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HW-26426

Subject Category: METALLURGY AND CERAMICS

INITIAL INVESTIGATION OF THE MECHANICAL
PROPERTIES OF URANIUM AT ELEVATED
TEMPERATURES

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Technical Information Service, Oak Ridge, Tennessee

AEC RESEARCH AND DEVELOPMENT REPORT

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OF URANIUM AT ELEVATED TEMPERATURES

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December 2, 1952

Price \$ 0.30

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

Classification cancelled (or changed to UNCLASSIFIED)
by authority of Gen AEC-341 DTD 2/28/57
by Jack Kuleshov TIE, date 3/7/57

Work performed under Contract No. W-31-109-Eng-52.

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INITIAL INVESTIGATION OF THE MECHANICAL PROPERTIES
OF URANIUM AT ELEVATED TEMPERATURES

INTRODUCTION

Knowledge of the mechanical properties of uranium at elevated temperatures is essential in order to understand and predict the fabrication characteristics and pile behavior of this metal. This report presents the experimental data obtained from beta heat-treated specimens which were originally machined from one production, alpha-rolled uranium rod.

SUMMARY

The mechanical properties of uranium have been determined in tension at temperatures ranging from room temperature to 800°C.

The ultimate and yield strength of uranium in the alpha phase was found to decrease regularly with increasing temperature. The strength values obtained for uranium tested in the beta phase are somewhat higher than those obtained by extrapolation just below the alpha-beta transformation temperature. There appears to be little variation in the ultimate and yield strength of uranium within the beta region. Percent reduction in area appears to increase uniformly through the alpha, beta, and gamma ranges. The type of fracture changed from a typical brittle fracture at room temperature to a typical ductile fracture at higher temperatures.

PREPARATION OF SPECIMENS

The uranium rod selected for these tests was rolled at the Bethlehem Steel Corporation's Lackawanna Plant at a rolling temperature of approximately 560°C. This rod was cut into six-inch sections and each section was heated at 725°C in a salt bath for two minutes and quenched in water. A standard ASTM .505-inch diameter tensile specimen was machined from each section.

Metallographic examination of wafers from this rod revealed a grain size ranging from .13 to .16 mm. These grain sizes were determined by a comparison with the Battelle grain size chart. The chemical analysis and density of samples from this rod are given below:

Iron	- 53 ppm	Carbon	- 543 ppm
Silicon	- 83 ppm	Density	- 18.89 gr/cc
Nitrogen	- 49 ppm		

EQUIPMENT AND PROCEDURE

The tests were conducted on a Baldwin Universal testing machine using a platen movement of 0.05-inch per minute. A high temperature microformer extensometer was used in conjunction with a Baldwin X-Y recorder to obtain a record of the stress-strain relationship.

The diagram of the experimental apparatus used for these tests is illustrated in Figure 1. Commercial argon gas, which was purified by passing it over hot uranium turnings, flowed continuously over the sample to prevent excessive oxidation of the specimens. During the course of the tests glass wool plugs were inserted in the bottom of the furnace tube to minimize back diffusion of air.

The furnace was calibrated for temperature distribution at the various testing temperatures. A mild steel specimen containing three thermocouples, one at the center and one at each end of the reduced section, was used to obtain the temperature gradient within the sample. The central thermocouple controlled the nominal temperature through a Foxboro controller. After holding the specimen at temperature

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for a minimum of one hour, the maximum observed variation in temperature within the specimen was 3°C. For the actual tests, the controlling thermocouple was placed at the center of the specimen and insulated by covering it with Sauereisen cement.

During the course of the tests some oxidation of the specimens was noted, especially at the higher temperatures. For the tests made at 670°C and 750°C helium was used in place of argon as the inert atmosphere, but no change was noted in the degree of oxidation of the uranium specimens.

RESULTS

The mechanical properties were determined at the following temperatures: 25°C (room temperature), 150°C, 300°C, 450°C, 600°C, 670°C, 700°C, 750°C, and 800°C. The values obtained for the mechanical properties at these temperatures are given in Table 1. The values for shear modulus given in Table 1 were calculated from Young's modulus and an average value of .27 for Poisson's ratio found at room temperature. In determining Poisson's ratio, SR-4 wire resistance strain gages were used to measure lateral and longitudinal strain of five beta heat-treated uranium specimens obtained from the center of production rods. The curves illustrating the variation of the properties with temperature are given in Figures 2, 3, 4, 5, 6, and 7. The stress-strain curves obtained at the various testing temperatures are shown in Figure 8. The values for Young's modulus were obtained by calculating the slope of the straight line portion of this curve. At room temperature the initial portion of the curve was not perfectly linear but a straight line was approximated and the slope of this line is given as Young's modulus. In this case, the intersection of this straight line with the stress-strain curve was given as the proportional limit. At elevated temperatures a straight line was obtained in the elastic range and the proportional limit given is that stress which caused a deviation from the straight line portion of the curve.

The band curve shown in Figure 9 is the result of plotting eleven stress-strain curves obtained at room temperature for beta heat-treated uranium. This band is presented to enable a comparison with the room temperature stress-strain curve obtained for the beta heat-treated uranium used in this elevated temperature study.

Photographs of typical fractured specimens shown in Figures 10, 11, 12, 13, 14, 15, and 16 illustrate the increase in per cent reduction in area with increasing temperature.

DISCUSSION

The ultimate and yield strength versus temperature curves indicate (1) a uniform decrease in these properties within the alpha phase with increasing temperature, (2) an increase in these properties at the alpha-beta transformation temperature, (3) constant values for these properties within the beta phase, and (4) a decrease in these properties at the beta-gamma transformation temperature. The per cent elongation changes quite rapidly from approximately 12 per cent at room temperature to approximately 30 per cent at 150°C but thereafter increases only a slight amount to approximately 37 per cent at 800°C. At room temperature the deformation is quite uniform over the entire reduced section of the sample while at higher temperatures necking down occurs and the elongation is concentrated within a localized area.

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The specimen tested at 600°C showed considerable surface roughening. The specimens tested in the gamma region showed considerable distortion and circumferential fissures on the specimen surface. Values obtained for the proportional limit and Young's modulus were inconsistent; however, oxidation of the samples may have affected these results to some extent.

Messrs. Schwope, Muehlenkamp, and Shober of Battelle Memorial Institute have made some tensile tests on beta annealed uranium.¹ These workers tested two beta annealed specimens at room temperature and one each at 300°C and 500°C. The results obtained for the ultimate and yield strength of these specimens were consistently lower than the values given in this report. However, the chemical composition of the uranium tested was not reported and the heat treatment given the material for the Battelle tests was a beta anneal at 700°C for 12 hours followed by a slow cool. Either of the above factors could account for the differences obtained for the properties of uranium.

1. Russell, H. W., Nelson, H. R., Dayton, R. W. - Progress Report for the Month of January, 1952, Battelle Memorial Institute - BMI-726.

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TABLE 1

Specimen	Test Temp. - °C	Ultimate Tensile Strength - psi	Yield Strength - (.2% offset) psi	Proportional Limit - psi	Young's Modulus - 10 ⁶ psi	Per Cent Elongation in 2"	Per Cent Reduction in Area	Shear Modulus* - 10 ⁶ psi
1	25	91,500	33,500	16,500	23	12.5	9.5	8.7
2	150	71,500	27,500	16,500	20	32.0	26.0	7.9
3	150	65,000	27,500	10,500	20	31.5	35.0	7.9
4	300	40,500	24,000	13,500	27**	31.5	32.5	10.6
5	300	41,000	23,500	10,000	19	33.0	40.5	7.5
6	450	19,500	16,000	8,000	16	30.0	62.5	6.3
7	450	22,000	17,500	9,500	10	28.0	53.0	4.0
8	450	16,000	12,500	6,500	18	34.0	48.0	7.1
9	600	8,000	6,000	3,000	14	34.5	77.5	5.5
10	670	6,000	5,500	3,500	6	35.0	71.0	2.4
11	700	6,000	6,000	2,700	8	***	75.0	3.2
12	700	6,500	6,500	2,700	10	***	84.0	4.0
13	750	7,000	5,000	****	4	***	***	1.6
14	800	370	370	****	****	35.0	100	-
15	800	440	440	****	****	38.0	100	-

* Shear Modulus calculated from Young's modulus using the average value of .27 for Poisson's ratio at room temperature.

** This value appears high and from the results of other tests could be discarded.

*** Samples broke outside gage marks.

**** Value too small or initial portion of curve too inaccurate to determine.

FIG. 1
HEATING FURNACE ASSEMBLY

1. ARGON INLET	5. FURNACE
2. TENSILE ARMS	6. EXTENSOMETER ARMS
3. COPPER COOLING COIL	7. THERMOCOUPLE
4. SPECIMEN	8. EXTENSOMETER

FIG. 5

VARIATION OF
% ELONGATION
WITH TEMPERATURE

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FIGURE 8

FIGURE 9

THE BAND CONTAINING STRESS STRAIN CURVES
OF 11 SAMPLES
TESTED AT ROOM TEMPERATURE

FIGURE 10

Typical Fractured Tensile Specimen Tested at Room Temperature. 1X

FIGURE 11

Tensile Specimen Tested at
150°C. 1X

FIGURE 12

Tensile Specimen Tested at
300°C. 1X

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FIGURE 13

Tensile Specimen Tested at
450°C. 1X

FIGURE 14

Tensile Specimen Tested at
600°C. 1X

FIGURE 15

Tensile Specimen Tested at
700°C. 1X

FIGURE 16

Tensile Specimen Tested at
800°C. 1X