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THERMAL CONDUCTIVITY OF GLASS FIBER/EPOXY COMPOSITE SUPPORT BANDS FOR CRYOGENIC DEWARS, PHASE II

National Bureau of Standards
U.S. Department of Commerce
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THERMAL CONDUCTIVITY OF GLASS FIBER/EPOXY COMPOSITE SUPPORT BANDS FOR CRYOGENIC DEWARS, PHASE II

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The thermal conductivities of three specimens of glass fiber/epoxy composites were measured and reported for the temperature range 4 to 300 K. These specimens were fabricated from two cryogenic dewar support bands. An average conductivity curve for the three specimens is presented. The data for the three specimens are within ±5% of this average curve. The average curve is compared to a similar curve obtained five years ago in Phase I of this continuing study of composite materials.

Key words: composite; epoxy; glass fiber; low temperature; thermal conductivity

1. INTRODUCTION

Composite materials have significant advantages in applications requiring high strength and low thermal conduction. As a consequence, the National Bureau of Standards has been researching the mechanical and thermal properties of composites used in technological applications.

The purpose of this study is to measure the thermal conductivity of several composite specimens fabricated from actual cryogenic support bands. These data, in addition to being valuable for general composite characterization, will be used to calculate the support band portion of the heat leak into an in-flight liquid helium dewar.

2. MATERIAL AND SPECIMEN CHARACTERIZATION

This report provides thermal conductivity data on two filament wound glass fiber/epoxy support bands. The bands are used as support members for the superfluid helium dewar to be used in the Cosmic Background Explorer (COBE) Observatory. Three specimens were fabricated from these bands by sectioning the straps. The cut pieces were epoxied together to form the final specimens measured. The characteristics of these specimens are given in Table 1.

Additional fabrication and characterization details can be found in the report of Phase I of this work by Hust and Arvidson (1978). The supplier of these bands has indicated that the fabrication materials and procedures are very similar to the previously measured bands. It is noted, however, that the above densities of the new bands are about 4% lower than those measured previously. The densities previously measured (four specimens) ranged from 2.09 to 2.12 g/cm^3. Also the coloration of the two sets is considerably different. The bands measured in 1978 are dark brown, while the current bands are amber.

One additional difference between the current specimens and those previously measured is the thickness. It has been found that the optimum accuracy for this apparatus with low conductivity specimens is obtained at a lower thickness than

Table 1. Characteristics of Specimens

Part Number	Band Serial Number	Specimen Number	Specimen Dimensions (cm) Thickness	Width A	Width B	Weight (g)	Density (g/cm^3)
151490-1	25A	25-A	0.540	1.879	1.737	3.562	2.02
151490-1	25A	25-B	0.644	1.920	1.735	4.358	2.03
151490-1	26	26	0.540	1.905	1.798	3.707	2.00

The fibers are S-2 glass (essentially the same as MIL SPEC S901) and the resin is SCI REZ 081. (The previously used resin is SCI REZ 080). The use of trades is necessary for material identification. No endorsement or approval of the product is intended.

previously used. The thickness is in the direction of the fibers and in the direction of the measured heat flow. The previous specimens were measured at about 2.4 cm thickness, while these at about 0.6 cm thickness. In Table 1, the width (A) is parallel to the pieces cut from the strap while width B is perpendicular to the pieces (both are perpendicular to the glass fibers and heat flow). Previous measurements on similar composites indicate that this change in form factor should not affect the results of these measurements beyond the stated uncertainty.

3. EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

The measurements on the test specimens are performed in an apparatus previously described by Hust and Arvidson (1978). The accuracy, based on considerable experience with this apparatus, including the measurement of Standard Reference Materials, is given as 10%. The imprecision of the data has been found to be near 1% for a given specimen mounting and no more than 5% for specimen remounting in the apparatus.

The experimental data are actually thermal conductivity integral values, since large temperature differences are used. The methods used to analyze these data to obtain thermal conductivity values are described by Hust and Lankford (1982). It is to be noted that the differences between the values obtained by the usual difference technique and the values obtained by the thermal conductivity integral technique are quite small because of the monotonic nature of the curve for this material.

4. RESULTS AND DISCUSSION

The direct experimental data for the three specimens are presented in the appendix. These data were analyzed by both the difference method and the thermal conductivity integral method. The results of these calculations for all of the data are illustrated in Fig. 1. The function chosen for the integral method is

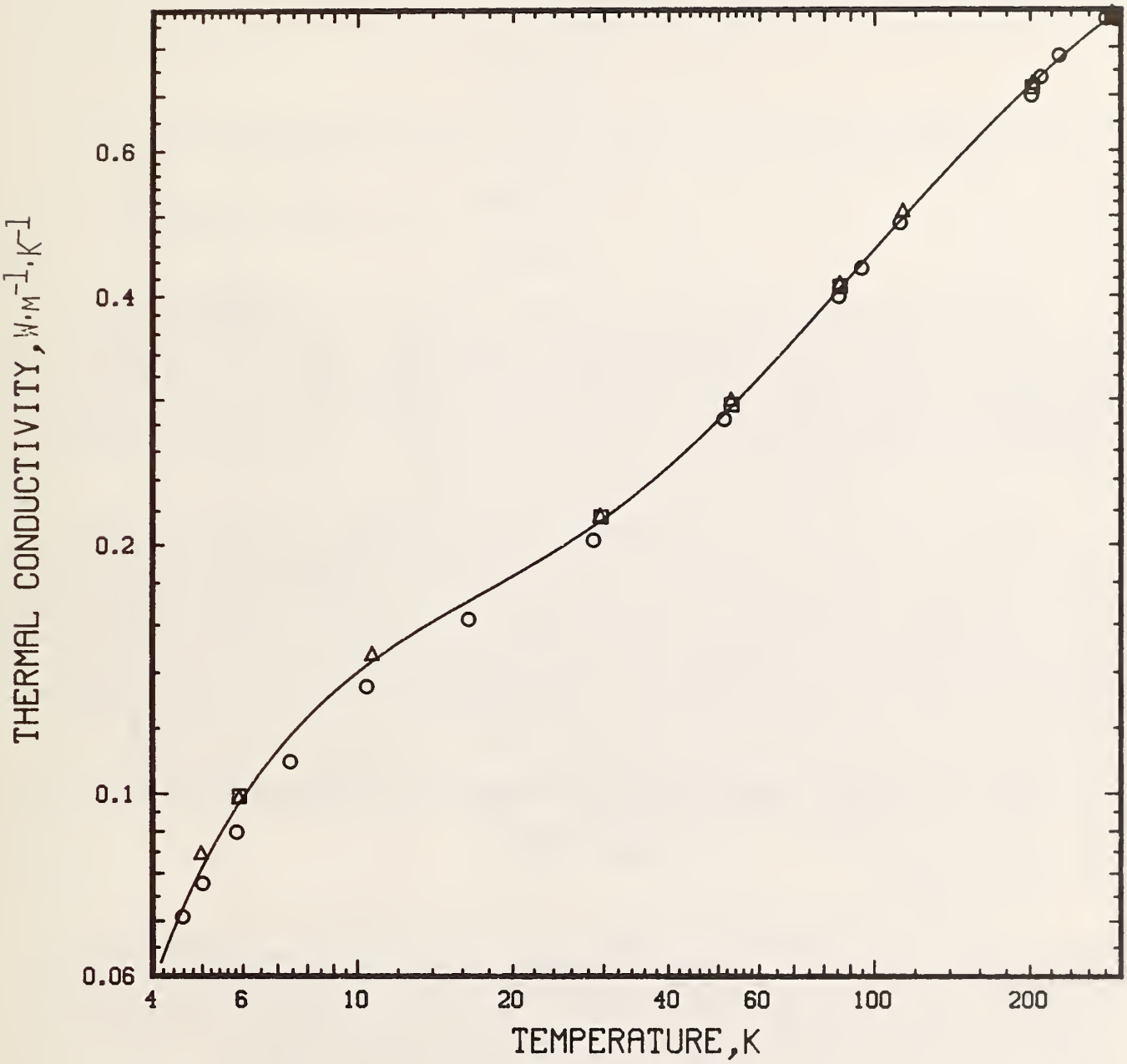

Figure 1. Thermal conductivity of glass fiber/epoxy composite support bands, present measurements.

O = Specimen 25-B
△ = Specimen 25-A
□ = Specimen 26
} From difference method.

Solid line = values from equation 1

$$K(T) = \sum_{i=1}^{5} A_i [\ell n(T+1)]^i \qquad (1)$$

where K(T) is thermal conductivity, T is temperature in Kelvin, and the A_i resulting from the least squares fit are:

$$A_1 = -0.30274718$$

$$A_2 = 0.43272669$$

$$A_3 = -0.18794186$$

$$A_4 = 0.034528862$$

$$A_5 = -0.0021756062$$

The deviations of the measured thermal conductivity integrals from those calculated from (1) are illustrated in Fig. 2. As can be seen, these three specimens are nearly the same in thermal conductivity. However, the differences are somewhat larger than for the specimens measured previously. The current differences are ±5% from the mean at low temperatures, decreasing to ±1% at higher temperatures. The previous results showed differences of about ±2% from the mean at low temperatures and ±4% at higher temperatures.

More important are the differences between the means of the two sets of measurements. Figures 3 and 4 compare the two sets of data. The present values differ from the earlier results by as much a 27% at low temperatures, decreasing to 7% at higher temperatures. The reason for this difference is not understood. It may be connected with the observed difference in density referred to earlier. The thickness difference between the two sets of specimens may be partly responsible for the difference. However, it is noted that Kapitza resistance differences should not be effective to such high temperatures, and the ordinary radiative thickness effect should be most effective at the higher temperatures.

Table 2 contains values of thermal conductivity as calculated from eq. (1) for the present specimens.

5. ACKNOWLEDGMENTS

The author acknowledges the support of Dr. Steve Castles of the Goddard Space Flight Center, NASA. Also acknowledged is Structural Composite Industries for supplying the material and characterization data. Finally I thank Richard Hopkins of Ball Aerospace Systems Division (BASD) for expediting specimen acquisition and miscellaneous interactions with the sponsor and supplier. BASD is under contract to build the helium dewar for the COBE Observatory.

Hust, J. G. and Arvidson, J. M., Thermal Conductivity of Glass Fiber/Epoxy Composite Support Bands for Cryogenic Dewars, Report 275.03-78-2, 80 pages, 1978.

Hust, J. G. and Lankford, A. B., Comments on the Measurement of Thermal conductivity and Presentation of a Thermal Conductivity Integral Method, International Journal of Thermophysics, Vol. 3, No. 1, 67-77 (1982).

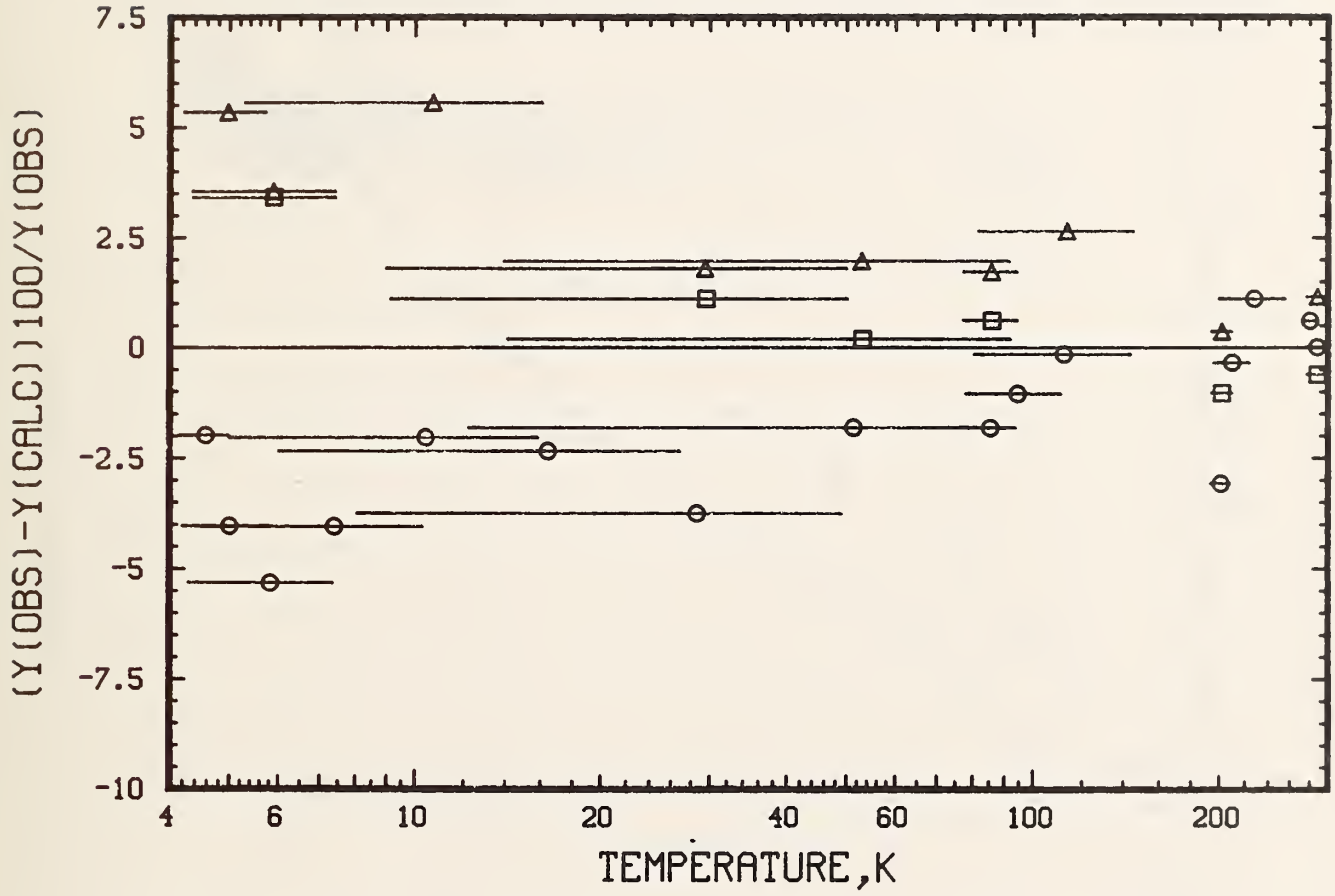

Figure 2. Deviations of observed thermal conductivity integrals from those calculated with equation 1. The horizontal bars indicate the temperature span of the measurement for glass fiber/epoxy composite support bands.

O = Specimen 25-B
△ = Specimen 25-A
□ = Specimen 26

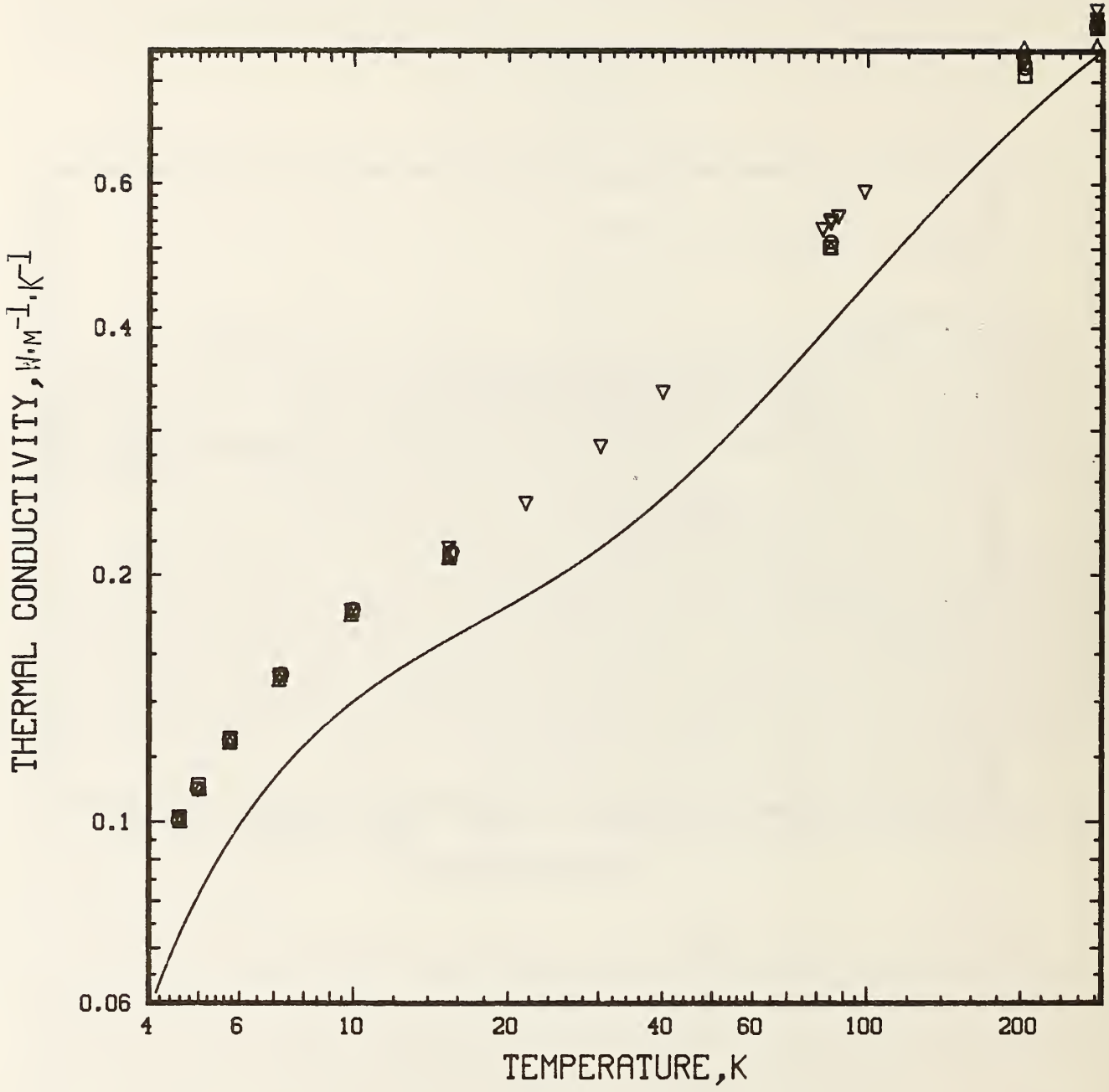

Figure 3. Comparison of current results to those obtained in 1978 for glass fiber/epoxy composite support bands.

Discrete symbols = 1978 results on four specimens
Solid line = current results

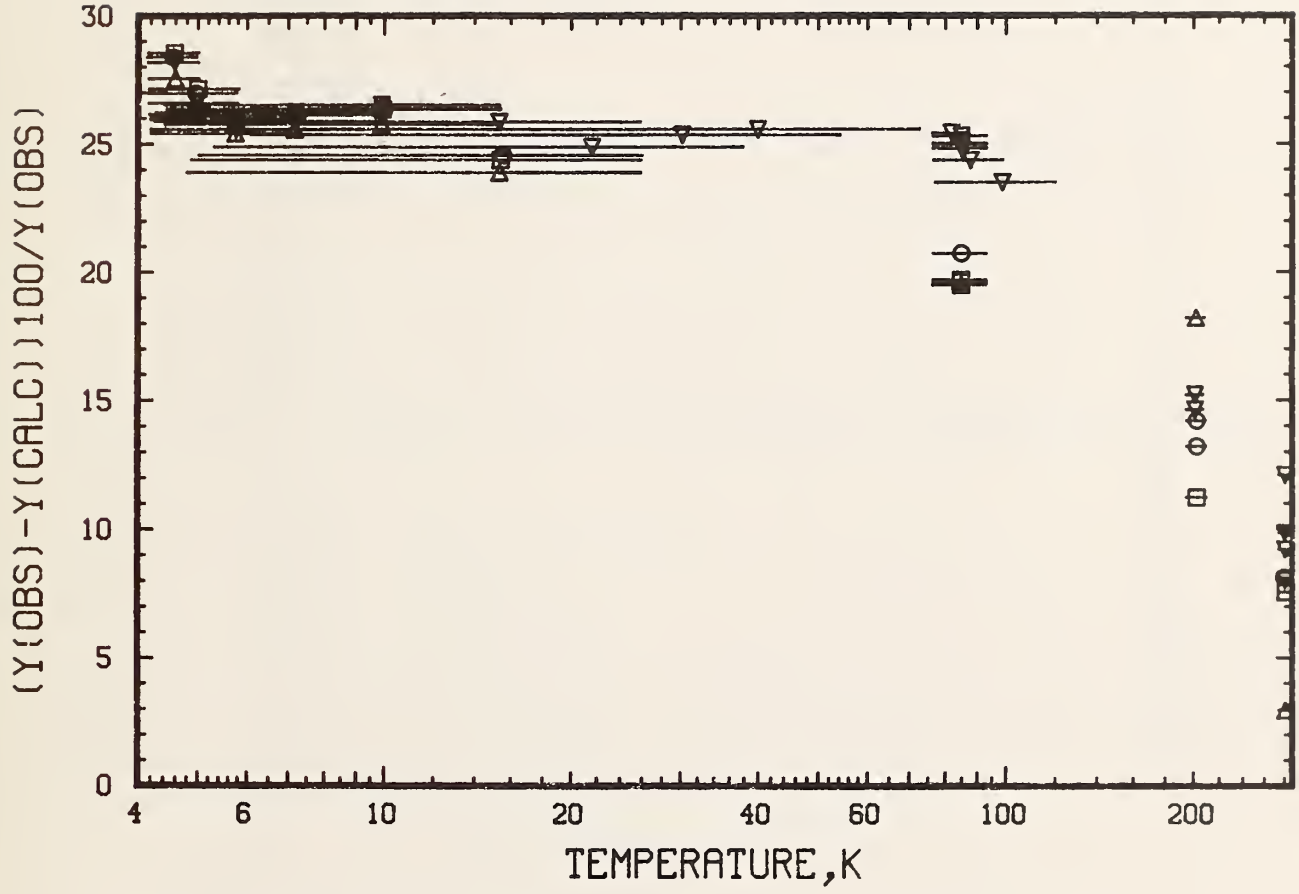

Figure 4. Deviations of 1978 thermal conductivity integrals from values calculated with equation 1 using current coefficients for glass fiber/epoxy composite support bands.

Table 2. Thermal Conductivity Values for the Combined Glass Fiber/Epoxy Composite Support Bands of this Research as Calculated from Equation 1.

Temperature (K)	Thermal Conductivity ($W \cdot m^{-1} \cdot K^{-1}$)
4	0.0584
5	0.0814
6	0.0990
8	0.124
10	0.140
15	0.165
20	0.183
30	0.215
40	0.248
50	0.285
60	0.318
80	0.388
100	0.454
150	0.600
200	0.719
300	0.890

APPENDIX

Direct Experimental Data

For potential future reference it is desirable to record the direct experimental data. These data along with some pertinent calculated quantities are recorded in the following format for each run:

1st line - specimen identification, data, time

2nd line - variable identification

3rd line - variable values

Remaining lines are identified - thermal conductivity is expressed in $W \cdot m^{-1} \cdot K^{-1}$.

Abbreviations in the 2nd line have the following meaning:

HTR VOLT = voltage across heater in volts

HTR CURR = current through heater in milliamps

DELTA E = Emf of differential thermocouple between blocks in microvolts

BTH = code indicating the cryogen

= 1. = liquid helium

= 2. = liquid hydrogen

= 3. = liquid nitrogen

= 4. = dry ice - alcohol mixture

= 5. = ice - water mixture

PRB = code indicating the probe

= 1. = bonded probe

= 2. = compression probe

DIAMETER = equivalent diameter for specimen cross-section in centimeters

TEMP = cryogen temperature in Kelvins

DELE ZERO = spurious emf of differential thermocouple at zero power from heater in microvolts

DELTA X = specimen length in centimeter

Specimen 25-B

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/7/83,1400

  HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
   8.5277   42.8800    299.17   3.    2.    1.9690     76.00       0.00      .5439

THERMAL CONDUCTIVITY=      .3988E+00    UNCERTAINTY=        5.  PERCENT
AT A MEAN TEMP OF        85.316
WITH BLOCK TEMPS OF      93.695  AND      76.936  DELT=      16.760
HERE TOTAL HEAT FLOW=  .3657E+00  AND SPEC HEAT FLOW=  .3161E+00( 86. PCT)
Q/T.DELT(TOTAL)=  .2557E-03 (EMPTY PROBE)=  .3469E-04  (SPECIMEN)=  .2210E-03
HEATER RESISTANCE=      198.874 AND HEATER VOLTAGE=        .8528E+01

--------------------------------------------------------------------------------
THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/7/83,1530

  HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
  12.4213   62.4680    600.21   3.    2.    1.9690     76.00       0.00      .5439

THERMAL CONDUCTIVITY=      .4314E+00    UNCERTAINTY=        5.  PERCENT
AT A MEAN TEMP OF        94.432
WITH BLOCK TEMPS OF     110.877  AND      77.986  DELT=      32.891
HERE TOTAL HEAT FLOW=  .7759E+00  AND SPEC HEAT FLOW=  .6710E+00( 86. PCT)
Q/T.DELT(TOTAL)=  .2498E-03 (EMPTY PROBE)=  .3377E-04  (SPECIMEN)=  .2161E-03
HEATER RESISTANCE=      198.843 AND HEATER VOLTAGE=        .1242E+02

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/7/83,1730

  HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
  18.3937   92.4430   1199.70   3.    2.    1.9690     76.00       0.00      .5439

THERMAL CONDUCTIVITY=      .4896E+00    UNCERTAINTY=        5.  PERCENT
AT A MEAN TEMP OF       112.062
WITH BLOCK TEMPS OF     143.770  AND      80.353  DELT=      63.417
HERE TOTAL HEAT FLOW=  .1700E+01  AND SPEC HEAT FLOW=  .1468E+01( 86. PCT)
Q/T.DELT(TOTAL)=  .2393E-03 (EMPTY PROBE)=  .3266E-04  (SPECIMEN)=  .2066E-03
HEATER RESISTANCE=      198.973 AND HEATER VOLTAGE=        .1839E+02

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1255

  HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
     .7701    3.8740      9.98   1.    2.    1.9690      4.02       -.30      .6439

THERMAL CONDUCTIVITY=      .7081E-01    UNCERTAINTY=        4.  PERCENT
AT A MEAN TEMP OF         4.577
WITH BLOCK TEMPS OF       4.996  AND       4.158  DELT=        .838
HERE TOTAL HEAT FLOW=  .2983E-02  AND SPEC HEAT FLOW=  .2807E-02( 94. PCT)
Q/T.DELT(TOTAL)=  .7776E-03 (EMPTY PROBE)=  .4587E-04  (SPECIMEN)=  .7317E-03
HEATER RESISTANCE=      198.787 AND HEATER VOLTAGE=        .7701E+00

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Specimen 25-B

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1305

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP    DELE ZERO  DELTA X
    1.1188    5.6300    19.99   1.    2.    1.9690     4.02      -.30      .6439

THERMAL CONDUCTIVITY=     .7776E-01    UNCERTAINTY=      4.  PERCENT
AT A MEAN TEMP OF        5.005
WITH BLOCK TEMPS OF      5.811  AND      4.199  DELT=      1.612
HERE TOTAL HEAT FLOW=  .6299E-02  AND SPEC HEAT FLOW=  .5928E-02( 94. PCT)
Q/T.DELT(TOTAL)=  .7806E-03 (EMPTY PROBE)=  .4594E-04  (SPECIMEN)=  .7347E-03
HEATER RESISTANCE=     198.721 AND HEATER VOLTAGE=       .1119E+01

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1320

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP    DELE ZERO  DELTA X
    1.6587    8.3520    39.95   1.    2.    1.9690     4.02      -.30      .6439

THERMAL CONDUCTIVITY=     .8986E-01    UNCERTAINTY=      4.  PERCENT
AT A MEAN TEMP OF        5.827
WITH BLOCK TEMPS OF      7.360  AND      4.294  DELT=      3.066
HERE TOTAL HEAT FLOW=  .1385E-01  AND SPEC HEAT FLOW=  .1303E-01( 94. PCT)
Q/T.DELT(TOTAL)=  .7754E-03 (EMPTY PROBE)=  .4612E-04  (SPECIMEN)=  .7293E-03
HEATER RESISTANCE=     198.599 AND HEATER VOLTAGE=       .1659E+01

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1335

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP    DELE ZERO  DELTA X
    2.5136   12.6600    79.99   1.    2.    1.9690     4.02      -.30      .6439

THERMAL CONDUCTIVITY=     .1094E+00    UNCERTAINTY=      4.  PERCENT
AT A MEAN TEMP OF        7.398
WITH BLOCK TEMPS OF     10.283  AND      4.514  DELT=      5.769
HERE TOTAL HEAT FLOW=  .3182E-01  AND SPEC HEAT FLOW=  .2984E-01( 94. PCT)
Q/T.DELT(TOTAL)=  .7456E-03 (EMPTY PROBE)=  .4653E-04  (SPECIMEN)=  .6991E-03
HEATER RESISTANCE=     198.547 AND HEATER VOLTAGE=       .2514E+01

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1350

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP    DELE ZERO  DELTA X
    3.8392   19.3400   159.93   1.    2.    1.9690     4.02      -.30      .6439

THERMAL CONDUCTIVITY=     .1346E+00    UNCERTAINTY=      4.  PERCENT
AT A MEAN TEMP OF       10.413
WITH BLOCK TEMPS OF     15.823  AND      5.003  DELT=     10.819
HERE TOTAL HEAT FLOW=  .7425E-01  AND SPEC HEAT FLOW=  .6889E-01( 93. PCT)
Q/T.DELT(TOTAL)=  .6590E-03 (EMPTY PROBE)=  .4758E-04  (SPECIMEN)=  .6115E-03
HEATER RESISTANCE=     198.511 AND HEATER VOLTAGE=       .3839E+01

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Specimen 25-B

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1410

   HTR VOLT   HTR CURR   DELTA E   BTH    PRB   DIAMETER     TEMP     DELE ZERO   DELTA X
    5.9210    29.8220    319.95    1.     2.     1.9690      4.02       -.30       .6439

THERMAL CONDUCTIVITY=      .1622E+00     UNCERTAINTY=          4.  PERCENT
AT A MEAN TEMP OF         16.431
WITH BLOCK TEMPS OF       26.844  AND       6.017  DELT=      20.827
HERE TOTAL HEAT FLOW=   .1766E+00  AND SPEC HEAT FLOW=  .1598E+00( 90. PCT)
Q/T.DELT(TOTAL)=   .5160E-03 (EMPTY PROBE)=   .4910E-04  (SPECIMEN)=   .4669E-03
HEATER RESISTANCE=       198.545 AND HEATER VOLTAGE=         .5921E+01

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1430

   HTR VOLT   HTR CURR   DELTA E   BTH    PRB   DIAMETER     TEMP     DELE ZERO   DELTA X
    9.4112    47.3700    639.92    1.     2.     1.9690      4.02       -.30       .6439

THERMAL CONDUCTIVITY=      .2023E+00     UNCERTAINTY=          4.  PERCENT
AT A MEAN TEMP OF         28.591
WITH BLOCK TEMPS OF       49.121  AND       8.061  DELT=      41.059
HERE TOTAL HEAT FLOW=   .4458E+00  AND SPEC HEAT FLOW=  .3928E+00( 88. PCT)
Q/T.DELT(TOTAL)=   .3798E-03 (EMPTY PROBE)=   .4517E-04  (SPECIMEN)=   .3346E-03
HEATER RESISTANCE=       198.674 AND HEATER VOLTAGE=         .9411E+01

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1520

   HTR VOLT   HTR CURR   DELTA E   BTH    PRB   DIAMETER     TEMP     DELE ZERO   DELTA X
   15.4600    77.7600   1280.14    1.     2.     1.9690      4.02       -.30       .6439

THERMAL CONDUCTIVITY=      .2835E+00     UNCERTAINTY=          4.  PERCENT
AT A MEAN TEMP OF         51.255
WITH BLOCK TEMPS OF       90.272  AND      12.238  DELT=      78.034
HERE TOTAL HEAT FLOW=   .1202E+01  AND SPEC HEAT FLOW=  .1046E+01( 87. PCT)
Q/T.DELT(TOTAL)=   .3006E-03 (EMPTY PROBE)=   .3899E-04  (SPECIMEN)=   .2616E-03
HEATER RESISTANCE=       198.817 AND HEATER VOLTAGE=         .1546E+02

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/9/83,920

   HTR VOLT   HTR CURR   DELTA E   BTH    PRB   DIAMETER     TEMP     DELE ZERO   DELTA X
   10.7195    53.8300    306.97    4.     2.     1.9690    192.00       0.00       .6439

THERMAL CONDUCTIVITY=      .6991E+00     UNCERTAINTY=          4.  PERCENT
AT A MEAN TEMP OF        200.991
WITH BLOCK TEMPS OF      208.210  AND     193.771  DELT=      14.439
HERE TOTAL HEAT FLOW=   .5770E+00  AND SPEC HEAT FLOW=  .4773E+00( 83. PCT)
Q/T.DELT(TOTAL)=   .1988E-03 (EMPTY PROBE)=   .3435E-04  (SPECIMEN)=   .1645E-03
HEATER RESISTANCE=       199.136 AND HEATER VOLTAGE=         .1072E+02

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Specimen 25-B

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/9/83,1155

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELF ZERO  DELTA X
   15.3225   76.9400    599.62   4.    2.    1.9690   192.00       0.00      .6439

THERMAL CONDUCTIVITY=      .7357E+00     UNCERTAINTY=       4.  PERCENT
AT A MEAN TEMP OF       209.627
WITH BLOCK TEMPS OF     223.635  AND     195.619  DELT=      28.015
HERE TOTAL HEAT FLOW=  .1179E+01  AND SPEC HEAT FLOW=  .9747E+00( 83. PCT)
Q/T.DELT(TOTAL)=  .2007E-03 (EMPTY PROBE)=  .3477E-04  (SPECIMEN)=  .1660E-03
HEATER RESISTANCE=      199.149 AND HEATER VOLTAGE=        .1532E+02

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/9/83,1515

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
   22.3430  112.2000   1200.50   4.    2.    1.9690   192.00       0.00      .6439

THERMAL CONDUCTIVITY=      .7808E+00     UNCERTAINTY=       4.  PERCENT
AT A MEAN TEMP OF       227.421
WITH BLOCK TEMPS OF     255.145  AND     199.696  DELT=      55.449
HERE TOTAL HEAT FLOW=  .2507E+01  AND SPEC HEAT FLOW=  .2047E+01( 82. PCT)
Q/T.DELT(TOTAL)=  .1988E-03 (EMPTY PROBE)=  .3644E-04  (SPECIMEN)=  .1624E-03
HEATER RESISTANCE=      199.135 AND HEATER VOLTAGE=        .2234E+02

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/10/83,1110

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
   10.7640   54.0000    239.15   5.    2.    1.9690   273.20       0.00      .6439

THERMAL CONDUCTIVITY=      .8661E+00     UNCERTAINTY=       5.  PERCENT
AT A MEAN TEMP OF       279.941
WITH BLOCK TEMPS OF     285.329  AND     274.554  DELT=      10.774
HERE TOTAL HEAT FLOW=  .5813E+00  AND SPEC HEAT FLOW=  .4413E+00( 76. PCT)
Q/T.DELT(TOTAL)=  .1927E-03 (EMPTY PROBE)=  .4641E-04  (SPECIMEN)=  .1463E-03
HEATER RESISTANCE=      199.333 AND HEATER VOLTAGE=        .1076E+02

--------------------------------------------------------------------------------
THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/10/83,1345

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
   15.8097   79.3500    505.90   5.    2.    1.9690   273.20       0.00      .6439

THERMAL CONDUCTIVITY=      .8718E+00     UNCERTAINTY=       5.  PERCENT
AT A MEAN TEMP OF       287.516
WITH BLOCK TEMPS OF     298.910  AND     276.123  DELT=      22.787
HERE TOTAL HEAT FLOW=  .1254E+01  AND SPEC HEAT FLOW=  .9394E+00( 75. PCT)
Q/T.DELT(TOTAL)=  .1915E-03 (EMPTY PROBE)=  .4809E-04  (SPECIMEN)=  .1434E-03
HEATER RESISTANCE=      199.240 AND HEATER VOLTAGE=        .1581E+02

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Specimen 25-A

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THERMAL CONDUCTIVITY DATA FOR EPOX/FI8 STRAP 25-A,6/13/83,1118

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
    1.2635    6.3600    18.53   1.    2.    2.0380     4.02       -.33      .5400

THERMAL CONDUCTIVITY=      .8483E-01    UNCERTAINTY=        3.  PERCENT
AT A MEAN TEMP OF         4.972
WITH BLOCK TEMPS OF       5.722  AND       4.221  DELT=      1.501
HERE TOTAL HEAT FLOW=  .8036E-02  AND SPEC HEAT FLOW=  .7693E-02( 96. PCT)
Q/T.DELT(TOTAL)=  .1077E-02 (EMPTY PROBE)=  .4593E-04  (SPECIMEN)=  .1031E-02
HEATER RESISTANCE=      198.664 AND HEATER VOLTAGE=       .1264E+01

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THERMAL CONDUCTIVITY DATA FOR EPOX/FI8 STRAP 25-A,6/13/83,1135

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
    1.9521    9.8300    40.00   1.    2.    2.0380     4.02       -.33      .5400

THERMAL CONDUCTIVITY=      .9922E-01    UNCERTAINTY=        3.  PERCENT
AT A MEAN TEMP OF         5.891
WITH BLOCK TEMPS OF       7.422  AND       4.360  DELT=      3.063
HERE TOTAL HEAT FLOW=  .1919E-01  AND SPEC HEAT FLOW=  .1836E-01( 96. PCT)
Q/T.DELT(TOTAL)=  .1064E-02 (EMPTY PROBE)=  .4612E-04  (SPECIMEN)=  .1017E-02
HEATER RESISTANCE=      198.586 AND HEATER VOLTAGE=       .1952E+01

-------------------------------------------------------------------------------
THERMAL CONDUCTIVITY DATA FOR EPOX/FI8 STRAP 25-A,6/13/83,1145

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
    4.4901   22.6200   160.00   1.    2.    2.0380     4.02       -.33      .5400

THERMAL CONDUCTIVITY=      .1477E+00    UNCERTAINTY=        4.  PERCENT
AT A MEAN TEMP OF        10.680
WITH BLOCK TEMPS OF      16.064  AND       5.295  DELT=     10.769
HERE TOTAL HEAT FLOW=  .1016E+00  AND SPEC HEAT FLOW=  .9610E-01( 95. PCT)
Q/T.DELT(TOTAL)=  .8831E-03 (EMPTY PROBE)=  .4757E-04  (SPECIMEN)=  .8355E-03
HEATER RESISTANCE=      198.501 AND HEATER VOLTAGE=       .4490E+01

-------------------------------------------------------------------------------
THERMAL CONDUCTIVITY DATA FOR EPOX/FI8 STRAP 25-A,6/13/83,1155

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
   10.8462   54.5800   640.00   1.    2.    2.0380     4.02       -.33      .5400

THERMAL CONDUCTIVITY=      .2171E+00    UNCERTAINTY=        4.  PERCENT
AT A MEAN TEMP OF        29.475
WITH BLOCK TEMPS OF      49.965  AND       8.985  DELT=     40.980
HERE TOTAL HEAT FLOW=  .5920E+00  AND SPEC HEAT FLOW=  .5374E+00( 91. PCT)
Q/T.DELT(TOTAL)=  .4901E-03 (EMPTY PROBE)=  .4519E-04  (SPECIMEN)=  .4449E-03
HEATER RESISTANCE=      198.721 AND HEATER VOLTAGE=       .1085E+02

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Specimen 25-A

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A,6/13/83,1225

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB   DIAMETER    TEMP    DELE ZERO  DELTA X
   17.6722   88.8800   1280.30   1.    2.    2.0380      4.02      -.33      .5400

THERMAL CONDUCTIVITY=      .3000E+00    UNCERTAINTY=         4.  PERCENT
AT A MEAN TEMP OF         52.841
WITH BLOCK TEMPS OF       91.744  AND      13.938  DELT=      77.806
HERE TOTAL HEAT FLOW=   .1571E+01  AND SPEC HEAT FLOW=   .1410E+01( 90. PCT)
Q/T.DELT(TOTAL)=   .3820E-03 (EMPTY PROBE)=   .3903E-04  (SPECIMEN)=   .3430E-03
HEATER RESISTANCE=       198.832 AND HEATER VOLTAGE=        .1767E+02

-------------------------------------------------------------------------------
THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAR 25-A,6/13/83,1505

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB   DIAMETER    TEMP    DELE ZERO  DELTA X
   9.7428    48.9900    304.40   3.    2.    2.0380    76.00       0.00      .5400

THERMAL CONDUCTIVITY=      .4146E+00    UNCERTAINTY=         4.  PERCENT
AT A MEAN TEMP OF         85.739
WITH BLOCK TEMPS OF       94.257  AND      77.222  DELT=      17.035
HERE TOTAL HEAT FLOW=   .4773E+00  AND SPEC HEAT FLOW=   .4267E+00( 89. PCT)
Q/T.DELT(TOTAL)=   .3268E-03 (EMPTY PROBE)=   .3468E-04  (SPECIMEN)=   .2921E-03
HEATER RESISTANCE=       198.873 AND HEATER VOLTAGE=        .9743E+01

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAR 25-A,6/13/83,1630

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB   DIAMETER    TEMP    DELE ZERO  DELTA X
   20.8630  104.8600   1206.80   3.    2.    2.0380    76.00       0.00      .5400

THERMAL CONDUCTIVITY=      .5079E+00    UNCERTAINTY=         4.  PERCENT
AT A MEAN TEMP OF        113.413
WITH BLOCK TEMPS OF      145.226  AND      81.600  DELT=      63.625
HERE TOTAL HEAT FLOW=   .2188E+01  AND SPEC HEAT FLOW=   .1952E+01( 89. PCT)
Q/T.DELT(TOTAL)=   .3032E-03 (EMPTY PROBE)=   .3265E-04  (SPECIMEN)=   .2705E-03
HEATER RESISTANCE=       198.961 AND HEATER VOLTAGE=        .2086E+02

-------------------------------------------------------------------------------
THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A,6/14/83,925

   HTR VOLT  HTR CURR  DELTA E  BTH   PRB   DIAMETER    TEMP    DELE ZERO  DELTA X
   12.3414   61.9500    320.57   4.    2.    2.0380   192.00       0.00      .5400

THERMAL CONDUCTIVITY=      .7251E+00    UNCERTAINTY=         4.  PERCENT
AT A MEAN TEMP OF        201.881
WITH BLOCK TEMPS OF      209.415  AND     194.347  DELT=      15.068
HERE TOTAL HEAT FLOW=   .7645E+00  AND SPEC HEAT FLOW=   .6600E+00( 86. PCT)
Q/T.DELT(TOTAL)=   .2513E-03 (EMPTY PROBE)=   .3437E-04  (SPECIMEN)=   .2170E-03
HEATER RESISTANCE=       199.215 AND HEATER VOLTAGE=        .1234E+02

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Specimen 25-A

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 THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A,6/14/83,1205
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   HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
   17.4400   87.5000    504.30   5.    2.    2.0380   273.20       0.00      .5400
-------------------------------------------------------------------------------
 THERMAL CONDUCTIVITY=      .8628E+00    UNCERTAINTY=         4.  PERCENT
 AT A MEAN TEMP OF       288.113
 WITH BLOCK TEMPS OF     299.470  AND     276.756  DELT=      22.714
 HERE TOTAL HEAT FLOW=  .1526E+01  AND SPEC HEAT FLOW=  .1211E+01( 79. PCT)
 Q/T.DELT(TOTAL)=  .2332E-03 (EMPTY PROBE)=  .4808E-04  (SPECIMEN)=  .1851E-03
 HEATER RESISTANCE=      199.314 AND HEATER VOLTAGE=      .1744E+02

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THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 26,6/15/83,1004

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
1.9979	10.0600	40.00	1.	2.	2.0880	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .9926E-01 UNCERTAINTY= 3. PERCENT
AT A MEAN TEMP OF 5.901
WITH BLOCK TEMPS OF 7.432 AND 4.371 DELT= 3.061
HERE TOTAL HEAT FLOW= .2010E-01 AND SPEC HEAT FLOW= .1927E-01(96. PCT)
Q/T.DELT(TOTAL)= .1113E-02 (EMPTY PROBE)= .4612E-04 (SPECIMEN)= .1067E-02
HEATER RESISTANCE= 198.598 AND HEATER VOLTAGE= .1998E+01

THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 26,6/15/83,1030

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
11.0648	55.7000	640.00	1.	2.	2.0880	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .2161E+00 UNCERTAINTY= 4. PERCENT
AT A MEAN TEMP OF 29.615
WITH BLOCK TEMPS OF 50.099 AND 9.131 DELT= 40.967
HERE TOTAL HEAT FLOW= .6163E+00 AND SPEC HEAT FLOW= .5615E+00(91. PCT)
Q/T.DELT(TOTAL)= .5080E-03 (EMPTY PROBE)= .4519E-04 (SPECIMEN)= .4628E-03
HEATER RESISTANCE= 198.650 AND HEATER VOLTAGE= .1106E+02

THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 26,6/15/83,1100

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
17.9290	90.2000	1280.00	1.	2.	2.0880	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .2953E+00 UNCERTAINTY= 4. PERCENT
AT A MEAN TEMP OF 53.024
WITH BLOCK TEMPS OF 91.905 AND 14.143 DELT= 77.762
HERE TOTAL HEAT FLOW= .1617E+01 AND SPEC HEAT FLOW= .1456E+01(90. PCT)
Q/T.DELT(TOTAL)= .3922E-03 (EMPTY PROBE)= .3903E-04 (SPECIMEN)= .3532E-03
HEATER RESISTANCE= 198.769 AND HEATER VOLTAGE= .1793E+02

THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 26,6/15/83,1330

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
9.9520	50.0500	307.00	3.	2.	2.0880	76.00	0.00	.5400

THERMAL CONDUCTIVITY= .4104E+00 UNCERTAINTY= 4. PERCENT
AT A MEAN TEMP OF 85.863
WITH BLOCK TEMPS OF 94.450 AND 77.275 DELT= 17.175
HERE TOTAL HEAT FLOW= .4981E+00 AND SPEC HEAT FLOW= .4470E+00(90. PCT)
Q/T.DELT(TOTAL)= .3378E-03 (EMPTY PROBE)= .3467E-04 (SPECIMEN)= .3031E-03
HEATER RESISTANCE= 198.841 AND HEATER VOLTAGE= .9952E+01

Specimen 26

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THERMAL CONDUCTIVITY DATA FOR EPOX/FI8 STRAP 26,6/15/83,1900

  HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
  17.6407   88.5000    503.40   5.    2.    2.0880   273.20       0.00      .5400

THERMAL CONDUCTIVITY=      .8674E+00    UNCERTAINTY=        4.  PERCENT
AT A MEAN TEMP OF       288.174
WITH BLOCK TEMPS OF     299.511  AND     276.838  DELT=      22.674
HERE TOTAL HEAT FLOW=  .1561E+01  AND SPEC HEAT FLOW=  .1247E+01( 80. PCT)
Q/T.DELT(TOTAL)=  .2389E-03 (EMPTY PROBE)=  .4807E-04  (SPECIMEN)=  .1909E-03
HEATER RESISTANCE=      199.330 AND HEATER VOLTAGE=        .1764E+02

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THERMAL CONDUCTIVITY DATA FOR EPOX/FI8 STRAP 26,6/15/83,1600

  HTR VOLT  HTR CURR  DELTA E  BTH   PRB  DIAMETER    TEMP     DELE ZERO  DELTA X
  12.5503   63.0000    321.68   4.    2.    2.0880   192.00       0.00      .5400

THERMAL CONDUCTIVITY=      .7153E+00    UNCERTAINTY=        4.  PERCENT
AT A MEAN TEMP OF       201.987
WITH BLOCK TEMPS OF     209.546  AND     194.427  DELT=      15.118
HERE TOTAL HEAT FLOW=  .7907E+00  AND SPEC HEAT FLOW=  .6857E+00( 87. PCT)
Q/T.DELT(TOTAL)=  .2589E-03 (EMPTY PROBE)=  .3437E-04  (SPECIMEN)=  .2246E-03
HEATER RESISTANCE=      199.211 AND HEATER VOLTAGE=        .1255E+02

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5. AUTHOR(S)

J. G. Hust

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The thermal conductivities of three specimens of glass fiber/epoxy composites were measured and reported for the temperature range 4 to 300 K. These specimens were fabricated from two cryogenic dewar support bands.

An average conductivity curve for the three specimens is presented. The data for the three specimens are within ±5% of this average curve. The average curve is compared to a similar curve obtained five years ago in Phase I of this continuing study of composite materials.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

composite; epoxy; glass fiber; low temperature; thermal conductivity

13. AVAILABILITY

☒ Unlimited

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