DYNATECH

THERMAL CONDUCTIVITY OF HOT PRESSED BERYLLIUM BETWEEN 4 AND 600 K

MT-004-0

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Thermal Conductivity of Hot Pressed Beryllium Between 4 and 600 K

(a) Material Studied

The material provided for the investigation was stated to be hot pressed beryllium. Eight samples were provided in the form of rods approximately 12.7 mm diameter and 150 mm long. They were in two batches of four.

Chemical compositions have been supplied for the material but at the present time there is a discrepancy between the data given to Westinghouse by the supplier and that actually determined by Westinghouse. Four analyses are being carried out and the confirmed final results will be provided in the final report.

On receipt of the samples each was given a Dynatech identification. Then the dimensions, weight and derived density of each were measured. Following this the electrical resistivity at approximately 21C was determined for a given length approximately 100 mm long between two knife edges. Each rod was then sent away to be machined into a suitable test sample for the thermal conductivity measurements. This test sample was approximately 100 mm long and of uniform diameter of approximately 12.7 mm. It had a hole 6 mm diameter and 25 mm deep drilled at the centre of one end and a taper machined at the other end to fit into the base of the appropriate test stack. Small holes approximately 0.3 mm diameter were drilled in four positions along the centre line some 10 mm apart giving a total of 40 mm between extremes. Two further small longitudinal holes were drilled 12 mm deep into the material at the end of the rod containing the 6 mm hole. Table I contains details of the identification of the samples and the electrical resistivity at room temperature.

Specimen Serial #	Dynatech Sample Number	Electrical Resistivity at 21C $10^{8}\ \Omega m$
A89242 Longitudinal	1	4.48
A89291 Longitudinal	2	4.45
C 596 Longitudinal	3	4.98
C 597 Longitudinal	4	4.98
A89285 Transverse	5	4.34

Specimen Serial #	Dynatech Sample Number	Electrical Resistivity at 21C 10^8 Ωm
A89286 Transverse	6	4.36
C 602 Transverse	7	4.84
C 603 Tranverse	8	4.84

(b) Experimental Method

Measurements of thermal conductivity were carried out by the basic absolute axial rod longitudinal heat flow method.

The sample was fitted into a base and an integral pencil heater and cap fitted into the opposite end. A cylindrical guard tube heated at the top was fixed around the sample and anchored to the base. Fine gauge thermocouples of different materials appropriate to the temperature range were fitted tightly into the various small holes in the sample and in holes in similar positions in the guard tube. A steady temperature gradient distribution was maintained in the rod by means of a fixed d. c. power input to the heater and a controlled rate of fluid flow through the base plate. The fluids used were liquid helium, nitrogen, and water. A heater was also fitted into the base such that the overall temperature of the sample could be raised while still maintaining a flow of cooling fluid through it. The power to the guard heater was controlled automatically by means of differential thermocouples attached to the guard and sample such that the temperature gradient on the guard tube closely matched that in the sample.

At equilibrium conditions the power to the main heater was measured using a precision resistor network, the temperature difference was obtained from readings of the respective thermocouples, all measurements being made using a precision microvolt potentiometer. The thermal conductivity was derived from the above measurements and the known dimensions of the sample from the usual equation

$$= \frac{Q\,x}{A\,d\theta}$$

where Q is the power input in Watts

$d\theta$ is the temperature difference, Celsius (C) or Kelvin (K)

A the area,m^2

x the distance between appropriate thermocouples, m

The units used for this report will be metric. Thus λ will be given at temperatures, K in W m^{-1} deg K^{-1}. A conversion table is provided at the end of the report to convert this unit to any of the other recognized units.

(c) Results

The experimental results for the eight samples are given in Table II and shown in Figure 1a and b. The following comments can be made regarding the results:

(I) There is a definite difference between the two batches. This is particularly noticeable below approximately 300 K. This difference is probably due to variations in composition. We still await confirmed compositions for the material.

(II) Each batch is extemely consistent within the four samples and a curve can be drawn through the data for each which will give representative results for that material. All experimental points for a batch are within $\pm$ 2% of the curve.

(III) There is little anisotropy effect in the material. Within each batch of four the values for the transverse and longitudinal directions are within the experimental limits.

(IV) Between 300 and 600 K a curve representative of all eight samples can be drawn through the experimental points such that any one point is within $\pm$ 3% of the curve. However even at these temperatures the experimental points for the C materials are always consistently below those for the A materials.

(V) Below 300 K the two curves diverge as would be expected and the maxima in the thermal conductivity versus temperature behaviour are obtained at approimately 118 and 140 K for the A and C materials respectively. The quantitative thermal conductivity limits for these maxima are 330 and 260 W m^{-1} deg K^{-1}

respectively. Both the higher value and the lower temperature of the maximum for the A material would indicate that it is of higher purity than the C material. This is also confirmed by the fact that below the maxima the curve for the A material remains above that for the C material.

(VI) Limited electrical resistivity measurements were undertaken at room temperature only in order to characterize the material. The results obtained for the four samples of material A show a variation of approximately 3% as do those for the material C. This again confirms little anisotropy in the materials. However, the absolute values for A are lower than those for C and this again in consistent with the thermal conductivity results for the A material being higher.

(d) Conclusions and Recommendations

From the results obtained the following remarks can be made:

(I) The thermal conductivity of hot pressed beryllium is dependent upon the material particularly below 300 K. A particular batch of material is self consistent and there is only a minor anisotropic effect.

(II) A representative curve of thermal conductivity versus temperature cannot be obtained for beryllium. It would not be practical or economic for measurements of thermal conductivity to be made on every new batch of material to be used by Westinghouse. Thus some other method of obtaining reliable conductivity data has to be sought.

(III) Electrical resistivity determinations should be made on the present eight samples over the complete temperature range in order to characterize the materials further and obtain data from which the behaviour of the Lorenz Function, L, (the product of thermal conductivity and electrical resistivity divided by the absolute temperature) can be studied. In the experience of the author [1,2,3]* it has been found that the thermal conductivity and electrical resistivity for hot pressed beryllium does vary as for the present results but that the derived Lorenz Function had a more constant type of behaviour for the different samples.

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*See references at end of report.

It is, therefore, recommended that electrical resistivity measurements be made for the present beryllium materials+ and the behaviour of the Lorenz Function studied in detail. It is confidently expected that for any subsequent hot pressed beryllium an accurate thermal conductivity value can be obtained from the use of the Lorenz Function behaviour derived for the present eight samples together with a rapid measurement of its electrical resistivity.

(e) References

1. Tye, R. P. and Quinn, J. E. (1968) "The Thermal Conductivity of Hot Pressed Beryllium Block". Proceedings of Fourth Symposium on Thermophysical Properties, A.S.M.E. New York, pp 144-149.

2. Tye, R. P. and Brazel, J. P. "The Thermophysical Properties of Hot Pressed Beryllium". Presented at the Second European Conference on Thermal Properties at Salford, England, April, 1970. In course of being printed.

3. Hust, J. G. Powell, R. L., and Weitzel, D. H. (1969) "Thermal Conductivity Electrical Resistivity, and Thermopower of Aerospace Alloys From 4 to 300 K" NBS Report 9732, 188 pp.

+N.B. it should be included for all the materials to be studied under the complete investigation as originally suggested.

TABLE II

Thermal Conductivity, λ , W m^{-1} deg K^{-1} at Temperatures, T, K, for Eight Samples of Hot Pressed Beryllium

A 89291		A 89292		A 89285		A 89286		C 596		C 597		C 602		C 603	
T	λ	T	λ	T	λ	T	λ	T	λ	T	λ	T	λ	T	λ
6.6	26.5	5.4	21	15.2	59	5.1	18	5.4	12.5	4.6	11.0	33.1	84.5	6.7	16
12.1	46.5	10.6	38.5	18.6	76	35.9	142	8.2	20	10.1	25.5	105.2	234	16.5	42
84.8	300	95.7	310	111.0	331	120.1	331	121.2	248	21.0	51.2	127.2	254	106.7	242
92.0	316	126.2	330	133.2	336	163.2	291.5	145.2	258	82.7	218	154.7	254	141.2	260
105.3	328	322.2	187.5	138.2	326	228.2	239.5	196.7	236	96.7	236	186.7	242	214.1	230
114.2	330.5	430.3	152	159.9	308	267.7	214	219.1	224	115.2	252	213.2	229.5	349.2	170
117.2	329	540.4	135	186.0	285	315.7	191	353.7	167.7	121.1	256	244.6	211	482.3	137
128.2	328			231.1	239	384.2	166	461.5	142.7	143.8	261	322.2	180.2		
131.2	323			340.7	182	465.7	148.5	577.7	126.3	211.1	230	408.2	153.2		
137.2	319.5			380.4	168	542.2	135.3			315.2	183.7	533.2	132.7		
148.2	311			422.2	155.5					361.2	167.2				
182.7	279			538.2	134.5					448.7	148.2				
227.7	241.5														
312.2	195.3														
386.2	167.3														
477.2	145.2														
570.7	129.5														

Figure 1a - Thermal Conductivity of Hot Pressed Beryllium Between 5 and 100k

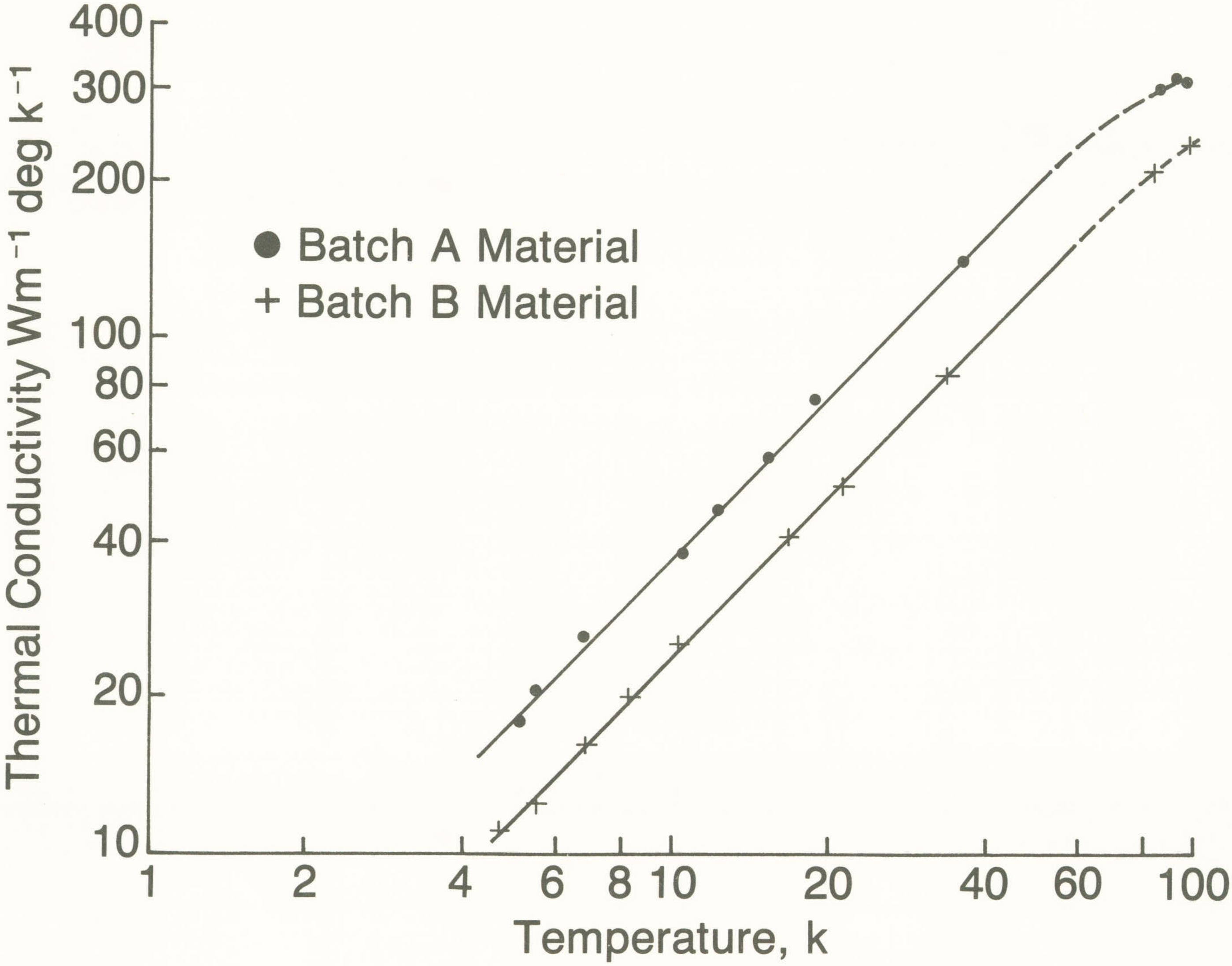
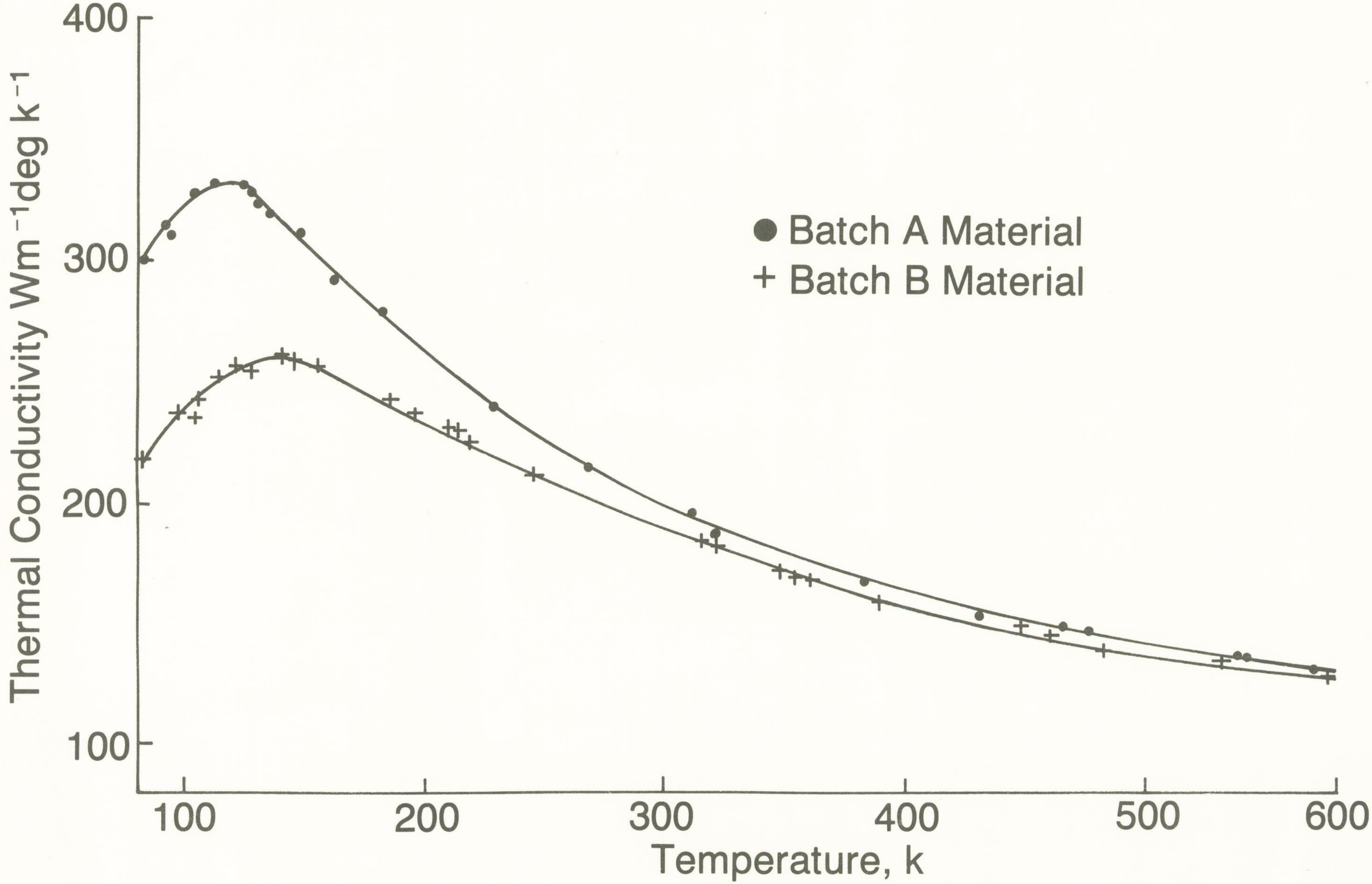


Figure 1b - Thermal Conductivity of Hot Pressed Beryllium Between 80 and 600k



DYNATECH

Report on
THE THERMAL CONDUCTIVITY OF FOUR SAMPLES OF BERYLLIUM

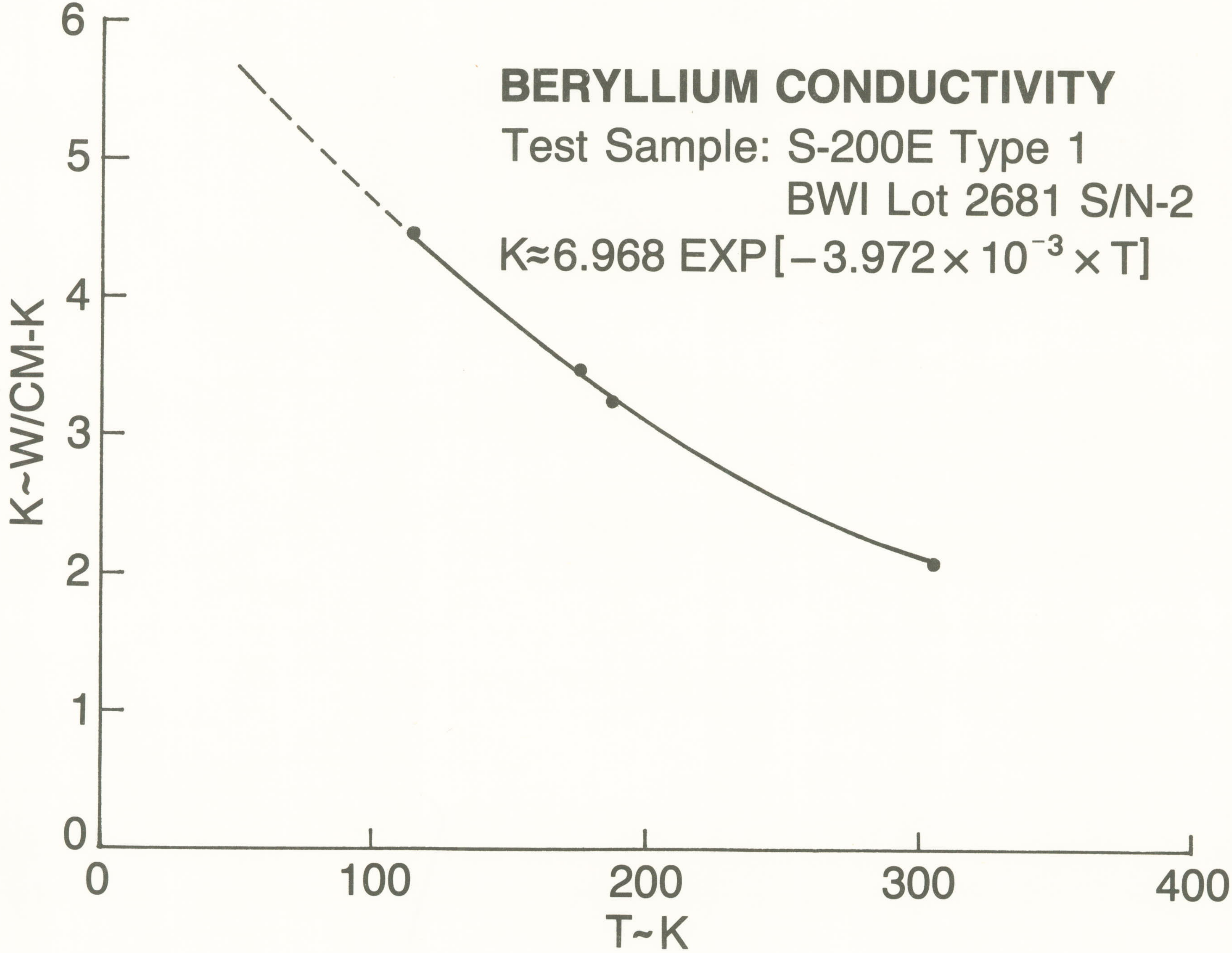
For: Texas Instruments, Inc.
P.O. Box 6015
Dallas, Texas 75222

The samples submitted for evaluation over the approximate range 77 to 300K were described as commercial beryllium metal materials. They were supplied in the form of rod approximately 13 mm diameter and 100 mm long with a taper at one end a 6 mm diameter hole 25 mm deep drilled at the centre of the other end. Four small holes were drilled 3 mm deep at regular positions along the central 38 mm length of the sample.

Prior to any thermal conductivity measurements the sample was laid on knife edges a fixed distance apart, a thermocouple was fixed to the central section and current leads clipped at each end. A steady d.c. current was applied and the potential difference across the knife edges together with that across a calibrated 0.001 Ω shunt in series with the sample were measured on a potentiometer. The current was reversed and the potential differences measured again in order to eliminate thermal voltages. The electrical resistivity was determined in terms of the ratio of the potential difference, the value of the shunt, and the distance between the knife edges and the area of cross-section of the sample.

The prepared sample was fitted into a matching tapered hole in a large copper heat sink, and a heating unit cap with a 6 mm diameter self-contained central heater was fitted around the end of the sample containing the hole. A copper cylindrical guard tube with a heater cap was fitted around the sample and anchored securely to the heat sink. Thermocouple instrumentation was attached both the top and bottom and along the length of the guard tube. The composite sample configuration was mounted on a fluid cooled base with a subsidiary heater and surrounded by a further cylindrical heater and an outer shroud. The interspaces and surrounds were filled with a pre-dried low conductivity insulating powder.

Reference: TEX-6
November, 1976


BERYLLIUM CONDUCTIVITY
Test Sample: S-200E Type 1
BWI Lot 2681 S/N-2
K≈6.968 EXP[−3.972 × 10^−3 × T]
K~W/CM-K
0
1
2
3
4
5
6
0
100
200
300
400
T~K

A steady temperature distribution was maintained in the system and by running liquid nitrogen through the heat sink and by adjustment of the heaters on the guard, the heat sink and the outer cylindrical guard, both the temperature of the top part of the sample and guard cap were made identical and the gradient in the guard tube was matched to that along the sample in order to ensure that heat losses were kept to an absolute minimum. At equilibrium conditions the temperature gradient along the end was obtained from readings of the thermocouples and the d.c. power dissipated in the central heater was measured using a precision resistor network.

The thermal conductivity was derived in terms of the power dissipation, the temperature gradient, and the dimensions of the rod.

Electrical resistivity measurements were carried out at the same time as the above measurements. Current leads had been fixed to the sample heater cap and the heat sink. After each thermal conductivity determination electrical resistivity measurements were taken as described previously but in this case the potential difference across the sample was measured using the "like" arms of the extreme thermocouples.

The overall temperature of the system was adjusted by means of the rate of flow of liquid nitrogen through the heat sink and the power to the various heaters and the mean temperature was changed at regular increments from -160C to approximately 25C. All measurements were undertaken in an environment of dry nitrogen gas at one atmosphere.

The results for the particular samples tested, obtained from smooth curves drawn through the experimental points, are given in the following table.

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THERMAL CONDUCTIVITY, λ , W $m^{-1}K^{-1}$ AND ELECTRICAL RESISTIVITY

$10^8\rho$, Ω m, of FOUR BERYLLIUM SAMPLES (I-70A)

Temperature	#1		#3		#4		#5	
K	λ	$10^8\rho$	λ	$10^8\rho$	λ	$10^8\rho$	λ	$10^8\rho$
77	-	0.90	-	0.92	-	0.88	-	1.05
100	310	1.03	288	1.10	308	1.03	265	1.22
125	350	1.15	320	1.25	345	1.15	292	1.35
150	324	1.50	305	1.55	320	1.45	270	1.70
200	263	2.30	265	2.35	260	2.32	245	2.50
250	222	3.45	220	3.50	220	3.45	215	3.60
296	195	4.77	192	4.87	193	4.79	190	4.90

Note:
Handling Aluminum-Beryllium Alloys in solid form poses no special health risk. Like many industrial materials, beryllium-containing materials may pose a health risk if recommended safe handling practices are not followed. Inhalation of airborne beryllium may cause a serious lung disorder in susceptible individuals.

The Occupational Safety and Health Administration (OSHA) has set mandatory limits on occupational respiratory exposures. Read and follow the guidance in the Material Safety Data Sheet (MSDS) before working with this material.

For additional information on safe handling practices or technical data on Aluminum Beryllium Alloys, contact Brush Wellman Inc.