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ABSTRACT

The creep properties of thorium have been determined at 200 F, 400 F, and 600 F under constant load conditions. The deformation of thorium by creep at 400 F and 600 F appears to be modified by an aging process which results in a lower creep rate at 400 F than the same stress would produce at 200 F.

From the observed results, design considerations for the use of thorium under cyclic load conditions in the temperature range from 200 F to 600 F should be based largely on fatigue strength, rather than on creep strength.

September 11, 1953

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INTRODUCTION

The creep characteristics of thorium at 200 F, 400 F, and 600 F have been investigated in conjunction with the program on the "Mechanical and Metallurgical Properties of Thorium". Other metallurgical topics of this program have been described previously in a report, BMI-784.(1)

CHEMICAL ANALYSIS

The thorium used in this study was from Ames Billet No. A-388. The impurity content is tabulated below.

Analysis By	Elements Detected, ppm										
	N	C	Al	Si	Be	Mn	Fe	W	Cr	B	Cd
BMI	70	600	20	60	40	--	300	< 300	90	--	--
ANL	105	435	40	< 50	35	< 4	210	--	--	< 0.3	< 0.2

FABRICATION HISTORY

Material from Billet A-388 was hot rolled at 1450 F to 1/8 x 7-in. slabs. The slabs were pickled to remove oxidation scale and cold rolled to 0.080-in. sheet equivalent to a reduction in area of 36 per cent. The sheet was annealed 3 hr at 1350 F in an argon atmosphere and had a resulting grain size of 0.010 mm. The room-temperature hardness was 74 VPHN using a load of 5 kg. The annealed 0.080-in.-thick thorium sheet was surface ground to 0.060 ± 0.005 in. by removing 0.010 in. from each of the two faces. The test specimens were machined to the following pertinent dimensions: a 3-in. reduced section with 1-1/4-in.-radius fillets and a gage-section width of 0.500 ± 0.005 in.

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(1) References are given at the end of this report.

CREEP PROPERTIES

Experimental Technique

The creep-testing units used in this study were the constant-load - lever-arm type. An optical comparator was used to measure specimen deformation relative to a graduated platinum gage (2-1/2-in. gage length) attached to the specimen. The measurements of strain were sensitive to 50 microinches, with an accuracy of ±25 microinches. The 200 F tests were conducted in air, and the 400 F and 600 F tests were conducted in vacuum. Temperature was controlled to ±1-1/2 F.

Data and Discussion of Results

Tensile data obtained at room temperature, 200 F, 400 F, and 600 F on thorium-sheet specimens having the same dimensions as the creep specimens are presented in Table 1. The tensile specimens were from Ames Billet A-388 and had the same fabrication and thermal history as the creep specimens. A protective atmosphere of helium or argon was used at the test temperatures above room temperature. Data are given for two strain rates, 0.007 and 0.33 per min.

The results of the creep tests at 200 F, 400 F, and 600 F are tabulated in Table 2 and are shown graphically in Figures 1 through 4. The data illustrated in Figure 4 show that, for stresses greater than 15,000 psi and within the range covered, the resultant creep rates are greater at 200 F than those obtained at 400 F. A partial return to normal creep characteristics, as established by the majority of metals, is observed at 600 F. Such behavior is not unusual among metals as it has been observed in steels and recently in titanium(2). In steels, the process producing the modification in the mechanical properties at the test-temperature range from 100 C to 300 C is termed "blue brittleness". "Blue brittleness" in steels is observed at test temperature and is the result of strain aging during testing, as contrasted to "temper brittleness", which is observed when a material is slow cooled through a definite temperature range and tested at temperatures in the vicinity of room temperature.

TABLE 1. TENSILE PROPERTIES OF AMES THORIUM BILLET A-338 AT VARIOUS TEMPERATURES

Temp, F	Yield Strength (0.2% Offset), psi	Ultimate Strength, psi	Elon-gation, psi	Reduc-tion in Area, %	n[(a)]	B[(a)], psi	Nominal Uniform Elongation at Max. Load, %	True Plastic Strain at Max. Load	Uniform Elongation From Specimen (2-In. Gage Length), %
					Strain Rate 0.00 Per Min				
70	16,370	28,100	49	61	--	--	29	0.25	37
200	11,600	23,000	51	55	0.25	42,800	--	--	32
400	9,050	19,800	29	44	0.22	34,600	23	0.20	18
600	8,700	18,900	28	38	0.21	32,300	21	0.20	--
					Strain Rate 0.33 Per Min				
70	19-20,000[(b)]	30,800	41	64	--	--	--	--	--
200	11-12,000[(b)]	23,600	39	63	--	--	--	--	--
400	9-11,000[(b)]	19,300	34	67	--	--	--	--	--
600	6-8,000[(b)]	18,100	28	61	--	--	--	--	--

(a) "n" and "B" in the above table are constants in the equation $\sigma = B\,\delta^n$, where σ is the true stress, δ is the true plastic strain, B is the flow stress at $\delta = 1$, and n is the strain-hardening exponent.

(b) Approximate range.

TABLE 2. TIME-TEMPERATURE-STRESS DEFORMATION CHARACTERISTICS OF THORIUM SHEET

Nominal Stress, psi	Time, hr	Deformation, per cent			Creep Rate, %/hr(c)	Vickers Hardness After Testing
		Initial Extension On Loading	Total	After Rupture		
			200 F			
28,000	(a)	--	--	49.0	--	95.3
25,000	(a)	--	--	--	--	97.0
22,000	3.4(b)	--	--	18.0	--	89.7
21,000	--	--	--	39.5 (1273 hr)	--	95.0
20,000	2115	4.8	19.7	30.7 (2121 hr)	0.0017(d) (650 hr)	89.6
15,000	498.5	1.6	2.9	--	0.0001	82.8
			400 F			
21,000	(a)	--	--	45.0	--	93.7
20,000	2975	11.7	13.4	--	0.0001(d) (2400 hr)	89.9
18,000	1678	6.5	6.73	--	0.00005	88.2
16,000	1290	3.5	3.75	--	0.000036	91.4
14,000	1517	1.35	1.54	--	Nil	83.2
			600 F			
20,000	(a)	--	--	11.6	--	88.5
17,000	3475	6.65	16.0	--	0.00072(d) (1600 hr)	91.8
15,000	1295	4.0	6.13	--	0.00043	85.8
12,000	1632	1.3	3.0	--	0.00015	83.4
10,000	2613	0.6	1.51	--	0.00006	80.7

(a) Failed on loading.

(b) Failed in grip section.

(c) Minimum creep rate at end of test, except for the tests designated (d), which entered third-stage creep at the indicated time.

(d) Entered third-stage creep at indicated time.

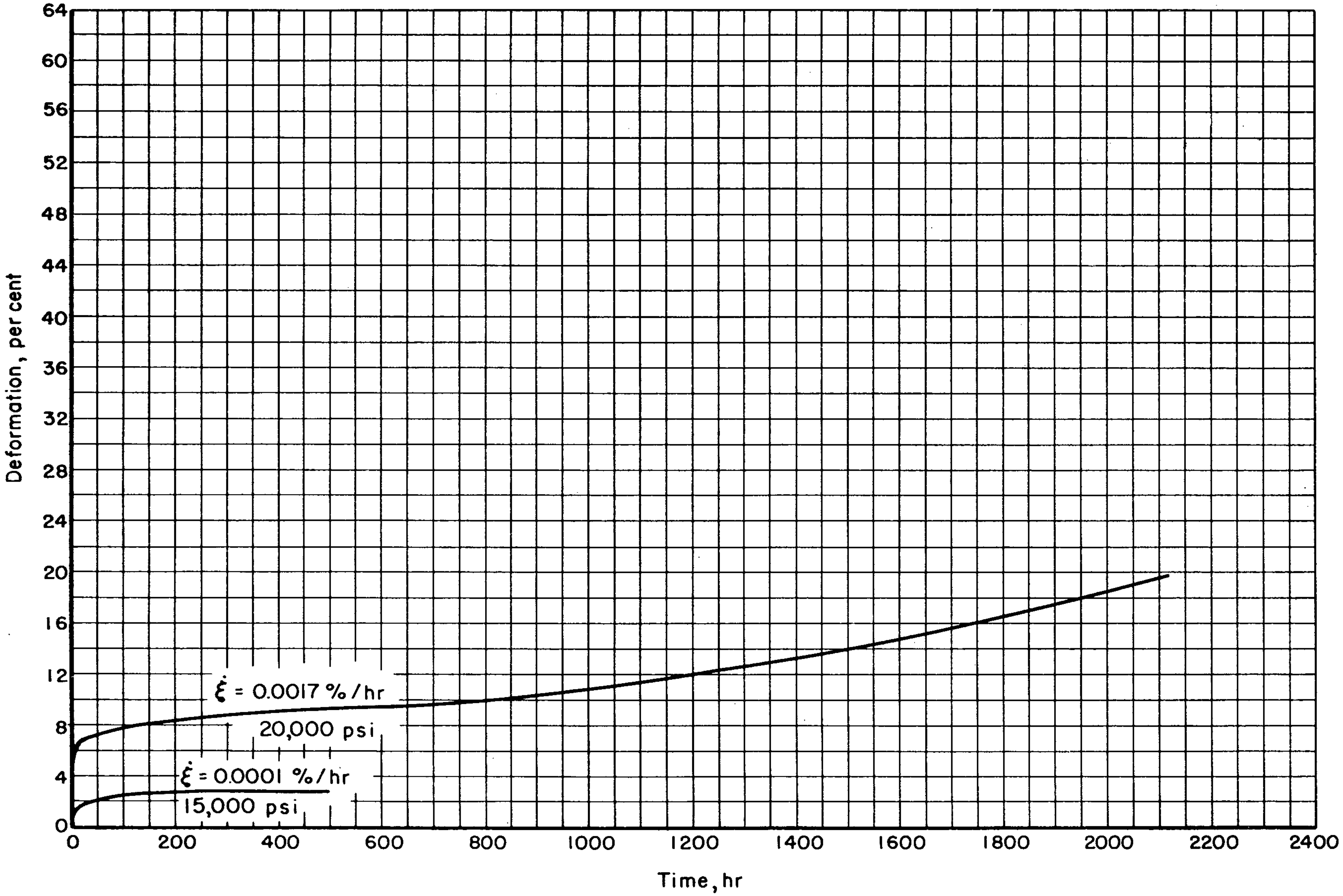

FIGURE 1. CREEP CURVES FOR AMES THORIUM AT 200 F

A-7632

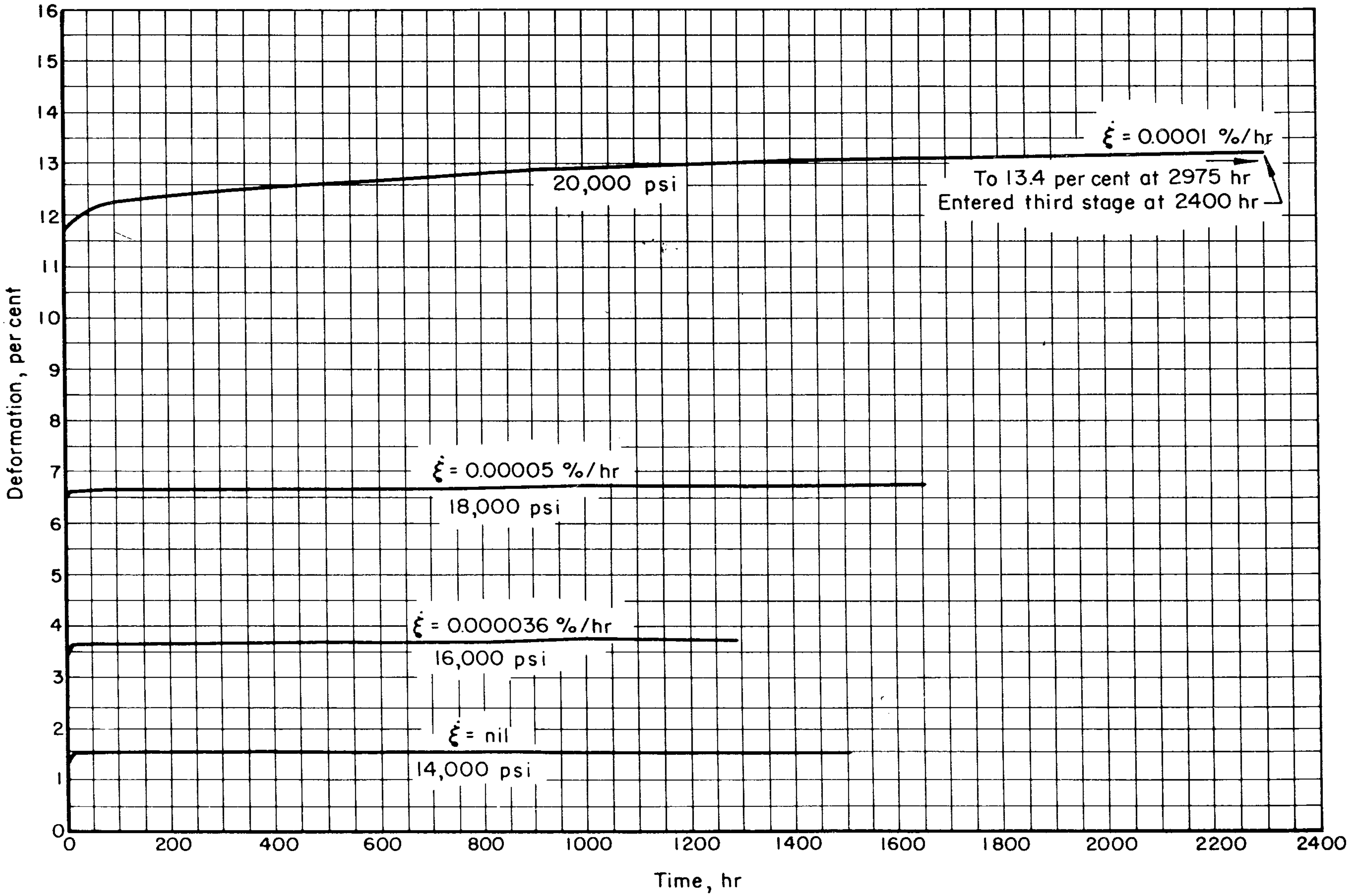

FIGURE 2. CREEP CURVES OF AMES THORIUM AT 400 F

A-7633

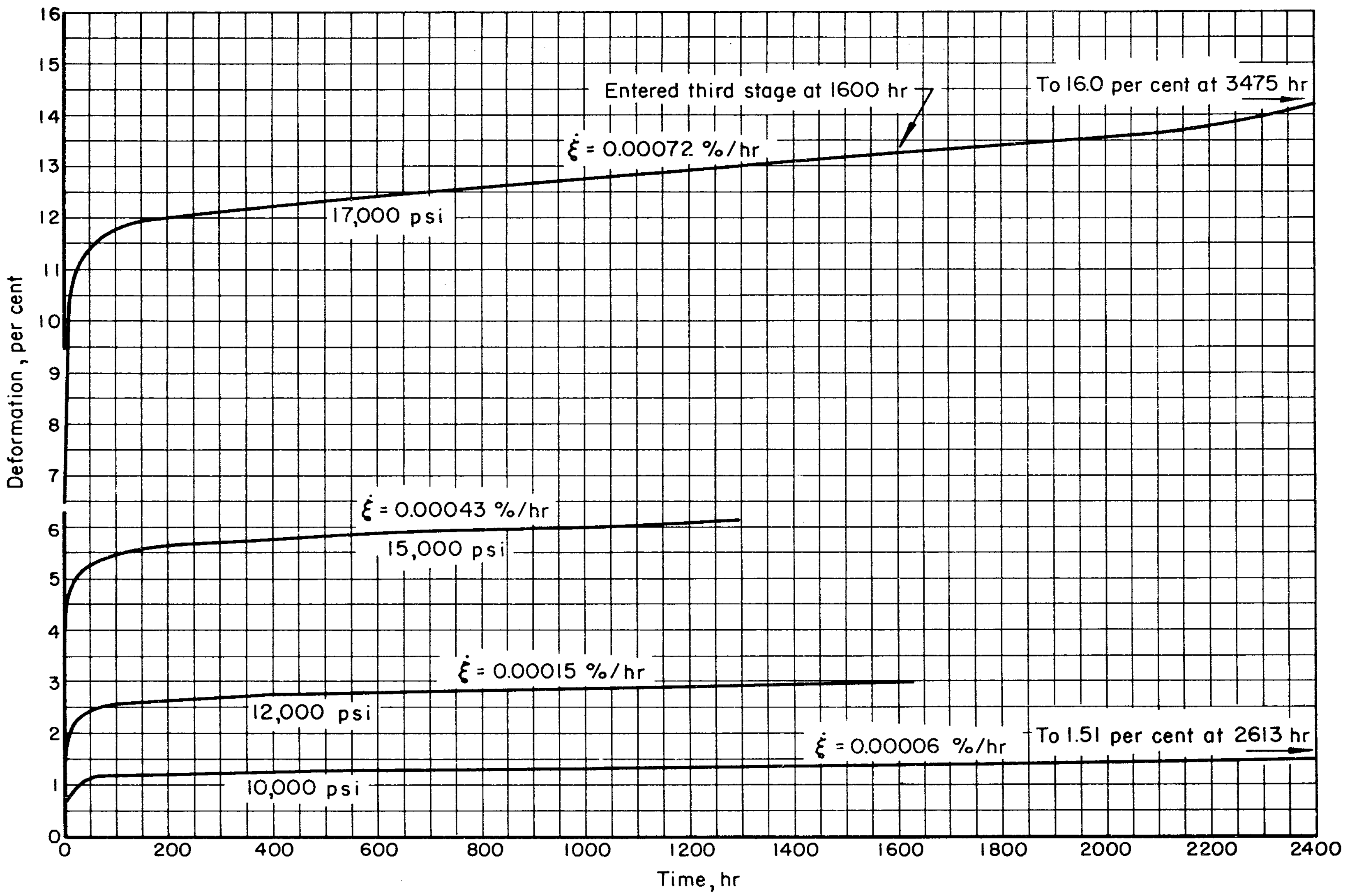

FIGURE 3 CREEP CURVES OF AMES THORIUM AT 600 F

A-7634

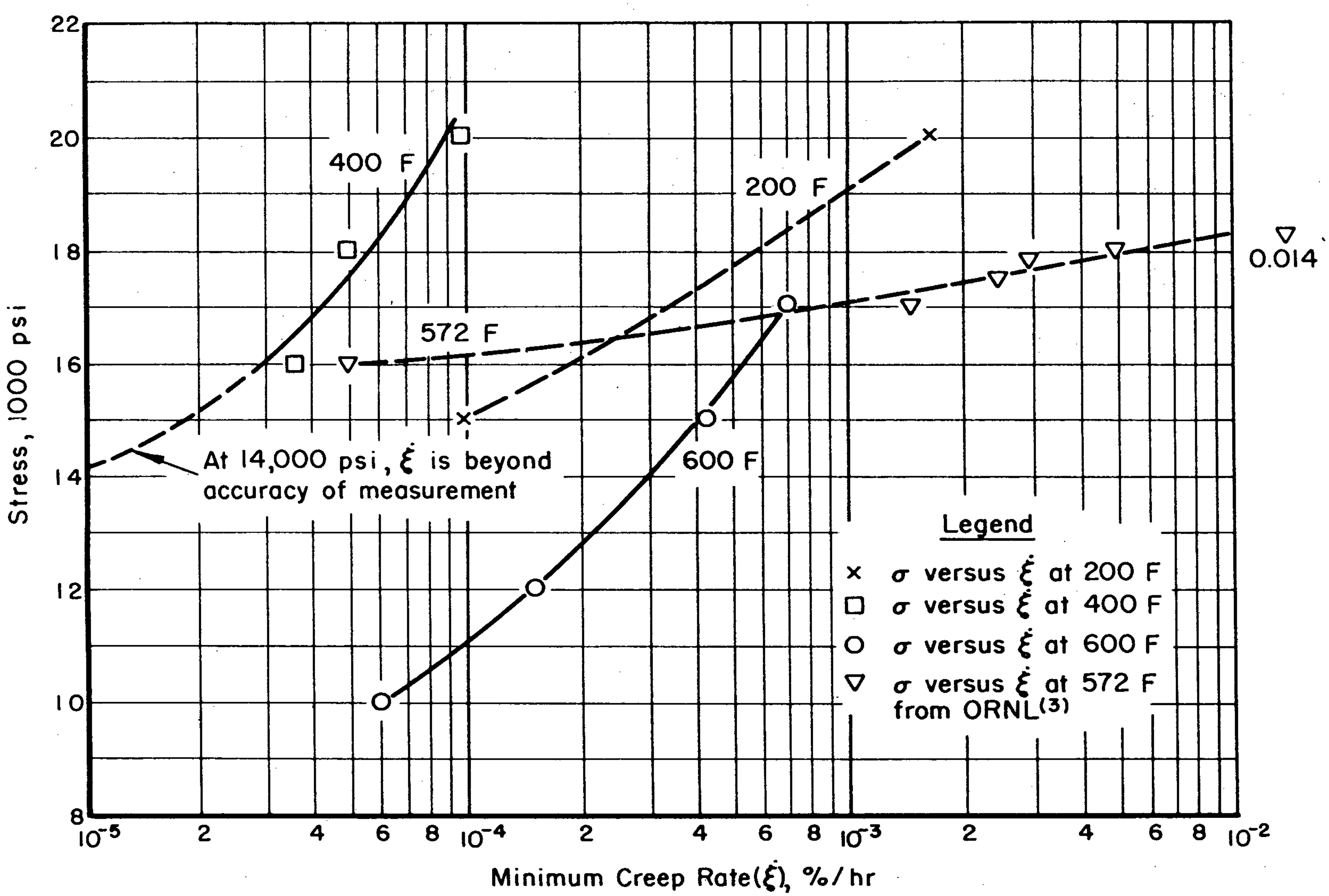

FIGURE 4. STRESS VERSUS MINIMUM CREEP RATE OF THORIUM SHEET AT 200,400, AND 600 F

A-7635

The data obtained from tensile tests also support the conclusion that, at 400 F and 600 F, the mechanical properties of thorium are being modified by a type of process which produces a similar modification in steels susceptible to "blue brittleness". The results of the tests at the strain rate of 0.007 per min indicate the following: (a) virtually the same yield stresses at 400 F and 600 F, (b) continued decrease in per cent elongation and reduction in area with increasing temperature up to 600 F, and (c) a similar trend for the amount of uniform elongation (amount of deformation prior to necking), measured on the specimens both after fracture and during the test (nominal strain at maximum load is equal to uniform elongation and is composed of plastic and elastic deformations). A further check on the value of the plastic data of the above tests was made by calculating the true strain at maximum load, since this value of strain should be numerically equal to n, the strain-hardening exponent. A comparison of the values in Table 2 indicates that reasonably good agreement was obtained. However, the uniform elongations measured on the specimens after fracture do not agree too well with that obtained during the test. This difference is largely the result of a minor, nonuniform, deformation of the specimen as evidenced by a slight taper along the gage section of the specimen.

This behavior, resulting in a modification of the creep and tensile properties, is generally indicative of materials which strain age and have a "blue brittle" temperature range, similar to certain steels. Thorium is known to possess a yield point(1), especially at high strain rates, and this has been associated with strain aging in metals. Since "blue brittleness" is believed to be the result of strain aging during testing, its presence in thorium should not be unexpected. The effect of strain rate on the temperature needed to eliminate the yield point from thorium has also been described(1). The conclusion was that the faster the strain rate the higher the temperature needed to eliminate the yield point. Similar reasoning may be applied to the "blue brittle" aging process. The faster the strain rate of testing at temperature, the less will be the effect of the "blue brittle" aging. Figure 5 shows an example of the case in point, if the temperature of testing is at (a). If the test temperature is at Point (b) in Figure 5, the effect of greater strain rate would be to increase the effect on the property. The results of tensile tests at a strain rate of 0.33 per min in Table 1 tend to indicate that this is true. Similarly, the initial extensions produced in the creep tests exhibit little effect, as would be expected with the high strain rate during loading. However, the deformations measured at the end of 100 hr, where the strain rate or creep rate is much lower, reveal a change in the ease of deformation. This is shown in Figure 6. Little deformation beyond the initial extension was observed at 400 F, as compared with the deformation at 200 F over the same time period of 100 hr.

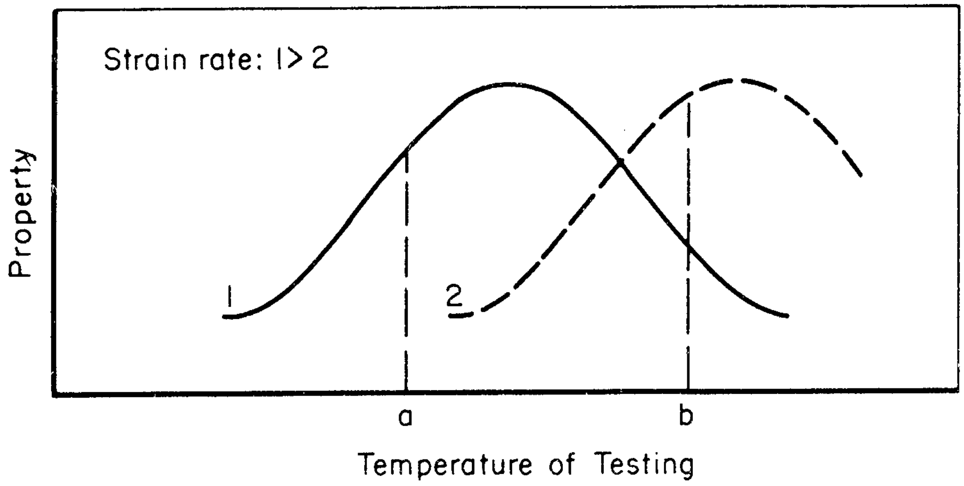

FIGURE 5. THE EFFECT OF TESTING STRAIN RATE ON A PROPERTY SENSITIVE TO "BLUE BRITTLENESS"

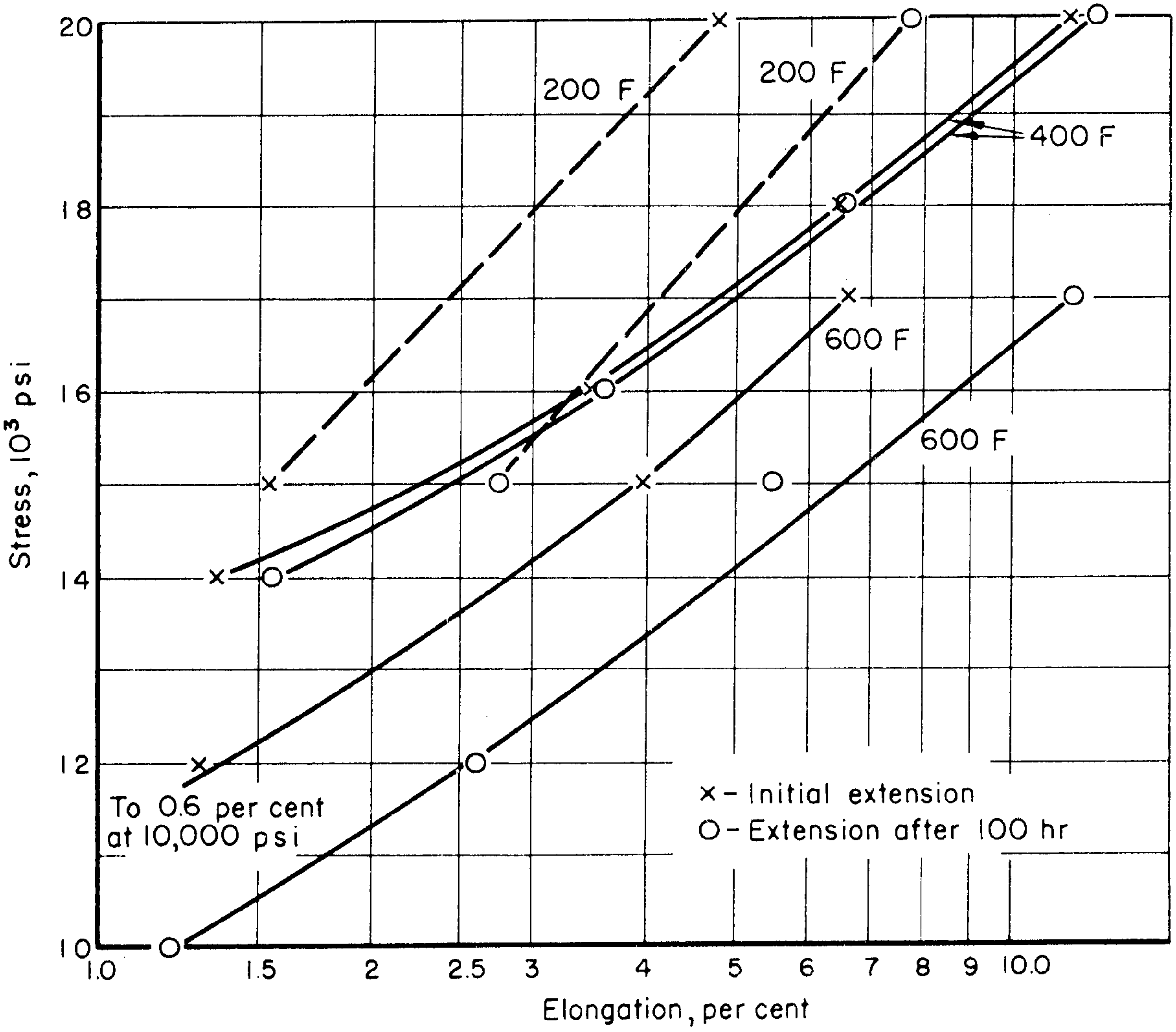

FIGURE 6. VARIATION OF ELONGATION WITH STRESS AT 200,400, AND 600 F

A-7636

The creep tests at 200 F and 400 F at a stress of 20,000 psi are an example of such behavior. Both tests are of approximately the same duration, with the 400 F test having about 2-1/2 times the initial extension, but a miminum steady-state creep rate of approximately 0.06 that of the 200 F test. Hardness values obtained on the creep specimens after completion of the tests also indicate strengthening at 400 F (see Figure 7), since the hardness of specimens strained the same amount was greater the higher the temperature of straining. Such is normally not the case, since, for equal strains, the hardness should be lower the higher the temperature of straining.

The creep test at 400 F at a stress level of 20,000 psi is misleading, since this stress is above the tensile strength (19,800 psi) of thorium when tested at a strain rate of 0.007 per min. At the high strain rate during creep loading, thorium would still exhibit an upper and lower yield point at 400 F. The stress of 20,000 psi was probably somewhere below the upper yield stress and, after an incubation period, the resulting creep deformation was sufficient to work harden the thorium so that the specimen could support this stress. Consequently, this particular creep test, as is true of several others where the initial extensions are large, is actually a test on worked, rather than annealed, material.

The creep data obtained at Oak Ridge(3) on 0.505-in.-diameter extruded thorium are also shown in Figure 4. The observed difference may be due to a number of metallurgical variables, such as chemical composition, method of fabrication, specimen size, or method of stress application (strain rate).

On the basis of thorium fatigue data obtained at room temperature and reported in BMI-784(2), failure would occur under certain cyclic load applications at stress levels where failure by creep would not appear to be a factor. The axial-load fatigue results on thorium sheet indicate that, at room temperature, a lifetime of 10^8 cycles can be expected at a stress level of 14,000 psi ± 1000 psi. The results are under test conditions of complete stress reversal (load ratio R = -1.0) and maximum stress to a small positive stress (R = +0.02). Assuming a normal decrease in fatigue strength with increasing temperature and a slight increase in the temper-brittle temperature range, thorium would probably still have lower fatigue strength than creep strength.

The room-temperature fatigue strength of thorium in plate bending(3) for R = -1.0 and R = +0.0 is greater than for axial-loading: approximately 17,000 psi, as compared with 14,000 psi. Under bending fatigue-stress conditions, the strength of thorium in fatigue may be equivalent to its creep strength in service conditions requiring long lifetime.

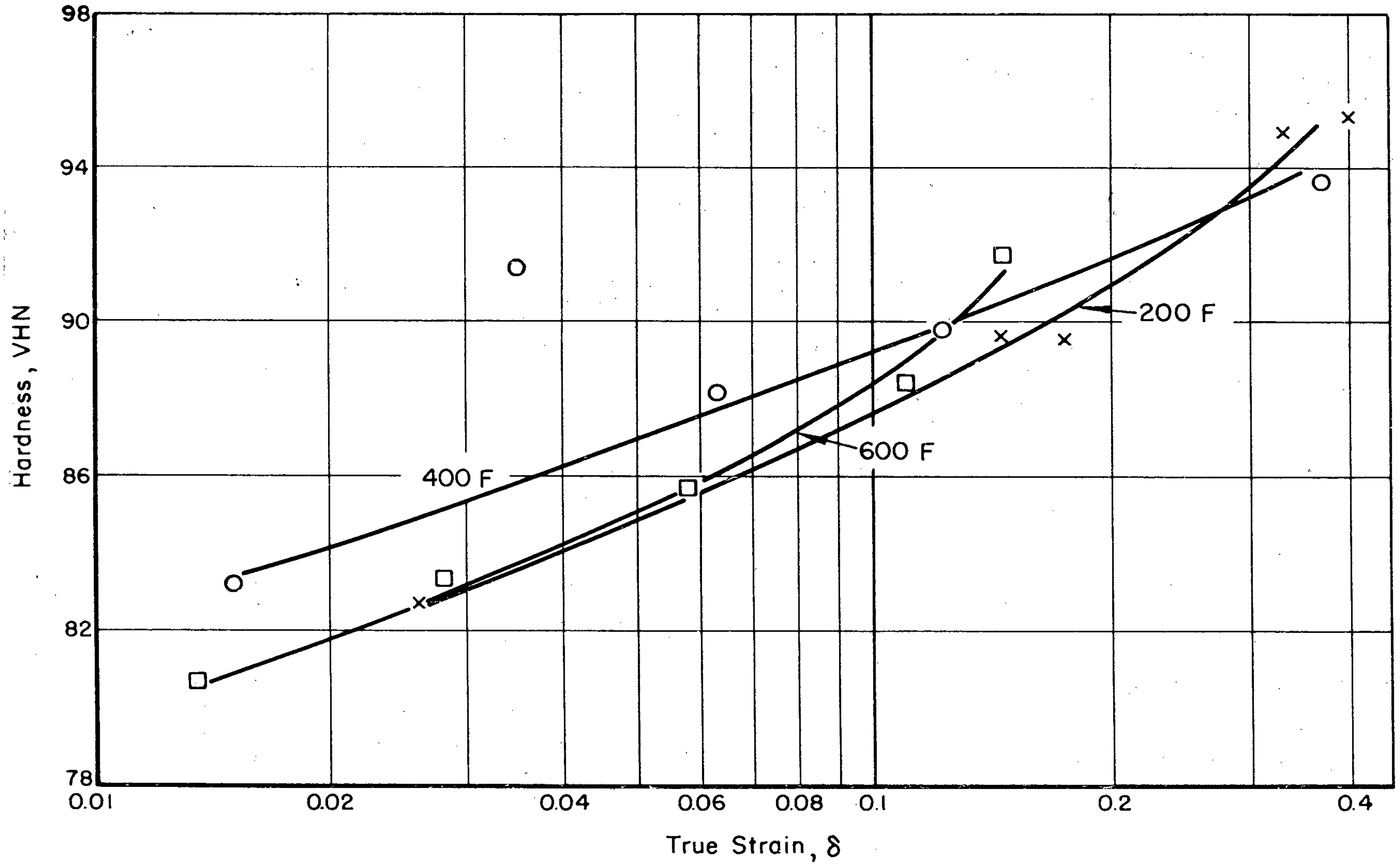

FIGURE 7. VARIATION OF ROOM-TEMPERATURE HARDNESS WITH STRAIN AT 200, 400, AND 600 F

A-7637

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2. Luster, D. R., Wentz, W. W., and Kaufman, D. W., "Creep Properties of Titanium", Materials & Methods, 37, No. 6, June, 1953.

3. Metallurgy Division Quarterly Progress Report, July 31, 1952, ORNL-1366.