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THERMAL CONDUCTIVITY OF ZIRCONIUM AND ZIRCONIUM-TIN ALLOYS

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July 10, 1953

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ABSTRACT

The thermal conductivities of zirconium-tin alloys and a zirconium-uranium-tin-iron-chromium-nickel alloy were measured over the temperature range 50 to 400 C. Thermal-conductivity values at 300°C ranged from 0.19 watts/(cm)(C) for unalloyed zirconium to 0.11 watts/(cm)(C) with 7 wt % tin. At lower temperatures the spread is greater.

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APPARATUS AND METHOD

Thermal-conductivity measurements were made by the steady-heat-flow method on three zirconium-tin alloys and two specimens of zirconium. The apparatus and method were essentially those described by Van Dusen and Shelton*. The specimen was placed in series with an Armco-iron standard heat-flow meter. A constant rate of heat flow was maintained through the specimen and heat-flow meter. The thermal conductivity of the specimen was determined from the temperature gradient along the specimen and standard, and the calculated heat flow. Radial heat flow into, or away from, the specimen was reduced by thermal insulation and an encircling guard tube in which temperatures were adjusted to match those in the specimen and standard at corresponding levels. Figure 1 is a diagrammatic sketch of the apparatus.

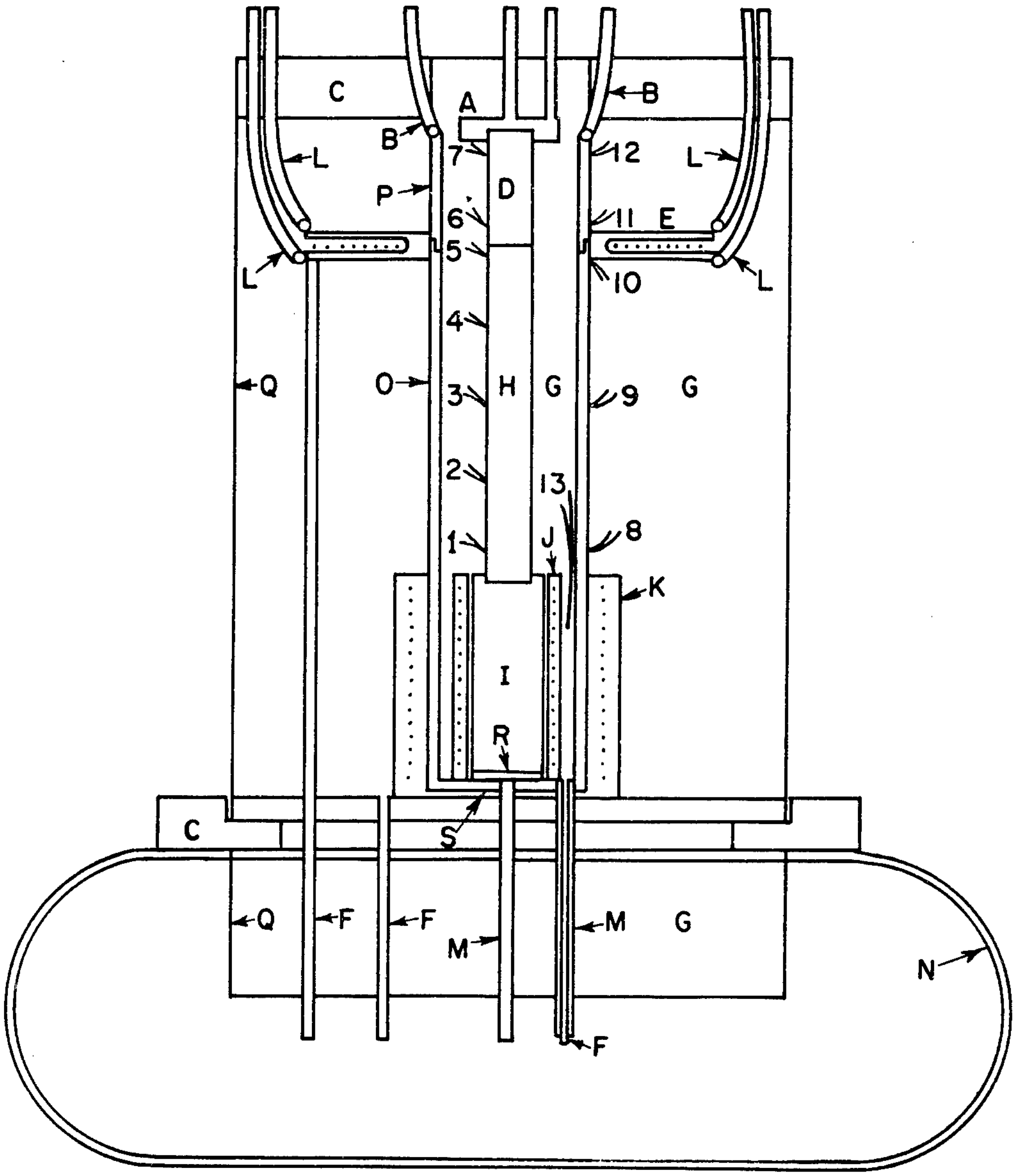
Tin solder was used to join the heater cylinder, I, specimen, H, Armco-iron standard, D, and cooling plate, A. Ends of the specimen were first coated with zinc by immersion in molten $ZnCl_2$ at 450 C for 5 to 10 min. After the adhering salt was washed off, the ends were tin coated in molten tin, using a paste flux, and the assembly was tin soldered together.

Thermocouple beads were inserted in small, shallow holes in the specimen and standard and were held in place by small wedged pins. Chromel-Alumel 36-gage thermocouple wire was used.

Voltage-regulated power was used in all heaters to insure a steady heat input. Water of constant temperature and flow rate, circulated through the heat sink, A, insured a steady rate of heat withdrawal. In operation, heat was supplied to the specimen to give the desired maximum temperature. The guard heaters and cooler were adjusted to make temperatures on the guard cylinder as nearly as possible the same as those at corresponding levels on the specimen and standard. After equilibrium was established, and a good temperature balance existed between specimen and guard, thermocouple millivolt readings were taken, using a Type K Leeds and Northrup potentiometer. Each heat-flow equilibrium produced data from which the thermal conductivity was calculated at each of four mean temperatures from adjacent pairs of thermocouples in the specimen. Two or three heat-flow equilibria were obtained for each specimen to cover a temperature range 25 to 425 C.

Purified argon, introduced through Tube M and passing upward through the Silocel insulation, provided the specimen with partial protection against oxidation.

* Van Dusen, M. S., and Shelton, S. M., "Apparatus for Measuring Thermal Conductivity of Metals up to 600 C", J. Res. Natl. Bur. Standards, 12 (R.P. 668), 429-440 (1934).



A - Cooling Plate
B - Cooling Tube
C - Transite
D - Standard
E - Ring Heater
F - Heater Leads
G - Thermal Insulation
H - Sample
I - Inconel Heater Block
J - Main Heater

K - Guard Heater
L - Air Cooling Coils
M - Inconel Tubes
N - Supports
O - Inconel Guard Tube
P - Nickel Guard Tube
Q - Steel Container
R - Alundum Disk
S - Inconel Bottom
Numbers — Thermocouples

FIGURE 1. DIAGRAMMATIC SKETCH OF APPARATUS USED FOR THERMAL-CONDUCTIVITY MEASUREMENTS

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SPECIMENS

The specimens were solid cylinders nominally 2 cm in diameter and 15 cm long. Specimen compositions and pertinent processing data are given in Table 1.

TABLE 1. COMPOSITION AND PROCESSING DATA FOR ZIRCONIUM AND ZIRCONIUM ALLOY THERMAL-CONDUCTIVITY SPECIMENS

Specimen[a]	Composition, wt %: Nominal	Composition, wt %: Actual	Processing Data
498	Zr 100	-	WAPD Grade I crystal bar, arc melted
2682A	Zr 100	-	Bureau of Mines sponge, arc melted
513	-	U 4.34	WAPD alloy of a (50-50 A and B) blend sponge, arc melted, forged and rolled at 1600 F
	-	Sn 1.33	
	-	Cr 0.09	
	-	Ni 0.027	
		Fe 0.125	
		B 0.04	
		N_2 0.013	
		Zr Bal	
370	Zr 97.5	Zr Bal	Bureau of Mines alloy prepared from sponge zirconium, re-melted (arc-melting), forged and rolled at 1600 F
	Sn 2.5	Sn 2.3	
	-	N_2 0.002	
315	Zr 97.5	Zr Bal	WAPD Grade I crystal bar, cp tin, arc melted, forged at 1700 F
	Sn 2.5	Sn 2.51	
	-	N_2 0.005	
1009	Zr 93	-	Foote Grade I crystal bar, cp tin, arc melted
	Sn 7	-	

(a) All zirconium used was low hafnium.

RESULTS

Figure 2 shows specimen thermal conductivity vs. mean temperature. Thermal-conductivity measurements were made at three equilibria for Specimens 2682A, 498, and 315, at four equilibria for Specimens 513 and 370, and at eight equilibria for Specimen 1009. The curves shown in Figure 2 are best curves drawn through points obtained from these equilibria. The points are not shown because of their large number (four for each equilibrium). The maximum deviation of any one point from any curve was 5 per cent and the mean deviation of all points was 0.2 per cent.

Specimens 2682A and 498, with no tin content, show a decrease in thermal conductivity with increasing temperature, while the specimens containing tin show an increasing thermal conductivity with temperature. All of the curves are slightly concave upwards. The addition of tin appears to reduce the thermal conductivity of zirconium despite an anomaly that exists in the positions and slopes of Specimens 315 and 370 having tin contents of 2.51 per cent and 2.30 per cent, respectively.

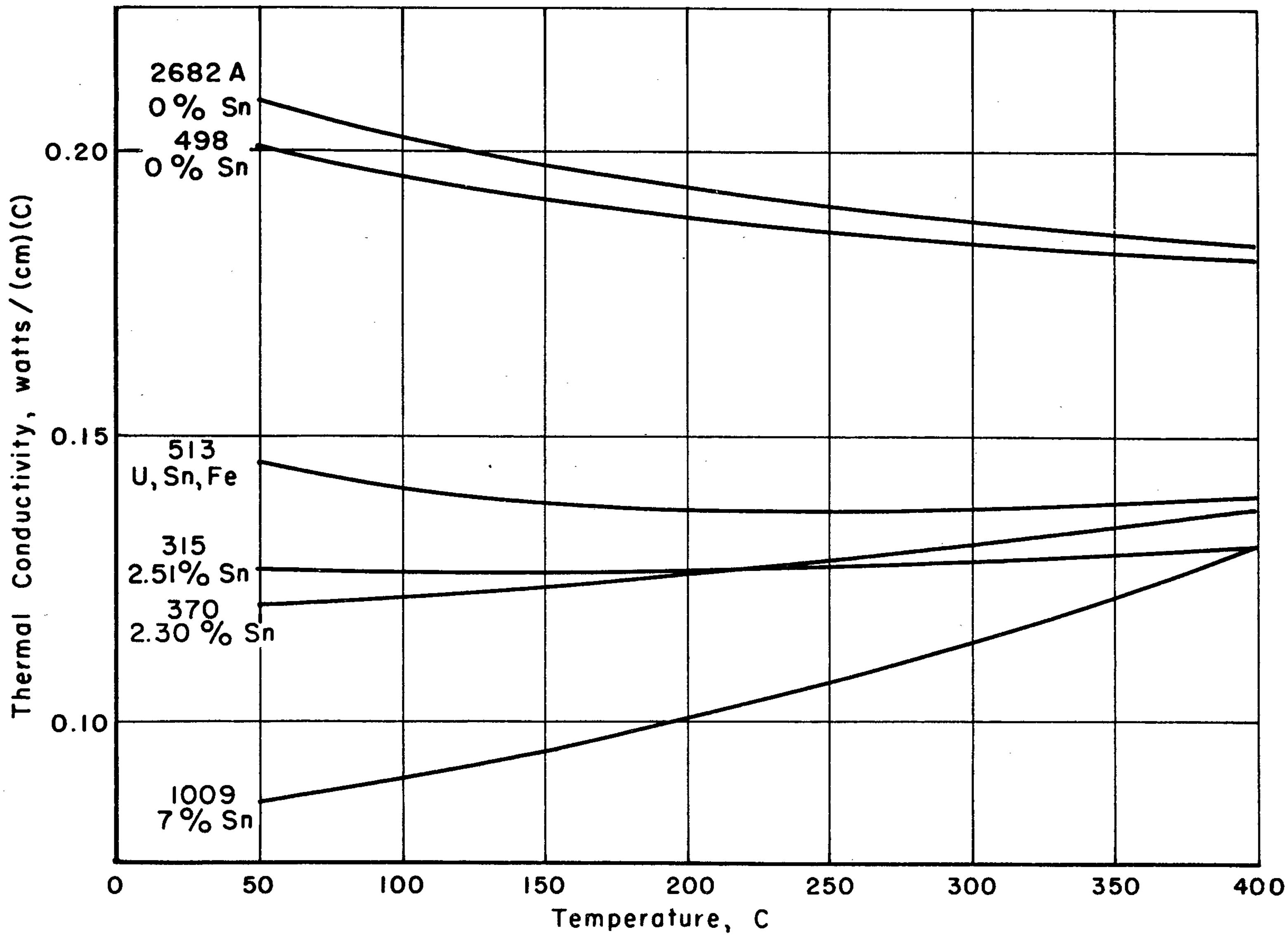

FIGURE 2. THERMAL CONDUCTIVITIES OF ZIRCONIUM–TIN ALLOYS

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