P-04-55

Oskarshamn site investigation

Drill hole KAV01

Thermal properties: heat conductivity and heat capacity determined using the TPS method and Mineralogical composition by modal analysis

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Keywords: Thermal properties, Rock mechanics, Thermal conductivity, Thermal diffusivity, Heat capacity, Transient Plane Source method, Modal analysis.

Abstract

Thermal properties on five specimens of drill hole KAV01, Oskarshamn, were measured at ambient temperature (20°C). The rock type of all samples is Ävrö granite. The mineralogical content was determined by using modal analysis.

The determination of the thermal properties are based on a direct measurement method, the so called "Transient Plane Source Method" (TPS), Gustafsson, 1991 /1/.

Thermal conductivity and thermal diffusivity of specimens at different depth at 20°C were in the range of 3.01–3.76 W/(m, K) and 1.28–1.57 mm^2/s respectively.

Contents

1 Introduction

The objective of this investigation was to measure thermal properties of borehole KAV01, Oskarshamn, see Figure 1-1, at different temperature levels by using the TPS-method /1/. The thermal properties were determined for water-saturated specimens. The specimens, in form of circular discs, were 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. The principle of the TPS method is to place a sensor between two rock samples. The sensor consists of a thin metal double spiral, embedded in an insulation material. During the measurement the sensor works both as a heat emitter and a heat receptor. The input data and results of the direct measurement are registered and analysed by the same software and electronics that govern the measurement. The method gives information on the heat conductivity and diffusivity of a material and from this the volumetric heat capacity can be determined, if the density is known.

The test programme follows the activity plan AP PS 400-03-091 (SKB internal controlling document) and is controlled by SP-QD 13.1 (SP quality document).

The samples were water saturated and stored in this condition for 7 days. This yields complete water saturation whereupon the density and the thermal properties were determined. The specimens were photographed when measuring was completed.

Modal analyses, based on point counting using a polarising microscope were performed on 7 specimens that were sampled on the same level as the specimens for thermal properties.

The rock cores arrived to SP in December 2003. The testing was performed during February–March, 2004.

Determination of thermal properties was made in accordance to SKB's method description SKB MD 191.001, version 1.9 (SKB internal controlling document) at the department of Fire Technology at SP. Density was determined in accordance to SKB MD 160.002, version 1.9 (SKB internal controlling document) at the department of Building Technology at SP.

Modal analyses are performed according to SKB MD 160.001, version 1.9 (SKB internal controlling document) and BMm-P54 (SP quality document).

Figure 1-1. *Map of Oskarshamn site.*

2 Objective and scope

The purpose of the testing is to determine the thermal properties of rock specimens. The properties are used in the rock thermal model, which will be established for the candidate area selected for site investigations at Oskarshamn.

The samples are from the borehole KAV01 in Oskarshamn, which is a telescope borehole of SKB-standard type with a bore depth of 1000 m. The specimens were sampled at one level: 510 m. The investigated rock type is mapped as Ävrö granite.

3 Equipment

Technical devices for determination of thermal properties used were:

- Kapton sensor 5501, radius of the sensor was 6.403 mm, and output of power was 0.7 W. The sensor 5501 fulfils the recommended relation between the radius of sensor and geometry of the samples in /2/.
- TPS-apparatus, Source meter Keithley 2400, Multi-meter Keithley 2000 and bridge, see Figure 3-1.
- PC + Microsoft Office and Hot Disk version 5.4.
- Stainless Sample holder.
- Water bath with immersion heater.
- Immersion heater, Grant, type TD, The accuracy of the thermostat is 0.004°C.
- Hand instrument for control measuring of the water bath temperature.

More information about the design of the water bath is given in /3/. Specimen mounting is shown in Figure 3-2.

Technical devices used for modal analyses (point counting) were:

- Leitz Orthoplan optical microscope (inv nr 100276).

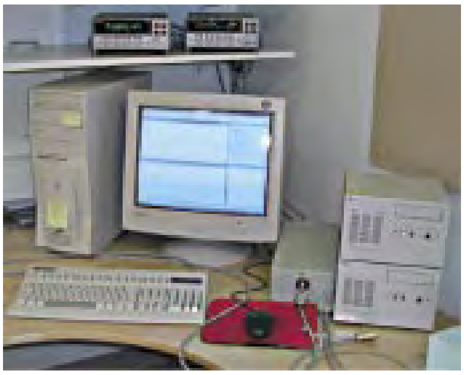

Figure 3-1. *TPS-apparatus with source meter, multi-meter, bridge, and computer.*

Figure 3-2. *Specimens prior to mounting (left), mounted in stainless sample holder (middle), and sample holder with mounted specimens wrapped in plastic (right).*

4 Execution

Determination of thermal properties was made in accordance to SKB's method description SKB MD 191.001, version 1.9 (SKB internal controlling document) and Hot Disc Instruction Manual /2/ at the department of Fire Technology at SP.

Density was determined in accordance to SKB MD 160.002, version 1.9 (SKB internal controlling document) and ISRM /4/. Modal analysis was determined in according to SKB MD 160.001, version 1.9 (SKB internal controlling document) and Chayes /5/, Streckeisen /6, 7, 8, 9/, Le Maitre /10/, Le Bas & Streckeisen /11/ and Sigmond & Gjelle /12/ at the department of Building Technology at SP.

4.1 Description of the samples

Five cores were sampled from one level of drill hole KAV01, Oskarshamn, Sweden. This level was between 508 m and 510 m. The ten specimens, with a thickness of 25 mm each were prepared from the samples at SP, see Figure 3-2. The diameter of the specimens was 50 mm. The rock type, identification marks and depth of the specimens are presented in Table 4-1. Detailed geological description of the rock is given in SKB's BOREMAP of KAV01 and in the SICADA database (FN 178) at SKB.

Shortened sample identification KAV-90V has been used through out the report.

Table 4-1. Rock type and identification marks. (Rock-type classification according to bore map.)

Identification	Rock type	Sampling depth (Sec low)
KAV01-90V-7	Ävrö granite	508.32
KAV01-90V-8	Ävrö granite	508.38
KAV01-90V-9	Ävrö granite	509.14
KAV01-90V-10	Ävrö granite	509.20
KAV01-90V-11	Ävrö granite	509.26

4.2 Test procedure

4.2.1 Thermal properties

The following steps were performed:

1. Samples were cut and polished by SP Building Technology.
2. Samples were water saturated and wet density was determined by SP Building Technology.
3. Samples were sent from SP Building Technology to SP Fire Technology.
4. Thermal properties were determined.
5. Samples were sent from SP Fire Technology to SP Building Technology.
6. Dry density of samples determined at SP Building Technology.
7. Samples were sprayed with water and photographed by SP Building Technology.

Thermal properties of water-saturated specimens were measured in ambient air (20°C). In order to remain water saturation the samples and the sensor were kept in a plastic bag during the measurement, see Figure 3-2.

Each core pair was measured five times. The time lag between two repeated measurements was at least 20 minutes. The result of each measurement was evaluated separately. The average value of these five measurements was calculated.

Function control of TPS instrumentation was performed according to BRk-QB-M26-02 (SP quality document), see Appendix A.

Measured raw data were saved as text files. Analysed data were saved as Excel files. These files were stored on the hard disc of the measurement computer. These stored files were sent to SKB catalogue at SP network. Further calculations of mean values and standard deviations were performed in the same catalogue.

Thermal properties, density and porosity measurements were performed during February–March, 2004.

Dry weight was measured after the specimens had been dried to constant mass according to ISMR /4/ at 105°C. The drying procedure took seven days.

4.2.2 Modal analysis

Modal analysis, based on point counting with at least 500 points counted in each sample, was performed by SP Building Technology.

The analysis was performed on 8 specimens that were sampled on the same level as the specimens for thermal properties (see Sec low in Table 4-1). The modal analysis was done in order to calculate the thermal properties based on the specimen's mineralogical composition.

5 Results

5.1 Thermal properties

Mean values of measured data, five repeated measurements, are reported in 5.1.1 and 5.1.2 and in the SICADA database (FN 178) at SKB. Values of each separate measurement as described in 4.2 are reported in Appendix B. Furthermore, the total measuring time, the ratio between total measuring time and characteristic time, and the number of analysed points are presented in Appendix C. In a correct measurement the ratio between the total measuring time and the characteristic time should be between 0.4 and 1.

5.1.1 Test results, sample by sample

Sample KAV-90V-07

Figure 5-1. *Specimens KAV-90V-07.*

Table 5-1. Porosity, wet and dry density of specimens KAV-90V-07, average values.

Sample	Density, wet (kg/m3)	Density, dry (kg/m3)	Porosity (%)
KAV-90V-07			
Sec low: 508.32	2660	2656	0.36

Table 5-2. Thermal properties of sample KAV-90V-07.

KAV-90V-07 Sec low: 508.32	Conductivity (W/(m, K))	Diffusivity (mm2/s)	Heat capacity (MJ/(m3, K))
20°C			
Mean value	3.01	1.28	2.36
Standard deviation	0.002	0.005	0.010

Sample KAV-90V-08

Figure 5-2. Specimens KAV-90V-08.

Table 5-3. Porosity, wet and dry density of specimens KAV-90V-08, average values.

Sample	Density, wet (kg/m3)	Density, dry (kg/m3)	Porosity (%)
KAV-90V-08			
Sec low: 508.38	2640	2637	0.26

Table 5-4. Thermal properties of sample KAV-90V-08.

KAV-90V-08 Sec low: 508.38	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity ($MJ/(m^3, K)$)
20°C			
Mean value	3.76	1.57	2.39
Standard deviation	0.014	0.017	0.031

Sample KAV-90V-09

Figure 5-3. *Specimens KAV-90V-09.*

Table 5-5. Porosity, wet and dry density of specimens KAV-90V-09, average values.

Sample	Density, wet (kg/m3)	Density, dry (kg/m3)	Porosity (%)
KAV-90V-09			
Sec low: 509.14	2679	2675	0.31

Table 5-6. Thermal properties of sample KAV-90V-09.

KAV-90V-09 Sec low: 509.14	Conductivity (W/(m, K))	Diffusivity (mm2/s)	Heat capacity (MJ/(m3, K))
20°C			
Mean value	3.17	1.45	2.19
Standard deviation	0.011	0.014	0.027

Sample KAV-90V-10

Figure 5-4. Specimens KAV-90V-10.

Table 5-7. Porosity, wet and dry density of specimens KAV-90V-10, average values.

Sample	Density, wet (kg/m3)	Density, dry (kg/m3)	Porosity (%)
KAV-90V-10			
Sec low: 509.20	2680	2676	0.41

Table 5-8. Thermal properties of sample KAV-90V-10.

KAV-90V-10 Sec low: 509.20	Conductivity (W/(m, K))	Diffusivity (mm2/s)	Heat capacity (MJ/(m3, K))
20°C			
Mean value	3.18	1.48	2.14
Standard deviation	0.005	0.003	0.004

Sample KAV-90V-11

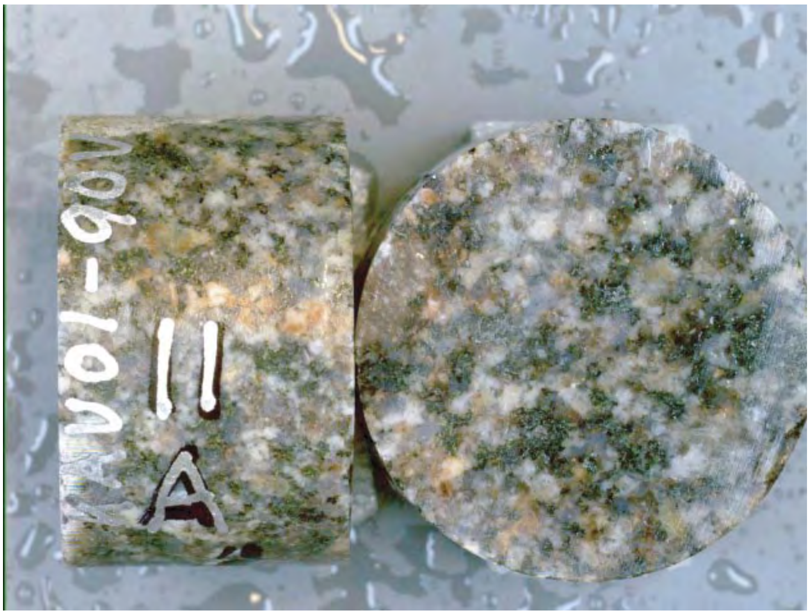

Figure 5-5. Specimens KAV-90V-11.

Table 5-9. Porosity, wet and dry density of specimens KAV-90V-11, average values.

Sample	Density, wet (kg/m3)	Density, dry (kg/m3)	Porosity (%)
KAV-90V-11			
Sec low: 509.26	2686	2683	0.36

Table 5-10. Thermal properties of sample KAV-90V-11.

KAV-90V-11 Sec low: 509.26	Conductivity (W/(m, K))	Diffusivity (mm2/s)	Heat capacity (MJ/(m3, K))
20°C			
Mean value	3.15	1.35	2.34
Standard deviation	0.009	0.010	0.023

5.1.2 Results for the entire test series

Table 5-11 shows the mean value of five repeated measurements of the thermal properties. Standard deviation at different temperature levels is shown in Table 5-12.

Thermal conductivity and thermal diffusivity of specimens at different depth at 20°C were in the range of 3.01–3.76 W/(m, K) and 1.28–1.57 mm²/s respectively.

Table 5-11. Mean value of thermal properties of samples at 20°C.

Sample identification	Conductivity (mm2/s)	Diffusivity (W/(m, K))	Heat capacity (MJ/(m3, K))
KAV-90V-07	3.01	1.28	2.36
KAV-90V-08	3.76	1.57	2.39
KAV-90V-09	3.17	1.45	2.19
KAV-90V-10	3.18	1.48	2.14
KAV-90V-11	3.15	1.35	2.34
Mean value, level 510	**3,25**	**1,43**	**2,28**

Table 5-12. Standard deviation of measured values at 20°C.

Sample identification	Conductivity (mm2/s)	Diffusivity (W/(m, K))	Heat capacity (MJ/(m3, K))
KAV-90V-07	0.002	0.005	0.010
KAV-90V-08	0.014	0.017	0.031
KAV-90V-09	0.011	0.014	0.027
KAV-90V-10	0.005	0.003	0.004
KAV-90V-11	0.009	0.010	0.023

Graphical presentation of results

Variation of the thermal conductivity and heat capacity in relation to depth of the sampling at 20°C are shown in Figure 5-6.

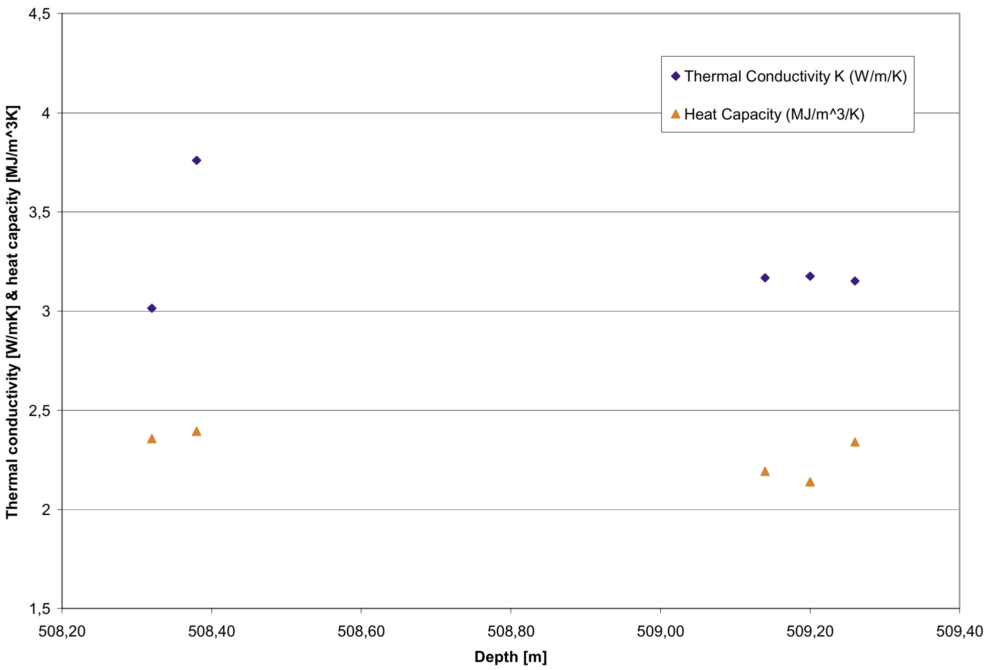

Figure 5-6. *Thermal conductivity and heat capacity at different depth at 20 °C.*

5.2 Modal analysis

Modal analyses, based on point counting using a polarising microscope were performed on 2 specimens that were sampled on the same level as the specimens for thermal properties (see Sec low in Table 4-1). The modal analyses were done in order to calculate the thermal properties based on the specimen's mineralogical composition.

Table 5-13. Mineralogical composition (in vol. %) of the investigated specimens from KAV01, 500 points are counted on each specimen.

Identification	Sampling depth (Sec up)	Qtz	Kfs	Pl	Bt	Ch	Op	As
KAV01-200-3	509.07	29	47	10	11	0	0.2	3
KAV01-200-4	509.68	23	46	19	0	9	0.4	3

The mineral mode is based on point counting using a polarising microscope.

Qtz = Quartz, Kfs = K-feldspar, Pl = Plagioclase, Bt = Biotite, Ch = chlorite, Op = opaque minerals. Assessory minerals (= As) are amphibole, epidote and sphene.

5.3 Discussion

There is a large difference in thermal properties of two samples, KAV-90V-07 and KAV-90V-08, these two samples are close together, see Table 4-1. An extra control of these samples showed that the difference might depend on the different rocks types (alteration and grainsize) in the samples.

The following deviation to the plans occurred: The specimens were photographed when measuring was completed.

6 References

/1/ **Gustafsson S E, 1991.** "Transient plane source techniques for thermal conductivity and thermal diffusivity measurements of solid materials". Rev. Sci. Instrum. 62 (3), American Institute of Physics.

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Appendix A

Calibration protocol for Hot Disk Bridge System

Electronics:	Keithley 2400	Serial No. 0925167
	Keithley 2000	Serial No. 0921454
Hot Disk Bridge:		Serial No. 2003-0004
Computation Device:		Serial No. 2003-0003, ver 1.4.2
Computer:	Hot Disk computer	Serial No. 2003-0003
Test sample:	SIS2343, mild steel	Serial No. 3.52
Sensor for testing:	C5501	

Test measurement: 10 repeated measurements on the test sample at room temperature.

Conditions: Power 1 W, Measurement time 10 s

Results

Thermal Conductivity:	13.48 W/(m, K)	±0.04%
Thermal Diffusivity:	3.528 mm^2/s	±0.16%
Heat Capacity:	3.955 MJ/(m^3, K)	±0.15%

This instrument has proved to behave according to specifications described in BRk-QB-M26-02.

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Appendix B

Table B-1. Thermal properties of samples at 20°C.

Measurement number	Conductivity (W/(m, K))	Diffusivity (mm2/s)	Heat capacity (MJ/(m3, K))
KAV-90V-07			
1	3.02	1.27	2.37
2	3.01	1.28	2.36
3	3.01	1.29	2.34
4	3.02	1.28	2.35
5	3.01	1.28	2.36
KAV-90V-08			
1	3.77	1.59	2.37
2	3.74	1.58	2.36
3	3.77	1.55	2.43
4	3.76	1.57	2.39
5	3.77	1.56	2.42
KAV-90V-09			
1	3.16	1.46	2.16
2	3.15	1.45	2.17
3	3.17	1.43	2.22
4	3.17	1.43	2.21
5	3.18	1.45	2.20
KAV-90V-10			
1	3.18	1.49	2.13
2	3.18	1.48	2.14
3	3.18	1.49	2.14
4	3.17	1.48	2.14
5	3.17	1.48	2.14
KAV-90V-11			
1	3.15	1.36	2.32
2	3.15	1.35	2.33
3	3.16	1.34	2.36
4	3.16	1.33	2.37
5	3.14	1.35	2.32

Appendix C

Table C-1. Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 20°C.

Measurement number	Total time(s)	Total/Char. Time	Points
KAV-90V-07			
1	20	0.62	42– 200
2	20	0.62	59– 200
3	20	0.62	46– 200
4	20	0.62	36– 200
5	20	0.62	53– 199
KAV-90V-08			
1	20	0.77	82– 199
2	20	0.77	98– 200
3	20	0.75	96– 200
4	20	0.75	93– 197
5	20	0.74	87– 196
KAV-90V-09			
1	20	0.71	72– 200
2	20	0.71	61– 200
3	20	0.69	80– 200
4	20	0.70	80– 200
5	20	0.70	86– 200
KAV-90V-10			
1	20	0.72	69– 198
2	20	0.72	56– 200
3	20	0.71	61– 196
4	20	0.72	61– 200
5	20	0.72	70– 200
KAV-90V-11			
1	20	0.66	52– 200
2	20	0.66	58– 200
3	20	0.65	63– 200
4	20	0.65	63– 200
5	20	0.66	60– 200