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THERMAL CONDUCTIVITY OF METAL INTERFACES

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Thermal Conductivity of Metal Interfaces

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Abstract

The coefficients of thermal conductivity of aluminum-bismuth metal-to-metal bonds, and of aluminum and bismuth surfaces in contact under pressure, were measured. The coefficient of thermal conductivity of the metal-to-metal bond was at least 30,000 BTU/hr ft^2 °F, i.e., thermal resistance was negligible, and the coefficient for the metal surfaces in contact was found to be 2000 BTU/hr ft^2 °F.

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The problem of inspecting the soundness of the metal-to-metal bonds in solid-type accelerator targets has been approached through an investigation of the coefficient of thermal conductivity across a sound metal-to-metal bond and across an unbonded metal-to-metal interface in the temperature range of 400 °F to 500 °F.

Apparatus

A simple apparatus was used which consisted of a six inch length of four inch diameter steel pipe, which enclosed a four inch length of two inch diameter alundum guard tube uniformly wound for three inches with No. 32 nichrome wire. The test samples were cylindrical rods, one inch in diameter by eight inches long, and were mounted with-in the guard tube. The latter was insulated from both the steel pipe and the test sample by glass wool.

Two thermocouples were embedded in the glass wool insulation midway between the guard tube and the test sample. Temperatures were measured with iron-constantan thermocouples connected through an eleven point switch to a Leeds Northrup double range indicating potentiometer (Type No. 8657 - C).

The test specimen of a metal-to-metal bond was prepared by casting a one-inch-diameter bismuth rod onto a pre-wet inch diameter 2S aluminum rod.* Thermocouple holes, 0.098 inches in diameter, were drilled perpendicularly into the center of the rod at one inch intervals,

*This test specimen was prepared by C. D. Newman of California Research Corporation.

starting at a distance of 0.08 inches from the interface. Three thermocouples were thus located in each part of the composite rod.

The test sample for the unbonded metal surfaces in contact was prepared by coupling a cast bismuth rod to a stock 2S aluminum rod, each one inch in diameter. Machine polishing and threading of the adjacent ends followed. A stainless steel coupling (Type 302) 0.44 inches long, of 0.06 inches wall thickness, and one inch inside diameter, was threaded inside, and then the two rods were screwed into the coupling, until finger-tight. Thermocouple holes were drilled as in the previous specimen. A contact pressure between the two surfaces was provided during the thermal conductivity measurements by the unequal thermal expansions of the three metals.

The test samples were heated at the aluminum end by a Bunsen burner, and were cooled at the bismuth end with tap water; the aluminum half of the rod was used as a heat meter, because of the smaller temperature difference between it and the guard tube.

The most serious problem encountered was that of reaching a steady state. Heating with a Bunsen burner does not provide a uniform rate of heat input. In addition, the thermocouple holes were relatively large in diameter, so that the location of the thermocouples was not known very accurately. The experimental accuracy was also limited by the sensitivity of the potentiometer and thermocouples used.

Experimental Results

Aluminum-bismuth bond

Four test runs were made with the specimen described, each of three to four hours duration, with frequent measurements of the temperature distribution to insure that steady-state conditions would be measured. The rate of heat flow was calculated from the aluminum temperatures and the conductivity across the interface from this rate and from the temperature drop at the interface as calculated by extrapolation from the two nearest thermocouples. Typical calculations are shown in the appendix. The results of the tests are given in Table I.

Following the suggestions of Professor J. E. Dorn, of the University of California Metallurgy Division, a tensile specimen was cut from the test sample. Examination of this specimen revealed a layer of voids existing approximately 0.2 inches from the interface; these are shown in five-fold magnification in Figure 1. The specimen broke under shear, while being prepared for the tensile test; this revealed that the interface was not completely wetted and that voids also existed at the interface, as shown in Figure 2.

The dark areas in Figure 2 indicate breakage within the bismuth, away from the interface, and therefore represent areas of satisfactory bonding. From this observation it is concluded that a completely satisfactory bond would show about twice the thermal conductivity, i.e. 30,000 BTU/hr ft^2 °F. Within the accuracy of the present measurements, this is practically an infinite value.

Unbonded aluminum and bismuth surfaces in contact

Nine test runs were made with the specimen described and in the manner previously indicated. The results were calculated in the same manner. Results given in published literature[1] indicate an increase in coefficient of thermal conductivity with pressure. Values given in Table II are in agreement with this.

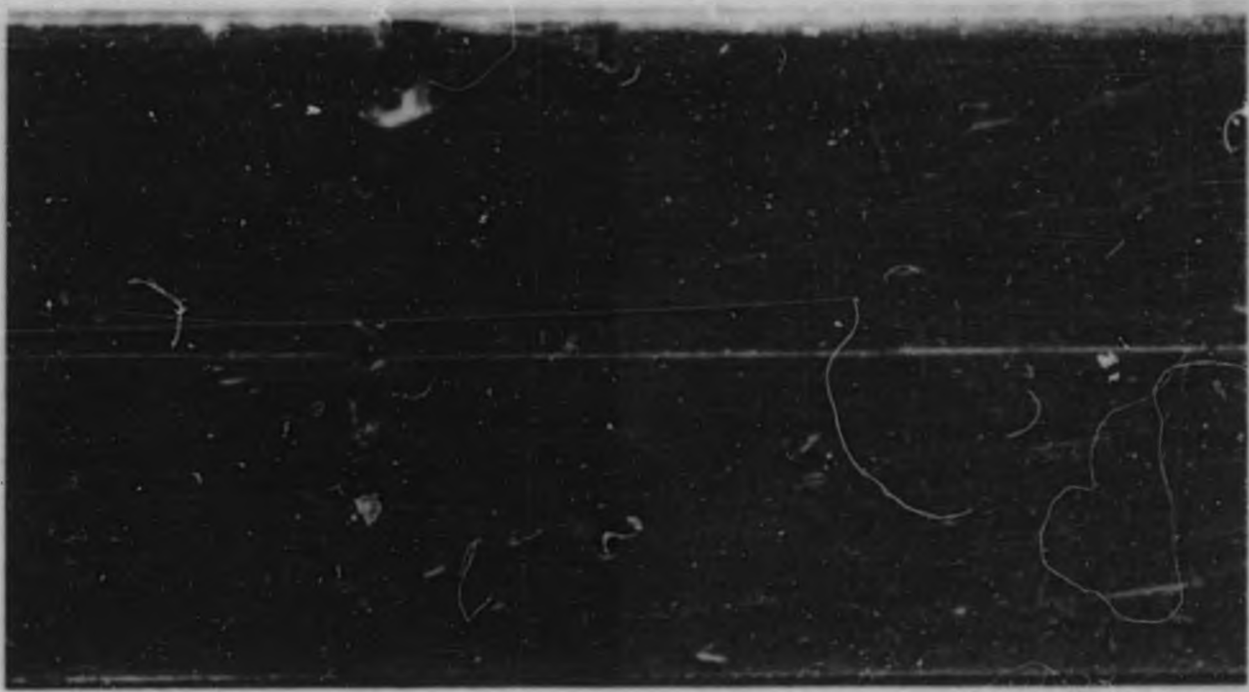

FIG. I

TENSILE TEST SPECIMEN OF ALUMINUM AND BISMUTH BONDED TOGETHER (5X). NOTE VOIDS IN BISMUTH (DARKER COLORED METAL) AT AND NEAR THE INTERFACE.

OZ 1039

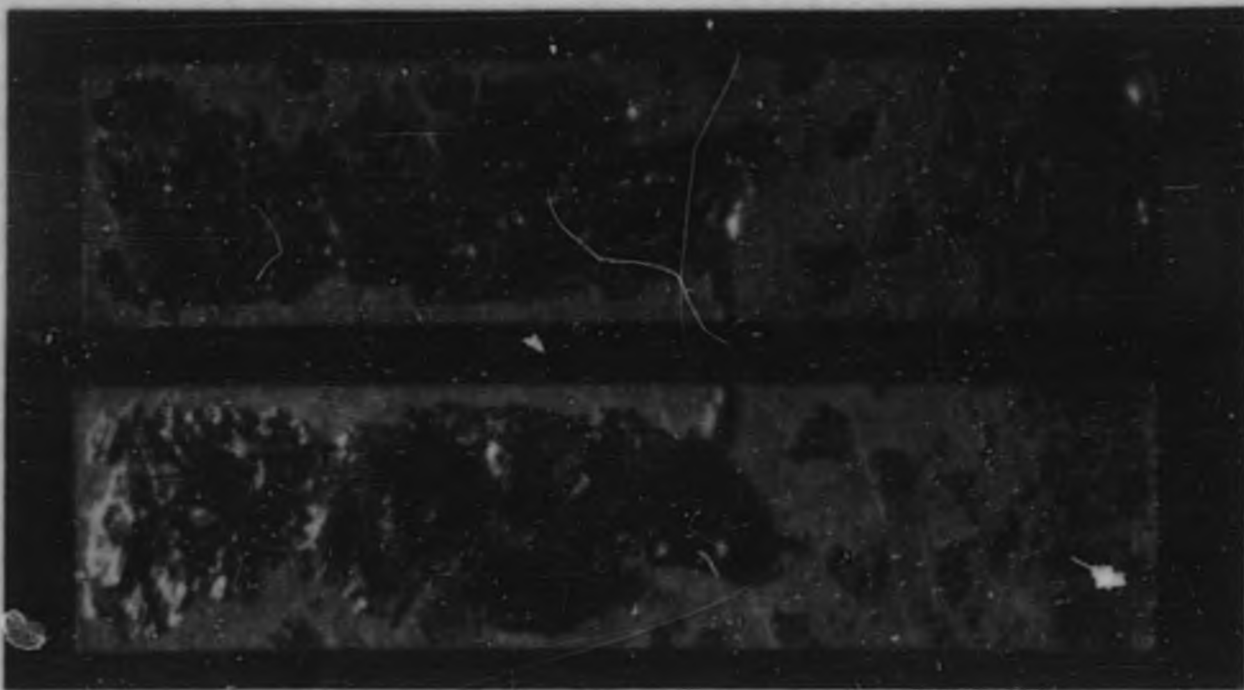

FIG. 2

BROKEN TENSILE TEST SPECIMEN (5X). NOTE UNWETTED AREA AND APPEARANCE OF VOIDS AT THE INTERFACE.

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Table I. Coefficient of Thermal Conductivity of Metal to Metal Bonds

Run	Temp. of Interface °F	Coefficient of Thermal Conductivity BTU/hr ft^2 °F
1	446	too large to measure
2	465	13,100
3	495	15,800
4	474	18,600

Table II. Coefficient of Thermal Conductivity of Metal to Metal Surfaces, in Contact, Under Pressure

Run	Temp. of Interface °F	Coefficient of Thermal Conductivity BTU/hr ft^2 °F	Pressure psi
1	413	2300	2000
2	424	2300	2100
3	424	2900	2100
4	445	2400	2200
5	441	3900	2200
6	440	2500	2200
7	470	3300	2400
8	503	3900	2600
9	492	6500	2600

Appendix

Sample Calculations

Nomenclature

$$q = \frac{kA\Delta t}{l} = hA\Delta t$$

q = heat transferred BTU/hr

k = thermal conductivity BTU/hr ft^2 °F/ft

Δt = temperature difference °F

l = length ft

h = coefficient of thermal conductivity BTU/hr ft^2 °F

For Run 7 in Table II

Using aluminum as heat meter

$$\Delta t = 471.9 - 467.4 = 4.5 \text{ °F}$$

mean temp $= \frac{471.9 + 467.4}{2} = 470.2$ °F

from Perry[2] k = 127.2 BTU/hr ft °F/ft

$$A = \frac{\pi}{4}\left(\frac{0.9}{12}\right)^2 = 0.00539 \text{ ft}^2$$

l = .0820 ft

$$q = \frac{kA\Delta t}{l} = \frac{(127.2)(.00539)(4.5)}{.0820}$$

$$q = 37.6 \text{ BTU/hr}$$

Heat lost to insulation and coupling = 0.4 BTU/hr

Heat passing through interface

$$q_1 = 37.2 \text{ BTU/hr}$$

temperature drop from thermocouple to interface in aluminum

$$\Delta t = \frac{lq}{kA}$$

$$\Delta t = \frac{(.00656)(37.6)}{(127.2)(.00539)} = 0.4 \text{ °F}$$

Temperature at aluminum interface

$$467.4 - .4 = 467.0\ ^\circ F$$

Temperature drop from interface to thermocouple in bismuth

$$\Delta t = \frac{lq}{kA}$$

$$\Delta t = \frac{(.00984)(36.8)}{(4.35)(.00539)} = 14.3\ ^\circ F$$

Temperature at bismuth interface

$$450.6 + 14.3 = 464.9\ ^\circ F$$

Temperature drop at the interface: $467.0 - 464.9 = 2.1^\circ F$

$$h = \frac{q}{A\Delta t}$$

$$h = \frac{37.2\ \text{BTU/hr}}{(.00539\ \text{ft}^2)(2.1\ ^\circ F)}$$

$$h = 3300\ \ \text{BTU/hr ft}^2\ ^\circ F$$

Bibliography

1. Harrison, W. B., Summary of Heat Transfer Data, ORNL-156.

2. Perry, J., Chem. Eng. Handbook, 3rd Edition, McGraw Hill (1949).

3. California Research Corporation, General Description and Properties of Bismuth, File 280.50, August 28, 1950.

END