P-05-60

Forsmark site investigation

Drill hole: KFM01A

Extensometer measurement of the coefficient of thermal expansion of rock (SINTEF)

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Abstract

The coefficient of thermal expansion and the wet density has been determined on 10 specimens from drill hole KFM01A, Forsmark, Sweden. SINTEF in Trondheim, Norway received the specimens from The Swedish National Testing and Research Institute (SP) in Borås, Sweden and they were all marked with id number and had fixing points (Demec) for extensometer measurement of the coefficient of thermal expansion. All specimens tested by SINTEF have been sampled from level 490 m in the drill hole. The rock type is mapped as medium-grained metagranite, with various degree of foliation. The coefficient of thermal expansion has been determined within the temperature interval 20–80°C.

It has been difficult to get reliable results at 80°C, because the glue used detaches from the rock face upon exposure to water and high temperatures (80°C and for one specimen also 60°C). The data gained at 80°C are therefore not reliable for several of the specimens and have not been used in the calculation of coefficient of thermal expansion and length change.

The results indicate that the thermal expansion was linear for some of the specimens (7, 9, 14 and 15) and curvilinear for others (8, 11 and 13). The coefficient of thermal expansion ranges from 1.6×10^{-5} mm/mm°C to 4.7×10^{-5} mm/mm°C.

Sammanfattning

Värmeutvidgningskoefficienten och våtdensiteten bestämdes på 10 bergprover från borrhål KFM01A i Forsmark. SINTEF i Trondheim, Norge, fick proverna levererade från SP, Borås. Alla prover var markerade med id-nummer och var försedda med fixeringspunkter (Demec) för extensometermärningar för bestämning av värmeutvidgningskoefficienten. Alla prover som testades av SINTEF var provtagna på 490-metersnivån i borrhålet. Bergarten är hanterad som medelkornig metagranit, med varierande grad av foliation. Värmeutvidgnings-koefficienten bestämdes för temperaturintervallet 20–80 °C.

Det visade sig svårt att erhålla tillförlitliga resultat vid 80°, därför att limmet lossnar från bergytan då den exponeras för vatten och höga temperaturer (80 °C och för ett prov till och med vid 60 °C). Data från 80 °C är därför inte tillförlitliga för flera av proverna och har inte utnyttjats vid beräkningarna av värmeutvidgningskoefficient och längdförändring.

Resultaten indikerar att värmeutvidgningen var linjär för vissa prover (7, 9, 14 och 15) och kroklinjig för andra (8, 11 and 13). Värmeutvidgningskoefficienten varierar från $1{,}6\times10^{-5}$ mm/mm°C till $4{,}7\times10^{-5}$ mm/mm°C.

Contents

1 Introduction

This document reports the data from extensometer measurement performed by SINTEF in Trondheim, Norway, on 10 specimens received from The Swedish National Testing and research Institute (SP) and representing rock core samples from the Forsmark area. This is one of the activities performed as part of the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-03-019 (SKB internal controlling document).

The principle of the measurement is to determine the coefficient of thermal expansion at different temperatures.

SINTEF has received the following information from SP about sampling: The cores are sampled from borehole KFM01A in the Forsmark area, see Figure 1-1. The sampling was performed on February 24, 2003, by Urban Åkesson (SP) and Rolf Christiansson (SKB). The samples were selected based on the preliminary core logging, and with the strategy to primarily investigate the properties of the dominant rock types. Specimens were taken from three levels in the rock core: level 1 between 225 and 238 m, level 2 between 490 and 494 m (SINTEF's specimens) and level 3 between 689 and 691 m. The rock cores were transported by SP from Forsmark and arrived at SP on February 25, 2003.

SINTEF received the specimens on the 27th of February, 2004, from SP. Testing at SINTEF was conducted within the period 3rd of March to 27th of March.

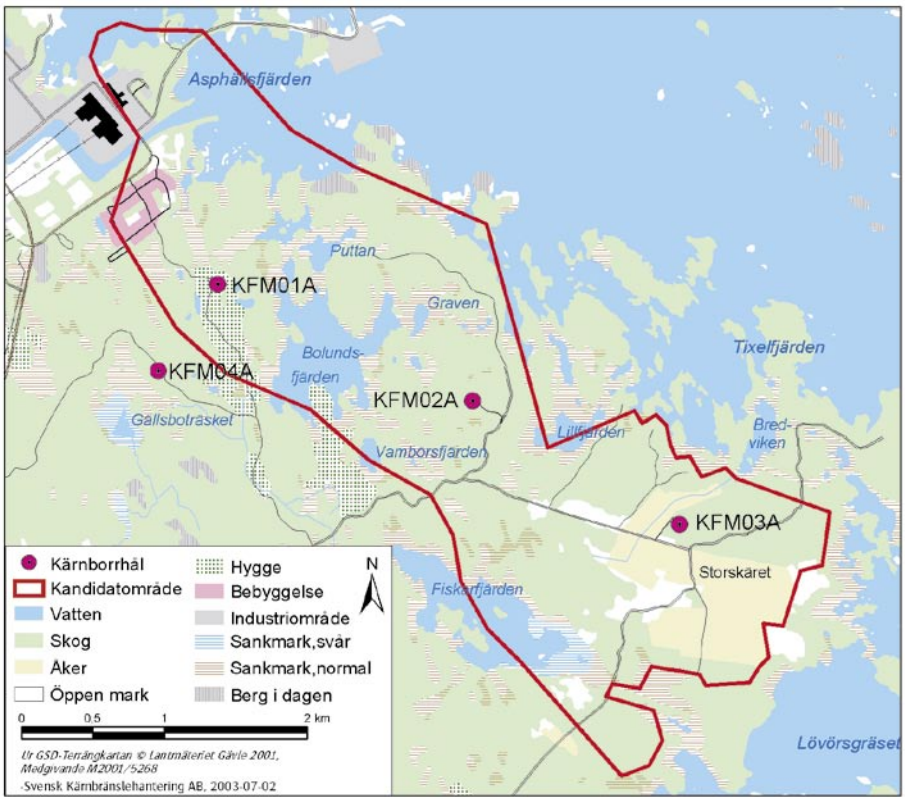

Figure 1-1. *Location of the drill hole KFM01A at the Forsmark area.*

2 Objective and scope

The purpose is to determine the linear coefficient of thermal expansion for rock cores in water-saturated condition between +20°C and +80°C. SP has determined the linear coefficient of thermal expansion on the rock cores and an evaluation of the results presented in this report in comparison with the SP results will be performed in a separate report.

These parameters will be included in site descriptive rock mechanical and thermal model for the Forsmark area, performed by SKB. The specimens and the results will be presented in tables, diagrams and spreadsheets.

3 Equipment

The following equipment has been used for the measurements:

- Extensometer (MERCER) for measurements of the thermal expansion. Calibration of the instrument was done by measurement on the reference bar before and after every measuring day (see Appendix).
- Reference bar in invar steel for calibration of the extensometer.
- Oven (Termaks) for heating up the specimens.
- A covered stainless steel box filled with water for keeping the specimens water saturated.
- Temperature measuring device and termocouples from Jenway (producer) for water temperature recording.
- SINTEF has during the last year not made calculations of the uncertainty of the equipment used.

4 Execution

Determination of the coefficient of thermal expansion was made in accordance with SKB's method description SKB MD 191.002-version 1.9 and NT Build 479. SINTEF Civil and Environmental Engineering, Department of Rock and Soil Mechanics, performed the tests in co-operation with Department of Cement and Concrete.

4.1 Description of the samples

All 10 specimens received from SP were marked with id number as shown in Table 4-1 and had measuring points (Demec) fixed with a glue, type HBM X60, to the surface. The specimens have a diameter of 50 mm and a length of 250 mm. The fixing points give a measuring distance of around 200 mm.

Several of the fixings had detached from the surface upon arrival, and on the rest of the specimens all of these could easily be removed by hand. All measuring points on the specimens had to be re-fixed, see Section 4.2.

The identification reported by SP will be used in the following.

Table 4-1. Identification marks and informed sampling depth on specimens from the Forsmarks area.

Id number on specimens received from SP	Identification reported by SP	Sampling depth, according to the marks on the drill-core boxes (Sec up)	Rock type
FO1A-90L-7	KFM01A-90L-7	490.72	Metagranodiorite-granite
FO1A-90L-8	KFM01A-90L-8	490.98	Metagranodiorite-granite
FO1A-90L-9	KFM01A-90L-9	491.25	Metagranodiorite-granite
FO1A-90L-10	KFM01A-90L-10	491.51	Metagranodiorite-granite
FO1A-90L-11	KFM01A-90L-11	491.84	Metagranodiorite-granite
FO1A-90L-12	KFM01A-90L-12	492.12	Metagranodiorite-granite
FO1A-90L-13	KFM01A-90L-13	492.38	Metagranodiorite-granite
FO1A-90L-14	KFM01A-90L-14	492.85	Metagranodiorite-granite
FO1A-90L-15	KFM01A-90L-15	493.47	Metagranodiorite-granite
FO1A-90L-16	KFM01A-90L-16	493.73	Metagranodiorite-granite

4.2 Testing

The following steps were performed:

Item	Date	Activity
1	2/3-04	The specimens received from SP were photographed in JPEG-format.
2	3/3–8/3-04	All measuring points (Demec) already glued on the specimens by SP were taken off. The rock surface for the measuring points was rubbed by the use of sand paper and then cleaned with acetone before the two Demec points were re-glued by use of HBM X60 on the specimens, giving a measuring distance of 200 mm. The glue was allowed to dry/cure for one week
3	8/3–15/3-04	The specimens were water saturated (temperature 19.5°C) for one week.
4	15/3	The wet density was determined.
5	15/3–27/3-04	The coefficient of thermal expansion was determined. The length/thermal expansion was measured at 20, 40, 60 and 80°C. On each temperature level three measurements were done with 24 h intervals in order to assure that the expansion was completed for each temperature level. The coefficient of thermal expansion was determined between 20–80°C. Calibration of the instrument was done before the measurements on every new temperature by the use of an invar steel bar.

In order to secure stability in the temperature of the specimens at each measurement, the box with the specimens was kept in the oven, and the specimens were taken out one by one for measurement.

4.3 Nonconformitites

The execution procedure followed the prescription in SKB MD 191.002-version 1.9 and SKB MD 160.002-version 2.0 (SKB internal controlling document).

In order to secure stability in the temperature of the specimens at each measurement, the box with the specimens was kept in the oven, and the specimens were taken out one by one for measurement.

Measurement of expansion during heating on fully water saturated specimens is challenging especially due to the difficulty to achieve a permanent attachment of the measuring points when exposed to cyclic heating in water. Both SP and SINTEF have met with problems of this kind. Typically the measuring point detached from the glue at the third cycle. During the two first cycles the adhesion between the glue and the rock face was more stabile, but yet also here problems arose. Several of SINTEF's measurements at 80°C are for this reason uncertain. Thus, the measurement of specimen KFM01A-90L-10 was unsuccessful, and also specimen KFM01A-90L-12 behaved strange, without any clear detachment of the measuring points. A comment to the test is that the glue used (type HBM X60) is not fully stable upon heating in water.

5 Results

5.1 Description of the specimen and presentation of test results

The temperature of water for water saturation was 19.5°C and the density of the water was 998 kg/m^3. The coefficient of thermal expansion was determined between +20°C and +80°C.

It has been difficult to get reliable results at 80°C, because the glue used detaches from the rock face upon exposure to water and high temperatures (80°C and for one specimen also at 60°C). The data gained at 80°C are therefore not reliable for some of the specimens and have not been used in the calculation of coefficient of thermal expansion and length change. This has been remarked in the below description of each sample.

KFM01A-90L-7 (470.72 m)

The coefficient of thermal expansion for specimen KFM01A-90L-7 was calculated to be 4.1×10^{-5} mm/mm°C in the interval (20–80°C). Here, one measuring point detached from the surface at the 2nd measurement at 80°C, so only the 1st measurement at this temperature was included in the calculations. The specimen had a wet density of 2,649 Kg/m^3.

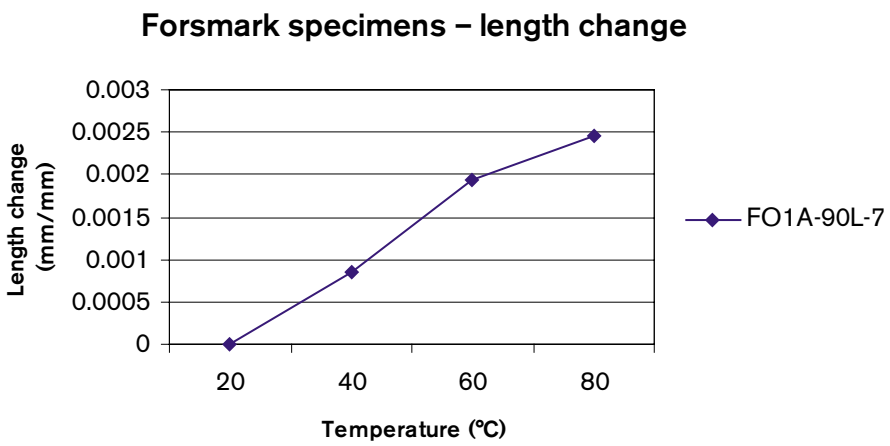

Figure 5-1. *Specimen KFM01A-90L-7.*

KFM01A-90L-8 (490.98 m)

The coefficient of thermal expansion for specimen KFM01A-90L-8 was calculated to be 1.7×10^{-5} mm/mm°C in the interval (20–80°C). Here one measuring point detached from the surface at the 3rd measurement at 80°C. Only the 1st measurement at this temperature was included in the calculation. The specimen had a wet density of 2,656 Kg/m^3.

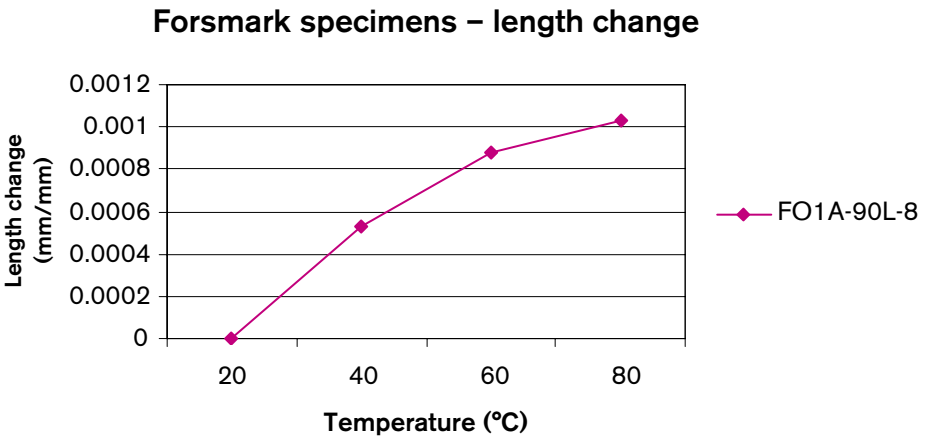

Figure 5-2. *Specimen KFM01A-90L-8.*

KFM01A-90L-9 (491.25 m)

The coefficient of thermal expansion for specimen KFM01A-90L-9 was calculated to be 3.6×10^{-5} mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,658 Kg/m^3.

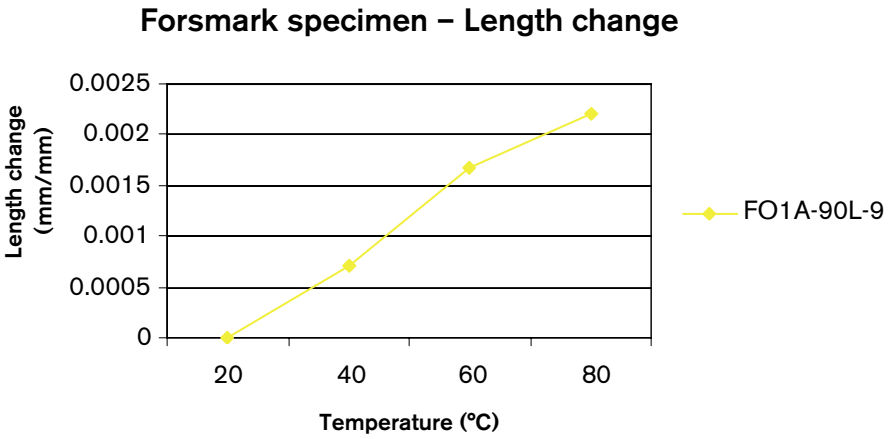

Figure 5-3. *Specimen KFM01A-90L-9.*

KFM01A-90L-10 (492.51 m)

Here one measuring point detached from the surface already at the 2nd measurement at 60°C. Within the interval of 20°C to 40°C the coefficient of thermal expansion for specimen KFM01A-90L-10 was calculated to be 3.1×10^{-5} mm/mm°C. The specimen had a wet density of 2,665 Kg/m^3.

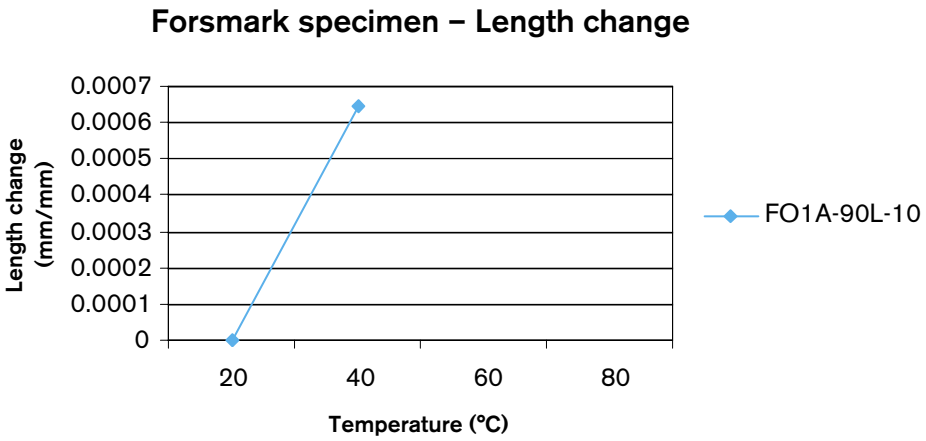

Figure 5-4. *Specimen KFM01A-90L-10.*

KFM01A-90L-11 (491.84 m)

The coefficient of thermal expansion for specimen KFM01A-90L-11 was calculated to be 1.7×10^{-5} mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,669 Kg/m^3.

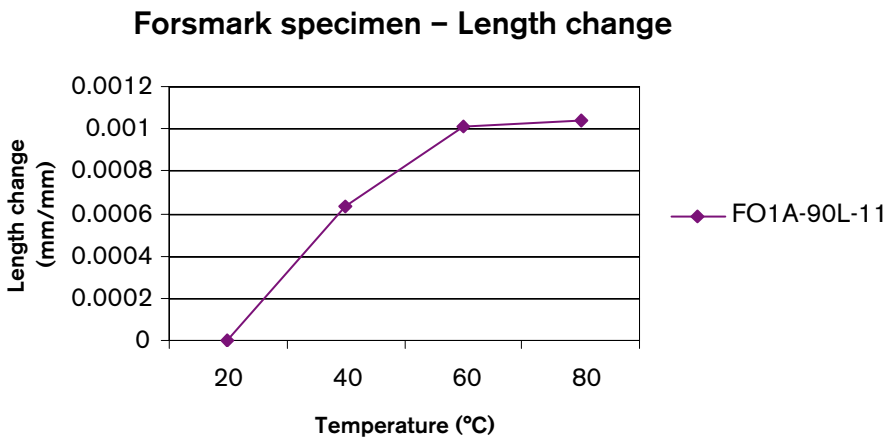

Figure 5-5. *Specimen KFM01A-90L-11.*

KFM01A-90L-12 (492.12 m)

Here several measurements at both 60°C and 80°C are uncertain. When the 3rd measurement at 80°C is deleted the coefficient of thermal expansion for specimen KFM01A-90L-12 was calculated to be 4.6×10^{-6} mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,663 Kg/m^3.

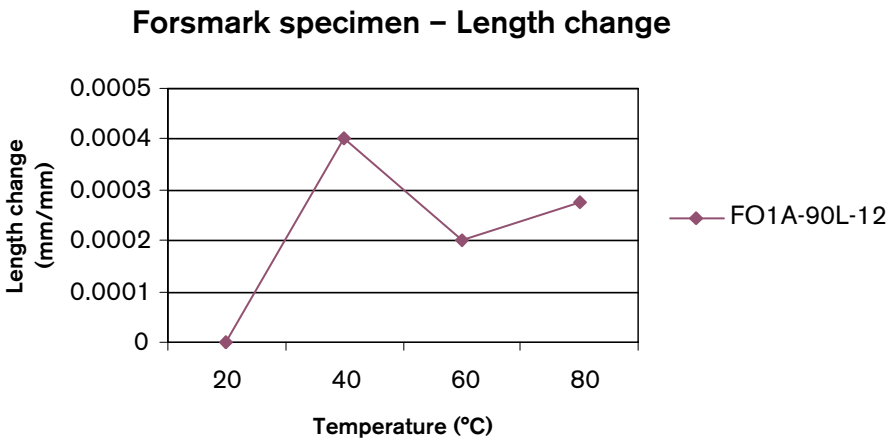

Figure 5-6. *Specimen KFM01A-90L-12.*

KFM01A-90L-13 (492.38 m)

The 3rd measurement at 80°C is uncertain and not included in the data set for calculation. The coefficient of thermal expansion for specimen KFM01A-90L-13 was calculated to be 1.6×10^{-5} mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,660 Kg/m^3.

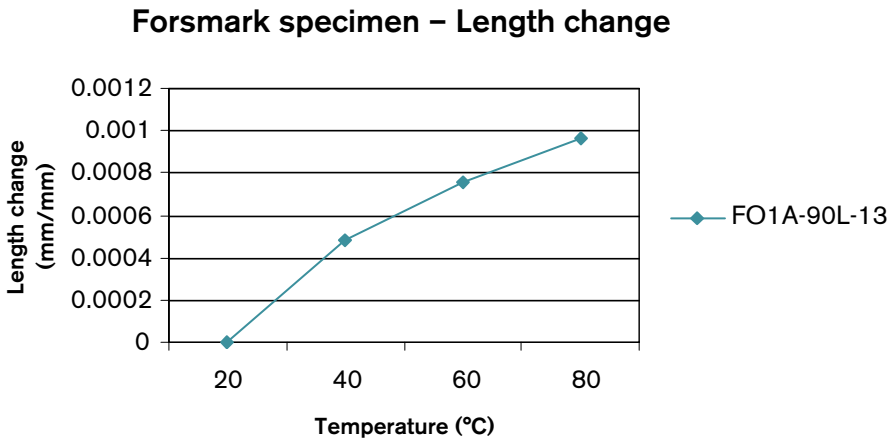

Figure 5-7. *Specimen KFM01A-90L-13.*

KFM01A-90L-14 (492.85 m)

The coefficient of thermal expansion for specimen KFM01A-90L-14 was calculated to be 4.7×10^{-5} mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,656 Kg/m^3.

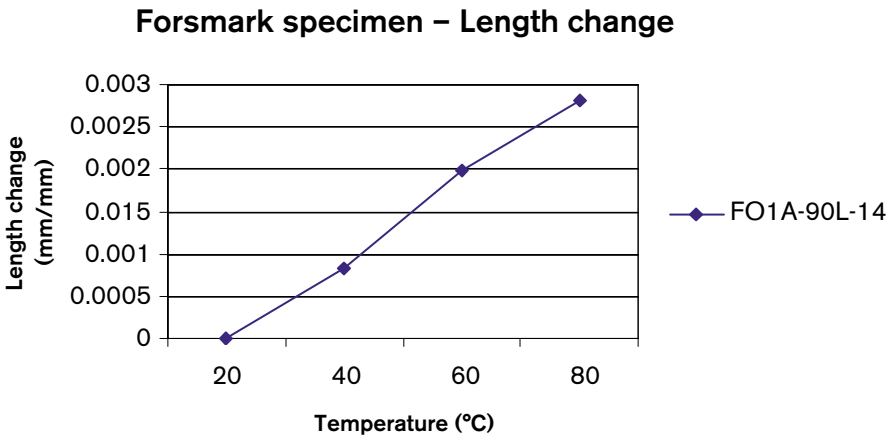

Figure 5-8. *Specimen KFM01A-90L-14.*

KFM01A-90L-15 (493.47 m)

The 3rd measurement at 80°C is uncertain and not included in the data set for calculation. The coefficient of thermal expansion for specimen KFM01A-90L-15 was calculated to be 2.8×10^{-5} mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,658 Kg/m^3.

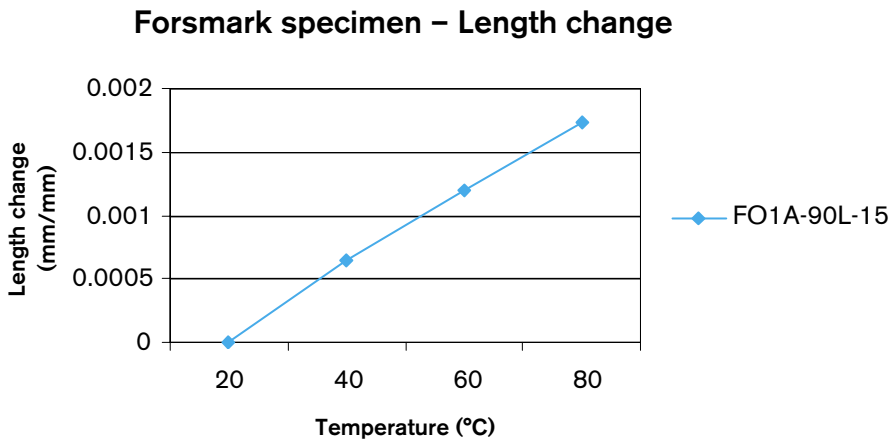

Figure 5-9. *Specimen KFM01A-90L-15.*

KFM01A-90L-16 (493.73 m)

The 2nd and 3rd measurement at 80°C are uncertain and not included in the data set for calculation. The coefficient of thermal expansion for specimen KFM01A-90L-16 was calculated to be 2.8×10^{-5} mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,664 Kg/m^3.

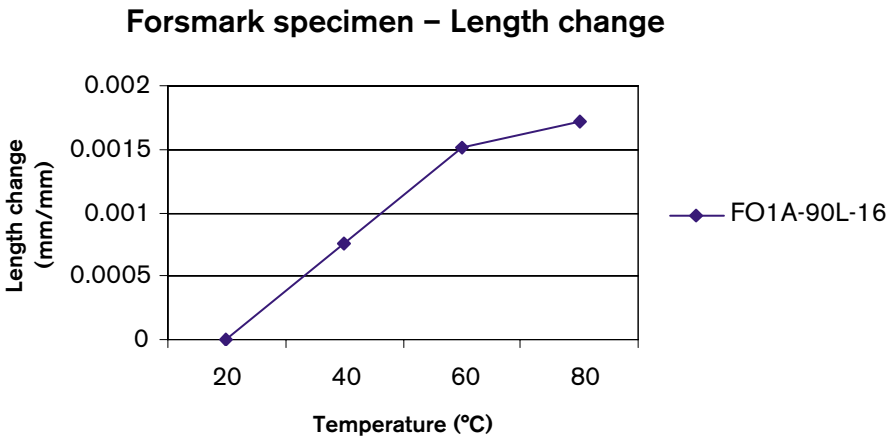

Figure 5-10. *Specimen KFM01A-90L-16.*

5.2 Results for the entire test series

Tables 5-1 and 5-2 and Figures 5-11 and 5-12 provide a summary of the results.

Table 5-1. Summary of the results for the coefficient of thermal expansion, length changes and wet density of the specimens from level 2, KFM01A.

Specimen	Measurements between between 20 and 80°C			
	Coefficient of thermal expansion (mm/mm°C)	Length change (mm)	Length change (mm/mm)	Wet density (Kg/m^3)
KFM01A-90L-7	4.1×10^{-5}	0.490	2.46×10^{-3}	2,649
KFM01A-90L-8	1.7×10^{-5}	0.200	1.00×10^{-3}	2,656
KFM01A-90L-9	3.6×10^{-5}	0.435	2.18×10^{-3}	2,658
KFM01A-90L-10	–	–	–	2,665
KFM01A-90L-11	1.7×10^{-5}	0.215	1.00×10^{-3}	2,669
KFM01A-90L-12	–	–	–	2,663
KFM01A-90L-13	1.6×10^{-5}	0.200	9.61×10^{-4}	2,660
KFM01A-90L-14	4.7×10^{-5}	0.190	2.81×10^{-3}	2,656
KFM01A-90L-15	2.8×10^{-5}	0.560	1.71×10^{-3}	2,658
KFM01A-90L-16	2.8×10^{-5}	0.340	1.71×10^{-3}	2,664

Table 5-2. Summary of the results for the coefficient of thermal expansion (mm/mm°C) in the temperature interval (20–80°C) for the whole sample set.

Depth (m)	Coefficient of thermal expansion (mm/mm°C)		
	Min value	Median value	Max value
490 m	1.6×10^{-5}	2.6×10^{-5}	4.7×10^{-5}

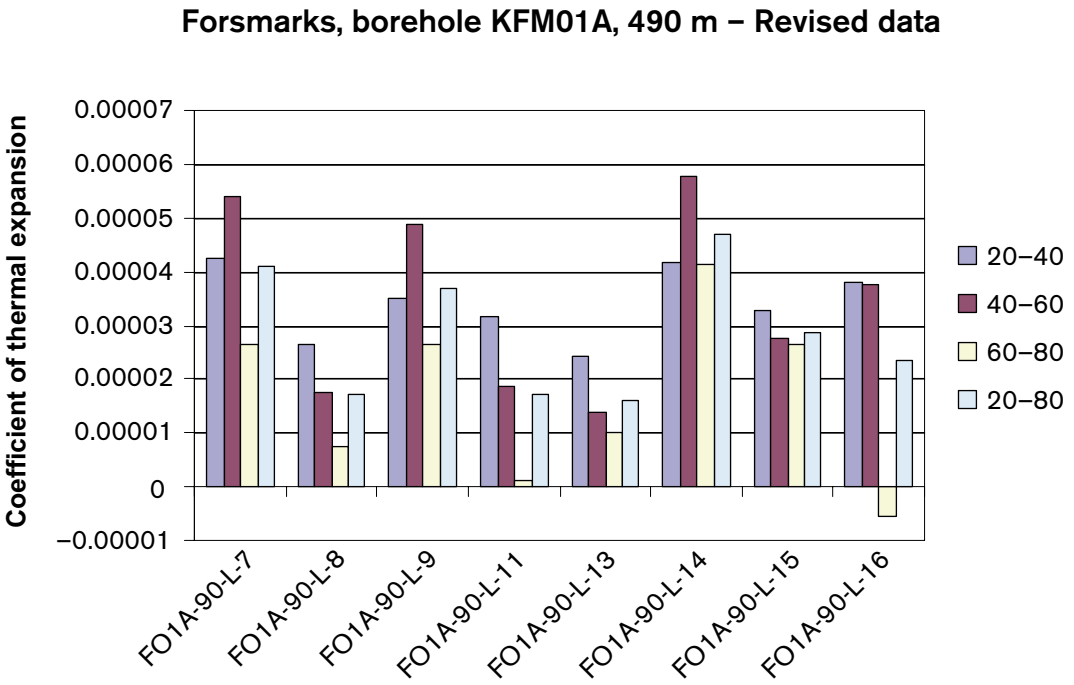

Figure 5-12. *Thermal expansion/length change (mm) for the specimens.*

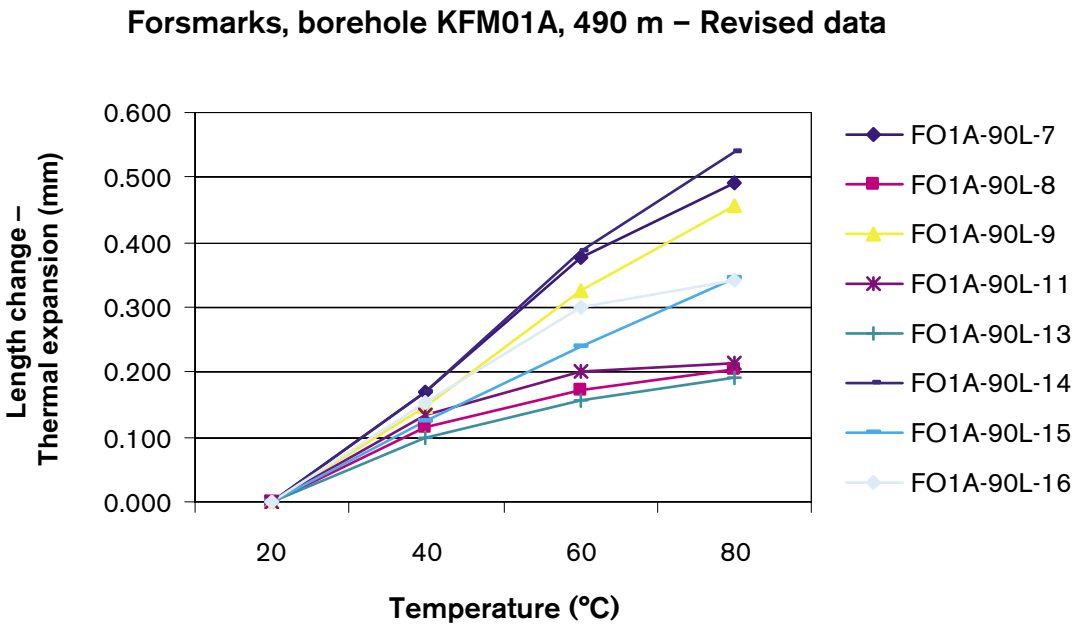

Figure 5-11. *Coefficient of thermal expansion for each specimen in various temperature intervals.*

References

NT BUILD 479, Natural Building stones: Coefficient of thermal expansion.

Appendix 1

Forsmark specimens received from SP