NATIONAL BUREAU OF STANDARDS REPORT

9655

CALCULATION OF THE THERMAL CONDUCTIVITY

OF AN INVAR SAMPLE

FROM ELECTRICAL RESISTIVITY DATA

by

D. R. Flynn
Environmental Engineering Section
Building Research Division
Institute for Applied Technology

Report to

National Aeronautics and Space Administration
Lewis Research Center

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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1. Introduction

This report presents thermal conductivity values in the range 0 to 100 °C for a sample of invar supplied by the National Aeronautics and Space Administration, Lewis Research Center. Since the available sample size was not sufficiently large to permit a direct experimental measurement of thermal conductivity using existing equipment, measurements were made of the electrical resistivity of the sample and the thermal conductivity was then calculated from the electrical resistivity data using an empirical correlating formula derived from measurements on two larger samples of invar.

2. Electrical Resistivity Measurements

The sample provided was in the form of a circular rod, 0.635 cm in diameter and 10 cm long. After receipt of the sample, holes were drilled and tapped into each end of the sample to facilitate attachment of the electrical current leads. Three transverse slits, 0.013 cm in width and depth, were cut into the convex surface of the specimen. One slit was at the midplane of the specimen and the other slits were 2.54 cm on either side of the center slit.

Copper thermocouple wires, 0.013 cm in diameter, were pressed into one end of each slit and constantan wires of the same diameter were pressed into the other end of each slit. This resulted in the specimen and thermocouple configuration shown in figure 1. The wires were secured to the specimen with a drop of epoxy cement and were insulated by flexible fiber glass sleeving.

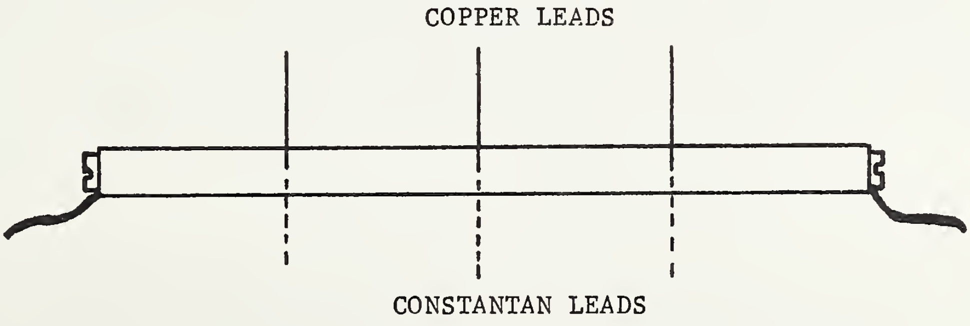

Figure 1. Configuration of sample used for electrical resistivity measurements.

The specimen was placed in series with a calibrated standard resistor and a regulated d-c power supply operating in a constant current mode. The resistance of the specimen (between each combination of the copper thermocouple leads) was determined by comparing the voltage drop between the copper thermocouple leads with that across the standard resistor. In order to minimize thermoelectric effects, voltage drops in the specimen were measured with the current flowing normally and reversed. All voltage measurements were made using a precision d-c potentiometer. Each resistivity value was computed from the observed resistance, the specimen cross-sectional area, and the separation between the appropriate copper thermocouple leads.

The electrical resistivity was measured at four mean temperatures; the average values obtained at each temperature are presented in Table 1. The point at 0 °C was taken with the specimen in an ice bath, that at 24.2 °C was taken in a water bath, and the two higher temperature points were taken in a furnace. The mean temperature of the specimen was computed from the observed temperatures at the three thermocouple locations.

Table 1. Observed values for the electrical resistivity of the invar sample.

Temperature	Electrical Resistivity
°C	Ω m
0.0	7.53×10^{-7}
24.2	7.85
78.0	8.48
104.6	8.76

3. Computation of Thermal Conductivity Values

In a recent paper, Powell [1] 1/, who references earlier works, discusses the validity of correlating equations of the type $\lambda = L(T/\rho) + C$, where λ is thermal conductivity, T is absolute temperature, ρ is electrical resistivity, and L and C are empirically derived constants. Powell shows that this correlating equation is quite suitable for predicting thermal conductivity values from measured electrical resistivity values.

1/ Figures in brackets indicate the literature references at the end of this report.

In 1961, Watson and Robinson [2] of NBS published a paper giving the thermal conductivity of a number of iron-nickel alloys, including invar and free-cut invar, over the temperature range -150 to +540 °C. Since that time, determinations of electrical resistivity over this temperature range have been completed for the same samples. Using the thermal conductivity and electrical resistivity data for these alloys, a number of correlating equations have been developed [3].

In figure 2, the thermal conductivity of the invar and free-cut invar samples studied by Watson and Robinson is plotted versus the quotient of absolute temperature divided by electrical resistivity. These data, which cover the temperature range 125 to 400 °K, are seen to conform very well to the straight line,

$$\lambda = 2.83 + 2.96 \times 10^{-8} \frac{T}{\rho}, \qquad (1)$$

where λ is expressed in W m^{-1} deg^{-1}, T in °K, and ρ in Ω m.

For the invar sample which is the subject of the present investigation, the electrical resistivity values at 0, 50, and 100 °C, as read from a smooth curve drawn through the experimental data given in Table 1, are presented in Table 2. The last column in Table 2 presents the corresponding thermal conductivity values computed using equation (1). These thermal conductivity values are estimated to be uncertain by not more than three percent.

Table 2. Smoothed experimental values for the electrical resistivity and computed values for the thermal conductivity of the invar sample used in the present investigation.

Temperature		Electrical Resistivity	Thermal Conductivity
°C	°K	Ω m	W m^{-1} deg^{-1}
0	273.15	7.53×10^{-7}	13.6
50	323.15	8.16	14.5
100	373.15	8.73	15.5

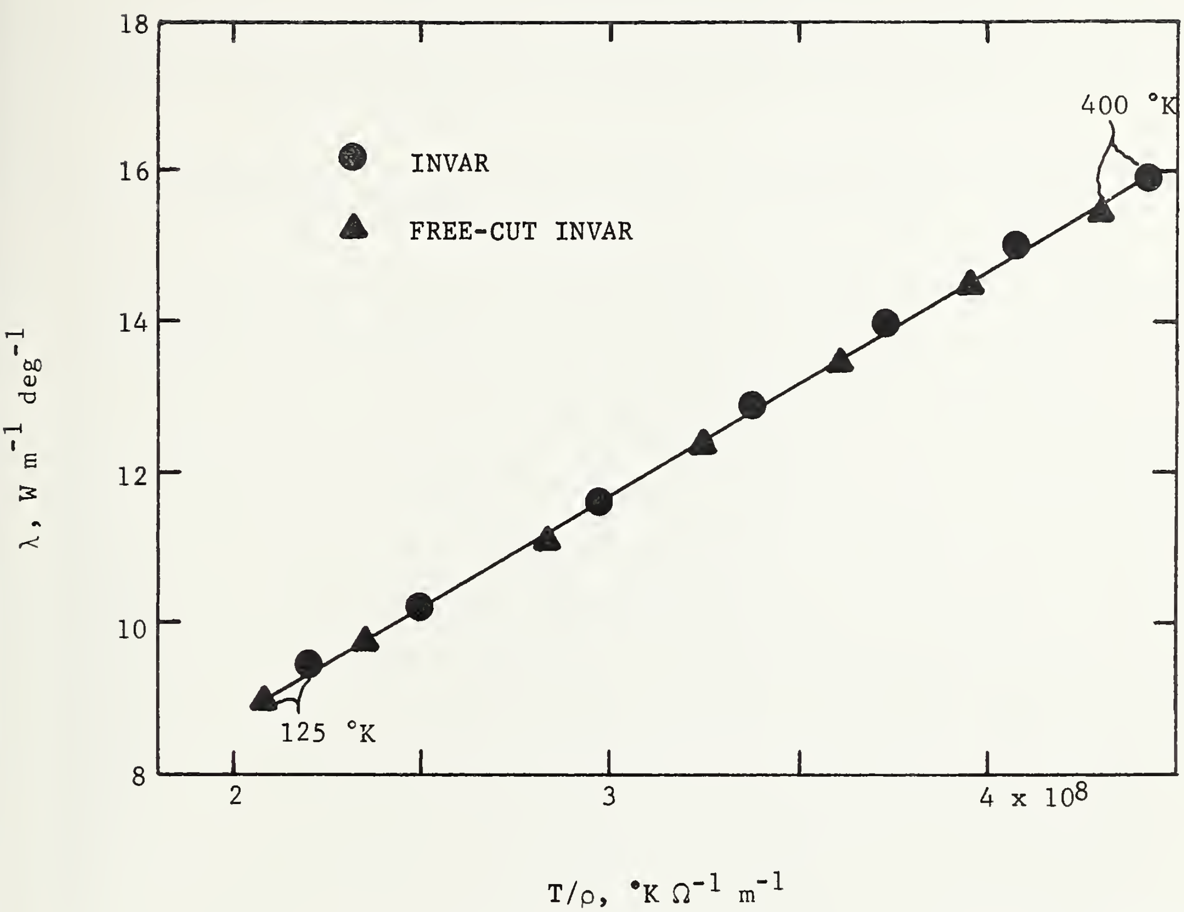

Figure 2. Invar and free-cut invar: thermal conductivity as a function of the quotient of absolute temperature divided by electrical resistivity.

4. References

[1] R. W. Powell, Correlation of Metallic Thermal and Electrical Conductivities for Both Solid and Liquid Phases, Int. J. Heat Mass Transfer 8, 1033 (1965).

[2] T. W. Watson and H. E. Robinson, Thermal Conductivity of Some Commercial Iron-Nickel Alloys, Trans. ASME J. Heat Transfer 83C, 403 (1961).

[3] D. R. Flynn, Thermal and Electrical Conductivities of Some Iron-Nickel Alloys (to be published).

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