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TECHNICAL NOTE 4074

COMPRESSIVE STRESS-STRAIN PROPERTIES OF 17-7 PH AND AM 350 STAINLESS-STEEL SHEET AT ELEVATED TEMPERATURES

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SUMMARY

Compressive stress-strain test results for 17-7 PH and AM 350 stainless-steel sheet in the heat-treated and annealed conditions are presented for temperatures from room temperature to 1,200° F. The 17-7 PH specimens were heat-treated to Condition TH 1,050 and the AM 350 specimens were heat-treated to the double-aged condition. Tests were conducted in both the with-grain and cross-grain directions. All specimens were exposed to test temperatures for 1/2 hour before loading and were tested at a strain rate of approximately 0.002 per minute.

Representative stress-strain curves are given for both materials at the test temperatures. From these curves significant design data which were obtained, such as compressive yield stress, Young's modulus, and secant and tangent moduli, are presented in graphical and tabular form.

An empirical equation that describes the stress-strain curves is presented and the variation of the parameters in this equation with temperature is given for the temperature range investigated.

INTRODUCTION

Recently developed precipitation-hardening stainless steels may be useful in aircraft structures which operate at elevated temperatures. Two such stainless steels are 17-7 PH and AM 350. These alloys can be fabricated comparatively easily in the annealed condition and then can be heat-treated to obtain substantially higher strengths. Because of this characteristic and the desirable high-temperature properties of these stainless steels, AM 350 and 17-7 PH are useful in structural applications where previously developed stainless steels were generally not considered.

Some tensile test results for these alloys are available (refs. 1 to 4), but very little compressive stress-strain data on these stainless

steels are available as yet. For this reason an investigation was made to determine the significant mechanical properties of these two materials in compression in the temperature range from room temperature to 1,200° F. Compressive stress-strain tests were made on both heat-treated and annealed specimens in the with-grain and cross-grain directions. The results of these tests are presented herein and comparisons are made between some of the properties of the two stainless steels.

TEST SPECIMENS, EQUIPMENT, AND PROCEDURE

Test specimens were machined from annealed sheets supplied by the manufacturers. The 17-7 PH stainless-steel specimens were obtained from three 0.050-inch-thick sheets. The AM 350 stainless-steel specimens were obtained from two sheets with thicknesses of 0.045 and 0.063 inch. Specimens were cut from several random locations on each sheet.

All compressive stress-strain specimens were 1.00 inch wide and 2.52 inches long. The majority of the specimens were heat-treated in accordance with the manufacturers' instructions to Condition TH 1,050 for 17-7 PH and to the double-aged condition for AM 350. The remaining specimens were not heat-treated. The details of the heat treatments, the nominal chemical compositions, and the other data for these sheets are presented in table I.

Rockwell superficial hardness tests were performed at several points on a few sample specimens at room temperature to appraise the uniformity of the heat treatment. The hardness results obtained on the Rockwell 15 N scale were approximately 82.0 ± 1 for the 17-7 PH and 80.5 ± 1 for the AM 350. (These values correspond to Rockwell C numbers of 43 ± 2 for the 17-7 PH and 40 ± 2 for the AM 350.)

The equipment used for the compressive stress-strain tests is shown in figure 1. Buckling of the specimens was prevented by the use of a grooved-plate compression fixture suitable for high-temperature testing. Use of a fixture of this type at room temperatures is described in reference 5. Strains were measured over a 1-inch gage length on the specimen by means of two extensometer frames with clamped knife edges. The strains were transferred by two vertical rods on each side of the fixture to a differential transformer-gage system. The tests were performed in a 120,000-pound-capacity universal hydraulic testing machine.

The specimen was inserted into the fixture which had been preheated to the test temperature. Uniform specimen temperatures were achieved by use of independently controlled heating elements in both the upper and lower loading rams and in the furnace. Temperatures at the top, middle, and bottom of the specimen were measured with the use of chromel-alumel

thermocouples and a temperature recorder. During the test, the specimen temperature was kept within ±5° F of the test temperature, and the temperature variation along the specimen was within 5° F. Each specimen was exposed to the test temperature for 1/2 hour before loading. During the test the strain rate was maintained as closely as possible to 0.002 per minute. Stress-strain and time-strain records were obtained autographically on a drum-type modified Brown potentiometer

RESULTS AND DISCUSSION

Test Results

The test results for 17-7 PH and AM 350 stainless steels are listed in tables II to IV.

Compressive stress-strain curves for 17-7 PH (Condition TH 1,050) and AM 350 (double-aged condition) stainless steels are presented in figures 2 and 3 for the temperature range from room temperature to 1,200° F. Each curve is representative of at least three tests at each temperature with the material loaded in the rolling direction of the sheet. Results obtained from tests with the material loaded perpendicularly to the rolling direction were not significantly different from the results shown in figures 2 and 3. For AM 350 no appreciable difference in compressive stress-strain results was obtained for the two different sheet thicknesses tested.

A few specimens of both 17-7 PH and AM 350 were tested in the annealed condition in both grain directions. The results of these tests are presented in table IV.

The variation of the 0.2-percent-offset yield stress with temperature for both alloys in the heat-treated and annealed conditions is shown in figure 4. The heat-treated 17-7 PH loses strength rapidly above approximately 700° F. The heat-treated AM 350 loses strength rapidly above approximately 800° F. The compressive yield strength of the heat-treated 17-7 PH is greater than that of the heat-treated AM 350 up to approximately 825° F for 1/2-hour exposure to temperature. Above 825° F the heat-treated AM 350 has greater compressive yield strength than the 17-7 PH. The 0.2-percent-offset yield stresses for the two stainless steels in the annealed condition indicated only a slight decrease in strength from room temperature to 1,200° F. At 1,200° F the yield strength of the annealed material exceeded slightly that of the heat-treated sheet for both 17-7 PH and AM 350.

The variation of Young's modulus obtained in the tests is plotted against temperature in figure 5. The average values of Young's modulus

for both stainless steels are approximately equal for a given temperature from room temperature to 1,100° F. Specific modulus values are not indicated in figure 5; the curves represent an average of the values listed in tables II to IV.

Secant and tangent moduli are plotted against stress in figures 6 to 9 for the two stainless steels in the heat-treated conditions. These curves were obtained from the stress-strain curves in figures 2 and 3. Secant- and tangent-modulus curves are sensitive to strain rate at high temperatures; different results would be expected if the strain rate were significantly different from that used in this investigation.

Empirical Approximation of Stress-Strain Curves

An empirical approximation of stress-strain curves (ref. 6) was investigated to determine whether the stress-strain curves for the stainless steels 17-7 PH (Condition TH 1,050) and AM 350 (double-aged condition) could be approximated at any given temperature by the following relationship:

$$\epsilon = \frac{\sigma}{E} + 0.002\left(\frac{\sigma}{\sigma_{cy}}\right)^n \tag{1}$$

where

ϵ	total strain
σ	stress, psi
E	Young's modulus, psi
σ_{cy}	0.2-percent-offset compressive yield stress, psi
n	stress-strain curve shape parameter

Values of n were obtained from the slope of a logarithmic plot of plastic strain $\epsilon - \frac{\sigma}{E}$ against the stress parameter $\frac{\sigma}{\sigma_{cy}}$. Curves showing the variation of the parameter n with temperature are presented in figure 10.

Empirical stress-strain curves were calculated by substituting appropriate values for n (fig. 10), E (fig. 5), and σ_{cy} (fig. 4) into equation (1). In figure 11, the symbols represent values calculated by this method; whereas, the solid lines represent the experimental

stress-strain curves presented in figures 2 and 3. The correlation is good for AM 350 for the complete range of stresses shown. For 17-7 PH, correlation between the empirical and experimental data is good up to the yield stress.

CONCLUDING REMARKS

The results of compressive stress-strain tests of 17-7 PH and AM 350 stainless steels in both the heat-treated and annealed conditions have been presented. These results indicate that either alloy has essentially the same mechanical properties in the with-grain or cross-grain direction. The 0.2-percent-offset compressive yield stress for 17-7 PH (Condition TH 1,050) is greater than that of AM 350 (double aged) up to 825° F for 1/2-hour exposure to temperature. From 825° F to 1,200° F the compressive yield stress of AM 350 is greater. The average values of Young's modulus for both 17-7 PH and AM 350 stainless steels are approximately equal for the temperature range investigated.

Correlation is good between the experimental stress-strain curves and the empirical relation.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 28, 1957.

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TABLE I.- DESCRIPTION OF SHEET MATERIALS AND NOMINAL CHEMICAL COMPOSITIONS

(a) Description of sheet materials

Material	Nominal sheet thickness, in.	Condition as received	Heat treatment	Designation of heat treatment	Source of material
17-7 PH	0.050	Annealed	Heated at 1,400° ± 25° F for $1\frac{1}{2}$ hr; air cooled to 60° F within 1 hr after removal from furnace; heated at 1,050° ± 10° F for $1\frac{1}{2}$ hr; air cooled	Condition TH 1,050	Armco Steel Corp.
AM 350	0.045 and 0.063	Annealed	Heated at 1,350° ± 25° F for $1\frac{1}{2}$ hr; air cooled; heated at 850° ± 25° F for $1\frac{1}{2}$ hr; air cooled	Double aged	Allegheny Ludlum Steel Corp.

(b) Nominal chemical composition

Element, percentage by weight	Material	
	17-7 PH	AM 350
Carbon	0.09 maximum	0.08 to 0.12
Manganese	1.00 maximum	0.50 to 1.25
Phosphorus	0.04 maximum	0.04 maximum
Sulfur	0.03 maximum	0.03 maximum
Silicon	1.00 maximum	0.50 maximum
Chromium	16.00 to 18.00	16.00 to 17.00
Nickel	6.50 to 7.75	4.00 to 5.00
Aluminum	0.75 to 1.50	
Molybdenum		2.50 to 3.55
Iron	Remainder	Remainder

TABLE II.- COMPRESSIVE PROPERTIES OF

17-7 PH STAINLESS-STEEL SHEET, CONDITION TH 1,050

[Nominal sheet thickness, 0.050 inch; nominal strain rate, 0.002 per minute; $\frac{1}{2}$-hour exposure at elevated temperatures]

Temperature, °F	Grain direction	Yield stress, ksi	Young's modulus, psi
Room	With	190.0	30.6×10^6
	With	183.0	29.8
	With	178.6	30.4
	Cross	185.8	28.3
200	With	176.2	30.9×10^6
	With	176.9	31.1
	With	179.8	31.3
	Cross	177.5	29.4
400	With	171.6	27.1×10^6
	With	169.6	27.5
	With	171.1	28.0
	Cross	170.0	30.3
600	With	172.5	28.2×10^6
	With	157.0	26.4
	With	158.6	26.4
700	With	150.5	27.1×10^6
	With	149.2	26.7
	With	153.2	27.0
	Cross	144.0	25.4
800	With	139.3	23.8×10^6
	With	134.7	24.6
	With	128.5	25.0
	Cross	130.8	24.6
900	With	101.1	24.0×10^6
	With	99.0	23.8
	With	97.5	23.5
	Cross	98.5	24.0
1,000	With	68.6	23.0×10^6
	With	61.9	23.8
	With	66.0	23.0
1,100	With	40.2	15.4×10^6
	With	38.4	15.7
	With	37.3	15.8
	Cross	42.0	16.9
1,200	With	19.2	15.9×10^6
	With	20.8	13.2
	With	19.2	18.3
	Cross	20.7	10.3

TABLE III.- COMPRESSIVE PROPERTIES OF

AM 350 STAINLESS-STEEL SHEET, DOUBLE AGED

[$\frac{1}{2}$-hour exposure at elevated temperatures; strain rate, 0.002 per minute]

Temperature, °F	Grain direction	Nominal sheet thickness, in.	Yield stress, ksi	Young's modulus, psi
Room	With	0.045	168.2	30.1×10^6
	With	.045	165.1	29.4
	With	.063	163.1	30.5
	With	.063	161.0	29.8
	Cross	.063	165.9	29.5
200	With	0.045	155.4	30.5×10^6
	With	.045	150.9	30.8
	With	.063	149.9	28.3
	With	.063	150.9	28.9
400	With	0.045	146.6	28.5×10^6
	With	.045	143.2	29.8
	With	.063	140.8	29.2
	With	.063	139.6	29.8
	Cross	.063	143.6	29.8
500	With	0.045	140.0	26.6×10^6
	With	.045	142.0	30.6
	With	.063	138.4	30.0
	With	.063	138.3	27.3
	Cross	.045	147.5	30.0
600	With	0.045	140.9	26.8×10^6
	With	.045	148.4	27.4
	With	.063	137.5	26.5
	With	.063	138.6	26.6
	Cross	.063	140.9	28.1
700	With	0.045	139.6	28.0×10^6
	With	.045	131.4	26.2
	With	.063	128.1	26.4
	With	.063	128.8	25.0
	Cross	.063	134.6	26.7
800	With	0.045	125.0	24.4×10^6
	With	.045	124.8	24.9
	With	.063	124.8	25.0
	With	.063	124.8	24.6
	Cross	.045	127.0	25.9
900	With	0.045	113.8	24.8×10^6
	With	.045	113.8	24.2
	With	.063	111.5	23.9
	With	.063	111.5	23.5
	Cross	.063	115.8	23.1
1,000	With	0.045	94.4	22.3×10^6
	With	.045	93.1	21.7
	With	.063	87.9	23.1
	With	.063	87.5	21.5
	Cross	.045	98.2	22.5
1,100	With	0.045	61.2	17.6×10^6
	With	.045	57.3	16.9
	With	.063	54.4	18.0
	With	.063	60.0	17.0
	Cross	.063	61.9	18.6
1,200	With	0.045	35.3	13.1×10^6
	With	.045	36.4	13.9
	With	.063	33.7	15.2
	With	.063	34.9	13.7
	Cross	.045	35.9	15.0

TABLE IV.- COMPRESSIVE PROPERTIES OF 17-7 PH AND AM 350

ANNEALED STAINLESS-STEEL SHEET

[$\frac{1}{2}$- hour exposure at elevated temperatures; nominal strain rate, 0.002 per minute]

Temperature, °F	Grain direction	Nominal sheet thickness, in.	Compressive yield stress, ksi	Young's modulus, psi
17-7 PH				
Room	With	0.050	35.0	30.6×10^6
	Cross	.050	37.8	28.2
400	With	.050	25.3	33.2
700	With	.050	26.2	24.5
1,000	With	.050	27.8	24.3
	Cross	.050	26.7	19.1
1,200	With	.050	23.6	21.5
AM 350				
Room	With	0.063	68.0	28.0×10^6
	Cross	.063	72.1	30.0
400	Cross	.045	58.5	29.5
700	Cross	.045	56.6	26.6
1,000	With	.045	50.0	20.1
	Cross	.045	56.8	21.4
1,200	Cross	.063	42.4	22.9

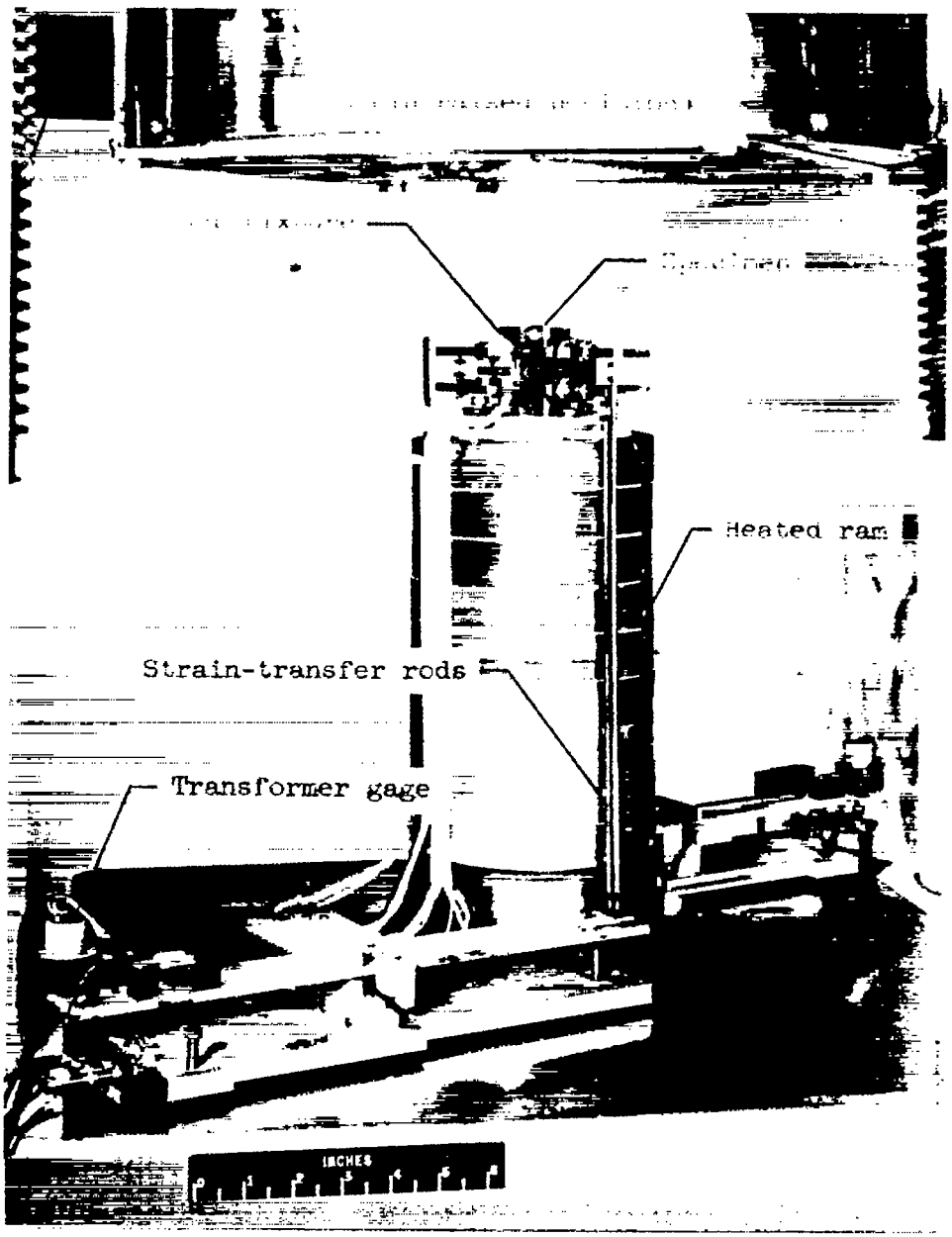


Figure 1.- Compressive stress-strain test equipment. L-85457.2

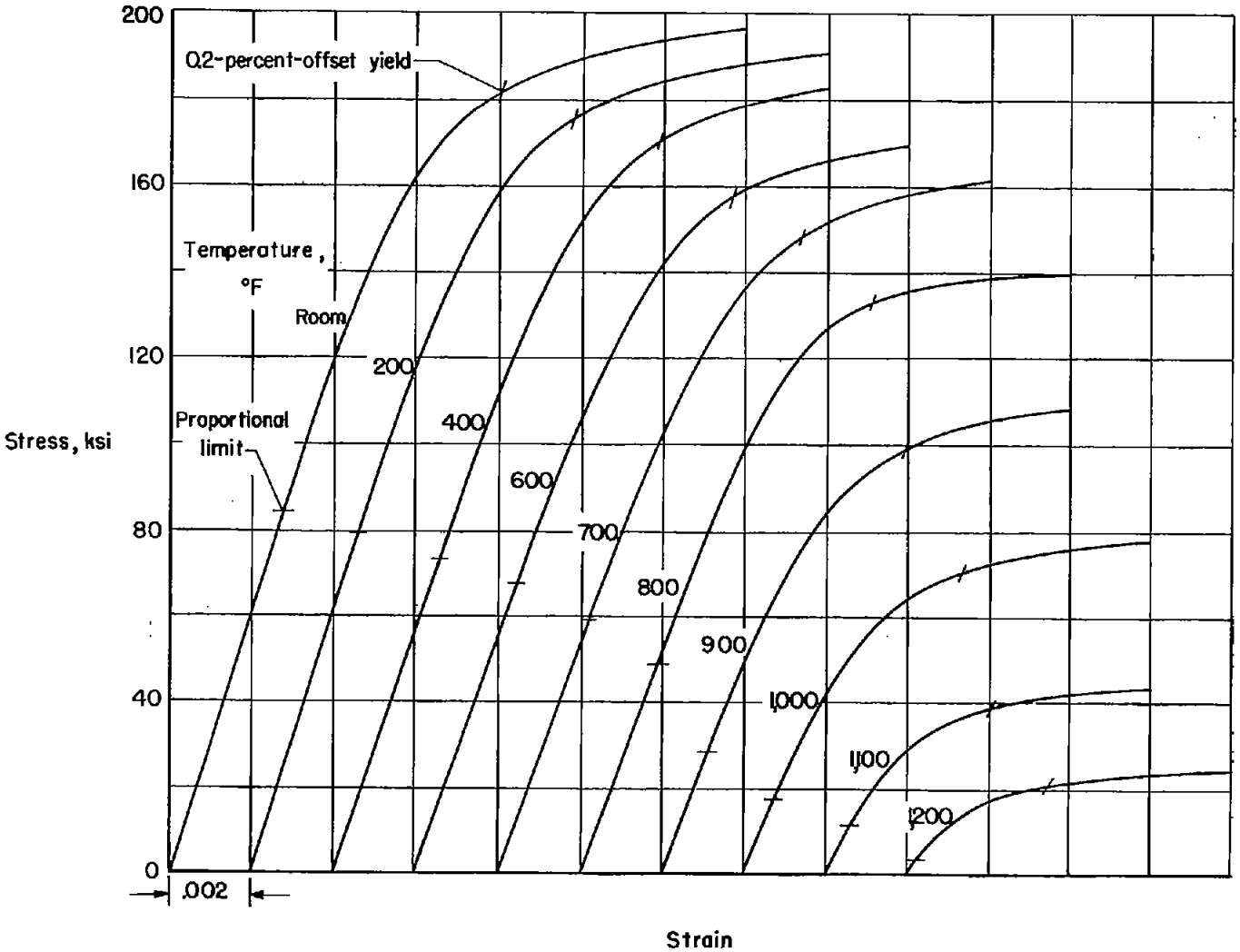


Figure 2.- Compressive stress-strain curves for 17-7 PH stainless-steel sheet, Condition TH 1,050. Strain rate, 0.002 per minute; 1/2-hour exposure to temperature.

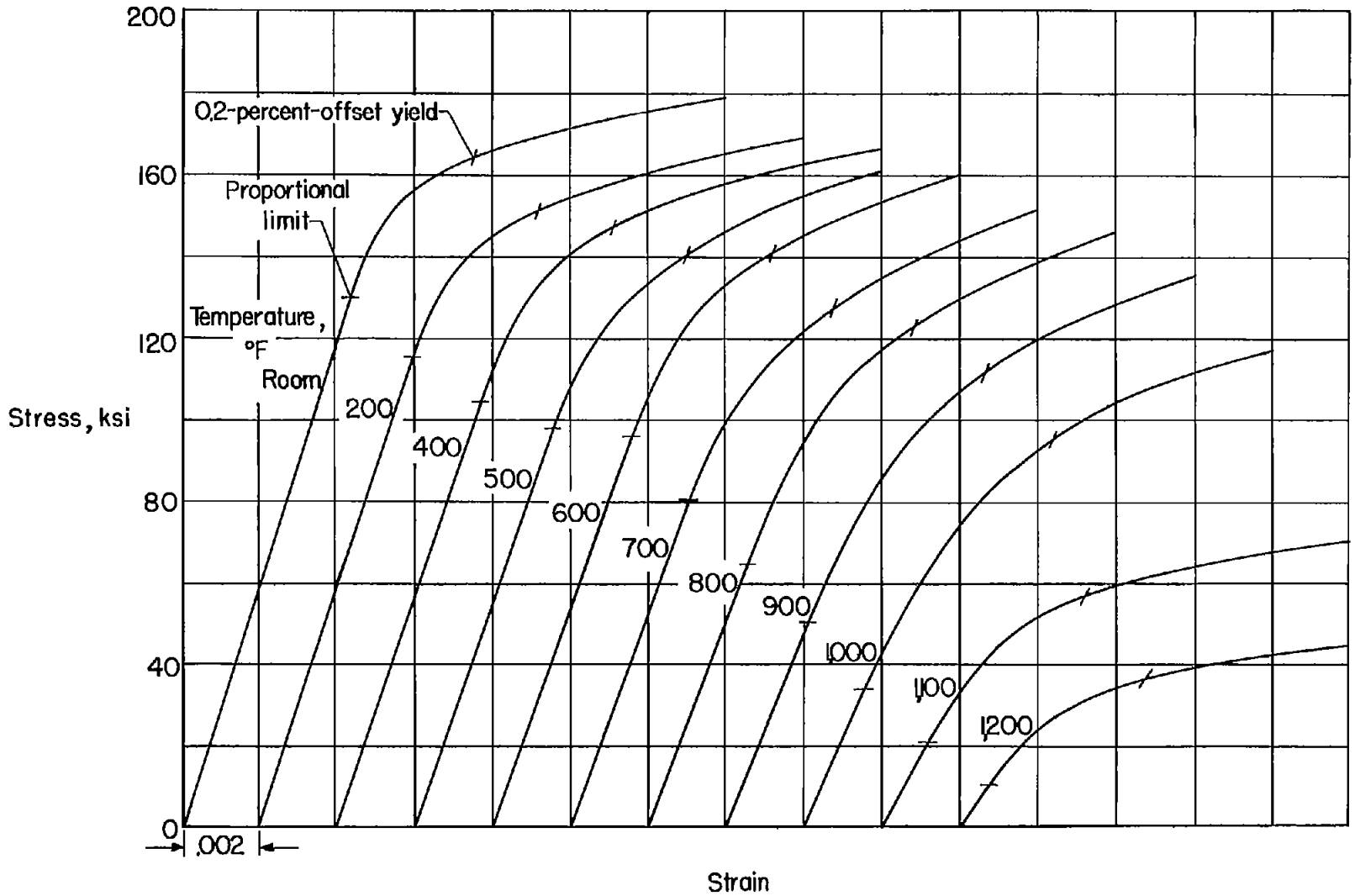


Figure 3.- Compressive stress-strain curves for AM 350 stainless-steel sheet, double aged. Strain rate, 0.002 per minute; 1/2-hour exposure to temperature.

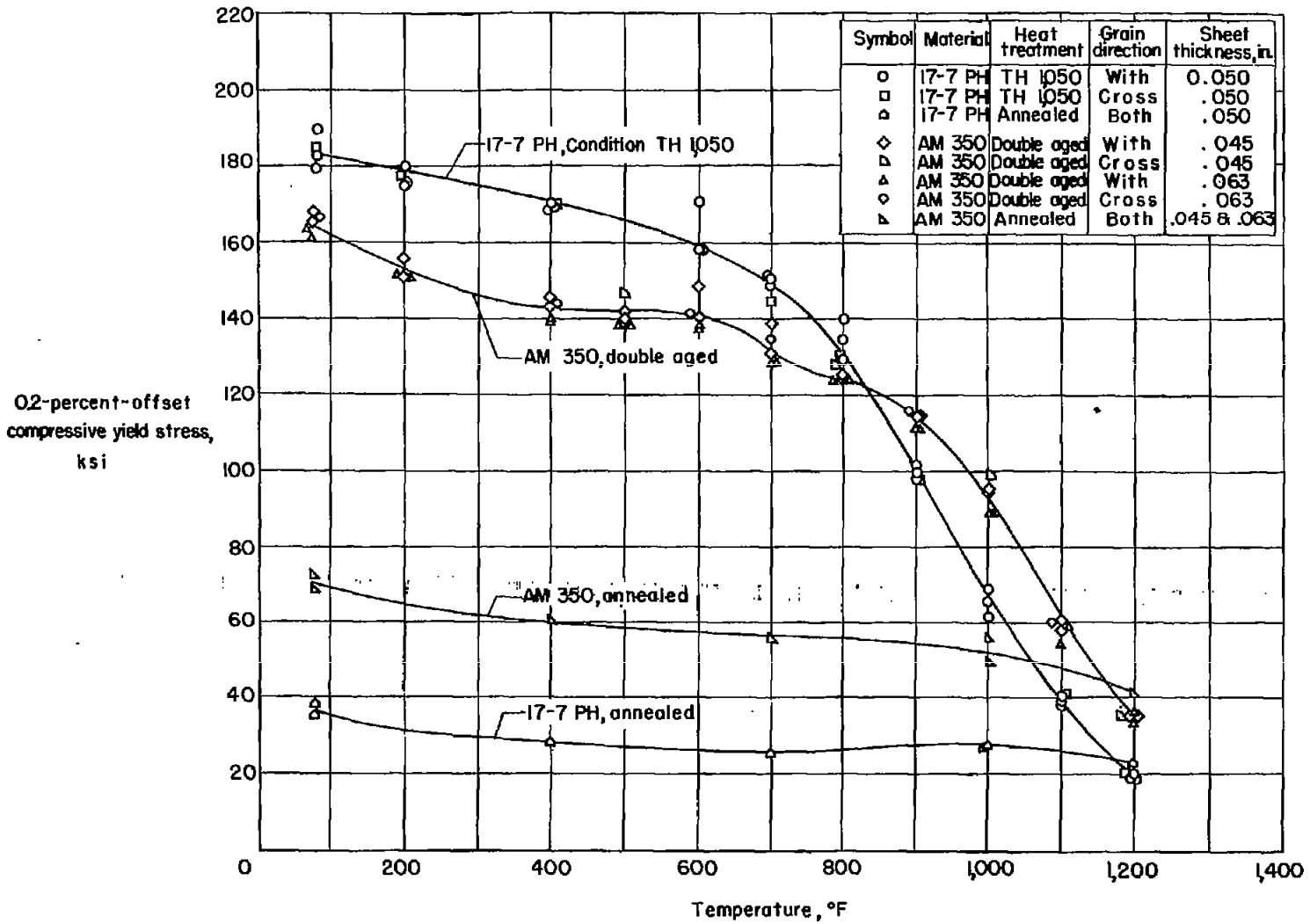


Figure 4.- Variation of 0.2-percent-offset compressive yield stress with temperature for 17-7 PH and AM 350 stainless-steel sheet. One-half hour exposure to temperature.

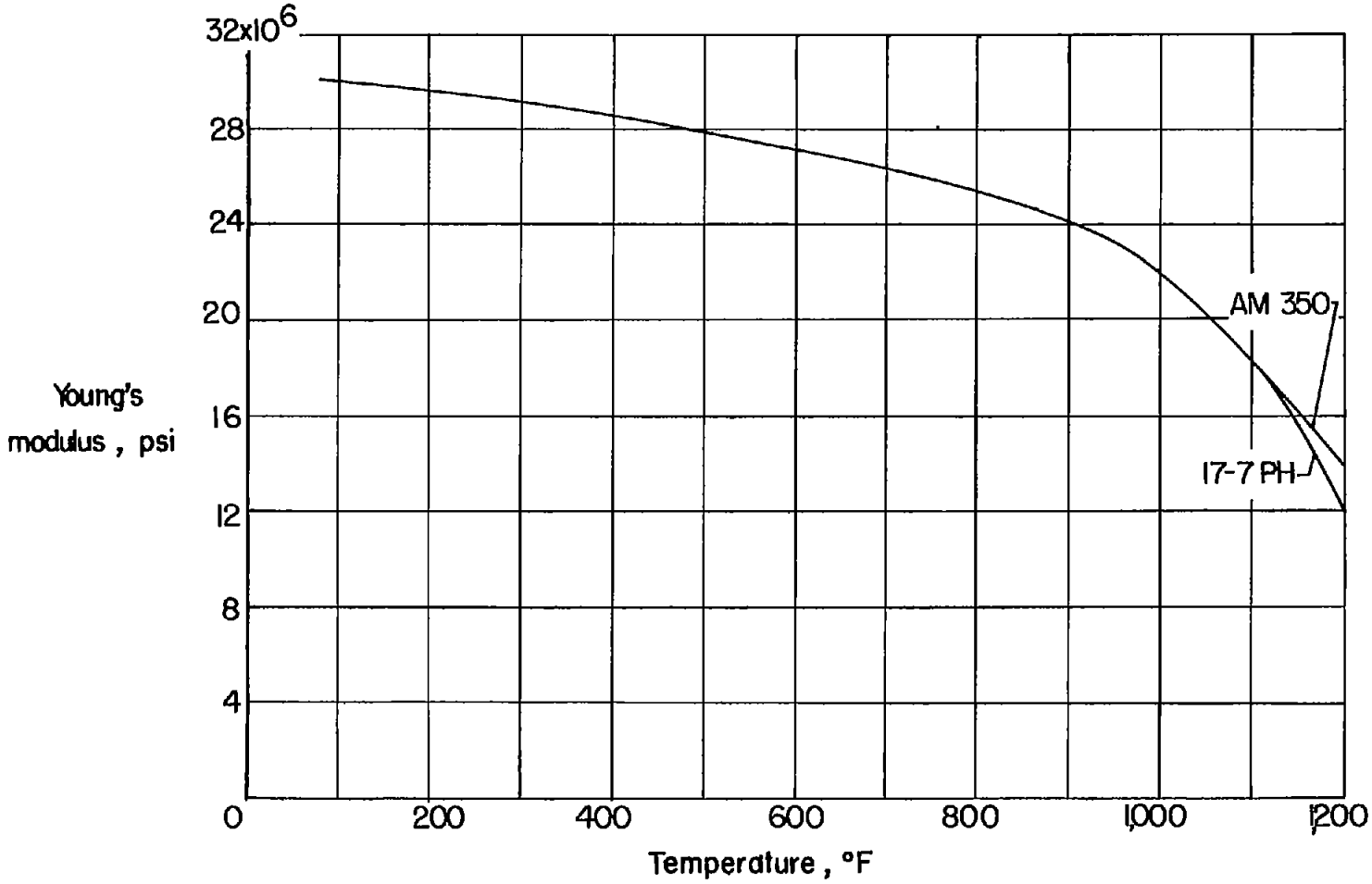


Figure 5.- Variation of Young's modulus with temperature for 17-7 PH and AM 350 stainless-steel sheet.

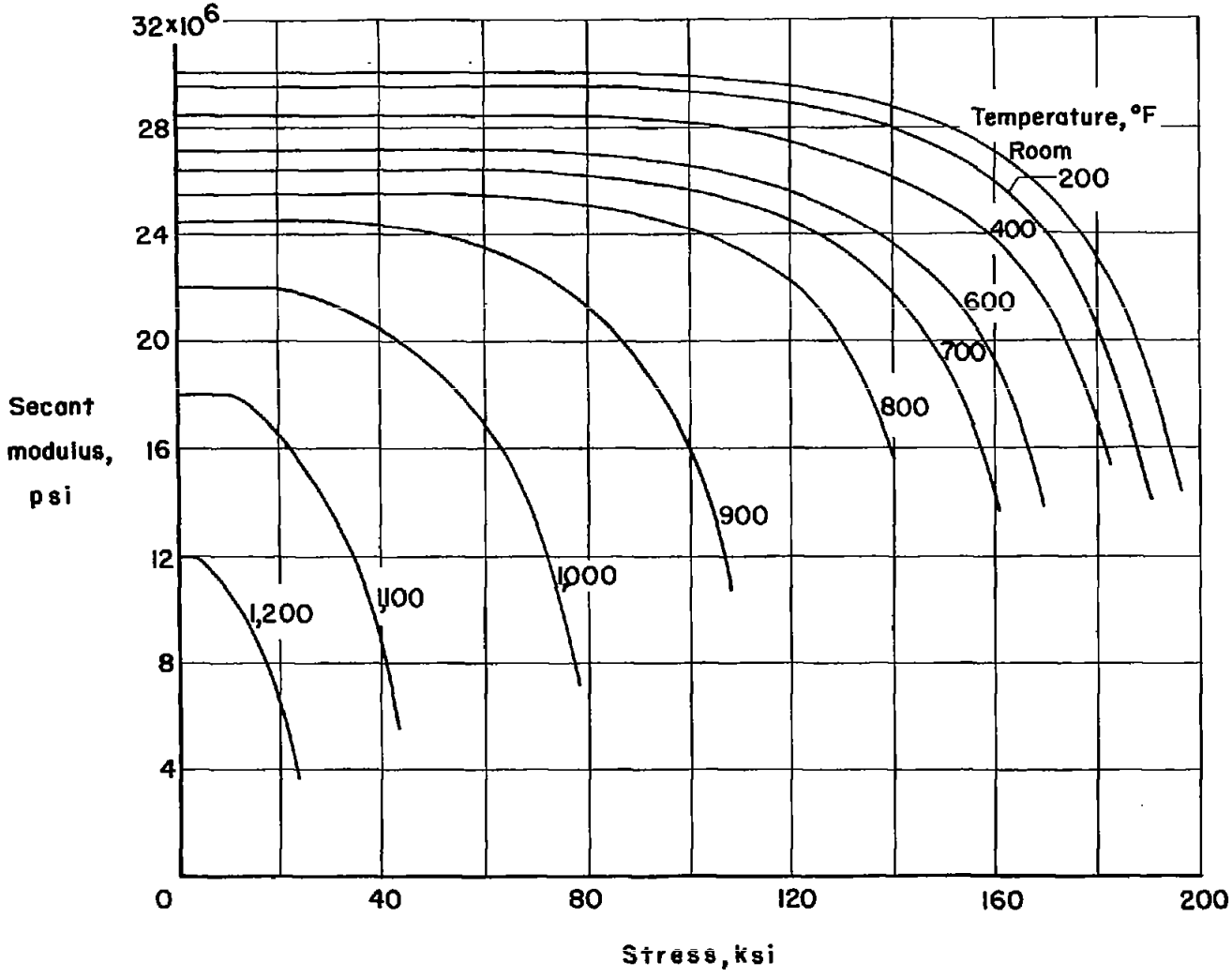


Figure 6.- Variation of secant modulus with stress for 17-7 PH stainless-steel sheet, Condition TH 1,050. Strain rate, 0.002 per minute; 1/2-hour exposure to temperature.

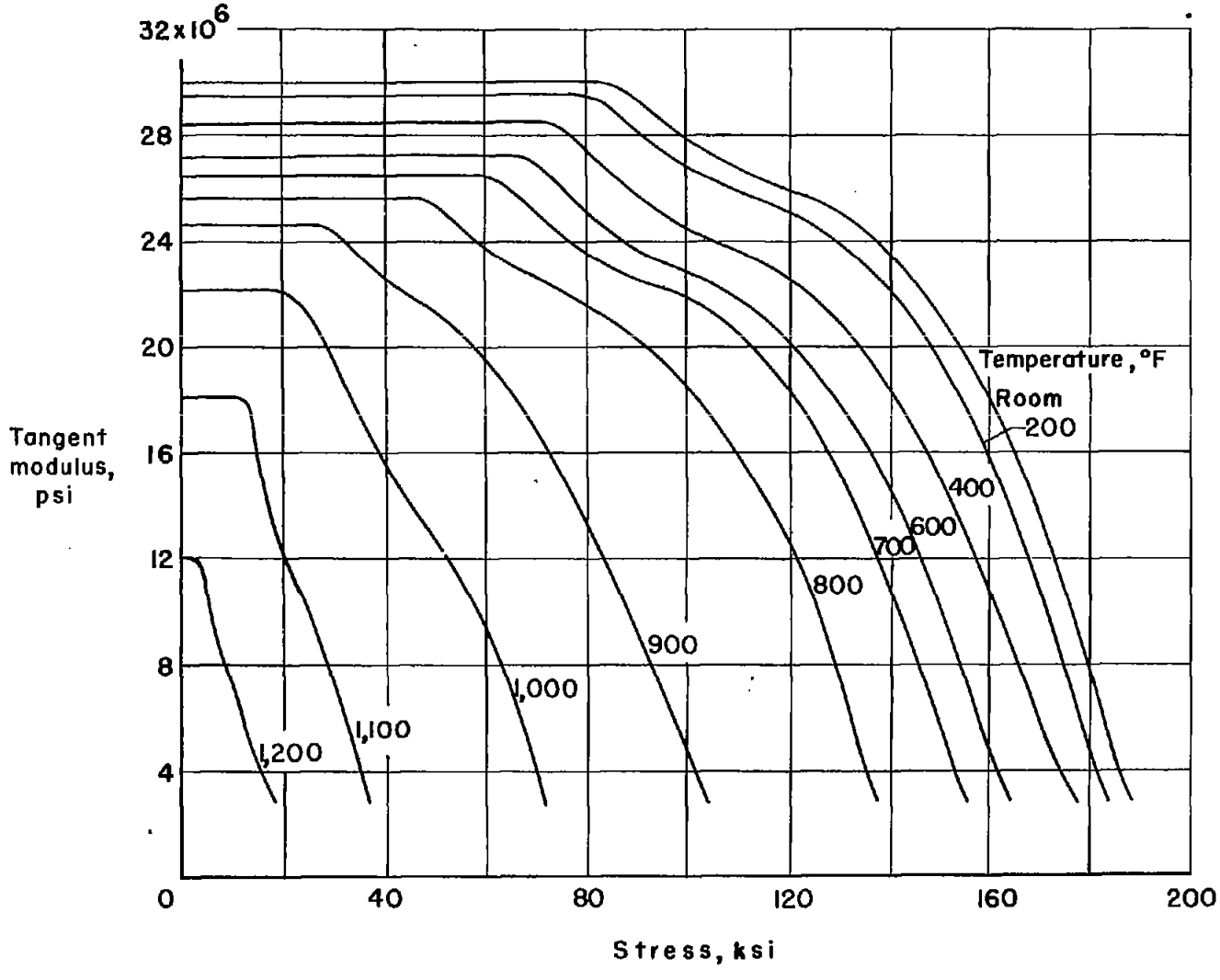


Figure 7.- Variation of tangent modulus with stress for 17-7 PH stainless-steel sheet, Condition TH 1,050. Strain rate, 0.002 per minute; 1/2-hour exposure to temperature.

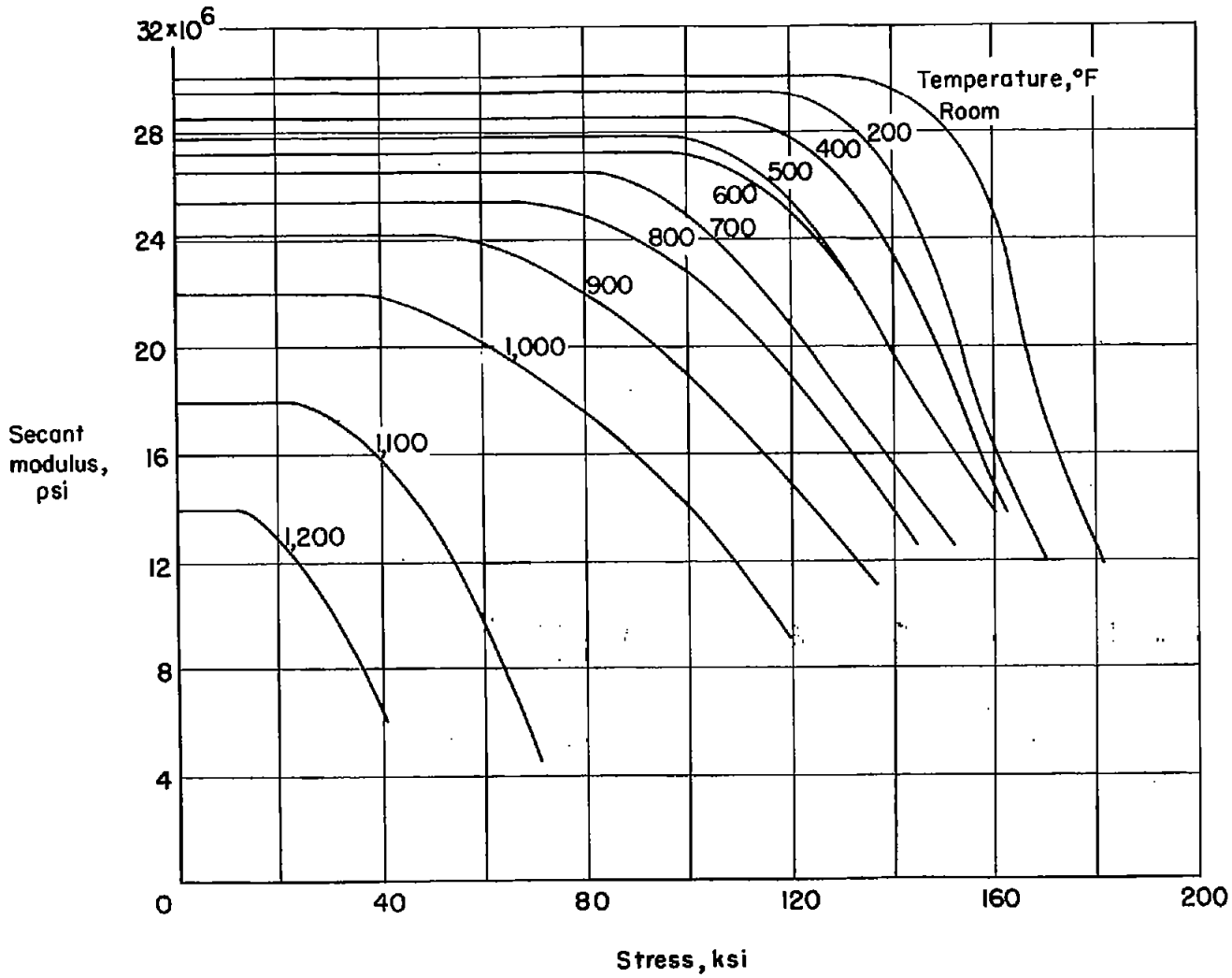


Figure 8.- Variation of secant modulus with stress for AM 350 stainless-steel sheet, double aged. Strain rate, 0.002 per minute; 1/2-hour exposure to temperature.

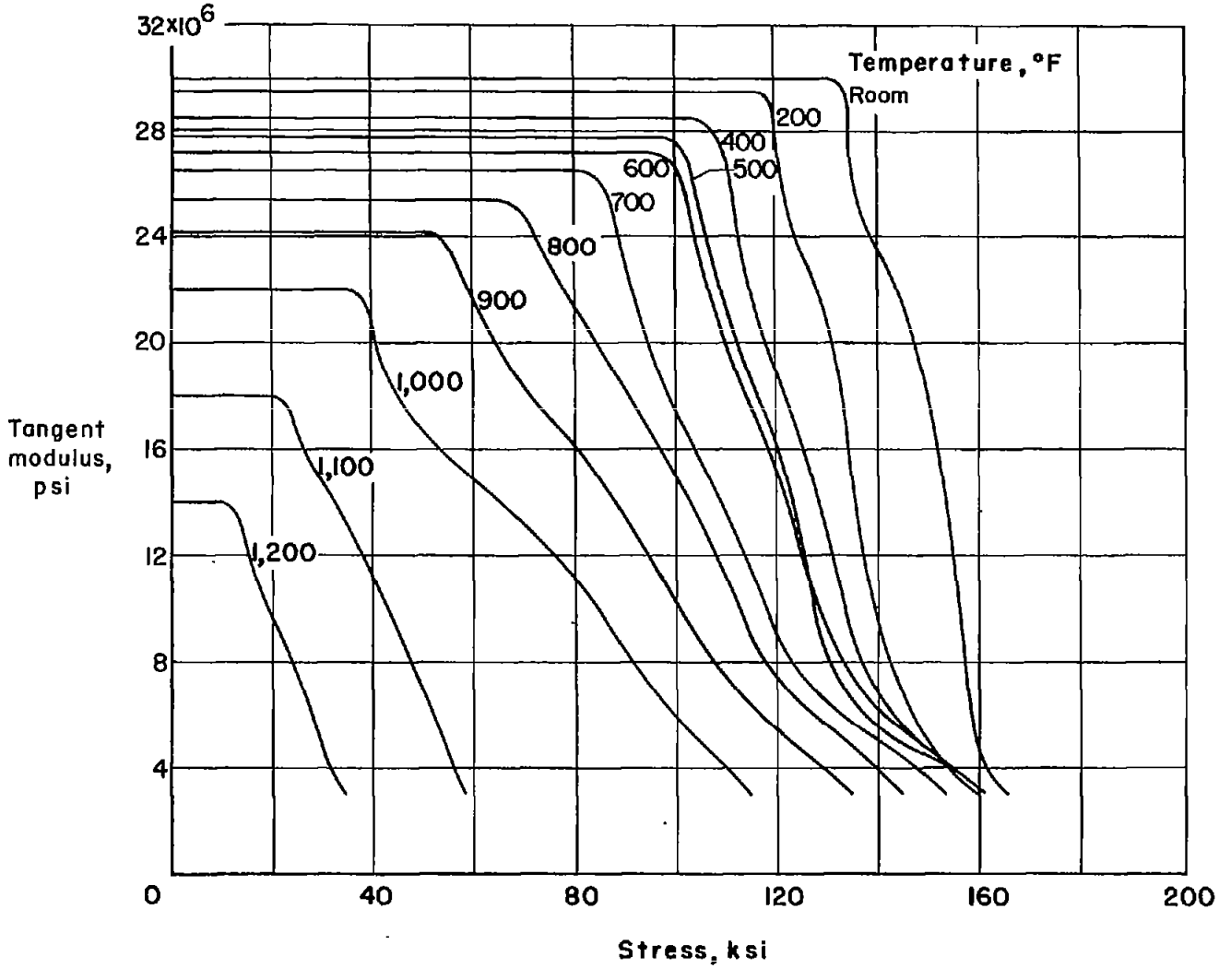


Figure 9.- Variation of tangent modulus with stress for AM 350 stainless-steel sheet, double aged. Strain rate, 0.002 per minute; 1/2-hour exposure to temperature.

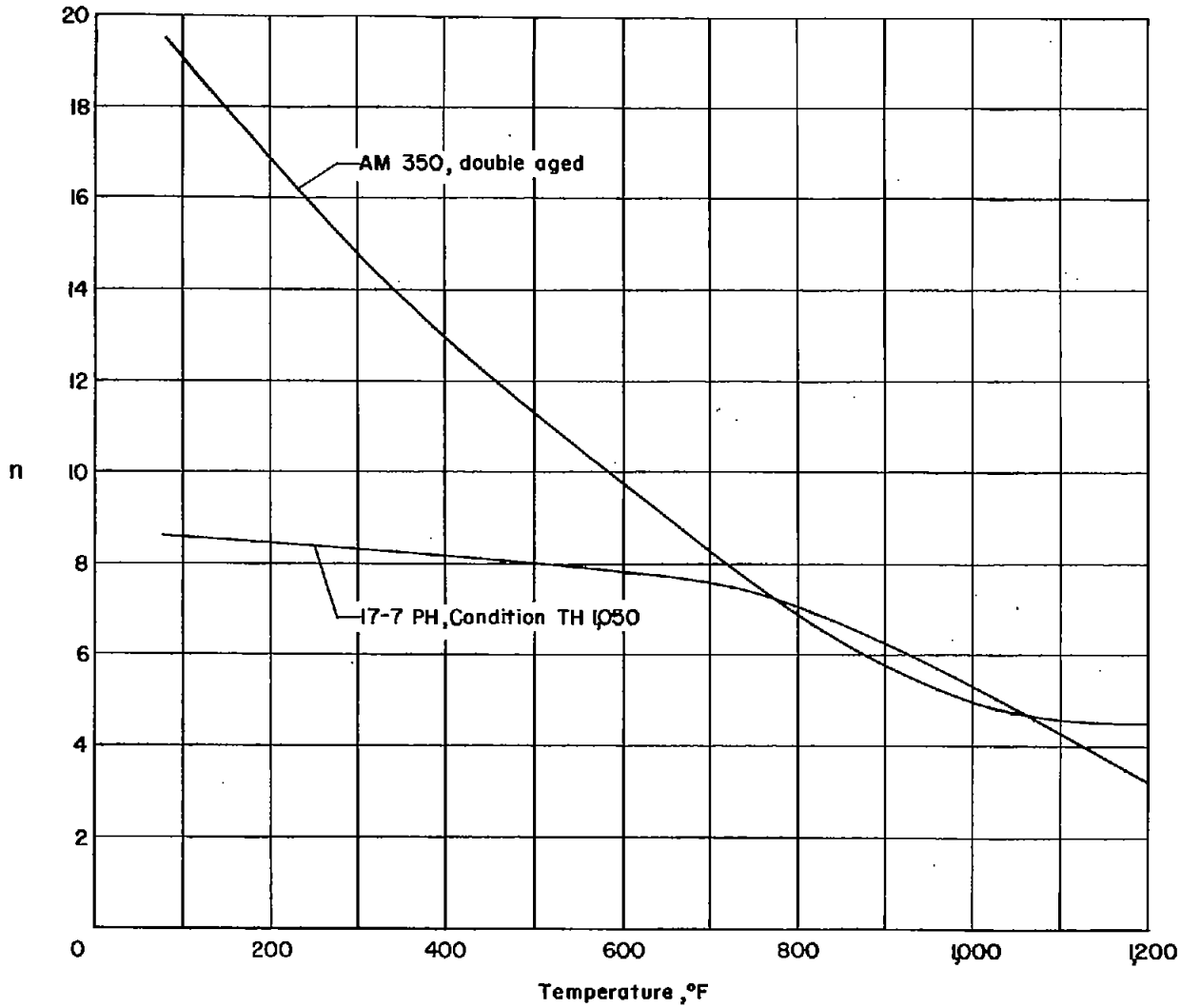
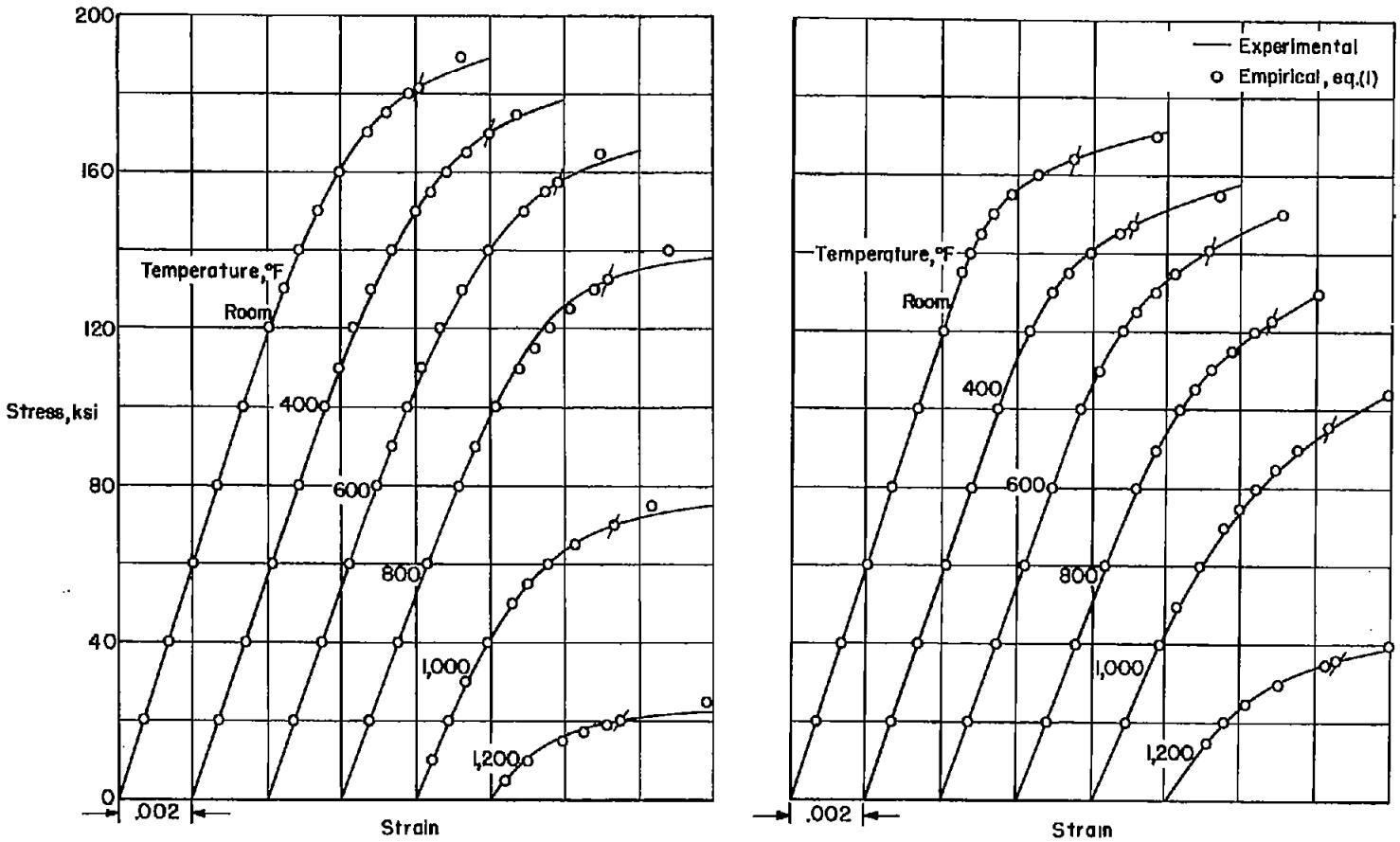


Figure 10.- Variation of the stress-strain curve shape parameter n with temperature for 17-7 PH and AM 350 stainless-steel sheet.



(a) 17-7 PH.

(b) AM 350.

Figure 11.- Comparison of experimental compressive stress-strain curves with empirical approximations for 17-7 PH and AM 350 stainless-steel sheet in the heat-treated conditions. Tick marks indicate 0.2-percent-offset compressive yield stresses.

NACA - Langley Field, Va.