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RESEARCH MEMORANDUM

THERMAL CONDUCTIVITY OF 14 METALS AND ALLOYS UP TO 1100° F

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
March 2, 1951

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SUMMARY

The thermal conductivity of 14 metals and alloys was determined in temperature ranges having a maximum of 1100° F. The metals included steels, high-temperature alloys, molybdenum disilicide, aluminum alloys, brass, and silver. The steels, high-temperature alloys, and brass, with one exception, have conductivities that increase with increasing temperature. AISI 403 steel, silver, molybdenum disilicide, and also 14S aluminum alloy after heat treatment, have conductivities that decrease as the temperature is increased. No definite trend was established for 14S and 24S aluminum alloys unless heat-treated before testing. The conductivity of the 355 aluminum alloy was fairly constant after the first run although it received no heat treatment other than that which it might have obtained during the test.

A comparison method was used to obtain the results in which the thermal conductivity of the test sample was compared with the conductivity of high-purity lead.

INTRODUCTION

An accurate knowledge of the thermal conductivity of materials at high temperatures is essential for the proper design of the cooling systems of turbine blades and rockets. The thermal conductivity of several steels, high-temperature alloys, molybdenum disilicide, and silver was measured at the NACA Lewis laboratory from 200° to 1100° F; aluminum alloys and brass from 200° to 700° F. These measurements were made as the needs arose in connection with turbine-cooling research.

APPARATUS

The method used to measure the thermal conductivity of the materials reported herein is described in detail in reference 1. It consists essentially in comparing the thermal conductivity of the test specimen with that of a standard sample whose conductivity is known, using the apparatus shown in figure 1. The test sample is soldered to the standard sample; the combined specimen is placed in an apparatus that applies heat at one end and cools the opposite end. Radial heat loss from the specimen is prevented by a cylindrical guard tube heated and cooled so that a given point on the guard tube is at the same temperature as the adjacent point on the specimen. The space between specimen and guard tube is filled with powdered insulation. Then the heat flux is the same in both the test and standard sample when a steady state is reached. By measuring the thermal gradients along the specimen, the thermal conductivity of the test sample can be obtained. The results reported herein were obtained either by directly comparing the specimen with National Bureau of Standards melting-point standard lead, or by comparing the specimen with another metal that had been carefully measured by comparison with lead. The nominal manufacturer's analyses of the materials are presented in table I. The results are believed to be accurate within 4 percent.

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DISCUSSION OF RESULTS

The experimental results are shown in figures 2 to 12 in Btu/(hr)(ft)(^{o}F). Steels and high-temperature alloys are shown in figures 2 to 5.

The conductivity of porous 301 stainless steel (fig. 3) can be compared with the conductivity of S816 (fig. 2), which is similar to rolled 301. The 25-percent porosity decreased the thermal conductivity approximately 60 percent. All the conductivities shown in figures 2 to 5 increase with increasing temperatures with the exception of the steel AISI 403. The conductivity of this steel decreases slightly with increasing temperature.

Figures 6 to 9 are the results of measurements on the aluminum alloys 24S, 14S, and 355. In figure 6, run 1 is the result of making measurements at low temperatures and increasing the temperature step by step to obtain the results at higher temperatures. The temperature was then lowered and this procedure repeated to obtain the results of run 2. It is seen that some change in the conductivity was caused by heating the specimen. Figure 7 is the result of making similar measurements on 14S aluminum alloy, which was in heat-treat condition T (reference 2) at the beginning of the test. The same erratic changes were observed with the 14S alloy as were observed with the 24S alloy. The fact that these alloys have copper in solid solution, which undergoes changes during the age-hardening process at low temperatures, probably accounts for the uncertainty of their conductivity. In an attempt to stabilize the conductivity of the 14S alloy, it was heated to 775^{o} F, held there for 50 hours, and cooled slowly. The material was then tested again and is shown to be stabilized in figure 8, although the scatter of the experimental points is rather large.

Figure 9 is the thermal conductivity of 355 aluminum alloy. Although heating the specimen had some effect on its conductivity, the change was not as much as that for the 24S and 14S aluminum alloys, probably because the 355 alloy contains less copper than the other two alloys. Figure 10 gives the conductivity of the intermetallic compound, molybdenum disilicide. It has an extremely high pouring temperature (above 3000° F) and its conductivity-temperature curve is much like that of a pure metal or low-alloy steel. Some additional properties of molybdenum disilicide are given in reference 3.

The thermal conductivity of brass is shown in figure 11. The conductivity also increases with increasing temperature. The results of the measurements on pure silver (fig. 12) are somewhat higher at the low temperatures and somewhat lower at the high temperatures than results obtained by Bailey (reference 4). The curve obtained by Bailey is shown in figure 12 for comparison.

SUMMARY OF RESULTS

The high-temperature alloys S816, refractaloy 26, Inconel X, X-40, N-155(low C) and nimonic 80; the porous 301 stainless steel, and brass all have conductivities that increase with increasing temperature. AISI 403 steel, silver, molybdenum disilicide, and also 14S aluminum alloy after heat treatment, have conductivities that decrease as the temperature is increased. The results for the aluminum alloys 14S and 24S in the untreated condition are too erratic to show definite trends. The 355 aluminum alloy is fairly constant after the first run although it was given no heat treatment other than that which it might have obtained during the course of the test.

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REFERENCES

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2. Anon: Metals Handbook, 1948 Edition. Am. Soc. Metals (Cleveland), 1948, pp. 803-809.

3. Long, Roger A.: Fabrication and Properties of Hot-Pressed Molybdenum Disilicide. NACA RM E50F22, 1950.

4. Bailey, L. C.: The Thermal Conductivities of Certain Approximately Pure Metals and Alloys at High Temperatures. Proc. Roy. Soc. (London), vol. 134, no. A823, ser. A, Nov. 3, 1931, pp. 57-76.

TABLE I - NOMINAL MANUFACTURER'S COMPOSITION OF MATERIALS TESTED

Material	Al	Ni	Fe	Cr	Co	W	Mo	Ti	Cb	C	Cu	Si	Mn	Mg	Zn	Pb	Ag
Inconel X	0.7	73.4	6.9	14.6				2.3	1.0	0.05							
N-155 (low C)		20.0	bal.	20.0	20.0	2.5	3.25		1.1	0.2							
Nimonic 80	0.63	74.2		21.2				2.4		0.04							
AISI 403			bal.	12.0						0.15							
Refractaloy 26	0.3	37.0	bal.	18.0	20.0		3.0	3.0		0.03							
S816		20.0	bal.	20.0	45.0												
X-40		10.5	2.0	25.5	bal.	7.5				0.53							
Porous 301 stainless[a]		7.0	bal.	17.0						0.11							
Aluminum alloy 24S	bal.										4.5		0.6	1.5			
Aluminum alloy 14S	bal.										4.4	0.8	0.8	0.4			
Aluminum alloy 355	bal.										1.3	5.0		0.5			
Molybdenum disilicide	Intermetallic compound, $MoSi_2$																
Brass											61.5				35.5	3.0	
Silver																	99.4

[a]Porosity of 301 stainless-steel specimen is 25 percent.

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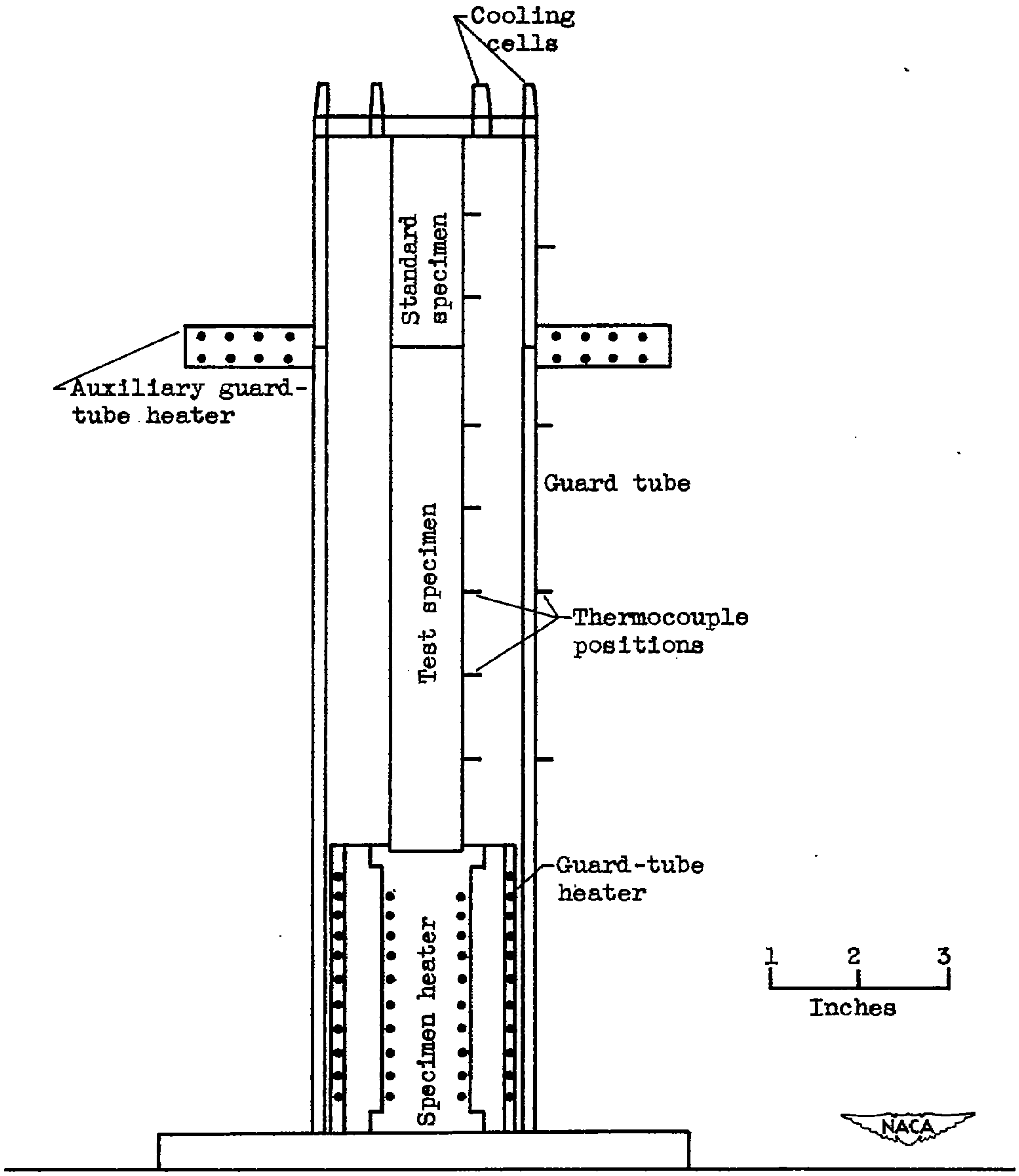

Figure 1. - Schematic sketch of thermal-conductivity apparatus.

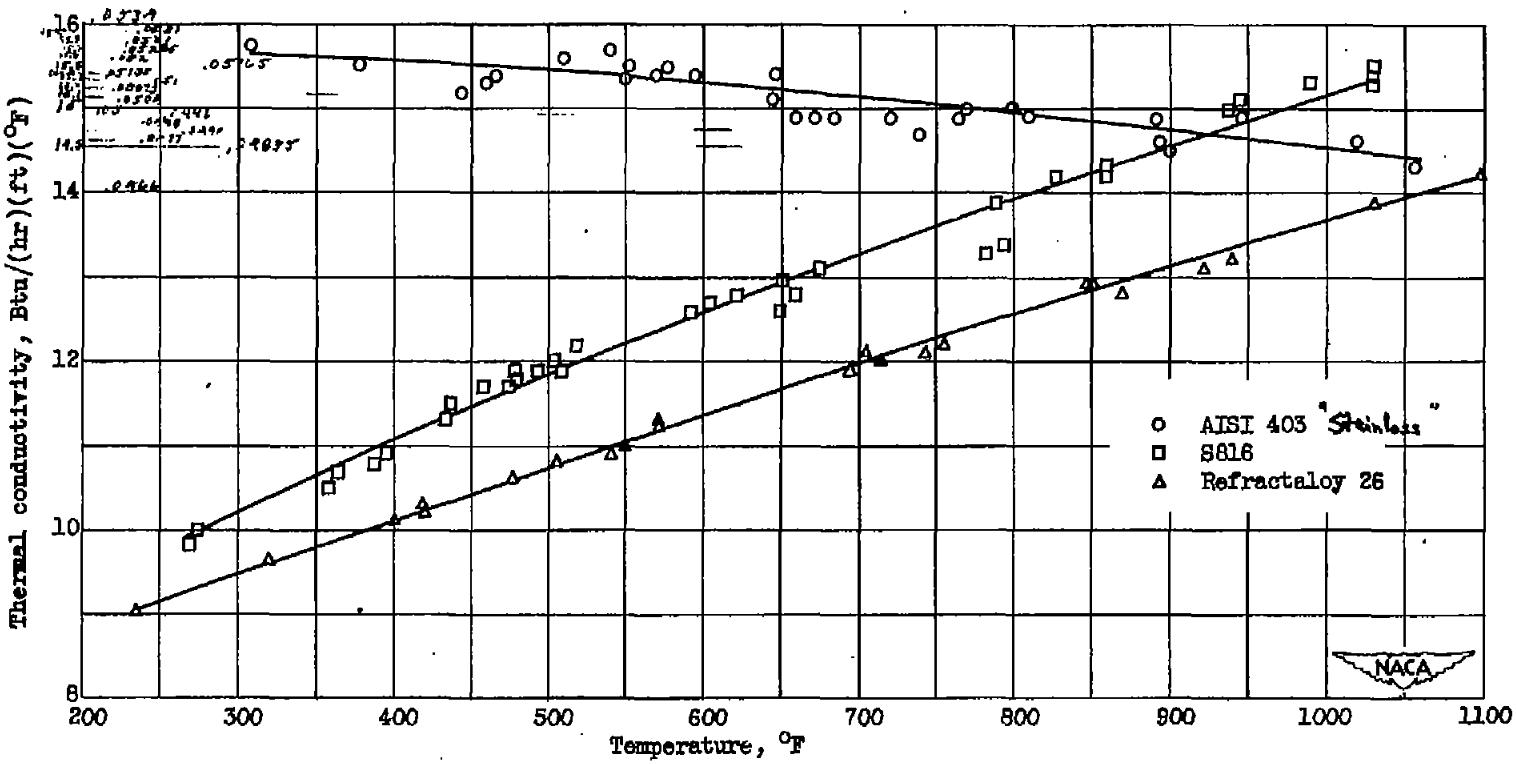

Figure 2. - Thermal conductivity of AISI 403 steel, refractaloy 26, and S816 alloy.

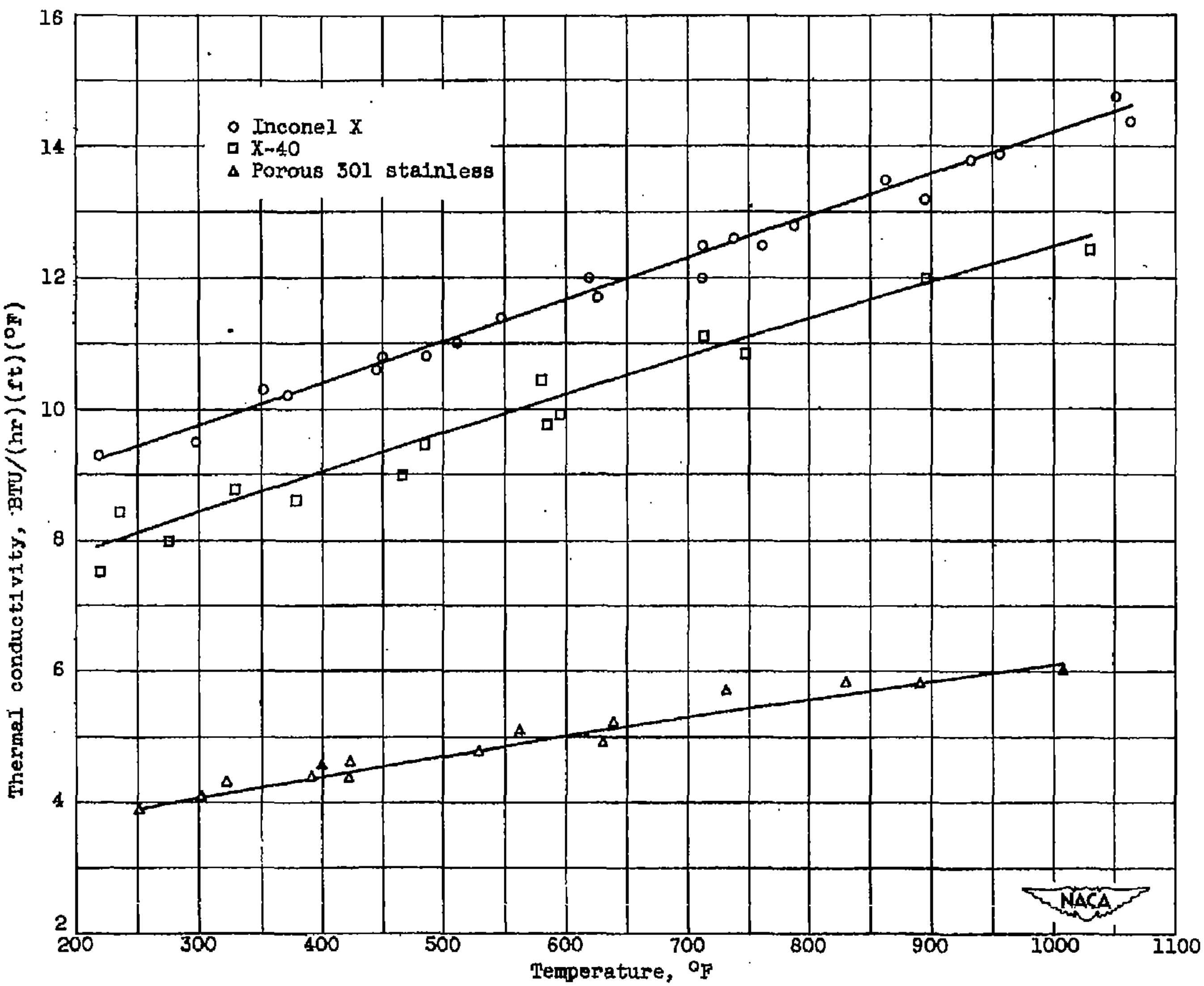

Figure 3. - Thermal conductivity of porous 301 stainless steel, X-40 alloy, and Inconel X.

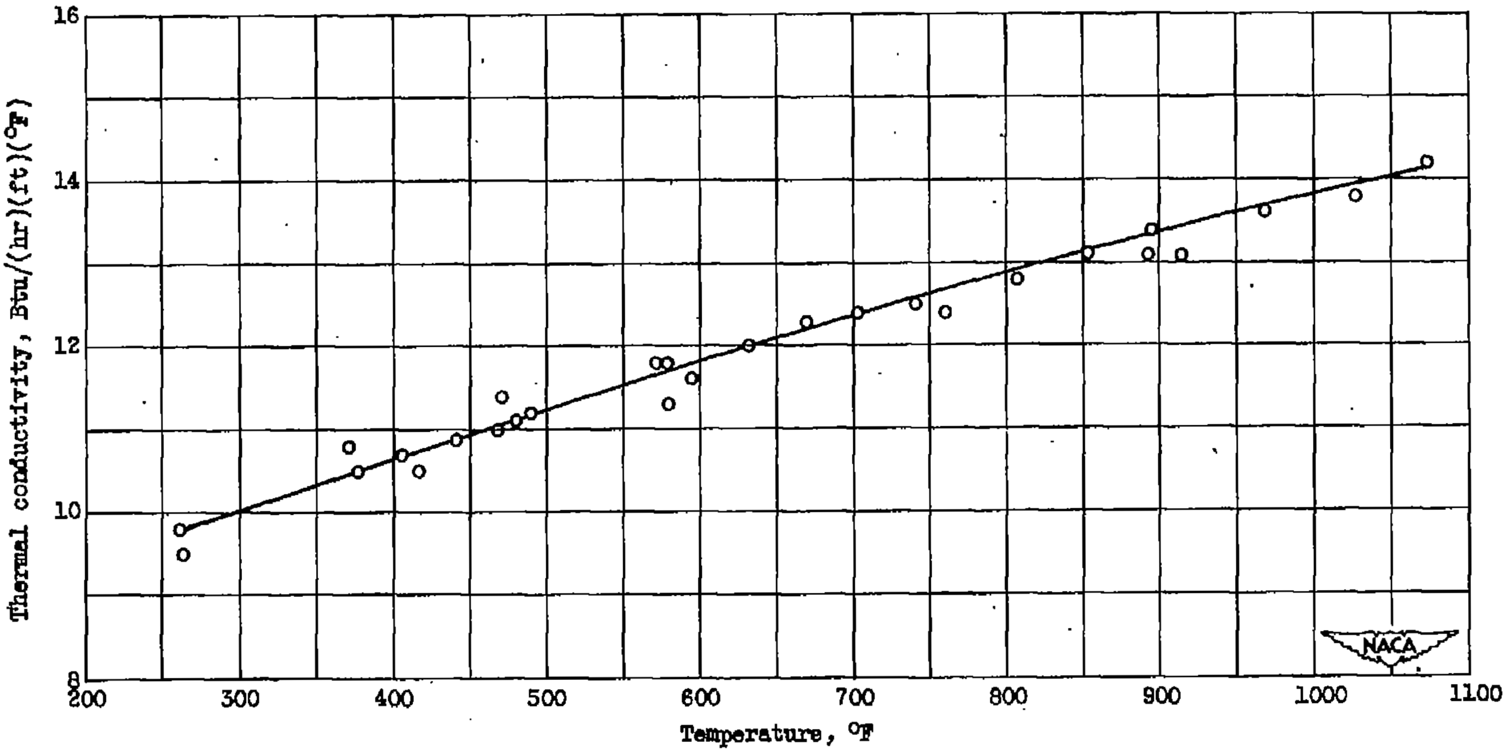

Figure 4. - Thermal conductivity of N-155 (low C) alloy.

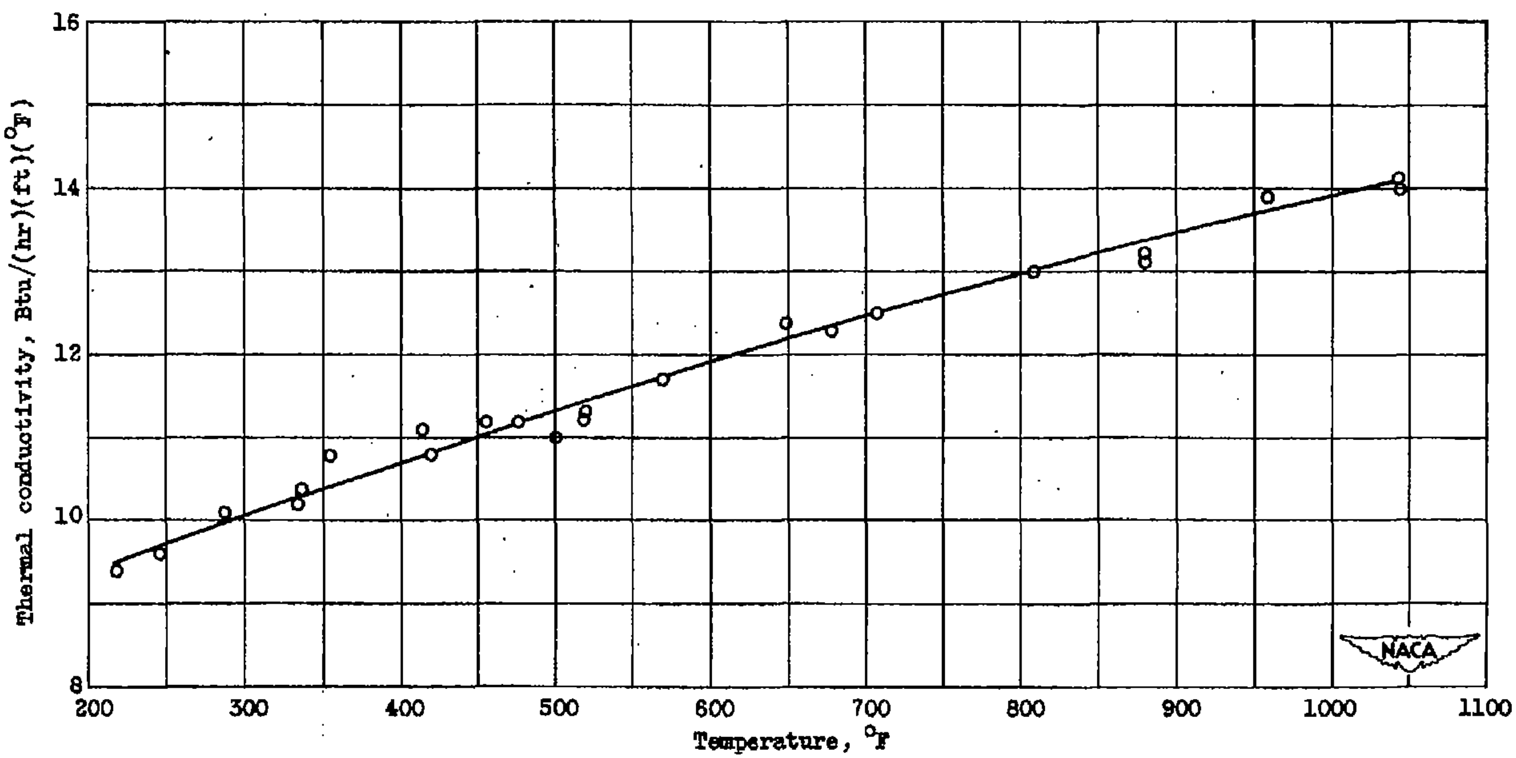

Figure 5. - Thermal conductivity of nimonic 80 alloy.

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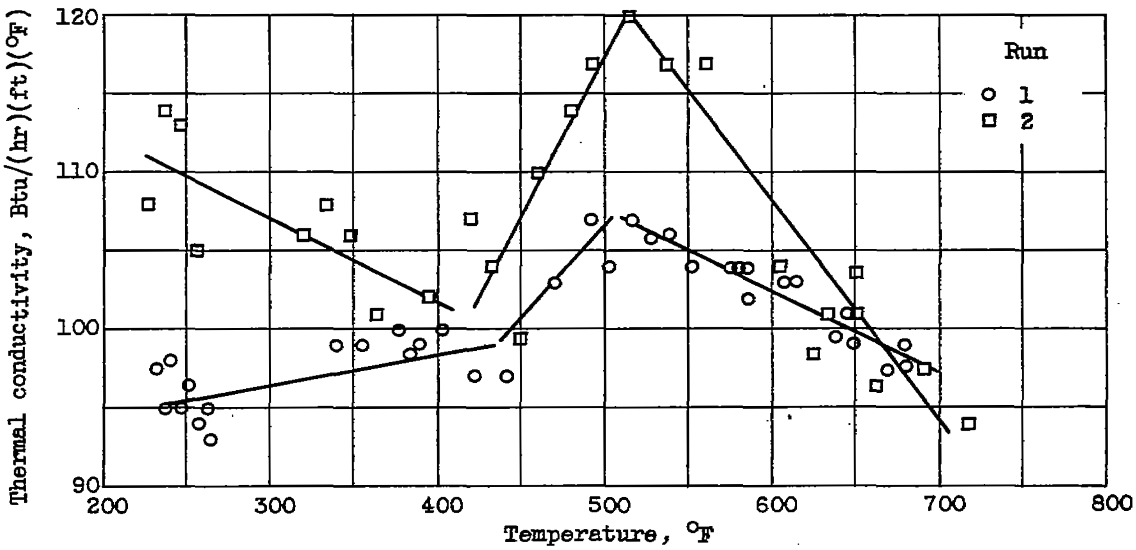

Figure 6. - Thermal conductivity of aluminum alloy 24S.

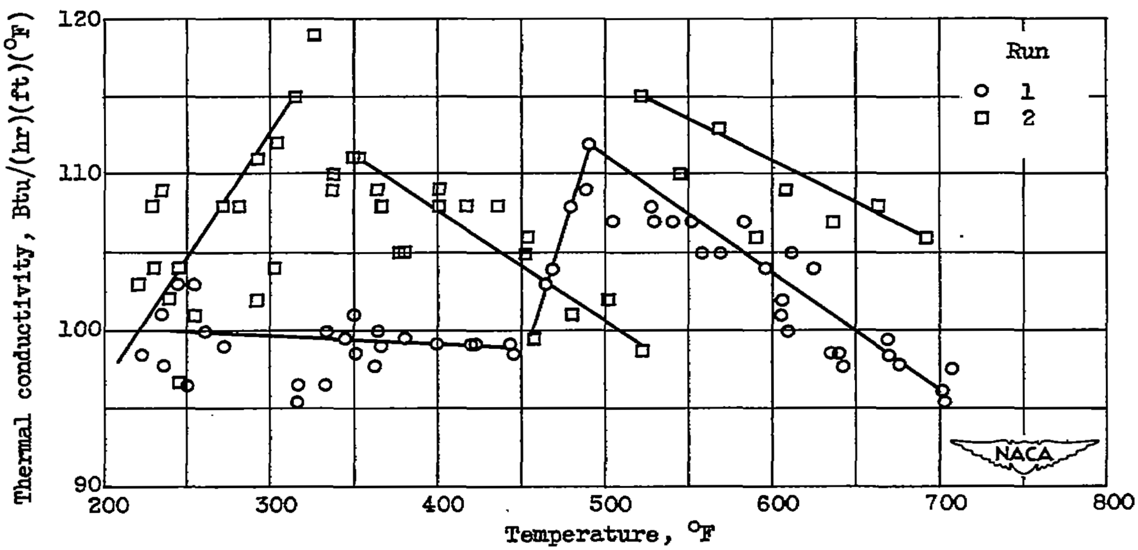

Figure 7. - Thermal conductivity of aluminum alloy 14S.

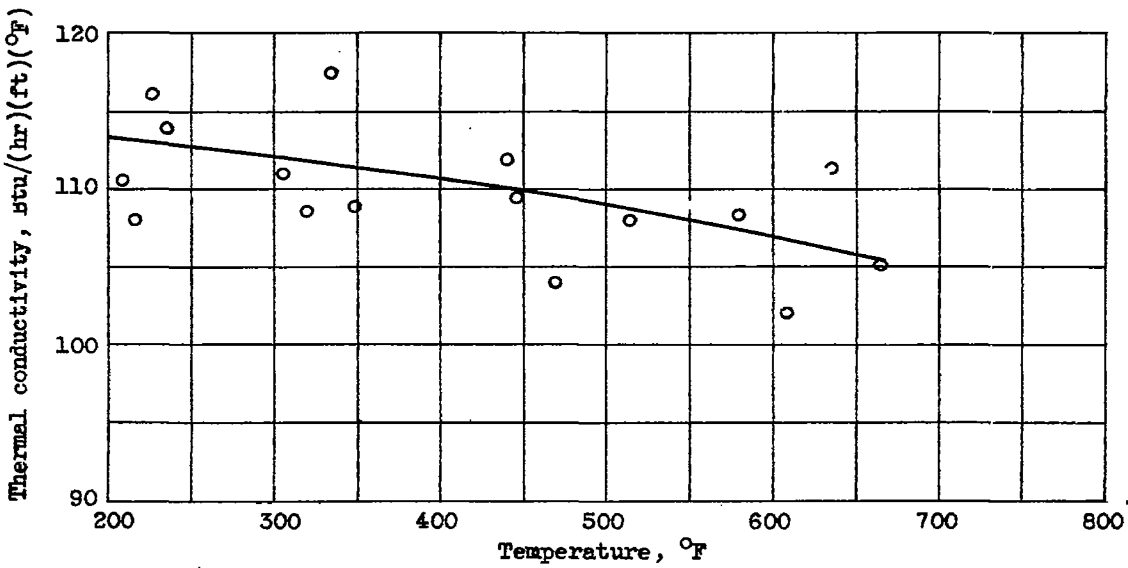

Figure 8. - Thermal conductivity of 14S aluminum alloy (treated).

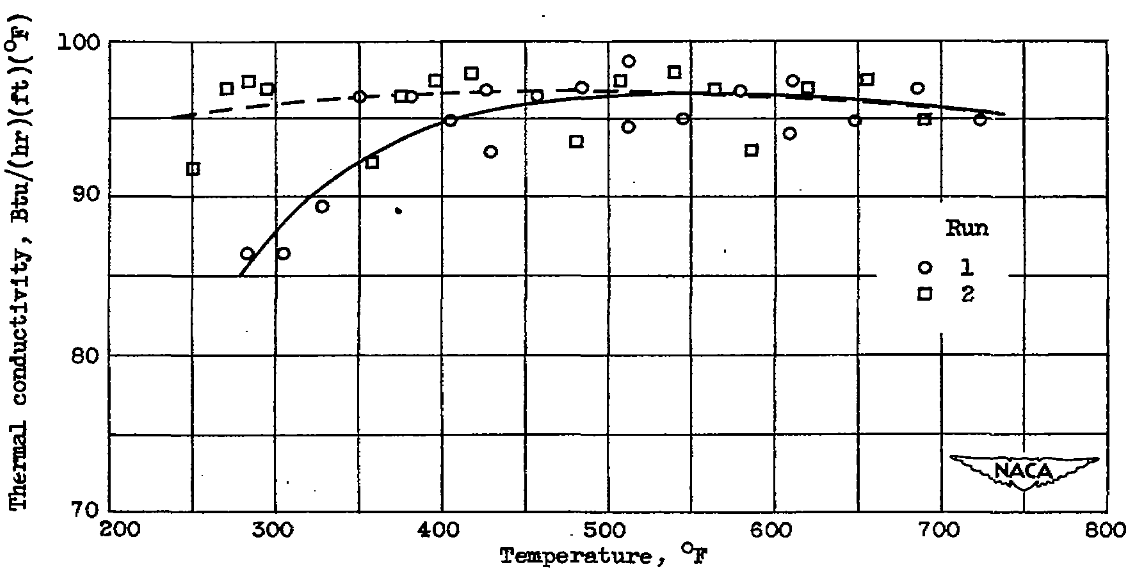

Figure 9. - Thermal conductivity of 355 aluminum alloy.

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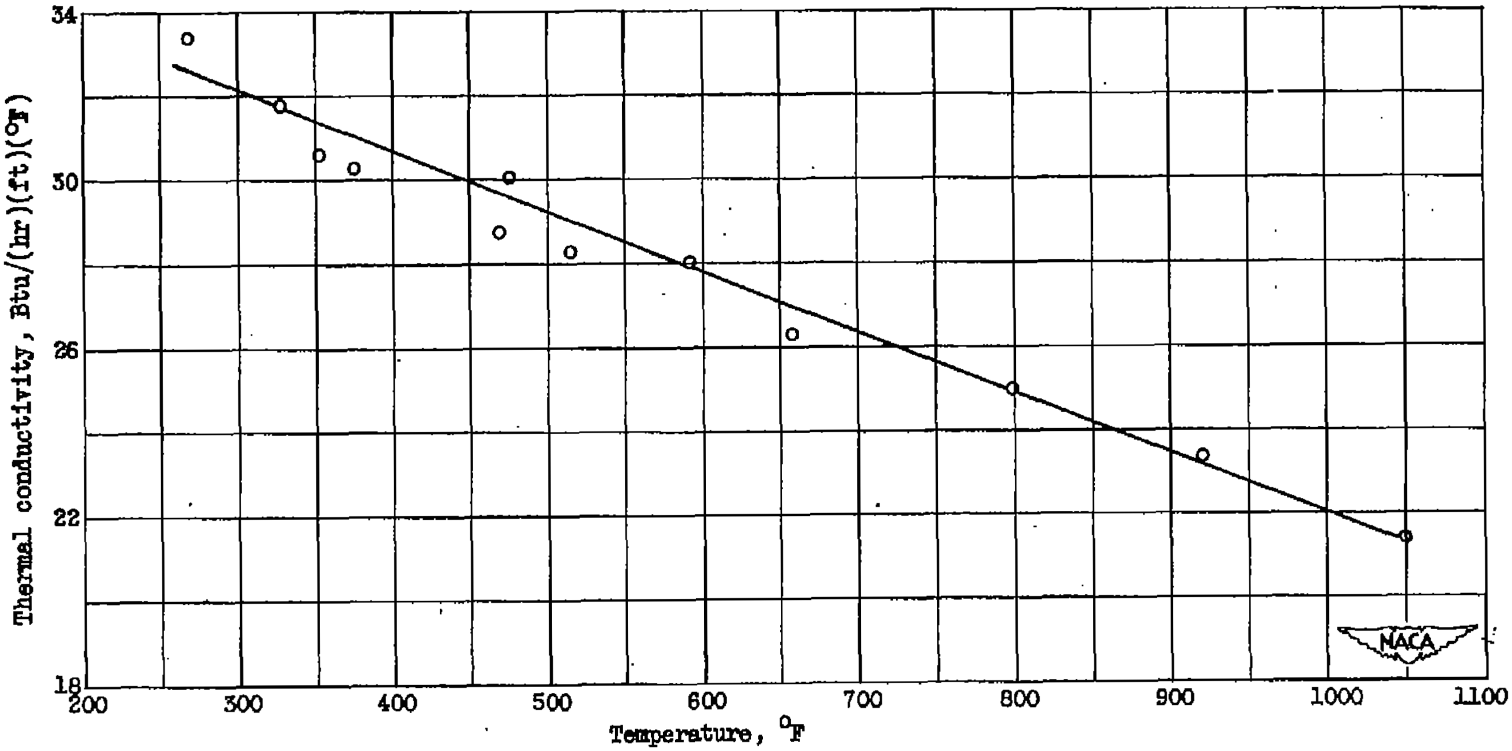

Figure 10. - Thermal conductivity of molybdenum disilicide.

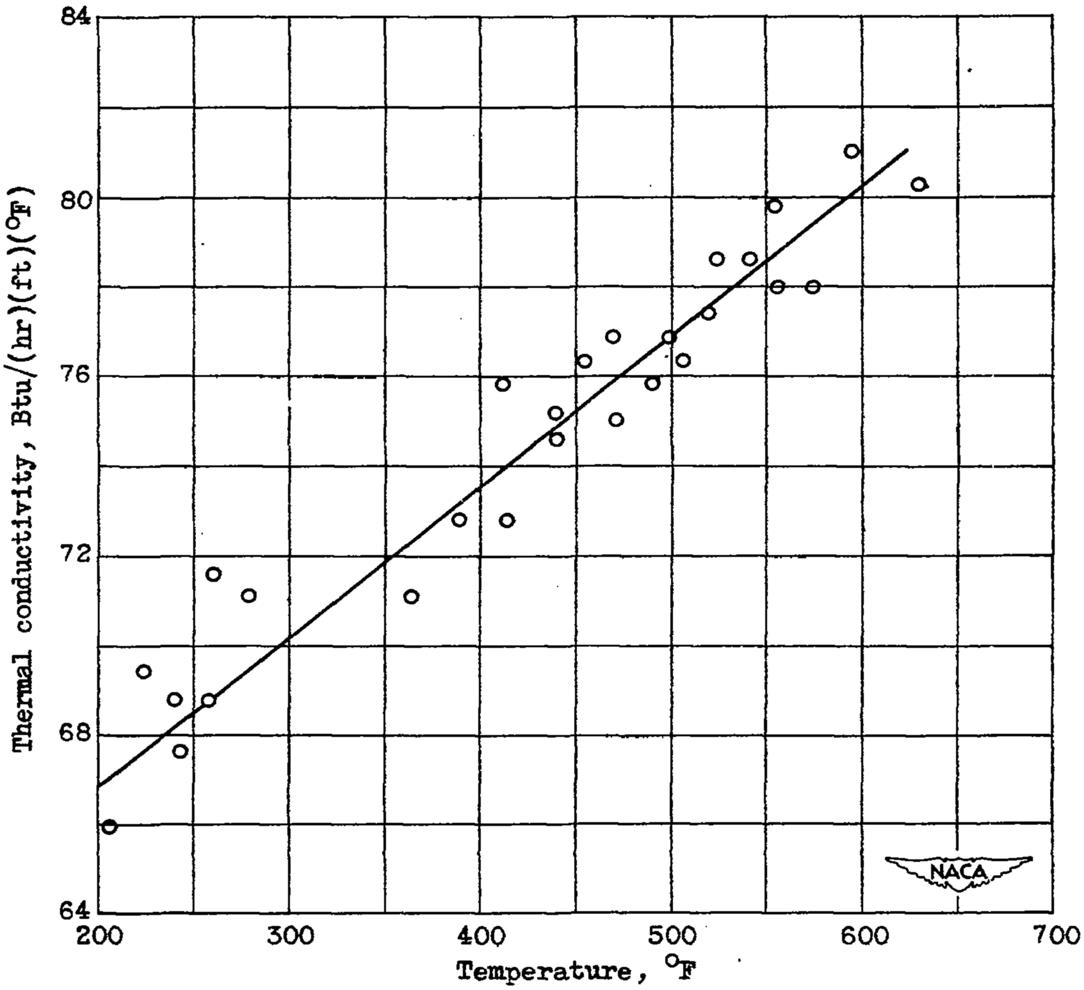

Figure 11. - Thermal conductivity of brass.

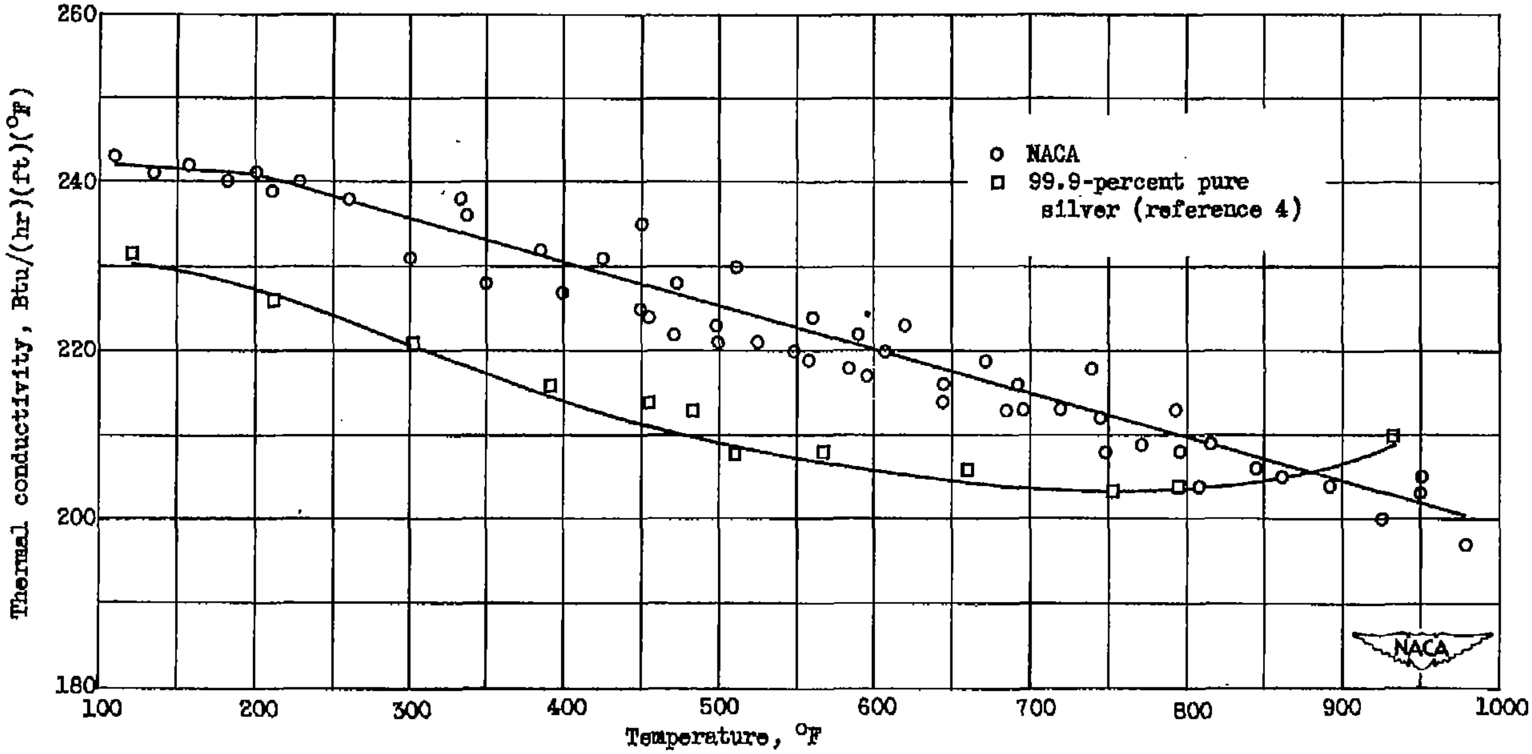

Figure 12. - Thermal conductivity of silver.

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