214
10-30-80
97C

Dr. 1910

Y-2224

Y-12

OAK
RIDGE
Y-12
PLANT

THE PREPARATION, HEAT TREATMENT, AND MECHANICAL PROPERTIES OF THE URANIUM-5 WEIGHT PERCENT CHROMIUM EUTECTIC ALLOY

A. B. Townsend

October 1980

MASTER

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A02
Microfiche copy: A01

— **DISCLAIMER** —

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Date of Issue: **October 28, 1980**
Distribution Category: **UC-25**

Y-2224

**THE PREPARATION, HEAT TREATMENT, AND MECHANICAL
PROPERTIES OF THE URANIUM-5 WEIGHT PERCENT
CHROMIUM EUTECTIC ALLOY**

A. B. Townsend

**Metals and Ceramics Department
Y-12 Development Division**

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Oak Ridge Y-12 Plant

P. O. Box Y, Oak Ridge, Tennessee 37830

**Prepared for the Department of Energy
Under US Government Contract W-7405-eng-26**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

leg

ABSTRACT

The eutectic alloy of uranium-5 wt % chromium (U-5Cr) was prepared from high-purity materials and cast into 1-in.-thick ingots. This material was given several simple heat treatments; the mechanical properties of these heat-treated samples were determined; and the microstructure was examined. Some data on the melting point and transformation temperatures were obtained.

CONTENTS

SUMMARY	4
INTRODUCTION	5
EXPERIMENTAL PROCEDURE	6
Alloy Preparation	6
Heat Treatment	6
Results and Discussion	6
Examination of the Eutectic Temperature and Composition	9
REFERENCES	11

SUMMARY

An alloy of uranium with a nominal chromium content of 5 wt % (U-5Cr) was prepared, and the mechanical properties were determined after the cast material had been given several different heat treatments. The alloy is a eutectic of nearly pure chromium in nearly pure uranium. The heat treatments were largely intended to improve the ductility of the cast alloy, but the possibility of improving strength by a precipitation-hardening mechanism was examined. Ductility was increased from 6 to 7% in the as-cast alloy to better than 16% for samples solution heat treated at 800°C and then cooled to and held at 600°C for several hours before further cooling. Quenching the alloy from 600°C and then aging at 350°C gave no significant hardening or increase in strength.

The alpha-to-beta uranium transformation temperature was found to range from 625 to 638°C and the beta-to-gamma transformation temperature to be 740°C. The melting point was observed to be 850 to 853°C.

INTRODUCTION

The system U-5Cr is a eutectic system described by Hansen¹ as being a simple one between essentially pure uranium and nearly pure chromium, where the solubility of uranium in solid chromium is described as negligible and of chromium in solid alpha-uranium as being less than an estimated 0.2 at %. The eutectic temperature is indicated in Hansen as $859 \pm 10^\circ\text{C}$ at a composition of 5.0 wt % chromium and later, by Shunk,² as being at 895 to 870°C and a composition of 4.43 wt %.

This eutectic system with no intermetallic compounds and with a melting point under 900°C suggests that the alloy would fill the need for a low-melting uranium alloy with essentially the properties of alpha-uranium. This report describes the preliminary work done in the Oak Ridge Y-12 Plant^(a) on the preparation of the alloy, the checking of the eutectic composition and temperature, and the results of some simple heat treatments on the mechanical properties of the alloy.

(a) Operated by the Union Carbide Corporation, Nuclear Division, for the Department of Energy.

EXPERIMENTAL PROCEDURE

ALLOY PREPARATION

The alloy was prepared by melting together, in a vacuum induction furnace, a charge consisting, typically, of 920 g of chromium flake of 99.7% purity with 17 080 g of high-purity depleted-uranium derby metal. The metal was melted, the temperature taken to 1250°C, the temperature then lowered to 1150°C, and the charge poured. The crucibles and molds were made of graphite and coated with a protective wash of yttria. Although the charge was made up at approximately 5.1 wt % chromium, the billets analyzed about 4.5 to 4.6%.

HEAT TREATMENT

The structure of the as-cast alloy is shown in Figure 1 and displays a typical eutectic structure.

The alloy was given a homogenizing treatment at 800°C, in vacuum for 16 hours. It was hoped that this would, to some extent, spheroidize the structure and increase the alloy's ductility. One sample was water quenched from 800°C, and the remainder of the heat-treated samples were furnace cooled to room temperature or furnace cooled to 600°C, at which temperature the specimens were held for 1 or 2 hours before further furnace-cooling to room temperature under vacuum.

RESULTS AND DISCUSSION

Sample A - Sample A was water quenched from 800°C. If the chromium was substantially soluble in the uranium and had been retained in solution by the quenching, perhaps 350°C would be a temperature low enough to have a minimum of solubility and hot enough to encourage any precipitation hardening mechanism to operate. Sample A was heated in air at 350°C for 1 hour.

At that time, the specimen was removed from the aging-oven and cooled in water prior to making hardness measurements. The sample broke into several pieces upon cooling. Hardness measurements on the pieces indicated a hardness of 71 to 74, Rockwell A. As-cast hardness was 64, Rockwell A.

Sample B - Sample B was furnace cooled from 800°C, and the hardness was 51 to 54, Rockwell A. The structure is shown in Figure 2, and the mechanical properties are given in Table 1.

Samples C and D - Samples C and D were homogenized, furnace cooled, reheated to 600°C and held for 1 hour, and water quenched. Sample C was then aged at 350°C, and Sample D was held for examination in the quenched condition. As-quenched hardness of the alloy was about 60, Rockwell A. These samples were aged to examine for the possibility of a

MS-79-0547-1

Figure 1. EUTECTIC STRUCTURE OF NOMINAL URANIUM-5 WEIGHT PERCENT CHROMIUM ALLOY, AS-CAST. (Bright-field illumination; 500X.)

MS-79-0532-8

Figure 2. URANIUM-5 WEIGHT PERCENT CHROMIUM ALLOY EUTECTIC STRUCTURE AFTER 800°C HEAT TREATMENT FOR 16 HOURS AND FURNACE COOL. (Bright-field illumination; 500X.)

Table 1
MECHANICAL PROPERTIES OF URANIUM-5 WEIGHT PERCENT CHROMIUM ALLOY WITH
VARIOUS HEAT TREATMENTS

	Hardness (Rockwell A)	Ultimate Tensile Strength		0.2% Yield Strength		Elongation (%)
		(MPa)	(ksi)	(MPa)	(ksi)	
Sample G: As-Cast All Remaining Samples: Vacuum Heat Treated, 800°C, 16 Hours, Then:	64	660.7	95.8	383.5	55.6	6.8
Sample A: Water Quench +350°C, 1 Hour, Water Quench	71-74			Broke		
Sample B: Furnace Cooled	51-54	683.5	99.1	345.5	50.1	8.0
Sample C: Furnace Cool to Room Temperature +600°C, 1 Hour, Water Quench +350°C, 16 Hours	58-60	715.2	103.7	357.3	51.8	8.2
Sample D: Furnace Cool to Room Temperature +600°C, 1 Hour, Furnace Cool	59-61	700.7	101.6	331.7	48.1	8.0
Sample E: Furnace Cool to 600°C Hold 2 Hours, Water Quench +350°C, 5 Hours	58-61	819.4	118.8	353.8	51.3	21.0
Sample H: Furnace Cool to 600°C Hold 2 Hours, Furnace Cool	62	795.2	115.3	299.3	43.7	16.3

strengthening mechanism operating by virtue of the solubility of chromium in uranium at a temperature just below the beta-alpha transition temperature. Aging at 350°C for 1, 2, 4, 8, and 16 hours had very little effect on the hardness as shown in Table 2. The aged-sample Blank C and unaged Blank D were tested for mechanical properties which are shown in Table 1. The microstructure of both were similar to that shown in Figure 2.

Samples E and F - Hansen¹ quotes several authors suggesting that small amounts of chromium tend to slow the transformation of the higher phases to the alpha upon cooling and White³ has described the kinetics of these transformations up to 0.9-wt % (4-at %) chromium. To prevent possible damage to the samples by too rapid a cooling rate through the critical beta-alpha transformation, Samples E and F were solution-treated at 800°C and then cooled to 600°C (high alpha phase) and held for 2 hours to allow the transformation; then Sample E was water-quenched; and Sample F was furnace cooled. Sample E was then aged for 5 hours at 350°C. Again, aging caused no increase in hardness. The microstructure of Sample E in Figure 3 shows no difference from previous homogenized samples. The tensile properties obtained with Sample E are given in Table 1. Sample F could not be made into mechanical property specimens, and the test was repeated with Sample H. Its properties are given in Table 1.

This treatment appeared to give the greatest ductility of the samples with Sample E testing at 21% elongation. Sample H gave an elongation of 16.3%.

Table 2
AGE-HARDENING RESPONSE OF A
URANIUM-5 WEIGHT PERCENT
CHROMIUM ALLOY SOLUTION
HEAT TREATED AT 600°C
AND AGED AT 350°C

Procedure		Hardness (Rockwell A)
Water Quenched from 600°C		60, 60, 60
Hours Aged at 350°C	1	57, 58.5, 59
	2	58, 58, 59
	4	55, 57.5, 58
	8	56, 57, 60
	16	58.5, 60, 60

Sample G - Sample G provided comparison mechanical properties of the material in the as-cast condition.

EXAMINATION OF THE EUTECTIC TEMPERATURE AND COMPOSITION

Samples taken from a billet having an alloy composition of 4.5 to 4.6-wt % chromium were examined by differential thermal analysis. By comparing the DTA curves for these samples with curves obtained from pure uranium and by assuming an alpha-to-beta phase transformation temperature of 663°C for the pure uranium and a beta-to-gamma transformation temperature of 770°C, it was estimated that the alloy had transformation temperatures of 638 and 739°C. The melting point was determined to be 853°C.

Additional information was obtained from temperature data taken when melting and pouring 25-kg lots of the alloy. The charges were made by melting together chromium with an advertised purity of 99.5% chromium and high-purity depleted uranium.

The alloy was melted in a vacuum-induction furnace and poured into a mold which approximated the shape of a right cylinder, 152 mm (6 in.) in diameter and 76 mm (3 in.) high. A graphite tube, held in the center of this mold, carried a Chromel-Alumel^(b) thermocouple. The mold was insulated by Fiberfrax^(c) batting, about 25 mm (1 in.) thick beneath which surrounded and partially covered the mold. The temperature of the cooling/solidifying charge was recorded.

Following the preparation of the alloy billet, the same setup and procedure were used to produce a pure uranium billet. By comparison of the two recordings and by accepting the transformation temperatures of pure uranium to be 663 to 770°C, it was found that the beta-to-alpha transformation of the alloy was depressed to 625°C and the gamma-to-beta transformation was depressed to 740°C. The eutectic temperature was found to be near 850°C, which is more in agreement with Hansen¹ than with Shunk.²

(b) Hoskins Mfg. Co., Detroit, Mich.

(c) Carborundum Co., Niagara Falls, N.Y.

MS-79-0532-11

Figure 3. SAMPLE E: EUTECTIC STRUCTURE OF URANIUM-5 WEIGHT PERCENT CHROMIUM ALLOY AFTER HOMOGENIZATION AT 800°C, ISOTHERMAL TRANSFORMATION AT 600°C FOR 2 HOURS, THEN WATER QUENCHED. (Bright-field illumination; 500X.)

Several billets, 38- X 127- X 178-mm (1-1/2- X 5- X 7-in.), were cast to provide heat-treated study stock. These were made up to a nominal composition of 5-wt % chromium; on the lower ends of the billets where the alloy solidified rapidly, that composition was determined analytically to be 0.04962-g chromium per gram of alloy. When sampled on the upper ends, which were held hotter and provided a hot-top, 0.04585 and 0.04587-g chromium per gram of alloy were found.

On another occasion, during overheating of an alloy part, molten metal liquidated and ran free of the part being heat-treated. This material analyzed 0.04468-g chromium per gram of alloy. These analyses would lead one to believe that the eutectic composition is closer to 4.6 or 4.5 wt % which is nearer to that proposed by Shunk's Reference 1 (4.43%).

REFERENCES

1. M. Hansen, *Constitution of Binary Alloys* (McGraw-Hill Book Co., New York, 1958), p. 569.
2. F. A. Shunk, *Constitution of Binary Alloys, Second Supplement* (McGraw-Hill Book Co., New York, 1969), p. 284.
3. D. W. White, "Transformation Kinetics in Uranium-Chromium Alloys," TID-5061, *Proceedings of the Metallurgy and Materials Information Meeting* (April 16-18, 1951) Vol I, p. 117.

Distribution

Ballistics Research Laboratory - Aberdeen (DRDAR-BLT)

Bruchey, W.

Ballistics Research Laboratory - Dover (DRDAR-SCM)

Hulbert, R. R.

Department of Energy - Oak Ridge

Hickman, H. D.

Poteat, R. M.

Lawrence Livermore National Laboratory

Arnold, W. F.

Robbins, J.

Root, G. S.

Wood, D. H.

Los Alamos National Scientific Laboratory

Hockett, J. E.

Hoyt, H. C.

Sandstrom, D. J.

Straw, J. B.

Wechsler, J. J.

Oak Ridge Gaseous Diffusion Plant

Armstrong, R. C.

Stief, S. S.

Wilcox, W. J., Jr.

Oak Ridge National Laboratory

Hopkins, C. C.

Ogle, J. C.

Vandermeer, R. A.

Weir, J. R., Jr.

Oak Ridge Y-12 Plant

Anderson, R. C.

Beck, D. E.

Bieber, C. R.

Clift, J. H.

Dillon, J. J.

Dobbins, A. G.

Dodson, W. H./Googin, J. M.

Evans, P. A.

Fraser, R. J.

Haeusler, K. R./Kay, A. (AWRE)

Hovis, V. M., Jr.

Jessen, N. C., Jr.

Keith, A.

Kite, H. T.

Koger, J. W.

Kollie, T. G.

Lewis, P. S., Jr.

Ludwig, R. L.

Mills, J. M., Jr.

Montgomery, C. D.

Northcutt, W. G., Jr.

Perkins, M. A.

Pfeiler, W. A.

Scott, D. G.

Smith, G. H.

Townsend, A. B. (10)

Y-12 Central Files (master copy)

Y-12 Central Files (route copy)

Y-12 Central Files (Y-12RC)

Y-12 Central Files (5)

Paducah Gaseous Diffusion Plant

Bewley, H. D.

Rockwell International - Rocky Flats

Jackson, R. J.

Mataya, M. C.

Sandia National Laboratories - Albuquerque

Eckelmeyer, K. H.

MacDougall, H. R.

Magnani, N. J.

Schmitt, H. W.

Spencer, W. J.

Sandia National Laboratories - Livermore

Adolphson, D. R.

Hoover, W. R.

Mote, M. W., Jr.

Union Carbide Corporation - New York

Tinsley, S. W.

In addition, this report is distributed in accordance with the Category UC-25, **Materials**, as given in the *Standard Distribution for Unclassified Scientific and Technical Reports*, DOE/TIC-4500.