P-04-172

# Forsmark site investigation

# Drill hole KFM02A

# Indirect tensile strength test

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June 2004

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*Keywords:* AP PF 400-04-19, Field note no Forsmark 142, Rock mechanics, Indirect tensile strength, Tension test.

# Abstract

The density and the indirect tensile strength of 30 wet specimens of intact rock stored in water from borehole KFM02A at Forsmark have been determined. The samples were collected at three depth levels ranging between 331-336 m, 528-537 m and 704-718 m. Moreover, the rock type was Medium-grained metagranite (-granodioite). The specimens were photographed before and after the mechanical test.

The measured density for the water stored specimens were in the range 2640-2660 kg/m$^3$, which yields a mean value of 2650 kg/m$^3$ and the obtained values for the indirect tensile strength were in the range 11.1- 17.0 MPa with a mean value of 13.7 MPa.

# Contents

# 1 Introduction

Indirect tensile strength tests have been conducted on water-saturated specimens sampled from borehole KFM02A at Forsmark, see map in Figure 1-1. These tests belong to one of the activities performed as part of the site investigation in the Forsmark area conducted by the Swedish Nuclear Fuel and Waste Management Co (SKB). The tests were carried out in the material and rock mechanics laboratories at the department of Building Technology and Mechanics at the Swedish National Testing and Research Institute (SP). All work is carried out in accordance with the activity plan AP PF 400-04-19 (SKB internal controlling document) and is controlled by SP-QD 13.1 (SP internal quality document).

SKB supplied SP with rock cores and they arrived at SP in September 2003 and were tested during March and April 2004. The specimens, in form of cylindrical discs, were cut from the cores and selected based on the preliminary core logging with the strategy to primarily investigate the properties of the dominant rock type. The specimens were then put into water and stored in water for minimum 7 days. This yields a water saturation, which is intended to resemble the in-situ moisture condition. The density was determined on each specimen and the indirect tensile tests were carried out at this moisture condition. The rock material is characterized by foliations in the rock structure at some sampling depths, which may imply

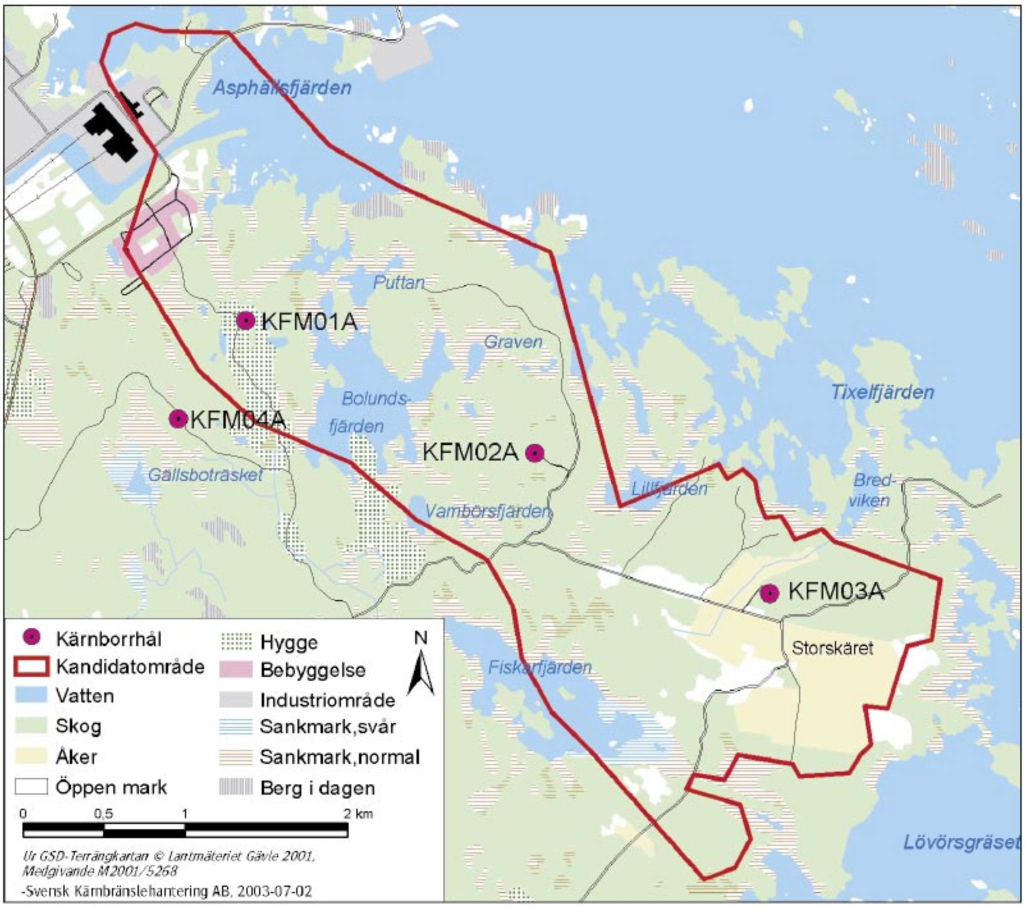



***Figure 1-1.*** *Location of borehole KFM02A at the Forsmark site.*

an anisotropic mechanical response. An isotropic mechanical response is expected on specimens with a homogenous material structure. The direction of loading is displayed on the specimens by a drawn line on each specimen. The specimens were photographed before and after the mechanical testing.

The method description SKB MD 190.004e, version 1.9 (SKB internal controlling document), was followed for the sampling and for the indirect tensile strength tests, whereas the method description SKB MD 160.002, version 1.9 (SKB internal controlling document), was followed when the density was determined.

# 2 Objective and scope

The purpose of the testing is to determine the density and the indirect tensile strength of a cylindrical intact rock core. The specimens are collected from borehole KFM02A, which is a telescope borehole of SKB chemistry type with a drilling depth of c. 1000 m.

The results from the tests are going to be used in the site descriptive model of rock mechanics, which will be established for the candidate area selected for site investigations at Forsmark.

# 3 Equipment

A circular saw with a diamond blade was used to cut the specimens to their final lengths. Samples with a rough cutting surface were levelled in a grinding machine. The measurements of the dimensions were made with a sliding calliper. Furthermore, the tolerances were checked by means of a dial indicator and a stone face plate.

The specimens and the water were weighed using a weighing scale. A thermometer was used for the water temperature measurement. The calculated wet density was determined with an uncertainty of ± 5 $kg/m^3$.

The mechanical testing was carried out in a load frame where the crossbar is mechanically driven by screws and has a maximum load capacity of 100 kN in compression. The axial compressive load was measured by an external 100 kN load cell. The uncertainty of the load measurement is less than 1%.

The frame was equipped with a pair of curved bearing blocks, radius 39 mm and width 29 mm, with pins for guiding the vertical deformation. The top platen includes a spherical seating in order to have a fully centred loading position. The samples were photographed with a 4.0 Mega pixel digital camera at highest resolution and the photographs were stored in a jpeg-format.

# 4 Execution

The water saturation and determination of the density of the wet specimens were made in accordance with the method description SKB MD 160.002, version 1.9 (SKB internal controlling document). This includes determination of density in accordance with ISRM [1] and water saturation by SS EN 13755 [2]. The determination of the indirect tensile strength was carried out in compliance with the method description SKB 190.004e, version 1.9 (SKB internal controlling document). The test method follows ASTM D3967-95a [3].

## 4.1 Description of the samples

The rock type characterisation was made according to Stråhle [4] using the SKB mapping system (Boremap). The identification marks, upper and lower sampling depth (Secup and Seclow) and the rock type are shown in Table 4-1.

**Table 4-1. Specimen identification, sampling depth and rock type for all specimens.**

| Identification | Secup [m] | Seclow [m] | Rock type |
|---|---|---|---|
| KFM02A-110-1 | 334.67 | 334.72 | Metagranite |
| KFM02A-110-2 | 335.08 | 335.13 | (All specimens) |
| KFM02A-110-3 | 335.13 | 335.18 | |
| KFM02A-110-4 | 330.60 | 330.65 | |
| KFM02A-110-5 | 335.61 | 335.66 | |
| KFM02A-110-6 | 335.66 | 335.71 | |
| KFM02A-110-7 | 335.71 | 335.76 | |
| KFM02A-110-8 | 335.76 | 335.80 | |
| KFM02A-110-9 | 335.80 | 335.85 | |
| KFM02A-110-10 | 335.85 | 335.90 | |
| KFM02A-110-13 | 527.87 | 527.92 | |
| KFM02A-110-14 | 531.61 | 531.66 | |
| KFM02A-110-15 | 532.21 | 532.26 | |
| KFM02A-110-16 | 534.58 | 534.62 | |
| KFM02A-110-17 | 534.62 | 534.67 | |
| KFM02A-110-18 | 537.12 | 537.17 | |
| KFM02A-110-19 | 537.17 | 537.21 | |
| KFM02A-110-20 | 537.21 | 537.26 | |
| KFM02A-110-21 | 537.26 | 537.30 | |
| KFM02A-110-22 | 537.30 | 537.35 | |
| KFM02A-110-25 | 704.39 | 704.44 | |
| KFM02A-110-26 | 706.38 | 706.42 | |
| KFM02A-110-27 | 706.42 | 706.46 | |
| KFM02A-110-28 | 706.46 | 706.51 | |
| KFM02A-110-29 | 706.51 | 706.55 | |
| KFM02A-110-30 | 706.78 | 706.83 | |
| KFM02A-110-31 | 709.27 | 709.32 | |
| KFM02A-110-32 | 716.64 | 716.69 | |
| KFM02A-110-33 | 716.69 | 716.73 | |
| KFM02A-110-34 | 718.17 | 718.22 | |

## 4.2 Testing

A step-by step description of the full test procedure is as follows:

| Step | Activity |
|---|---|
| 1 | The drill cores were marked where the samples are to be collected. |
| 2 | The samples were cut to the specified length according to markings. If the cutting surfaces were rough, they were slightly grinded. |
| 3 | The tolerances were checked: parallel and perpendicular surfaces, smooth and straight circumferential surface. |
| 4 | The diameter and thickness were measured three times each. The respective mean value determines the dimensions that are reported. |
| 5 | The direction of compressive loading was marked as a line on one of the plane surfaces with a marker pen. |
| 6 | The samples were then put into water and stored in water for minimum 7 days. The weight of water together with one specimen was determined. The specimen was taken out from the water container and the weight of the water and rock specimen was determined separately, and by using the known density of the water, the wet density could be computed. This procedure was repeated for each specimen. |
| 7 | Digital photos were then taken on each sample. |
| 8 | The wet samples were inserted into the loading device one by one, with the correct orientation given by the marked line, and then loaded up to failure during deformation control. The load frame crossbar speed was set to 0.3 mm/min, which yielded a loading rate of approximately 9.5 MPa/min. The maximum compressive load, which also defines the failure load, was registered. |
| 9 | Digital photos were then taken on each sample after the mechanical testing. |

The temperature of the water was 19.4 °C, which equals to a water density of 998.3 kg/m$^3$, when the density determination of the rock specimens was carried out. Further, the specimens had been stored during 7 days in water when the density was determined and stored during 40 days in water when the indirect tensile strength was determined.

An auto-calibration of the load frame was run prior to the mechanical test in order to check the system. Further, an individual check-list was filled in and checked for every sample during all the steps in the execution. Moreover, comments were made during the mechanical testing upon observed phenomena that are relevant for the interpretation of the results. The check-list form is a SP internal quality document.

The diameter and thickness were entered into the test software which computed the indirect tensile strength together with the mean value and standard deviation for the whole test series. The results were then exported as text-files and stored in a file server on the SP computer network. The results were imported to the program MS Excel and rearranged to the SICADA database format. Moreover, the diagram was produced using MS Excel.

# 5 Results

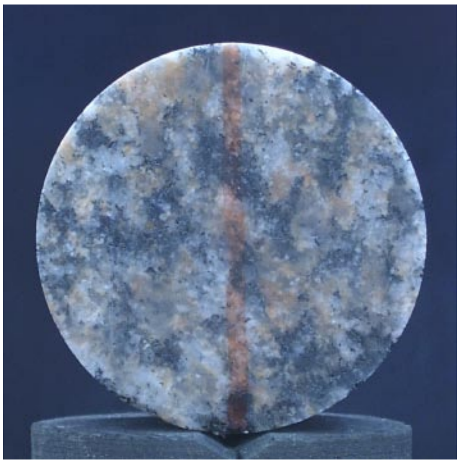
The results of the testing of individual specimens are presented in Section 5.1 and a summary of the results is given in Section 5.2. The original results, unprocessed raw data obtained from the testing, were reported to the SICADA database under field note no Forsmark 142. These data together with the digital photographs of the individual specimens were stored on a CD and handed over to SKB. The handling of the results follows SDP-508 (SKB internal controlling document) in general.

## 5.1 Description and presentation of the specimens

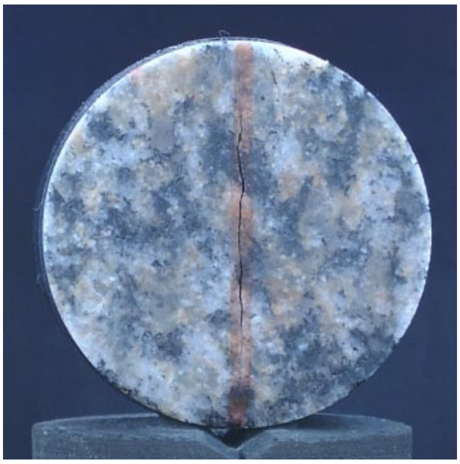
The results for the individual specimens are as follows:

**Specimen ID:** KFM02A-110-1

Before mechanical test



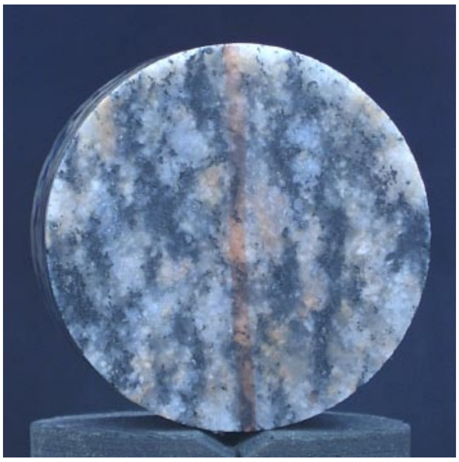
After mechanical test



| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 26.0 | 2660 | 14.4 |

**Comments:** None

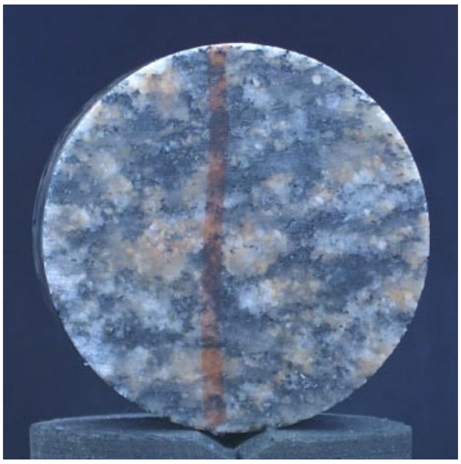
**Specimen ID:** KFM02A-110-2

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 25.8 | 2660 | 13.8 |

**Comments:** None

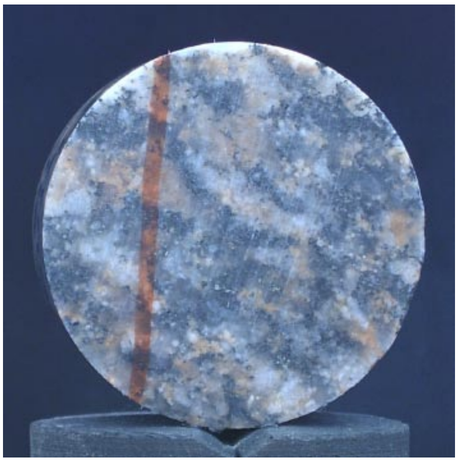
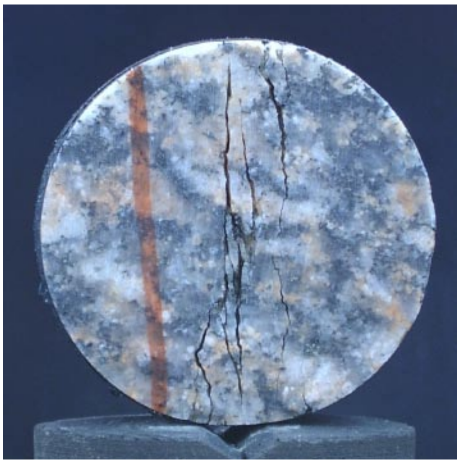
**Specimen ID:** KFM02A-110-3

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 25.9 | 2670 | 14.3 |

**Comments:** None

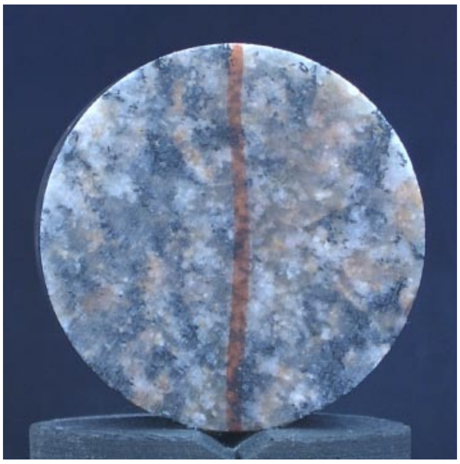
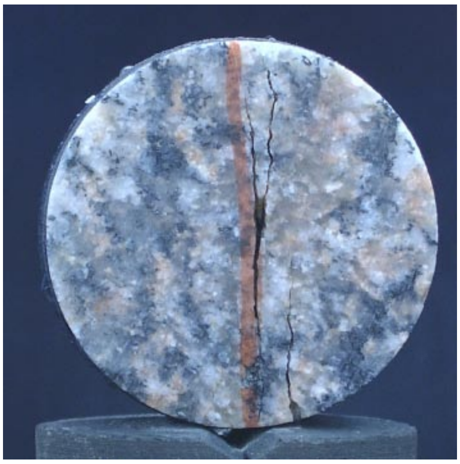
**Specimen ID:** KFM02A-110-4

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.9 | 25.9 | 2660 | 14.7 |

**Comments:** None

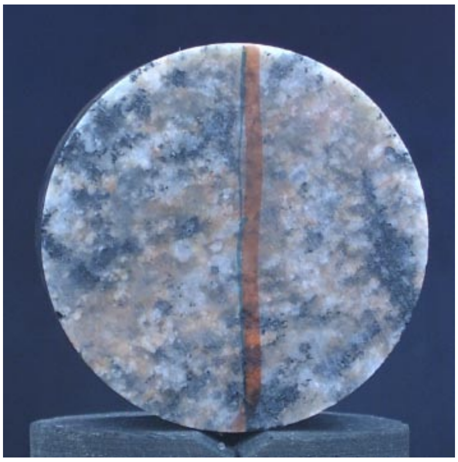
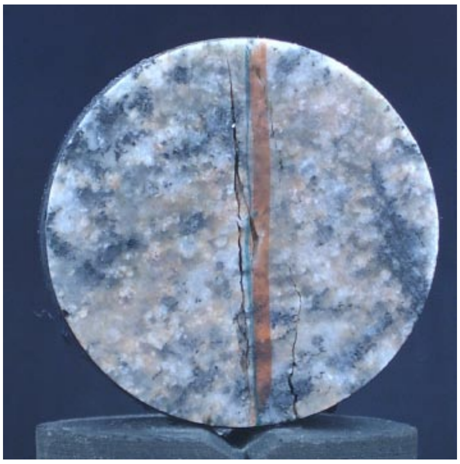
**Specimen ID:** KFM02A-110-5

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 25.9 | 2650 | 14.3 |

**Comments:** None

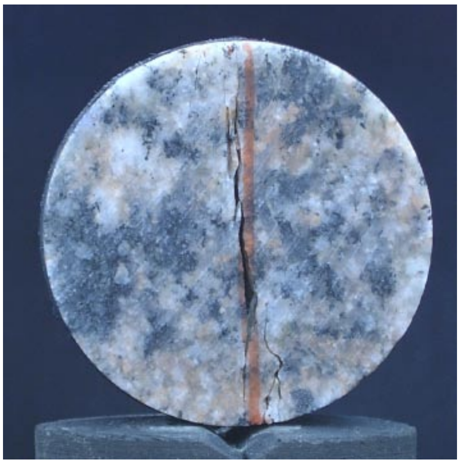
**Specimen ID:** KFM02A-110-6

| Before mechanical test | After mechanical test |
| --- | --- |
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
| --- | --- | --- | --- |
| 50.7 | 25.9 | 2650 | 15.9 |

**Comments:** None

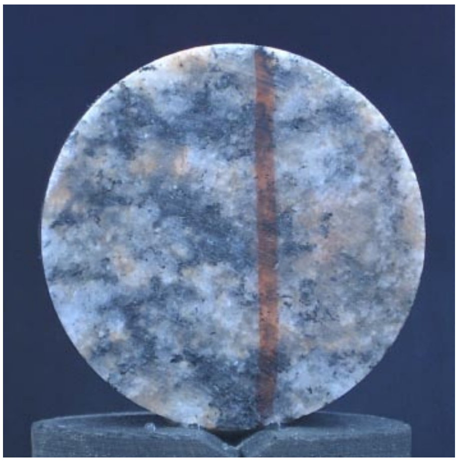
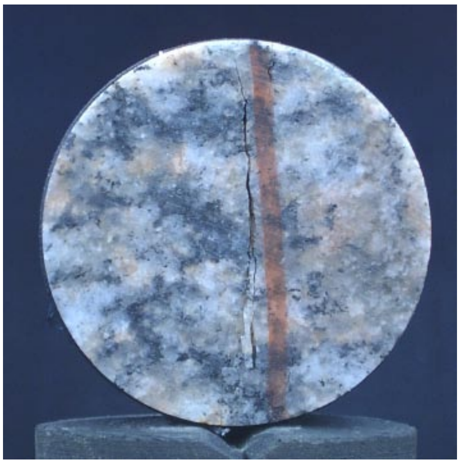
**Specimen ID:** KFM02A-110-7

| Before mechanical test | After mechanical test |
| --- | --- |
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
| --- | --- | --- | --- |
| 50.7 | 25.8 | 2650 | 13.9 |

**Comments:** None

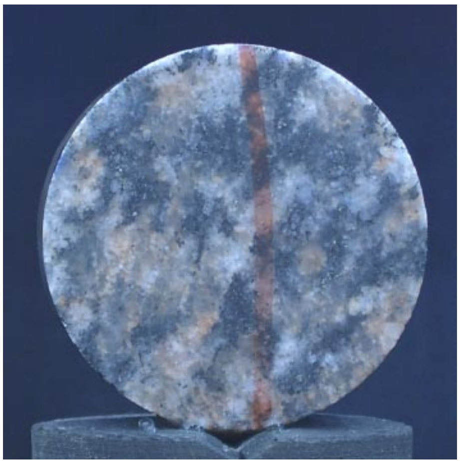
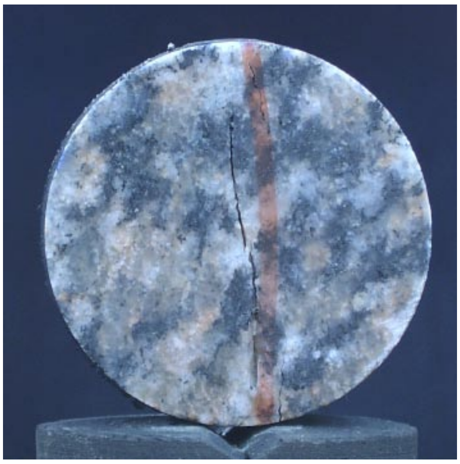
**Specimen ID:** KFM02A-110-8

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 25.9 | 2660 | 17.0 |

**Comments:** None

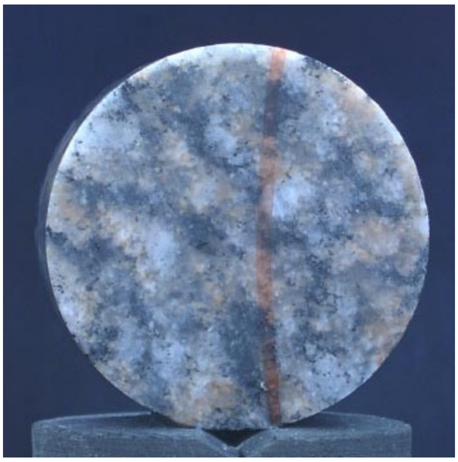
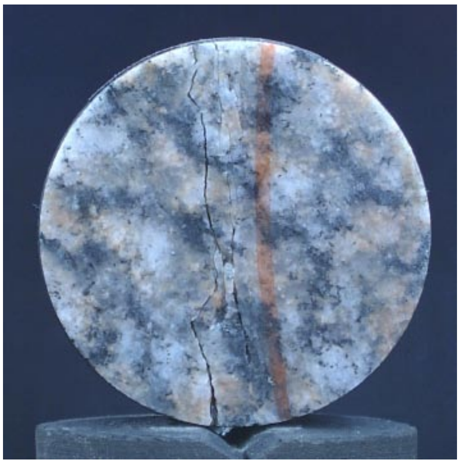
**Specimen ID:** KFM02A-110-9

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 26.0 | 2660 | 14.3 |

**Comments:** None

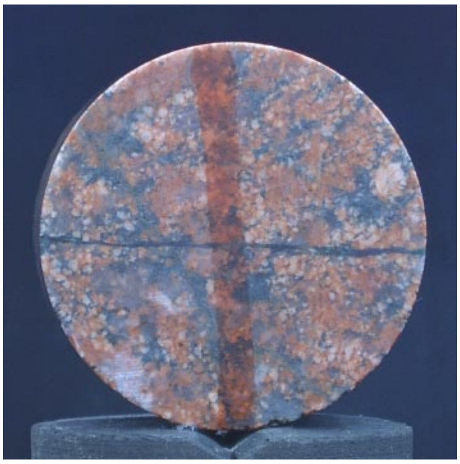
**Specimen ID:** KFM02A-110-10

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 25.9 | 2660 | 15.4 |

**Comments:** None

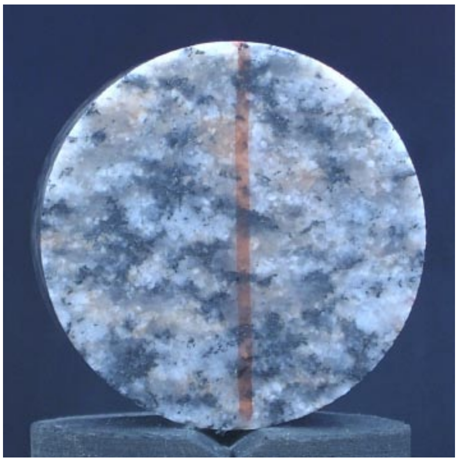
**Specimen ID:** KFM02A-110-13

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.9 | 26.3 | 2640 | 16.6 |

**Comments:** None

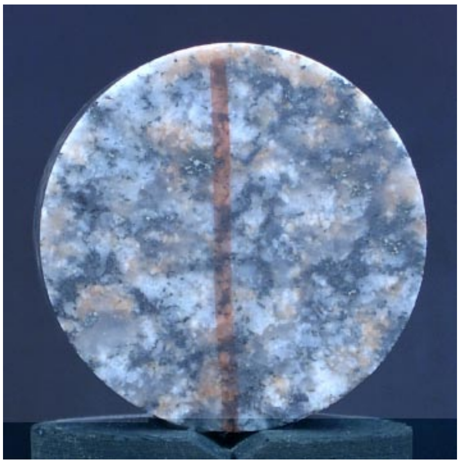
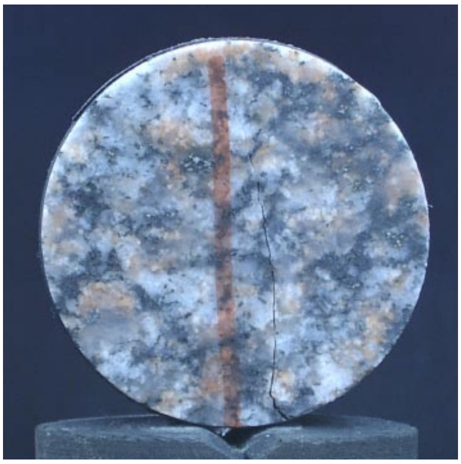
**Specimen ID:** KFM02A-110-14

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| **Diameter [mm]** | **Height [mm]** | **Density [kg/m$^3$]** | **Tensile strength [MPa]** |
|---|---|---|---|
| 50.9 | 25.3 | 2650 | 12.3 |

**Comments:** None

**Specimen ID:** KFM02A-110-15

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| **Diameter [mm]** | **Height [mm]** | **Density [kg/m$^3$]** | **Tensile strength [MPa]** |
|---|---|---|---|
| 50.8 | 26.1 | 2650 | 12.6 |

**Comments:** None

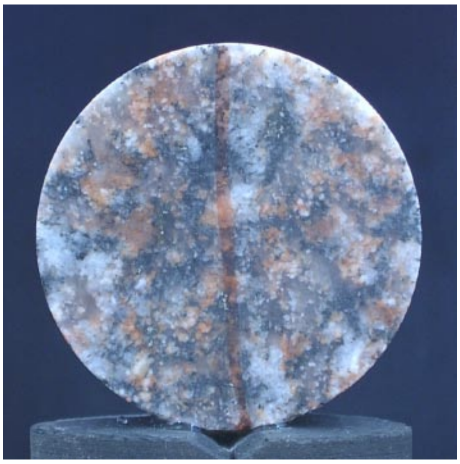
**Specimen ID:** KFM02A-110-16

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.8 | 26.0 | 2650 | 16.5 |

**Comments:** None

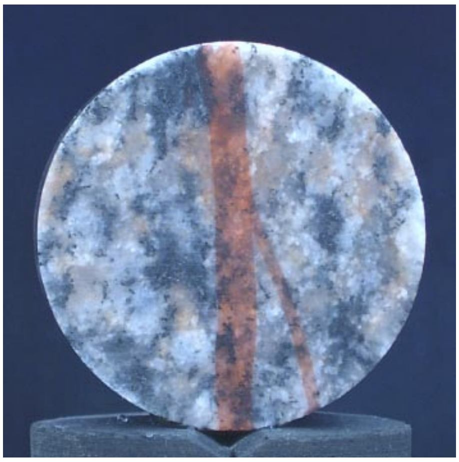
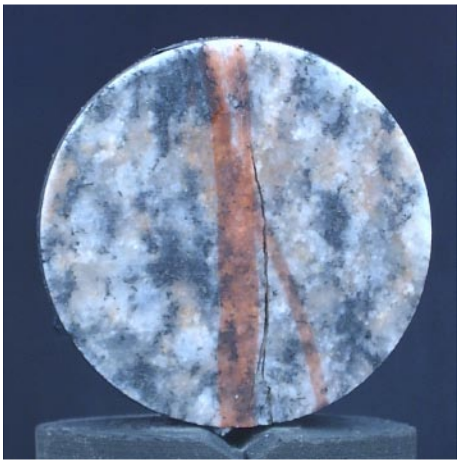
**Specimen ID:** KFM02A-110-17

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.8 | 26.1 | 2650 | 12.9 |

**Comments:** None

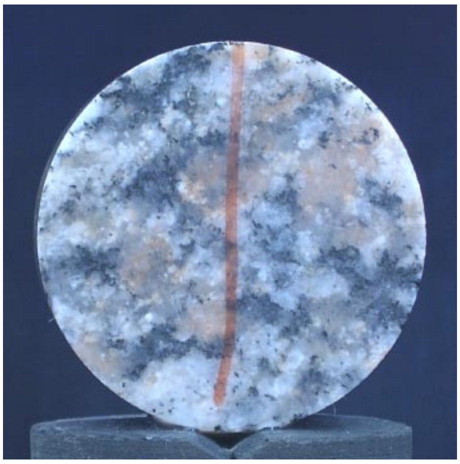
**Specimen ID:** KFM02A-110-18

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 51.0 | 26.3 | 2650 | 12.5 |

**Comments:** None

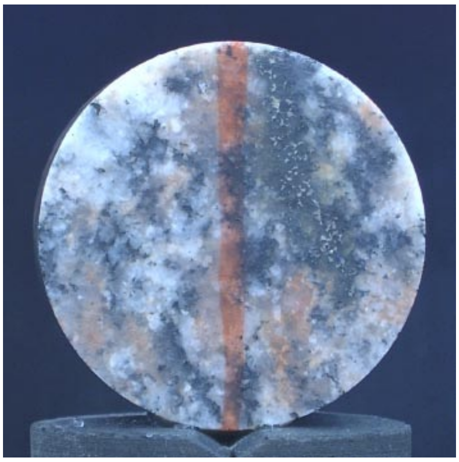
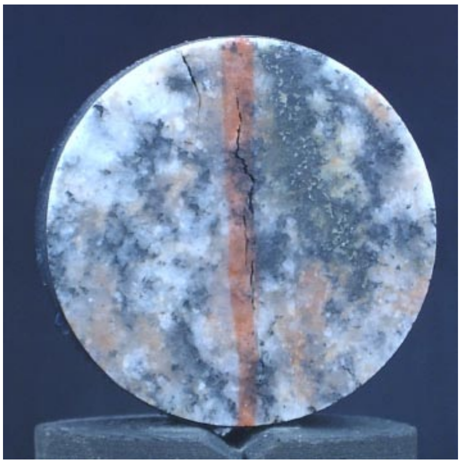
**Specimen ID:** KFM02A-110-19

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 51.0 | 26.3 | 2650 | 11.1 |

**Comments:** None

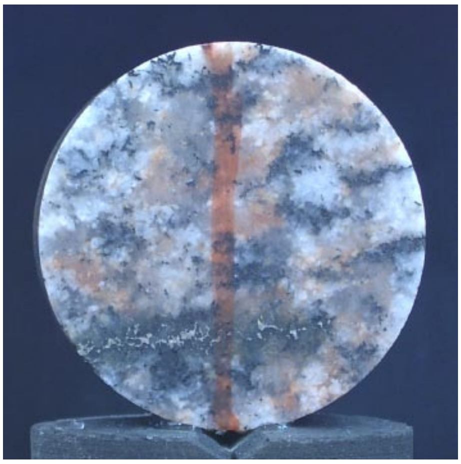
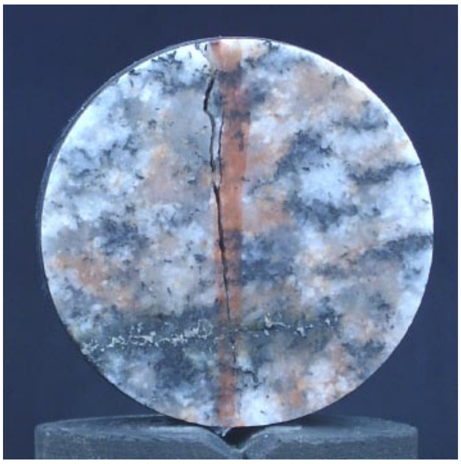
**Specimen ID:** KFM02A-110-20

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 51.0 | 26.1 | 2660 | 14.2 |

**Comments:** None

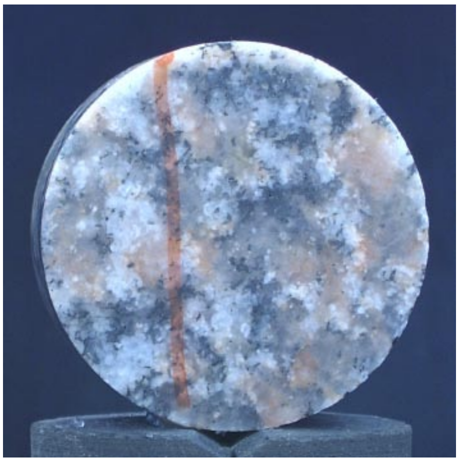
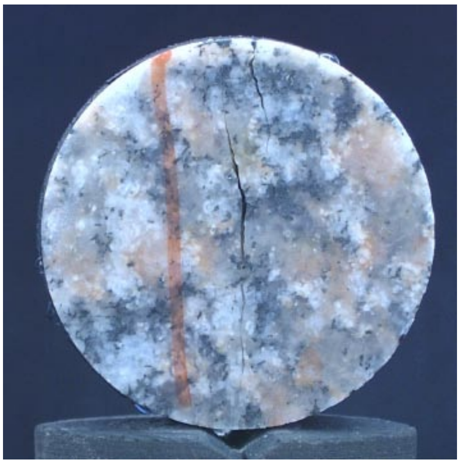
**Specimen ID:** KFM02A-110-21

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 51.0 | 26.3 | 2650 | 11.6 |

**Comments:** None

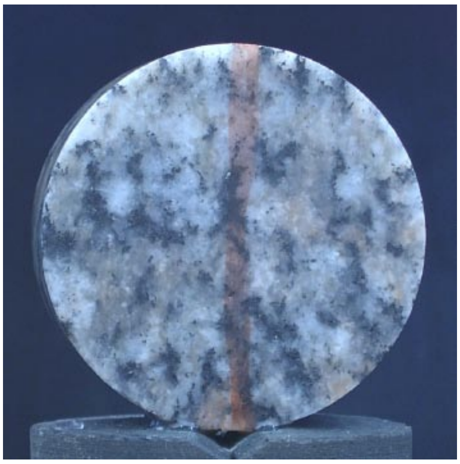
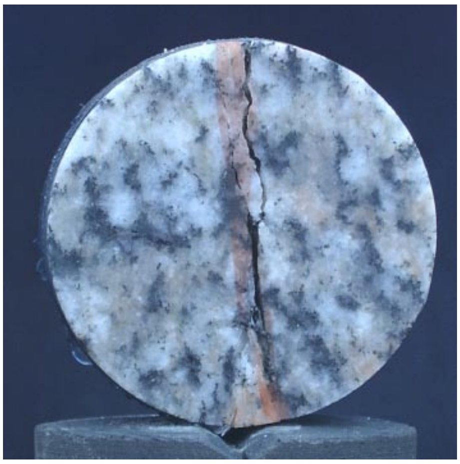
**Specimen ID:** KFM02A-110-22

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 51.0 | 26.3 | 2650 | 12.3 |

**Comments:** None

**Specimen ID:** KFM02A-110-25

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

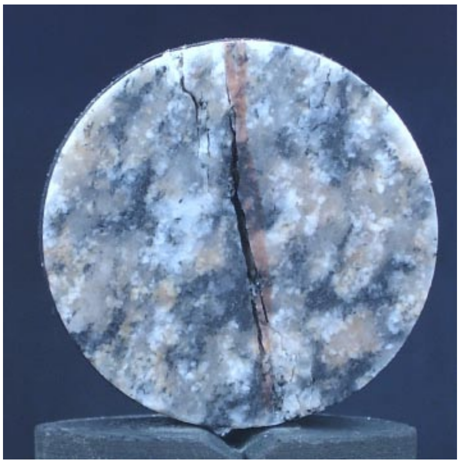
| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 25.8 | 2660 | 12.3 |

**Comments:** None

**Specimen ID:** KFM02A-110-26

Before mechanical test

After mechanical test

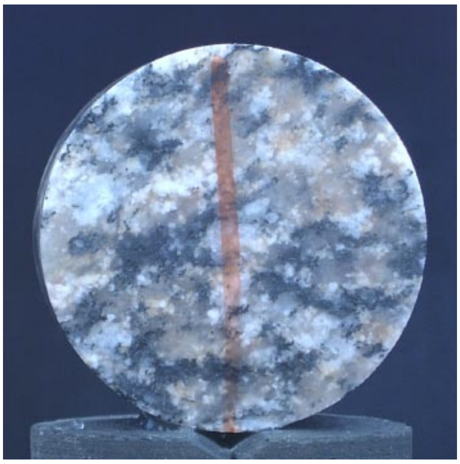


| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 25.8 | 2650 | 13.7 |

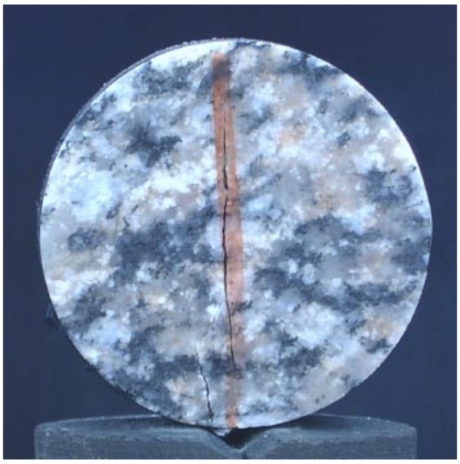
**Comments:** None

**Specimen ID:** KFM02A-110-27

Before mechanical test



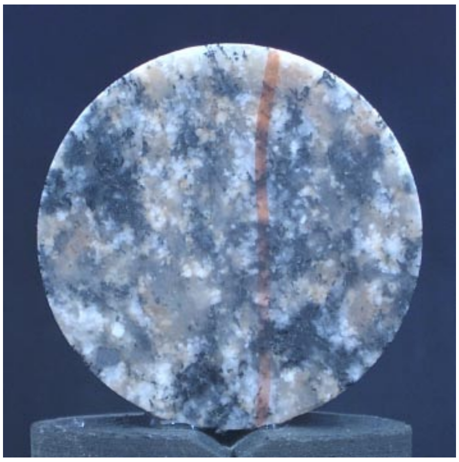
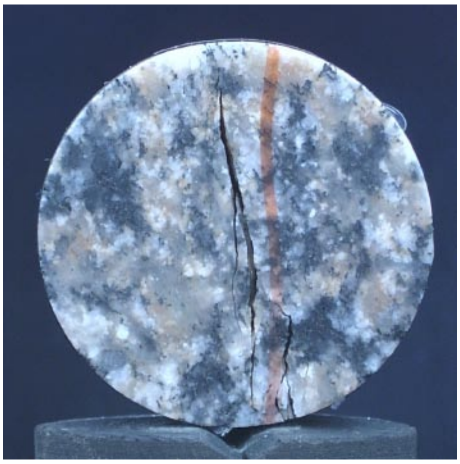
After mechanical test



| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 25.6 | 2650 | 14.5 |

**Comments:** None

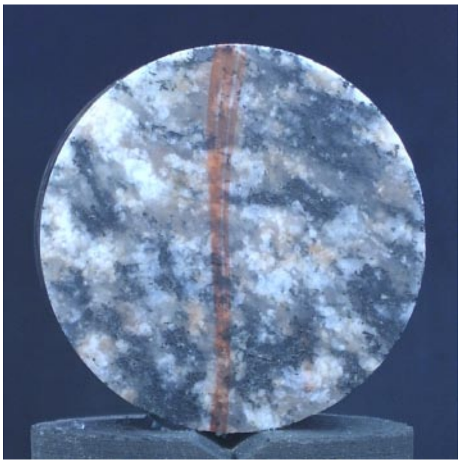
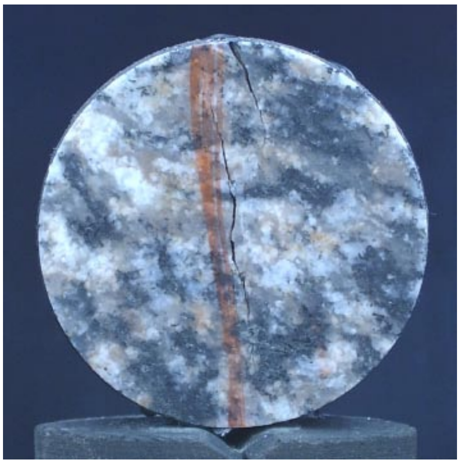
**Specimen ID:** KFM02A-110-28

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 25.6 | 2650 | 12.4 |

**Comments:** None

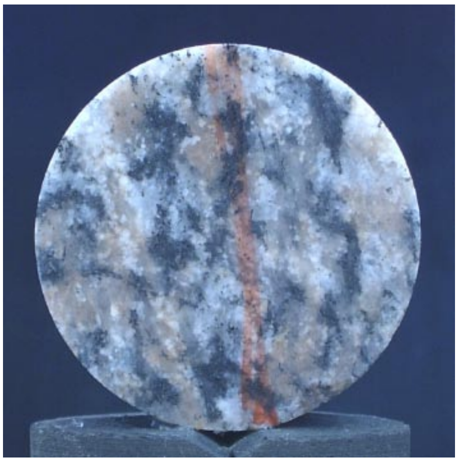
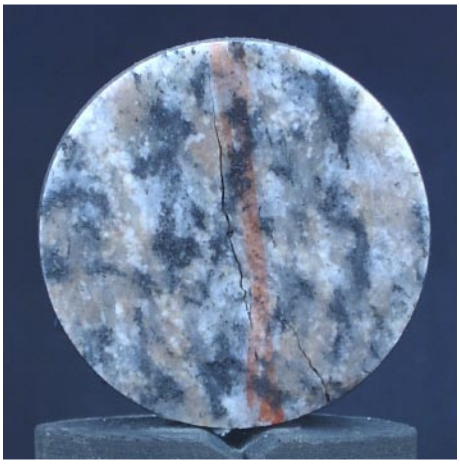
**Specimen ID:** KFM02A-110-29

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 25.7 | 2660 | 14.3 |

**Comments:** None

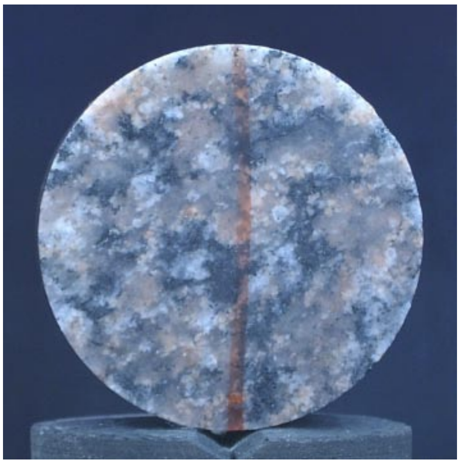
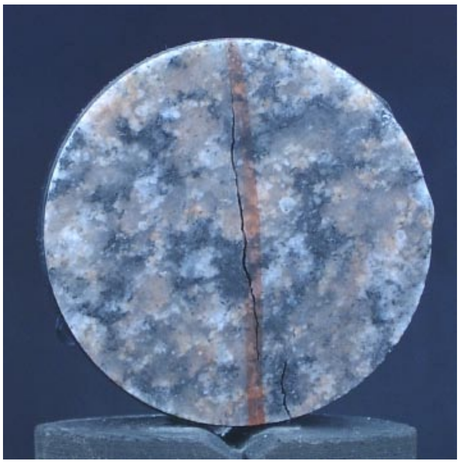
**Specimen ID:** KFM02A-110-30

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 26.1 | 2650 | 12.8 |

**Comments:** None

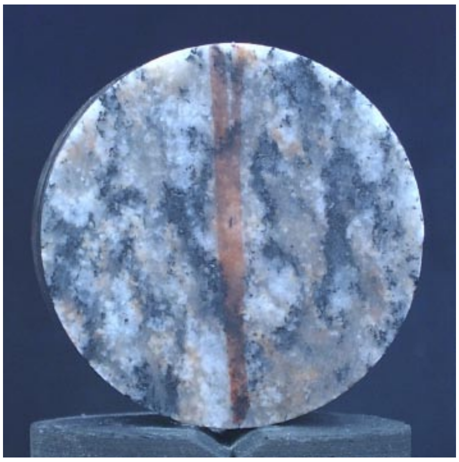
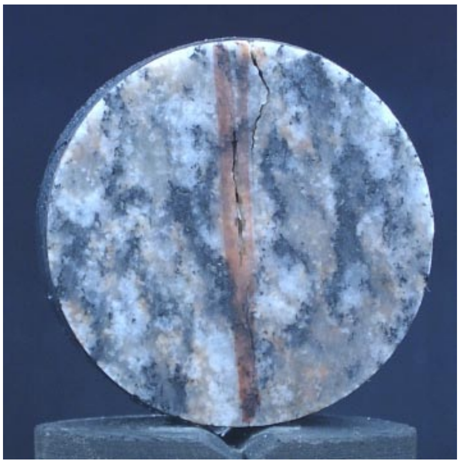
**Specimen ID:** KFM02A-110-31

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 26.2 | 2650 | 11.8 |

**Comments:** None

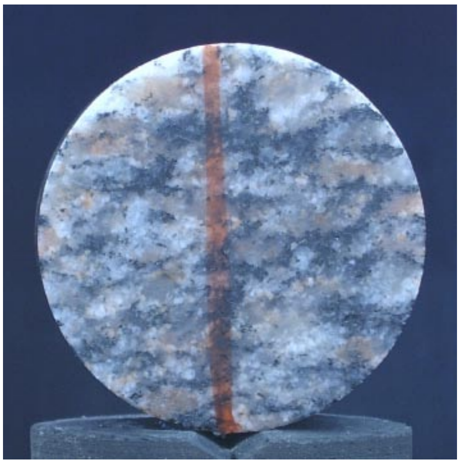
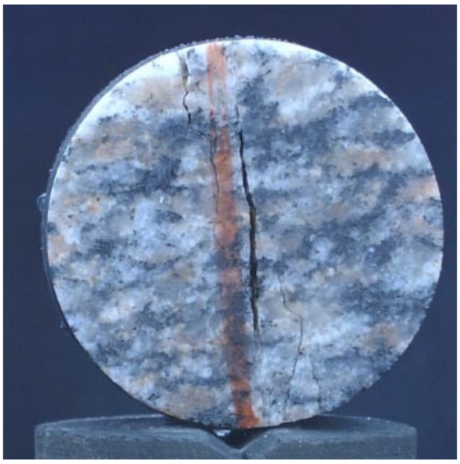
**Specimen ID:** KFM02A-110-32

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 26.2 | 2660 | 12.1 |

**Comments:** None

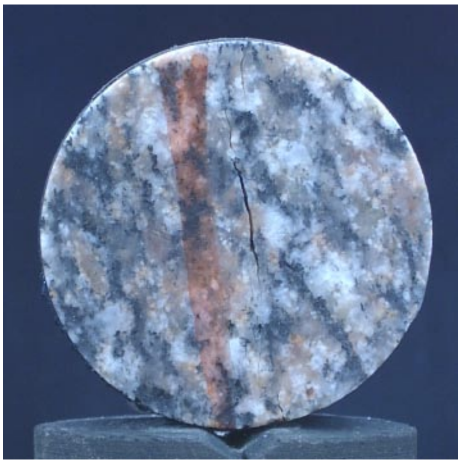
**Specimen ID:** KFM02A-110-33

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.8 | 26.2 | 2650 | 15.0 |

**Comments:** None

**Specimen ID:** KFM02A-110-34

| Before mechanical test | After mechanical test |
|---|---|
|  |  |

| Diameter [mm] | Height [mm] | Density [kg/m$^3$] | Tensile strength [MPa] |
|---|---|---|---|
| 50.7 | 26.0 | 2650 | 12.6 |

**Comments:** None

## 5.2 Results for the entire test series

A summary of the test results is shown in Tables 5-1 and 5-2. The densities and tensile strength versus sampling depth are shown in Figures 5-1 and 5-2.

**Table 5-1. Summary of results.**

| Identification | Density [kg/m³] | Tensile strength [MPa] | | Comments |
|---|---|---|---|---|
| | | Across (┴) foliaiton | Along (‖) foliation | |
| KFM02A-110-1 | 2660 | 14.4 | | |
| KFM02A-110-2 | 2660 | | 13.8 | |
| KFM02A-110-3 | 2670 | 14.3 | | |
| KFM02A-110-4 | 2660 | | 14.7 | |
| KFM02A-110-5 | 2650 | 14.3 | | |
| KFM02A-110-6 | 2650 | | 15.9 | |
| KFM02A-110-7 | 2650 | 13.9 | | |
| KFM02A-110-8 | 2660 | | 17.0 | |
| KFM02A-110-9 | 2660 | 14.3 | | |
| KFM02A-110-10 | 2660 | | 15.4 | |
| KFM02A-110-13 | 2640 | 16.6 | | |
| KFM02A-110-14 | 2650 | | 12.3 | |
| KFM02A-110-15 | 2650 | 12.6 | | |
| KFM02A-110-16 | 2650 | | 16.5 | |
| KFM02A-110-17 | 2650 | 12.9 | | |
| KFM02A-110-18 | 2650 | | 12.5 | |
| KFM02A-110-19 | 2650 | 11.1 | | |
| KFM02A-110-20 | 2660 | | 14.2 | |
| KFM02A-110-21 | 2650 | 11.6 | | |
| KFM02A-110-22 | 2650 | | 12.3 | |
| KFM02A-110-25 | 2660 | 12.3 | | |
| KFM02A-110-26 | 2650 | | 13.7 | |
| KFM02A-110-27 | 2650 | 14.5 | | |
| KFM02A-110-28 | 2650 | | 12.4 | |
| KFM02A-110-29 | 2660 | 14.3 | | |
| KFM02A-110-30 | 2650 | | 12.8 | |
| KFM02A-110-31 | 2650 | 11.8 | | |
| KFM02A-110-32 | 2660 | | 12.1 | |
| KFM02A-110-33 | 2650 | 15.0 | | |
| KFM02A-110-34 | 2650 | | 12.6 | |

**Table 5-2. Calculated mean values (Mean val) and standard deviation (Std dev) of wet density and tensile strength at the different sampling levels and for all specimens.**

| | Density [kg/m³] | Tensile strength [MPa] | |
|---|---|---|---|
| | | Across (┴) foliation | Along (‖) foliation |
| Mean val (331-336 m) | 2660 | 14.2 | 15.4 |
| Mean val (528-537 m) | 2650 | 13.0 | 13.6 |
| Mean val (704-718 m) | 2650 | 13.6 | 12.7 |
| Mean val (All specimens) | 2650 | 13.6 | 13.9 |
| Std dev (331-336 m) | 6.3 | 0.2 | 1.2 |
| Std dev (528-537 m) | 4.7 | 2.2 | 1.8 |
| Std dev (704-718 m) | 4.8 | 1.4 | 0.6 |
| Std dev (All specimens) | 6.1 | 1.5 | 1.7 |

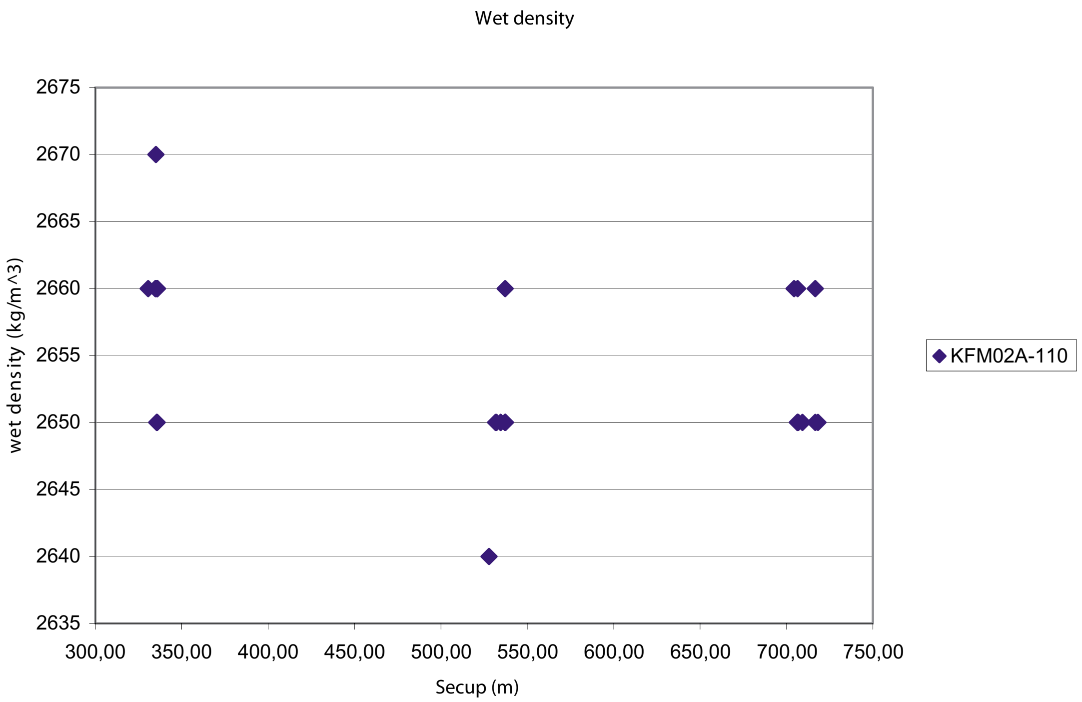



*Figure 5-1. Density versus sampling depth in the borehole.*

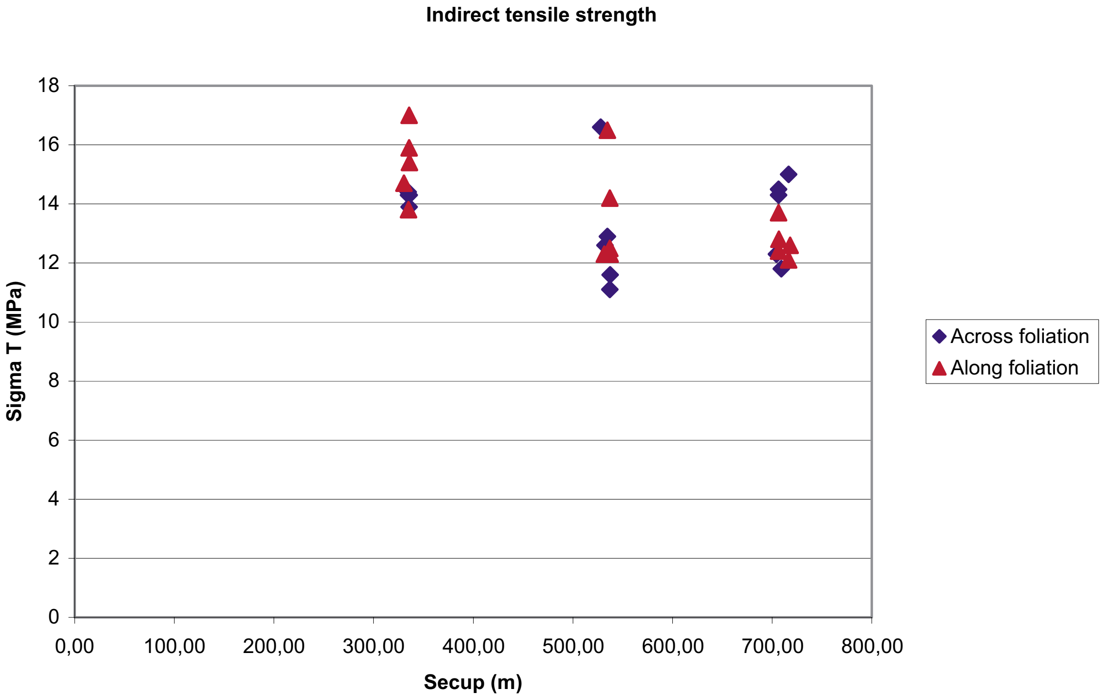



***Figure 5-2.*** *Tensile strength versus sampling depth in the borehole.*

## 5.3 Nonconformities

The testing was conducted according to the method description and the activity plan with no departures.

# References


[1] **ISRM, 1979.** Suggested Method for Determining Water Content, Porosity, Density, Absorption and Related Properties and Swelling and Slake-durability Index Properties. Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr. 16(2), pp. 141-156.

[2] **SS-EN 13755.** Natural stone test methods – Determination of water absorption at atmospheric pressure.

[3] **ASTM 4543-01, 2001.** Standard practice for preparing rock core specimens and determining dimensional and shape tolerance.

[4] **Stråhle A, 2001.** Definition och beskrivning av parametrar för geologisk, geofysisk och bergmekanisk kartering av berg, SKB-01-19. Svensk Kärnbränslehantering AB. In Swedish.