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Thermal Conductivity Measurements of a Variety of Epoxies and Greases Used for CDF/D0 Silicon Detector Ladder Construction

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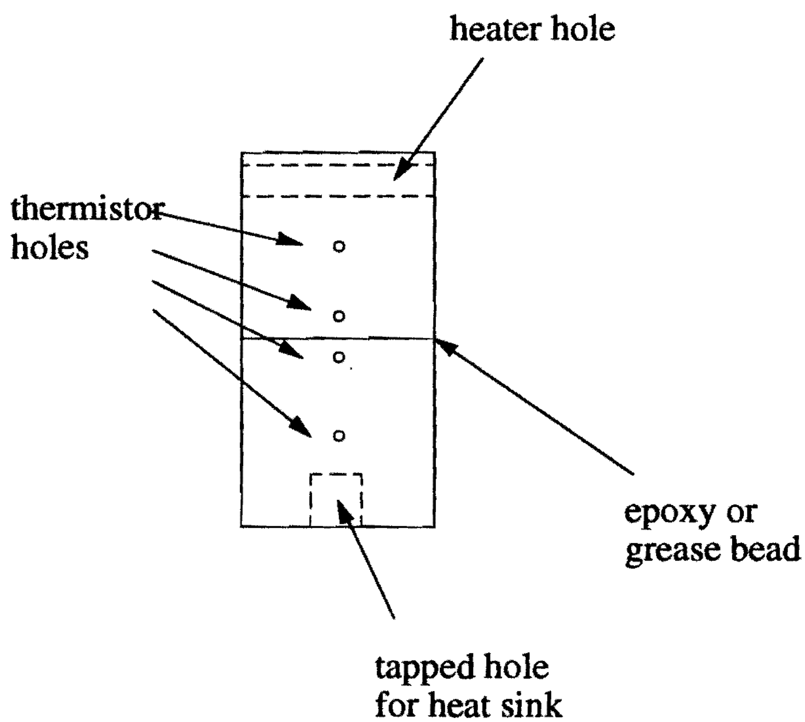
Test Setup

The bulk thermal conductivity of several epoxy mixtures was measured with a setup at Lab D. Samples are prepared by using two aluminum cylinders of 3/4" diameter. The cylinders have holes drilled in them for insertion of temperature sensors (0.040" diameter thermistors), a heating element (standard resistor), and a tapped hole for heat sinking to a plate.



The two cylinders are held together during gluing, and the thickness of the glue bead is controlled by using a shim of kapton tape, nominally 3.5 mils thickness per ply of tape.

A resistor is glued into the hole using 5 minute epoxy. Care is taken to avoid shorting the leads to the aluminum cylinder. Once the sample is prepared, the sample is fixed to the heat sink using the tapped hole provided. Thermistors are carefully insterted into the four holes.

Once set up, the data acquisition program is run for a half-hour prior to turning on the heater power. This is done to ensure that all temperatures stabilize, and this is checked when doing the analysis. The power is then turned on and run until the temperatures have stabilized, which takes two additional hours.

The data acquistion program outputs the four measured temperatures in the form of a voltage, which is read across the thermistor. With known temperatures, a known geometry, and known joint thickness, the temperature drop accross the joint can be extrapolated and the bulk thermal conductivity of the interface material can be calculated.

The power is measured directly using an ammeter in series with the power supply, and measuring the voltage across the resistor while powered up. The resistor value is measured using a hand held device in order to cross-correlate the measurements. The voltage and current are independently measured using the data acquisition program. Their product has been consistently found to be a factor of 10.7 +/- 0.1 lower than the manual measurement of power and has proven to be a good cross-check to the measurement of the power dissipation (the current and voltage readouts to the acquisition program are stepped down with series and parallel resistors, hence off by a factor).

The gradient within the aluminum yields the thermal conductivity of the aluminum, knowing the power and geometry of the piece. The measured aluminum conductivity has been consistently 207 W/m-K with a standard deviation of 13 W/m-K for a large number of measurements, in good agreement with published values. This calculation provides additional cross-check as to the validity of the measurement.

Epoxy

Hexcel 5313/DEH 24 is considered the baseline resin/hardener for ladder construction. Previous measurements indicated [1] that a standard unfilled resin with hardener had a measured bulk conductivity of 0.20-0.26 W/m-K (measurements of Epon 815 with hardener and Araldite 106 with hardener). Araldite AY103/HY991 is a resin/hardener system considered as a backup to 5313/DEH 24 for ladder construction.

Ablestick 563K is an electrically insulating and thermally conducting b-stage epoxy, filled with $Al2O3$. Sheets are 50 microns in thickness and can be easily cut to size using a razor blade. It is a candidate for gluing flex hybrids to substrates. It must be cured at 125°C.

Tra-Con 2902 is a silver filled epoxy which is sold in "bi-pax". It is a candidate where thermal and electrical conductivity is required in a joint. D0 has proposed using this epoxy on the joint between the ladder and the bulkhead.

A number of samples were made in an attempt to improve the thermal conductivity of the glue joint while maintaining electrical insulation. This is accomplished by filling the epoxy resin (Hexcel 5313 in these cases) with diamond particles. Diamond has a bulk thermal conductivity of ~2000 W/m-K and is an electical insulator. In addition, its radiation length is favorable compared to other materials with these properties, and it is readily available in a number of particle sizes.

Three sized of diamond particle were purchased from Weaver Enterprises; 1-3 microns, 6-10 microns, and 17-23 microns. A few combinations of diamond sizes was tried in order to see how the bulk epoxy thermal conductivity could be improved with variations on the volumetric fill fraction of diamond.

Shown below are the results of the measurements on the non-diamond filled epoxies.

test date	sample name (for testing)	Epoxy	filler	joint thickness (mils)	conductivity (W/m-K)
11/9/95	s1_hex.deh24_3.5_11/9	Hexcel 5313/DEH 24	none	3.5	0.21
11/9/95	s2_hex.deh24_7_11/9	Hexcel 5313/DEH 24	none	7.0	0.24
11/10/95	s1_hex.hex_3.5_11/10	Hexcel 5313/Hexcel 5313	none	3.5	0.19
11/10/95	s2_hex.hex_7_11/10	Hexcel 5313/Hexcel 5313	none	7.0	0.28
11/20/95	s3_2902_3.5_11/2C	Tra-Con 2902	silver	3.5	0.87
11/21/95	s4_2902_3.5_11/21	Tra-Con 2902	silver	3.5	0.98
11/21/95	s5_2902_3.5_11/21	Tra-Con 2902	silver	3.5	1.07
11/3/95	s1_arald_3.5_11/3	Araldite AY 103/HY 991	none	3.5	0.22
11/3/95	s2_araldite_7_11/3	Araldite AY 103/HY 991	none	7.0	0.26
10/26/95	s1_563k_10/26	Ablestick 563 K	Al2O3	2.0	1.03
10/27/95	s2_563k_10/27	Ablestick 563 K	Al2O3	2.0	1.02
10/27/95	s3_563k_10/27	Ablestick 563 K	Al2O3	2.0	0.89
10/30/95	s4_563k_10/30	Ablestick 563 K	Al2O3	2.0	1.10

The following are the results of the diamond filled epoxies. Fill fraction (volumetric) is the only fill parameter shown, although in some cases the particle size was varied.

test date	sample name (for testing)	Epoxy	% fill	joint thickness (mils)	conductivity (W/m-K)
10/20/95	s1_hex.diamnd_3.5_10/20	Hexcel 5313/DEH 24	43.5	3.5	1.26
10/20/95	s2_hex.diamnd_3.5_10/20	Hexcel 5313/DEH 24	43.5	3.5	1.40
10/23/95	s4_hex.diamnd_3.5_10/23	Hexcel 5313/DEH 24	43.0	3.5	1.04
10/23/95	s5_hex.diamnd_3.5_10/23	Hexcel 5313/DEH 24	41.1	3.5	1.39
10/24/95	s6_hex.diamnd_3.5_10/24	Hexcel 5313/DEH 24	41.1	3.5	1.12
10/19/95	s7_hex.diamnd_3.5_10/19	Hexcel 5313/DEH 24	43.6	3.5	0.94
11/30/95	s8_hex.diamnd_3.5_11/30/95	Hexcel 5313/DEH 24	43.6	3.5	1.25
10/25/95	s9_hex.diamnd_3.5_10/25	Hexcel 5313/DEH 24	41.3	3.5	0.83
11/28/95	s10_hex.diamnd_3.5_11/28	Hexcel 5313/DEH 24	41.3	3.5	0.79
10/31/95	s11_hex.diamnd_3.5_10/31	Hexcel 5313/DEH 24	48.5	3.5	0.87
10/31/95	s12_hex.diamnd_3.5_10/31	Hexcel 5313/DEH 24	48.5	3.5	1.20
11/1/95	s13_hex.diamnd_3.5_11/1	Hexcel 5313/DEH 24	52.3	3.5	1.20
12/1/95	s14_hex.diamnd_3.5_12/1	Hexcel 5313/DEH 24	52.3	3.5	1.03
12/1/95	s15_hex.diamnd_3.5_12/1	Hexcel 5313/DEH 24	43.5	3.5	0.73
11/13/95	s16_hex.diamnd_3.5_11/13	Hexcel 5313/DEH 24	43.5	3.5	0.94
11/14/95	s17_hex.diamnd_3.5_11/14	Hexcel 5313/DEH 24	43.5	3.5	0.91
12/4/95	s18_hex.diamnd_7_12/4	Hexcel 5313/DEH 24	43.5	7.0	1.37
11/17/95	s19_hex.diamnd_7_11/17	Hexcel 5313/DEH 24	43.5	7.0	1.22

The sample numbers reside in the sample name. Sample 1, for instance, begins with s1 in the name and is named s1_hex.diamnd_3.5_10/20. Sample number 3 was lost, so the diamond filled epoxies, 18 of them in total, are labeled 1-19.

Samples 1 and 2 were prepared using only the 17-23 micron diamond particles. They were both identical to one another. Sample 4 was similar to 1/2, but had slightly more hardener. Samples 5/6 were from the sample 4 mixture, but additional hardener was added.

Samples 7/8 were with a mixture of 17-23 microns and 6-10 microns diamond. Samples 9/10 were of the 7/8 batch with additional hardener.

Samples 11/12 were a mixture of 17-23 microns diamond and 1-3 microns diamond.

Samples 13/14 were with only 6-10 micons diamond.

Samples 15-19 were identical to the sample 1/2 mixture.

There does not appear to be a large correlation between the diamond fill fraction and the bulk conductivity. To get the high fill fractions (>50%) of diamond in epoxy it was necessary to heat the resin during the mixing process. The last two samples tested were with 7 mils thick beads. The calculated bulk conductivity was ~30% higher than was calculated for the thinner joints of identical mixture. This would be attributed either to the bead thickness uncertainty or perhaps to the interface resistance of the epoxy to metal contact. Fractionally this value would contribute less to the overall bulk conductivity, resulting in a higher calculated bulk conductivity. This trend can be seen also in the conductivities presented in the first table.

Grease

Dow 340 and Wakefield Engineering Thermal Compound #120-2 are two candidate thermal greases which could be used, for instance, to enhance the thermal contact between the bulkhead ledge and the ladder. Both were tested in the above setup in thicknesses of 3.5 and 7.0 mils. Following are the grease results:

test date	sample name (for testing)	Grease	joint thickness (mils)	conductivity (W/m-K)
1/5/96	s1_wakfld_3.5_1/5	Wakefield	3.5	0.75
1/9/96	s2_wakfld_7_1/9	Wakefield	7.0	0.75
1/10/96	s1_dow_3.5_1/10	Dow	3.5	0.71
1/11/96	s2_dow_7_1/11	Dow	7.0	0.68

[1] Preliminary Results of epoxy measurements dated 2/1/94, presented by T. Heger of TS at Fermilab.