

NISTIR 89-3914

**LOW-TEMPERATURE  
THERMAL CONDUCTIVITY OF  
COMPOSITES:  
Alumina Fiber/Epoxy and  
Alumina Fiber/PEEK**

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Boulder, Colorado 80303-3328

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## List of Units and Symbols

### Definition of Symbols

$\lambda$  = thermal conductivity, W/(m•K)

$\Delta X$  = mean specimen thickness, m

$A$  = mean specimen area, m<sup>2</sup>

$\Delta T$  = steady-state temperature difference, K

### Unit Conversions

Temperature  $T_C = T_K - 273.15$

$T_C = (T_F - 32)/1.8$

where  $T_K$  is temperature in kelvins,

$T_C$  is temperature in degrees Celsius,

$T_F$  is temperature in degrees Fahrenheit,

Thermal Conductivity  $1.000 \text{ W/(m}\cdot\text{K)} = 0.578 \text{ Btu/(hr}\cdot\text{ft}\cdot\text{°F)}$   
 $= 6.94 \text{ Btu}\cdot\text{in/(hr}\cdot\text{ft}^2\cdot\text{°F)}$

Pressure  $1.000 \text{ Pa} = 7.501 \times 10^{-3} \text{ torr}$

Force  $1.000 \text{ N} = 0.22481 \text{ lb force}$



## Low-Temperature Thermal Conductivity of Composites:

### Alumina Fiber/Epoxy and Alumina Fiber/PEEK

The thermal conductivities of poly-ether-ether-ketone (PEEK), of alumina fiber in a matrix of PEEK, and of alumina fiber in a matrix of epoxy, were determined along with the effects of fiber orientation and thermal cycling. Thermal conductivity was measured over the temperature range 4.2 to 310 K using a steady-state apparatus.

These data are presented and discussed relative to specimen characteristics. It appears that after accounting for different fiber fractions in the specimens, the thermal conductivity of the PEEK composite material is less than that of the epoxy composite material in particular temperature ranges.

Key words: alumina; composite; epoxy; low temperature; PEEK; poly-ether-ether-ketone; thermal conductivity.

## Introduction

Polymer composites reinforced with alumina fibers have the potential of being excellent thermal-isolation materials for cryogenic applications. The higher elastic modulus of alumina compared to the traditional glass fiber will improve fatigue resistance. Utilization of the thermoplastic matrix material, poly-ether-ether-ketone (PEEK), also improves the fatigue performance compared to that of epoxy resins. PEEK, being a thermoplastic material, provides attractive advantages for production or fabrication and can be repaired more readily than thermoset materials.

Both thermal and mechanical behavior of composites to be used in cryogenic applications are important. The remainder of this paper deals with experimentally determined thermal conductivities; mechanical properties are being studied in a parallel NIST program.

## Apparatus

The system used to perform measurements of thermal conductivity is a modified version of a previously described "fixed-point" apparatus [1]. The specimen chamber is shown schematically in figure 1. It allows the thermal conductivity to be determined using fixed cold-side temperatures of 4 K (liquid helium), 76 K (liquid nitrogen), 194 K (mixture of dry ice and alcohol), and 273 K (mixture of ice and water). Measurements were performed by placing the chamber in one of the temperature-controlled baths and monitoring the power required to maintain a fixed temperature difference between the top and bottom blocks. The temperature differences between the hot and cold blocks were typically 1, 2, 4, 8, ..., 64 K.

Thermal conductivity measurements of a standard reference material, SRM 735, [2] indicated a total uncertainty of  $\pm 5\%$ . The  $2\sigma$  uncertainty of the composite data being reported is less than  $\pm 5\%$ , as evidenced by the deviation plots. Specimen-to-apparatus thermal contact resistance may cause the accuracy to be slightly worse for the composites than for the metallic SRM.

## Specimens

The materials studied were supplied by Ronald D. Kriz (Fracture & Deformation Division, National Institute of Standards & Technology). All of the alumina fibers contained in the epoxy and PEEK specimens are from a single source. While these fibers are actually composed of about 85 wt%  $\text{Al}_2\text{O}_3$  and 15 wt%  $\text{SiO}_2$  they will be referred to as alumina fibers. Neat PEEK is a specimen with no fiber reinforcement material. All specimens tested were prepared by two private companies. The specimens and nomenclature are identified in table 1.

Table 1 Specimen Identification

Specimen Identification	Comments
EP-Al-0°	Epoxy/Alumina heat flow parallel to fiber direction
EP-Al-90°	Epoxy/Alumina heat flow perpendicular to fiber direction
PK-Al-1-0°	PEEK/Alumina heat flow parallel to fiber direction
PK-Al-1-90°	PEEK/Alumina heat flow perpendicular to fiber direction
PK-Al-2-0°	PEEK/Alumina heat flow parallel to fiber direction
Neat-PK	Neat PEEK absent of fibers

The specimens were constructed by cementing smaller segments together with a thin layer of cyanoacrylate adhesive. The laminated specimens were ground to the shape of a uniform block with parallel ( $\pm 0.003$  cm) faces. The physical characteristics of the specimens are given in table 2. An estimate of the fiber content of the specimens is also given in table 2. These values were determined from photomicrographs of the specimen plane perpendicular to the fiber axes (Appendix A).

The steady-state measurements were made with a specimen in a vacuum environment of  $1.07 \times 10^{-2}$  Pa ( $8 \times 10^{-5}$  torr). In each case the specimens had thermally conductive grease and indium foil ( $76 \mu\text{m}$  thick) on each contact surface to reduce thermal resistance. The load applied to the specimens, at room temperature, was a constant 4270 N (960 lb).

Table 2 Physical Characteristics of Specimens

Specimen Identification	Area cm <sup>2</sup>	Thickness cm	Number of Segments	Alumina Fiber Volume Ratio %
EP-A1-0°	0.5623	0.6359	2	59
EP-A1-90°	1.1909	0.3002	2	
PK-A1-1-0°	2.7327	0.8376	4	43
PK-A1-1-90°	3.0067	0.7239	2	
PK-A1-2-0°	1.4341	0.8310	4	52
Neat-PK	2.8159	0.6426	2	

## Results

The thermal conductivities of alumina fiber/epoxy and alumina fiber/PEEK were measured parallel (0°) and perpendicular (90°) to the fiber direction. A neat PEEK specimen was also measured. Data were taken over the temperature range 4.2 to 310 K. Since large temperature gradients are used and the thermal conductivity as a function of temperature is not simply linear, a thermal conductivity integral method [3] was used.

The function chosen to fit the thermal conductivity data is

$$\lambda(T) = \sum_{i=1}^n a_i [\ln(T+1)]^i \quad (1)$$

The experimental data, resulting values of  $a_i$ , and tabular data of the function for each of the six specimens, are presented in tables 4 through 21. To obtain proper fits it was necessary to weight some data. Plots of thermal conductivity and relative deviations, as a function of temperature, are given in figures 2 through 13. For

convenience, table 3 is an index of the plots and tables for all of the specimens tested.

Table 3 Location Index for Figures and Tables of All Specimens.

Specimen Identification	Tables			Figures	
	Table of Data	Table of Coeff's	Table of $\lambda(T)$	Plot of $\lambda(T)$	Plot of Deviations
EP-Al-0°	4	5	6	2	3
EP-Al-90°	7	8	9	4	5
PK-Al-1-0°	10	11	12	6	7
PK-Al-1-90°	13	14	15	8	9
PK-Al-2-0°	16	17	18	10	11
Neat-PK	19	20	21	12	13

## Discussion

### Heat Flow Parallel to Fiber Direction

A direct comparison of the thermal conductivities of the PEEK/alumina composites with those of the epoxy/alumina composite cannot be made due to differences in the fiber content of the specimens tested (values listed in table 2). Because the alumina fiber material is a better thermal conductor than either matrix material, an increased fiber content should increase the thermal conductivity of a specimen. A simple parallel heat flow model was applied to the PEEK/alumina composites. It was found to be insufficient for predicting the thermal conductivity in other composites with different fiber volume ratios.

Figure 14 shows the thermal conductivity for the PK-Al-1-0° and PK-Al-2-0°. The curves for these two specimens are of similar shape with a vertical shift between them. The magnitude of this shift is  $\approx 17\%$  and is uniform over the entire temperature range tested. It is likely that this shift can be attributed to the different fiber volume ratios of the specimens.

The thermal conductivity is related to the fiber volume ratio in the PEEK composite materials. Figures 15 and 16 shows this relationship for a family of temperatures using the data of PK-Al-1-0°, PK-Al-2-0° and Neat-PK. This relationship may be a good model for predicting results for other fiber volume ratios in the PEEK composite materials. A comparison of the thermal conductivity between the PEEK material and the epoxy material can be approximated. By utilizing the thermal conductivity-fiber volume ratio relationship, a PEEK-alumina fiber specimen with the same fiber volume ratio as the EP-Al-0° specimen can be determined. A linear extrapolation of the



fiber volume ratio, using the two PEEK-alumina specimens, was used to determine thermal conductivity as a function of temperature for a fiber volume ratio of 59%. Because the relationship between thermal conductivity and fiber volume ratios may not be a linear function, additional experimental data would be required to establish a more accurate relationship. The resulting calculated curve is compared with the EP-Al-0° data in figures 17 and 18. From this comparison, the thermal conductivity of a PEEK/alumina composite is slightly less than an epoxy/alumina composite of similar fiber volume ratio above  $\approx 100$  K and below  $\approx 9$  K. The thermal conductivity as a function of temperature between 9 and 100 K, for one matrix material, does not differ appreciably from that of the other material.

#### Heat Flow Perpendicular to Fiber Direction

The thermal conductivities of the specimens tested with the heat flow perpendicular to the alumina fibers are shown in figures 21 and 22. A crossover occurs at  $\approx 23$  K between the Neat-PK curve and the PK-Al-1-90° curve. Further study is required before an explanation of this effect can be suggested. The heat transfer characteristics may be further complicated by anisotropy in the PEEK material itself. The importance of this effect has yet to be determined.

#### Thermal Cycling of PEEK Composite

After initial tests were conducted on one of the original PEEK/alumina specimens (PK-Al-1-0°) it was thermally cycled. This experiment was done to determine if the conductivity of the PEEK composite material is affected by strains induced due to repeated thermal cycles. The specimen was cycled 25 times between room temperature and liquid nitrogen temperature (one of these cycles was to 4 K) and retested as before. Thermal conductivity was measured with the heat flow parallel to the fiber direction only. No effect on thermal conductivity due to this thermal cycling was detectable within the total experimental uncertainty ( $\pm 5\%$ ) outlined above.

The remaining figures are various comparisons giving additional perspectives. Logarithmic and linear presentations of the data are given to highlight the behavior of conductivity over ranges of both high and low temperatures.

#### **Acknowledgments**

The authors wish to recognize B. J. Filla and J. G. Hust for their contributions in developing the apparatus and automating the control and acquisition features of this system. R. D. Kriz was primarily responsible for acquiring the specimens. Materials and fabrication were due to the efforts of I.C.I. Americas, Inc., Structural Composites Industries and Sumitomo Corporation.

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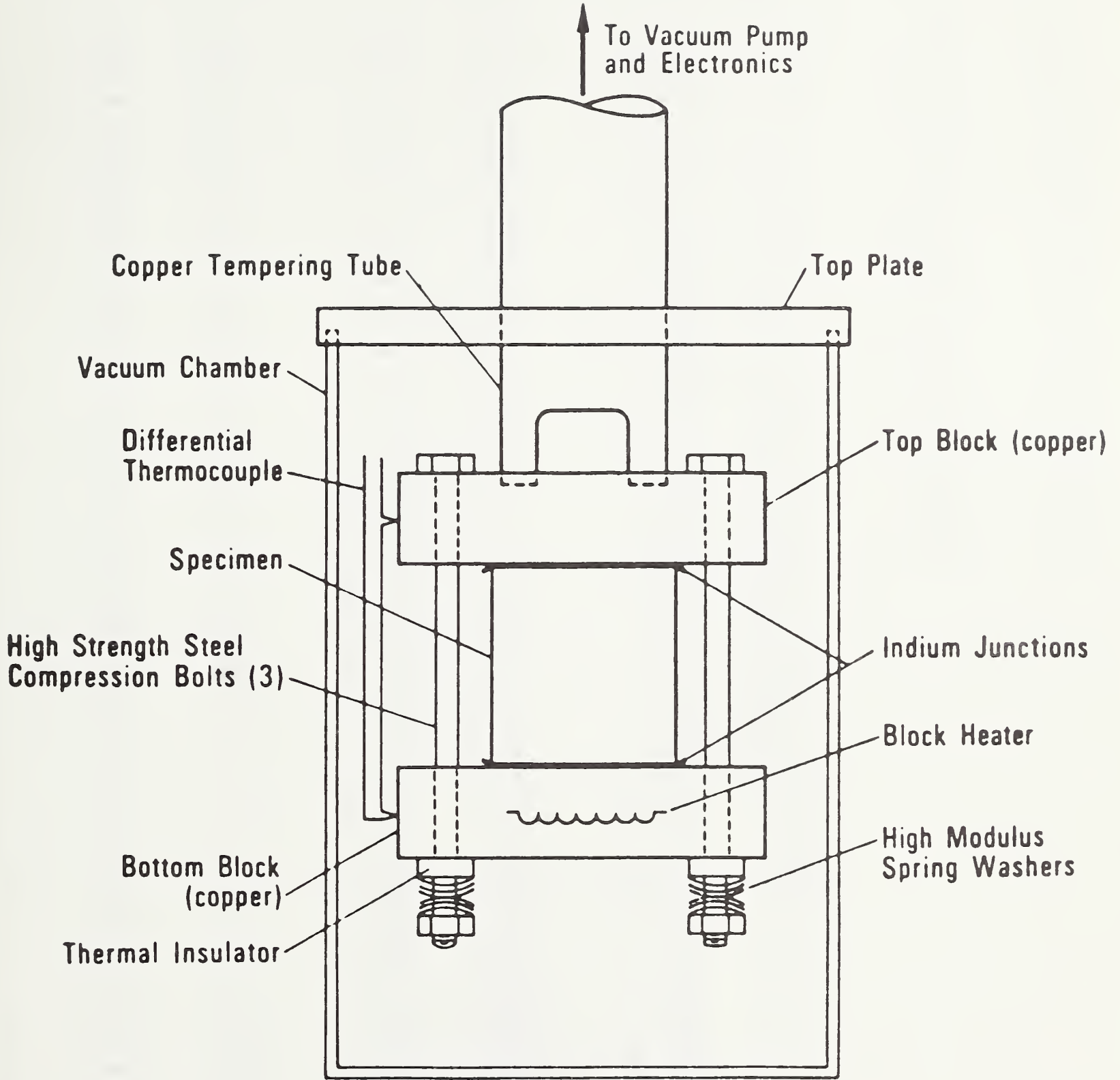


Figure 1 Specimen chamber for "fixed point" compression probe.

**Table 4** Experimental Data for EP-Al-0°

Average Temperature Kelvin	Thermal Conductivity, W/(m·K)
5.132	0.025
6.154	0.027
8.189	0.035
12.314	0.055
20.940	0.116
38.727	0.280
76.522	0.597
77.043	0.596
78.088	0.615
80.180	0.628
84.376	0.659
92.820	0.723
109.892	0.840
192.557	1.300
193.119	1.368
194.235	1.333
196.478	1.348
200.974	1.343
210.038	1.363
228.463	1.402
273.716	1.527
274.280	1.487
275.412	1.501
277.681	1.509
282.233	1.541
291.435	1.558
310.207	1.647

**Table 5** Coefficients of  $\lambda(T)$  for EP-Al-0°

a <sub>1</sub>	9.4838610E-02
a <sub>2</sub>	-1.4612297E-01
a <sub>3</sub>	1.1101024E-01
a <sub>4</sub>	-4.5386804E-02
a <sub>5</sub>	9.5660835E-03
a <sub>6</sub>	-7.1230263E-04

Table 6 Thermal Conductivity Values as a Function of Temperature  
for Specimen EP-Al-0°

T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)
4.1000	0.0234	9.1000	0.0364	51.0000	0.3811	110.0000	0.8646
4.2000	0.0235	9.2000	0.0368	52.0000	0.3903	120.0000	0.9318
4.3000	0.0237	9.3000	0.0372	53.0000	0.3996	130.0000	0.9947
4.4000	0.0238	9.4000	0.0377	54.0000	0.4088	140.0000	1.0537
4.5000	0.0239	9.5000	0.0381	55.0000	0.4180	150.0000	1.1088
4.6000	0.0241	9.6000	0.0385	56.0000	0.4272	160.0000	1.1602
4.7000	0.0242	9.7000	0.0389	57.0000	0.4363	170.0000	1.2081
4.8000	0.0244	9.8000	0.0393	58.0000	0.4454	180.0000	1.2526
4.9000	0.0245	9.9000	0.0398	59.0000	0.4545	190.0000	1.2940
5.0000	0.0247	10.0000	0.0402	60.0000	0.4636	200.0000	1.3322
5.1000	0.0248	11.0000	0.0448	61.0000	0.4726	210.0000	1.3675
5.2000	0.0250	12.0000	0.0499	62.0000	0.4816	220.0000	1.4000
5.3000	0.0252	13.0000	0.0554	63.0000	0.4905	230.0000	1.4298
5.4000	0.0254	14.0000	0.0612	64.0000	0.4995	240.0000	1.4571
5.5000	0.0256	15.0000	0.0674	65.0000	0.5084	250.0000	1.4820
5.6000	0.0258	16.0000	0.0739	66.0000	0.5172	260.0000	1.5044
5.7000	0.0260	17.0000	0.0807	67.0000	0.5260	270.0000	1.5247
5.8000	0.0262	18.0000	0.0877	68.0000	0.5348	280.0000	1.5428
5.9000	0.0264	19.0000	0.0950	69.0000	0.5435	290.0000	1.5588
6.0000	0.0267	20.0000	0.1025	70.0000	0.5522	300.0000	1.5728
6.1000	0.0269	21.0000	0.1103	71.0000	0.5609	310.0000	1.5849
6.2000	0.0271	22.0000	0.1182	72.0000	0.5695	320.0000	1.5952
6.3000	0.0274	23.0000	0.1263	73.0000	0.5780	330.0000	1.6037
6.4000	0.0276	24.0000	0.1345	74.0000	0.5866	340.0000	1.6105
6.5000	0.0279	25.0000	0.1429	75.0000	0.5951		
6.6000	0.0281	26.0000	0.1514	76.0000	0.6035		
6.7000	0.0284	27.0000	0.1600	77.0000	0.6119		
6.8000	0.0287	28.0000	0.1687	78.0000	0.6203		
6.9000	0.0290	29.0000	0.1776	79.0000	0.6286		
7.0000	0.0293	30.0000	0.1865	80.0000	0.6369		
7.1000	0.0295	31.0000	0.1954	81.0000	0.6451		
7.2000	0.0298	32.0000	0.2045	82.0000	0.6533		
7.3000	0.0301	33.0000	0.2136	83.0000	0.6614		
7.4000	0.0304	34.0000	0.2227	84.0000	0.6695		
7.5000	0.0308	35.0000	0.2319	85.0000	0.6776		
7.6000	0.0311	36.0000	0.2411	86.0000	0.6856		
7.7000	0.0314	37.0000	0.2504	87.0000	0.6935		
7.8000	0.0317	38.0000	0.2597	88.0000	0.7015		
7.9000	0.0321	39.0000	0.2690	89.0000	0.7094		
8.0000	0.0324	40.0000	0.2783	90.0000	0.7172		
8.1000	0.0327	41.0000	0.2877	91.0000	0.7250		
8.2000	0.0331	42.0000	0.2970	92.0000	0.7327		
8.3000	0.0334	43.0000	0.3064	93.0000	0.7404		
8.4000	0.0338	44.0000	0.3158	94.0000	0.7481		
8.5000	0.0342	45.0000	0.3251	95.0000	0.7557		
8.6000	0.0345	46.0000	0.3345	96.0000	0.7633		
8.7000	0.0349	47.0000	0.3438	97.0000	0.7708		
8.8000	0.0353	48.0000	0.3531	98.0000	0.7783		
8.9000	0.0357	49.0000	0.3625	99.0000	0.7857		
9.0000	0.0361	50.0000	0.3718	100.0000	0.7931		

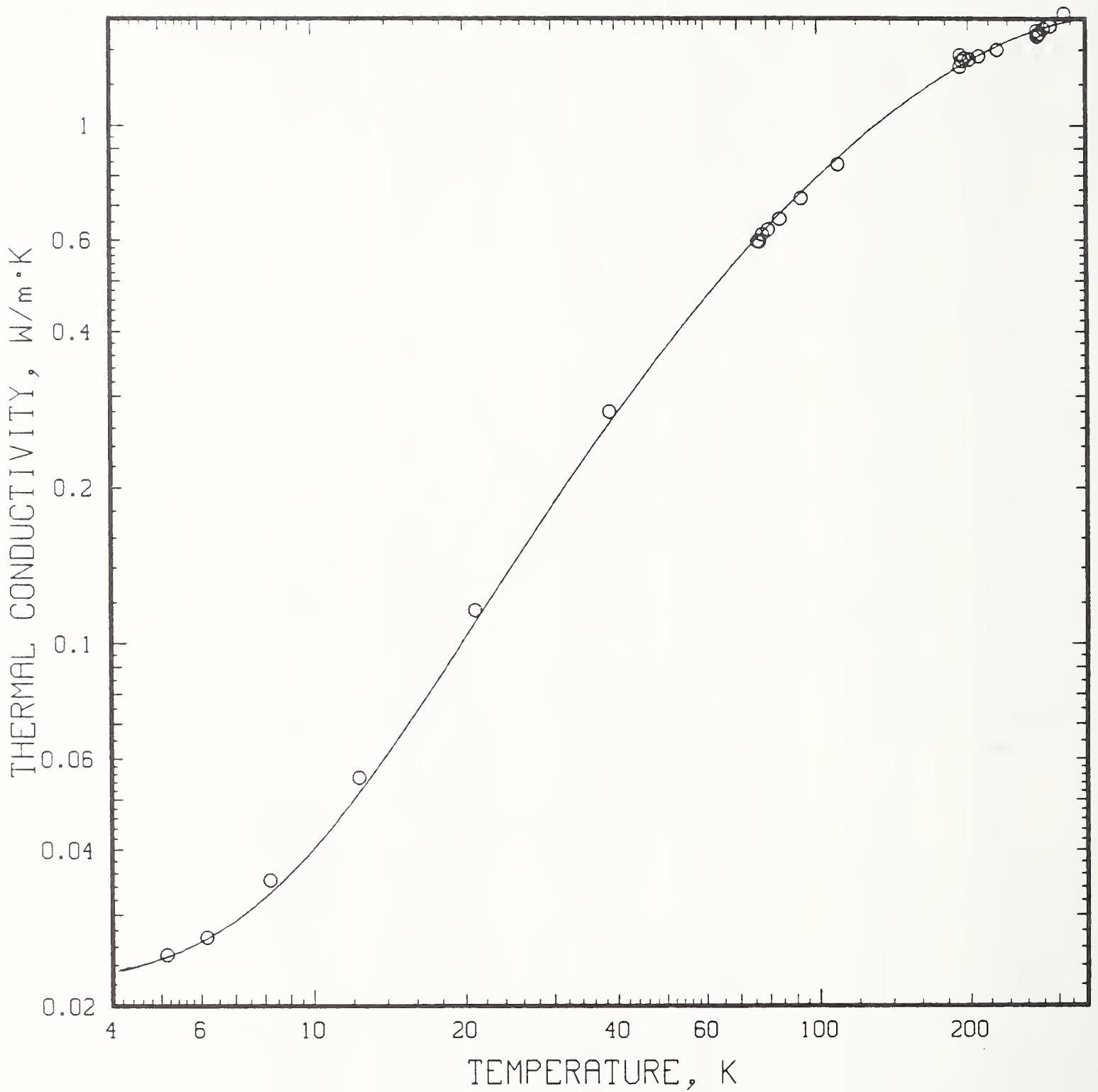
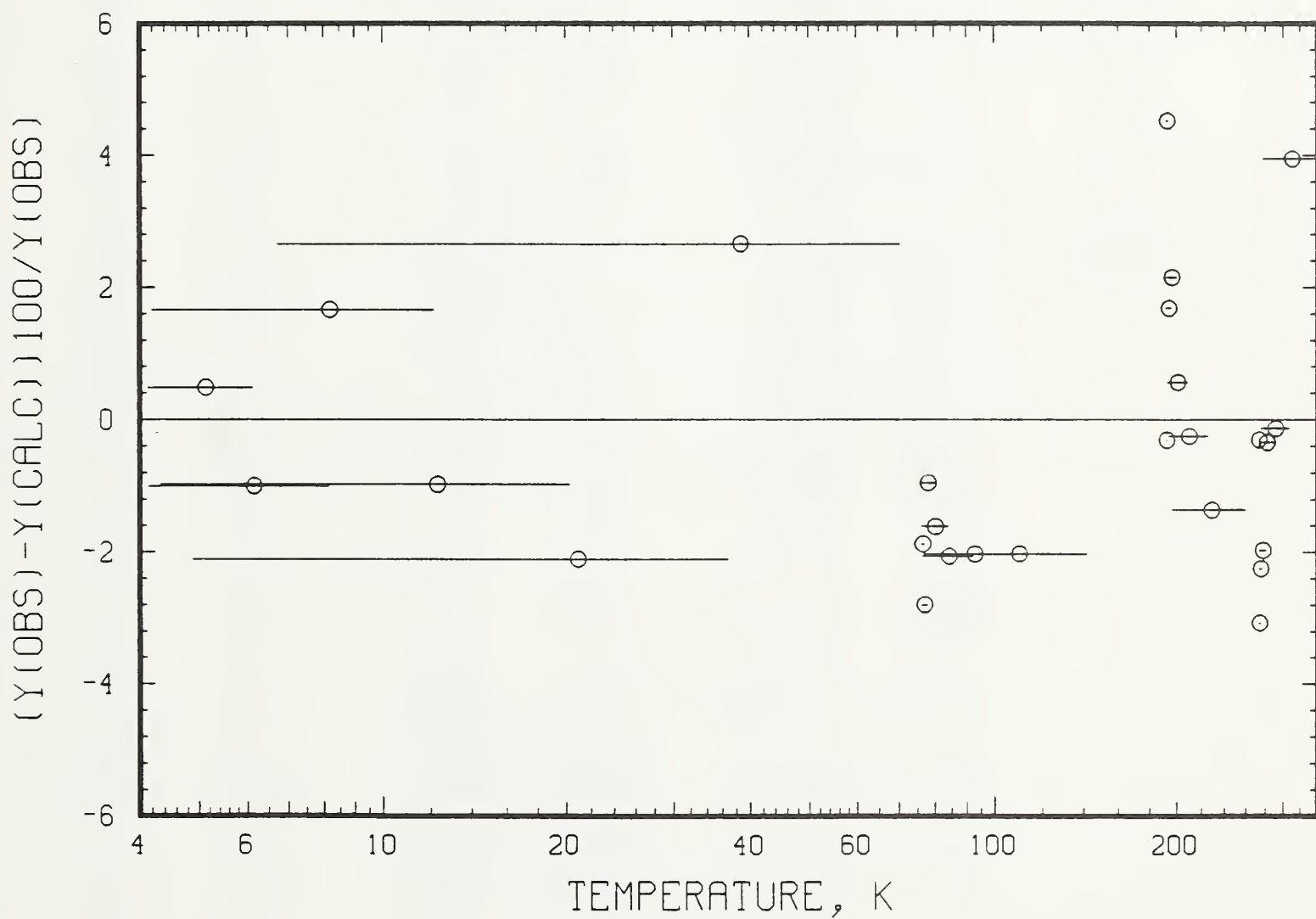


Figure 2 Thermal conductivity of specimen EP-Al-0°. Experimental data are presented as discrete points.



**Figure 3** Relative deviations of the experimental and calculated thermal conductivity integrals for specimen EP-Al-0°. (The horizontal bar indicates the span of temperature for each run).

Table 7 Experimental Data for EP-Al-90°

Average Temperature Kelvin	Thermal Conductivity W/(m·K)
4.630	0.014
5.140	0.016
6.169	0.019
8.273	0.027
12.610	0.047
21.908	0.103
41.595	0.231
76.552	0.427
77.103	0.427
78.208	0.434
80.427	0.444
84.890	0.465
93.923	0.499
112.346	0.563
192.620	0.801
193.241	0.806
194.484	0.808
196.977	0.811
201.987	0.819
212.081	0.827
278.117	0.926
283.123	0.937
293.259	0.961
306.262	0.962

Table 8 Coefficients of  $\lambda(T)$  for EP-Al-90°

a <sub>1</sub>	-4.7747384E-02
a <sub>2</sub>	9.8421893E-02
a <sub>3</sub>	-6.4348531E-02
a <sub>4</sub>	1.7615317E-02
a <sub>5</sub>	-1.4383095E-03



Table 9 Thermal Conductivity Values as a Function of Temperature  
for Specimen EP-Al-90°

T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)
4.1000	0.0128	9.1000	0.0288	51.0000	0.2868	110.0000	0.5699
4.2000	0.0131	9.2000	0.0292	52.0000	0.2927	120.0000	0.6063
4.3000	0.0133	9.3000	0.0296	53.0000	0.2986	130.0000	0.6401
4.4000	0.0136	9.4000	0.0300	54.0000	0.3045	140.0000	0.6714
4.5000	0.0139	9.5000	0.0304	55.0000	0.3103	150.0000	0.7004
4.6000	0.0142	9.6000	0.0309	56.0000	0.3161	160.0000	0.7274
4.7000	0.0144	9.7000	0.0313	57.0000	0.3218	170.0000	0.7524
4.8000	0.0147	9.8000	0.0317	58.0000	0.3275	180.0000	0.7756
4.9000	0.0150	9.9000	0.0321	59.0000	0.3331	190.0000	0.7972
5.0000	0.0153	10.0000	0.0326	60.0000	0.3387	200.0000	0.8173
5.1000	0.0155	11.0000	0.0371	61.0000	0.3443	210.0000	0.8359
5.2000	0.0158	12.0000	0.0419	62.0000	0.3498	220.0000	0.8531
5.3000	0.0161	13.0000	0.0471	63.0000	0.3553	230.0000	0.8691
5.4000	0.0164	14.0000	0.0524	64.0000	0.3607	240.0000	0.8838
5.5000	0.0166	15.0000	0.0580	65.0000	0.3661	250.0000	0.8975
5.6000	0.0169	16.0000	0.0638	66.0000	0.3714	260.0000	0.9101
5.7000	0.0172	17.0000	0.0697	67.0000	0.3768	270.0000	0.9217
5.8000	0.0175	18.0000	0.0758	68.0000	0.3820	280.0000	0.9323
5.9000	0.0178	19.0000	0.0819	69.0000	0.3873	290.0000	0.9421
6.0000	0.0181	20.0000	0.0882	70.0000	0.3924	300.0000	0.9510
6.1000	0.0184	21.0000	0.0946	71.0000	0.3976	310.0000	0.9592
6.2000	0.0187	22.0000	0.1010	72.0000	0.4027	320.0000	0.9665
6.3000	0.0190	23.0000	0.1075	73.0000	0.4078	330.0000	0.9732
6.4000	0.0193	24.0000	0.1140	74.0000	0.4128		
6.5000	0.0196	25.0000	0.1206	75.0000	0.4178		
6.6000	0.0199	26.0000	0.1272	76.0000	0.4227		
6.7000	0.0202	27.0000	0.1338	77.0000	0.4276		
6.8000	0.0205	28.0000	0.1404	78.0000	0.4325		
6.9000	0.0208	29.0000	0.1470	79.0000	0.4373		
7.0000	0.0211	30.0000	0.1536	80.0000	0.4421		
7.1000	0.0215	31.0000	0.1602	81.0000	0.4469		
7.2000	0.0218	32.0000	0.1668	82.0000	0.4516		
7.3000	0.0221	33.0000	0.1734	83.0000	0.4563		
7.4000	0.0225	34.0000	0.1800	84.0000	0.4609		
7.5000	0.0228	35.0000	0.1865	85.0000	0.4656		
7.6000	0.0232	36.0000	0.1930	86.0000	0.4701		
7.7000	0.0235	37.0000	0.1995	87.0000	0.4747		
7.8000	0.0239	38.0000	0.2060	88.0000	0.4792		
7.9000	0.0242	39.0000	0.2124	89.0000	0.4836		
8.0000	0.0246	40.0000	0.2188	90.0000	0.4881		
8.1000	0.0249	41.0000	0.2252	91.0000	0.4925		
8.2000	0.0253	42.0000	0.2315	92.0000	0.4968		
8.3000	0.0257	43.0000	0.2378	93.0000	0.5012		
8.4000	0.0260	44.0000	0.2441	94.0000	0.5055		
8.5000	0.0264	45.0000	0.2503	95.0000	0.5097		
8.6000	0.0268	46.0000	0.2565	96.0000	0.5140		
8.7000	0.0272	47.0000	0.2626	97.0000	0.5182		
8.8000	0.0276	48.0000	0.2687	98.0000	0.5223		
8.9000	0.0280	49.0000	0.2748	99.0000	0.5265		
9.0000	0.0284	50.0000	0.2808	100.0000	0.5306		

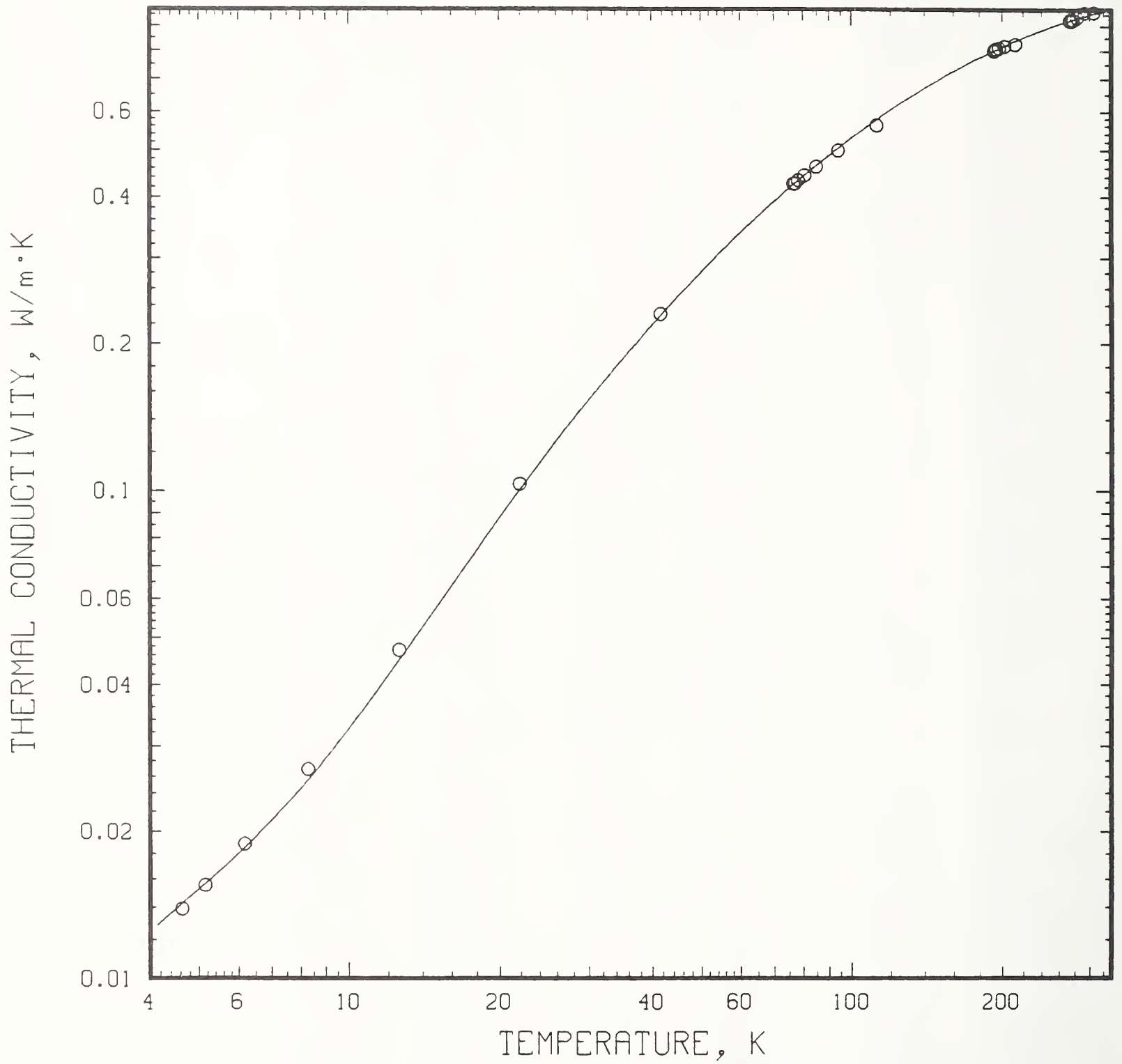


Figure 4 Thermal conductivity of specimen EP-Al-90°. Experimental data are presented as discrete points.

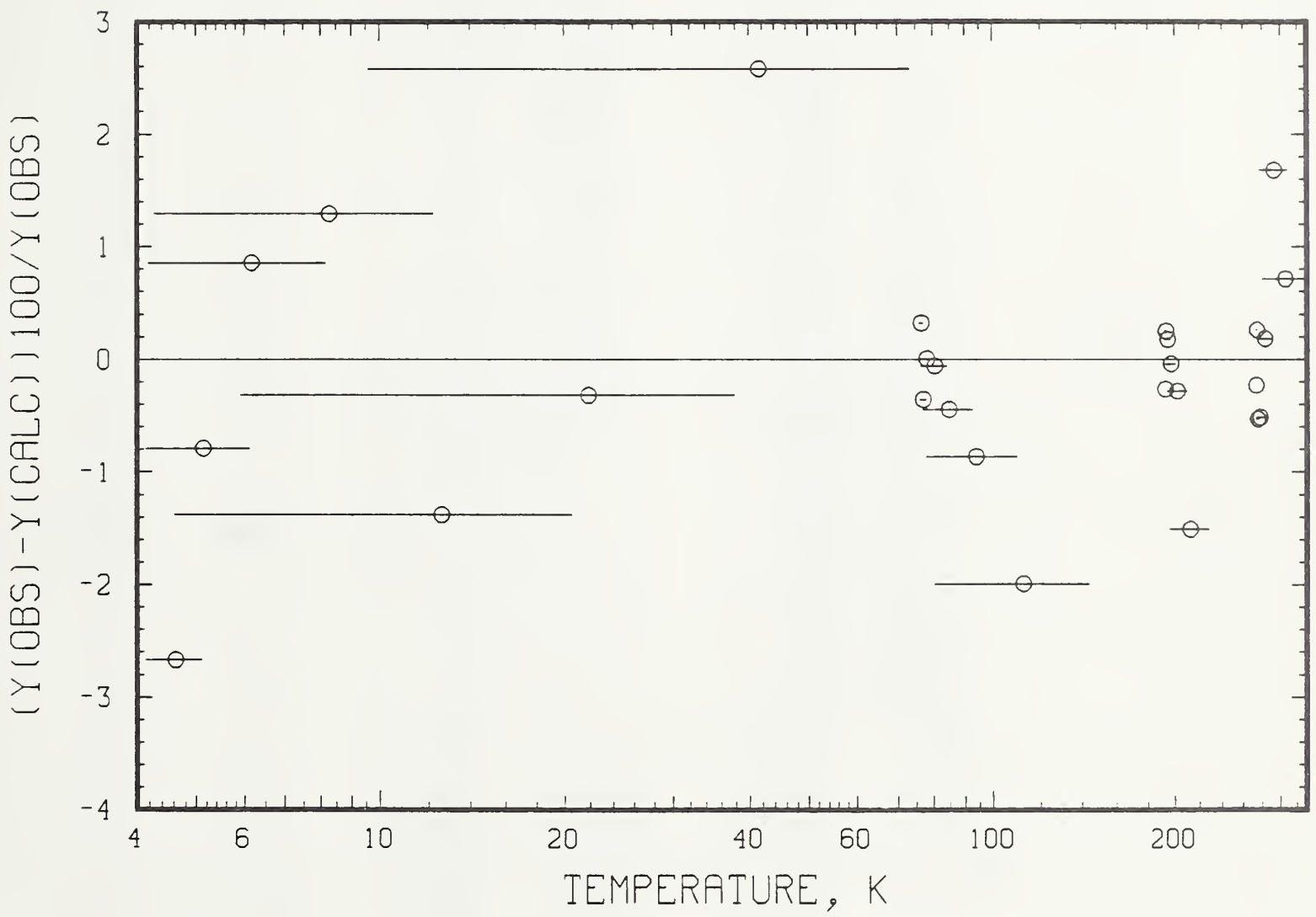


Figure 5 Relative deviations of the experimental and calculated thermal conductivity integrals for specimen EP-Al-90°.

Table 10 Experimental Data for PK-Al-1-0°

Average Temperature Kelvin	Thermal Conductivity W/(m·K)
4.628	0.013
5.138	0.014
6.160	0.017
8.250	0.024
12.508	0.041
21.525	0.088
40.611	0.203
40.625	0.205
76.542	0.406
77.085	0.411
78.173	0.419
80.354	0.431
84.743	0.455
93.635	0.501
111.841	0.590
192.617	0.944
193.233	0.937
194.467	0.939
196.941	0.942
201.921	0.955
211.988	0.975
232.568	1.015
273.769	1.119
274.390	1.126
275.630	1.124
278.119	1.129
283.131	1.146
293.267	1.173
305.906	1.196

Table 11 Coefficients of  $\lambda(T)$  for PK-Al-1-0°

a <sub>1</sub>	1.2517495E-01
a <sub>2</sub>	-2.1465594E-01
a <sub>3</sub>	1.5127037E-01
a <sub>4</sub>	-5.2639361E-02
a <sub>5</sub>	9.2557441E-03
a <sub>6</sub>	-6.0375954E-04

Table 12 Thermal Conductivity Values as a Function of Temperature  
for Specimen PK-Al-1-0°

T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)
4.1000	0.0124	9.1000	0.0267	51.0000	0.2609	110.0000	0.5903
4.2000	0.0125	9.2000	0.0270	52.0000	0.2670	120.0000	0.6386
4.3000	0.0126	9.3000	0.0274	53.0000	0.2731	130.0000	0.6845
4.4000	0.0127	9.4000	0.0278	54.0000	0.2792	140.0000	0.7282
4.5000	0.0129	9.5000	0.0282	55.0000	0.2852	150.0000	0.7697
4.6000	0.0130	9.6000	0.0286	56.0000	0.2913	160.0000	0.8090
4.7000	0.0132	9.7000	0.0290	57.0000	0.2973	170.0000	0.8463
4.8000	0.0133	9.8000	0.0294	58.0000	0.3033	180.0000	0.8816
4.9000	0.0135	9.9000	0.0298	59.0000	0.3093	190.0000	0.9151
5.0000	0.0137	10.0000	0.0302	60.0000	0.3153	200.0000	0.9466
5.1000	0.0139	11.0000	0.0344	61.0000	0.3213	210.0000	0.9764
5.2000	0.0141	12.0000	0.0388	62.0000	0.3273	220.0000	1.0045
5.3000	0.0143	13.0000	0.0432	63.0000	0.3332	230.0000	1.0310
5.4000	0.0146	14.0000	0.0479	64.0000	0.3392	240.0000	1.0559
5.5000	0.0148	15.0000	0.0526	65.0000	0.3451	250.0000	1.0792
5.6000	0.0150	16.0000	0.0575	66.0000	0.3510	260.0000	1.1011
5.7000	0.0153	17.0000	0.0625	67.0000	0.3569	270.0000	1.1216
5.8000	0.0156	18.0000	0.0675	68.0000	0.3628	280.0000	1.1408
5.9000	0.0158	19.0000	0.0727	69.0000	0.3686	290.0000	1.1586
6.0000	0.0161	20.0000	0.0779	70.0000	0.3744	300.0000	1.1751
6.1000	0.0164	21.0000	0.0833	71.0000	0.3803	310.0000	1.1904
6.2000	0.0167	22.0000	0.0887	72.0000	0.3861	320.0000	1.2046
6.3000	0.0169	23.0000	0.0942	73.0000	0.3918	330.0000	1.2176
6.4000	0.0172	24.0000	0.0997	74.0000	0.3976		
6.5000	0.0175	25.0000	0.1053	75.0000	0.4033		
6.6000	0.0178	26.0000	0.1110	76.0000	0.4091		
6.7000	0.0181	27.0000	0.1167	77.0000	0.4148		
6.8000	0.0185	28.0000	0.1224	78.0000	0.4204		
6.9000	0.0188	29.0000	0.1282	79.0000	0.4261		
7.0000	0.0191	30.0000	0.1341	80.0000	0.4317		
7.1000	0.0194	31.0000	0.1399	81.0000	0.4373		
7.2000	0.0198	32.0000	0.1458	82.0000	0.4429		
7.3000	0.0201	33.0000	0.1518	83.0000	0.4485		
7.4000	0.0204	34.0000	0.1577	84.0000	0.4541		
7.5000	0.0208	35.0000	0.1637	85.0000	0.4596		
7.6000	0.0211	36.0000	0.1697	86.0000	0.4651		
7.7000	0.0215	37.0000	0.1757	87.0000	0.4706		
7.8000	0.0218	38.0000	0.1818	88.0000	0.4760		
7.9000	0.0222	39.0000	0.1878	89.0000	0.4815		
8.0000	0.0225	40.0000	0.1939	90.0000	0.4869		
8.1000	0.0229	41.0000	0.2000	91.0000	0.4923		
8.2000	0.0233	42.0000	0.2061	92.0000	0.4976		
8.3000	0.0236	43.0000	0.2122	93.0000	0.5030		
8.4000	0.0240	44.0000	0.2183	94.0000	0.5083		
8.5000	0.0244	45.0000	0.2244	95.0000	0.5136		
8.6000	0.0247	46.0000	0.2305	96.0000	0.5189		
8.7000	0.0251	47.0000	0.2366	97.0000	0.5241		
8.8000	0.0255	48.0000	0.2427	98.0000	0.5294		
8.9000	0.0259	49.0000	0.2488	99.0000	0.5346		
9.0000	0.0263	50.0000	0.2548	100.0000	0.5398		

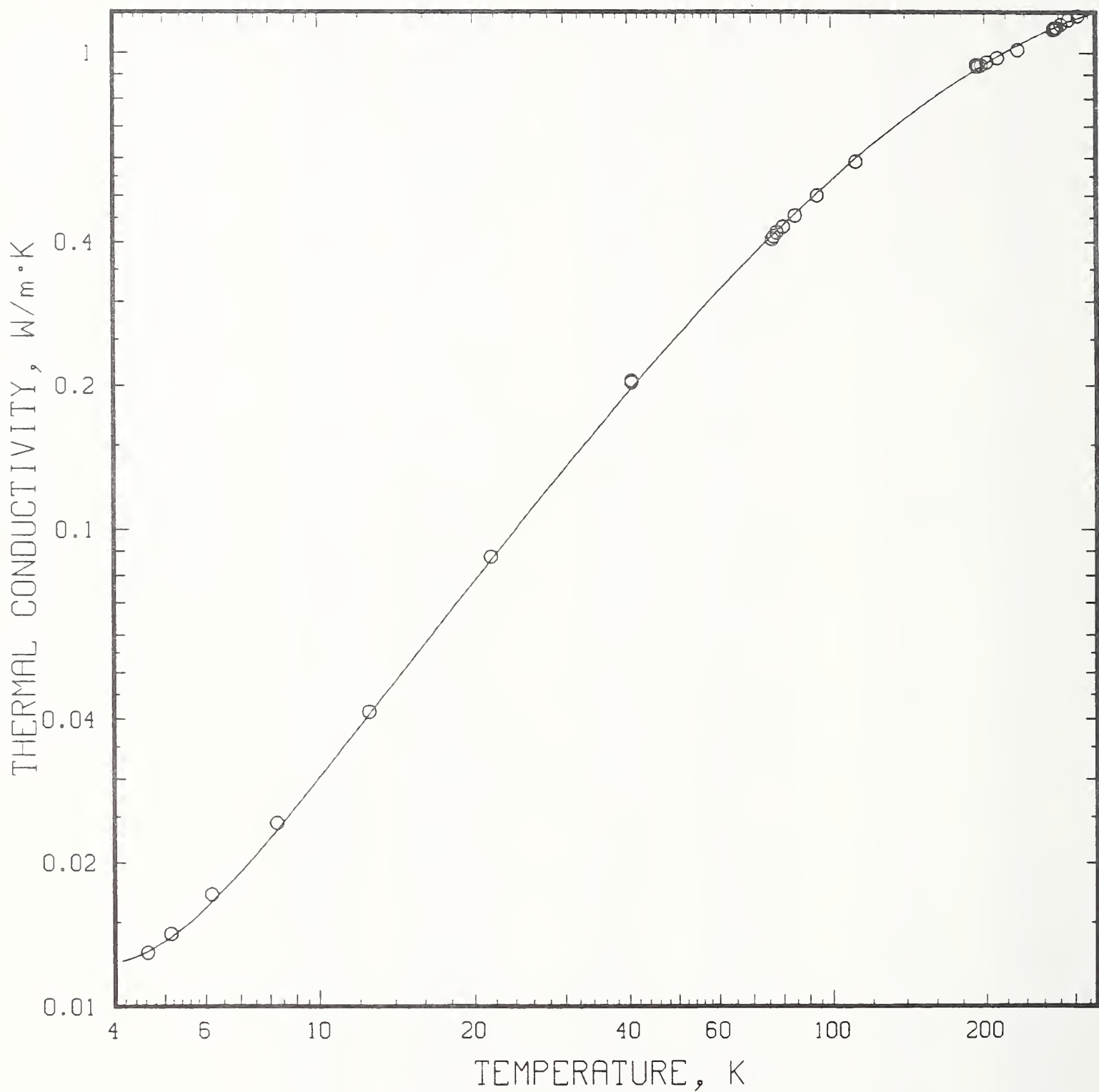


Figure 6 Thermal conductivity of specimen PK-Al-1-0°. Experimental data are presented as discrete points.

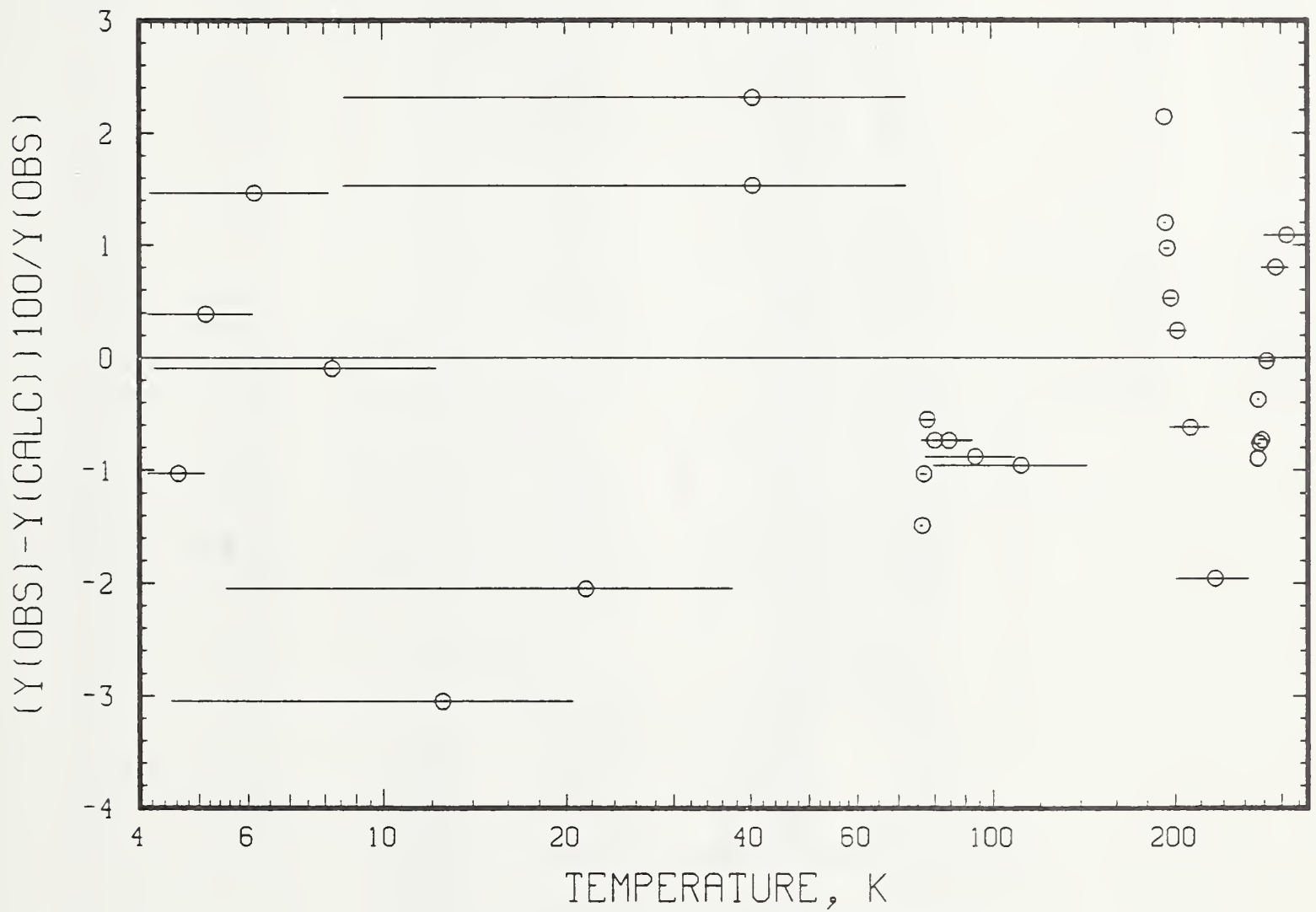


Figure 7 Relative deviations of the experimental and calculated thermal conductivity integrals for specimen PK-Al-1-0°.

Table 13 Experimental Data for PK-Al-1-90°

Average Temperature Kelvin	Thermal Conductivity W/(m·K)
4.627	0.008
5.136	0.009
6.160	0.012
8.232	0.018
12.506	0.033
21.522	0.068
40.280	0.141
76.536	0.260
77.071	0.257
78.143	0.261
80.292	0.265
84.607	0.276
93.302	0.296
98.107	0.308
192.582	0.470
193.162	0.461
194.327	0.463
196.667	0.471
201.362	0.477
210.844	0.487
230.137	0.502
273.738	0.553
274.325	0.544
275.510	0.573
277.856	0.547
282.589	0.551
292.145	0.560
311.721	0.593

Table 14 Coefficients of  $\lambda(T)$  for PK-Al-1-90°

a <sub>1</sub>	3.5119232E-03
a <sub>2</sub>	7.4568227E-03
a <sub>3</sub>	-1.0401511E-02
a <sub>4</sub>	4.4786925E-03
a <sub>5</sub>	-4.1507969E-04



Table 15 Thermal Conductivity Values as a Function of Temperature  
for Specimen PK-Al-1-90°

T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)
4.1000	0.0073	9.1000	0.0200	51.0000	0.1805	110.0000	0.3370
4.2000	0.0075	9.2000	0.0203	52.0000	0.1839	120.0000	0.3572
4.3000	0.0076	9.3000	0.0207	53.0000	0.1872	130.0000	0.3760
4.4000	0.0078	9.4000	0.0210	54.0000	0.1905	140.0000	0.3936
4.5000	0.0080	9.5000	0.0213	55.0000	0.1937	150.0000	0.4100
4.6000	0.0082	9.6000	0.0217	56.0000	0.1970	160.0000	0.4254
4.7000	0.0083	9.7000	0.0220	57.0000	0.2002	170.0000	0.4399
4.8000	0.0085	9.8000	0.0224	58.0000	0.2033	180.0000	0.4535
4.9000	0.0087	9.9000	0.0227	59.0000	0.2065	190.0000	0.4663
5.0000	0.0089	10.0000	0.0230	60.0000	0.2096	200.0000	0.4784
5.1000	0.0091	11.0000	0.0266	61.0000	0.2127	210.0000	0.4897
5.2000	0.0093	12.0000	0.0303	62.0000	0.2157	220.0000	0.5005
5.3000	0.0095	13.0000	0.0341	63.0000	0.2188	230.0000	0.5106
5.4000	0.0097	14.0000	0.0380	64.0000	0.2218	240.0000	0.5202
5.5000	0.0099	15.0000	0.0420	65.0000	0.2248	250.0000	0.5292
5.6000	0.0101	16.0000	0.0461	66.0000	0.2277	260.0000	0.5378
5.7000	0.0104	17.0000	0.0501	67.0000	0.2307	270.0000	0.5459
5.8000	0.0106	18.0000	0.0542	68.0000	0.2336	280.0000	0.5535
5.9000	0.0108	19.0000	0.0584	69.0000	0.2365	290.0000	0.5608
6.0000	0.0111	20.0000	0.0625	70.0000	0.2393	300.0000	0.5676
6.1000	0.0113	21.0000	0.0666	71.0000	0.2422	310.0000	0.5741
6.2000	0.0115	22.0000	0.0708	72.0000	0.2450	320.0000	0.5803
6.3000	0.0118	23.0000	0.0749	73.0000	0.2478	330.0000	0.5861
6.4000	0.0120	24.0000	0.0790	74.0000	0.2506	340.0000	0.5915
6.5000	0.0123	25.0000	0.0831	75.0000	0.2533		
6.6000	0.0126	26.0000	0.0872	76.0000	0.2560		
6.7000	0.0128	27.0000	0.0913	77.0000	0.2587		
6.8000	0.0131	28.0000	0.0953	78.0000	0.2614		
6.9000	0.0134	29.0000	0.0994	79.0000	0.2641		
7.0000	0.0136	30.0000	0.1034	80.0000	0.2667		
7.1000	0.0139	31.0000	0.1073	81.0000	0.2693		
7.2000	0.0142	32.0000	0.1113	82.0000	0.2719		
7.3000	0.0145	33.0000	0.1152	83.0000	0.2745		
7.4000	0.0147	34.0000	0.1191	84.0000	0.2771		
7.5000	0.0150	35.0000	0.1230	85.0000	0.2796		
7.6000	0.0153	36.0000	0.1268	86.0000	0.2821		
7.7000	0.0156	37.0000	0.1306	87.0000	0.2846		
7.8000	0.0159	38.0000	0.1344	88.0000	0.2871		
7.9000	0.0162	39.0000	0.1381	89.0000	0.2895		
8.0000	0.0165	40.0000	0.1418	90.0000	0.2920		
8.1000	0.0168	41.0000	0.1455	91.0000	0.2944		
8.2000	0.0171	42.0000	0.1491	92.0000	0.2968		
8.3000	0.0174	43.0000	0.1527	93.0000	0.2992		
8.4000	0.0177	44.0000	0.1563	94.0000	0.3015		
8.5000	0.0181	45.0000	0.1599	95.0000	0.3039		
8.6000	0.0184	46.0000	0.1634	96.0000	0.3062		
8.7000	0.0187	47.0000	0.1669	97.0000	0.3085		
8.8000	0.0190	48.0000	0.1703	98.0000	0.3108		
8.9000	0.0193	49.0000	0.1738	99.0000	0.3131		
9.0000	0.0197	50.0000	0.1772	100.0000	0.3153		

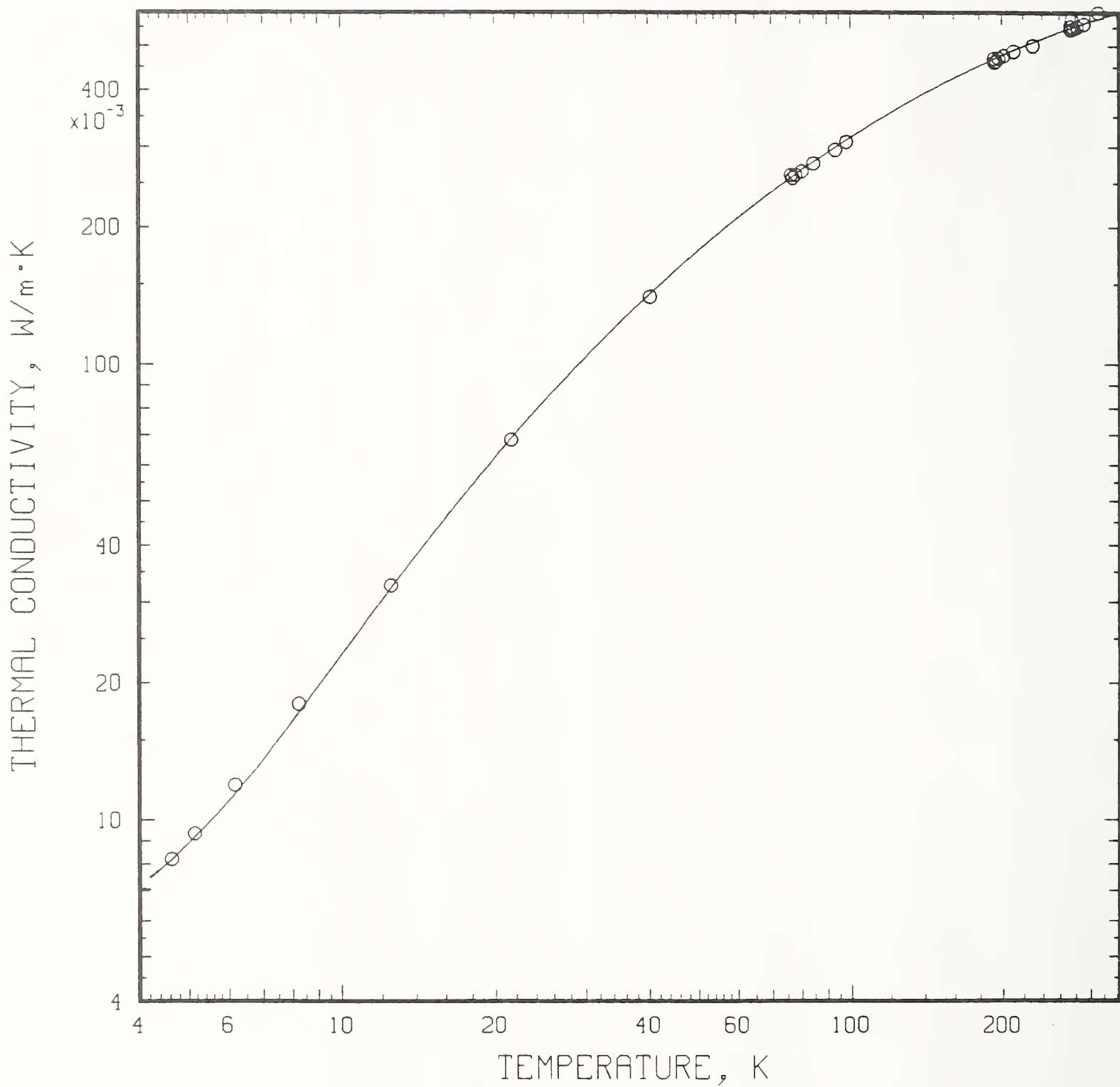


Figure 8 Thermal conductivity of specimen PK-Al-1-90°. Experimental data are presented as discrete points.

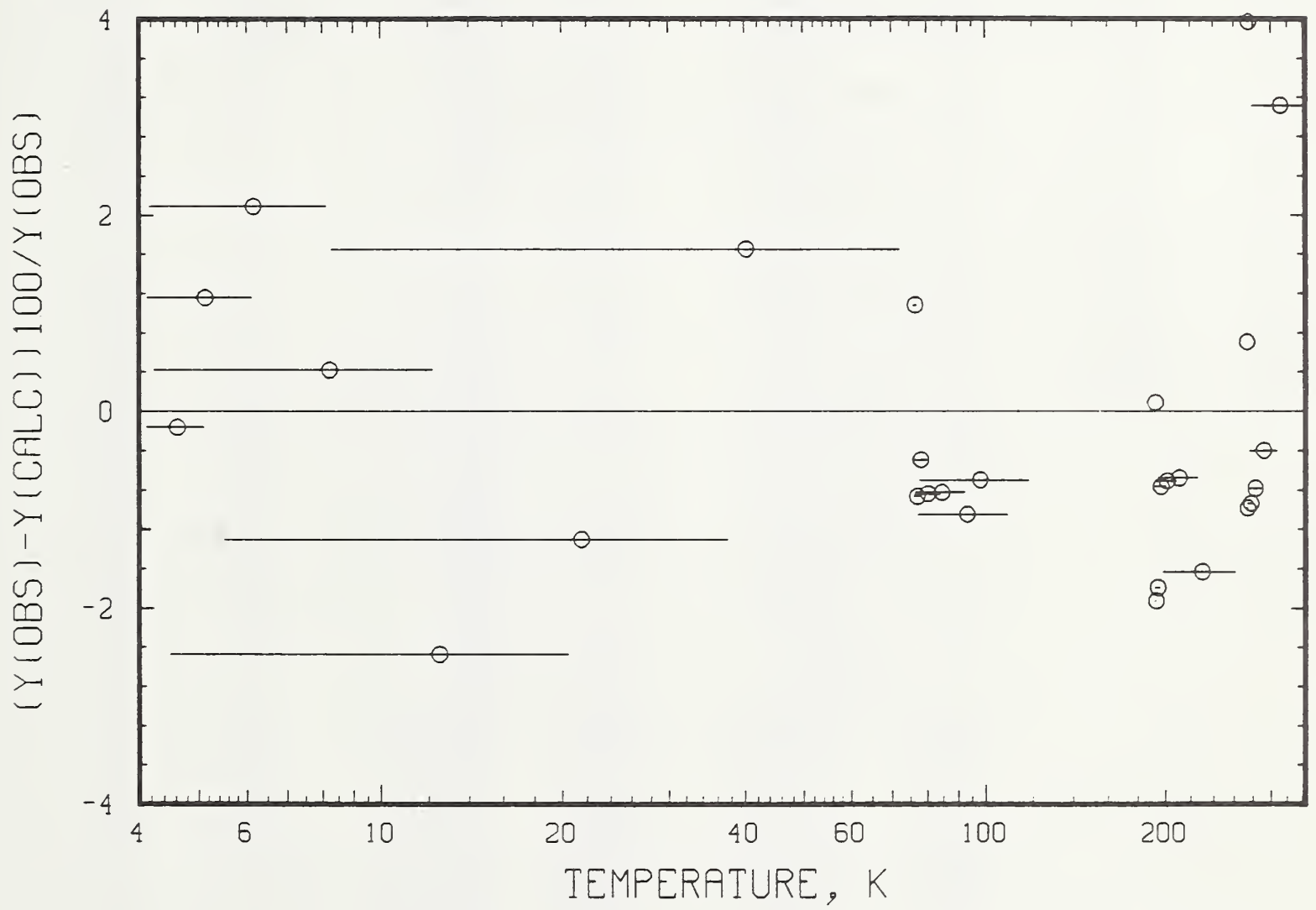


Figure 9 Relative deviations of the experimental and calculated thermal conductivity integrals for specimen PK-Al-1-90°.

Table 16 Experimental Data for PK-Al-2-0°

Average Temperature Kelvin	Thermal Conductivity W/(m·K)
5.134	0.016
6.157	0.019
8.200	0.028
12.419	0.050
21.195	0.108
39.561	0.243
76.530	0.494
77.058	0.488
78.120	0.494
80.247	0.509
84.515	0.534
93.129	0.589
110.632	0.691
110.639	0.693
192.582	1.117
192.582	1.116
193.159	1.081
194.320	1.080
196.648	1.091
201.328	1.107
210.770	1.129
230.056	1.185
273.735	1.261
274.321	1.269
275.492	1.265
277.841	1.272
282.563	1.285
292.104	1.316
311.595	1.378

Table 17 Coefficients of  $\lambda(T)$  for PK-Al-2-0°

a <sub>1</sub>	1.9787333E-01
a <sub>2</sub>	-3.4326128E-01
a <sub>3</sub>	2.3817078E-01
a <sub>4</sub>	-8.0759153E-02
a <sub>5</sub>	1.3746504E-02
a <sub>6</sub>	-8.8121097E-04

Table 18 Thermal Conductivity Values as a Function of Temperature  
for Specimen PK-Al-2-0°.

T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)
4.1000	0.0135	9.1000	0.0321	51.0000	0.3162	110.0000	0.7012
4.2000	0.0136	9.2000	0.0326	52.0000	0.3234	120.0000	0.7567
4.3000	0.0137	9.3000	0.0331	53.0000	0.3306	130.0000	0.8091
4.4000	0.0138	9.4000	0.0336	54.0000	0.3378	140.0000	0.8587
4.5000	0.0139	9.5000	0.0342	55.0000	0.3449	150.0000	0.9054
4.6000	0.0141	9.6000	0.0347	56.0000	0.3520	160.0000	0.9494
4.7000	0.0143	9.7000	0.0352	57.0000	0.3592	170.0000	0.9908
4.8000	0.0145	9.8000	0.0358	58.0000	0.3663	180.0000	1.0295
4.9000	0.0147	9.9000	0.0363	59.0000	0.3733	190.0000	1.0658
5.0000	0.0149	10.0000	0.0368	60.0000	0.3804	200.0000	1.0998
5.1000	0.0151	11.0000	0.0423	61.0000	0.3875	210.0000	1.1314
5.2000	0.0154	12.0000	0.0480	62.0000	0.3945	220.0000	1.1608
5.3000	0.0157	13.0000	0.0538	63.0000	0.4015	230.0000	1.1881
5.4000	0.0160	14.0000	0.0597	64.0000	0.4085	240.0000	1.2133
5.5000	0.0163	15.0000	0.0658	65.0000	0.4155	250.0000	1.2366
5.6000	0.0166	16.0000	0.0719	66.0000	0.4224	260.0000	1.2580
5.7000	0.0169	17.0000	0.0781	67.0000	0.4293	270.0000	1.2775
5.8000	0.0172	18.0000	0.0844	68.0000	0.4362	280.0000	1.2952
5.9000	0.0176	19.0000	0.0908	69.0000	0.4431	290.0000	1.3113
6.0000	0.0179	20.0000	0.0973	70.0000	0.4499	300.0000	1.3257
6.1000	0.0183	21.0000	0.1039	71.0000	0.4568	310.0000	1.3384
6.2000	0.0187	22.0000	0.1105	72.0000	0.4636	320.0000	1.3497
6.3000	0.0191	23.0000	0.1172	73.0000	0.4703	330.0000	1.3595
6.4000	0.0195	24.0000	0.1239	74.0000	0.4771	340.0000	1.3678
6.5000	0.0199	25.0000	0.1307	75.0000	0.4838		
6.6000	0.0203	26.0000	0.1375	76.0000	0.4905		
6.7000	0.0207	27.0000	0.1444	77.0000	0.4972		
6.8000	0.0211	28.0000	0.1514	78.0000	0.5038		
6.9000	0.0215	29.0000	0.1583	79.0000	0.5105		
7.0000	0.0220	30.0000	0.1653	80.0000	0.5170		
7.1000	0.0224	31.0000	0.1724	81.0000	0.5236		
7.2000	0.0228	32.0000	0.1795	82.0000	0.5301		
7.3000	0.0233	33.0000	0.1866	83.0000	0.5367		
7.4000	0.0237	34.0000	0.1937	84.0000	0.5431		
7.5000	0.0242	35.0000	0.2008	85.0000	0.5496		
7.6000	0.0247	36.0000	0.2080	86.0000	0.5560		
7.7000	0.0251	37.0000	0.2152	87.0000	0.5624		
7.8000	0.0256	38.0000	0.2224	88.0000	0.5688		
7.9000	0.0261	39.0000	0.2296	89.0000	0.5751		
8.0000	0.0266	40.0000	0.2368	90.0000	0.5814		
8.1000	0.0270	41.0000	0.2440	91.0000	0.5877		
8.2000	0.0275	42.0000	0.2512	92.0000	0.5939		
8.3000	0.0280	43.0000	0.2585	93.0000	0.6001		
8.4000	0.0285	44.0000	0.2657	94.0000	0.6063		
8.5000	0.0290	45.0000	0.2729	95.0000	0.6125		
8.6000	0.0295	46.0000	0.2802	96.0000	0.6186		
8.7000	0.0300	47.0000	0.2874	97.0000	0.6247		
8.8000	0.0305	48.0000	0.2946	98.0000	0.6308		
8.9000	0.0310	49.0000	0.3018	99.0000	0.6368		
9.0000	0.0316	50.0000	0.3090	100.0000	0.6428		

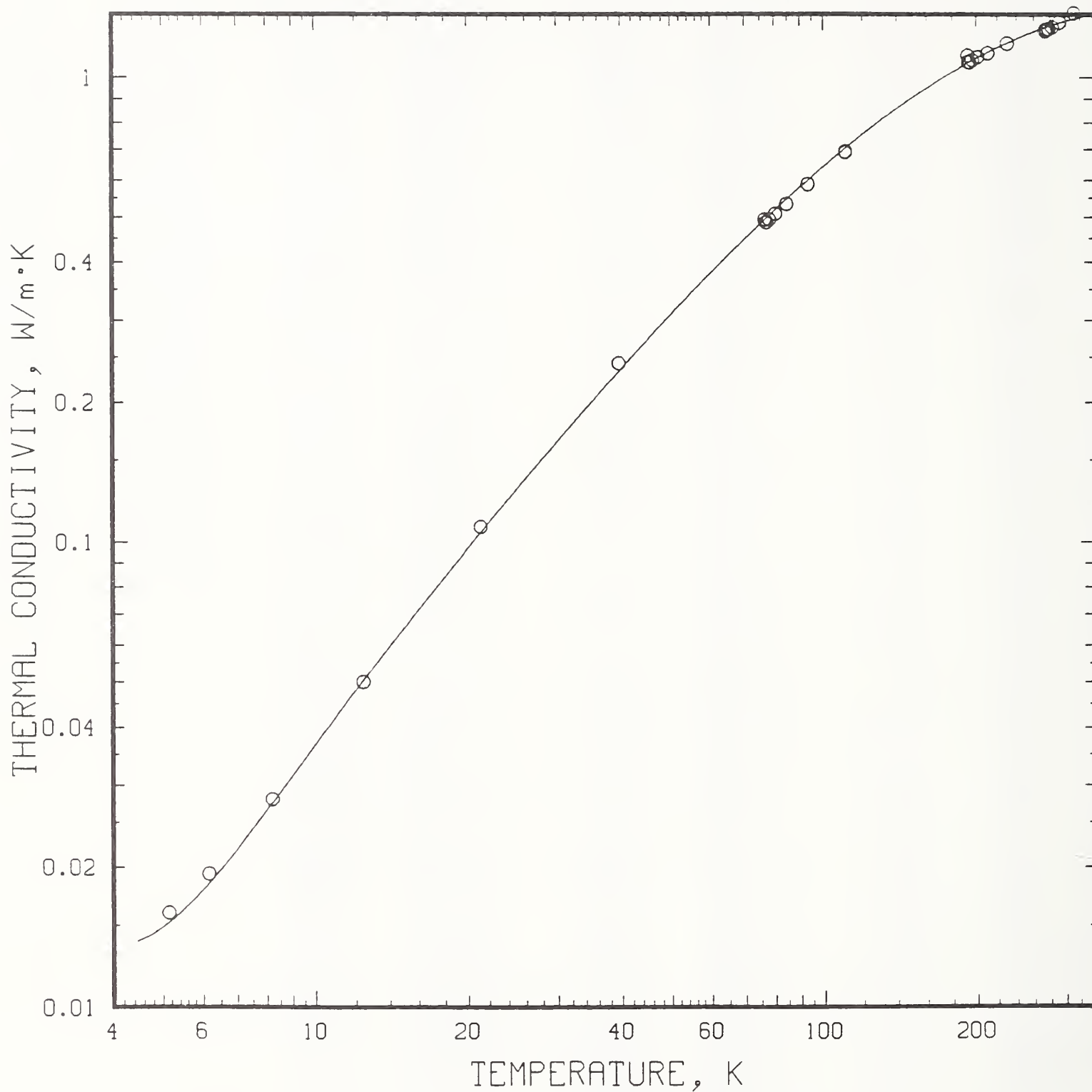


Figure 10 Thermal conductivity of specimen PK-Al-2-0°. Experimental data are presented as discrete points.

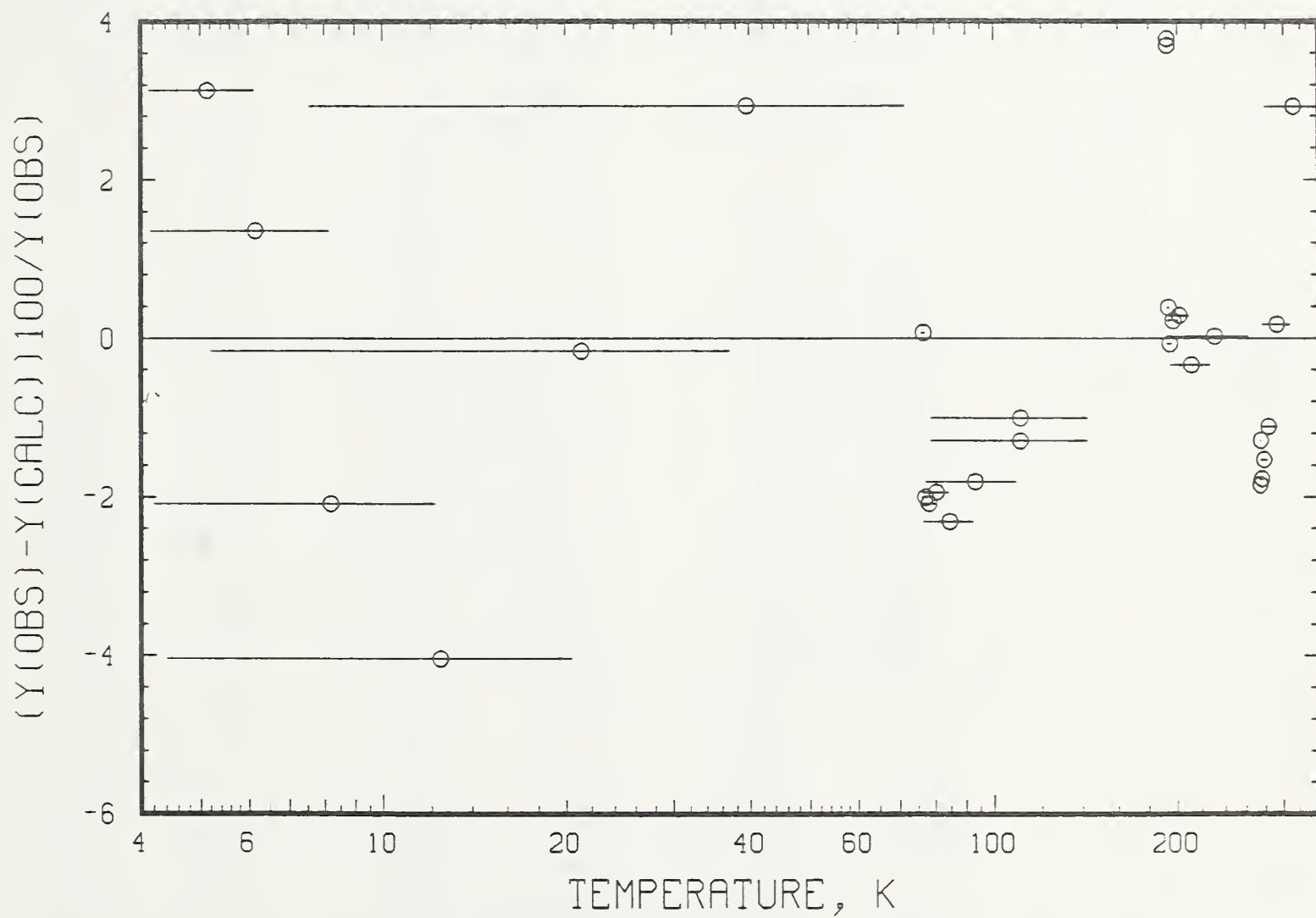


Figure 11 Relative deviations of the experimental and calculated thermal conductivity integrals for specimen PK-A1-2-0°.

**Table 19** Experimental Data for Neat-PK

Average Temperature Kelvin	Thermal Conductivity W/(m·K)
4.629	0.012
5.140	0.013
6.167	0.016
8.263	0.024
12.583	0.039
21.553	0.067
76.525	0.147
77.050	0.150
78.100	0.151
80.205	0.155
84.420	0.158
92.888	0.165
109.955	0.178
192.553	0.226
193.109	0.238
194.221	0.242
196.444	0.240
200.909	0.242
209.898	0.243
228.143	0.246
273.711	0.264
274.273	0.269
275.398	0.268
277.652	0.270
282.180	0.272
291.313	0.277
309.916	0.288

**Table 20** Coefficients of  $\lambda(T)$  for Neat-PK

a <sub>1</sub>	1.0636976E-01
a <sub>2</sub>	-1.6340006E-01
a <sub>3</sub>	9.4941322E-02
a <sub>4</sub>	-2.4117988E-02
a <sub>5</sub>	2.8797748E-03
a <sub>6</sub>	-1.3025208E-04



Table 21 Thermal Conductivity Values as a Function of Temperature for Specimen Neat-PK.

T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)	T Kelvin	$\lambda(T)$ W/(m·K)
4.1000	0.0108	9.1000	0.0271	51.0000	0.1252	110.0000	0.1801
4.2000	0.0110	9.2000	0.0275	52.0000	0.1265	120.0000	0.1871
4.3000	0.0111	9.3000	0.0279	53.0000	0.1277	130.0000	0.1938
4.4000	0.0112	9.4000	0.0283	54.0000	0.1290	140.0000	0.2003
4.5000	0.0114	9.5000	0.0287	55.0000	0.1302	150.0000	0.2065
4.6000	0.0116	9.6000	0.0291	56.0000	0.1314	160.0000	0.2124
4.7000	0.0118	9.7000	0.0295	57.0000	0.1326	170.0000	0.2182
4.8000	0.0120	9.8000	0.0299	58.0000	0.1338	180.0000	0.2239
4.9000	0.0122	9.9000	0.0303	59.0000	0.1349	190.0000	0.2293
5.0000	0.0124	10.0000	0.0307	60.0000	0.1361	200.0000	0.2347
5.1000	0.0127	11.0000	0.0347	61.0000	0.1372	210.0000	0.2399
5.2000	0.0129	12.0000	0.0387	62.0000	0.1383	220.0000	0.2450
5.3000	0.0132	13.0000	0.0425	63.0000	0.1394	230.0000	0.2499
5.4000	0.0135	14.0000	0.0462	64.0000	0.1405	240.0000	0.2548
5.5000	0.0138	15.0000	0.0498	65.0000	0.1415	250.0000	0.2596
5.6000	0.0140	16.0000	0.0533	66.0000	0.1426	260.0000	0.2642
5.7000	0.0143	17.0000	0.0566	67.0000	0.1436	270.0000	0.2688
5.8000	0.0147	18.0000	0.0598	68.0000	0.1446	280.0000	0.2733
5.9000	0.0150	19.0000	0.0629	69.0000	0.1457	290.0000	0.2777
6.0000	0.0153	20.0000	0.0659	70.0000	0.1467	300.0000	0.2821
6.1000	0.0156	21.0000	0.0688	71.0000	0.1476	310.0000	0.2863
6.2000	0.0160	22.0000	0.0716	72.0000	0.1486	320.0000	0.2905
6.3000	0.0163	23.0000	0.0743	73.0000	0.1496	330.0000	0.2946
6.4000	0.0166	24.0000	0.0769	74.0000	0.1505	340.0000	0.2986
6.5000	0.0170	25.0000	0.0794	75.0000	0.1515		
6.6000	0.0173	26.0000	0.0818	76.0000	0.1524		
6.7000	0.0177	27.0000	0.0842	77.0000	0.1534		
6.8000	0.0181	28.0000	0.0864	78.0000	0.1543		
6.9000	0.0184	29.0000	0.0887	79.0000	0.1552		
7.0000	0.0188	30.0000	0.0908	80.0000	0.1561		
7.1000	0.0192	31.0000	0.0929	81.0000	0.1570		
7.2000	0.0196	32.0000	0.0949	82.0000	0.1579		
7.3000	0.0199	33.0000	0.0969	83.0000	0.1587		
7.4000	0.0203	34.0000	0.0988	84.0000	0.1596		
7.5000	0.0207	35.0000	0.1006	85.0000	0.1605		
7.6000	0.0211	36.0000	0.1024	86.0000	0.1613		
7.7000	0.0215	37.0000	0.1042	87.0000	0.1622		
7.8000	0.0219	38.0000	0.1059	88.0000	0.1630		
7.9000	0.0223	39.0000	0.1076	89.0000	0.1639		
8.0000	0.0227	40.0000	0.1092	90.0000	0.1647		
8.1000	0.0231	41.0000	0.1109	91.0000	0.1655		
8.2000	0.0235	42.0000	0.1124	92.0000	0.1663		
8.3000	0.0239	43.0000	0.1140	93.0000	0.1671		
8.4000	0.0243	44.0000	0.1155	94.0000	0.1679		
8.5000	0.0247	45.0000	0.1169	95.0000	0.1687		
8.6000	0.0251	46.0000	0.1184	96.0000	0.1695		
8.7000	0.0255	47.0000	0.1198	97.0000	0.1703		
8.8000	0.0259	48.0000	0.1212	98.0000	0.1711		
8.9000	0.0263	49.0000	0.1225	99.0000	0.1719		
9.0000	0.0267	50.0000	0.1239	100.0000	0.1726		

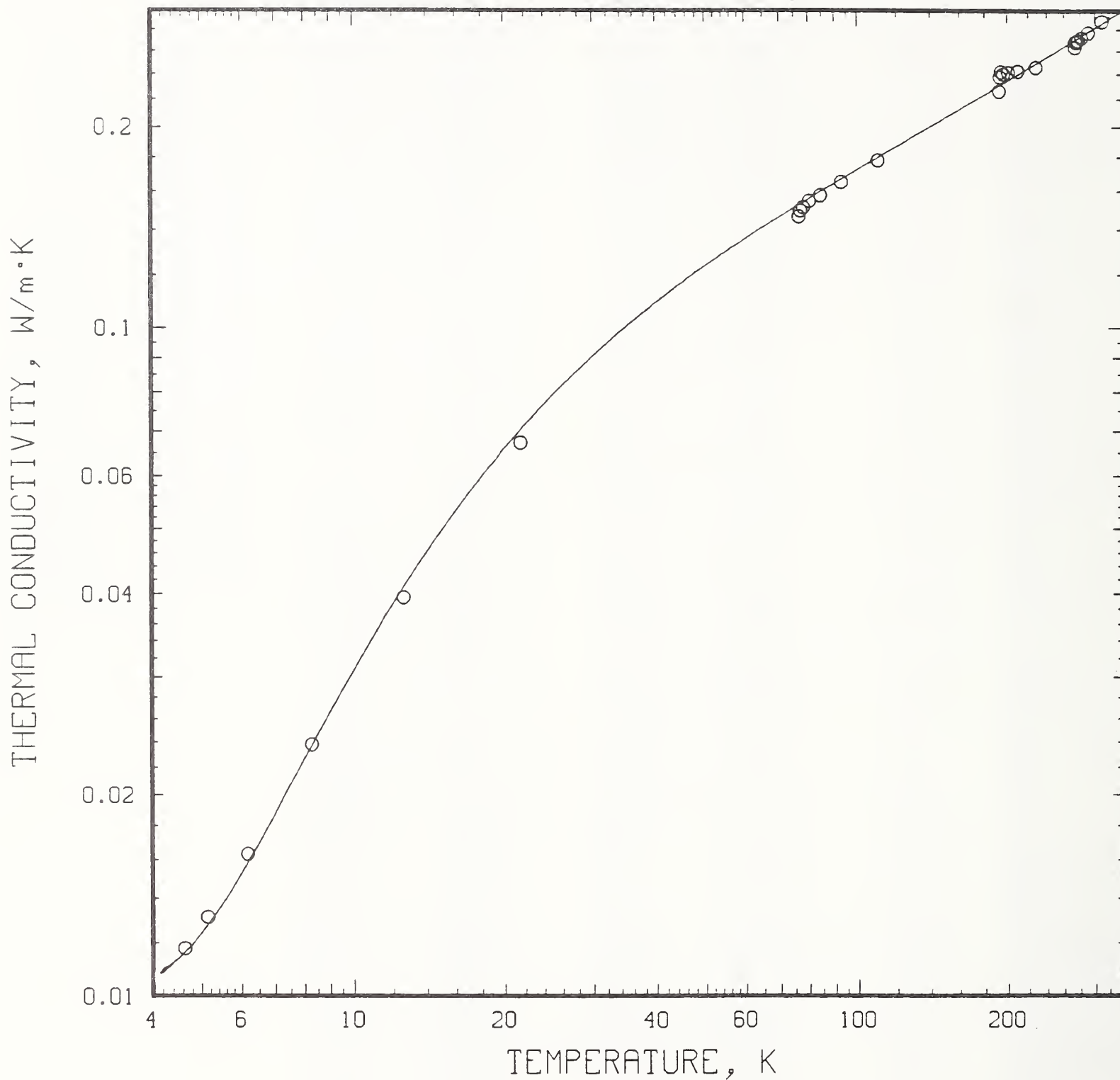


Figure 12 Thermal conductivity of specimen Neat-PK.  
 Experimental data are presented as discrete points.

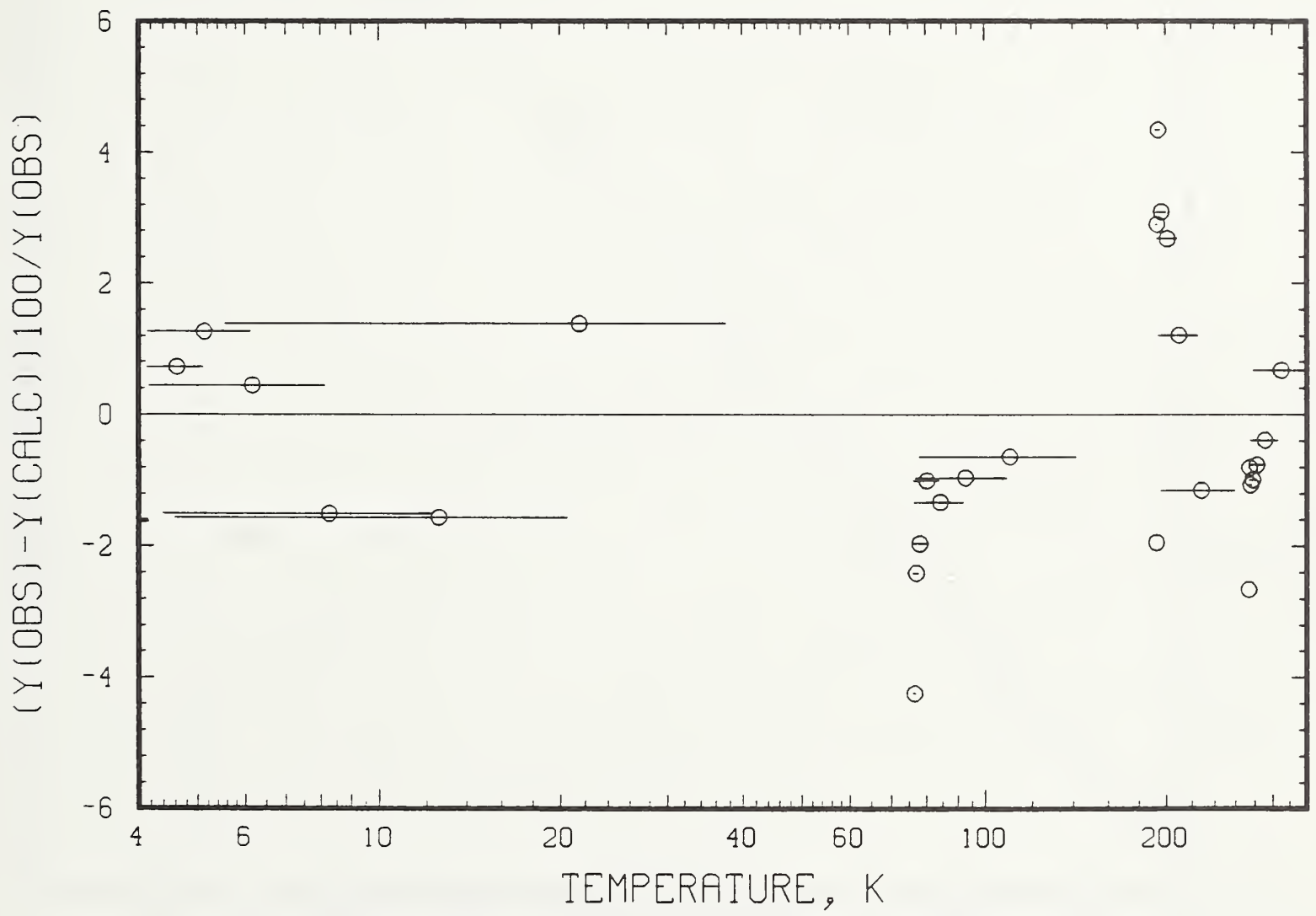


Figure 13 Relative deviations of the experimental and calculated thermal conductivity integrals for specimen Neat-PK.

○ PK-AL-1-0      △ PK-AL-2-0

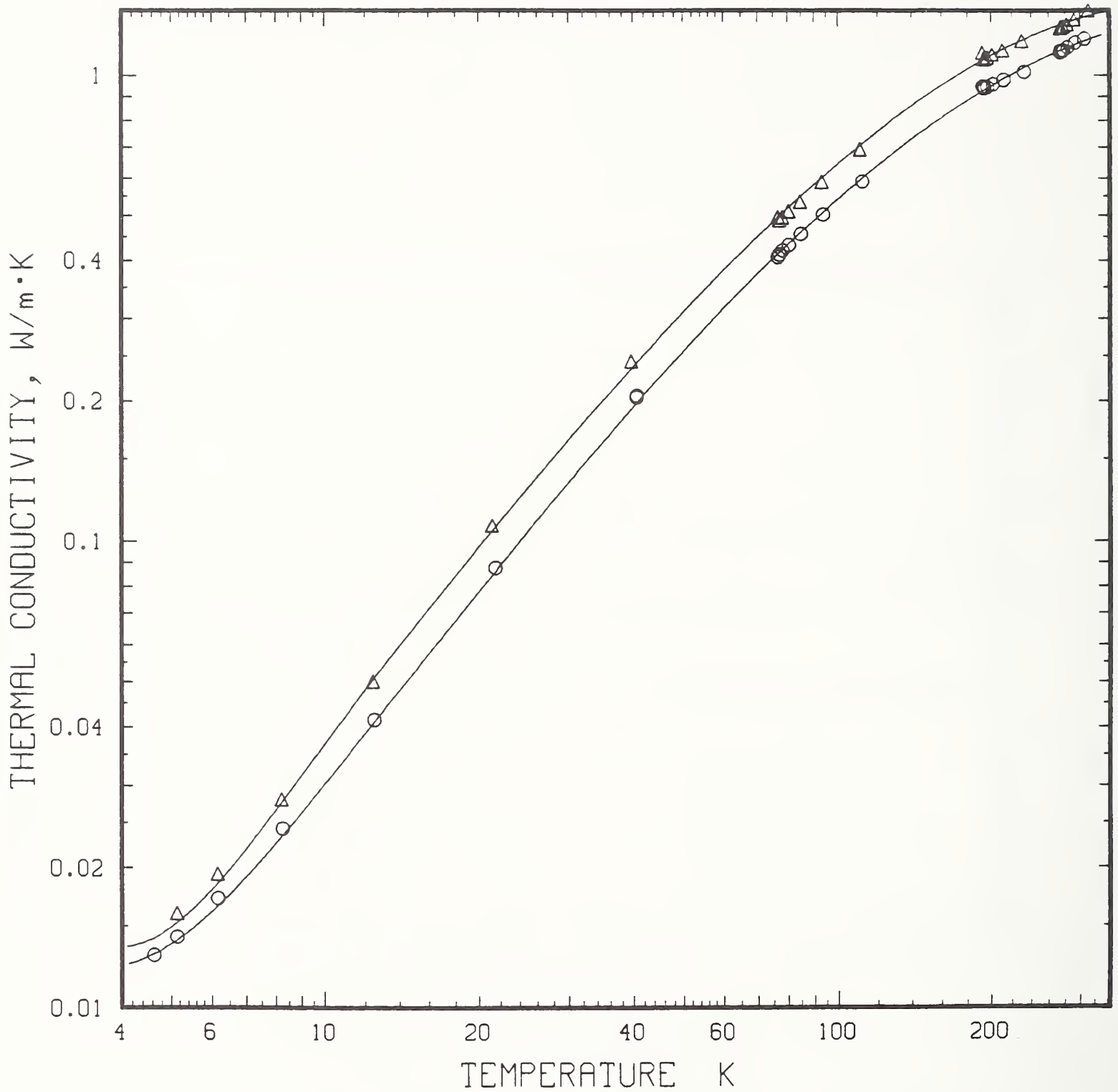


Figure 14 Thermal conductivity of PK-Al-1-0° and PK-Al-2-0° specimens where heat is flowing parallel to the alumina fibers.

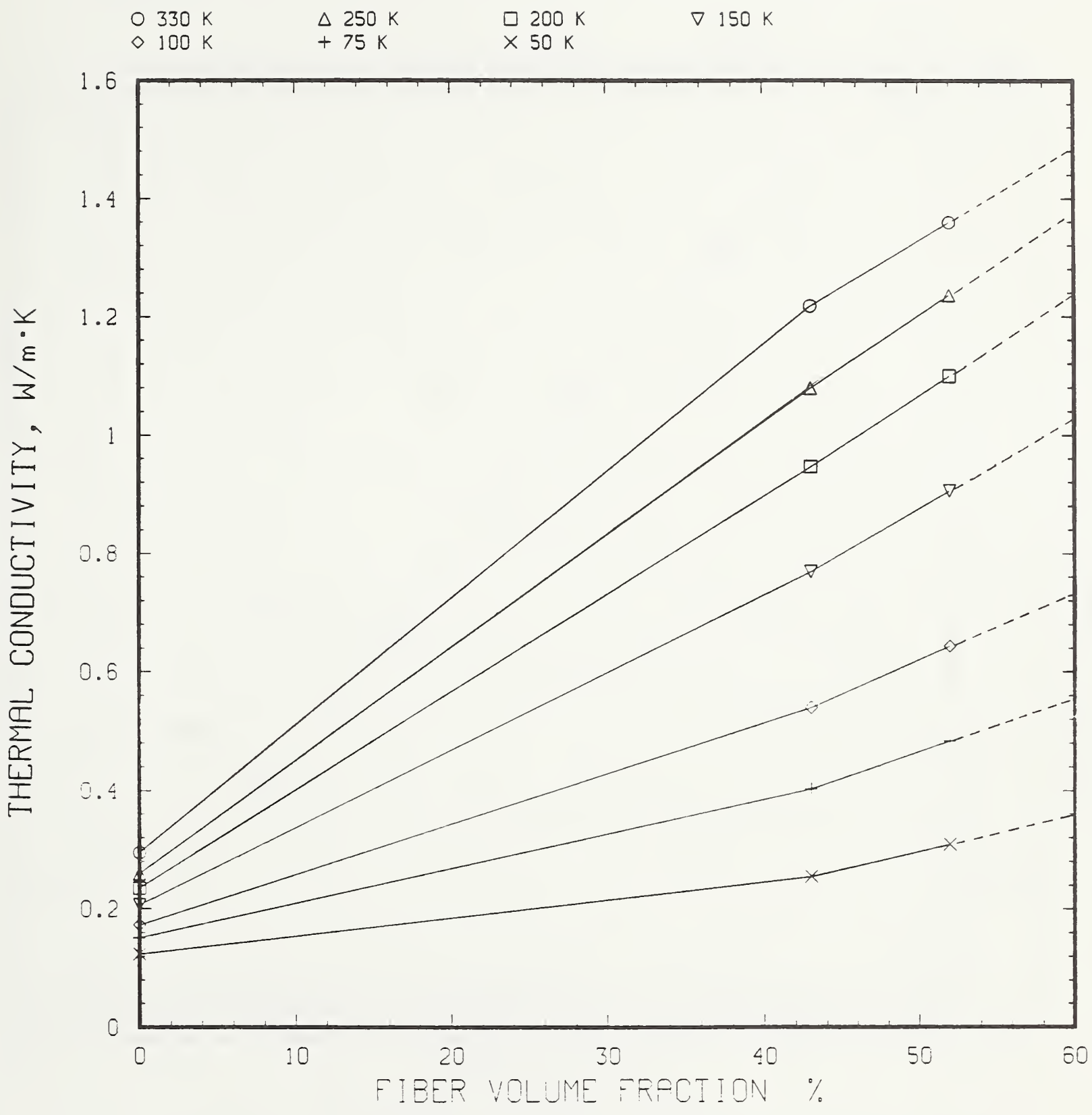


Figure 15 Thermal conductivity as a function of fiber volume ratios for various calculated temperatures (above 40 K). The dashed line shows linear extrapolation taken.

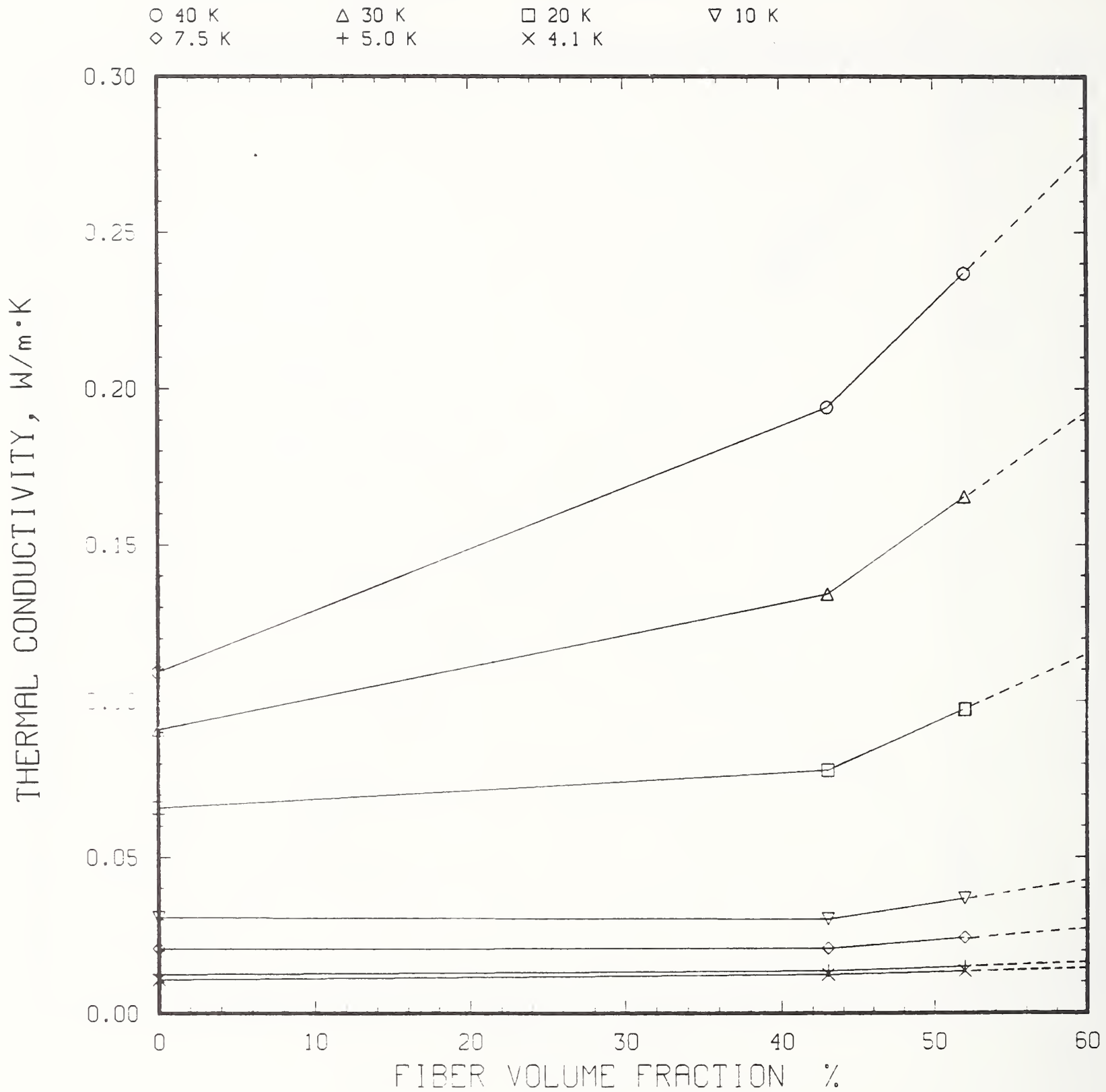
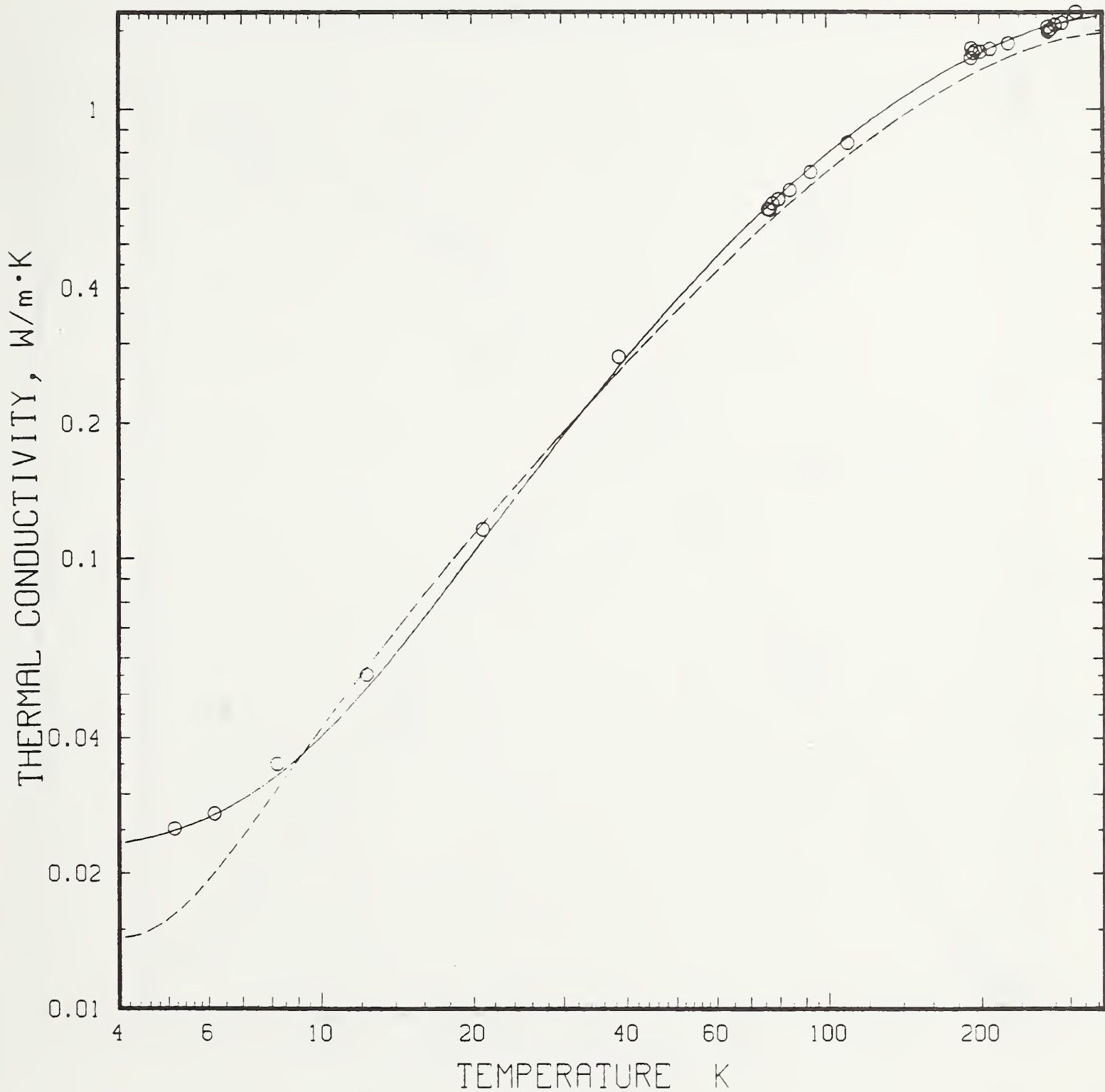


Figure 16 Thermal conductivity as a function of fiber volume ratios for various calculated temperatures (below 40 K). The dashed line shows linear extrapolation taken.

○ EP-AL-0



**Figure 17** Thermal conductivity as a function of temperature for the EP-Al-0° and the calculated PEEK/alumina curve (----). Comparison for the same fiber volume fraction. Note that both scales are logarithmic, which clarifies the behavior at low temperatures. Compare to Figure 18.

○ EP-AL-0

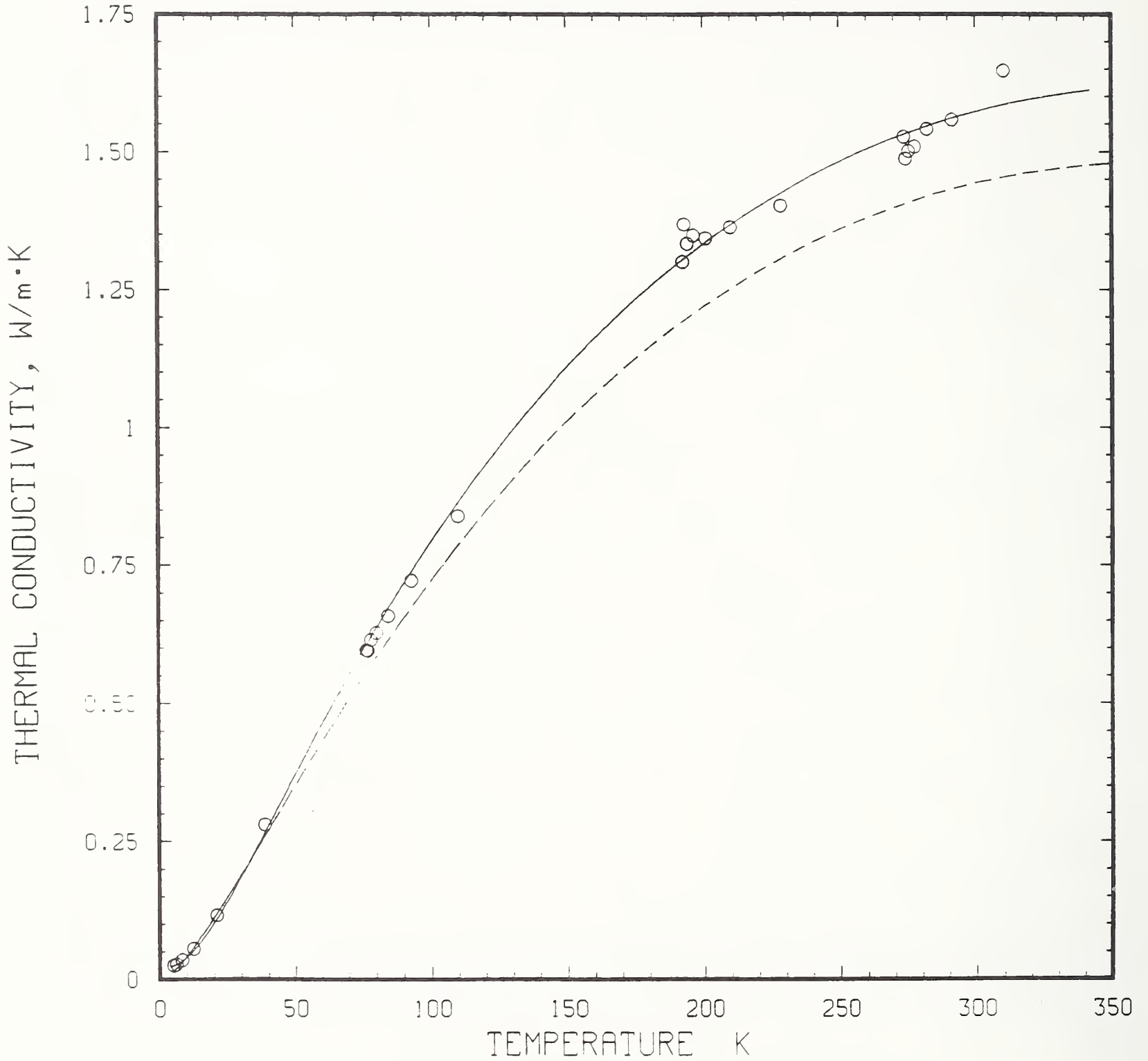
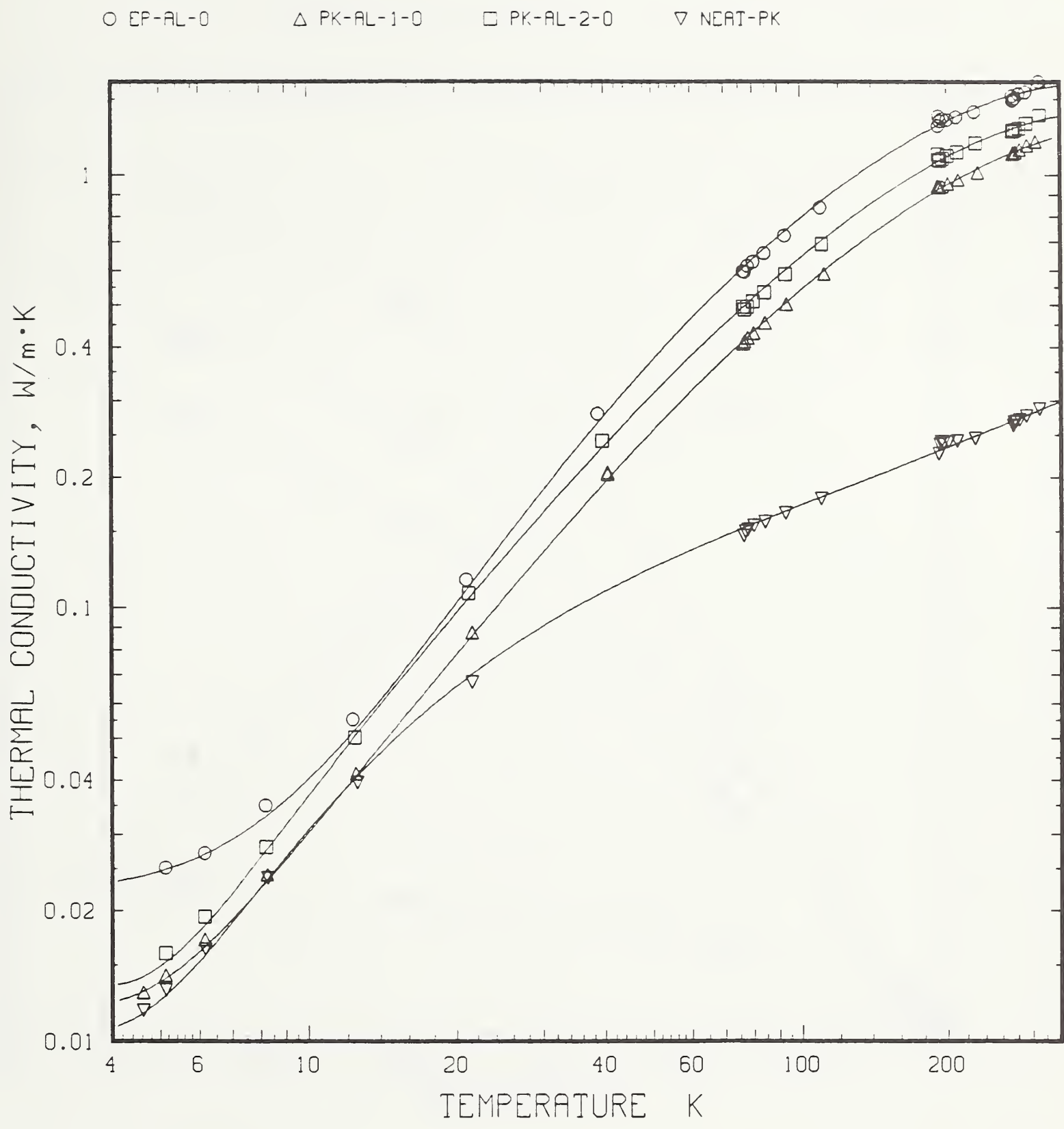


Figure 18 Thermal conductivity as a function of temperature for the EP-Al-0° and the calculated PEEK/alumina curve (----). Comparison for the same fiber volume fraction. Note that both scales are linear, which clarifies the behavior at high temperatures. Compare to Figure 17.





**Figure 19** Thermal conductivity of the specimens where heat is flowing parallel to the alumina fibers. The Neat-PEEK data are also included as a reference. Note that both scales are logarithmic, which clarifies the behavior at low temperatures. Compare to Figure 20.

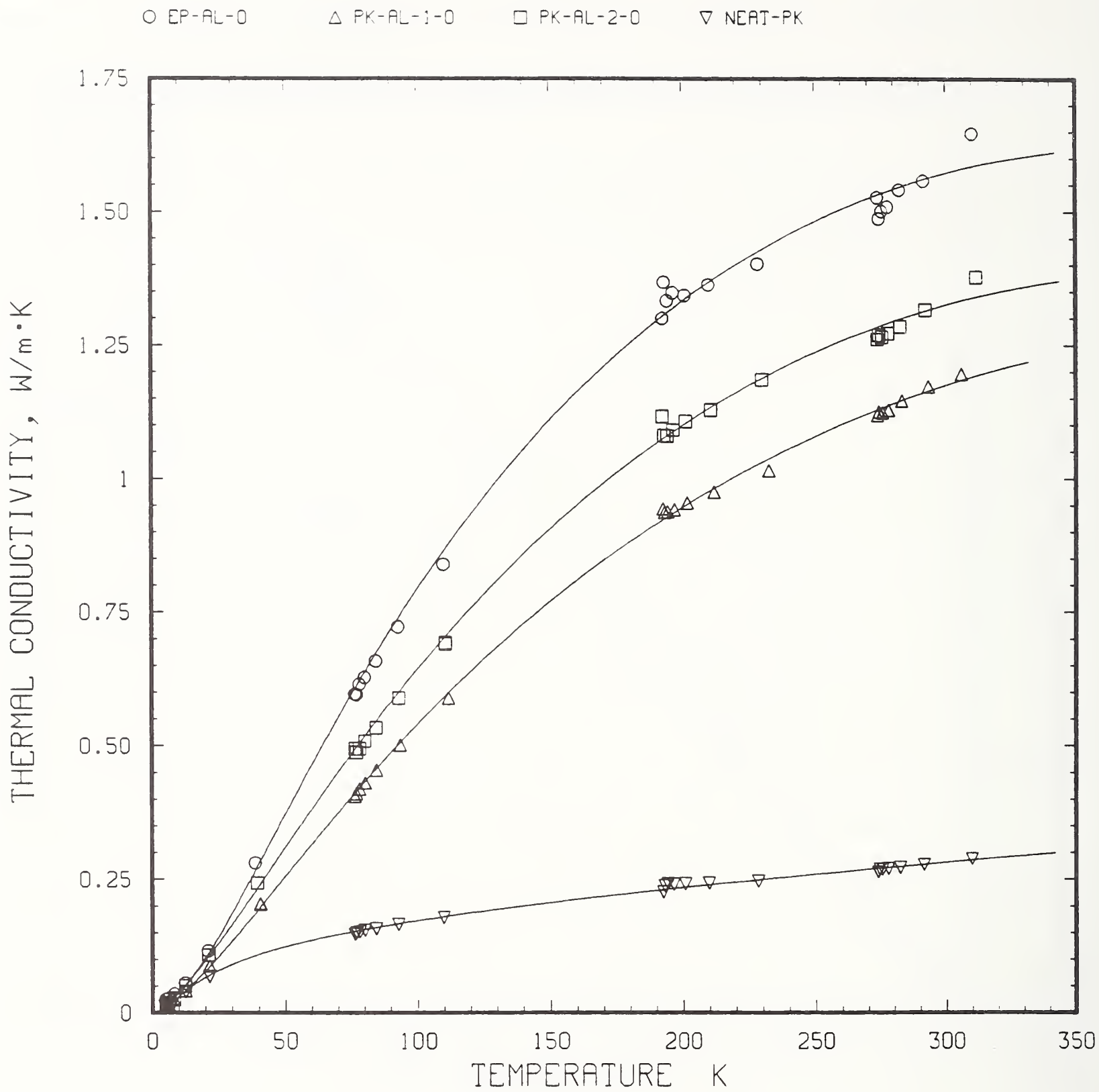


Figure 20 Thermal conductivity of the specimens where heat is flowing parallel to the alumina fibers. The Neat-PEEK data are also included as a reference. Note that both scales are linear, which clarifies the behavior at high temperatures. Compare to Figure 19.

○ EP-AL-90      △ PK-AL-1-90      □ NEAT-PK

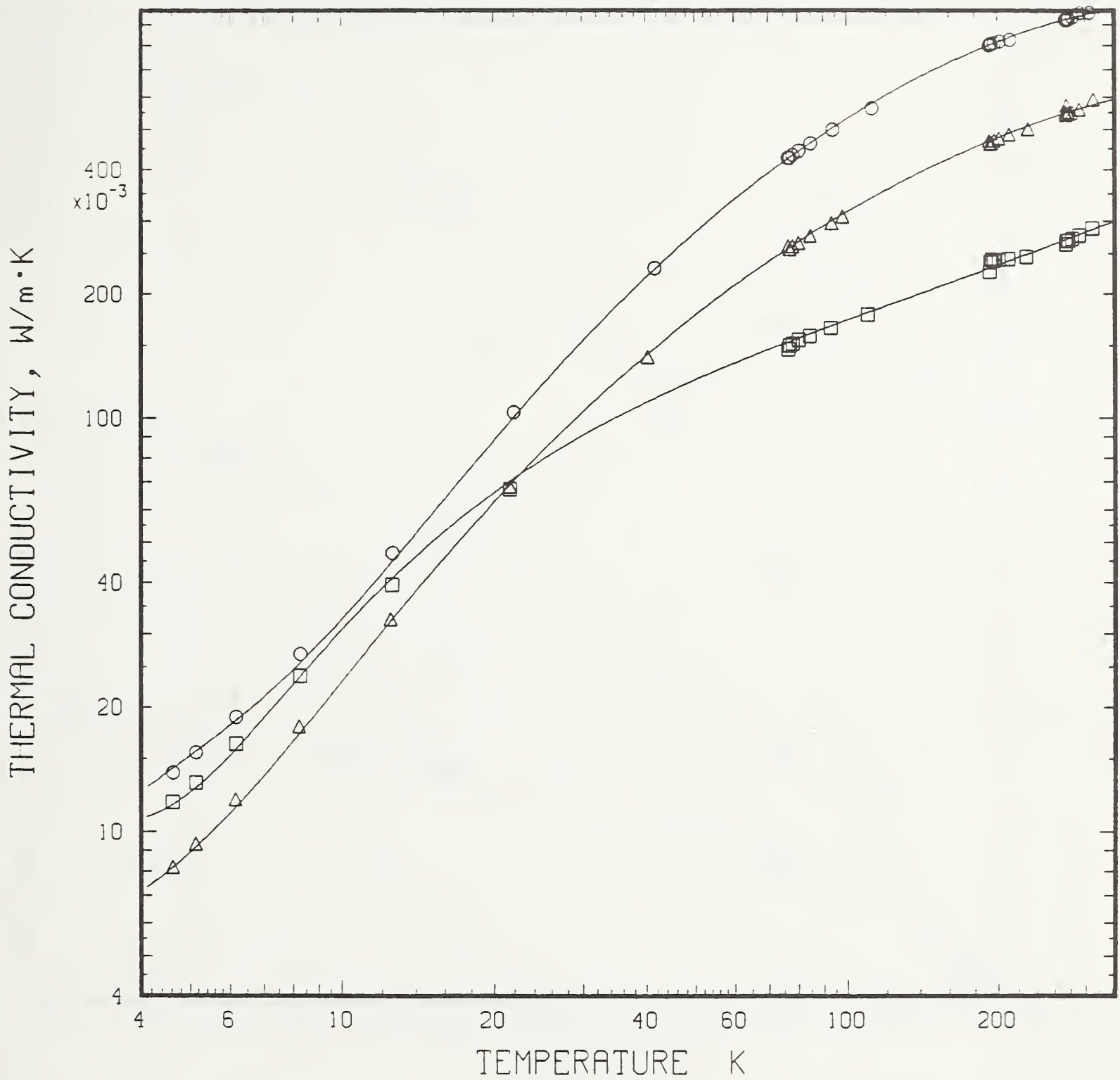


Figure 21 Thermal conductivity of the specimens where heat is flowing perpendicular to the alumina fibers. The Neat-PEEK data are also included as a reference. Note that both scales are logarithmic, which clarifies the behavior at low temperatures. Compare to Figure 22.

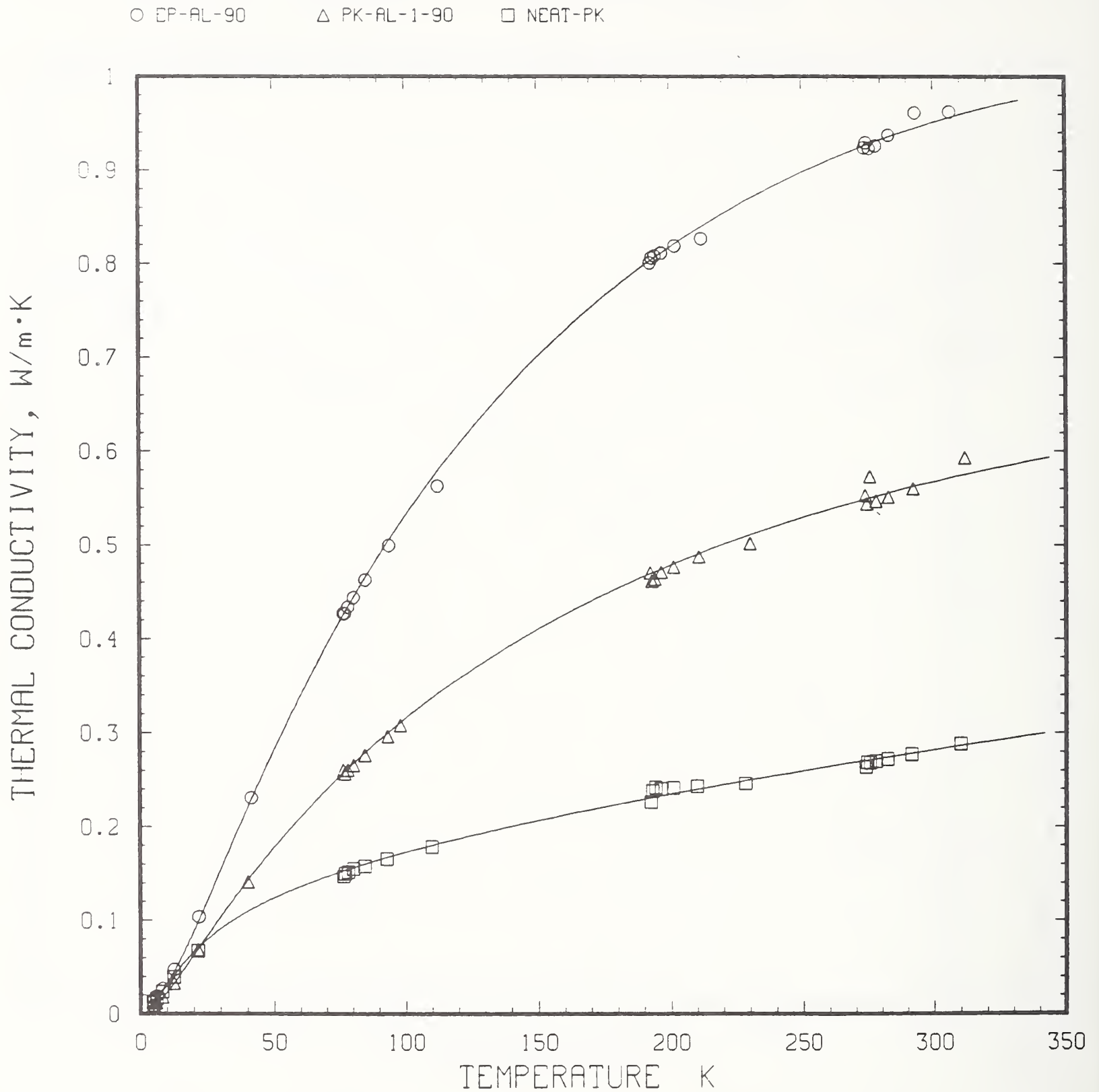


Figure 22 Thermal conductivity of the specimens where heat is flowing perpendicular to the alumina fibers. The Neat-PEEK data are also included as a reference. Note that both scales are linear, which clarifies the behavior at high temperatures. Compare to Figure 21.

○ EP-AL-0

△ EP-AL-90

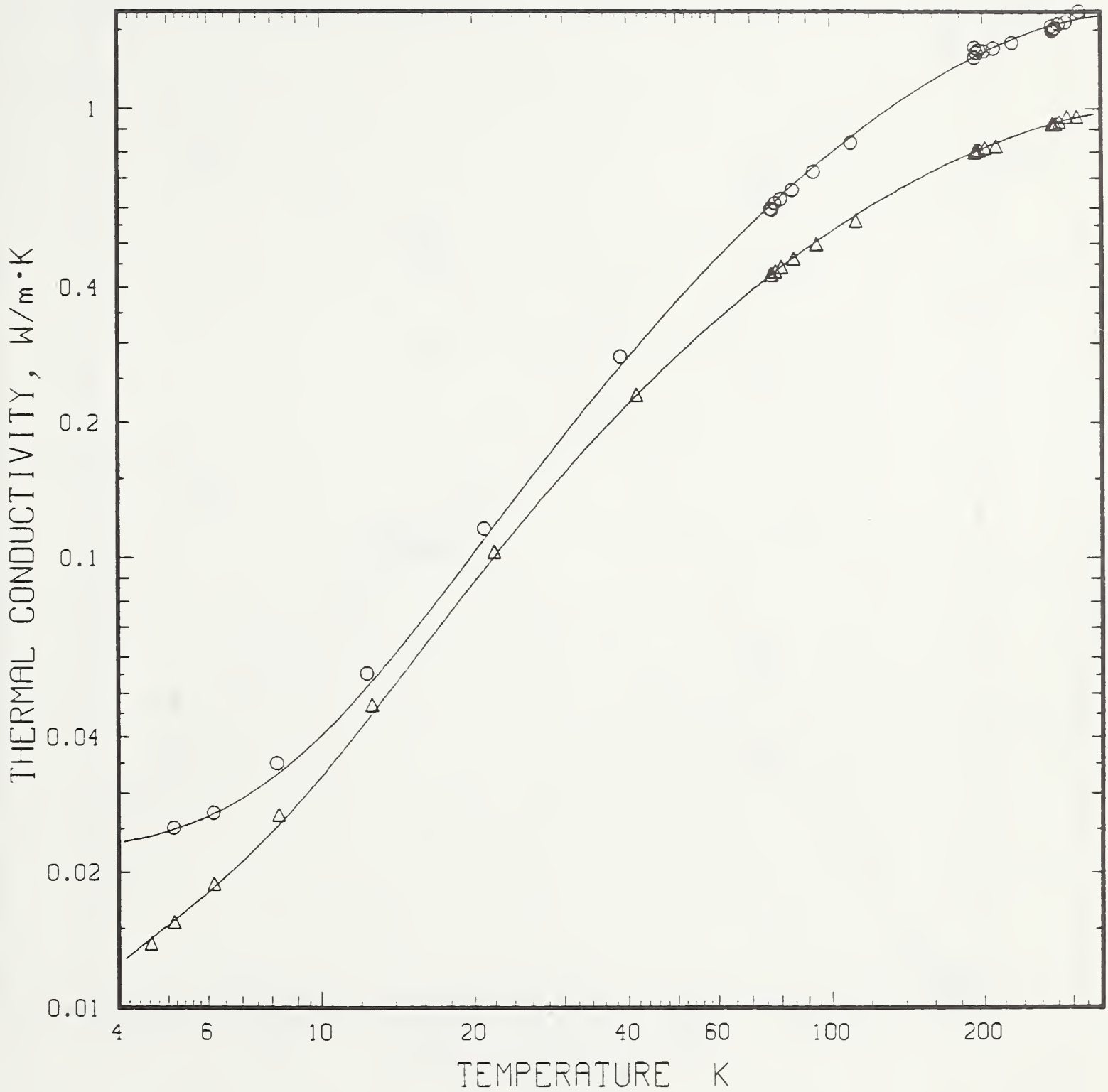
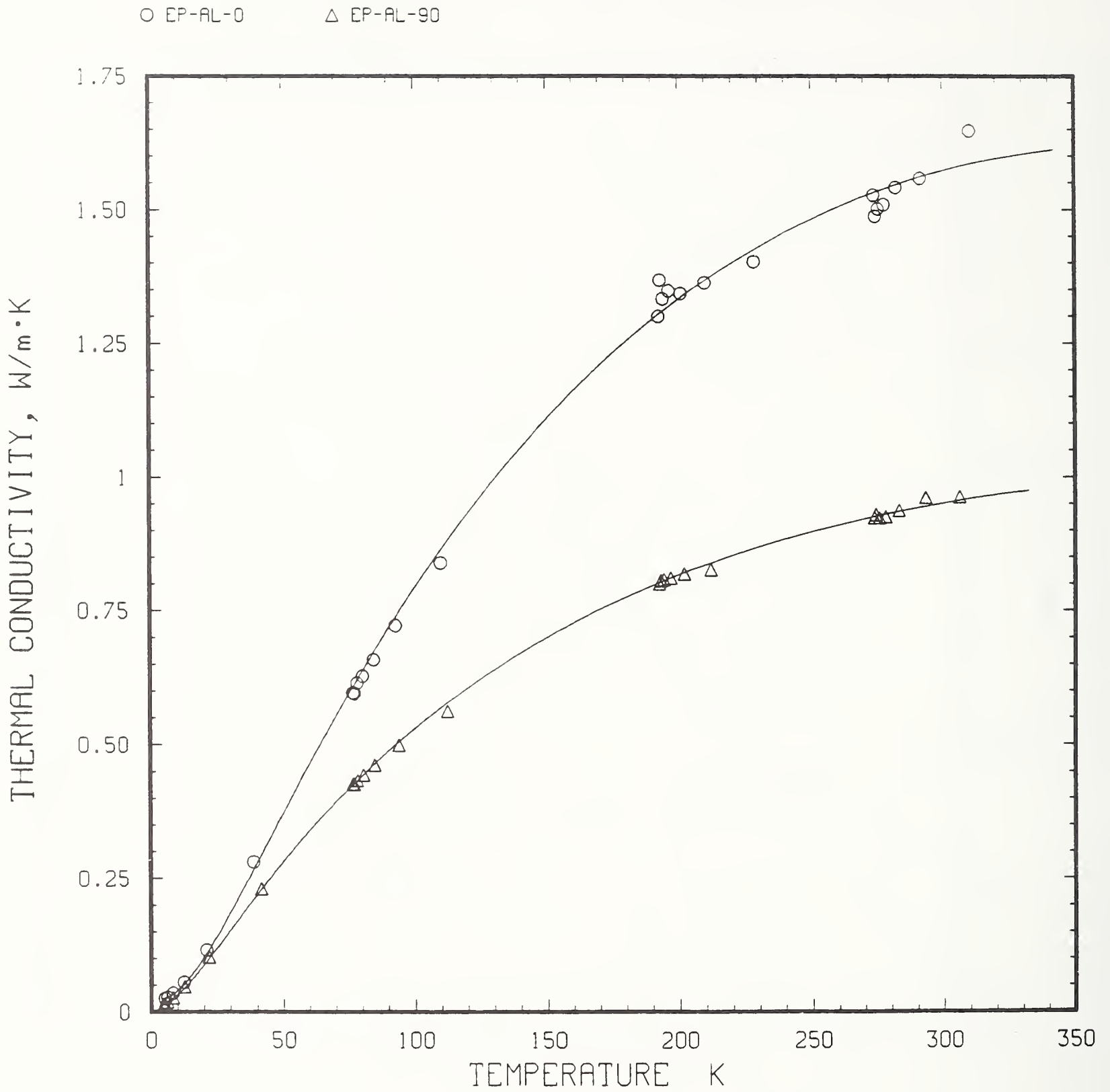
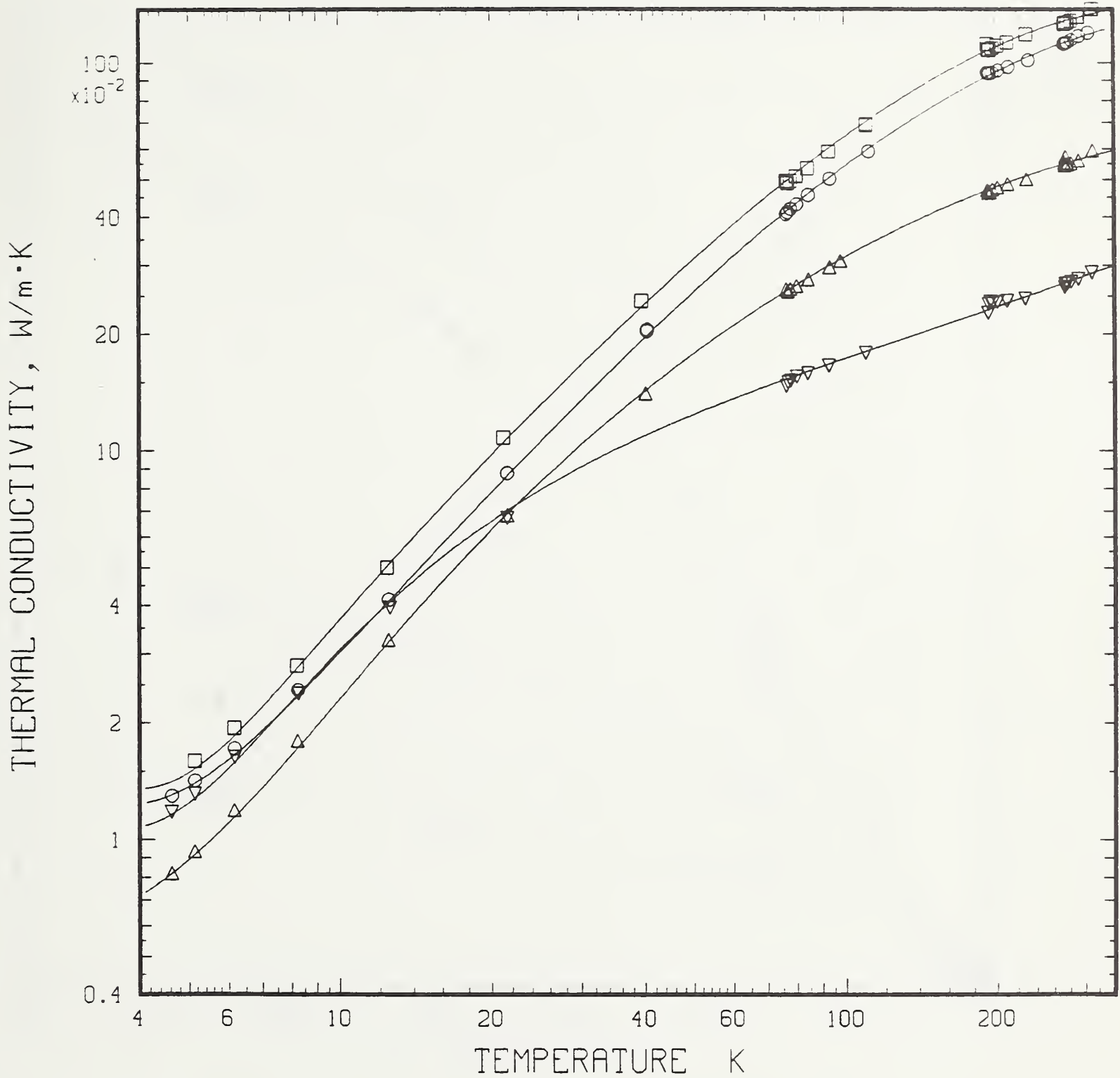


Figure 23 Thermal conductivity of the epoxy/alumina fibered data, both parallel and perpendicular to alumina fibers. Note that both scales are logarithmic, which clarifies the behavior at low temperatures. Compare to Figure 24.



**Figure 24** Thermal conductivity of the epoxy/alumina fibered data, both parallel and perpendicular to alumina fibers. Note that both scales are linear, which clarifies the behavior at high temperatures. Compare to Figure 23.

○ PK-AL-1-0    △ PK-AL-1-90    □ PK-AL-2-0    ▽ NEAT-PEEK



**Figure 25** Thermal conductivity of the PEEK/alumina fibered data, both parallel and perpendicular to fiber direction. The Neat-PEEK data also included. Note that both scales are logarithmic, which clarifies the behavior at low temperatures. Compare to Figure 26.

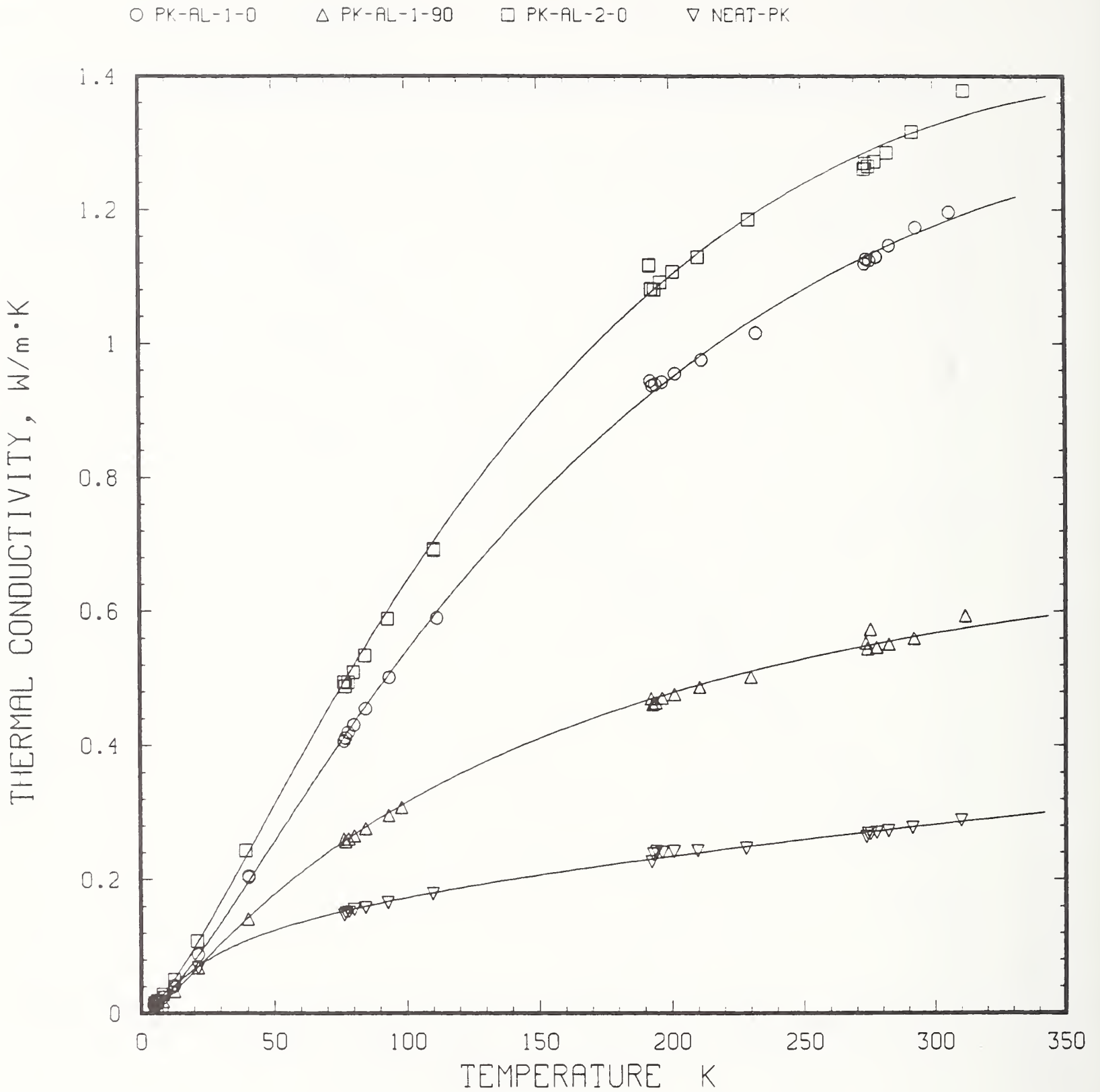


Figure 26 Thermal conductivity of the PEEK/alumina fibered data, both parallel and perpendicular to fiber direction. The Neat-PEEK data also included. Note that both scales are linear, which clarifies the behavior at high temperatures. Compare to Figure 25.



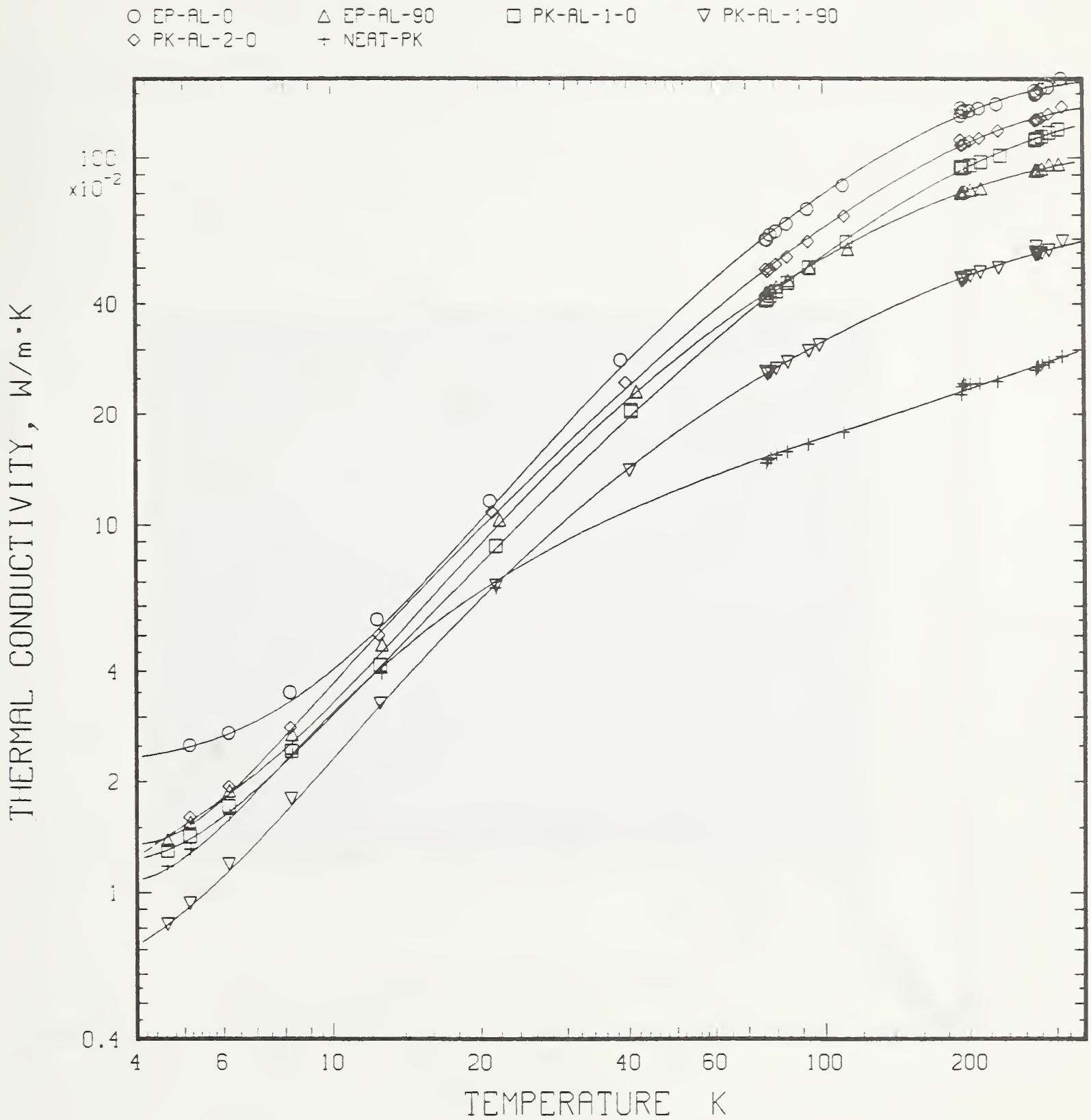


Figure 27 Thermal conductivity of all the specimens tested. Note that both scales are logarithmic, which clarifies the behavior at low temperatures. Compare to Figure 28.

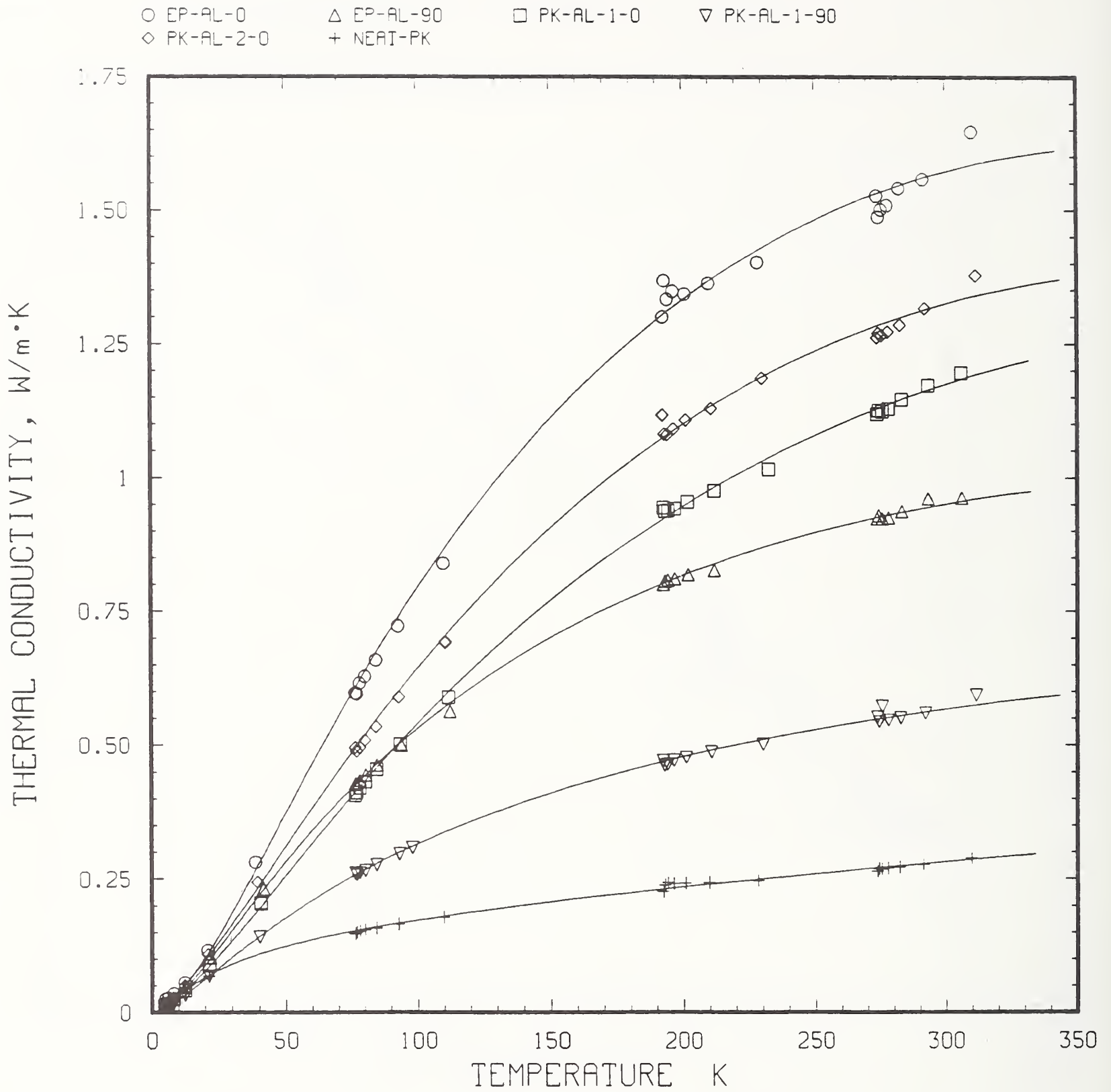
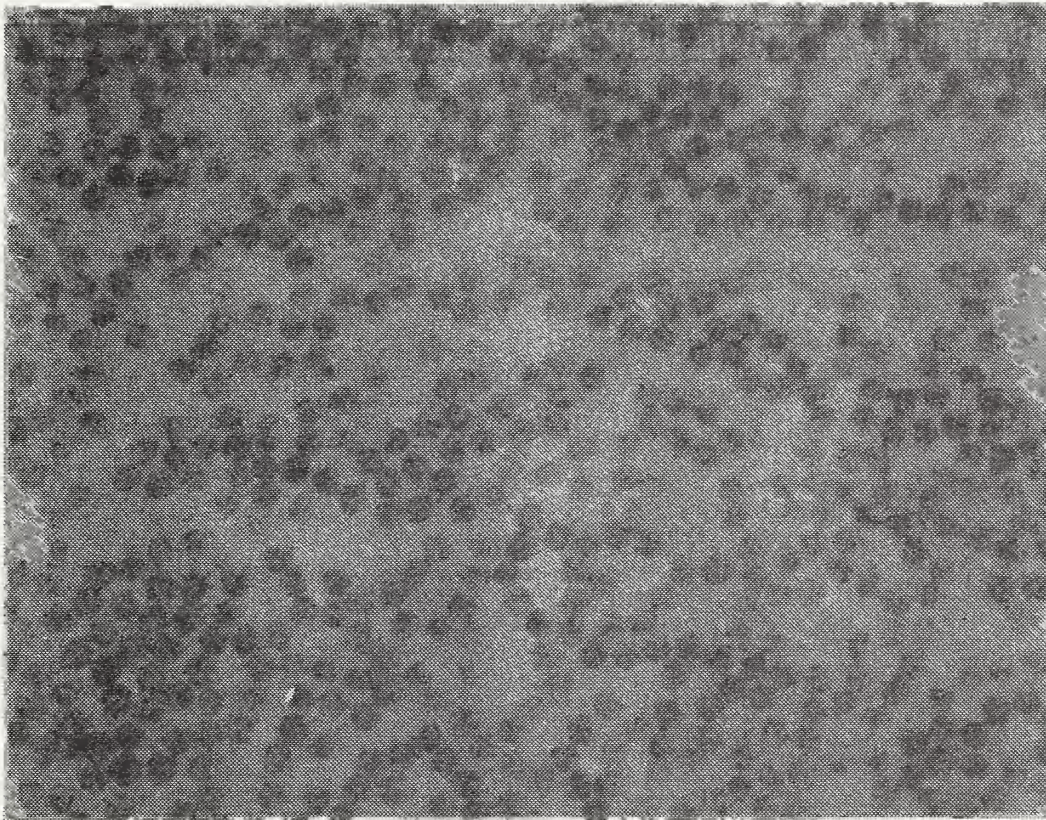


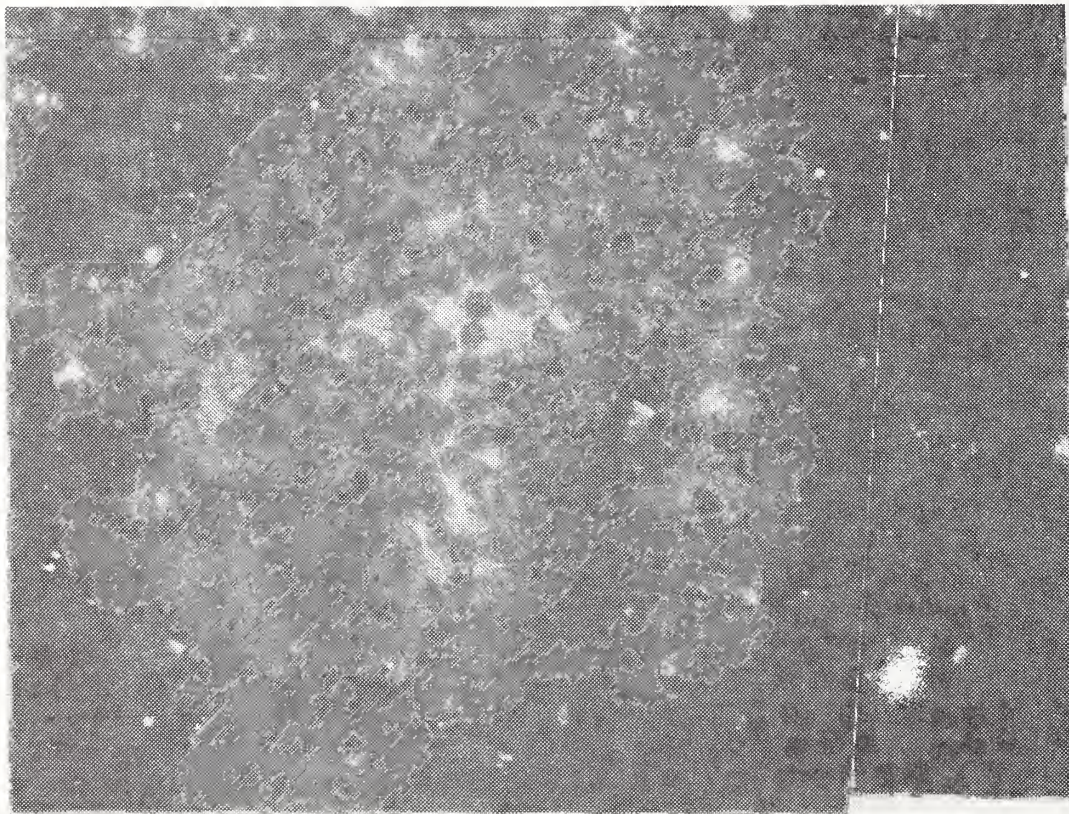
Figure 28 Thermal conductivity of all the specimens tested. Note that both scales are linear, which clarifies the behavior at high temperatures. Compare to Figure 27.

Appendix



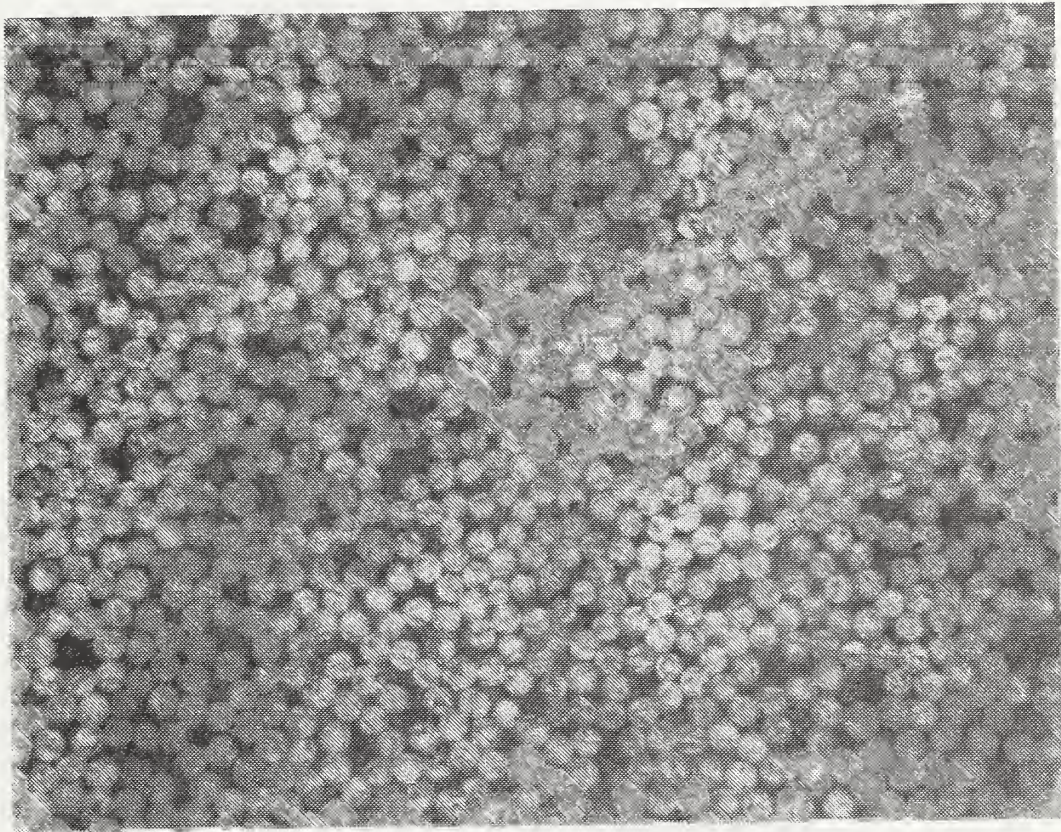
100  $\mu\text{m}$

PK-Al-1-0° photomicrograph. A larger section was used to determine the fiber volume ratio of 43%.



100  $\mu\text{m}$

PK-Al-2-0° photomicrograph. A larger section was used to determine the fiber volume ratio of 52%.



100  $\mu$ m

EP-Al-0° photomicrograph. A larger section was used to determine the fiber volume ratio of 59%.

U.S. DEPT. OF COMM. <b>BIBLIOGRAPHIC DATA SHEET</b> <i>(See instructions)</i>	<b>1. PUBLICATION OR REPORT NO.</b> NISTIR 89-3914	<b>2. Performing Organ. Report No.</b>	<b>3. Publication Date</b> May 1989
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<b>5. AUTHOR(S)</b> D.L. Rule and L.L. Sparks			
<b>6. PERFORMING ORGANIZATION</b> <i>(If joint or other than NBS, see instructions)</i>  <b>NATIONAL BUREAU OF STANDARDS          U.S. DEPARTMENT OF COMMERCE          GAITHERSBURG, MD 20899</b>		<b>7. Contract/Grant No.</b>	<b>8. Type of Report &amp; Period Covered</b>
<b>9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS</b> <i>(Street, City, State, ZIP)</i> <p style="text-align: center;">National Aeronautics and Space Administration          Ames Research Center          Moffett Field, California 94035</p>			
<b>10. SUPPLEMENTARY NOTES</b>  <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.			
<b>11. ABSTRACT</b> <i>(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)</i> <p>The thermal conductivities of poly-ether-ether-ketone (PEEK), of alumina fiber in a matrix of PEEK, and of alumina fiber in a matrix of epoxy, were determined along with the effects of fiber orientation and thermal cycling. Thermal conductivity was measured over the temperature range of 4.2 to 310 K using a steady-state apparatus.</p> <p>These data are presented and discussed relative to specimen characteristics. It appears that after accounting for different fiber fractions in the specimens, the thermal conductivity of the PEEK composite material is less than that of the epoxy composite material in particular temperature ranges.</p>			
<b>12. KEY WORDS</b> <i>(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)</i> alumina; composite; epoxy; low temperature; PEEK; poly-ether-ether-ketone; thermal conductivity			
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