U. S. Department of Commerce
Maurice H. Stans
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L. M. Branscomb, Director

Certificate of Analysis

STANDARD REFERENCE MATERIAL 736

Copper-Thermal Expansion

R. K. Kirby and T. A. Hahn

Thermal Expansion as a Function of Temperature (20-800 K)

T	$\frac{\Delta L}{L}$	α	T	$\frac{\Delta L}{L}$	α
20 K	-3239×10^{-6}	0.23×10^{-6}	320 K	450×10^{-6}	16.83×10^{-6}/K
30	-3234	1.04	340	789	17.03
40	-3217	2.28	360	1132	17.22
50	-3187	3.77	380	1478	17.40
60	-3141	5.40	400	1828	17.58
70	-3079	6.94	420	2181	17.74
80	-3004	8.21	440	2537	17.89
90	-2916	9.33	460	2897	18.04
100	-2817	10.33	480	3259	18.18
110	-2710	11.20	500	3624	18.32
120	-2594	11.97	520	3991	18.45
130	-2470	12.63	540	4362	18.57
140	-2341	13.20	560	4734	18.69
150	-2207	13.68	580	5109	18.81
160	-2068	14.09	600	5487	18.92
180	-1779	14.73	620	5866	19.04
200	-1480	15.18	640	6248	19.15
220	-1173	15.52	660	6632	19.26
240	-860	15.81	680	7018	19.37
260	-539	16.15	700	7407	19.48
273.15	-326	16.31	720	7798	19.60
280	-214	16.39	740	8191	19.72
293.15	0	16.54	760	8586	19.84
298.15	+85	16.59	780	8984	19.96
300	-116	16.61	800	9385	20.09

This SRM is available as a rod 6.4 mm (¼ inch) in diameter; SRM 736 L1 is 51 mm (2 inches) long, SRM 736 L2 is 102 mm (4 inches) long, and SRM 736 L3 is 152 mm (6 inches) long. (Note: Inquiries for longer continuous rods may be directed to the Office of Standard Reference Materials, National Bureau of Standards.) The copper rods have been annealed at 811 K with no significant increase in grain size.[1] The residual resistivity ratio, R_{273K}/R_{4K}, is 62.53 which would indicate a purity of 99.99 at % with about 0.012 at % effective (dissolved, ionized) impurities.[2] This copper is similar to SRM 45d freezing point standard.

The above expansion and expansivity versus temperature values are calculated from a least squares fit to the expansivity measurements made on five specimens from various positions of the entire sample. Third degree polynomials were fit to the data in three temperature intervals using the Omnitab Polyfit routine. Linear interpolation can be used between tabulated values with an error of less than one unit in the last reported digit. A description of the experimental method, fitting procedure, and estimate of uncertainties is given on the following pages.

The overall coordination and evaluation of data leading to certification of SRM 736 was performed by R. K. Kirby and T. A. Hahn.

The technical and support aspects involved in the preparation, certification, and issuance of this Standard Reference Material were coordinated through the Office of Standard Reference Materials by R. E. Michaelis.

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J. Paul Cali, Acting Chief
Office of Standard Reference Materials

PROCEDURE

The apparatus used for the expansion measurements was a Fizeau interferometer with 1-cm specimen lengths. Above room temperature, the measurements were made with the interferometer in a controlled atmosphere furnace using a calibrated Pt vs. Pt-10% Rh thermocouple. Below room temperature, a cryostat capable of operation with both liquid nitrogen and liquid helium was used with a calibrated platinum resistance thermometer. Values of expansivity were calculated between equilibrium temperatures.

The expansivity was then used in the analysis of the data since it was not always possible to project the expansion measurement back to the zero expansion value taken at 293.15 K in an unambiguous manner. Third order polynomials were fit to the expansivity values from each of the five specimens in the range from 0 to 70 K; 50 to 270 K; and 210 to 800 K to test for variation between the specimens. The deviations between the five equations were well within the standard deviation of the data for each of the specimens in the respective temperature intervals. All the expansivity values were then pooled and the following equations obtained:

$$20 \leq T < 66 \qquad \alpha \times 10^6 = 3.5927339 \times 10^{-1} - 7.982688 \times 10^{-2} T + 4.1210428 \times 10^{-3} T^2 - 2.3196061 \times 10^{-5} T^3$$

The standard deviations of the coefficients are 1.5940412×10^{-1}, 1.0496876×10^{-2}, 2.0740283×10^{-4}, 1.2442674×10^{-6} respectively and the standard deviation of the fit is 0.08 with 42 data points.

$$66 \leq T < 243 \qquad \alpha \times 10^6 = -6.5989607 + 2.6059173 \times 10^{-1} T - 1.0677137 \times 10^{-3} T^2 + 1.5459732 \times 10^{-6} T^3$$

The standard deviations of the coefficients are 1.6487758×10^{-1}, 3.6738712×10^{-3}, 2.4239378×10^{-5}, 4.8661822×10^{-8} respectively and the standard deviation of the fit is 0.10 with 95 data points.

$$243 \leq T < 775 \qquad \alpha \times 10^6 = 1.150461 \times 10^1 + 2.4346346 \times 10^{-2} T - 2.8812984 \times 10^{-5} T^2 + 1.4737859 \times 10^{-8} T^3$$

The standard deviations of the coefficients are 1.716981×10^{-1}, 1.223077×10^{-3}, 2.6906178×10^{-6}, 1.8471131×10^{-9} respectively and the standard deviation of the fit is .08 with 147 data points.

These equations and their integrals were used to calculate the tabulated values of expansion and expansivity. Consideration was given to smoothing the values in the overlapping regions of the three equations, but the differences between the curves in these regions were much smaller than the standard deviations of the data from the fitted curves.

The expansion values were calculated at each of the experimental temperatures to determine the standard deviation of the observed values from the equations. When a particular series of observed expansion values could not be projected to 293.15 K, the calculated value was used for the first value in the series and the above comparison made for each of the other values in the series. This procedure will reduce the standard deviation but not to any significant degree. A standard deviation of 6×10^{-6} was calculated for the expansion values.

Footnotes

[1] Vacuum annealing (G. E. Hicho)

[2] Residual resistivity ratios (V. A. Deason and R. L. Powell)

CORRECTION TO CERTIFICATE OF ANALYSIS FOR SRM 736

Copper, Thermal Expansion

The 0 value of $\frac{\Delta L}{L}$ is at 293 K rather than 293.15 K. $\frac{\Delta L}{L}$ should read $\frac{\Delta L}{L_{293}}$ and α should read $\frac{1}{L_{293}} \frac{\Delta L}{\Delta T}$. All values of $\frac{\Delta L}{L_{293}}$ are positive above 293 K. The units of α are K^{-1}.