P-04-160

Oskarshamn site investigation

Drill hole KSH01A

Thermal properties: thermal conductivity and specific heat capacity determined using the Hot Disk thermal constants analyser (the TPS technique) – Compared test

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August 2004

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Keywords: Thermal properties, Thermal conductivity, Specific heat capacity, Transient Plane source method.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author and do not necessarily coincide with those of the client.

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Abstract

The thermal conductivity and the specific heat capacity (Cp) of 9 drill core samples from drill hole KSH01A, Oskarshamn, have been measured with the Hot Disk® Thermal Constants Analyser (the TPS method). The rock types of the samples are Quartz monzodiorite and Fine–grained dioritoid.

The specimens were sampled on two levels in the drill hole: 300 and 400 m. The thermal conductivities at 20°C were in the range 2.81–2.94 W/mK (level 300 m) and 2.75–3.09 W/mK (level 400 m), at 50°C in the range 2.81–2.89 W/mK (level 300 m) and 2.76–3.04 W/mK (level 400 m) and at 80°C in the range range 2.76–2.84 W/mK (level 300 m) and 2.70–3.01 W/mK (level 400 m).

The specific heat capacity at 20°C were in the range 2.22–2.33 MJ/m^{3}K (level 300 m) and 2.17–2.41 MJ/m^{3}K (level 400 m), at 50°C in the range 2.39–2.64 MJ/m^{3}K (level 300 m) and 2.36–2.50 MJ/m^{3}K (level 400 m) and at 80°C in the range 2.47–2.67 MJ/m^{3}K (level 300 m) and 2.48–2.70 MJ/m^{3}K (level 400 m).

For the level 300 m samples the thermal conductivity in average decreased with 2.6% over the temperature interval 20–80°C and the Cp values increased with 11.9%.

For the level 400 samples the thermal conductivity in average decreased with 3.5% over the temperature interval 20–80°C and the Cp values increased with 13.7%.

Contents

1 Introduction

This document reports the data collected by site investigation, which is one of the activities performed as part of the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-04-012 (SKB internal controlling document) and method description MD 191.001 (SKB internal controlling document).

The objective of this investigation was to measure thermal properties of borehole KSH01A, Oskarshamn, (See Figure 1-1) at different temperature levels (20, 50 and 80°C) by using the TPS method. The measurements were carried out on water saturated cylindrical specimens cut from rock cores. The samples were selected based on the preliminary core logging and with the strategy to primarily investigate the properties of the dominant rock properties.

Specimens from borehole KSH01A were taken from the Simpevarp site on 13 May 2003 by SKB and Swedish National Testing and Research Institute (SP). The cores were marked and cut in SP laboratory and the thermal properties were measured in SP laboratory, during January 2004. The rock cores arrived to Hot Disk AB, Uppsala, 16 Febuary 2004 and the measurements were carried out in Febuary and March 2004. Prior to the measurements the samples were water saturated for at least 7 days and the density was determined in accordance to SKB MD 160.002, (SKB internal controlling document).

The principle of the TPS instrument is to place a circular temperature probe and heater between 2 pieces of the sample. This probe consists of a Ni-spiral covered by an insulating material (MICA or KAPTON). During the measurement a constant power is emitted by the sensor and the heating of the specimen is recorded simultaneously. The data is then treated in the Hot Disk software and the thermal conductivity (TC), thermal diffusivity (TD) and specific heat capacity (C_p) is determined.

Figure 1-1. *The site investigation at Oskarshamn.*

2 Scope

Hot Disk AB carries out this investigation which results are to be compared to measurements carried out at SP, Borås. The samples are from bore hole KSH01A in Oskarshamn. The specimens were sampled from 300 m (Quartz monzodiorite) and 400 m (Fine-grained dioritoid).

The results are also used in the rock thermal model, which will be established for the candidate area selected for site investigations at Simpevarp.

3 Equipment

The equipment used for the measurements was a Hot Disk thermal constants analyser.

The following items are included in the Hot Disk instrument (Figure 3-2):

1. Hot Disk bridge unit,
2. Keithley 2400 source/meter,
3. Keithley 2000 volt meter,
4. PC,
5. Computation Device,
6. Hot Disk SW version 5.7.

The sensor used for the measurements had a radius of 6.401 mm (S/N C5501) (Figure 3-1) and the temperature of the sample was regulated with a ThermoHaake C50P oilbaath. Sample set-up is shown in section 4.2.

Additional equipment was rubber bands, plastic bags, table cloth and plastic straps, see section 4.2.

Figure 3-1. *Hot Disk sensor.*

Figure 3-2. *Hot Disk instrument.*

4. Execution

4.1 Samples

The samples were recieved on the 16 Febuary and all the samples were carefully taken out of the box and catalogued in a table “SKB-sample register” (Table 4-1). This sample register was used as a log of the measurements. A cross was put into the table at each completed measurement. The samples were labeled SOIA-90V-X .

A total of 21 (42 samples, 25 mm high, 50 mm diameter) cores were sampled from two levels of drill hole KSH01A, Oskarshamn. The samples tested by Hot Disk came from the depths around 300 metres and 400 metres according to Table 4-2. Detailed geological description of the rock is given in SKB’s BOREMAP of KSH01A and in the SICADA database at SKB.

Table 4-1. SKB sample register. The two columns denoted “Weight” contains the two sample bodies individual weights.

Sample ID	Soaking date	Measure-ment date	Weight (g) (Wet)	Weight (g) (Wet)	22 C	50 C	80 C	Comment on measurement
SOIA-90V-2	17 feb	28/2	139,97	136.97	X	X	X	Ok
11	17 feb	1/3	133,12	133,81	X	X	X	Ok
10	17 feb	2/3	132,93	132,87	X	X	X	Ok
9	17 feb	4/3	139,90	139,73	X	X	X	Remeasurement Sensor break down
1	17 feb	3/3	140,66	139,19	X	X	X	Ok
5	17 feb	26/2	141,43	139,84	X	X	X	Ok
7	17 feb	25/2	140,56	140,74	X	X	X	Ok
3	17 feb	24/2	140,82	138,59	X	X	X	Ok
4	17 feb	27/2	138,58	140,19	X	X	X	Ok
Re-measurement								
SOIA-90V-9	7 days	19/3	139.89	139.74	X	X	X	Ok

Table 4-2. Rock type and identification marks.

Sample ID	Rock Type	Sampling depth (Sec Low)
S01A-090V-01	Quartz monzodiorite	299.27
02	Quartz monzodiorite	300.33
03	Quartz monzodiorite	300.45
04	Quartz monzodiorite	302.06
05	Quartz monzodiorite	306.01
07	Fine-grained dioritoid	399.39
09	Fine-grained dioritoid	401.75
10	Fine-grained dioritoid	404.12
11	Fine-grained dioritoid	404.24

4.2 Measurements

All the measurements were carried out with the Hot Disk Bridge system and an oil-bath (ThermoHaake C50P) for temperature regulations.

Prior to the measurement all samples were soaked in water for a period of at least 7 days. With a rough frequency of 1 sample per day the samples were taken out from the water and dried with a wet cloth and after that immediately weighed and measured.

The samples were then prepared for the measurement in the following way:

1. The sensor was sandwiched between the samples and the sample pieces were thoroughly forced together with a plastic strap, see Figure 4-1.

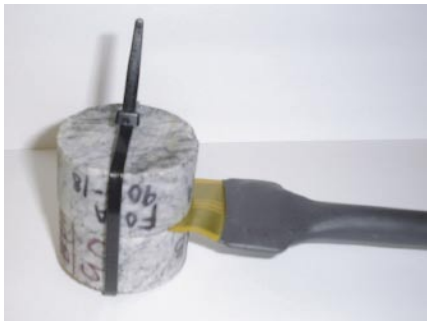


Figure 4-1.

2. The sensor, sample and plastic strap were then enclosed in a plastic bag (air was manually sucked out of the plastic bag and the bag was thereafter sealed off with a rubber band.), see Figure 4-2.

Figure 4-2.

3. The next layer was a wet cloth wrapped around the sample (fixation: a rubber band). This was done so that the plastic bags were not punctured, see Figure 4-3.

Figure 4-3.

4. Finally a last plastic bag enclosed the whole "sample package" (air was manually sucked out of the plastic bag and the bag was thereafter sealed off with a rubber band), see Figure 4-4.

Figure 4-4.

As a cooling and heating facility an oil bath was used with a special sample compartment immersed in the oil bath. The oil bath keeps the temperature stable whithin at least +/– 1°C. In order to allow fast heat transfer from the oil to the sample the sample compartment was filled with water. The plastic bags + sample were suspended in so that the sample was hanging freely in the water, see Figure 4-5.

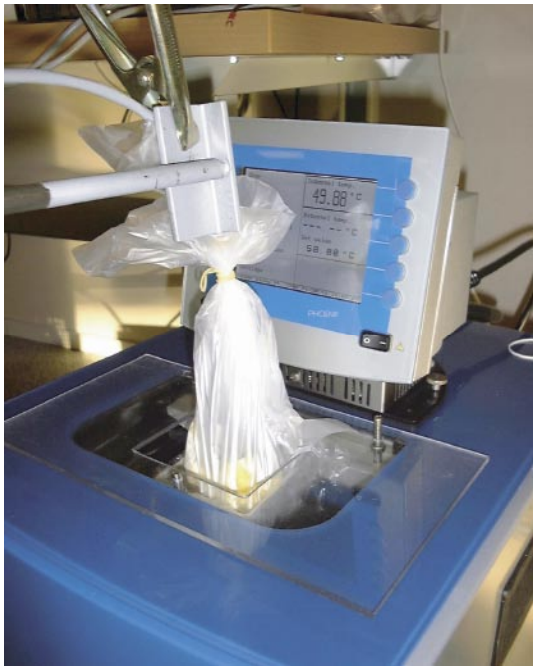


Figure 4-5.

Five measurements were carried out at each temperature (20°C, 50°C and 80°C) for each sample. The sensor chosen for the measurements were C5501 (radius 6.401 mm) and power and measurement time were 0.7W and 20s respectively. These measurement parameters proved to give a rough temperature increase of 0.5–1.5 K in the interval of calculation, a total to characteristic time well whithin the interval 0.3 and 1.0 and an experimental probing depth less than the maximum allowed probing depth.

Before increasing the temperature to the next temperature level, the measured files were monitored to assure that the measurement series was complete. In those cases where one measurement could be doubted (for any reason) an extra measurement was carried out. The measurement files (raw data files) were stored on the measurement computer and also on the server and one personal computer for safety. The files were named as:

SOIA-90V-Samplenumber_temperature. Sequence number.hot.

Example: SOIA-90V-1_80.3.hot.

After the measurements the samples were stored in room temperature (RT) without any cover.

Calculations of the measurement files were carried out according to the Hot Disk manual, meaning that the selected points of calculation were chosen so that the points as well as possible fitted the thermal conductivity equation. The data was then transported into Microsoft® Excel for further treatment.

Since the Hot Disk Constants Analyser is an absolute method, there is no need for calibration in between measurements. The quality of the sensors was checked regularly by measuring a SIS 2343 mildsteel sample. If no deviation to the normal value 13.88 +/– 0.7 W/mK (5%), the sensor was judged as fully functioning.

4.3 Nonconformities

Samples SOIA-90V-9 were remeasured since the sensor used was suspected to have been broken during the measurement. The sample was then again soaked in water for 7 days and then measured in the same manner as the other samples. The results from these measurements were compared to the original ones.

5 Results

Mean values of measured data, five repeated measurements, are reported in section 5.1 and in the SICADA database (FN 96) at SKB. Values of each separate measurement are reported in Appendix.

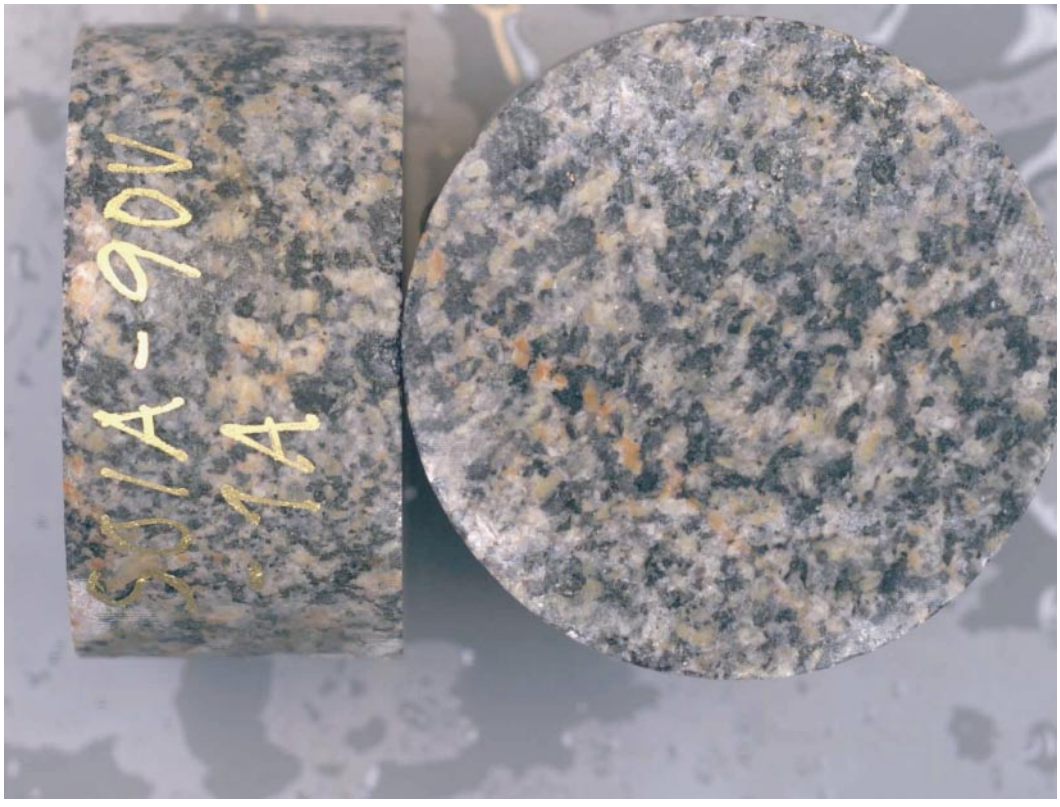
5.1 Measurement results

The results for the measurements are given in the following tables and figures (Tables and Figures 5-1 to 5-9). For all the graphs, please refer to Appendix. All values are means from 5 individual measurements.

SOIA-90V-1

Table 5-1 and Figure 5-1. Results and picture for sample SOIA-90V-1.

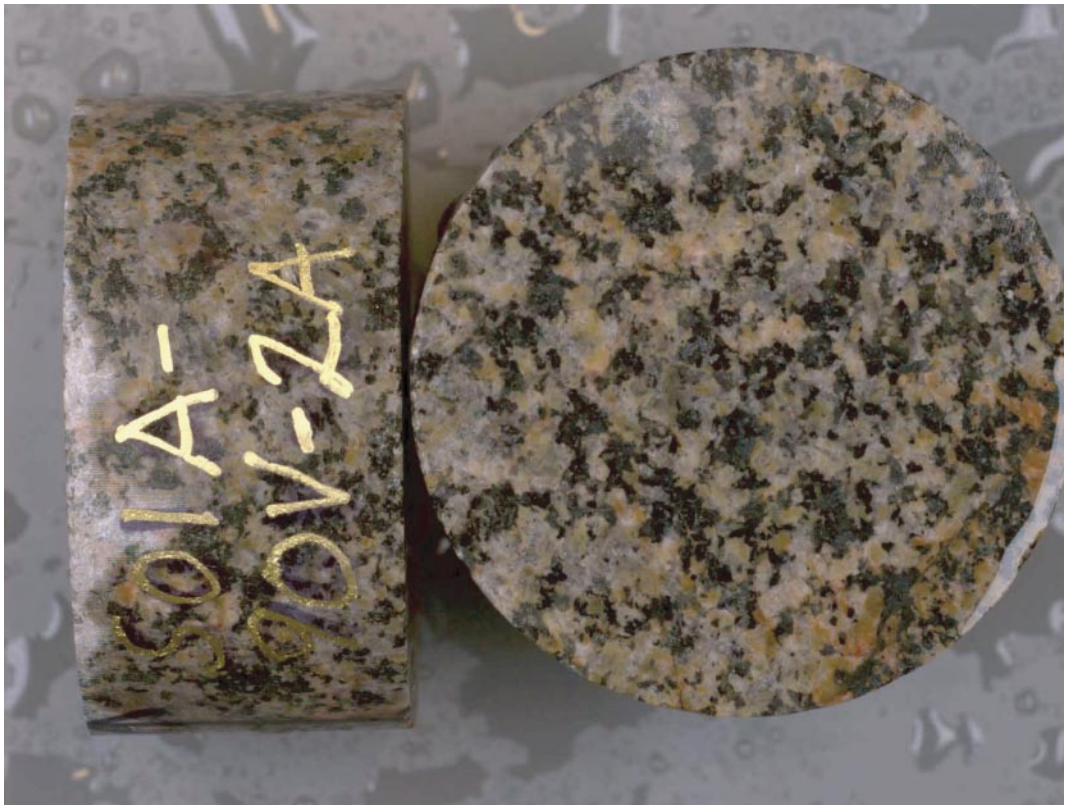
SOIA-90V-1 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m3K]	Std [MJ/m3K]
20	2.81	0.005	2.23	0.02
50	2.82	0.01	2.49	0.05
80	2.76	0.01	2.61	0.08



SOIA-90V-2

Table 5-2 and Figure 5-2. Results and picture for sample SOIA-90V-2.

SOIA-90V-2 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m3K]	Std [MJ/m3K]
20	2.88	0.01	2.33	0.009
50	2.89	0.01	2.41	0.05
80	2.80	0.004	2.67	0.007



SOIA-90V-3

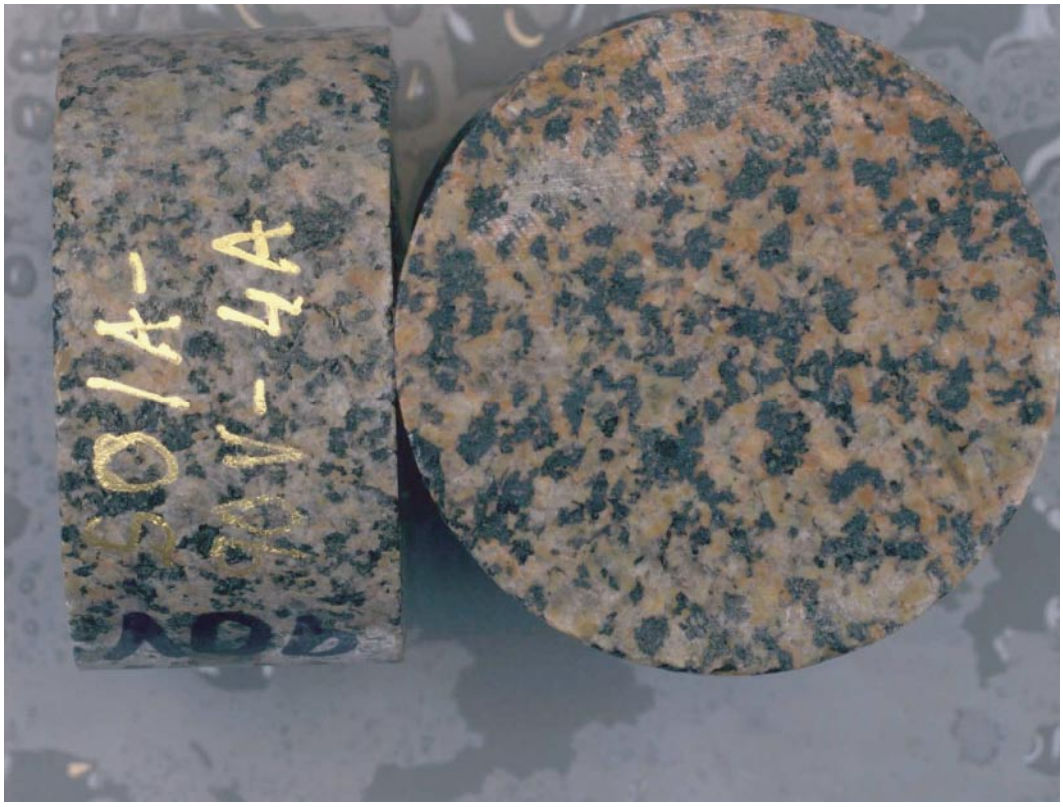
Table 5-3 and Figure 5-3. Results and picture for sample SOIA-90V-3.

SOIA-90V-3 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m3K]	Std [MJ/m3K]
20	2.85	0.02	2.22	0.03
50	2.81	0.003	2.39	0.008
80	2.77	0.006	2.58	0.03

SOIA-90V-4

Table 5-4 and Figure 5-4. Results and picture for sample SOIA-90V-4.

SOIA-90V-4 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m3K]	Std [MJ/m3K]
20	2.94	0.001	2.31	0.02
50	2.89	0.01	2.54	0.06
80	2.83	0.01	2.47	0.09



SOIA-90V-5

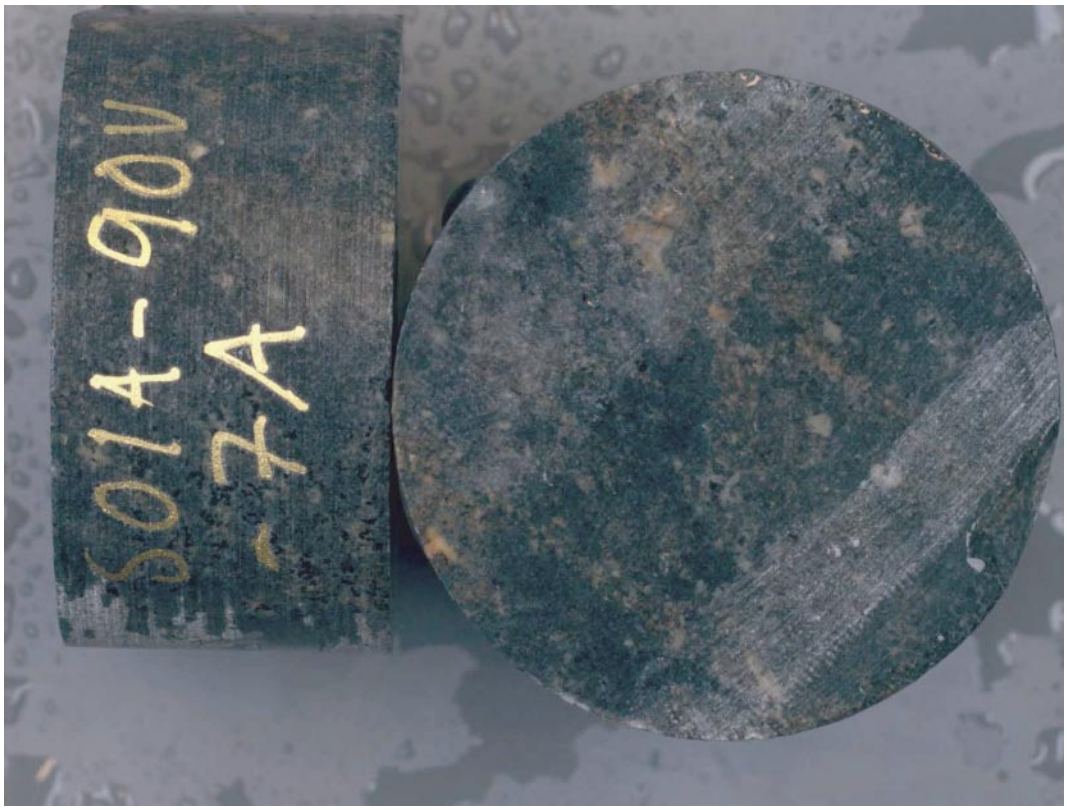
Table 5-5 and Figure 5-5. Results and picture for sample SOIA-90V-5.

SOIA-90V-5 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m3K]	Std [MJ/m3K]
20	2.88	0.002	2.26	0.003
50	2.85	0.003	2.64	0.07
80	2.83	0.006	2.56	0.01

SOIA-90V-7

Table 5-6 and Figure 5-6. Results and picture for sample SOIA-90V-7.

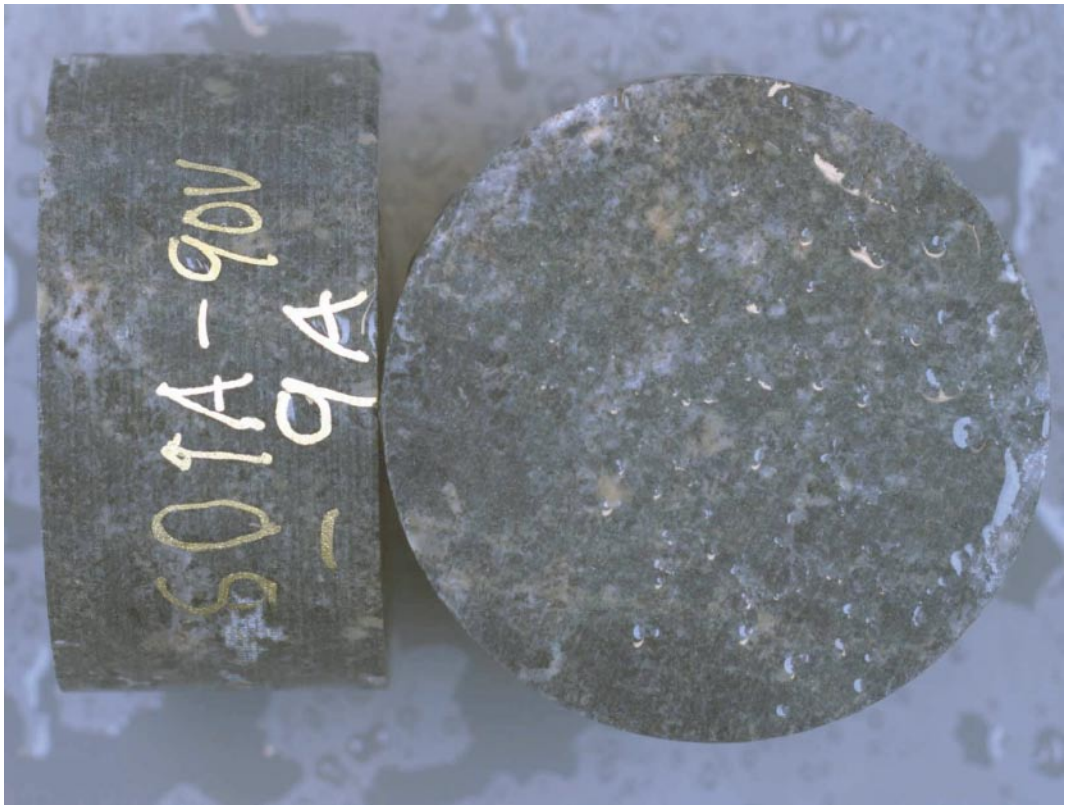
SOIA-90V-7 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m3K]	Std [MJ/m3K]
20	2.75	0.01	2.23	0.05
50	2.76	0.006	2.35	0.02
80	2.70	0.03	2.48	0.14



SOIA-90V-9

Table 5-7 and Figure 5-7. Results and picture for sample SOIA-90V-9.

SOIA-90V-9 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m3K]	Std [MJ/m3K]
20	3.09	0.007	2.33	0.01
50	3.04	0.006	2.50	0.02
80	3.01	0.01	2.67	0.07



SOIA-90V-10

Table 5-8 and Figure 5-8. Results and picture for sample SOIA-90V-10.

SOIA-90V-10 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m3K]	Std [MJ/m3K]
20	2.94	0.009	2.17	0.01
50	2.88	0.005	2.36	0.01
80	2.82	0.003	2.52	0.01

SOIA-90V-11

Table 5-9 and Figure 5-9. Results and picture for sample SOIA-90V-11.

SOIA-90V-11 Temp [C]	TC [W/mK]	Std [W/mK]	Cp [MJ/m3K]	Std [MJ/m3K]
20	2.86	0.006	2.41	0.02
50	2.81	0.03	2.50	0.1
80	2.72	0.01	2.70	0.01

5.2 Summary of results

Below, Table 5-10, the results for the thermal conductivity (TC) and the specific heat capacity (Cp) is presented for each temperature and the different specimens.

Table 5-10. Thermal conductivity and Specific heat capacity, with corresponding standard deviations for the samples in the SOIA-90V series. Included is the remeasured values.

Sample (20 degrees C)	TC [W/mK]	Std [W/mK]	Cp [MJ/m3K]	Std [MJ/m3K]
SOIA-90V-1	2.81	0.005	2.23	0.02
SOIA-90V-2	2.88	0.01	2.33	0.009
SOIA-90V-3	2.85	0.02	2.22	0.03
SOIA-90V-4	2.94	0.001	2.31	0.02
SOIA-90V-5	2.88	0.002	2.26	0.003
Mean level 300 m	**2.87**	**0.007**	**2.27**	**0.016**
SOIA-90V-7	2.75	0.01	2.23	0.05
SOIA-90V-9	3.09	0.007	2.33	0.01
SOIA-90V-10	2.94	0.009	2.17	0.01
SOIA-90V-11	2.86	0.006	2.41	0.02
SOIA-90V-9 Remeas	3.02	0.02	2.21	0.04
Mean level 400 m	**2.93**	**0.010**	**2.27**	**0.025**
Sample (50 degrees C)	**TC [W/mK]**	**Std [W/mK]**	**Cp [MJ/m3K]**	**Std [MJ/m3K]**
SOIA-90V-1	2.82	0.01	2.49	0.05
SOIA-90V-2	2.89	0.01	2.41	0.05
SOIA-90V-3	2.81	0.003	2.39	0.008
SOIA-90V-4	2.89	0.01	2.54	0.06
SOIA-90V-5	2.85	0.003	2.64	0.07
Mean level 300 m	**2.85**	**0.009**	**2.49**	**0.046**
SOIA-90V-7	2.76	0.006	2.35	0.02
SOIA-90V-9	3.04	0.006	2.50	0.02
SOIA-90V-10	2.88	0.005	2.36	0.01
SOIA-90V-11	2.81	0.03	2.50	0.1
SOIA-90V-9 Remeas	2.99	0.02	2.37	0.09
Mean level 400 m	**2.90**	**0.014**	**2.42**	**0.049**
Sample (80 degrees C)	**TC [W/mK]**	**Std [W/mK]**	**Cp [MJ/m3K]**	**Std [MJ/m3K]**
SOIA-90V-1	2.76	0.01	2.61	0.08
SOIA-90V-2	2.80	0.004	2.67	0.007
SOIA-90V-3	2.77	0.006	2.58	0.03
SOIA-90V-4	2.83	0.01	2.47	0.09
SOIA-90V-5	2.83	0.006	2.56	0.01
Mean level 300 m	**2.80**	**0.008**	**2.58**	**0.044**
SOIA-90V-7	2.70	0.03	2.48	0.14
SOIA-90V-9	3.01	0.01	2.67	0.07
SOIA-90V-10	2.82	0.003	2.52	0.01
SOIA-90V-11	2.72	0.01	2.70	0.01
SOIA-90V-9 Remeas	2.91	0.009	2.54	0.040
Mean level 400 m	**2.83**	**0.014**	**2.58**	**0.055**

The results from Table 5-10 are plotted vs. depth below in Figure 5-10 a,b and c (level 300 m) and Figure 5.11 a, b and c (level 400 m). The depths have been taken from Table 4-2. The thermal conductivities at 20°C were in the range 2.81–2.94 W/mK (level 300 m) and 2.75–3.09 W/mK (level 400 m), at 50°C in the range 2.81–2.89 W/mK (level 300 m) and 2.76–3.04 W/mK (level 400 m) and at 80°C in the range range 2.76–2.83 W/mK (level 300 m) and 2.70–3.01 W/mK (level 400 m).

The specific heat capacity at 20°C were in the range 2.22–2.33 MJ/m^{3}K (level 300 m) and 2.17–2.41 MJ/m^{3}K (level 400 m), at 50°C in the range 2.40–2.64 MJ/m^{3}K (level 300 m) and 2.36–2.50 MJ/m^{3}K (level 400 m) and at 80°C in the range 2.47–2.67 MJ/m^{3}K (level 300 m) and 2.48–2.70 MJ/m^{3}K (level 400 m).

For the level 300 m samples the thermal conductivity in average decreased with 2.6% over the temperature interval 20–80°C and the Cp values increased with 11.9%.

For the level 400 m samples the thermal conductivity in average decreased with 3.5% over the temperature interval 20–80°C and the Cp values increased with 13.7%.

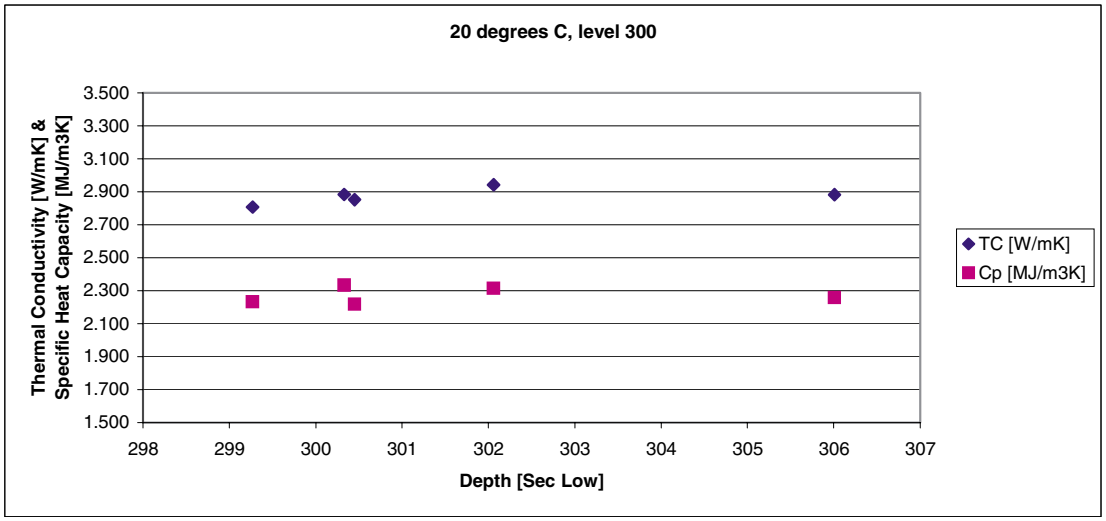


Figure 5-10a. *The results plotted vs. depth. Cp and TC at 20 degrees C, level 300 m.*

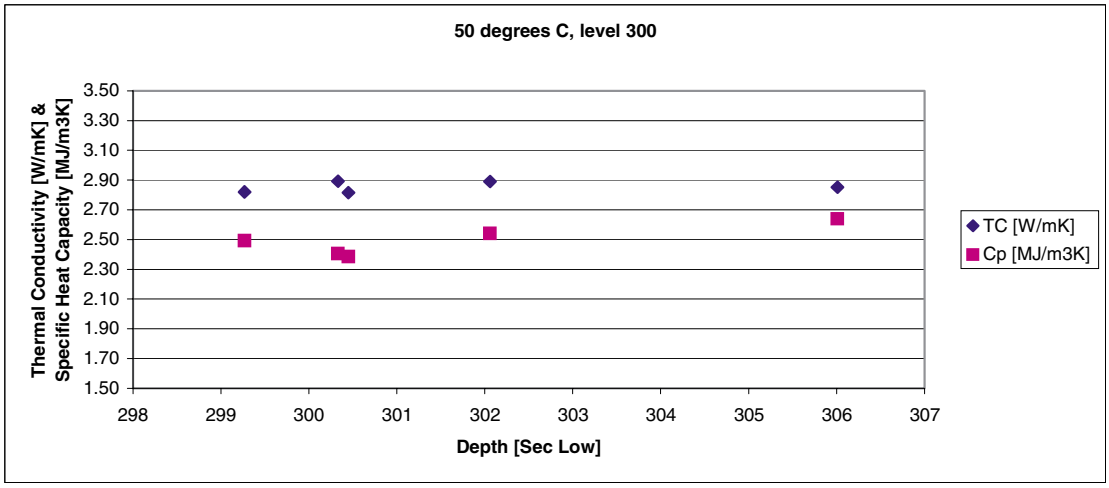


Figure 5-10b. *The results plotted vs. depth. Cp and TC at 50 degrees C, level 300 m.*

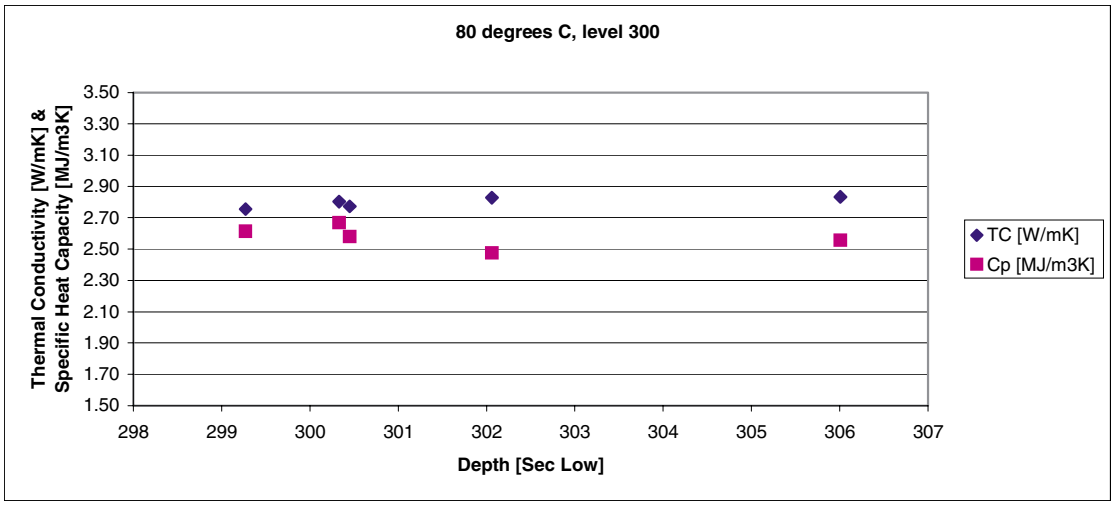


Figure 5-10c. *The results plotted vs. depth. Cp and TC at 80 degrees C, level 300 m.*

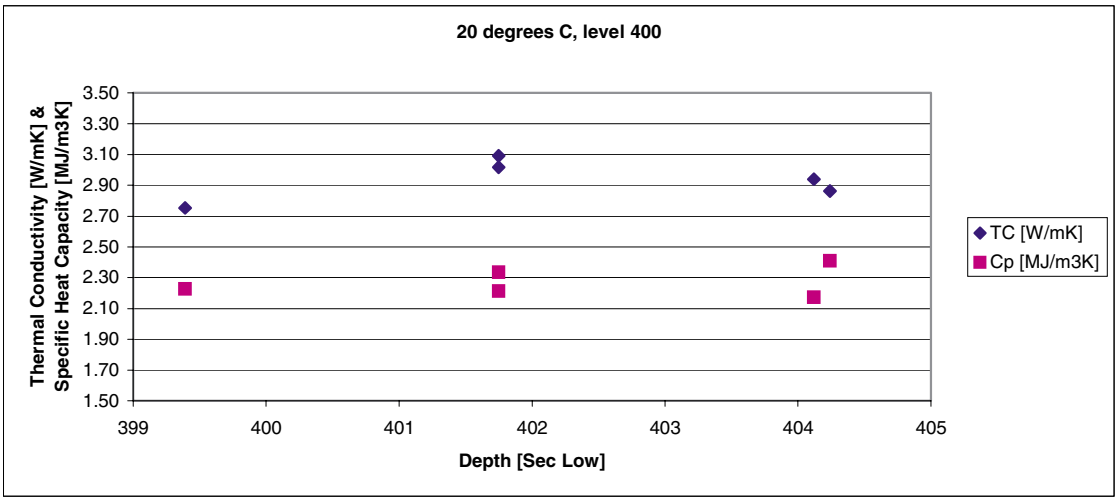


Figure 5-11a. *The results plotted vs. depth. Cp and TC at 20 degrees C, level 400 m.*

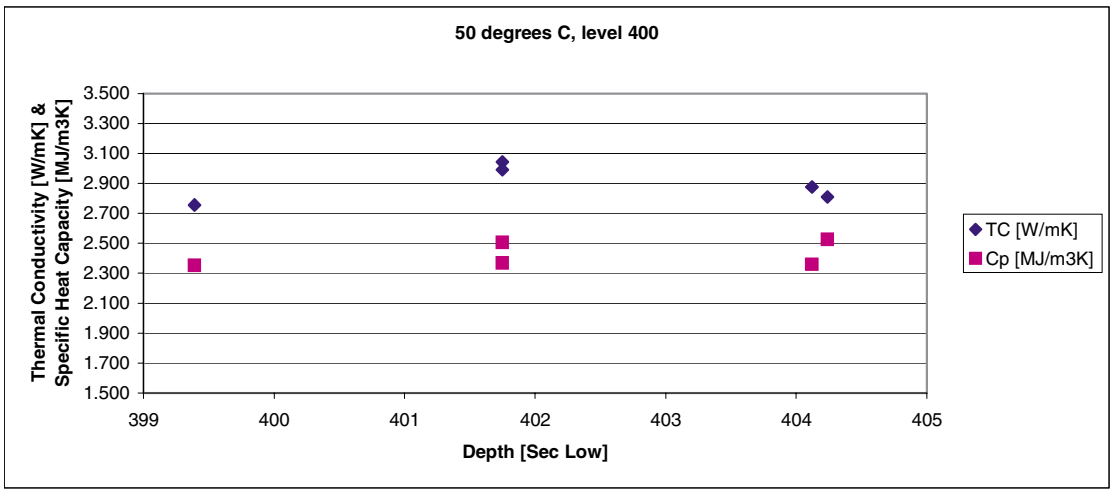


Figure 5-11b. *The results plotted vs. depth. Cp and TC at 50 degrees C, level 400 m.*

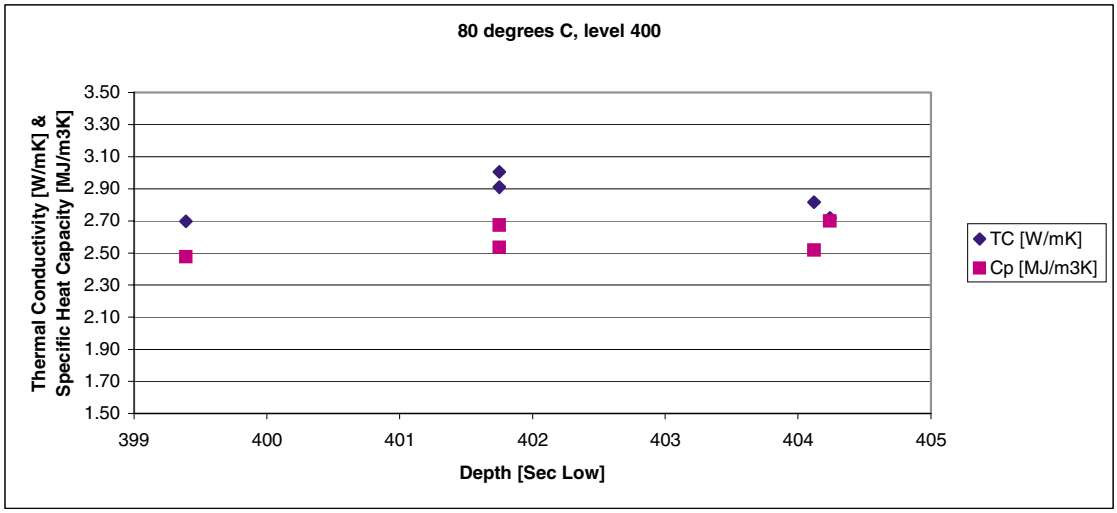


Figure 5-11c. *The results plotted vs. depth. Cp and TC at 80 degrees C, level 400 m.*

5.3 Deviations from measurement plan

In those cases where it was found necessary, additional measurements were carried out to ensure high quality of the data.

- For sample **SOIA-90V-7** the first measurement series (at 20°C) was ran with a measurement time of 10s instead of 20s. This was compensated for by running a fourth measurement series at 20°C after the 80°C measurements were completed. Thus it is possible that the sample could have lost water during the heating process. The original calculations for the 10s measurements can be found in the excel spreadsheets accompanying this report (the 10s measurements have not been included in the calculations. It has to be mentioned that the total to characteristic time of the 10s measurements was > 0.3, thus still valid in a theoretical way. Below are the results for each meas. time given:

  10s measurement at 20°C
  TC [W/mK] = 2.724 (0.21%)
  C_p [MJ/m^{3}K] = 2.112 (0.38%)

  20s measurement at 20°C
  TC [W/mK] = 2.753 (0.35%)
  C_p [MJ/m^{3}K] = 2.23 (2.1%)

- Sample **SOIA-90V-9** was remeasured due to suspected sensor malfunction (for procedure, see Execution section). Results for comparison are given below (Table 5-11). The sensor vs. sample orientation was not considered during these measurements. Thus the results can stem from different volumes of the sample.

Table 5-11 (a and b). The results for the original and re-measurement of sample SOIA-90V-9. a) Same as Table 5-7. b) Remeasured values are included in calculations in Table 5-10.

a)

SOIA-90V-9				
Temp [C]	**TC [W/mK]**	**Std [W/mK]**	**Cp [MJ/m3K]**	**Std [MJ/m3K]**
20	3.092	0.007	2.33	0.01
50	3.043	0.006	2.50	0.02
80	3.01	0.01	2.67	0.07

b)

SOIA-90V-9 remeasurement				
Temp [C]	**TC [W/mK]**	**Std [W/mK]**	**Cp [MJ/m3K]**	**Std [MJ/m3K]**
20	3.02	0.02	2.21	0.04
50	2.99	0.02	2.37	0.09
80	2.910	0.009	2.54	0.04

- The following measurements were replaced with extra measurements (Naming principles is *SOIA-90V-Samplenumber_temperature. Sequence number.hot)*:

  SOIA-90V-1_80. 6.hot (deviating disk resistance)

  SOIA-90V-2_50. 1.hot (slightly different differens graph in comparison with other measurements in series)

  SOIA-90V-3_80C.6.hot (slightly different differens graph in comparison with other measurements in series)

  SOIA-90V-11_80.3.hot (deviating disk resistance).

5.4 Discussion

Thermal conductivity and specific heat capacity of rock samples from borehole KSH01A, Oskarshamn, have been measured with the Hot Disk instrument at Hot Disk AB, Uppsala. The thermal conductivity of the measured samples is somewhat temperature dependent. Common for the samples is that the thermal conductivity is decreasing with increasing temperature and the specific heat capacity is increasing with increasing temperature. In average the thermal conductivity is decreasing with 2.6% (level 300 m) and 3.5% (level 400 m) over the temperature interval 20-80°C for the specimens. The remeasured values (new sensor and resoaked for at least 7 days) show little deviation from the original measurements. Thus, it is concluded that the original measurements are of the same quality as the other measurements. The specific heat capacity values tend to increase with temperature 11.9 and 13.7 % for the 2 depths respectively.

It is possible that the inhomogenities in the samples can affect the results, meaning that the mounting of the sensor is crucial for the measurement result.

Appendix 1

Measurement results and thermal conductivity and heat capacity plots

On the following pages the results per sample is given (Table A1. and figures following the table).

Table A1. The Measurement results for all individual measurements.

File:	Points of calculation	T[C]	TC [W/mK]	TD [mm2/s]	Cp [MJ/m3K]
SOIA-90V-1_20. 1.hot	(68- 200,tc)	20 C	2.800	1.269	2.207
SOIA-90V-1_20. 2.hot	(71- 200,tc)	20 C	2.809	1.260	2.230
SOIA-90V-1_20. 3.hot	(70- 200,tc)	20 C	2.806	1.257	2.233
SOIA-90V-1_20. 4.hot	(69- 200,tc)	20 C	2.814	1.242	2.265
SOIA-90V-1_20. 5.hot	(70- 200,tc)	20 C	2.804	1.257	2.230
AVERAGE			**2.807**	**1.257**	**2.233**
STDAV			**0.005**	**0.010**	**0.021**
STDAV %			**0.187**	**0.758**	**0.936**
SOIA-90V-1_50. 1.hot	(69- 200,tc)	50 C	2.837	1.118	2.538
SOIA-90V-1_50. 2.hot	(69- 200,tc)	50 C	2.833	1.112	2.548
SOIA-90V-1_50. 3.hot	(69- 200,tc)	50 C	2.811	1.146	2.453
SOIA-90V-1_50. 4.hot	(70- 200,tc)	50 C	2.809	1.142	2.460
SOIA-90V-1_50. 5.hot	(70- 200,tc)	50 C	2.809	1.140	2.463
AVERAGE			**2.820**	**1.131**	**2.492**
STDAV			**0.014**	**0.015**	**0.046**
STDAV %			**0.492**	**1.365**	**1.850**
SOIA-90V-1_80. 1.hot	(69- 200,tc)	80 C	2.757	1.058	2.607
SOIA-90V-1_80. 2.hot	(70- 200,tc)	80 C	2.770	1.047	2.646
SOIA-90V-1_80. 3.hot	(67- 200,tc)	80 C	2.751	1.066	2.581
SOIA-90V-1_80. 4.hot	(68- 200,tc)	80 C	2.758	1.015	2.717
SOIA-90V-1_80. 5.hot	(70- 200,tc)	80 C	2.743	1.092	2.513
AVERAGE			**2.756**	**1.055**	**2.613**
STDAV			**0.010**	**0.028**	**0.076**
STDAV %			**0.353**	**2.641**	**2.895**
SOIA-90V-2_20. 1.hot	(25- 200,tc)	20 C	2.884	1.239	2.327
SOIA-90V-2_20. 2.hot	(25- 200,tc)	20 C	2.882	1.231	2.341
SOIA-90V-2_20. 3.hot	(28- 200,tc)	20 C	2.876	1.237	2.324
SOIA-90V-2_20. 4.hot	(27- 200,tc)	20 C	2.876	1.235	2.329
SOIA-90V-2_20.1a.hot	(27- 200,tc)	20 C	2.900	1.237	2.343
AVERAGE			**2.884**	**1.236**	**2.333**
STDAV			**0.010**	**0.003**	**0.009**
STDAV %			**0.339**	**0.268**	**0.377**

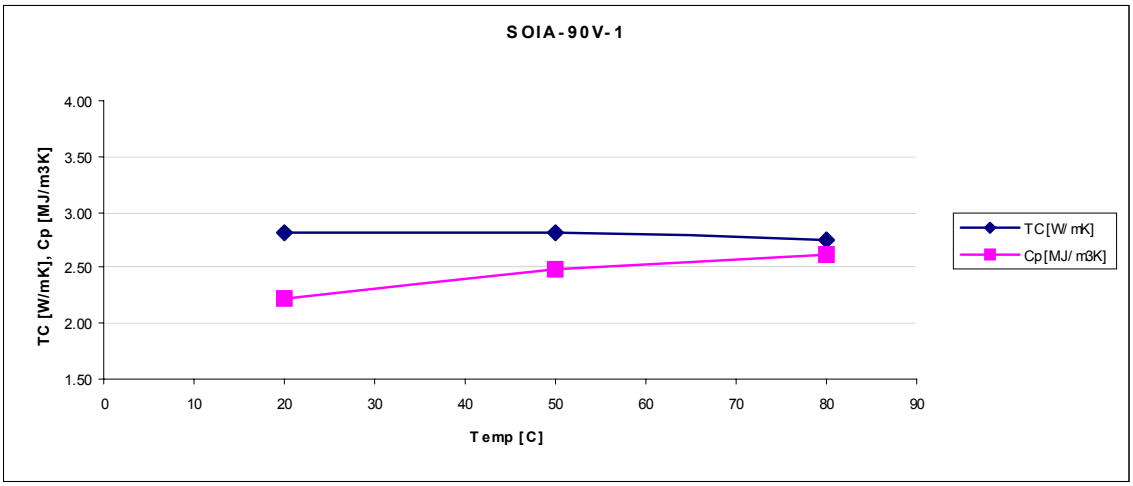
SOIA-90V-2_50. 2.hot	(83- 200,tc)	50 C	2.908	1.196	2.431
SOIA-90V-2_50. 3.hot	(84- 200,tc)	50 C	2.881	1.232	2.339
SOIA-90V-2_50. 4.hot	(77- 200,tc)	50 C	2.901	1.191	2.436
SOIA-90V-2_50. 5.hot	(75- 200,tc)	50 C	2.882	1.192	2.418
SOIA-90V-2_50. 6.hot	(76- 200,tc)	50 C	2.945	1.053	2.798
AVERAGE			**2.893**	**1.203**	**2.406**
STDAV			**0.014**	**0.019**	**0.045**
STDAV %			**0.467**	**1.620**	**1.881**
SOIA-90V-2_80. 1.hot	(27- 200,tc)	80 C	2.808	1.047	2.681
SOIA-90V-2_80. 2.hot	(26- 200,tc)	80 C	2.800	1.052	2.663
SOIA-90V-2_80. 3.hot	(26- 200,tc)	80 C	2.805	1.051	2.668
SOIA-90V-2_80. 4.hot	(27- 200,tc)	80 C	2.804	1.052	2.666
SOIA-90V-2_80. 5.hot	(27- 200,tc)	80 C	2.799	1.050	2.664
AVERAGE			**2.803**	**1.050**	**2.669**
STDAV			**0.004**	**0.002**	**0.007**
STDAV %			**0.137**	**0.171**	**0.278**
SOIA-90V-3_20C. 1.hot	(35- 200,tc)	20 C	2.884	1.269	2.273
SOIA-90V-3_20C. 2.hot	(34- 200,tc)	20 C	2.850	1.293	2.204
SOIA-90V-3_20C. 3.hot	(35- 200,tc)	20 C	2.846	1.291	2.204
SOIA-90V-3_20C. 4.hot	(35- 200,tc)	20 C	2.843	1.290	2.204
SOIA-90V-3_20C. 5.hot	(31- 200,tc)	20 C	2.840	1.286	2.208
AVERAGE			**2.853**	**1.286**	**2.219**
STDAV			**0.018**	**0.010**	**0.030**
STDAV %			**0.624**	**0.770**	**1.369**
SOIA-90V-3_50C. 1.hot	(32- 200,tc)	50 C	2.819	1.184	2.381
SOIA-90V-3_50C. 2.hot	(31- 200,tc)	50 C	2.814	1.177	2.391
SOIA-90V-3_50C. 3.hot	(35- 200,tc)	50 C	2.812	1.181	2.381
SOIA-90V-3_50C. 4.hot	(34- 200,tc)	50 C	2.813	1.182	2.379
SOIA-90V-3_50C. 5.hot	(34- 200,tc)	50 C	2.812	1.174	2.396
AVERAGE			**2.814**	**1.180**	**2.386**
STDAV			**0.003**	**0.004**	**0.008**
STDAV %			**0.099**	**0.355**	**0.318**
SOIA-90V-3_80C. 2.hot	(40- 200,tc)	80 C	2.779	1.076	2.582
SOIA-90V-3_80C. 3.hot	(31- 200,tc)	80 C	2.773	1.085	2.556
SOIA-90V-3_80C. 4.hot	(31- 200,tc)	80 C	2.764	1.048	2.636
SOIA-90V-3_80C. 5.hot	(36- 200,tc)	80 C	2.771	1.082	2.560
SOIA-90V-3_80C. 6.hot	(35- 200,tc)	80 C	2.776	1.084	2.562
AVERAGE			**2.773**	**1.075**	**2.579**
STDAV			**0.006**	**0.015**	**0.033**
STDAV %			**0.210**	**1.428**	**1.296**
SOIA-90V-4_20. 1.hot	(80- 200,tc)	20 C	2.943	1.283	2.294
SOIA-90V-4_20. 2.hot	(82- 200,tc)	20 C	2.943	1.269	2.319
SOIA-90V-4_20. 3.hot	(82- 200,tc)	20 C	2.943	1.270	2.318
SOIA-90V-4_20. 4.hot	(81- 200,tc)	20 C	2.945	1.261	2.336
SOIA-90V-4_20. 5.hot	(80- 200,tc)	20 C	2.941	1.275	2.306

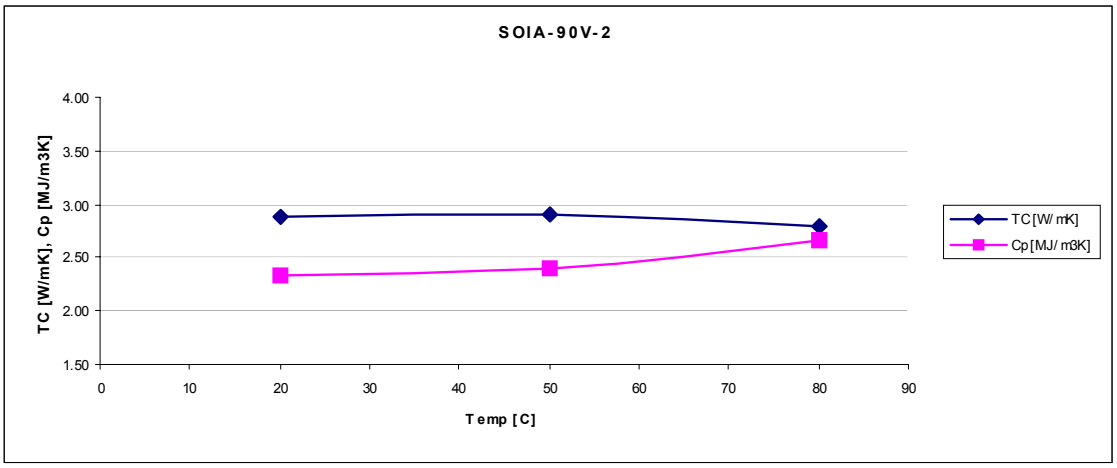
AVERAGE			**2.943**	**1.272**	**2.314**
STDAV			**0.001**	**0.008**	**0.015**
STDAV %			**0.051**	**0.643**	**0.668**
SOIA-90V-4_50. 1.hot	(54- 200,tc)	50 C	2.912	1.144	2.546
SOIA-90V-4_50. 2.hot	(58- 200,tc)	50 C	2.880	1.177	2.447
SOIA-90V-4_50. 3.hot	(61- 200,tc)	50 C	2.889	1.150	2.512
SOIA-90V-4_50. 4.hot	(60- 200,tc)	50 C	2.882	1.112	2.592
SOIA-90V-4_50. 5.hot	(60- 200,tc)	50 C	2.887	1.108	2.605
AVERAGE			**2.890**	**1.138**	**2.540**
STDAV			**0.013**	**0.029**	**0.064**
STDAV %			**0.443**	**2.508**	**2.529**
SOIA-90V-4_80. 1.hot	(73- 200,tc)	80 C	2.844	1.187	2.395
SOIA-90V-4_80. 2.hot	(72- 200,tc)	80 C	2.843	1.177	2.416
SOIA-90V-4_80. 3.hot	(70- 200,tc)	80 C	2.823	1.160	2.433
SOIA-90V-4_80. 4.hot	(70- 200,tc)	80 C	2.814	1.116	2.521
SOIA-90V-4_80. 5.hot	(71- 200,tc)	80 C	2.818	1.080	2.609
AVERAGE			**2.828**	**1.144**	**2.475**
STDAV			**0.014**	**0.045**	**0.089**
STDAV %			**0.504**	**3.921**	**3.585**
SOIA-90V-5_20C. 1.hot	(67- 200,tc)	20 C	2.887	1.281	2.253
SOIA-90V-5_20C. 2.hot	(62- 200,tc)	20 C	2.883	1.277	2.258
SOIA-90V-5_20C. 3.hot	(60- 200,tc)	20 C	2.883	1.275	2.261
SOIA-90V-5_20C. 4.hot	(62- 200,tc)	20 C	2.882	1.277	2.257
SOIA-90V-5_20C. 5.hot	(64- 200,tc)	20 C	2.881	1.277	2.256
AVERAGE			**2.883**	**1.277**	**2.257**
STDAV			**0.002**	**0.003**	**0.003**
STDAV %			**0.081**	**0.196**	**0.135**
SOIA-90V-5_50C. 1.hot	(92- 200,tc)	50 C	2.849	1.088	2.618
SOIA-90V-5_50C. 2.hot	(91- 200,tc)	50 C	2.849	1.090	2.613
SOIA-90V-5_50C. 3.hot	(91- 200,tc)	50 C	2.854	1.037	2.753
SOIA-90V-5_50C. 4.hot	(92- 200,tc)	50 C	2.853	1.081	2.639
SOIA-90V-5_50C. 5.hot	(92- 200,tc)	50 C	2.857	1.111	2.570
AVERAGE			**2.852**	**1.082**	**2.639**
STDAV			**0.003**	**0.027**	**0.068**
STDAV %			**0.116**	**2.529**	**2.593**
SOIA-90V-5_80C. 1.hot	(50- 200,tc)	80 C	2.824	1.115	2.532
SOIA-90V-5_80C. 2.hot	(50- 200,tc)	80 C	2.838	1.111	2.554
SOIA-90V-5_80C. 3.hot	(50- 200,tc)	80 C	2.835	1.106	2.564
SOIA-90V-5_80C. 4.hot	(50- 200,tc)	80 C	2.835	1.105	2.565
SOIA-90V-5_80C. 5.hot	(50- 200,tc)	80 C	2.836	1.105	2.567
AVERAGE			**2.834**	**1.108**	**2.557**
STDAV			**0.006**	**0.005**	**0.015**
STDAV %			**0.198**	**0.423**	**0.580**
SOIA-90V-7_20C_20s. 1.hot	(27- 200,tc)	20 C	2.740	1.273	2.153
SOIA-90V-7_20C_20s. 2.hot	(34- 200,tc)	20 C	2.746	1.243	2.209

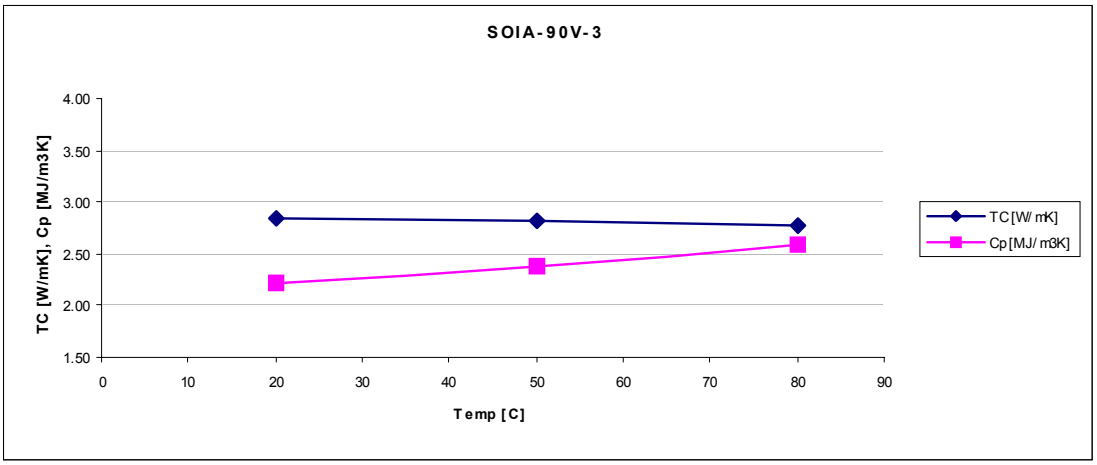
SOIA-90V-7_20C_20s. 3.hot	(26- 200,tc)	20 C	2.758	1.221	2.258
SOIA-90V-7_20C_20s. 4.hot	(30- 200,tc)	20 C	2.763	1.225	2.256
SOIA-90V-7_20C_20s. 5.hot	(31- 200,tc)	20 C	2.760	1.224	2.255
AVERAGE			**2.753**	**1.237**	**2.226**
STDAV			**0.010**	**0.022**	**0.046**
STDAV %			**0.356**	**1.750**	**2.057**
SOIA-90V-7_50C. 1.hot	(86- 200,tc)	50C	2.748	1.175	2.339
SOIA-90V-7_50C. 2.hot	(85- 200,tc)	50C	2.758	1.176	2.346
SOIA-90V-7_50C. 3.hot	(86- 200,tc)	50C	2.758	1.177	2.344
SOIA-90V-7_50C. 4.hot	(74- 200,tc)	50C	2.755	1.172	2.350
SOIA-90V-7_50C. 5.hot	(74- 200,tc)	50C	2.763	1.161	2.379
AVERAGE			**2.756**	**1.172**	**2.352**
STDAV			**0.006**	**0.006**	**0.016**
STDAV %			**0.203**	**0.533**	**0.674**
SOIA-90V-7_80C. 1.hot	(75- 200,tc)	80 C	2.722	1.140	2.387
SOIA-90V-7_80C. 2.hot	(75- 200,tc)	80 C	2.702	1.118	2.418
SOIA-90V-7_80C. 3.hot	(75- 200,tc)	80 C	2.682	1.126	2.381
SOIA-90V-7_80C. 4.hot	(76- 200,tc)	80 C	2.734	1.009	2.711
SOIA-90V-7_80C. 5.hot	(76- 200,tc)	80 C	2.646	1.065	2.486
AVERAGE			**2.697**	**1.092**	**2.477**
STDAV			**0.035**	**0.055**	**0.138**
STDAV %			**1.294**	**4.994**	**5.553**
SOIA-90V-9_20. 1.hot	(69- 200,tc)	20 C	3.103	1.329	2.334
SOIA-90V-9_20. 2.hot	(69- 200,tc)	20 C	3.095	1.320	2.344
SOIA-90V-9_20. 3.hot	(69- 200,tc)	20 C	3.087	1.328	2.324
SOIA-90V-9_20. 4.hot	(69- 200,tc)	20 C	3.085	1.326	2.326
SOIA-90V-9_20. 5.hot	(69- 200,tc)	20 C	3.089	1.318	2.343
AVERAGE			**3.092**	**1.324**	**2.334**
STDAV			**0.007**	**0.005**	**0.009**
STDAV %			**0.236**	**0.373**	**0.404**
SOIA-90V-9_50. 1.hot	(69- 200,tc)	50 C	3.053	1.210	2.524
SOIA-90V-9_50. 2.hot	(69- 200,tc)	50 C	3.038	1.221	2.488
SOIA-90V-9_50. 3.hot	(69- 200,tc)	50 C	3.040	1.224	2.485
SOIA-90V-9_50. 4.hot	(69- 200,tc)	50 C	3.039	1.213	2.505
SOIA-90V-9_50. 5.hot	(69- 200,tc)	50 C	3.045	1.207	2.523
AVERAGE			**3.043**	**1.215**	**2.505**
STDAV			**0.006**	**0.007**	**0.018**
STDAV %			**0.202**	**0.591**	**0.734**
SOIA-90V-9_80. 1.hot	(69- 200,tc)	80 C	3.023	1.084	2.788
SOIA-90V-9_80. 2.hot	(69- 200,tc)	80 C	3.008	1.134	2.651
SOIA-90V-9_80. 3.hot	(69- 200,tc)	80 C	3.003	1.123	2.675
SOIA-90V-9_80. 4.hot	(69- 200,tc)	80 C	3.004	1.136	2.645
SOIA-90V-9_80. 5.hot	(69- 200,tc)	80 C	2.989	1.147	2.607
AVERAGE			**3.005**	**1.125**	**2.673**
STDAV			**0.012**	**0.024**	**0.068**
STDAV %			**0.402**	**2.143**	**2.562**

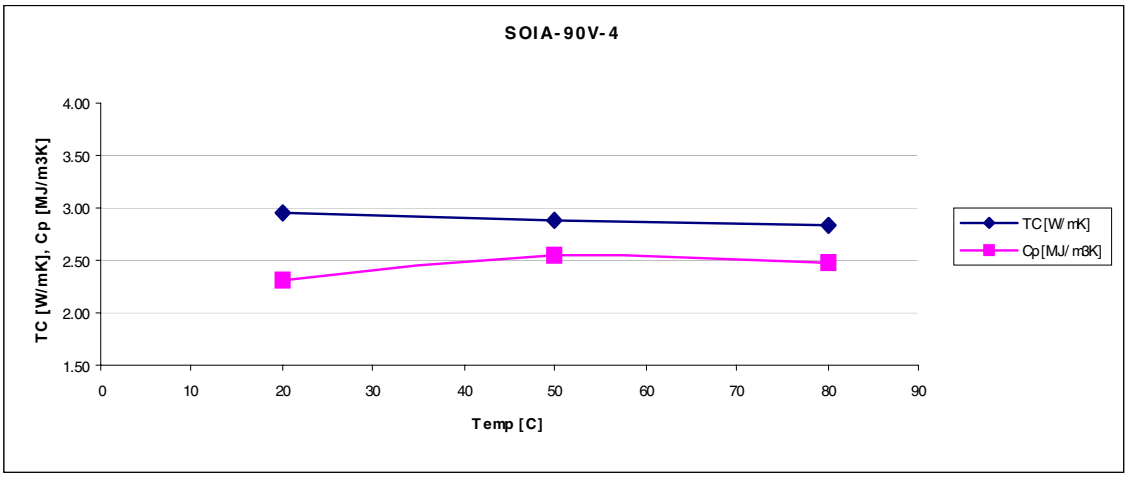
SOIA-90V-10_20. 1.hot	(23- 200,tc)	20 C	2.955	1.346	2.196
SOIA-90V-10_20. 2.hot	(29- 200,tc)	20 C	2.943	1.352	2.177
SOIA-90V-10_20. 3.hot	(25- 200,tc)	20 C	2.937	1.358	2.162
SOIA-90V-10_20. 4.hot	(26- 200,tc)	20 C	2.935	1.353	2.169
SOIA-90V-10_20. 5.hot	(25- 200,tc)	20 C	2.930	1.357	2.159
AVERAGE			**2.940**	**1.353**	**2.173**
STDAV			**0.009**	**0.005**	**0.015**
STDAV %			**0.317**	**0.376**	**0.676**
SOIA-90V-10_50. 1.hot	(27- 200,tc)	50 C	2.885	1.213	2.378
SOIA-90V-10_50. 2.hot	(26- 200,tc)	50 C	2.875	1.225	2.347
SOIA-90V-10_50. 3.hot	(26- 200,tc)	50 C	2.875	1.215	2.367
SOIA-90V-10_50. 4.hot	(27- 200,tc)	50 C	2.877	1.218	2.362
SOIA-90V-10_50. 5.hot	(29- 200,tc)	50 C	2.871	1.225	2.343
AVERAGE			**2.877**	**1.219**	**2.360**
STDAV			**0.005**	**0.006**	**0.015**
STDAV %			**0.183**	**0.473**	**0.620**
SOIA-90V-10_80. 1.hot	(28- 200,tc)	80 C	2.822	1.130	2.497
SOIA-90V-10_80. 2.hot	(27- 200,tc)	80 C	2.819	1.121	2.516
SOIA-90V-10_80. 3.hot	(27- 200,tc)	80 C	2.816	1.111	2.535
SOIA-90V-10_80. 4.hot	(27- 200,tc)	80 C	2.816	1.118	2.520
SOIA-90V-10_80. 5.hot	(26- 200,tc)	80 C	2.815	1.117	2.521
AVERAGE			**2.818**	**1.119**	**2.518**
STDAV			**0.003**	**0.007**	**0.014**
STDAV %			**0.105**	**0.644**	**0.551**
SOIA-90V-11_20. 1.hot	(29- 200,tc)	20 C	2.869	1.184	2.424
SOIA-90V-11_20. 2.hot	(27- 200,tc)	20 C	2.865	1.183	2.421
SOIA-90V-11_20. 3.hot	(28- 200,tc)	20 C	2.863	1.184	2.418
SOIA-90V-11_20. 4.hot	(28- 200,tc)	20 C	2.855	1.195	2.389
SOIA-90V-11_20. 5.hot	(28- 200,tc)	20 C	2.855	1.192	2.395
AVERAGE			**2.862**	**1.188**	**2.409**
STDAV			**0.006**	**0.006**	**0.016**
STDAV %			**0.215**	**0.474**	**0.677**
SOIA-90V-11_50. 1.hot	(63- 200,tc)	50 C	2.870	1.228	2.336
SOIA-90V-11_50. 2.hot	(59- 200,tc)	50 C	2.796	1.073	2.607
SOIA-90V-11_50. 3.hot	(61- 200,tc)	50 C	2.796	1.091	2.564
SOIA-90V-11_50. 4.hot	(60- 200,tc)	50 C	2.791	1.093	2.554
SOIA-90V-11_50. 5.hot	(27- 200,tc)	50 C	2.794	1.088	2.568
AVERAGE			**2.809**	**1.114**	**2.526**
STDAV			**0.034**	**0.064**	**0.108**
STDAV %			**1.203**	**5.757**	**4.270**
SOIA-90V-11_80. 1.hot	(31- 200,tc)	80 C	2.720	1.022	2.660
SOIA-90V-11_80. 1a.hot	(28- 200,tc)	80 C	2.738	1.007	2.719
SOIA-90V-11_80. 2.hot	(31- 200,tc)	80 C	2.719	1.013	2.683
SOIA-90V-11_80. 4.hot	(30- 200,tc)	80 C	2.709	1.004	2.697
SOIA-90V-11_80. 5.hot	(32- 200,tc)	80 C	2.711	1.003	2.702
AVERAGE			**2.719**	**1.007**	**2.700**
STDAV			**0.013**	**0.005**	**0.015**

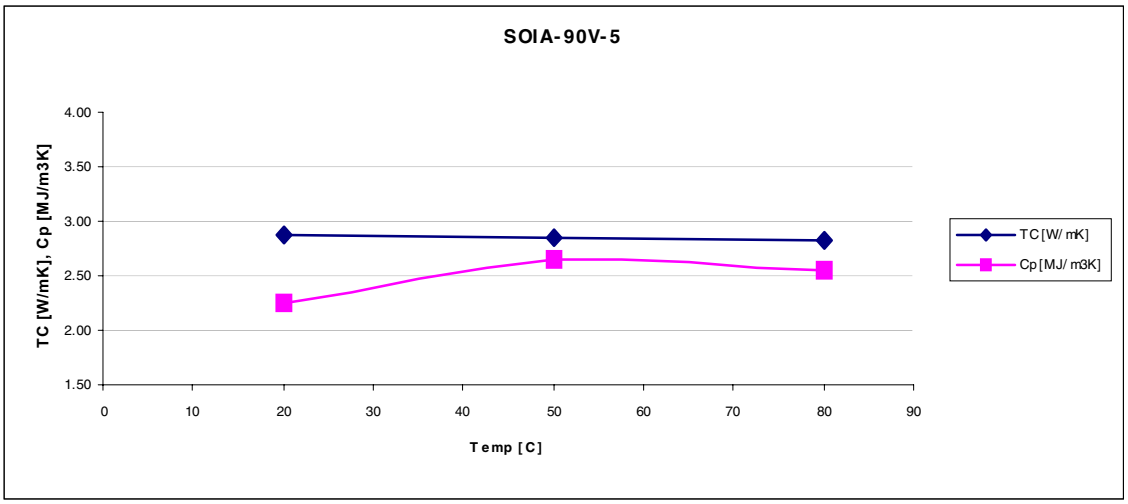
STDAV %		**0.485**	**0.450**	**0.547**
SOIA-90V-9_20_Ommät. 1.hot (60- 200,tc)	20 C	3.039	1.355	2.243
SOIA-90V-9_20_Ommät. 2.hot (60- 200,tc)	20 C	3.026	1.353	2.237
SOIA-90V-9_20_Ommät. 3.hot (60- 200,tc)	20 C	3.026	1.352	2.239
SOIA-90V-9_20_Ommät. 4.hot (60- 200,tc)	20 C	3.005	1.375	2.186
SOIA-90V-9_20_Ommät. 5.hot (60- 200,tc)	20 C	2.996	1.386	2.163
AVERAGE		**3.018**	**1.364**	**2.213**
STDAV		**0.017**	**0.015**	**0.037**
STDAV %		**0.566**	**1.131**	**1.660**
SOIA-90V-9_50_Ommät. 1.hot (69- 200,tc)	50 C	3.000	1.247	2.406
SOIA-90V-9_50_Ommät. 2.hot (69- 200,tc)	50 C	2.985	1.227	2.433
SOIA-90V-9_50_Ommät. 3.hot (69- 200,tc)	50 C	2.989	1.236	2.419
SOIA-90V-9_20_Ommät. 4.hot (69- 200,tc)	20 C	3.019	1.360	2.219
SOIA-90V-9_50_Ommät. 5.hot (69- 200,tc)	50 C	2.964	1.256	2.361
AVERAGE		**2.992**	**1.265**	**2.368**
STDAV		**0.020**	**0.054**	**0.087**
STDAV %		**0.676**	**4.296**	**3.684**
SOIA-90V-9_80_Ommät. 1.hot (63- 200,tc)	80 C	2.909	1.158	2.512
SOIA-90V-9_80_Ommät. 2.hot (60- 200,tc)	80 C	2.922	1.140	2.564
SOIA-90V-9_80_Ommät. 3.hot (60- 200,tc)	80 C	2.902	1.148	2.528
SOIA-90V-9_80_Ommät. 4.hot (60- 200,tc)	80 C	2.916	1.127	2.586
SOIA-90V-9_80_Ommät. 5.hot (60- 200,tc)	80 C	2.901	1.167	2.485
AVERAGE		**2.910**	**1.148**	**2.535**
STDAV		**0.009**	**0.015**	**0.040**
STDAV %		**0.310**	**1.347**	**1.585**

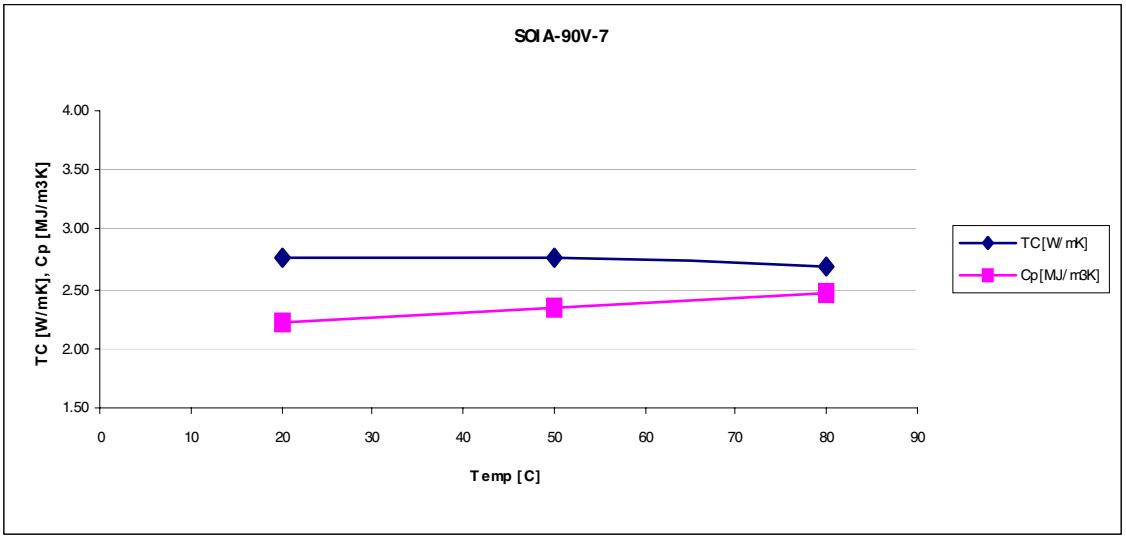

SOIA-90V-1
TC [W/mK], Cp [MJ/m3K]
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]

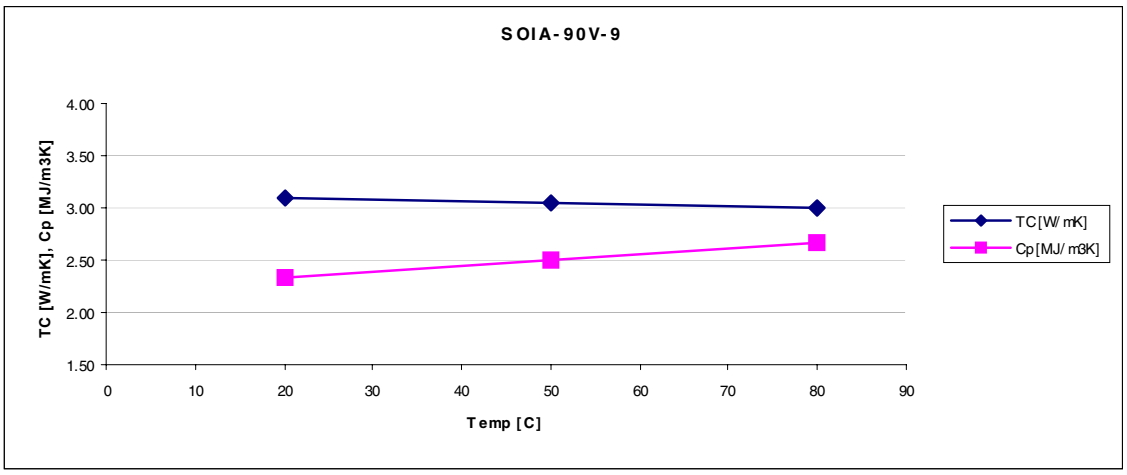

SOIA-90V-2
TC [W/mK], Cp [MJ/m3K]
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]

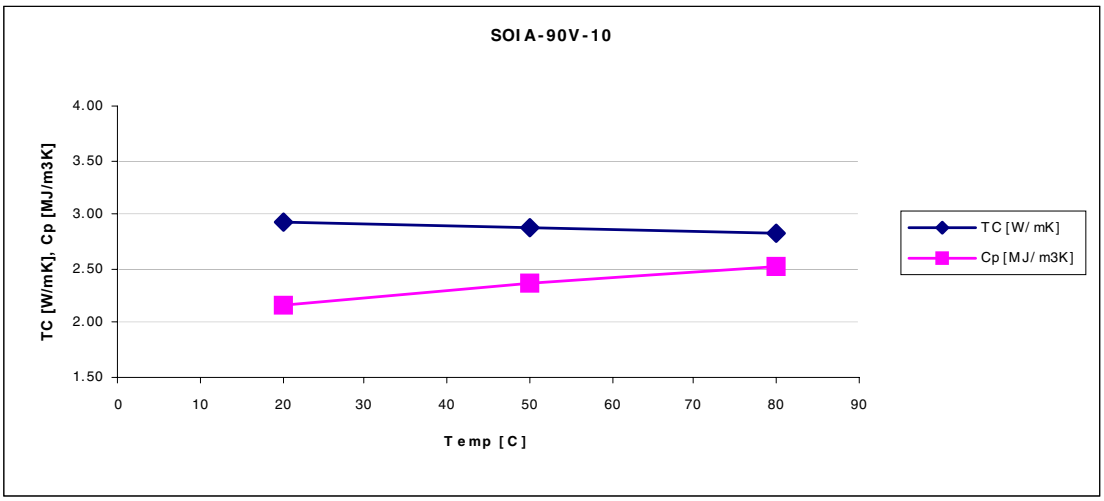

SOIA-90V-3
TC [W/mK], Cp [MJ/m3K]
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]

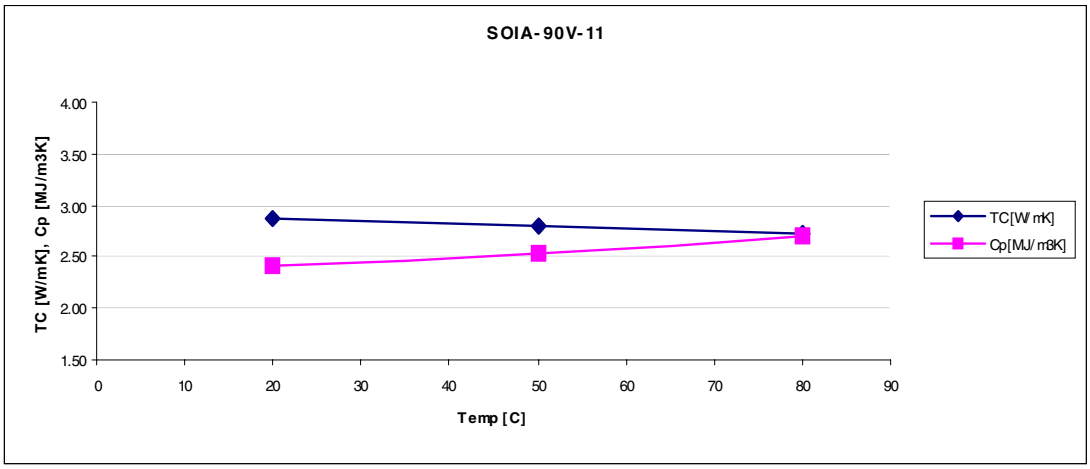

SOIA-90V-4
TC [W/mK], Cp [MJ/m3K]
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]


SOIA-90V-5
TC [W/mK], Cp [MJ/m3K]
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]


SOIA-90V-7
TC [W/mK], Cp [MJ/m3K]
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]


SOIA-90V-9
TC [W/mK], Cp [MJ/m3K]
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]


SOIA-90V-10
TC [W/mK], Cp [MJ/m3K]
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]


SOIA-90V-11
TC [W/mK], Cp [MJ/m3K]
4.00
3.50
3.00
2.50
2.00
1.50
0
10
20
30
40
50
60
70
80
90
Temp [C]
TC [W/mK]
Cp [MJ/m3K]