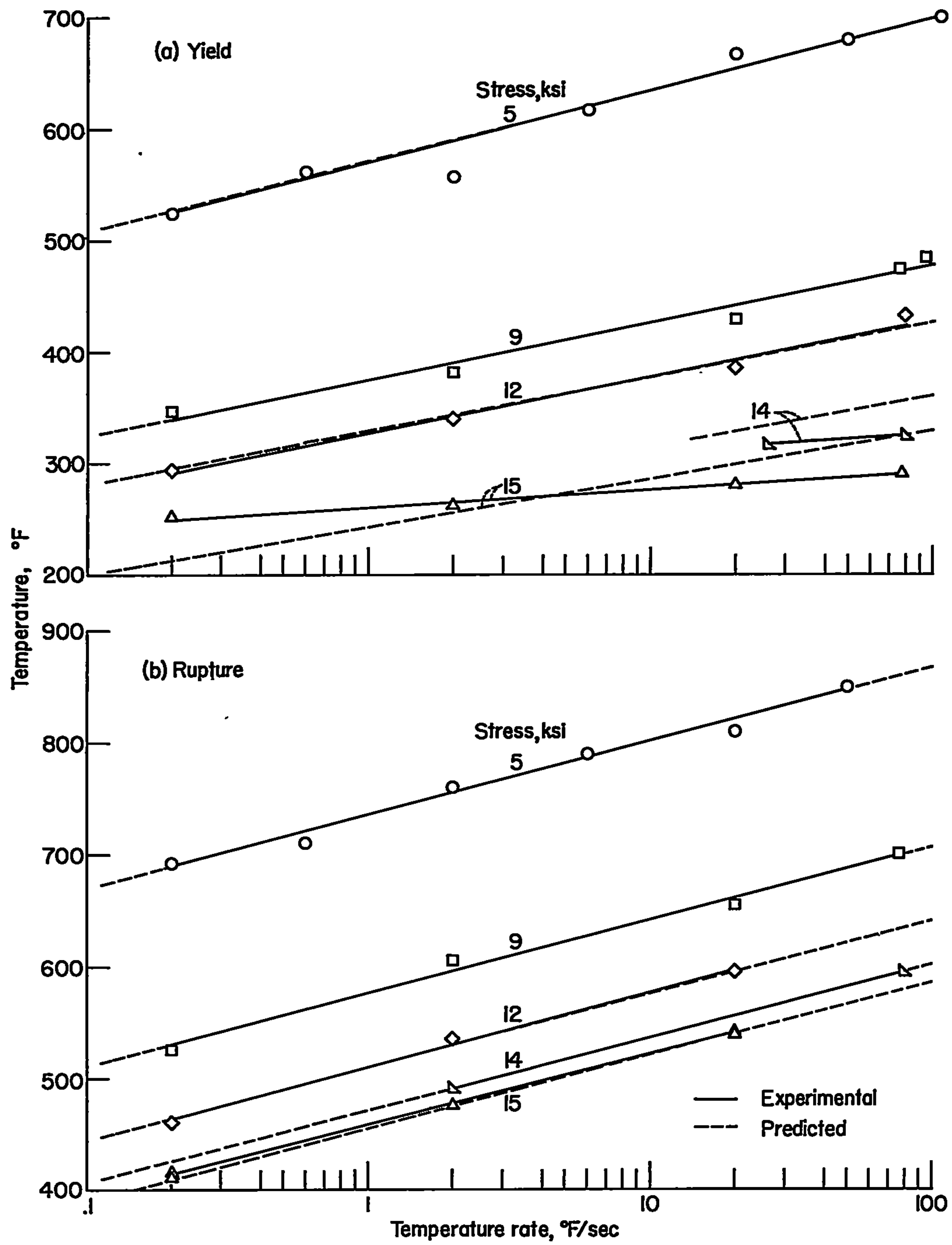


Figure 6.- Experimental and predicted yield and rupture temperatures for AZ31A-O magnesium-alloy sheet for temperature rates from 0.2° F to 107° F per second for various stresses.

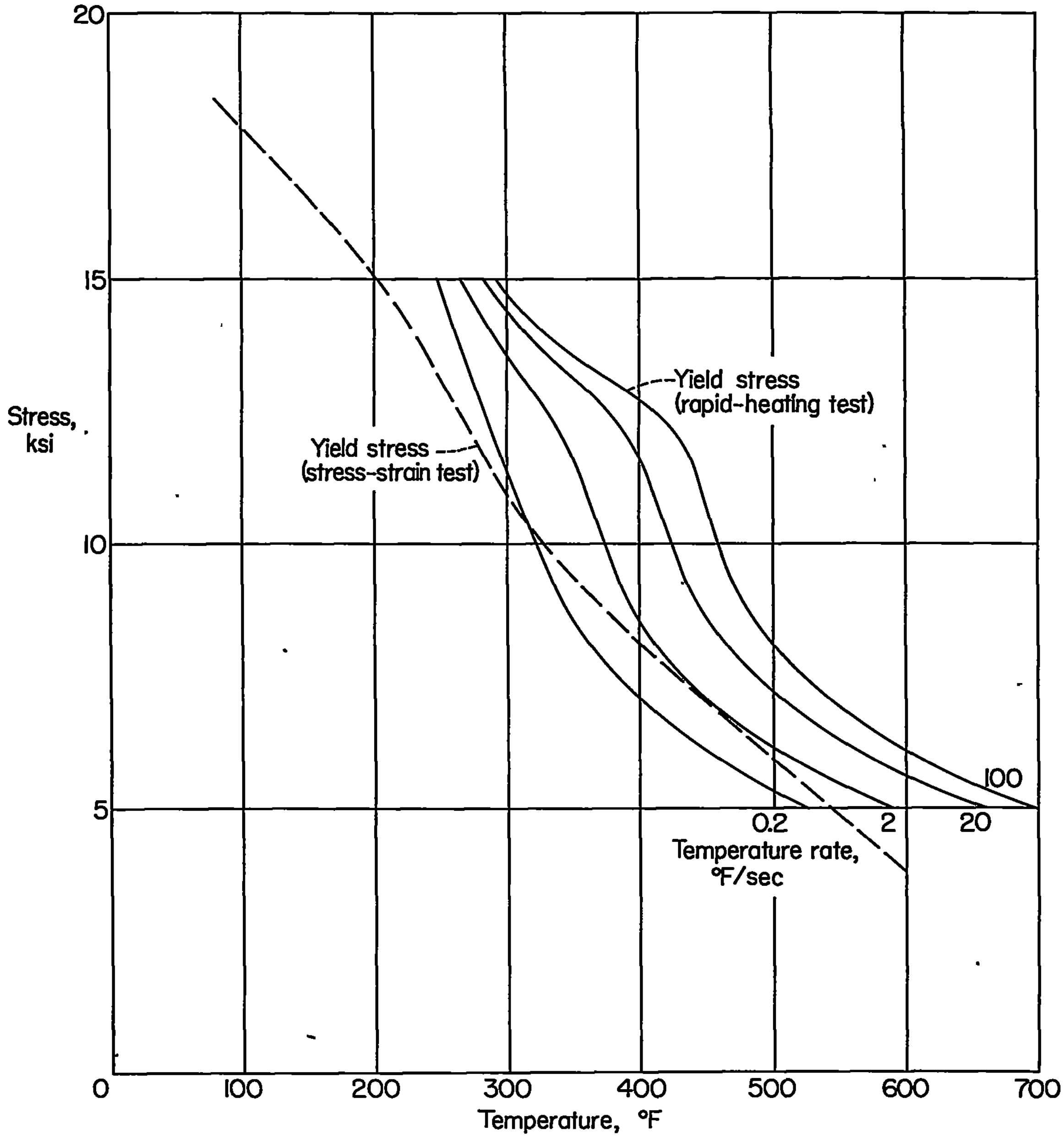


Figure 7.- Tensile yield stress of AZ31A-O magnesium-alloy sheet for rapid-heating tests from 0.2° F to 100° F per second and for stress-strain tests after 1/2-hour exposure for a strain rate of 0.002 per minute.

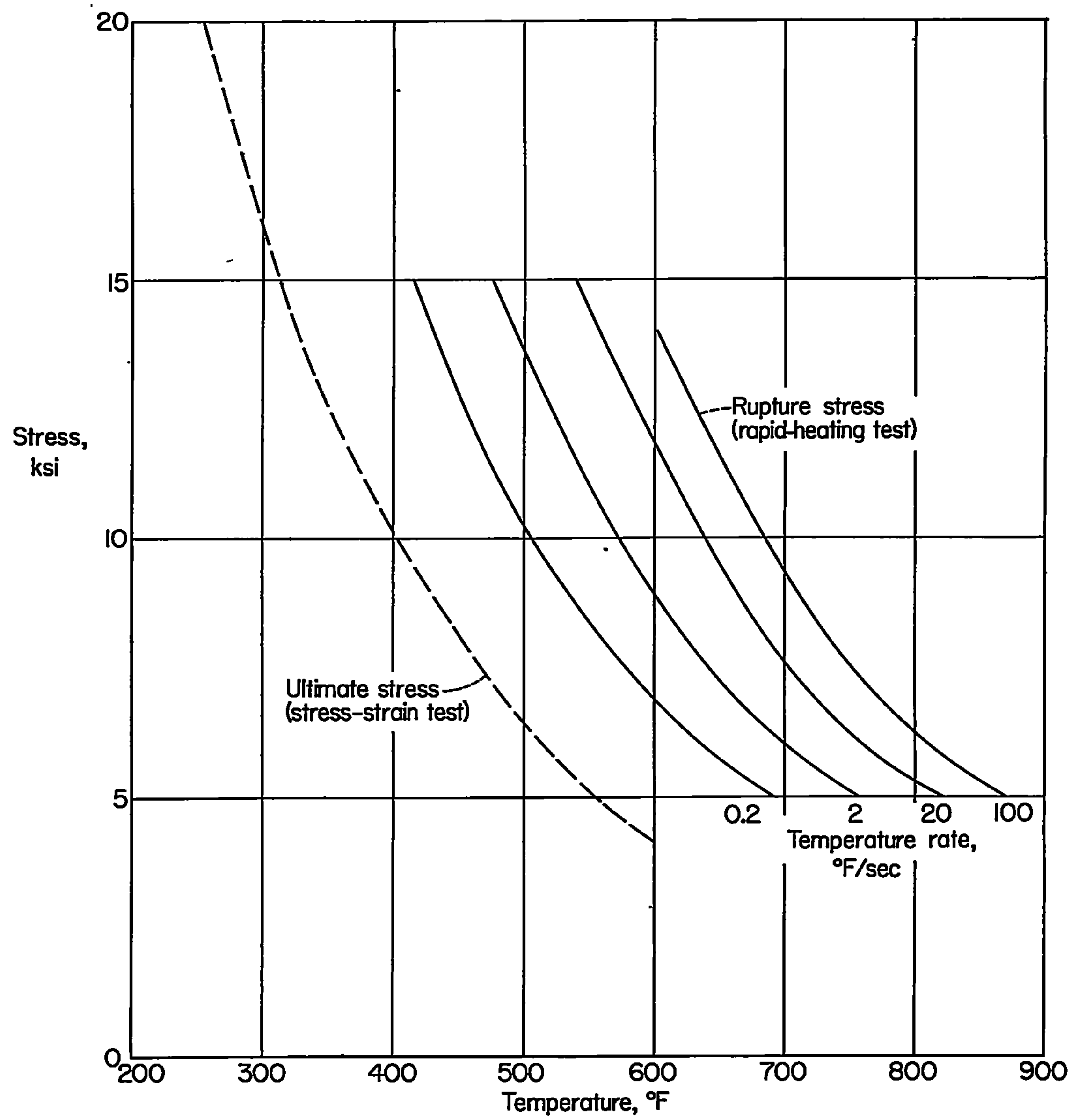


Figure 8.- Tensile rupture stress of AZ31A-O magnesium-alloy sheet for rapid-heating tests from 0.2° F to 100° F per second and tensile ultimate stress for stress-strain tests after 1/2-hour exposure for a strain rate of 0.002 per minute.

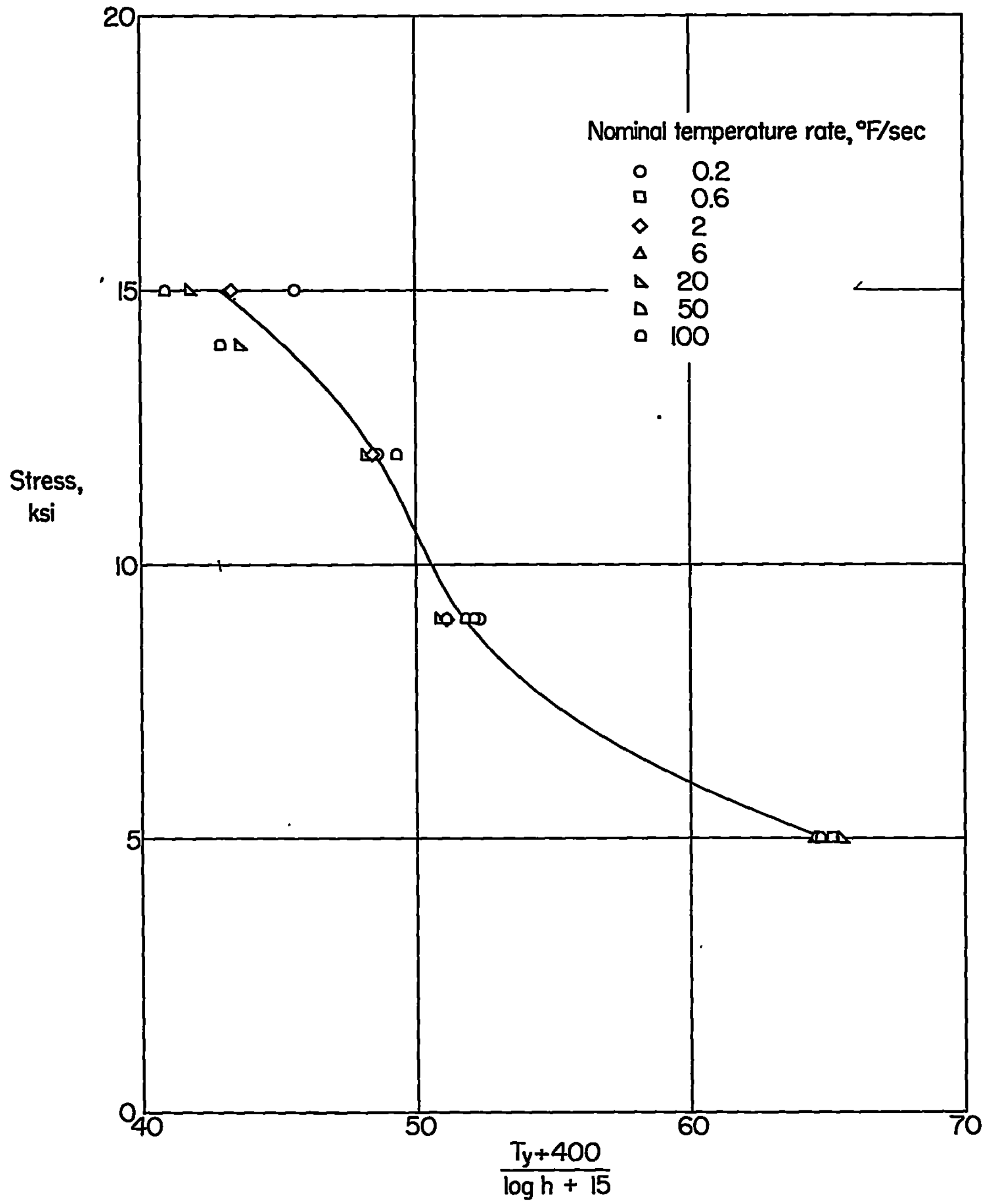


Figure 9.- Master yield-stress curve for AZ31A-O magnesium-alloy sheet using the temperature-rate parameter $\frac{T_y + 400}{\log h + 15}$ (T_y is in °F and h is in °F per second).

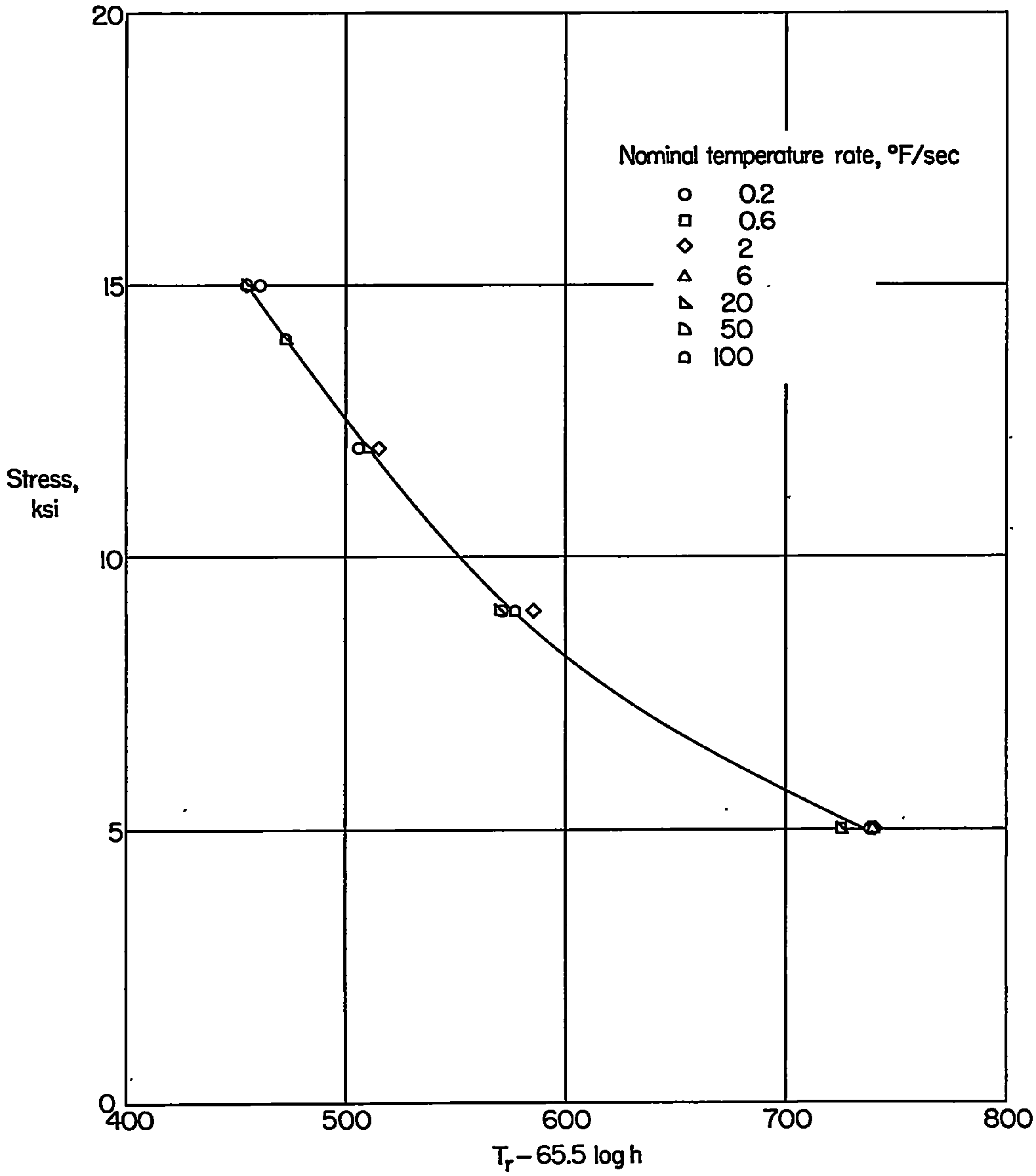


Figure 10.- Master rupture stress curve for AZ31A-0 magnesium-alloy sheet using the temperature-rate parameter $T_r - 65.5 \log h$ (T_r is in °F and h is in °F per second).

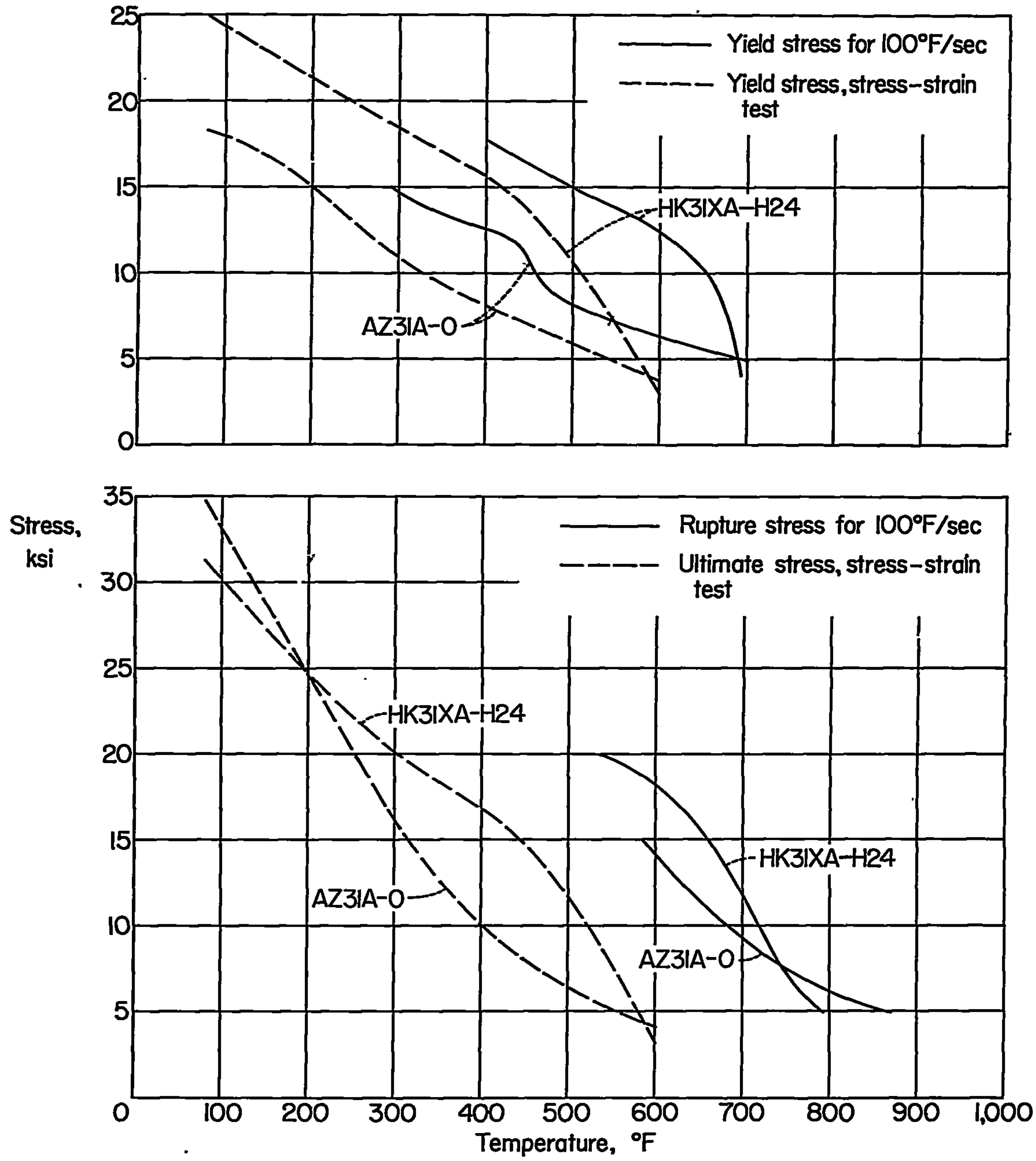


Figure 11.- Comparison of HK31XA-H24 and AZ31A-O magnesium-alloy sheet on the basis of yield and ultimate stresses from the stress-strain tests and yield and rupture stresses from the rapid-heating tests for 100° F per second.

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