NATIONAL BUREAU OF STANDARDS REPORT

5788

THERMAL CONDUCTIVITY OF A SPECIMEN OF STAINLESS STEEL TYPE 502

by

H. E. Robinson and T. W. Watson

Report to the
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
for
U. S. Department of the Army
Ordnance Corps, Redstone Arsenal
Huntsville, Alabama

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
[illegible]	February 14, 19[illegible]	[illegible]

THERMAL CONDUCTIVITY OF A SPECIMEN
OF STAINLESS STEEL TYPE 302

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Thermal Conductivity of a Specimen of Stainless Steel Type 502

H. E. Robinson and T. W. Watson

1. INTRODUCTION

A sample of stainless steel (Type 502) was submitted by the Ordnance Corps, Redstone Arsenal, Huntsville, Alabama, for measurement of its thermal conductivity in the temperature range 100°C to about 700°C (P.O. No. 17259-[illegible]). The sample was shipped by the Jet Propulsion Laboratory, Pasadena 3, California (P.O. No. [illegible]-04-495-[illegible]-10).

2. SAMPLE

The sample was a bar of metal machined to form a specimen 0.787 in. in diameter and 14 5/8 in. long. It was stated to be a sample of AISI Type 502 stainless steel. No analysis of the metal composition was furnished, or made here.

3. TEST APPARATUS AND METHOD

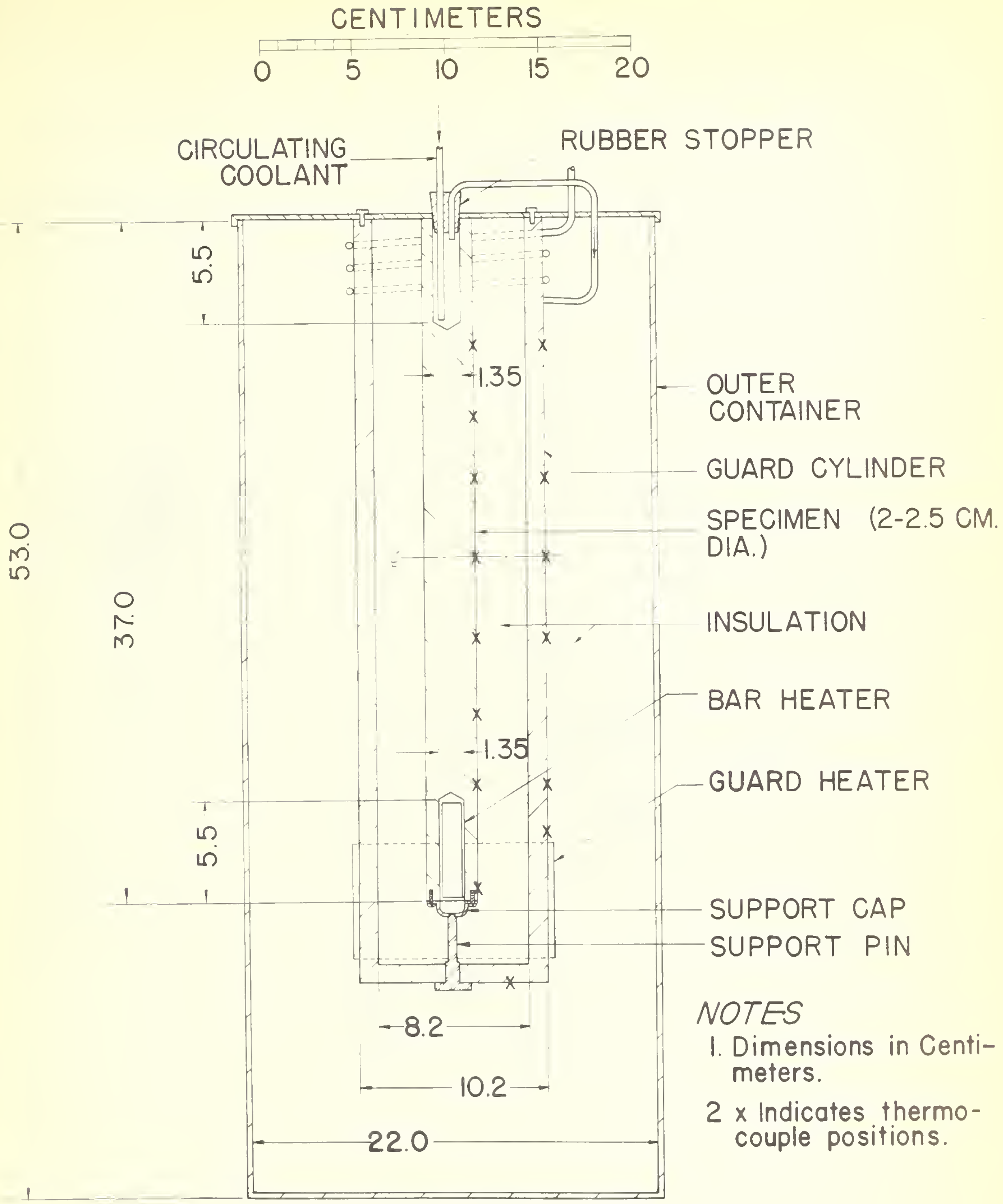
The thermal conductivity of the sample was determined by means of a steady-state flow of heat longitudinally in a bar specimen, with measurements of the temperatures existing at the ends of six consecutive approximately 3.5 cm spans along the central length of the bar. Each determination

required a pair of tests at moderately different temperature conditions, and yielded values of thermal conductivity at six different mean temperatures.

The test apparatus is shown schematically in Figure 1. The specimen was supported at the bottom upon a thin stainless steel pin, and held concentrically within a stainless steel guard tube of 1-cm wall thickness, which in turn was held concentrically within a cylindrical outer container. The specimen was drilled at each end with a 1.35-cm hole 5.5 cm deep. An electrical heater was inserted and secured in the hole at the bottom (hot) end, and a liquid-tight stopper at the top provided a connection for circulating a coolant (water at about 40°C) through the top drill-hole.

Temperatures along the specimen were indicated by seven thermocouples located symmetrically about the longitudinal center of the specimen, spaced approximately 3.47 cm apart, with one additional thermocouple near the bottom end of the specimen. Thermocouples were similarly located on the guard tube in seven positions, five of which corresponded very closely to longitudinal positions of thermocouples on the specimen.

The guard tube was equipped near its lower end with an external circumferential electric heater as shown. The guard tube was cooled at the top by means of a copper-tube coil



APPARATUS FOR MEASURING THE THERMAL CONDUCTIVITY OF METALS

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Figure 1

soldered circumferentially at a position corresponding in effect to that of the specimen coolant well. Coolant was pumped through the specimen well and guard coil in series connection, as shown.

The electric heater for the specimen consisted of a porcelain cylinder 1.27 cm in diameter and 5.2 cm long threaded longitudinally with 30-gage nichrome heater wire. Its resistance was approximately 55 ohms. Current was brought to the heater through relatively large heater leads, to which separate potential leads were connected at the point where they entered the porcelain core. The heater was energized by an adjustable constant-voltage d-c source. Heater current and voltage drop measurements were made using standard resistors and the high precision manual potentiometer used for thermocouple observations. The guard was heated with constant voltage a-c power.

The thermocouples were made from calibrated chromel and alumel 26-gage wires, electrically welded to form a spherical junction about 1.0 mm in diameter. Junctions in the specimen were inserted into radially-drilled holes 1.1 mm in diameter and 1.7 mm deep in the side of the bar, and tightly secured by punch-pricking the metal around the hole. The thermocouple wires were individually insulated electrically with fiberglass sleeving, and were wrapped around the bar (one in each

direction) and tied at the back to secure them in the transverse plane of the junction. The wires were brought out through the powder insulation near the guard tube. The thermocouples in the guard tube were similarly attached to its exterior surface. The longitudinal positions of the thermocouple junctions were taken as those of the centers of the drilled holes, measured to the nearest 0.01 cm with a laboratory cathetometer.

After installation of the specimen, the space between it and the guard tube was filled with diatomaceous earth powder insulation, which also was used to insulate the space surrounding the guard tube.

In principle, if there were no heat exchange between the specimen and its surroundings, the conductivity could be determined from the measured power input to the specimen and the average temperature gradient for each of the six spans along the specimen, all of uniform known cross-sectional area. In practice, a perfect balance of temperatures between the bar and guard all along their lengths is not possible because of differences in their temperature coefficients of conductivity, and the effect of the outward heat losses of the guard. In addition to heat exchanges between the bar and guard from this cause, a not insignificant longitudinal flow of heat occurs in the powder insulation surrounding the specimen, and

the contribution of the specimen to this heat flow must depend somewhat on the bar-to-guard temperature unbalance.

In order to evaluate the heat flow in the bar at the center points of each of the six spans, a partly empirical procedure was used. Two steady-state test-runs were made with slightly different bar and guard temperatures and power inputs. In the two tests, the heat flow and the observed temperature drop from end to end of a given span differed, as did also the approximate integral with respect to length of the observed temperature differences between bar and guard, summed from the hot end of the bar to the span center point. It is thus possible to write for each span two equations (one for each test-run) of the form:

$$\frac{kA\Delta t}{\Delta x} + fB = Q$$

where A is the cross-sectional area of the specimen.

k is the thermal conductivity of the specimen at the mean of the two span mean temperatures.

Δx is the length of the span.

Δt is the adjusted temperature drop from end to end of the span, corresponding to the mean of the span mean temperatures in the two test runs. This is obtained for each test-run from the observed temperature difference by an adjustment based on the variation of

temperature drop along the specimen with mean temperature, and on one-half of the difference between the observed mean temperatures of the span in the two test runs.

f is an average heat exchange coefficient which lumps the thermal conductance of the heat flow path from bar to guard, and the contribution of the specimen to the longitudinal heat flow in the insulation, up to the span center point.

S is the approximate integral with respect to length of the observed differences of bar and guard temperature, from the hot end of the bar to the span center point.

Q is the measured power input to the specimen heater.

By simultaneous solution of the two equations, the value of k for each span, corresponding to the mean span mean temperature, is obtained. All of the computation of results is effected by use of an IBM-704 digital computer, suitably programmed to compute the value of k for each of the six spans from input data consisting of the average observed temperature values at the several bar and guard positions, and the power input to the bar, for each of the two steady-state test-runs constituting a pair at nearly the same temperatures. Much time is saved by machine computation, and accidental errors in the considerable calculations are avoided.

4. RESULTS

The results of the thermal conductivity measurements are shown in Figure 2. The points plotted on the figure represent the individual values obtained in six runs on the specimen, each run yielding six values. The trend of the data appears to be best represented by two straight lines intersecting at a mean temperature of about 255°C. Values of conductivity indicated by the lines at particular values of mean temperature are tabulated below.

°C --------	150	200	255	300	400	500	600
watt/cm -	0.339	.342	.346	.342	.332	.322	.312

5. DISCUSSION OF RESULTS

The individual values of thermal conductivity plotted in Figure 2 show moderate scattering from the straight lines drawn to represent the trend of the data. The extreme departure (at 375°C) is about 1.5 percent; most departures are less than one percent.

The scattering is believed due chiefly to small inaccuracies in the temperatures at positions on the specimen, as indicated by its thermocouples. Such inaccuracies could arise from departure of a thermocouple from the temperature-emf calibration of the thermocouple wires, or from imprecision in ascertaining the exact longitudinal position of

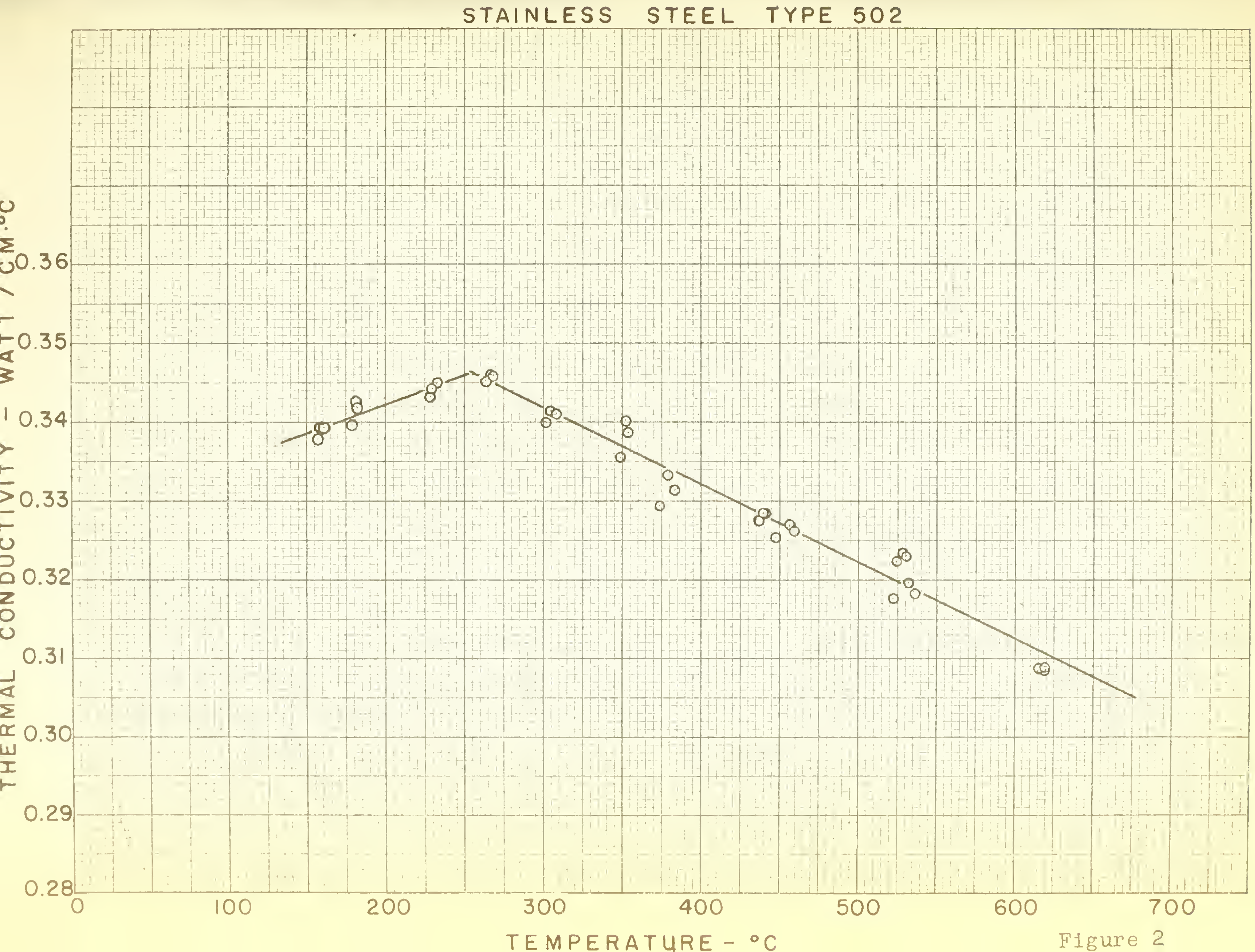
STAINLESS STEEL TYPE 502
THERMAL CONDUCTIVITY - WATT / CM·°C
0.36
0.35
0.34
0.33
0.32
0.31
0.30
0.29
0.28
0
100
200
300
400
500
600
700
TEMPERATURE - °C

Figure 2

the thermocouple junction, or possibly from heat conduction in the thermocouple wires near the junction. Although the wires encircled the specimen as nearly as possible in the transverse plane of the junction, the temperature gradients in the specimen were from 13 to 25 deg C/cm, and a slight displacement of the wires from that plane would cause a temperature gradient in them near the junction. However, an error in the indicated temperature at a point intermediate between two spans of the specimen would reduce the observed temperature drop for one span by as much as it would increase that for the other. Thus, the values of thermal conductivity for the two spans would be approximately equally, but oppositely, affected, and the position of a smooth curve drawn amongst a number of such individual points would be affected little.

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