ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Final Report

# THERMAL CONDUCTIVITY TESTS OF FIVE BRASS SUPERLOY RODS

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Project 2563

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NEW YORK, NEW YORK

April 1957

## INTRODUCTION

Five samples of Superloy brass rods as submitted by Phelps-Dodge were tested for thermal conductivity in the Heat Transfer Laboratory of the Mechanical Engineering Department of The University of Michigan.

The test method produced values for the thermal conductivities of the five samples at various temperatures in the range of 68°F to 400°F. A detailed description of the apparatus, the test method, and the method of calculation are included.

Results are reported in tabular form in Table I and in graphical form in Fig. 3.

## TEST APPARATUS, CALIBRATION, AND PROCEDURES

The five brass samples to be tested were rods one inch in diameter and twelve feet long. A copper rod of the same dimensions was obtained, the copper being "electrolytic tough pitch" with an oxygen content of 0.04%. The manufacturer of the copper furnished the following electrical and thermal conductivity data:

Electrical conductivity at 68°F; 101.6% IACS
Electrical conductivity at 400°F; 59.0% IACS
Thermal conductivity at 68°F; k = 227
Thermal conductivity at 400°F; k = 221.5

k in Btu per hr, per sq ft, per °F per ft.

A set of eleven copper-constantan thermocouples was made up and calibrated. These were attached to the rod to be tested by securely wiring them on at the points shown in Fig. 1.

An electric heater was placed over the end of the rod being tested and connected to a current source through variable resistors. An ammeter was connected in the circuit and a voltmeter connected to read the voltage drop across the heater.

The rod being tested was placed in the test box which was made of wood and was 22 in. by 22 in. in cross section and 12 ft long as shown in Fig. 1. Thermocouple leads were brought out and the box filled with loosely fluffed rock wool.

An insulated box of smaller size was made up to be used as a dry-ice container at one end of the test box as shown in Fig. 1. The rod was placed in the test box so that the end without the heater projected into the dry-ice box.

The first test was a calibration test of the box using the copper rod. The copper rod was placed in the test box and the heater turned on. Dry ice was placed in the dry-ice box so that it surrounded the rod on two sides and below but did not touch the rod. Readings were taken and adjustments made until desired temperatures were obtained.

Before readings to be used in calculations were taken, the apparatus was run over night with current on and dry ice in place. The following morning dry ice was added as required and additional readings taken. When stable conditions had been reached, temperature readings were taken at fifteen-minute intervals for a period of two hours.

When the calibration test with the copper rod had been completed, identical runs were made for each of the five test brass bars.

## METHOD OF CALCULATION

The basic equation for heat flow in a solid material is:

$$q = -kA\frac{dt}{dx} .$$

In this report

- $q$ = heat flow in Btu per hr;
- $k$ = thermal conductivity in Btu per hr, per sq ft, per °F per ft;
- $A$ = area in sq ft;
- $t$ = temperature in °F; and
- $x$ = distance in ft.

In commercial work the equation is simplified to:

$$q = k\frac{A}{x_1 - x_2}(t_1 - t_2)$$

when certain approximations can be made and reasonable accuracy still retained. These approximations are:

Area is constant in the direction of heat flow (one-dimensional flow); and k is constant in the temperature range of $(t_1 - t_2)$.

Using the data furnished by the manufacturer of the copper, a thermal conductivity vs temperature curve was plotted and from this curve values for k at the required temperatures were obtained.

A is the area of a one-inch-diameter circle. The distance between thermocouple stations is $x_1 - x_2$, which was ten inches between stations 10 and 11 and twelve inches between all other stations. Temperature readings $t_1$ and $t_2$ are the observed temperatures at adjacent thermocouple stations.

Using the above data in the basic heat-transfer equation, values for q, the heat flow, were calculated for each of the stations 1-1/2, 2-1/2, 3-1/2, etc., for the copper rod.

The amount of heat supplied to the copper rod by the electric heater was calculated from the current and voltage readings. From this and the calculated values of heat flow at the stations 1-1/2, 2-1/2, 3-1/2, etc., the heat lost from the rod between the electric heater and station 10-1/2 and between successive stations was obtained by subtraction.

Heat loss from the various sections of the brass rods was assumed to be the same as the loss from the corresponding section of the copper rod, adjustment being made as required for temperature differences. With these losses and the amount of heat supplied by the electric heater to the brass rods, the heat flow at the stations 1-1/2, 2-1/2, 3-1/2, etc., for the five brass rod samples was calculated.

Thermal conductivities for the five brass samples for the various stations were calculated from the heat flow and tabulated and plotted against temperatures as shown in Fig. 3 and Table I.

A set of sample calculations are attached which show the calculation method in detail.

## DISCUSSION OF RESULTS

The test method which was used establishes the thermal conductivity of metals in rod form by comparison with a metal rod of known thermal conductivity.

Errors in final results may occur because of a number of conditions:

(a) Any error in the values used for the thermal conductivity of the copper rod;

(b) Any deviation between the actual heat lost by the brass rods and the values calculated from the heat lost by the copper rod;

(c) The use of finite differences rather than differentials in the basic equation for heat flow, which introduces a small error; and

(d) The fact that the temperature plotted against position on the bar results in a curve rather than a straight line, which also introduces a small error.

No attempt has been made to use statistical techniques to estimate possible deviations of experimental data from true values of thermal conductivities, but a comprehensive review of the techniques used and a study of all curves and data lead us to believe that the calculated points reported here will all lie within a range of plus or minus 7% of the true thermal conductivity values.

## SAMPLE CALCULATIONS

### I. TEST BOX CALIBRATION

A. Method.—Calibration was accomplished by using a copper rod of known thermal conductivity as a reference standard.

B. Copper rod conductivity.—The reference copper rod was "electrolytic touch pitch" with $O_2$ content of 0.04%.

Electrical conductivity at 68°F; 101.6% IACS
Electrical conductivity at 400°F; 59.0% IACS
Thermal conductivity at 68°F; k = 227
Thermal conductivity at 400°F; k = 221.5

k in Btu per hr, per sq ft, per °F per ft.

(Data from manufacturer of copper rod)

C. Station designations.—See attached sketches. Thermocouples were attached to the rod at points designated as stations 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11. Heat flow along the rod was calculated for the points designated as stations 1-1/2, 2-1/2, 3-1/2, 4-1/2, 5-1/2, 6-1/2, 7-1/2, 8-1/2, 9-1/2, and 10-1/2.

D. Heat flow and heat loss calculations.—

1. Heat flows are all calculated from the expression

$$q = -k A \frac{dt}{dx}$$

with finite differences being used which reduce the expression to the form

$$q = A\ k/L\ (t' - t)$$

where

$q$ = the heat flow in Btu per hr,
$A$ = area in sq ft,
$k$ = thermal conductivity in Btu per hr, per sq ft, per °F per ft,
$L$ = the length of rod between which the temperature drops from $t'$ to $t$, and
$t$ and $t'$ are in °F.

2. Heat flow at station 10-1/2 (copper rod):

$$q = .00545 \times \frac{220.0}{10/12} (536.3 - 449.5)$$

$$q = 125.0 \text{ Btu per hr}$$

3. Heat flow at station 9-1/2:

$$q = .00545 \times \frac{221.3}{12/12} (449.5 - 269.2)$$

$$q = 96.8 \text{ Btu per hr}$$

4. Heat supplied to rod by heater:

$$q = 1.28 \text{ amp} \times 44 \text{ v} \times 3.41 = 192.5 \text{ Btu per hr}$$

5. Heat loss from rod between heater and station 10-1/2:

$$q = 192.5 - 125.0 = 67.5 \text{ Btu per hr}$$

6. Heat loss from rod between stations 10-1/2 and 9-1/2:

$$q = 125.0 - 96.8 = 28.2 \text{ Btu per hr}$$

II. THERMAL CONDUCTIVITY CALCULATIONS FOR ROD, SAMPLE 8

A. Heat supplied to rod by heater:

$$q = 1.11 \text{ amp} \times 38.2 \text{ v} \times 3.41 = 144.5 \text{ Btu per hr}$$

B. Heat loss from rod between heater and station 10-1/2 using heat loss from copper calibration test adjusted for new temperature difference:

$$q = 67.5 \left(\frac{557.0 - 75}{536.3 - 75}\right) = 70.4 \text{ Btu per hr}$$

C. Heat loss from rod between stations 10-1/2 and 9-1/2 as in B above:

$$q = 28.2 \left(\frac{431.6 - 75}{449.5 - 75}\right) = 26.8 \text{ Btu per hr}$$

D. Heat flow in rod at station 10-1/2:

$$q = 144.5 - 70.4 = 74.1 \text{ Btu per hr}$$

E. Heat flow in rod at station 9-1/2:

$$q = 74.1 - 26.8 = 47.3 \text{ Btu per hr}$$

F. Thermal conductivity at station 10-1/2:

$$k = \frac{qL}{A\,(t' - t)}$$

$$k = \frac{74.1 \times 10/12}{.00545\,(557.0 - 431.6)} = 90.0$$

G. Thermal conductivity at station 9-1/2:

$$k = \frac{47.3 \times 12/12}{.00545\,(431.6 - 328.4)} = 84.2$$

TABLE I

THERMAL CONDUCTIVITY PHELPS-DODGE SUPERLOY
(k in Btu per hr, per sq ft, per °F per ft)

Sample 1

| Station | 1-1/2 | 2-1/2 | 3-1/2 | 4-1/2 | 5-1/2 | 6-1/2 | 7-1/2 | 8-1/2 | 9-1/2 |
|---|---|---|---|---|---|---|---|---|---|
| k | 72.3 | 74.0 | 76.5 | 77.0 | 81.0 | 82.5 | 85.4 | 96.0 | 98.5 |
| Temperature, °F | 48.4 | 68.9 | 89.6 | 112.8 | 138.2 | 182.2 | 237.2 | 312.0 | 410.6 |

Sample 3

| Station | 1-1/2 | 2-1/2 | 3-1/2 | 4-1/2 | 5-1/2 | 6-1/2 | 7-1/2 | 8-1/2 | 9-1/2 |
|---|---|---|---|---|---|---|---|---|---|
| k | 61.2 | 61.5 | 61.8 | 63.8 | 64.8 | 65.7 | 68.0 | 75.4 | 76.0 |
| Temperature, °F | 64.1 | 77.5 | 92.1 | 110.5 | 135.7 | 170.1 | 217.6 | 285.7 | 384.4 |

Sample 8

| Station | 1-1/2 | 2-1/2 | 3-1/2 | 4-1/2 | 5-1/2 | 6-1/2 | 7-1/2 | 8-1/2 | 9-1/2 | 10-1/2 |
|---|---|---|---|---|---|---|---|---|---|---|
| k | 67.7 | 68.0 | 66.3 | 69.0 | 72.9 | 76.5 | 79.2 | 80.5 | 84.2 | 90.0 |
| Temperature, °F | 69.7 | 82.8 | 97.2 | 116.0 | 141.4 | 175.4 | 222.5 | 289.0 | 380.0 | 494.0 |

Sample 10

| Station | 1-1/2 | 2-1/2 | 3-1/2 | 4-1/2 | 5-1/2 | 6-1/2 | 7-1/2 | 8-1/2 | 9-1/2 |
|---|---|---|---|---|---|---|---|---|---|
| k | 60.8 | 61.2 | 61.6 | 63.7 | 66.3 | 70.1 | 71.6 | 74.8 | 78.6 |
| Temperature, °F | 67.2 | 80.3 | 95.4 | 114.0 | 140.4 | 176.2 | 223.5 | 292.8 | 392.8 |

Sample 14

| Station | 1-1/2 | 2-1/2 | 3-1/2 | 4-1/2 | 5-1/2 | 6-1/2 | 7-1/2 | 8-1/2 | 9-1/2 |
|---|---|---|---|---|---|---|---|---|---|
| k | 59.7 | 60.6 | 63.2 | 65.5 | 62.9 | 66.5 | 67.3 | 71.0 | 72.3 |
| Temperature, °F | 62.1 | 76.6 | 93.5 | 113.4 | 141.5 | 180.5 | 233.5 | 307.7 | 411.2 |

CONDUCTIVITY TEST APPARATUS
FOR
PHELPS DODGE SUPERLOY RODS

ROD ASSEMBLED IN TEST BOX

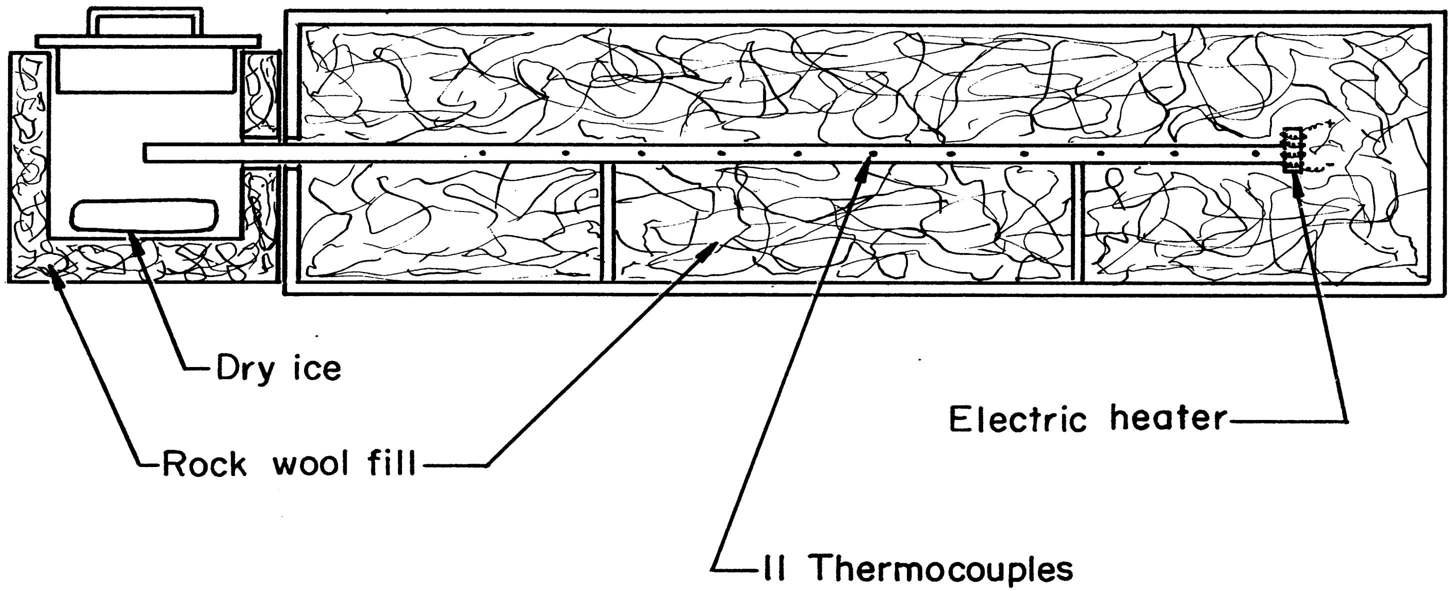


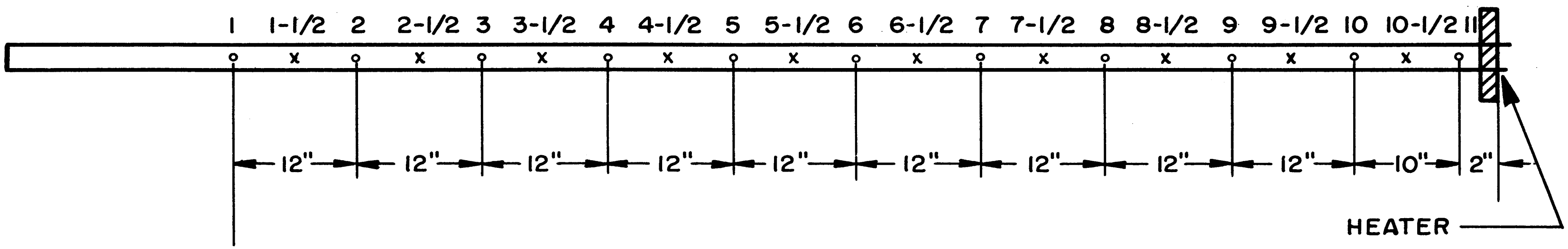

FIG. I

CONDUCTIVITY TEST APPARATUS

FOR

PHELPS DODGE SUPERLOY RODS

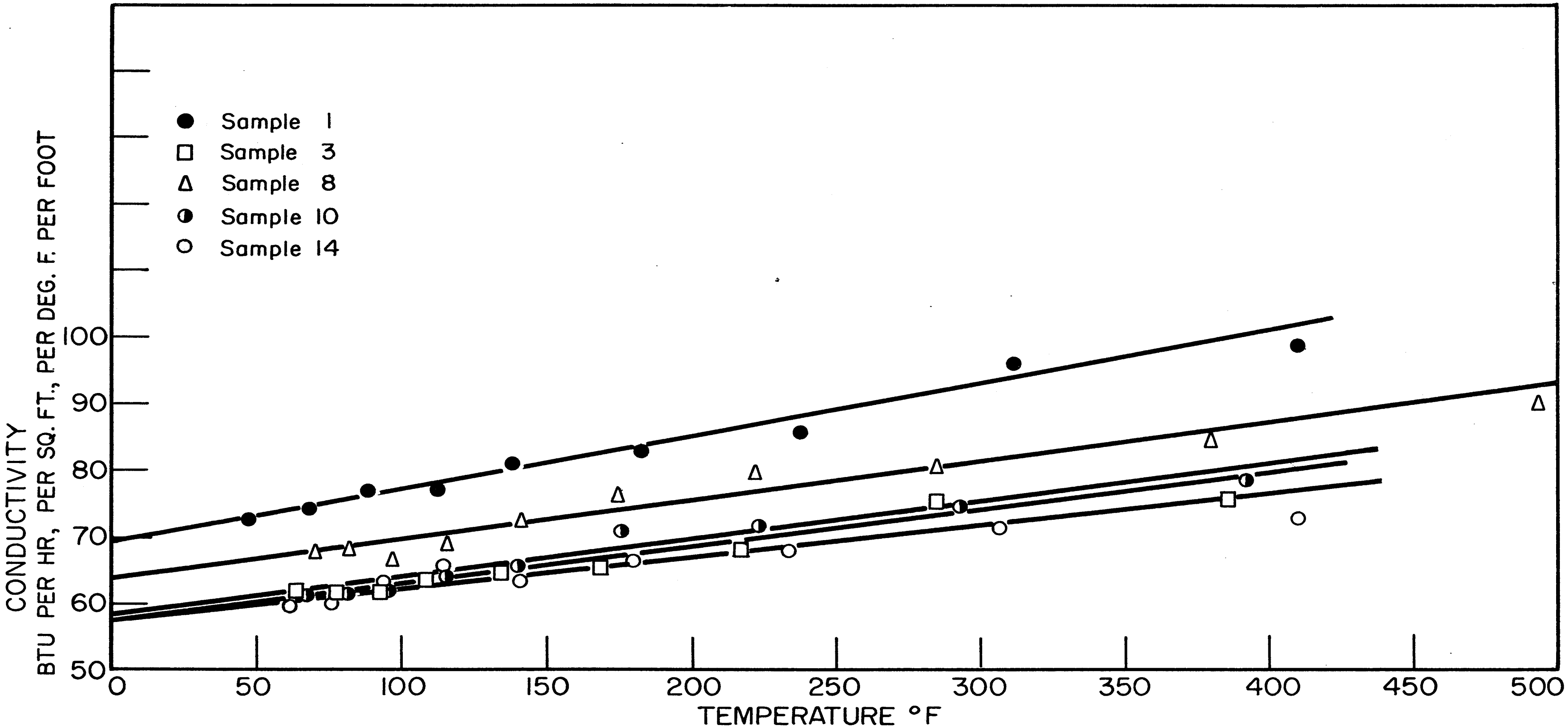
STATION LOCATIONS AND DESIGNATION




THERMOCOUPLES AT STATION 1-2-3-4-5-6-7-8-9-10-11

k CALCULATED FOR 1-1/2 – 2-1/2 – 3-1/2 – 4-1/2 – 5-1/2 – 6-1/2 – 7-1/2 – 8-1/2 – 9-1/2

FIG. 2.




THERMAL CONDUCTIVITY vs TEMPERATURE
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FIG. 3