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NATIONAL BUREAU OF STANDARDS REPORT

7052

THERMAL CONDUCTIVITY OF A SPECIMEN OF
CARPENTER 20 STAINLESS STEEL

by

Thomas W. Watson and Henry E. Robinson

Report to the
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Thermal Conductivity of a Specimen of Carpenter 20 Stainless Steel

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1. INTRODUCTION

A specimen of Carpenter 20 stainless steel was submitted by the National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland, for measurement of its thermal conductivity in the temperature range 200° to 1400°F.

2. SAMPLE

The test sample was a bar 2.54 cm in diameter and 46.0 cm long. A 9.0-cm length was cut from the submitted bar for use in chemical analysis. The letter of request (Ref. S-9482-G) stated that the bar had been X-rayed and had undergone ultrasonic inspection.

The chemical composition as determined by an analysis made at the National Bureau of Standards is given in Table 1.

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 3.51-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, a bar approximately 37 cm long and of uniform external dimensions, is supported at the top (coolant) end concentrically within a stainless steel guard tube of 0.8-cm wall thickness, which in turn is held concentrically within a cylindrical outer container. The specimen is drilled at each end with a 1.35-cm hole 5.5 cm deep. An electrical heater is inserted and secured in the hole at the bottom (hot)

end, and the supporting fixture at the top end provides a liquid-tight connection for circulating a coolant 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 3.51 cm apart, with one additional thermocouple near the bottom end of the specimen. Thermocouples were similarly located in almost exactly corresponding longitudinal positions on the guard tube.

The guard tube was equipped near its lower end with two external circumferential electric heaters, as shown. The guard tube was cooled at the top by means of a copper-tube coil soldered circumferentially at a position corresponding in effect to that of the specimen coolant well. Coolant was pumped through the guard coil and specimen well 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 26-gage nichrome heater wire. Its resistance was approximately 22 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 alternating current governed by a sensitive temperature controller actuated by the guard temperature at a selected position.

The thermocouples were made from calibrated chromel and alumel 26-gage wires, electrically welded to form a spherical junction about 0.10 cm in diameter. Junctions in the specimen were inserted into radially-drilled holes 0.11 cm in diameter and 0.17 cm 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

$$\frac{Ak\Delta t}{\Delta x} + fS = Q$$

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

k is the specimen conductivity at the mean temperature of the span,

Δt is the temperature drop from end to end of the span,

Δx is the length of the span,

fS represents the total net heat loss from the bar from its bottom end at the heater to the midpoint of the given span, expressed as the product of S, which is a close approximation of the integral

$\int_0^x (t_{bar} - t_{guard})dx$, and an average heat transfer coefficient f for the thermal path from bar to guard.

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 thermal conductivity and corresponding mean temperature for each of the six spans. The computer was used to fit a third-power equation to the thermal conductivity and temperature results, by the method of least squares.

4. RESULTS

The results of the thermal conductivity determinations are shown in Figure 2 and Table 2. The 30 individual values of thermal conductivity plotted represent five sets of tests, each with values for the six spans. The solid line represents the trinomial fitting the data, as determined by a digital computer, from which the values tabulated in Table 2 were taken.

5. DISCUSSION OF RESULTS

The individual values of thermal conductivity plotted in Figure 2 show moderate scattering from the smooth curve. The extreme departure of an individual value from the smooth curve is less than 3.0 percent.

TABLE 1

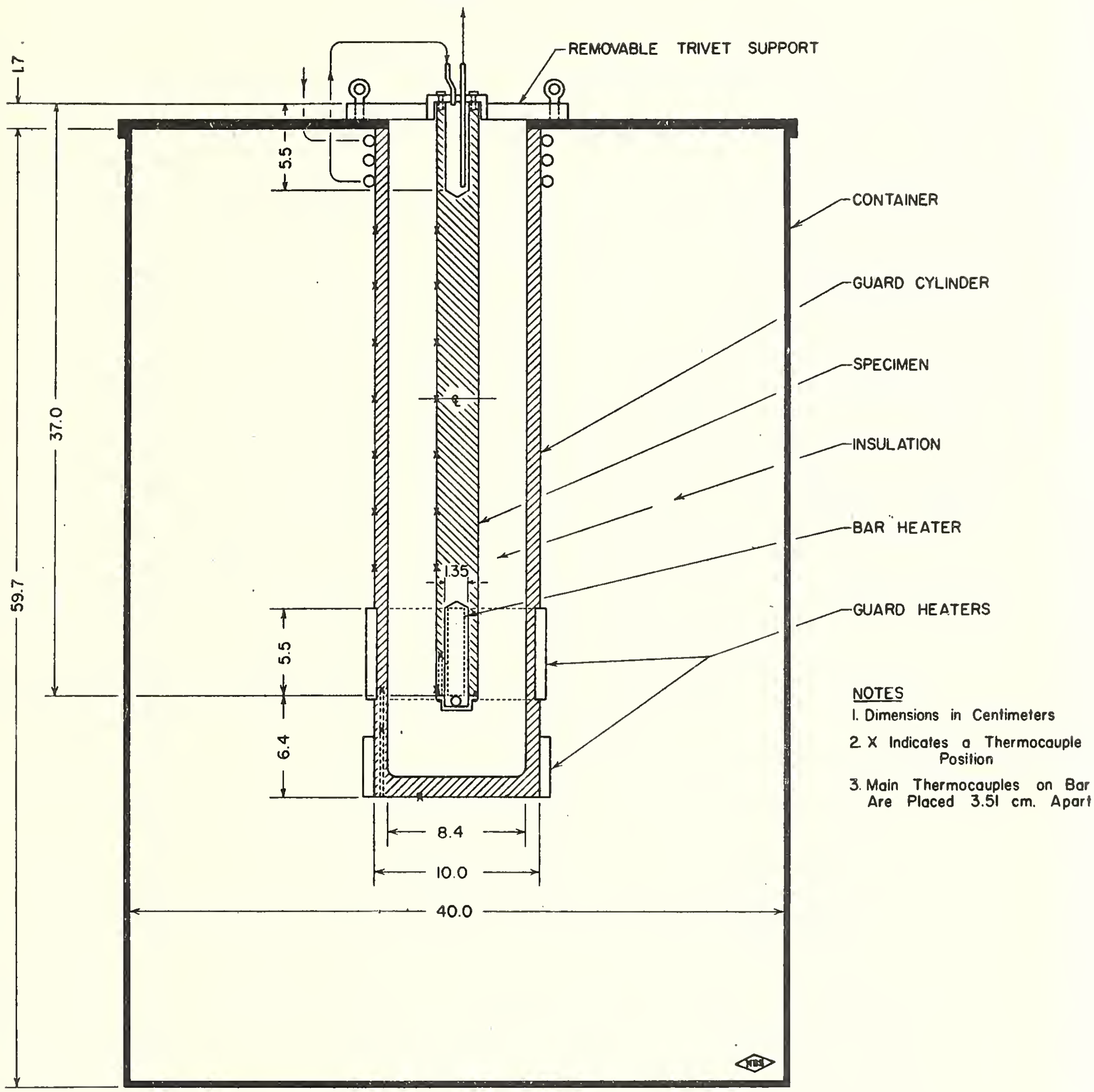
Chemical Composition - Percent

C	Mn	Si	Ni	Cr	Mo	Cu	Nb
0.042	0.75	0.70	28.6	19.8	2.2	3.3	Approx. 1.0

TABLE 2

Thermal Conductivity of a Sample of Carpenter 20 Stainless Steel

°F	Btu/hr ft^2(F/in.)	°F	Btu/hr ft^2(F/in.)
200	94.6	900	137.7
300	100.9	1000	143.8
400	107.1	1100	150.0
500	113.4	1200	156.2
600	119.6	1300	162.5
700	125.7	1400	168.8
800	131.7		



APPARATUS FOR MEASURING THE THERMAL CONDUCTIVITY OF METALS

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Fig. 1

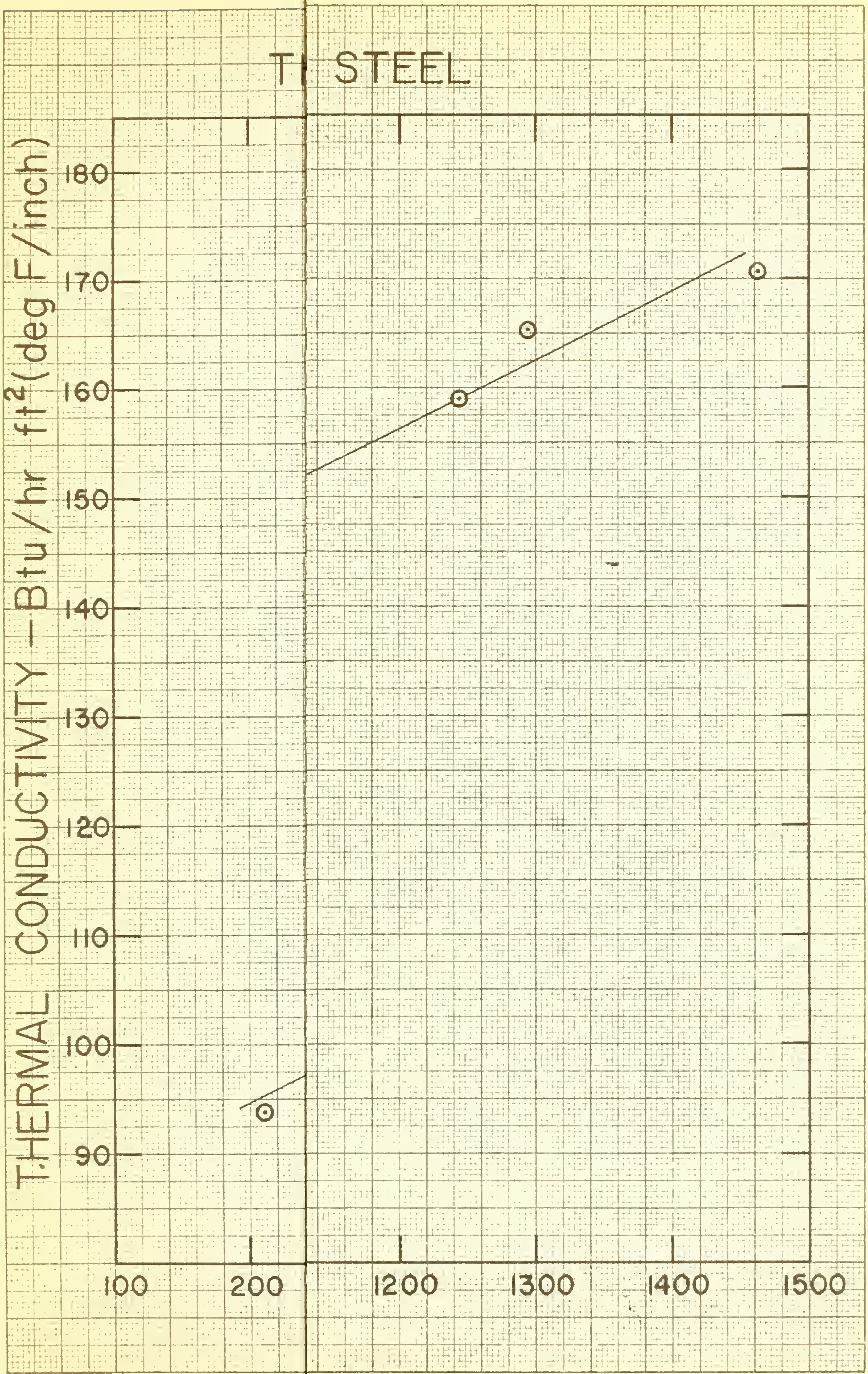
T1 STEEL
THERMAL CONDUCTIVITY - Btu / hr ft² (deg F / inch)
180
170
160
150
140
130
120
110
100
90
100
200
1200
1300
1400
1500

FIG. 2

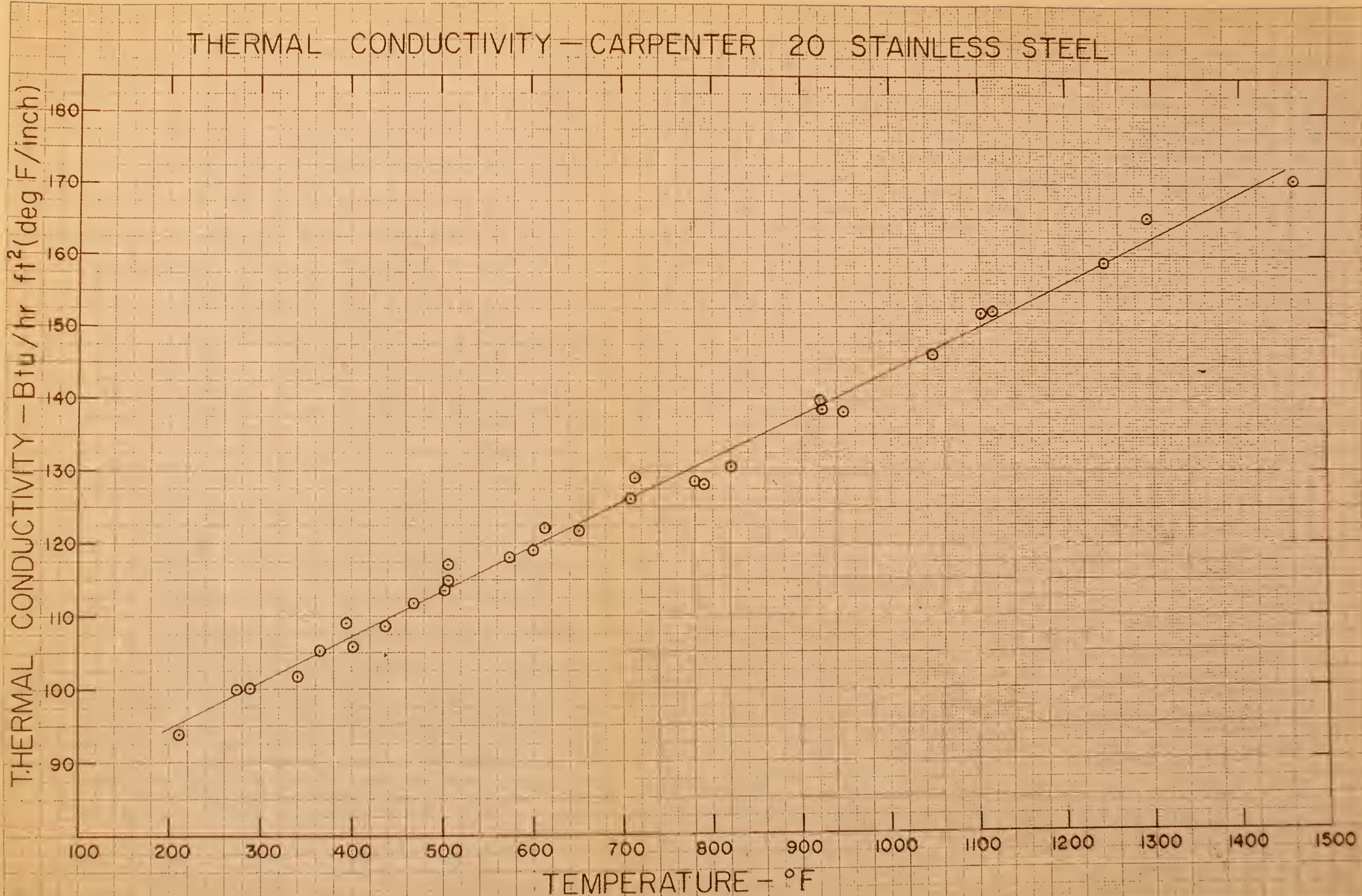
THERMAL CONDUCTIVITY — CARPENTER 20 STAINLESS STEEL
THERMAL CONDUCTIVITY - Btu/hr ft2(deg F/inch)
180
170
160
150
140
130
120
110
100
90
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
TEMPERATURE — °F

FIG. 2

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THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colo., is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

ELECTRICITY. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

METROLOGY. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

HEAT. Temperature Physics. Heat Measurements. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research. Equation of State. Statistical Physics. Molecular Spectroscopy.

RADIATION PHYSICS. X-Ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

CHEMISTRY. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

MECHANICS. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Combustion Controls.

ORGANIC AND FIBROUS MATERIALS. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

METALLURGY. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

MINERAL PRODUCTS. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

BUILDING RESEARCH. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

APPLIED MATHEMATICS. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

DATA PROCESSING SYSTEMS. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

ATOMIC PHYSICS. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics.

INSTRUMENTATION. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

IONOSPHERE RESEARCH AND PROPAGATION. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

RADIO PROPAGATION ENGINEERING. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

RADIO STANDARDS. High frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

RADIO SYSTEMS. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

UPPER ATMOSPHERE AND SPACE PHYSICS. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

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