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Thermophysical Properties Research Laboratory, Inc.

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Thermophysical Properties of Four Ceramic Materials

Report to ZYP Coatings

By

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Introduction

Four ceramic materials, identified as BNL, BNLN, BLNW, and ZMARC, were submitted for thermal conductivity testing from room temperature to 800°C.

Thermal diffusivity (α) was measured using the laser flash technique. Bulk density (d) values were calculated from the sample's geometry and mass. Specific heat (C_p) was measured using differential scanning calorimeters. Thermal conductivity (λ) values were calculated as a product of these quantities, i.e. $\lambda = \alpha \cdot C_p \cdot d$.

Thermal diffusivity is determined using the laser flash diffusivity method. In the flash method (ASTM E1461), the front face of a small disc-shaped sample is subjected to a short laser burst and the resulting rear face temperature rise is recorded and analyzed. A highly developed apparatus exists at TPRL and we have been involved in an extensive program to evaluate the technique and broaden its uses. The apparatus consists of a Korad K2 laser, a high vacuum system including a bell jar with windows for viewing the sample, a tantalum or stainless steel tube heater surrounding a sample holding assembly, a thermocouple or an i.r. detector, appropriate biasing circuits, amplifiers, A/D converters, crystal clocks and a microcomputer based digital data acquisition system capable of accurately taking data in the 40 microsecond and longer time domain. The computer controls the experiment, collects the data, calculates the results and compares the raw data with the theoretical model.

Specific heat is measured using a standard Perkin-Elmer Differential Scanning Calorimeter (ASTM E1269) with sapphire as the reference material. The standard and sample were subjected to the same heat flux as a blank and the differential powers required to heat the sample and standard at the same rate were determined using the digital data acquisition system. From the masses of the sapphire standard and sample, the differential power, and the known specific heat of sapphire, the specific heat of the sample is computed. The experimental data are visually displayed as the experiment progresses. All measured quantities are directly traceable to NIST standards.

A Netzsch Model 404 differential scanning calorimeter (DSC) is used to measure specific heats from 323 to 1673 K. Energetics of transformations and reactions can also be determined over the temperature range of 296 to 1773 K. The system is vacuum tight and therefore samples can be tested under pure inert, reducing or oxidizing atmospheres as well as under vacuum.

Results and Discussions

The thermal diffusivity samples dimensions, masses and bulk densities at room temperature are listed in table 2. The samples were measured in air from room temperature to 100°C. Then the measurement chamber was placed under a full vacuum, less than 5×10^{-5}torr. The samples were remeasured at 100°C and the difference applied to the higher temperatures. The results were not

corrected for changes in thickness with respect to temperature.

The specific heat results are listed in table 3 and plotted in figure 2. For samples BNL, BNLN, and BLNW, the samples were supplied as a powder material. This material was then placed into aluminum pans and compressed to create the largest mass and good contact throughout the sample. With the use of aluminum pans the samples were measured from room temperature to 600°C and then extrapolated to 800°C. The ZMARC sample was a solid sample and was first measured in a Perkin-Elmer DSC from room temperature to 500°C and then in a Netzsch DSC 404 from room temperature to 800°C.

The thermal conductivity calculations are shown in table 4 and the results plotted in figure 3.

Table 1
Sample Dimensions, Masses and Density Values

Sample Description	Thickness (cm)	Diameter (cm)	Mass (gm)	Density ($\mathrm{gm}/\mathrm{cm}^3$)
BNL	0.2340	1.3231	0.60485	1.879
BNLN	0.2180	1.3280	0.58881	1.949
BNLW	0.2319	1.3187	0.68767	2.171
ZMARC	0.3662	1.1810	1.35860	3.386

Table 2
Thermal Diffusivity Results

Temperature (°C)	BNL ($\mathrm{cm}^2/\mathrm{sec}$)	BNLN ($\mathrm{cm}^2/\mathrm{sec}$)	BNLW ($\mathrm{cm}^2/\mathrm{sec}$)	ZMARC ($\mathrm{cm}^2/\mathrm{sec}$)
23.0	0.03420	0.00758	0.00969	0.01903
50.0	0.03193	0.00733	0.00922	0.01771
100.0	0.02846	0.00692	0.00834	0.01592
200.0	0.02398	0.00639	0.00708	0.01378
300.0	0.02157	0.00625	0.00654	0.01233
400.0	0.01996	0.00625	0.00630	0.01149
500.0	0.01845	0.00636	0.00613	0.01090
600.0	0.01714	0.00650	0.00607	0.01038
700.0	0.01593	0.00666	0.00601	0.01000
800.0	0.01483	0.00683	0.00596	0.00962

Table 3
Specific Heat Results

Temperature (°C)	**BNL** ($^{W\cdot sec}/_{gm\cdot K}$)	**BNLW** ($^{W\cdot sec}/_{gm\cdot K}$)	**BNLN** ($^{W\cdot sec}/_{gm\cdot K}$)	**ZMARC** ($^{W\cdot sec}/_{gm\cdot K}$)
23.0	0.6224	0.6186	0.6810	0.5509
30.0	0.6430	0.6424	0.6904	0.5590
40.0	0.6718	0.6755	0.7038	0.5702
50.0	0.7000	0.7078	0.7171	0.5809
60.0	0.7275	0.7392	0.7304	0.5910
70.0	0.7544	0.7697	0.7436	0.6007
80.0	0.7808	0.7993	0.7567	0.6100
90.0	0.8065	0.8281	0.7698	0.6188
100.0	0.8318	0.8561	0.7828	0.6272
110.0	0.8565	0.8832	0.7957	0.6353
120.0	0.8807	0.9096	0.8086	0.6430
130.0	0.9044	0.9351	0.8214	0.6504
140.0	0.9277	0.9599	0.8341	0.6575
150.0	0.9505	0.9839	0.8467	0.6643
160.0	0.9730	1.0072	0.8593	0.6708
170.0	0.9951	1.0297	0.8717	0.6771
180.0	1.0168	1.0515	0.8841	0.6832
190.0	1.0381	1.0726	0.8964	0.6890
200.0	1.0592	1.0929	0.9086	0.6948
210.0	1.0799	1.1126	0.9207	0.7007
220.0	1.1003	1.1317	0.9327	0.7062
230.0	1.1205	1.1501	0.9446	0.7113
240.0	1.1404	1.1678	0.9565	0.7163
250.0	1.1601	1.1849	0.9682	0.7210
260.0	1.1796	1.2014	0.9798	0.7263
270.0	1.1989	1.2173	0.9913	0.7304
280.0	1.2179	1.2326	1.0027	0.7351
290.0	1.2368	1.2473	1.0140	0.7392
300.0	1.2556	1.2615	1.0252	0.7431
310.0	1.2742	1.2751	1.0363	0.7470
320.0	1.2927	1.2881	1.0473	0.7507
330.0	1.3111	1.3007	1.0581	0.7544
340.0	1.3294	1.3127	1.0688	0.7570
350.0	1.3476	1.3243	1.0794	0.7609
360.0	1.3657	1.3353	1.0899	0.7636
370.0	1.3837	1.3459	1.1003	0.7666
380.0	1.4017	1.3561	1.1105	0.7693
390.0	1.4197	1.3658	1.1206	0.7716
400.0	1.4376	1.3751	1.1306	0.7742
410.0	1.4555	1.3839	1.1404	0.7772
420.0	1.4734	1.3924	1.1501	0.7785

Table 3
Specific Heat Results (Continued)

Temperature (°C)	**BNL** $\left(\frac{W \cdot sec}{gm \cdot K}\right)$	**BNLW** $\left(\frac{W \cdot sec}{gm \cdot K}\right)$	**BNLN** $\left(\frac{W \cdot sec}{gm \cdot K}\right)$	**ZMARC** $\left(\frac{W \cdot sec}{gm \cdot K}\right)$
430.0	1.4912	1.4005	1.1597	0.7803
440.0	1.5091	1.4082	1.1691	0.7821
450.0	1.5270	1.4155	1.1784	0.7833
460.0	1.5449	1.4225	1.1875	0.7836
470.0	1.5629	1.4291	1.1965	0.7858
480.0	1.5808	1.4355	1.2053	0.7867
490.0	1.5988	1.4415	1.2140	0.7883
500.0	1.6169	1.4472	1.2226	0.7894
510.0	1.6350	1.4527	1.2309	0.7922
520.0	1.6531	1.4579	1.2392	0.7952
530.0	1.6713	1.4628	1.2472	0.7924
540.0	1.6896	1.4675	1.2551	0.7938
550.0	1.7079	1.4720	1.2629	0.7950
560.0	1.7263	1.4763	1.2705	0.7953
570.0	1.7448	1.4803	1.2779	0.8011
580.0	1.7634	1.4842	1.2851	0.7983
590.0	1.7820	1.4879	1.2922	0.8014
600.0	1.8007	1.4915	1.2991	0.8007
610.0	1.8194	1.4949	1.3058	0.8028
620.0	1.8382	1.4981	1.3124	0.8047
630.0	1.8571	1.5013	1.3188	0.8099
640.0	1.8761	1.5043	1.3249	0.8016
650.0	1.8952	1.5073	1.3309	0.8096
660.0	1.9143	1.5101	1.3368	0.8091
670.0	1.9334	1.5130	1.3424	0.8053
680.0	1.9527	1.5157	1.3478	0.8030
690.0	1.9720	1.5184	1.3531	0.8082
700.0	1.9913	1.5211	1.3581	0.8062
710.0	2.0107	1.5238	1.3630	0.8077
720.0	2.0302	1.5265	1.3677	0.8157
730.0	2.0497	1.5292	1.3721	0.8088
740.0	2.0692	1.5320	1.3764	0.8089
750.0	2.0887	1.5348	1.3804	0.8105
760.0	2.1083	1.5376	1.3843	0.8140
770.0	2.1279	1.5405	1.3879	0.8216
780.0	2.1475	1.5435	1.3914	0.8242
790.0	2.1671	1.5466	1.3946	0.8206
800.0	2.1867	1.5498	1.3976	0.8202

Table 4
Thermal Conductivity Calculations

Sample Description	Temperature (°C)	Temperature (°F)	Density (gm/cm^3)	Specific Heat ($W \cdot sec/gm \cdot K$)	Diffusivity (cm^2/sec)	Thermal Conductivity ($W/cm \cdot K$)	Thermal Conductivity ($BTU \cdot in/hr \cdot ft^2 \cdot F$)
BNL	23.0	73.4	1.8799	0.6224	0.03420	0.04002	27.7497
	50.0	122.0	1.8799	0.7000	0.03193	0.04202	29.1361
	100.0	212.0	1.8799	0.8318	0.02846	0.04450	30.8576
	200.0	392.0	1.8799	1.0592	0.02398	0.04776	33.1200
	300.0	572.0	1.8799	1.2556	0.02157	0.05092	35.3110
	400.0	752.0	1.8799	1.4376	0.01996	0.05395	37.4121
	500.0	932.0	1.8799	1.6169	0.01845	0.05608	38.8861
	600.0	1112.0	1.8799	1.8007	0.01714	0.05802	40.2309
	700.0	1292.0	1.8799	1.9913	0.01593	0.05963	41.3501
	800.0	1472.0	1.8799	2.1867	0.01483	0.06096	42.2707
BNLN	23.0	73.4	1.9499	0.6810	0.00758	0.01007	6.9825
	50.0	122.0	1.9499	0.7171	0.00733	0.01025	7.1128
	100.0	212.0	1.9499	0.7828	0.00692	0.01056	7.3242
	200.0	392.0	1.9499	0.9086	0.00639	0.01132	7.8542
	300.0	572.0	1.9499	1.0252	0.00625	0.01249	8.6636
	400.0	752.0	1.9499	1.1306	0.00625	0.01379	9.5679
	500.0	932.0	1.9499	1.2226	0.00636	0.01518	10.5272
	600.0	1112.0	1.9499	1.2991	0.00650	0.01646	11.4171
	700.0	1292.0	1.9499	1.3581	0.00666	0.01763	12.2298
	800.0	1472.0	1.9499	1.3976	0.00683	0.01861	12.9062
BNLW	23.0	73.4	2.1711	0.6186	0.00969	0.01301	9.0249
	50.0	122.0	2.1711	0.7078	0.00922	0.01417	9.8248
	100.0	212.0	2.1711	0.8561	0.00834	0.01550	10.7486
	200.0	392.0	2.1711	1.0929	0.00708	0.01682	11.6631
	300.0	572.0	2.1711	1.2615	0.00654	0.01793	12.4350
	400.0	752.0	2.1711	1.3751	0.00630	0.01881	13.0464
	500.0	932.0	2.1711	1.4472	0.00613	0.01929	13.3765
	600.0	1112.0	2.1711	1.4915	0.00607	0.01968	13.6456
	700.0	1292.0	2.1711	1.5211	0.00601	0.01985	13.7678
	800.0	1472.0	2.1711	1.5498	0.00596	0.02008	13.9268

Table 4
Thermal Conductivity Calculations (Continued)

Sample Description	Temperature (°C)	Temperature (°F)	Density (gm/cm^3)	Specific Heat ($W \cdot sec/gm \cdot K$)	Diffusivity (cm^2/sec)	Thermal Conductivity ($W/cm \cdot K$)	Thermal Conductivity ($BTU \cdot in/hr \cdot ft^2 \cdot F$)
ZMARC	23.0	73.4	3.3867	0.5509	0.01903	0.03551	24.6268
	50.0	122.0	3.3867	0.5809	0.01771	0.03484	24.1595
	100.0	212.0	3.3867	0.6272	0.01592	0.03383	23.4625
	200.0	392.0	3.3867	0.6948	0.01378	0.03244	22.4964
	300.0	572.0	3.3867	0.7431	0.01233	0.03105	21.5304
	400.0	752.0	3.3867	0.7742	0.01149	0.03013	20.8945
	500.0	932.0	3.3867	0.7894	0.01090	0.02916	20.2220
	600.0	1112.0	3.3867	0.8007	0.01038	0.02815	19.5184
	700.0	1292.0	3.3867	0.8062	0.01000	0.02733	18.9502
	800.0	1472.0	3.3867	0.8202	0.00962	0.02674	18.5467

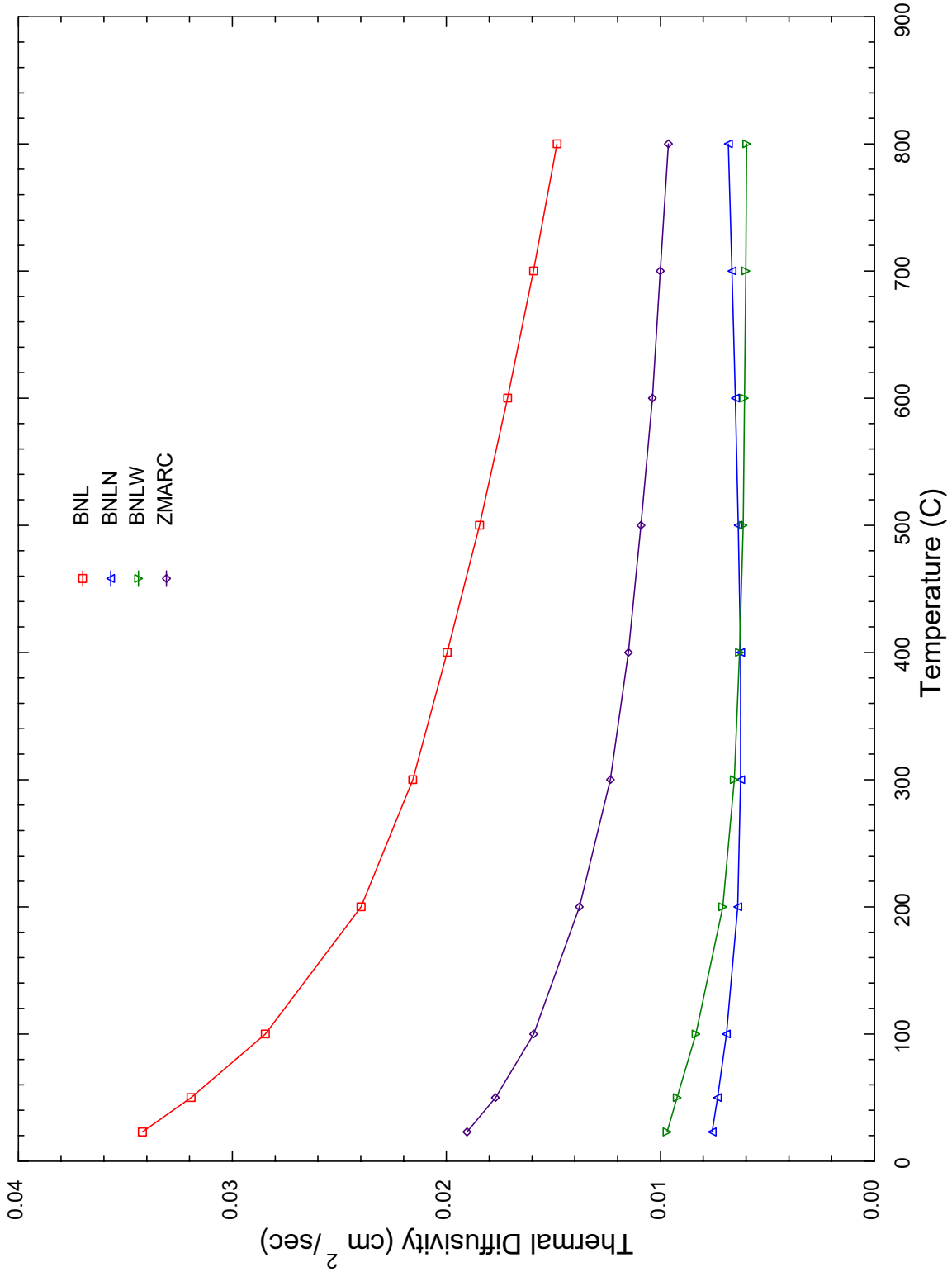

Figure 1: Thermal Diffusivity

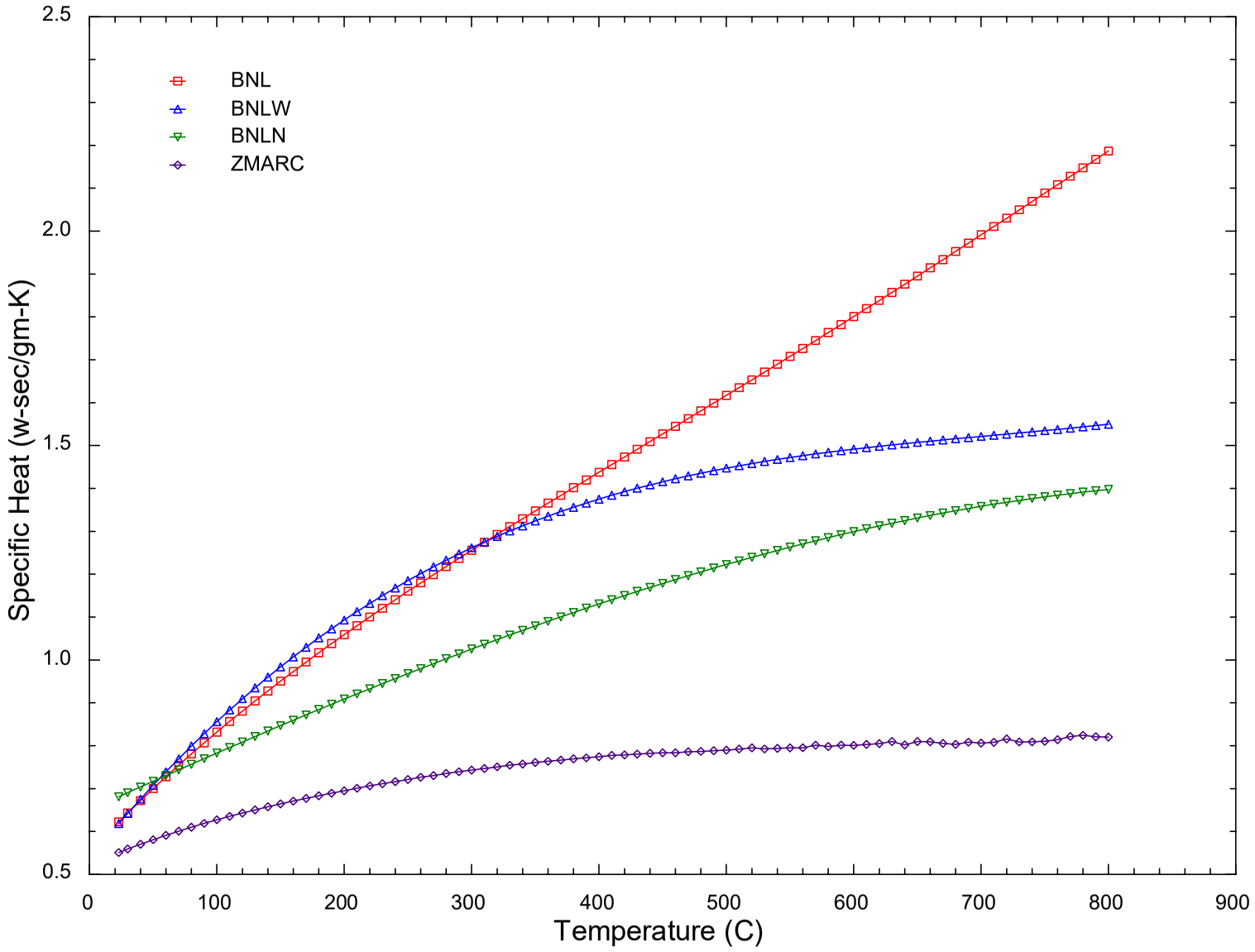

Figure 2: Specific Heat

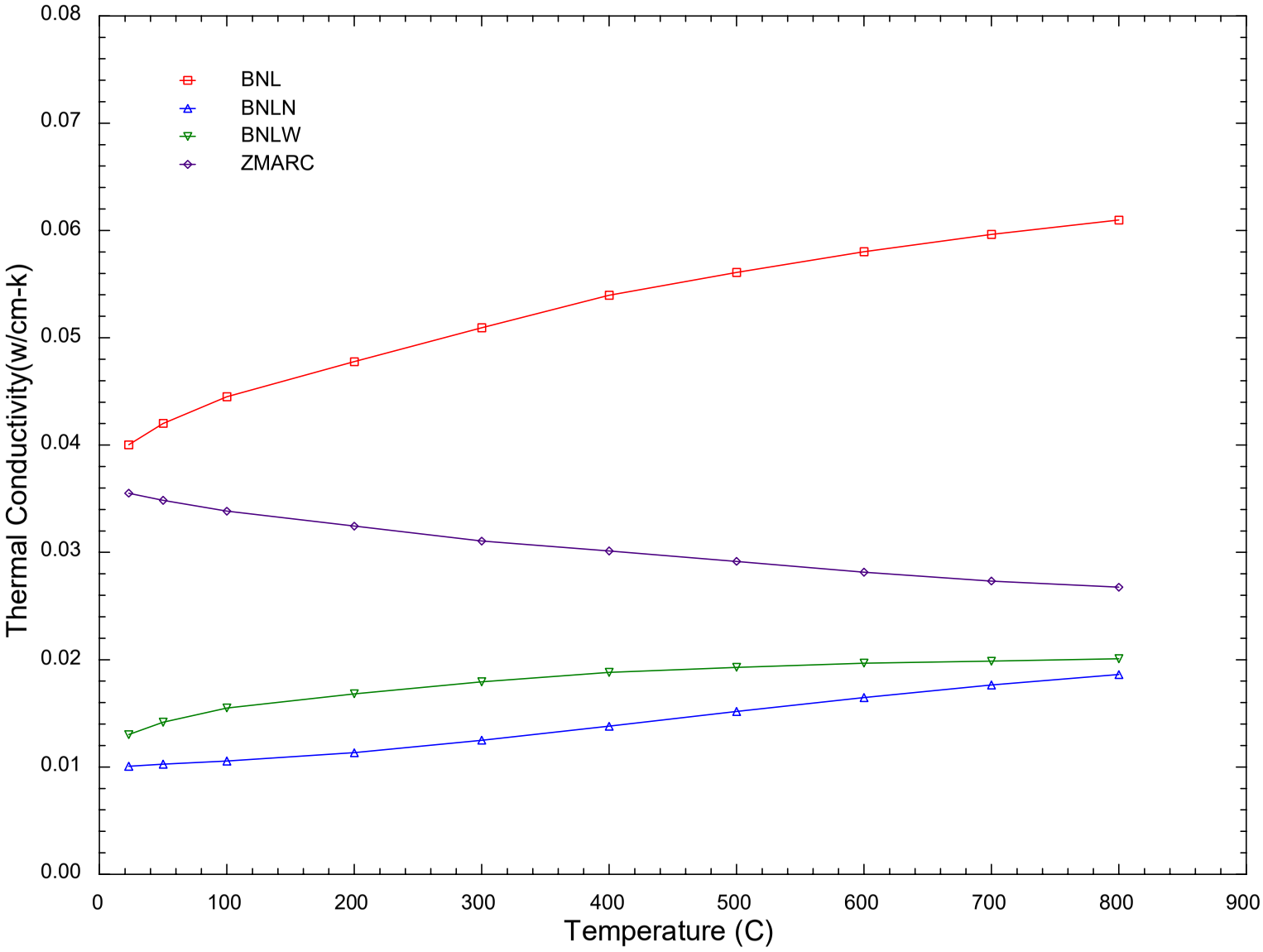

Figure 3: Thermal Conductivity