P-05-212

Forsmark site investigation

Drill hole KFM07A

Indirect tensile strength test including strain measurement

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September 2006

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ISSN 1651-4416
SKB P-05-212

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Keywords: Rock mechanics, Indirect tensile strength, Tension test, Strain measurement, Strain gauge, AP PF 400-05-024.

Abstract

The density and the indirect tensile strength of 7 water saturated specimens of intact rock have been determined. The strain along and across the direction of loading was measured using strain gauges. In total were six of the specimens sampled from borehole KFM07A and one specimen from borehole KFM08A at Forsmark. The specimens were collected at one depth level ranging between 678–681 m (borehole length) in borehole KFM07A and at 668 m (borehole length) in borehole KFM08A. The rock type in all specimens was pegmatite. The specimens were photographed before and after the mechanical test.

The measured densities for the water saturated specimens sampled in borehole KFM07A were in the range 2,610–2,640 kg/m^3, which yield a mean value of 2,621 kg/m^3. The adherent values for indirect tensile strength were in the range 8.4–11.5 MPa with a mean value of 9.9 MPa.

Sammanfattning

Densiteten och den indirekta draghållfastheten hos sju vattenmättade prover av intakt homogent berg har bestämts. Töjningen längs med och tvärs belastningsriktningen mättes med trådtöjningsgivare. Totalt var sex av proven från borrhål KFM07A och ett från borrhål KFM08A i Forsmark. Proven har tagits från en nivå som ligger mellan 678–681 m (borrhålslängd) i borrhål KFM07A och vid 668 m (borrhålslängd) i borrhål KFM08A. Bergarten hos alla prov var pegmatit. Provobjekten fotograferades före och efter de mekaniska proven.

Densiteten hos de vattenmättade proven var mellan 2 610–2 640 kg/m^3 vilket gav ett medelvärde på 2 621 kg/m^3. Värdena på den indirekta draghållfastheten var 8,4–11,5 MPa med ett medelvärde på 9,9 MPa.

Contents

1 Introduction

This document reports performance and results of indirect tensile strength tests on water-saturated specimens mainly sampled from borehole KFM07A at Forsmark. The exception is for one specimen that is sampled from KFM08A, which is a neighbouring borehole, see map in Figure 1-1. 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). The activity is part of the site investigation programme at Forsmark managed by SKB (The Swedish Nuclear Fuel and Waste Management Co).

The controlling documents for the activity are listed in Table 1-1. Both Activity Plan and Method Descriptions are SKB's internal controlling documents, whereas the Quality Plan referred to in the table is an SP internal controlling document.

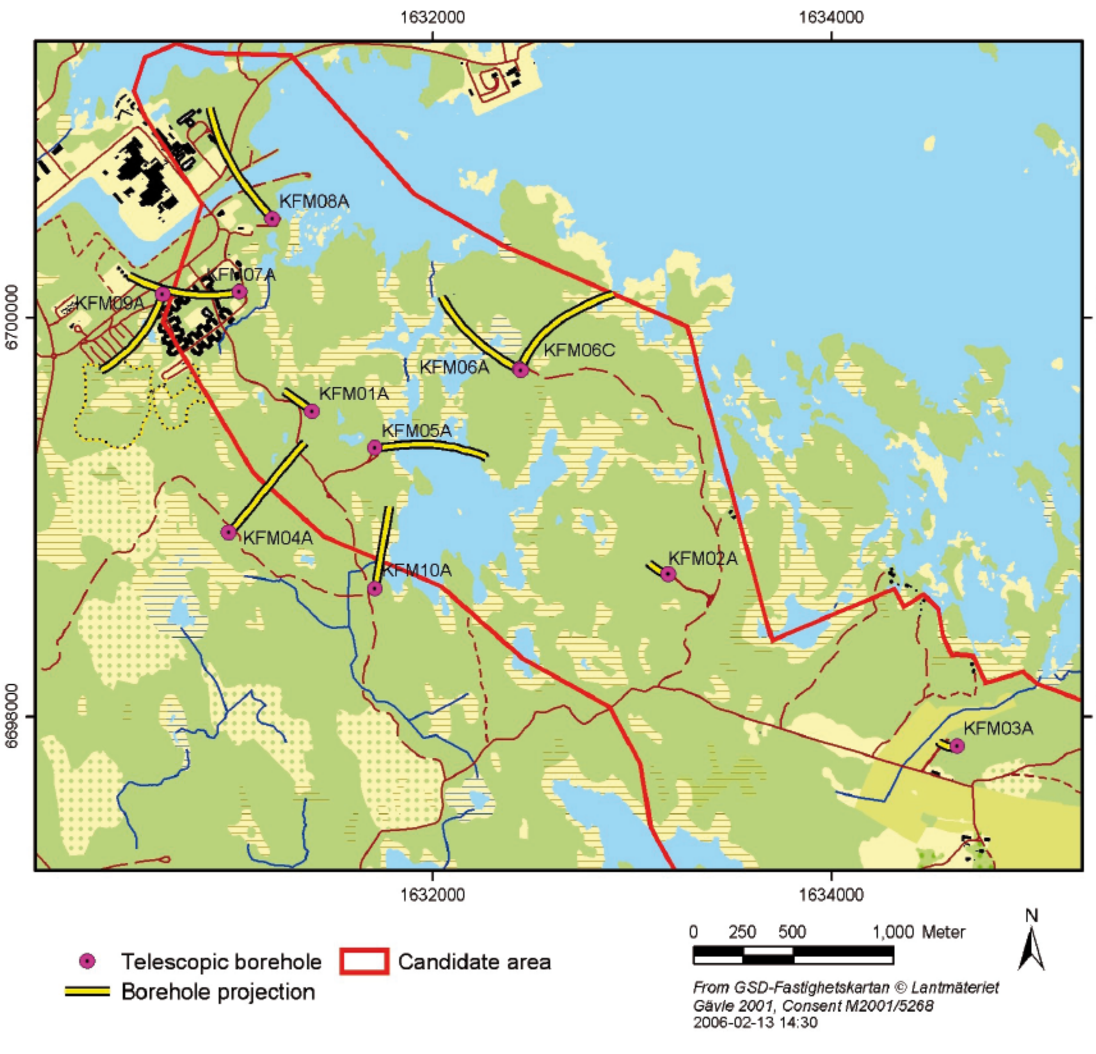


Figure 1-1. *Location of all telescopic boreholes drilled within or close to the Forsmark candidate area, up to April 2005. The projection of each borehole on the horizontal plane at top of casing is also shown in the figure.*

Table 1-1. Controlling documents for performance of the activity.

Activity Plan	Number	Version
KFM07A. Bergmekaniska och termiska laboratoriebestämningar	AP PF 400-05-024	1.0
Method Description	**Number**	**Version**
Indirect test of tensile strength	SKB MD 190.004	2.0
Determining density and porosity of intact rock	SKB MD 160.002	2.0
Quality Plan		
SP-QD 13.1		

Borehole KFM07A, see Figure 1-1, is a telescopic drilled borehole inclined c. 60° from the horizontal plane and with a total length of 1,001.55 m, which corresponds to a vertical depth of c. 820 m. The borehole section 0–100.40 m is percussion drilled, whereas section 100.40–1,001.55 m is core drilled. The borehole KFM08A is drilled very similar to borehole KFM07A.

SKB supplied SP with rock cores which arrived at SP in April 2005 (KFM07A) and August 2005 (KFM08A) and were tested during February and March 2006. 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 rock type pegmatite. The method description SKB MD 190.004 was followed for the sampling and for the indirect tensile strength tests, whereas the method description SKB MD 160.002, was followed when the density was determined.

The specimens were put into water and stored in water with a minimum of 7 days, up to testing. 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 had a homogenous structure, which implies that the mechanical response is expected to be approximately isotropic. The strain, along with and perpendicular to the loading direction at the center position of the circular surface on both sides of the specimens, were measured by means of bi-axial strain gauges.

Preliminary tests were carried out prior to the main tests in order to check the attachment of the strain gauges.

Diagrams showing the stress versus strains in the two directions and the strain versus each other in the two directions are reported. 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.

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. Moreover, strain measurements were carried out with the aim to provide results that may be used to detect the crack initiation stress. All except one specimen are collected from the borehole KFM07A, which has a drilling length depth of c. 1,000 m, corresponding to a vertical depth of c. 820 m. The remaining specimen is sampled from KFM08A which is a neighbouring borehole.

The results from the tests are going to be used in the site descriptive rock mechanics model, 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. Specimens 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 made 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 ± 4 kg/m^3.

The mechanical testing was carried out in a servo hydraulic testing machine which has a maximum capacity of 100 kN. 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, see Figure 3-1. The top platen includes a spherical seating in order to have a fully centred loading position.

Bi-axial strain gauges were used for the strain measurement. Strain gauges with 5 mm gauge length were used in the preliminary tests, whereas gauges with 10 mm gauge length were used in the main tests. The data from the load and strain measurements were sampled using a sampling frequency of 100 Hz and 40 Hz low-pass-filtering frequency.

The specimens were photographed with a 4.0 Mega pixel digital camera at highest resolution and the photographs were stored in a jpeg-format.

Figure 3-1. *Setup for the indirect tensile test. One specimen is inserted between the curved bearing blocks, which are mounted in the testing equipment.*

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 (SKB internal controlling document). This includes determination of density in accordance to 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 190.004 (SKB internal controlling document). The test method follows ASTM D3967-95a /3/.

4.1 Description of the specimens

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.

4.2 Preliminary tests

Indirect tensile strength tests on two specimens with mounted strain gauges were conducted. The tests were carried out in order to check the attachment of strain gauges that were glued onto the cutting surfaces. The specimens were of the same rock type as for the ones that were going to be tested after the preliminary tests belonging to the main activity. One specimen (KFM07A-110-6) was already water saturated when the strain gauges were attached and the other specimen (KFM07A-110-7) was dry when the strain gauges were attached, and was water saturated afterwards. A coating was applied right after gluing the strain gauges in order to protect the gauges. The results of the tests revealed that there was no problem with the attachment of the strain gauges, independently whether the strain gauges are mounted on a dry or on a water saturated specimen.

Table 4-1. Specimen identification, sampling level and rock type for all specimens (based on the overview mapping). Sampling level refers to borehole length.

Identification	Adj Secup (m)	Adj Seclow (m)	Rock type	Comment
KFM07A-110-6	678.49	678.52	Pegmatite	Preliminary test
KFM07A-110-7	678.52	678.55	Pegmatite	Preliminary test
KFM07A-110-8	678.55	678.58	Pegmatite	Replaces KFM07A-110-1
KFM07A-110-9	678.58	678.61	Pegmatite	Replaces KFM07A-110-2
KFM07A-110-4	681.39	681.42	Pegmatite	
KFM07A-110-5	681.42	681.45	Pegmatite	
KFM08A-110-10	668.54	668.60	Pegmatite	Replaces KFM07A-110-3

However, it was judged that the gauge length (5 mm) was too small compared to the relatively large grain size in the Pegmatite. The position of the tensile fracture is largely controlled by the grain structure, which may cause the fracture to pass beside the strain gauge. This makes the results hard to use to detect the crack initiation, which was the main aim with the strain measurements. It was therefore decided that strain gauges with a 10 mm gauge length were more suitable to use for this material, as the gauge can cover some grains, thereby yielding results corresponding to a more homogenized strain. The results from the preliminary tests are shown in Section 5.1.

The number of days the specimen had been in water when the mechanical tests were carried out is listed in Table 4-2. An overview of the activities during the mechanical testing is shown in the step-by-step description in Table 4-3.

4.3 Main tests

The water temperature and the number of days the specimen had been in water when the density was determined and the mechanical tests were carried out, are listed in Table 4-2.

An individual check-list was filled in and checked for every specimen 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.

An overview of the activities during the testing is shown in the step-by-step description in Table 4-3.

4.4 Data handling

The test results were exported as binary files from the sampling device and stored in a file server on the SP computer network. The main data processing, in which the indirect tensile stress was computed, has been carried out using the program MATLAB /7/. Moreover, MATLAB was also used to produce the diagrams shown in Sections 5.1 and 5.2. The summary of results presented in Section 5.3 containing mean values and standard deviations and diagrams were produced with help of the program MS Excel. MS Excel was also used for reporting data to the SICADA database.

Table 4-2. Days in water for the various specimens for respective activity.

Specimen	Density determination	Mechanical tests	Water data during the density determination
KFM07A-110-6	min 7 (*)	46	
KFM07A-110-7	min 7 (*)	29	
KFM07A-110-8	min 7 (*)	7	
KFM07A-110-9	min 7 (*)	7	
KFM07A-110-4	14	258	temperature 20.9°C, water density 998.0 kg/m^3
KFM07A-110-5	14	258	temperature 20.9°C, water density 998.0 kg/m^3
KFM08A-90V-12A	min 7 (**)	7	

(*) The density determination is described in /5/. (**) The density determination is described in /6/.

Table 4-3. Activities during the mechanical testing.

Step	Activity
1	The geometrical tolerances were checked: parallel and perpendicular surfaces, smooth and straight circumferential surface.
2	The diameter and thickness were measured three times each. The respective mean value determines the dimensions that are reported.
3	The direction of compressive loading was marked as a line on one of the plane surfaces with a marker pen.
4	The specimens 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 removed from the water and the weight of the water and rock specimen were determined separately, and by using the known density of the water, the wet density could be computed. This procedure was repeated for each specimen.
5	Digital photos were taken on each specimen.
6	Strain gauges were attached on the specimens.
7	The wet specimens were inserted into the loading device one by one, with the correct orientation given by the marked line. The strain gauges were connected to the sampling device and the signals were checked. The specimens were loaded up to failure during deformation control. The displacement rate was set to 0.3 mm/min during loading. The compressive force together with the strains were registered up to failure of the specimens.
8	Digital photos were taken on each specimen after the mechanical testing.

4.5 Nonconformities

The indirect tensile strength tests were conducted according to the method description. The strain measurement using strain gauges is additional compared to the method description. Two specimens, KFM07A-110-6 and KFM07A-110-7, were used in the preliminary tests which were not specified in the activity plan.

The specimens KFM07A-110-1 to KFM07A-110-3 were tested according to the specification. Unfortunately, the sampled data from these tests were accidentally not complete. The specimens KFM07A-110-1 to KFM07A-110-3 were therefore replaced by the specimens KFM07A-110-8, KFM07A-110-9 and KFM08A-110-10 in this investigation. This is a deviation from the activity plan.

5 Results

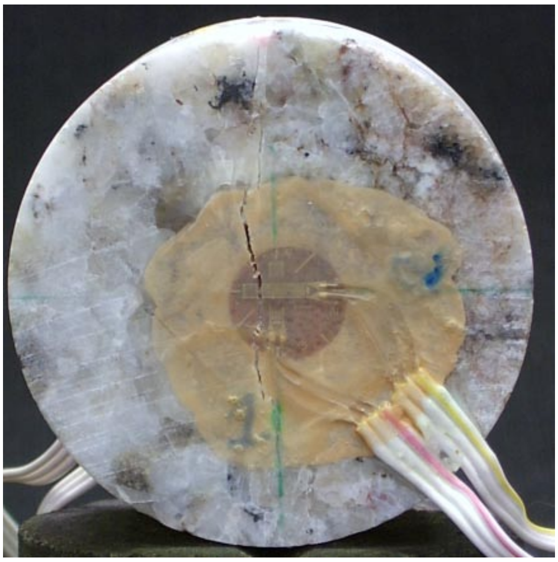
The results from the preliminary tests are shown in Section 5.1, whereas the results of the individual specimens from the main tests are presented in Section 5.2. A summary of the results is given in Section 5.3. The original results, unprocessed raw data obtained from the testing, were reported to the SICADA database, where they are traceable by the activity plan number. These data together with the digital photographs of the individual specimens were handed over to SKB. The handling of the results follows SDP-508 (SKB internal controlling document) in general.

5.1 Preliminary tests

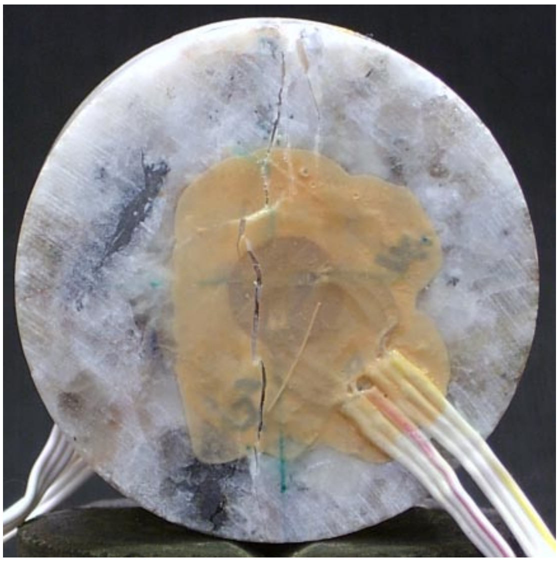
Pictures taken after the tests together with specimen data and tensile strength are presented. Moreover, stress-strain diagrams and diagrams showing vertical (in the loading direction) versus horizontal strain (perpendicular to the load) are also provided. The position at the peak load is marked with small rings in the diagrams. The strain measurements after peak are not reliable as they probably have been damaged due to the fracturing. The results for the individual specimens are as follows:

Specimen ID: KFM07A-110-6

Front side



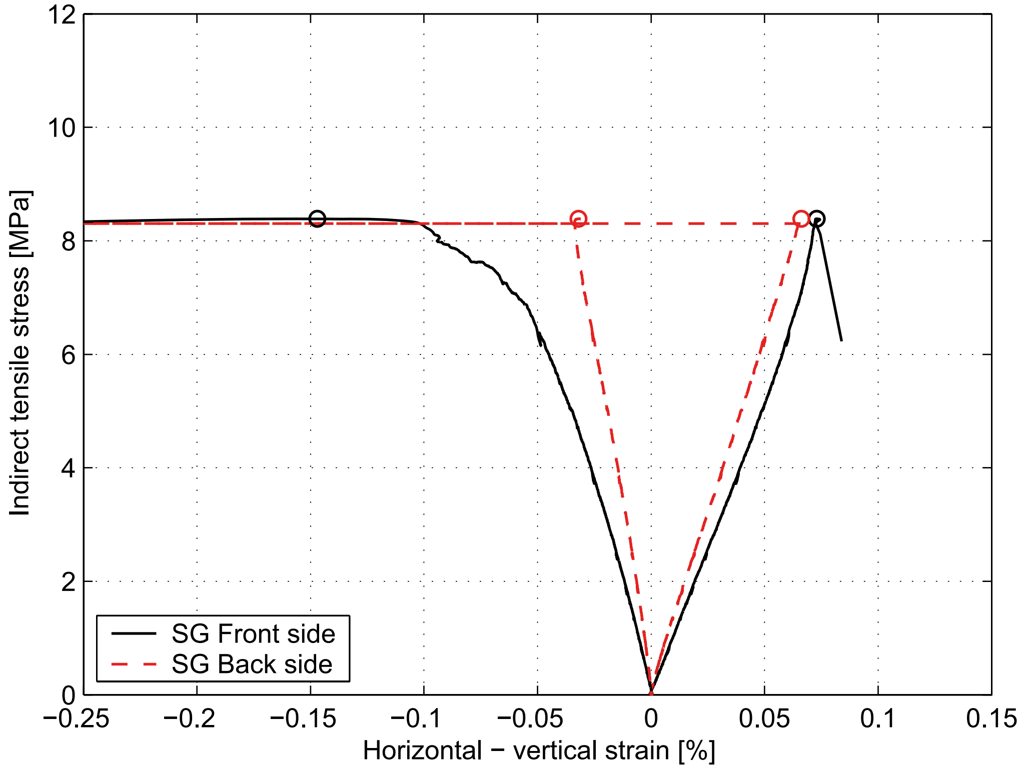
Rear side

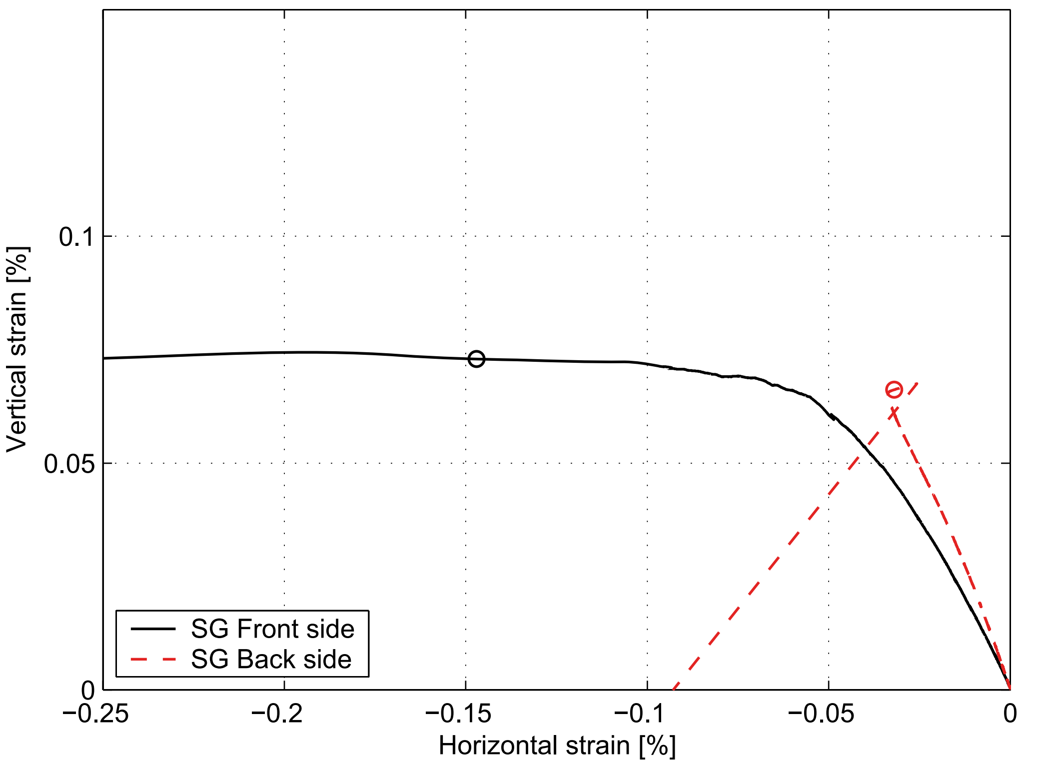


Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
51.0	28.2	2,610	8.4

Comments: The the non-linear horizontal strain on the front side indicates a crack opening starting right below 7 MPa.

Specimen ID: KFM07A−110−6





Specimen ID: KFM07A-110-7

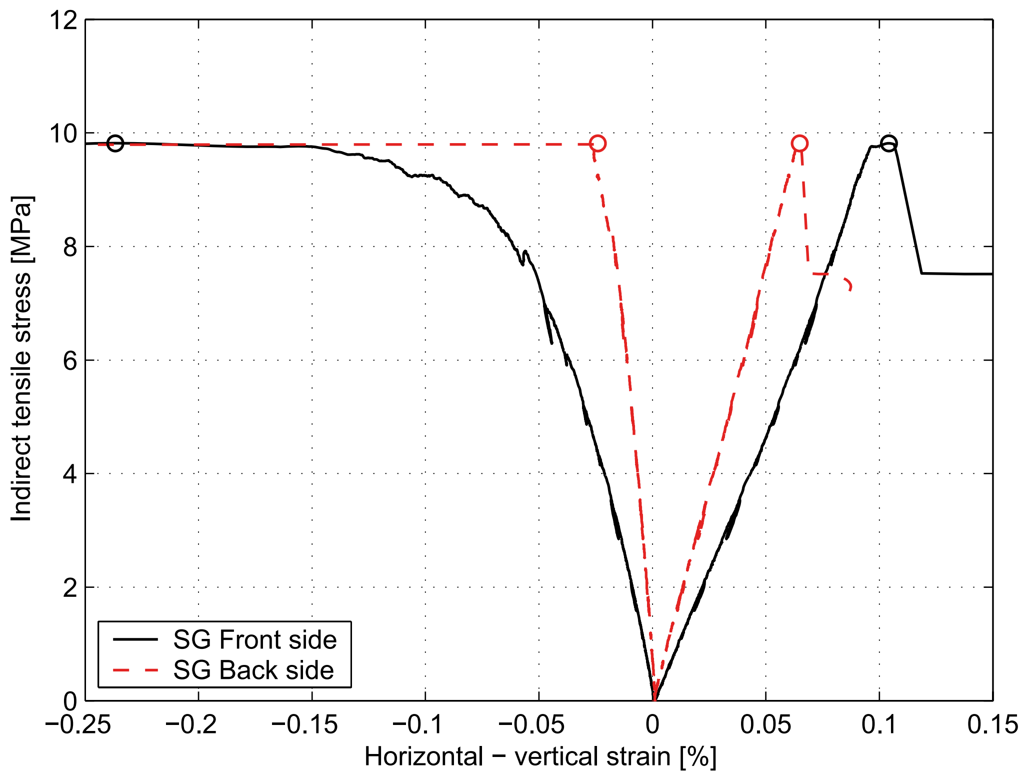
Front side

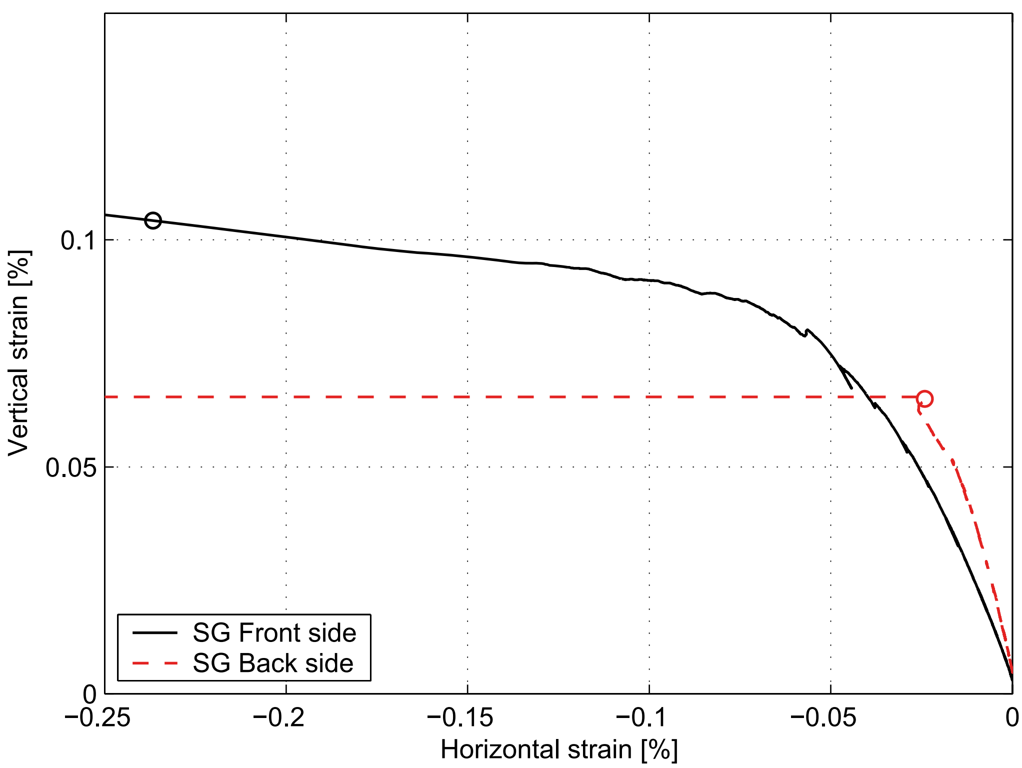
Rear side

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
51.0	28.5	2,610	9.8

Comments: The fracture on the front side is located under the strain gauge. The strain gauge has unstuck from the specimen during the fracturing. This caused the cover layer to crack beside the strain gauge. The strains on the front side are significantly larger than on the corresponding ones on the rear side. The the non-linear horizontal strain on the front side indicates a crack opening starting right below 8 MPa.

Specimen ID: KFM07A−110−7





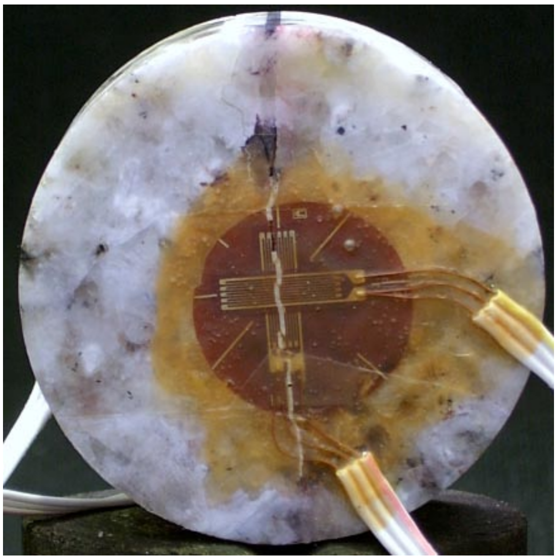
5.2 Description and presentation of the specimens for the main tests

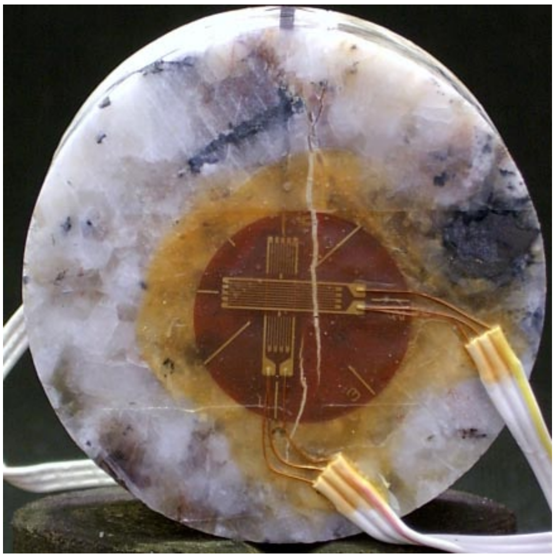
Pictures taken before and after the tests together with specimen data and tensile strength are presented. Moreover, stress-strain diagrams and diagrams showing vertical (in the loading direction) versus horizontal strain (perpendicular to the load) are also provided. The position at the peak load is marked with small rings in the diagrams. The strain measurements after peak are not reliable as they probably have been damaged due to the fracturing. The results for the individual specimens are as follows:

Specimen ID: KFM07A-110-8

Front side

Rear side

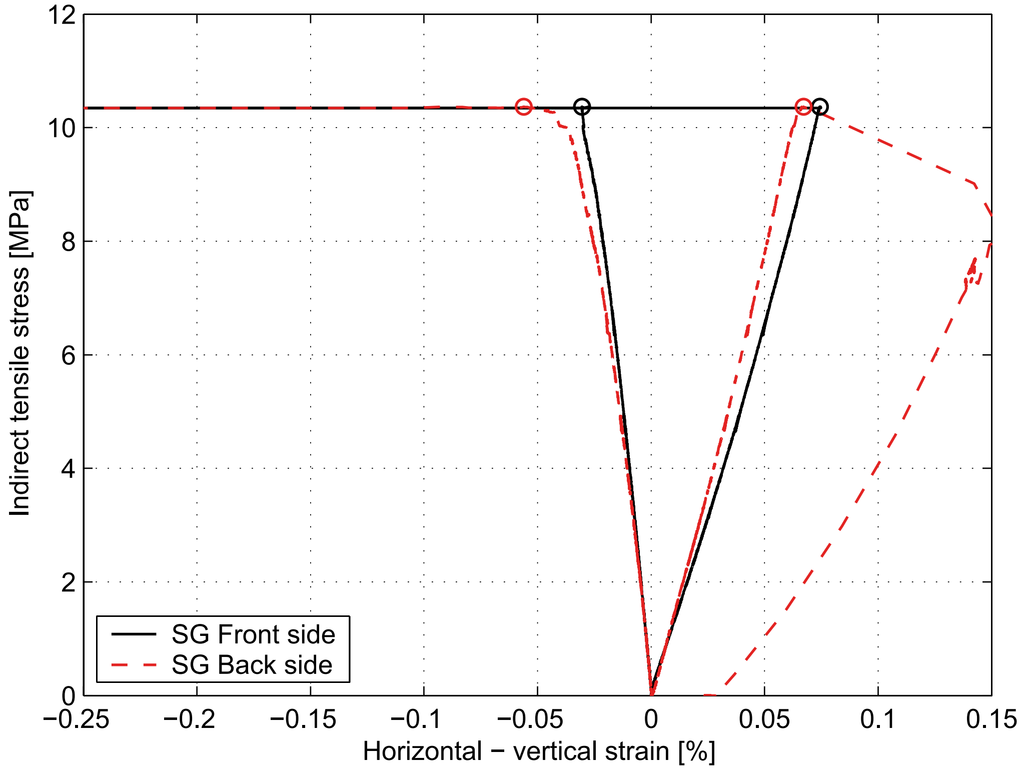


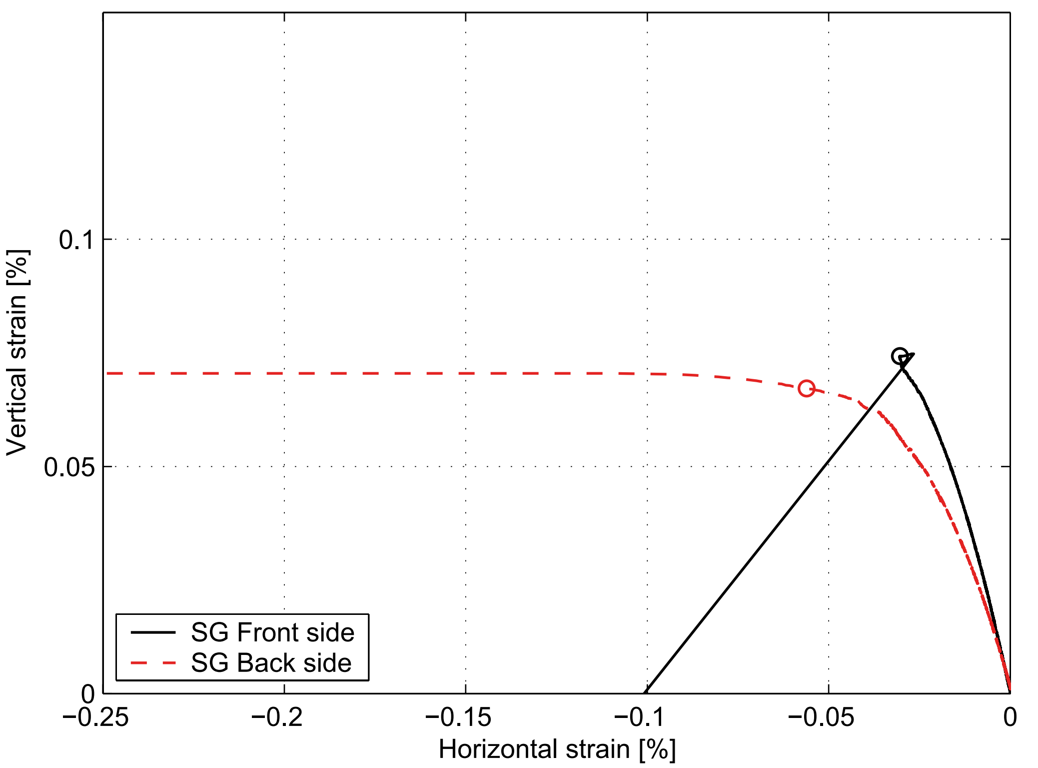


Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
50.8	28.1	2,640	10.4

Comments: The the non-linear horizontal strain on the front side indicates a crack opening starting around 10 MPa.

Specimen ID: KFM07A−110−8

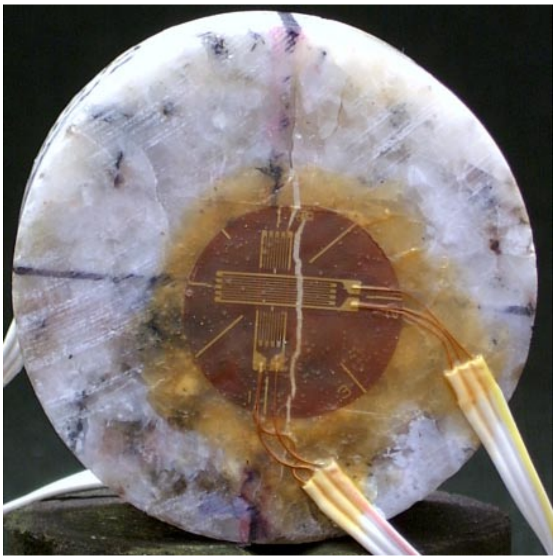


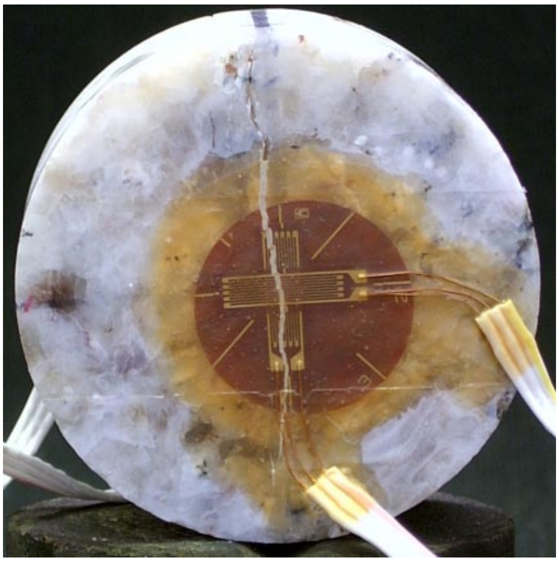


Specimen ID: KFM07A-110-9

Front side

Rear side

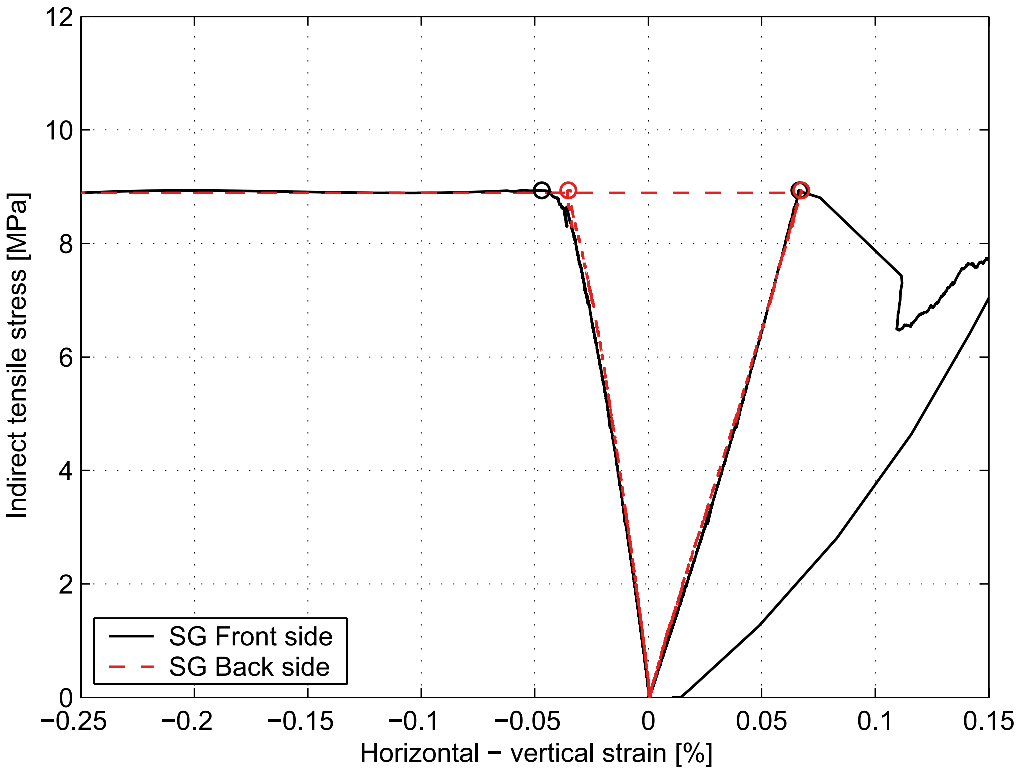


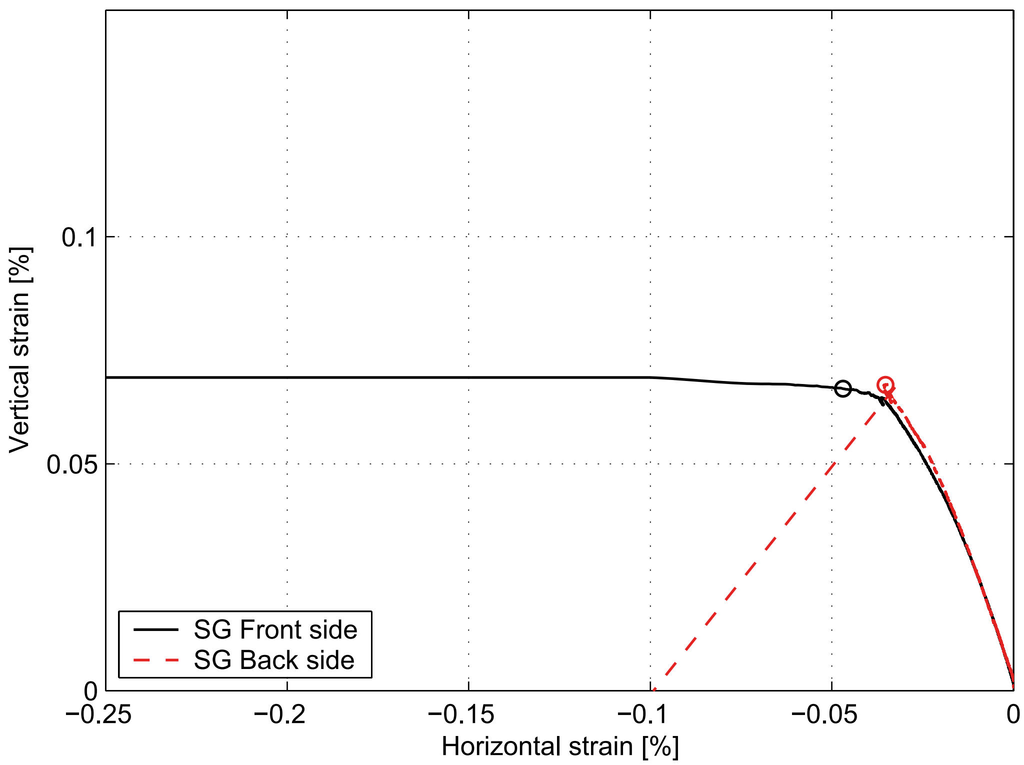


Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
50.8	28.1	2,620	8.9

Comments: The the non-linear horizontal strain on the front side indicates a crack opening starting around 8.5 MPa.

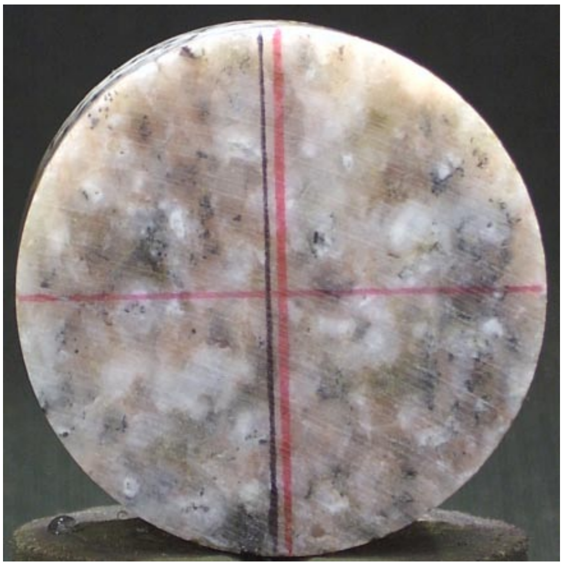
Specimen ID: KFM07A−110−9





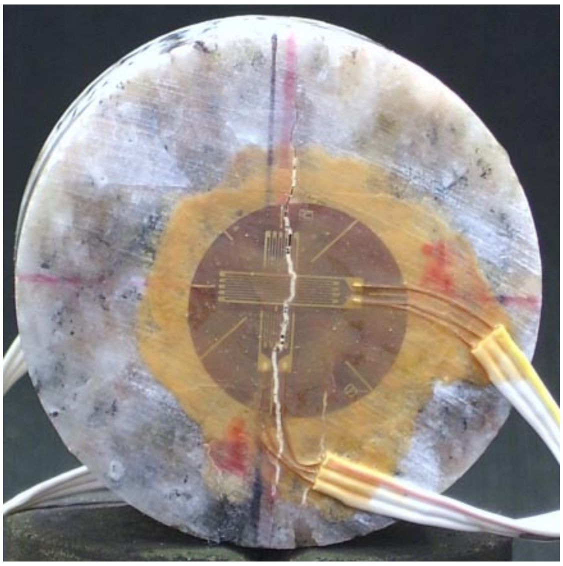
Specimen ID: KFM07A-110-4

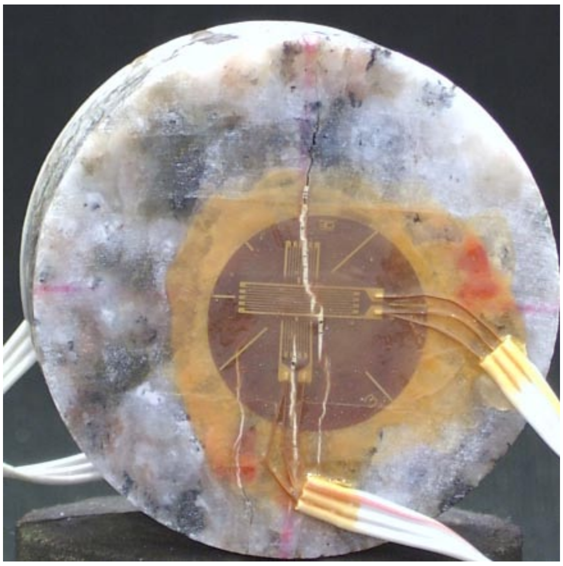
Front side



Rear side

No photo was taken

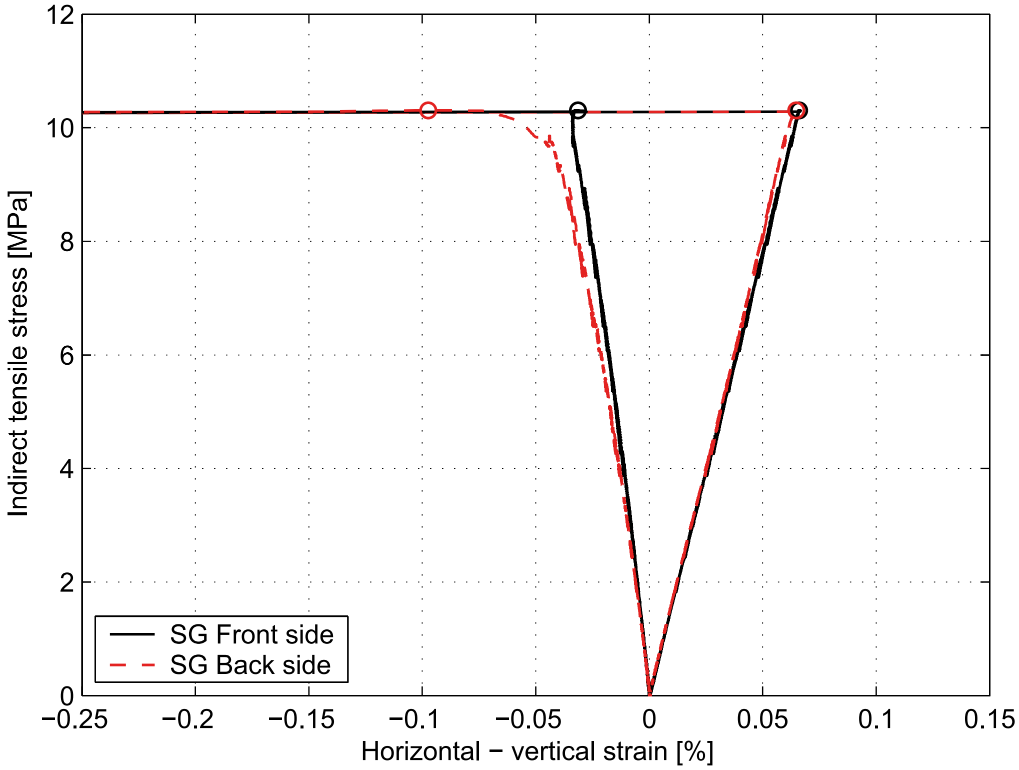


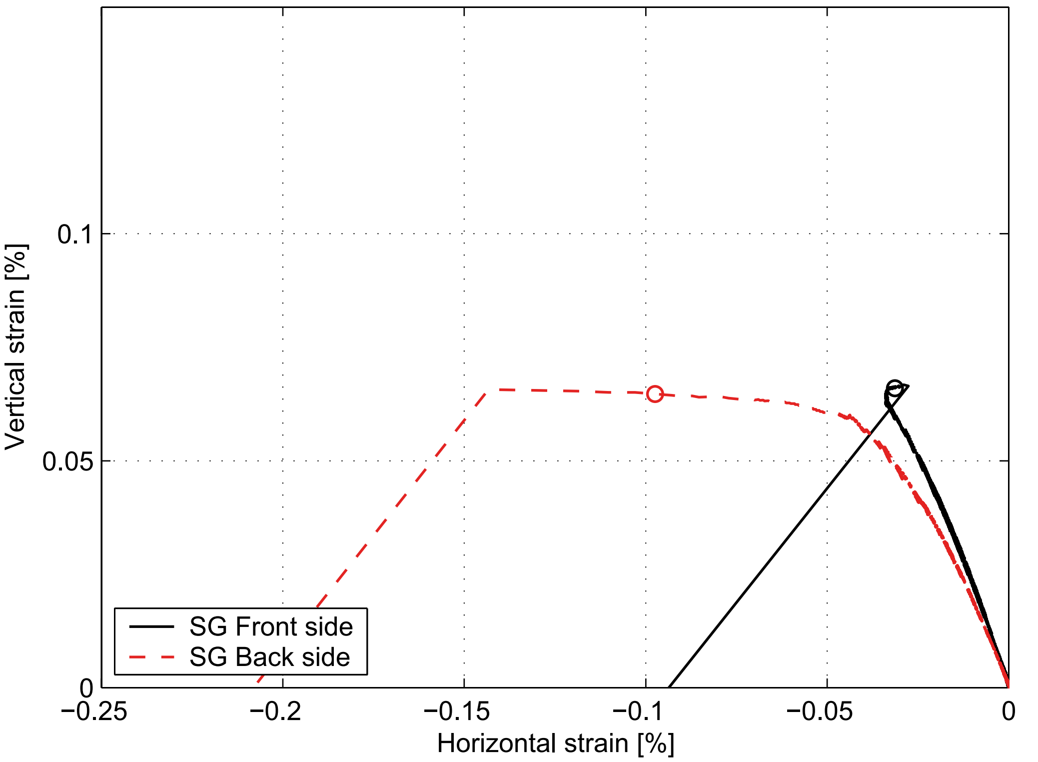


Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
50.7	28.0	2,630	10.3

Comments: The the non-linear horizontal strain on the front side indicates a crack opening starting right below 10 MPa.

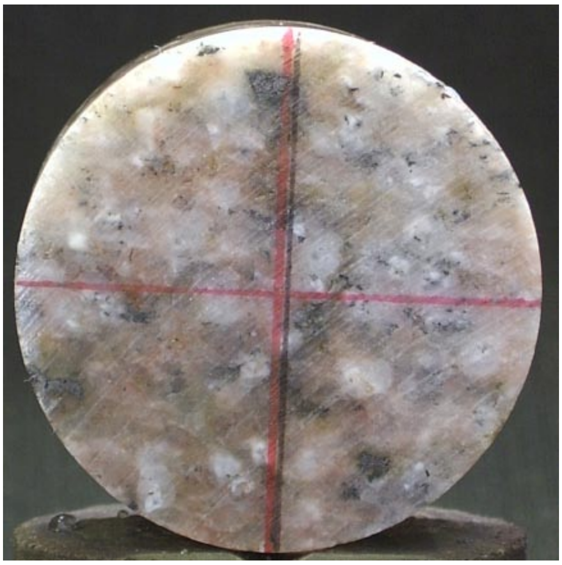
Specimen ID: KFM07A−110−4



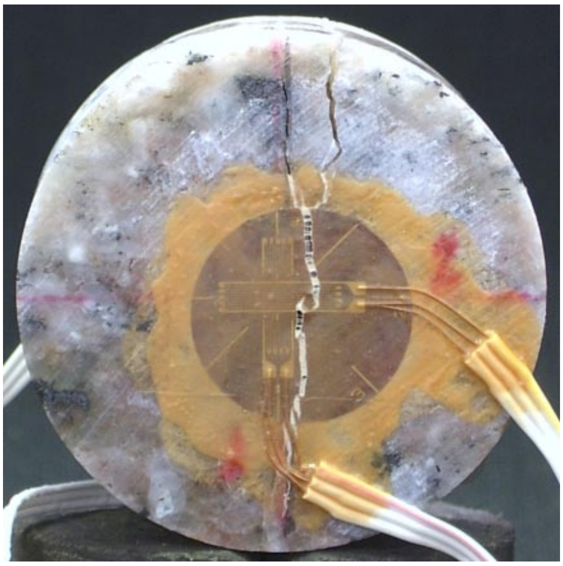


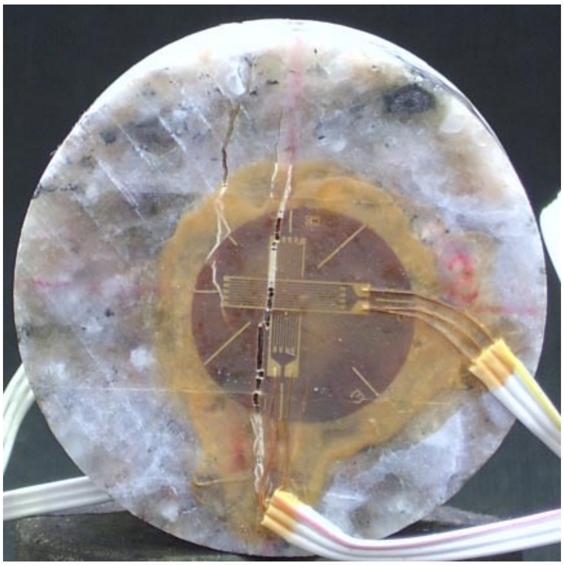
Specimen ID: KFM07A-110-5

Front side | Rear side



No photo was taken

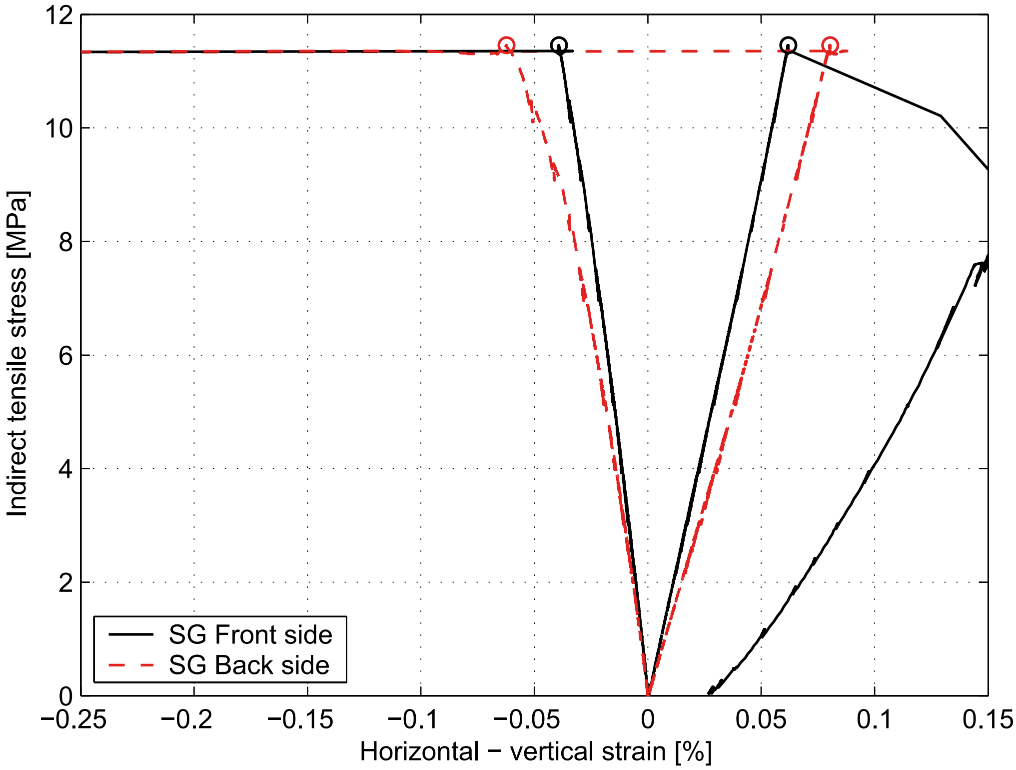


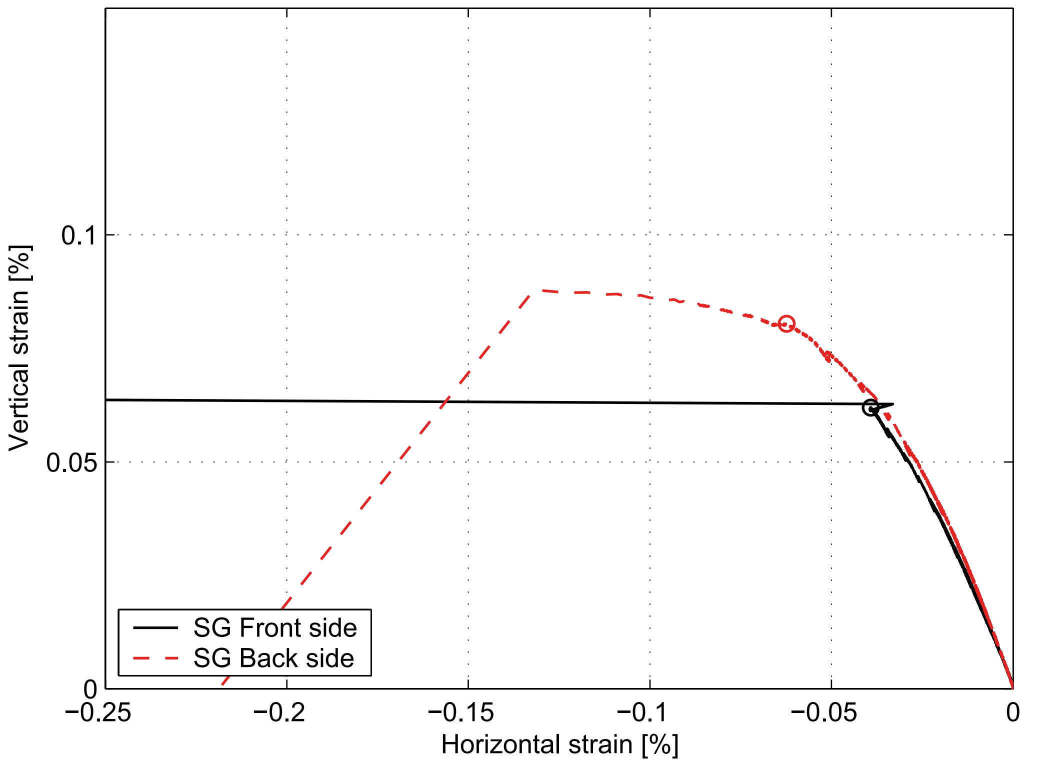


Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
50.7	27.4	2,630	11.5

Comments: No clear crack opening prior to failure can be observed.

Specimen ID: KFM07A−110−5

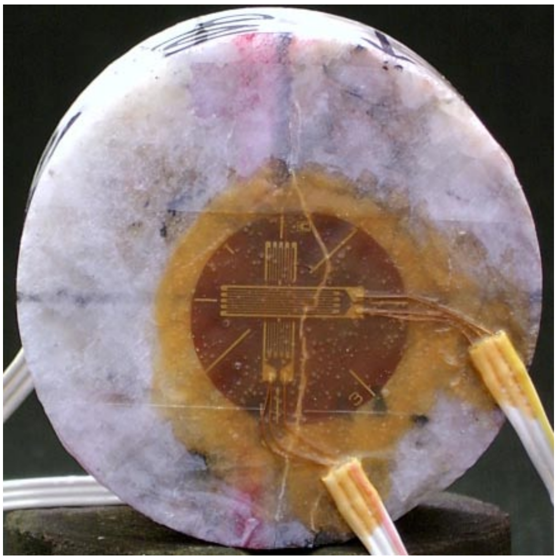


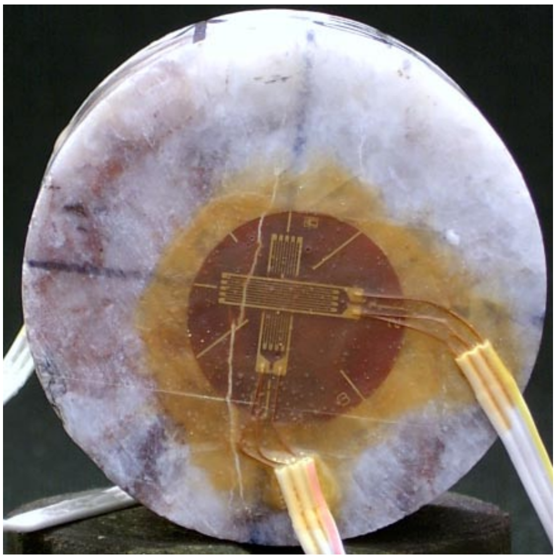


Specimen ID: KFM08A-110-10

Front side

Rear side

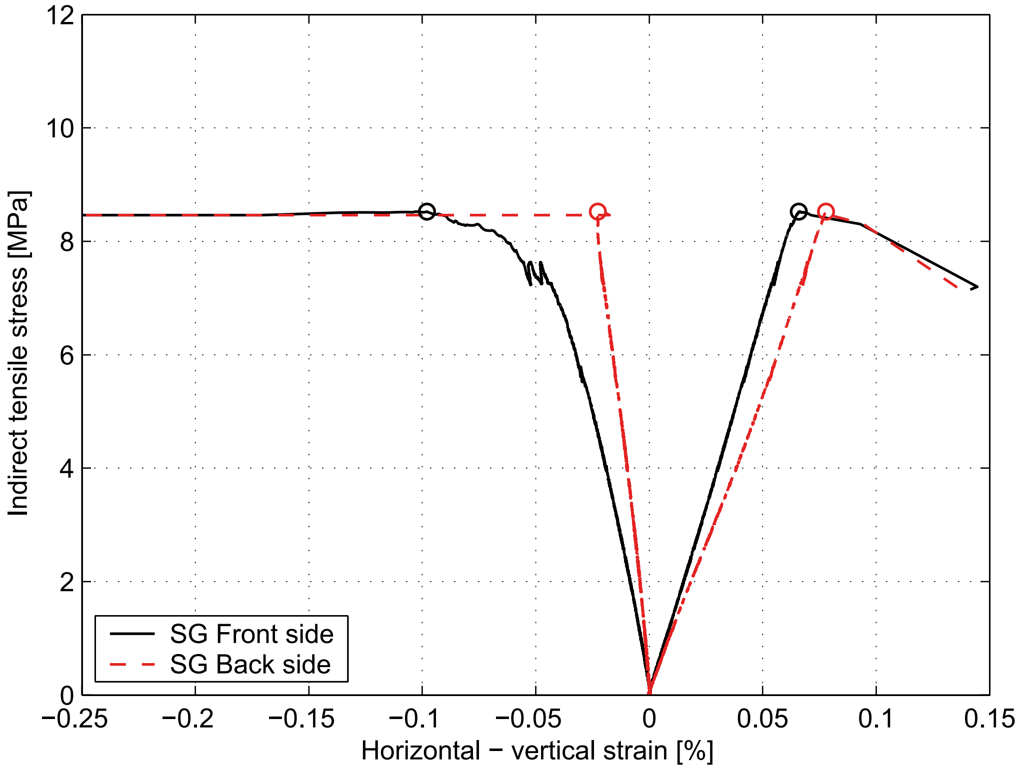


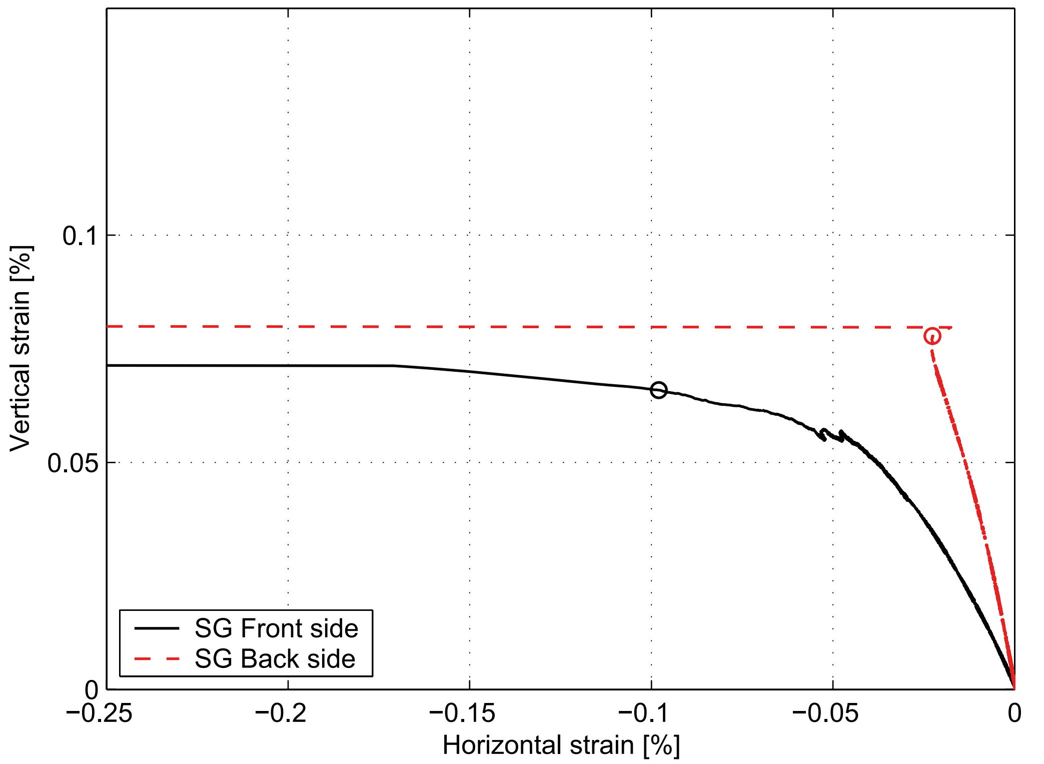


Diameter (mm)	Height (mm)	Density (kg/m³)	Tensile strength (MPa)
50.8	26.2	2,610	8.5

Comments: The the non-linear horizontal strain on the front side indicates a crack opening starting right above 7 MPa.

Specimen ID: KFM08A−110−10





5.3 General comments of the results

The strain measurements up to peak load are valid results, while the results after peak should be discarded and should not be used for result interpretations, as the strain gauges probably have been damaged due to rock fracturing. The results from the complete measurements were only included for the sake of completeness.

The rock type pegmatite is a coarse grained material. The grain sizes are in the same order or even larger than the gauge lengths of the strain gauges used for the measurements. The strain gauges record the average strain over the gauge length. Strain gauges with a gauge length of 5 mm were used in the preliminary tests, whereas 10 mm gauges were used in the main tests. The strain gauges with a larger gauge length should therefore better be able to represent the average smeared strain than strain gauges with a shorter gauge length. However, the strain gauges with longer gauge length have lower sensitivity with respect to detecting single crack openings. If the gauge length is too short, there is a chance that the opening of the main cracks takes place besides the strain gauge and consequently not detects by the strain gauges.

The main results show a quite uniform response between the front and the rear sides and between the specimens, except for the response of KFM08A-110-10. The results from the two specimens from the preliminary tests display some difference between the response on the front and rear sides, respectively. This is in accordance with the discussion above.

5.4 Summary of 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/m^3)	Tensile strength (MPa)	Comments
KFM07A-110-6	2,610	8.4	Preliminary test for evaluating strain gauges
KFM07A-110-7	2,610	9.8	Preliminary test for evaluating strain gauges
KFM07A-110-8	2,640	10.4	Replaces specimen KFM07A 110-1
KFM07A-110-9	2,620	8.9	Replaces specimen KFM07A 110-2
KFM07A-110-4	2,630	10.3	
KFM07A-110-5	2,630	11.5	
KFM08A-110-10	2,610	8.5	Replaces specimen KFM07A 110-3

Table 5-2. Calculated mean values and standard deviation (Std dev) of wet density and tensile strength for the specimens from boreholes KFM07A and KFM08A.

	Density (kg/m^3)	Tensile strength (MPa)
Mean value	2,621	9.9
Std dev	12.1	1.1

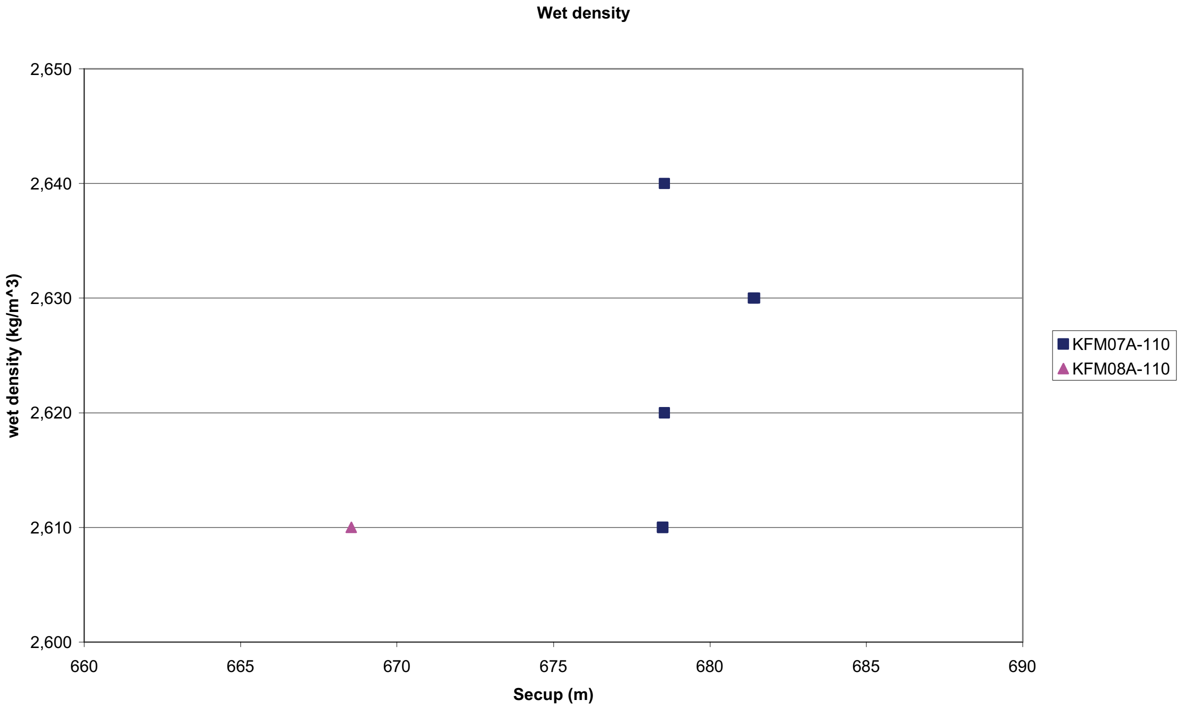


Figure 5-1. *Density versus sampling depth in boreholes.*

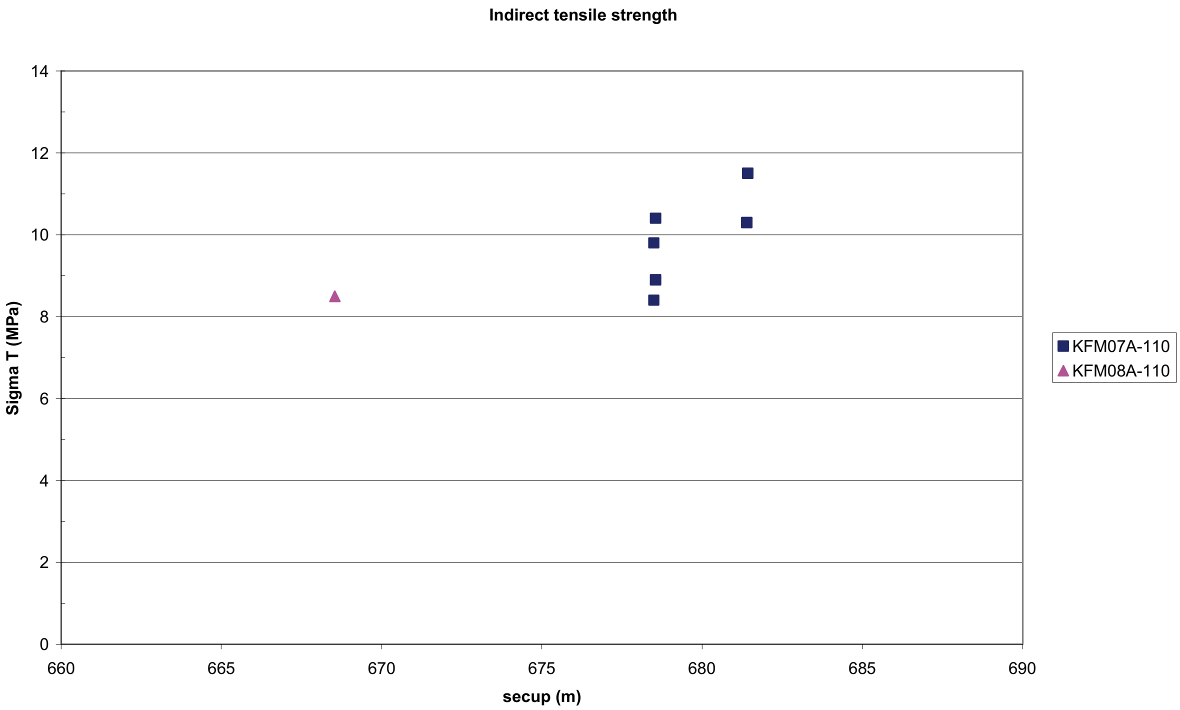


Figure 5-2. *Tensile strength versus sampling depth in the boreholes.*

References

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