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Outcrop samples from Forsmark

Determination of thermal properties by the TPS-Method

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Summary

Porosity, density and thermal properties were measured for five different outcrop samples from Forsmark namely: two samples of Metatonalit, Metadiorit, Metagranit and Metagranodiorit.

Measurements were performed according to SKB's method descriptions SKB MD 191.001 (Determination of thermal properties, thermal conductivity and specific heat, by using TPS-method) and SKB MD 160.002 (Determination of density and porosity of the intact rocks). In addition to material properties, the influence of orientation on thermal properties was investigated.

The amount of material delivered was too small to produce all needed samples for measurement of thermal properties and determination of the influence of orientation. Thus the influence of orientation on thermal properties was not made in accordance with SKB MD 191.001. The influence of orientation is determined by using a single sided method, which gives the relative relation between two major orientations of the rock.

Results obtained by these measurements were in the expected normal variation range.

The results indicated that the samples of Metatonalit (MBS020002b) and Metagranit behaved as an anisotropic material (the difference between orientations was about 20–24%) and the samples made of Metatonalit (MBS020002b) and Metagranodiorit could be assumed as an isotropic material (the difference between orientations was about 0.5–2%). The difference in thermal properties of different orientation in sample Metadiorit is about 13%.

Contents

1 Introduction

The scope of these tests was to determine thermal conductivity, thermal diffusivity, density and porosity of rocks. In addition the influence of orientation on the thermal properties was also investigated.

The Swedish Nuclear Fuel & Waste Management Co (SKB) delivered five different rocks to Swedish National Testing and Research Institute (SP). The rocks were delivered in June 2002 to SP.

Determination of thermal properties was made in accordance with SKB's method description SKB MD 191.001. Density and porosity were determined in accordance with SKB MD 160.002. The department of Building Technology (BT) at SP determined density and porosity. Thermal properties were measured and analyzed by the department of Fire Technology (BR) at SP.

2 General information

2.1 Specimen

The tested outcrop rocks from Forsmark were marked as shown in Table 2-1. A pair of specimens should be prepared from each rock type and each orientation (two orientations). The delivered rocks were not enough for this amount of samples. Thus one specimen was prepared for each rock type and orientation, totally 10 specimens.

2.2 Technical devices

Technical devices are prescribed in SKB MD 191.001 and SKB MD 160.002. Specific information about devices:

TPS-apparatus: Bridge version.

Software: Hot Disk version 5.4.

Radius of Kapton sensor for thermal measurements was 6.394 mm.

Table 2-1. Materials name and identification marks.

Rock type	Identification
Metatonalit	MBS020002B
Metadiorit	MBS020003B
Metagranit	MBS020004B
Metatonalit	MBS020007B
Metagranodiorit	MBS020009B

Other geological information was not precised by SKB.

2.3 Measurement procedure

The measurement procedure followed the prescription in SKB MD 191.001 and SKB MD 160.002.

The following steps were performed:

- The main mineral orientation (foliation) was determined based on visual estimations. This was done by a geologist at SP,BT, in order to prepare two samples parallel and perpendicular to the foliation.
- Samples were cut and polished.
- Samples were water saturated.
- After the saturation procedure, samples were weighed (wet weight under water).
- Samples were sent from BT to BRk.
- Thermal properties were determined.
- Samples were sent from BRk to BT.
- Drying of samples started and the dry weight was determined.

2.3.1 Deviations

- The test material was not photographed.
- Thermal properties were measured twice for each rocks. According to SKB MD 190.001, five measurements should be performed for each sample.
- All samples were in the same vessel during water saturation.
- The pressure was 1000 mbar instead of 800 mbar during water saturation.
- An additional weighting was performed for each sample during determination of thermal properties in order to find out the drying ratio of samples. These measurements were performed before starting the procedures for determination of thermal properties and after repeated thermal measurements. This measurement showed that the weight of the samples reduces during measuring of thermal properties.

3 Results

3.1 Test results for each sample

3.1.1 Thermal properties

The dimensions of the test specimens were about 50x50x20 mm (length, width and thickness). Two samples were prepared of the same rock for each thermal measurement. The first sample had a parallel orientation and the second one had a perpendicular orientation to the mineral fabric, see fig 1. In these measurements it was assumed that the orientation had no influence on the thermal properties. The temperature in the laboratory and specimens were 21°C.

The temperature of water for water saturation was 21.1°C and the density of the water was 998 kg/m^3.

Dry weight was measured after that samples had been dried to constant mass according to ISMR (1974) at 105°C. The drying procedure took eight days.

Radius of Kapton sensor for thermal measurements was 6.394 mm. Output of power was 0.75 W.

Density and porosity measurements were performed during July 2002. Thermal properties were determined during 27–28 August 2002.

Setup of the samples is shown in Figure 3-1.

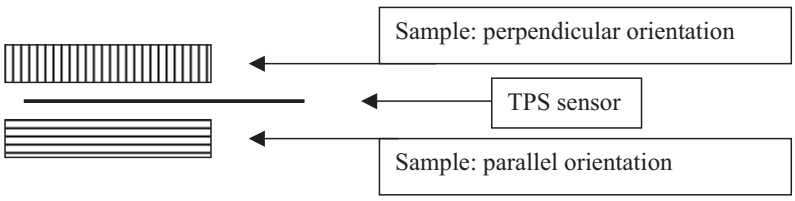

Figure 3-1. *Set up of the samples concerning orientation of the samples.*

Table 3-1. Metatonalit (MBS020002B) specimens with parallel orientation are marked with '*'.

Results of parallel and perpendicular orientation Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity[%]
2808*	2803*	0.46*
2810	2806	0.33

Table 3-2. Thermal properties of Metatonalit (MBS020002B).

Results of repeated measurements Conductivity [W/mK]	Diffusivity [mm²/s]	Heat capacity [MJ/m³K]
2.96	1.60	1.85
2.86	1.51	1.90

Table 3-3. Metadiorit (MBS020003B) specimens with parallel orientation are marked with '*'.

Results of parallel and perpendicular orientation Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity[%]
2981*	2977*	0.33*
2956	2952	0.37

Table 3-4. Thermal properties of Metadiorit (MBS020003B).

Results of repeated measurements Conductivity [W/mK]	Diffusivity [mm²/s]	Heat capacity [MJ/m³K]
2.27	0.96	2.36
2.29	1.00	2.29

Table 3-5. Metagranit (MBS020004B) specimens with parallel orientation are marked with '*'.

Results of parallel and perpendicular orientation Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity[%]
2655*	2650*	0.48*
2656	2652	0.48

Table 3-6. Thermal properties of Metagranit (MBS020004B).

Results of repeated measurements Conductivity [W/mK]	Diffusivity [mm²/s]	Heat capacity [MJ/m³K]
3.50	1.56	2.25
3.52	1.60	2.20

Table 3-7. Metatonalit (MBS020007B) specimens with parallel orientation are marked with '*'.

Results of parallel and perpendicular orientation Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity[%]
2769*	2763*	0.67*
2779	2772	0.67

Table 3-8. Thermal properties of Metatonalit (MBS020007B).

Results of repeated measurements Conductivity [W/mK]	Diffusivity [mm²/s]	Heat capacity [MJ/m³K]
2.44	1.27	1.92
2.46	1.27	1.94

Table 3-9. Metagranodiorit (MBS020009B) specimens with parallel orientation are marked with '*'.

Results of parallel and perpendicular orientation Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity[%]
2660*	2655*	0.51*
2658	2654	0.46

Table 3-10. Thermal properties of Metagranodiori (MBS020009B).

Results of repeated measurements Conductivity [W/mK]	Diffusivity [mm²/s]	Heat capacity [MJ/m³K]
3.44	1.86	1.85
3.44	1.80	1.91

Table 3-11. Total time of the measurement, the ratio of total time and characteristic time and the number of analyzed points.

Identification	Total time(s)	Total/ Char. Time	Points
MBS020002B (1)	40	0.99	74–127
MBS020002B (2)	40	0.97	61–140
MBS020002B (3)	20	0.73	58–200
MBS020003B (1)	20	0.39	45–165
MBS020003B (2)	20	0.43	35–175
MBS020004B (1)	20	0.54	65–141
MBS020004B (2)	20	0.53	45–135
MBS020007B (1)	20	0.56	20–180
MBS020007B (2)	20	0.63	90–172
MBS020009B (1)	20	0.61	45–140
MBS020009B (2)	20	0.86	45–190

More details is available in attached excel files.

3.1.2 Influence of anisotropy on the thermal properties

In order to determine the influence of anisotropy on thermal properties another setup was chosen. This setup is shown in Figure 3-2.

An additional measurement was performed in order to determine the drying ratio of sample during TPS measurements. The results of these measurements are presented in Table 3-13.

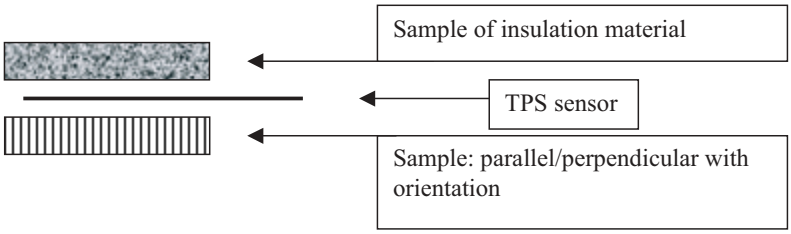

Figure 3-2. *Set up of the samples with thermal insulation material.*

Table 3-12. Results obtained with a setup according to Figure 3-2. These results show the influence of orientation in rocks on the thermal properties. 'P' signs parallel orientation and 'V' signs perpendicular to parallel orientation.

Identification	Conductivity [W/mK]	Diffusivity [mm^2/s]	Heat capacity [MJ/m^{3}K]
MBS020002B-P	1.35	1.61	0.84
MBS020002B-V	1.61	1.41	1.14
MBS020003B-P	1.28	1.01	1.27
MBS020003B-V	1.13	1.00	1.13
MBS020004B-P	2.07	1.89	1.09
MBS020004B-V	1.67	1.98	0.85
MBS020007B-P	1.21	1.18	1.03
MBS020007B-V	1.24	1.23	1.01
MBS020009B-P	1.76	1.74	1.01
MBS020009B-V	1.78	1.75	1.02

Note: The results in Table 3-12 could not be used as material properties for rocks.

Table 3-13. Weight before and after thermal measurements procedure.

Identification	m_B [g]	m_A[g]	Drying ratio 10^{-3}[g/min]	Drying/ m_B 10^{-5}
MBS020002B	189.503	189.500	0.17	2.60
MBS020003B	194.072	194.068	0.19	1.96
MBS020004B	198.678	198.663	0.75	7.55
MBS020007B	146.411	146.375	1.78	24.2
MBS020009B	204.257	204.244	1.22	6.56

Where m_B is the mass before thermal measurements and m_A is mass after thermal measurements. The accuracy of the balance was 0.0001 g.

Table 3-14. Thermal properties of insulation material.

Material	Conductivity [W/mK]	Diffusivity [mm²/s]	Heat capacity [MJ/m³K]
Polystyrene	0.0404	1.63	0.025

3.2 Test results for all samples

Due to the limited sample sizes standard deviation and mean value cannot be determined. Table 3-15 shows the mean value of the thermal properties of each specimen.

Table 3-15. The mean value of measured thermal properties

Identification	Conductivity [W/mK]	Diffusivity [mm²/s]	Heat capacity [MJ/m³K]	Specific heat [J/kg,K]
MBS020002B	2.94	1.51	1.95	694
MBS020003B	2.28	0.98	2.33	785
MBS020004B	3.51	1.58	2.22	836
MBS020007B	2.45	1.27	1.93	696
MBS020009B	3.47	1.82	1.90	715

Specific heat is calculated by using heat capacity and wet density.

Table 3-16. The mean value of porosity, wet- and dry density

Identification	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
MBS020002B	2809	2805	0.40
MBS020003B	2969	2965	0.35
MBS020004B	2656	2651	0.48
MBS020007B	2774	2768	0.67
MBS020009B	2659	2655	0.49

Excel file, digital format, concerning detailed measurement results is enclosed.

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