AECU-3381

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ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

ARF Project No. G022 D3

MEASUREMENT OF THERMAL
CONDUCTIVITY OF URANIUM OXIDE

Final Report

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YEARS OF SERVICE THROUGH RESEARCH

1936-1956

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ARMOUR RESEARCH FOUNDATION
of
ILLINOIS INSTITUTE OF TECHNOLOGY
Technology Center
Chicago 16, Illinois

Project No. G022 D3

MEASUREMENT OF THERMAL CONDUCTIVITY OF URANIUM OXIDE

Final Report

September 20, 1956

for

Westinghouse Electric Corporation
Atomic Power Division
Pittsburgh, Pennsylvania

copy 94

MEASUREMENT OF THERMAL CONDUCTIVITY OF URANIUM OXIDEABSTRACT

Thermal conductivity of UO_2 having a density of 8.17g/cc has been measured in the temperature range of 400 to 3030°F using the Powell stacked disk method. The thermal conductivity of Armco iron was measured on the apparatus used for this investigation and results which check within 2 per cent of the accepted values were obtained.

Since difficulties were encountered in the preparation of test specimens which were free of cracks, it was agreed to first attempt to obtain data up to 3000°F and then, if possible, to continue the measurement up to 4400°F. Upon examining the UO_2 disks after the measurement at 3030°F, it was evident that the disks were so badly cracked that further measurements were impossible.

MEASUREMENT OF THERMAL CONDUCTIVITY OF URANIUM OXIDEI. INTRODUCTION

This is the final report on the project whose objective was to determine the thermal conductivity of UO_2 from 1000°F to its melting point (about 4400°F).

Early in June 1956, it was apparent that the Ceramics Department of Armour Research Foundation would be unable to make UO_2 disks which would be free of cracks. Accordingly, on June 13, 1956, a meeting was held at ARF to discuss the situation, and following Dr. Lustman's suggestion it was agreed to attempt a thermal conductivity measurement up to 3000°F using the best available test specimens.

The results of the measurements in the temperature range of 400°F to 3030°F are contained in this report. Upon completion of the measurement at 3000°F , the apparatus was slowly returned to room temperature and examination of the samples showed that it would be impossible to attempt the measurements in the 3000 to 4400°F range with the present samples.

II. DESCRIPTION OF THERMAL CONDUCTIVITY APPARATUS

The thermal conductivity of UO_2 was measured using the radial heat flow method which was developed by R. W. Powell⁽¹⁾. The method consists of measuring, during steady state, the radial heat flow and radial temperature drop in a vertical stack of disks composed of the material whose thermal

(1) R. W. Powell, Proceedings of the Physical Society, 50, 407 (1938).

conductivity is to be measured. The disks were in the form of annular rings and the heat which flowed through the disks was supplied by an electric heater centered in the axial hole of the stacked disks. In order to attain high temperatures and to regulate the temperature drop over which the measurement is made, the column of stacked disks was placed in an electrically heated furnace in which a helium atmosphere was maintained. The radial heat flow through a section of the stacked disks 3-inches long, 1-1/2-inches above and below the vertical center of the column, was derived from measurement of the current and voltage drop along a 3-inch length of the axial heater adjacent to the test section. The temperature gradient was measured by means of thermocouples inserted in very small vertical holes, one near the axial hole containing the heater and the other near the outer edge of the disks. The thermal conductivity of the disk material was calculated under steady state conditions from the power input, the distance of the inner and outer thermocouples from the axis of the disks, and the temperature difference between these holes. A section through the apparatus which was used is shown in Fig. 1.

The UO_2 test specimens were disks having an inside diameter of 0.50-inch and an outside diameter of 3.0-inches. Twelve disks were 1/2-inch thick and three were 1-inch thick, making a total length of 9-inches. The specimens were arranged with the three 1-inch thick disks in the center and six 1/2-inch thick disks on each end.

As shown in Fig. 1, four holes were located in each disk to permit the insertion of thermocouples. The holes were drilled in the disks by the Cross Ultra Sonic Machine Company of Hazel Park, Michigan. Platinum-platinum

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Fig. 1
GENERAL LAYOUT OF THERMAL CONDUCTIVITY
APPARATUS

10 per cent rhodium thermocouples protected by twin-bore porcelain tubing were used for measuring temperatures. The thermocouples were moved up and down so that a temperature traverse along the length of the samples could be made. It was necessary to measure the axial temperature distribution in order to determine if any heat was flowing in the axial direction. Axial heat flow would introduce an error since it was assumed in the calculations that the heat flow in the three center disks was only in a radial direction. One reason for using disks rather than a single cylinder of UO_2 was that the poor thermal contact between disks offers considerable resistance to axial heat flow. In order to further insure that axial heat flow would not occur, molybdenum wound heaters were placed at both ends of the test specimens.

The radial heat flow through the UO_2 was accomplished by a molybdenum coil wound on a ceramic core and centered in the axial hole of the stacked disks. As shown in Fig. 1, the stacked disks were placed in a ceramic tube around the outer surface of which was wound a molybdenum coil. The outer heater provided most of the energy needed to raise the temperature of the sample while the inner heater provided a means of varying the temperature drop through the sample. The three 1-inch thick samples located in the center of the stack were considered as the test section. The current and voltage drop in the inner heater was measured over this 3-inch length. The outer heating elements were surrounded by bubble alumina insulation and a water cooled steel housing. The apparatus was purged with helium to provide an inert atmosphere for the UO_2 . The entire apparatus was placed in a hood which exhausted to the atmosphere.

The thermal conductivity was calculated by the following equation:

$$K = \frac{Q \ln \frac{r_2}{r_1}}{2 \pi l (\Delta t)}$$

where

K = thermal conductivity, B hr⁻¹ ft⁻¹ F⁻¹

Q = radial heat flow, B hr⁻¹

l = length of test section, ft

r₁ = radial distance from axis to inner thermocouple, ft

r₂ = radial distance from axis to outer thermocouple, ft

Δt = temperature drop over the distance between thermocouples, °F

III. CALIBRATION OF APPARATUS

Numerous investigators have measured the thermal conductivity of Armco iron in the temperature range of 800 to 1500°F and show good agreement. Therefore, it was decided to use Armco iron disks as a means for calibrating the apparatus which was to be used for measuring the thermal conductivity of UO₂. The most frequently quoted investigator to measure the conductivity of Armco iron at elevated temperatures is Powell⁽²⁾. Because of the high regard held for Powell's work, the results of the calibrated test were evaluated in terms of their agreement with Powell's results.

The results and comparison of the calibration tests are shown in Fig. 2. As can be seen from Fig. 2, Armour Research Foundation's results agree with Powell's within 2 per cent.

(2) Powell, R. W. "Proceedings of the Physical Society." London, Vol. 46, 1934.

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Fig. 2 RESULTS OF THERMAL CONDUCTIVITY TESTS OF ARMCO IRON

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IV. PREPARATION OF UO_2 DISKS

The 3-inch diameter disks of UO_2 were prepared in the Ceramics Department of ARF using the following procedure.

A mill batch which consisted of 500g of uranium oxide, 1.75g of stearic acid, 3.5g of methyl cellulose, 2.5cc of 0.5 per cent Aerosol OT in octyl alcohol and 160cc of water was ground for 16 hours in a glass lined mill using flint pebbles. After grinding, the open mill was placed in an oven and dried at 80°C for a period of 24 hours. The cake was crushed to pass a 20 mesh sieve and 3 weight per cent water was then added. The material was then cold pressed at 20 TSI and the green disks were then dried for 24 hours at 80°C . After drying, the disks were placed in a horizontal tube furnace and heated. Dry hydrogen was applied until a temperature of 1400°C was reached. The hydrogen was then replaced with steam and the temperature allowed to proceed to 1500°C where it was held for a period of 2 hours. The furnace and contents were then allowed to cool to room temperature in a hydrogen atmosphere.

The density of the UO_2 disks prepared in the manner described above was 8.17g/cc or 74.95 per cent of the maximum theoretical density.

V. EXPERIMENTAL RESULTS

The experimental results which were obtained are shown in Table I and Fig. 3. The results show that the conductivity of UO_2 decreases with increasing temperature, the slope of the curve is constant in the region of 400 to 1600°F , and from 2300 to 3000°F the conductivity of UO_2 is practically constant. A comparison of the results obtained from this investigation (3) with those obtained by Kingery, Francl, Coble, and Vasilos show that they

(3) Kingery, W.D., Francl, J., Coble, R.L., and Vasilos, T. Journal of American Ceramic Society. Vol. 37, No. 2, 1954. pp 107-110.

Table I

THERMAL CONDUCTIVITY OF UO_2

(Density 8.17g/cc)

Temperature at r_1 , °F	Temperature at r_2 , °F	Temperature Difference, °F	Mean Temperature °F	Thermal conductivity $\text{B hr}^{-1} \text{ft}^{-1} \text{F}^{-1}$
410.8	381.0	29.8	395.9	2.28
431.8	401.2	30.6	416.5	2.22
751.4	720.8	30.6	736.1	1.85
1196.0	1165.3	30.7	1180.6	1.50
1613.0	1571.3	41.7	1592.1	1.14
2039.0	1998.0	41.0	2018.5	1.01
2429.0	2385.0	44.0	2407.0	0.90
2580.0	2540.0	40.0	2560.0	0.86
2865.6	2825.7	39.9	2845.6	0.83
3048.0	3020.0	28.0	3034.0	0.84

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Fig. 3 THERMAL CONDUCTIVITY OF UO_2 (8.17 g/cc)

are approximately 30 per cent lower. It is difficult to say which of these two results are correct. The apparatus used by Kingery gave results which were about 25 per cent higher than those obtained by other well known investigators using the same method as mentioned in the introduction to this report. The samples which were used in this investigation had cracks and it is therefore impossible to claim that the results have the accuracy which is claimed for the method used in this investigation.

Respectfully submitted,

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