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Oskarshamn site investigation

Borehole KLX13A

Shear tests on sealed joints

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December 2006

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Abstract

Shear tests on sealed joints on 12 rock specimens from borehole KLX13A in Oskarshamn, Sweden, have been carried out. The specimens were taken from cores at a depth level ranging between 202–404 m borehole length.

Direct shear tests on rock specimens with a sealed joint subjected to a constant normal stress were initially conducted. From each sealed joint, three specimens were prepared and tested at three different normal stress levels. The initial test was followed by three shear cycles, at the normal stress levels 0.5 MPa, 5 MPa and 20 MPa, on the open joint that was created after breaking the sealed joint. The peak and residual shear stresses were deduced from the tests. The specimens were photographed before as well as after the mechanical tests.

In general, the shear strength of the sealed joints increased with increased value of the normal stress level. The mean values for the peak shear stress and the residual stress were 0.95 MPa respectively 0.81 MPa for the 0.5 MPa normal stress level, 5.40 MPa respectively 4.40 MPa for the 5 MPa normal stress level and 16.33 MPa respectively 14.23 MPa for the 20 MPa stress level.

Sammanfattning

Skjuvförsök har genomförts på 12 stycken bergprov med läkta sprickor från borrhål KLX13A i Oskarshamn. Proven har tagits från borrkärnor vid en djupnivå mellan 202–404 m borrhålslängd.

Först genomfördes direkta skjuvförsök på bergprover med läkt spricka vid en konstant normalspänning. Från varje läkt spricka bereddes tre provkroppar som testades vid tre olika normalbelastningsnivåer. Efter att brott uppstått i de läkta sprickorna genomfördes tre skjuvcykler på de nu öppna sprickorna med en konstant normalspänning på respektive 0,5 MPa, 5 MPa och 20 MPa. Toppvärdet och residualvärdet på skjuvspänningen vid de olika normalspänningsnivåerna bestämdes ur dessa försök. Provobjekten fotograferades såväl före som efter de mekaniska proven.

Generellt sett ökade skjuvhållfastheten för de läkta sprickorna med ökad normalspänning. Medelvärdena för toppvärdet och residualvärdet hos skjuvspänningen i de olika skjuvförsöken låg på respektive 0,95 MPa och 0,81 MPa med 0,5 MPa normalspänning, 5,40 MPa och 4,40 MPa med 5 MPa normalspänning samt 16,33 MPa respektive 14,23 MPa med 20 MPa normalspänning.

Contents

1 Introduction

Direct shear tests on sealed joints have been conducted on specimens sampled from borehole KLX13A in Oskarshamn, Sweden, see map in Figure 1-1. These tests belong to one of the activities performed as part of the site investigation in the Oskarshamn area managed by the Swedish Nuclear Fuel and Waste Management Co (SKB) /1/. The tests were carried out in the material and rock mechanics laboratories at the department of Building Technology and Mechanics at Swedish National Testing and Research Institute (SP).

The borehole KLX13A is a so called "medium long hole" with a total length of approximately 600 m and is located in the north-west part of Laxemar within the Oskarshamn site investigation area.

The controlling documents for the activity are listed in Table 1-1. Both Activity Plan and method description for the normal stress and shear strength tests on joints are SKB's internal controlling documents, whereas the Quality Plan referred to in the table is an SP (The Swedish National Testing and Research Institute) internal controlling document. The method description 190.005 is partly based on the ISRM suggested method /2/. Furthermore, the initial shear tests on the sealed joints followed the method description given in the SKB-report P-05-209 /3/.

Figure 1-1. *Location of boreholes drilled up to February 2007.*

SKB supplied SP with rock cores, which arrived at SP in October 2006 and were tested during December 2006. Specimens were cut from cores containing natural joints and selected based on the preliminary core logging with the strategy to primarily investigate the mechanical properties of joints of the dominant rock types.

Direct shear tests on rock specimens with a sealed joint subjected to a normal stress were initially conducted. From each sealed joint, three specimens were prepared and tested at three different normal stress levels; 2, 5 and 10 MPa. The initial test was followed by three shear cycles, at the normal stress levels 0.5 MPa, 5 MPa and 20 MPa, on the open joint that was created after breaking the sealed joint. The shear deformation was controlled and given a constant deformation rate and the shear stress and the normal deformation in the joint were recorded during the test. The peak and residual shear stress at each shear cycle were determined from the shear test. The specimens were photographed before as well as after the mechanical testing.

The shear strength on the specimens containing a sealed joint was expected to be higher than for similar specimens having an open joint. The increased shear force yields a higher stress on the fixation of the specimen in the specimen holders. A high strength concrete material was therefore used for grouting in order to prevent a failure in the fixation of the specimens.

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

Activity Plan	Number	Version
KLX13A. Bergmekaniska och termiska laboratoriebestämningar	AP PS 400-06-107	1.0
Method Description	**Number**	**Version**
Normal stress and shear tests on joints	SKB MD 190.005	3.0
Shear tests on sealed joints	SKB P-05-209	
Quality Plan		
SP-QD 13.1		

2 Objective and scope

The purpose of the tests in this report is to determine the mechanical properties of sealed natural joints in rock specimens from borehole KLX13A at Oskarshamn. The activity comprised testing of twelve rock samples with sealed joints from different levels of the borehole.The behaviour of the sealed joints is investigated during shear loading tests at a constant normal stress level. The aim is to determine the peak shear stress when the sealed joint fails. Further, the joint friction represented by the peak and residual shear stresses together with the dilatancy of the joints during shearing at different constant normal stress levels are obtained from the subsequent shear tests conducted on the open joints. 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 Oskarshamn.

3 Equipment

3.1 Specimen preparation

A circular saw with a diamond blade was used to cut out and trim the specimens to the final shape. The specimen dimensions were measured by means of a sliding calliper.

Before each of the shear test, the specimens were cast in special holders (one upper and one lower). A device for holding the specimens in a fixed position was used during casting. Further, a specially designed fixture was used to clamp the two halves of the holder in the exact position relative to each other. This is of great importance in order to obtain the correct initial conditions for the tests.

For the shear test, the high strength concrete material Ducorit D4, was used to cast the specimens. The suitability of using this material as grout was evaluated by the shear tests on intact rock specimens presented in /3/.

A digital camera with 4 Mega pixels has been used to photograph the specimens.

3.2 Mechanical testing

A servo hydraulic testing machine, designed for direct shear tests, has been used for the shear tests, see Figure 3-1. The machine is supplied with two shear boxes, one upper and one lower. The upper box can be moved vertically and the lower box horizontally. Two actuators, one acting vertically and one acting horizontally, are used to apply the forces in the two directions (degrees of freedoms). Two linear bearings are guiding the lower box in order to obtain a controlled linear movement. The maximum stroke is 100 mm in the vertical direction and +/– 50 mm in the shear direction.

In the shear test the normal and shear displacements are measured by means of LVDTs. The vertical displacement between the shear boxes is measured by four LVDTs, positioned in a square pattern around the specimen, one in each corner. Each of the LVDTs has a measurement range of 5 mm and a relative error less than 1%. The average value of these four LVDTs is used to represent the vertical (normal) displacement presented in the results section. The relative displacement between the shear boxes in the horizontal (shear) direction is measured by one LVDT, which has a 10 mm range and a relative error less than 1%.

The maximum vertical (normal) load that can be applied is 300 kN and the maximum load in the horizontal (shear) direction is +/– 300 kN. Load cells are used to measure the forces in both directions. The accuracy of the load measurement is within 1%. The machine is connected to a digital controller with a computer interface for setting up and running tests.

Figure 3-1. *Equipment for direct shear tests and digital controller unit.*

4 Execution

The mechanical tests were carried out according to activity plan and the method description SKB 190.005 (SKB internal controlling document). The test method follows ISRM suggested methods for determining shear strength /2/.

For each specimen, a form containing specimen dimensions is filled in. Further, the form also contains comments and observations during the different test steps. Moreover, a check list is filled in during the work in order to confirm that the different specified steps have been carried out. The specimens are photographed before and after the mechanical tests.

4.1 Description of the samples

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

4.2 Specimen preparation

The specimens are cut out from rock cores. Three specimens are prepared from each sealed joint. The pieces are shaped and trimmed to obtain a total thickness *h* of approximately 40 mm and a maximum length *l* of 60 mm, cf. Figure 4-1. The specimens therefore have similar shape and joint area size.

An overview of the activities during the specimen preparation is shown in the step-by-step description in Table 4-2.

Table 4-1. Specimen identification, sampling depth for all specimens (based on the Boremap).

Identification	Adj secup [m]	Adj seclow [m]	Fracture adj setup [m]	Fracture mineral
KLX13A-117-1a	202.20	202.46	202.30	Calcite/Chlorite
KLX13A-117-1b	202.20	202.46	202.30	Calcite/Chlorite
KLX13A-117-1c	202.20	202.46	202.30	Calcite/Chlorite
KLX13A-117-3a	261.83	262.23	262.04	Calcite/Chlorite
KLX13A-117-3b	261.83	262.23	262.04	Calcite/Chlorite
KLX13A-117-3c	261.83	262.23	262.04	Calcite/Chlorite
KLX13A-117-5a	327.65	327.90	327.87	Calcite
KLX13A-117-5b	327.65	327.90	327.87	Calcite
KLX13A-117-5c	327.65	327.90	327.87	Calcite
KLX13A-117-7a	403.49	403.91	403.96	Calcite/Chlorite/Epidote
KLX13A-117-7b	403.49	403.91	403.96	Calcite/Chlorite/Epidote
KLX13A-117-7c	403.49	403.91	403.96	Calcite/Chlorite/Epidote

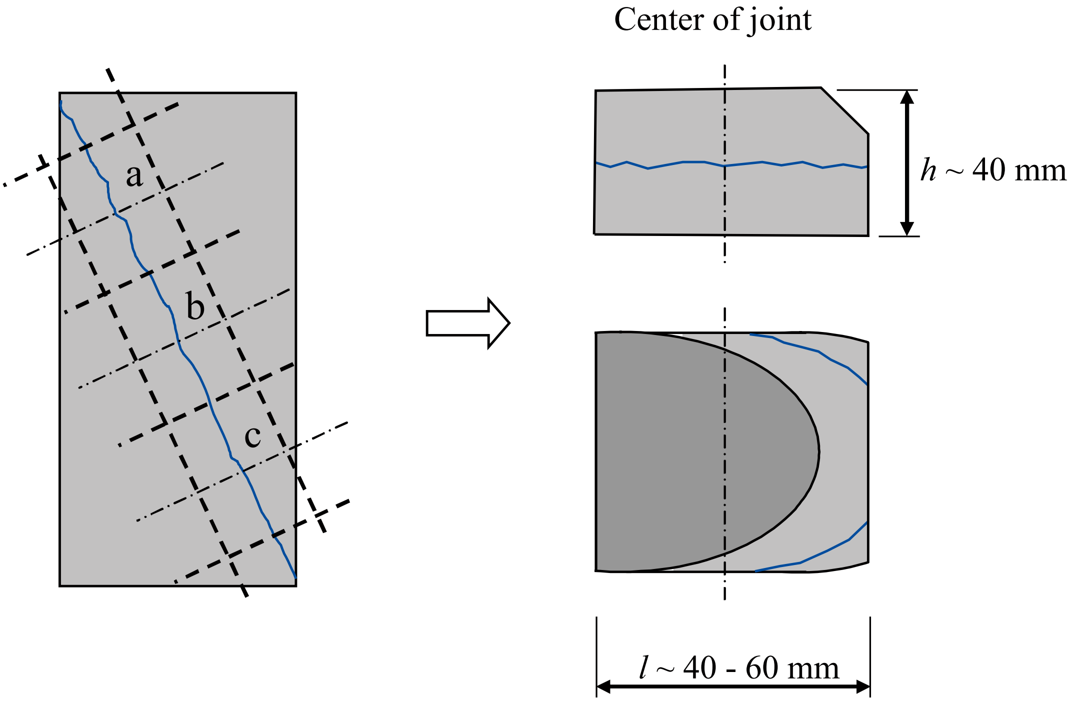


***Figure 4-1.** Principle of specimen processing. Left: Cylindrical core containing a sealed joint. The dashed lines show the cutting lines; Right: Example of specimen after processing.*

Table 4-2. Activities during the specimen preparation.

Step	Activity
1	Mark the drill cores at the position of the joints selected for testing.
2	Cut out the specimens from the cores and trim them to the specified dimensions.
3	Measure the specimen dimensions and calculate the joint surface area.
4	Take digital photos of each specimen.

4.3 Shear test

The program controlling the shear tests is divided into four parts, one part for the shear test on the sealed joint and one program each for the three subsequent shear tests, resulting in four separate data files for each specimen.

The specimens are cast in steel holders using a high strength concrete material, see Figure 4-2.

One half is cast first by pouring the grout into the holder with the specimen held in correct position. The grout is hard enough after three days to fixate the specimen. The second half of the holder is then mounted on top of the first one with a 6 mm gap between the two halves and turned upside down. The second half is cast by pouring grout into the holder. The grout is fully hardened after approximately two weeks in room temperature.

The behaviour of the sealed joints is investigated by shear loading tests on three specimens from each joint, tested at different constant normal stress levels; 2, 5 and 10 MPa respectively. The aim is to determine the peak shear stress when the sealed joint fails.

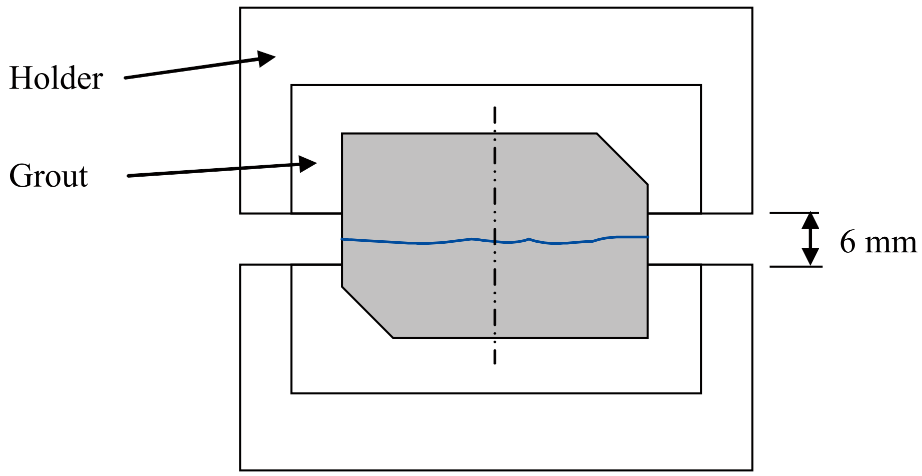


***Figure 4-2.** Specimen cast in the specimen holder for the shear tests.*

Subsequently, three successive shear tests were conducted with a constant normal stress, at 0.5, 5 and 20 MPa, respectively. Each joint was sheared with a constant displacement rate to a final displacement value slightly exceeding 2, 3 and 5 mm for the 0.5, 5 and 20 MPa normal stress levels. The shear tests were finished by unloading the shear stress to zero. The normal stress was lowered to 0.2 MPa before the shear position was restored to its starting point (zero shear displacement) for the following shear test. Both the normal and the shear displacements in the joint were recorded in the shear tests.

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

Table 4-4. Activities during the shear test.

Step	Activity
1	Cast the specimens into the specimen holders.
2	Mount the specimen holders in the shear testing machine.
3	Perform the shear test on the sealed joint at a constant normal stress level:
	• Apply a normal stress of 0.5 MPa and zero the deformation channels.
	• Increase the normal stress to the specified normal stress.
	• Apply a shear deformation with a rate of 0.5 mm/min and shear until the sealed joint fails.
	• Unload the shear stress to zero.
	• Unload the normal stress to 0.2 MPa and restore the shear deformation to zero (initial position).
4	Perform the shear tests on the open joint at the three constant normal stress levels, 0.5 MPa, 5 MPa and 20 MPa:
	• Apply a normal stress of 0.5 MPa and zero the deformation channels.
	• Increase the normal stress to the prescribed value for the actual test.
	• Apply a shear deformation with a rate of 0.5 mm/min and shear until the shear displacement reaches 2, 3 or 5 mm respectively for the 0.5 MPa, 5 MPa and 20 MPa stress levels.
	• Unload the shear stress to zero.
	• Unload the normal stress to 0.2 MPa and restore the shear deformation to zero (initial position).
	Repeat this for the three shear cycles.
5	Take out the specimens from the shear boxes.
6	Take digital photos of each specimen.
7	Store the test results on the computer network.

4.4 Data handling

The test results were exported as text files from the test software and stored in a file server on the SP computer network after each completed test. The main data processing, in which the peak and residual shear stresses were determined, has been carried out in the program MATLAB /5/. Moreover, MATLAB was used to produce the diagrams shown in Section 5.1. The summary of results in Section 5.2 with tables containing mean value and standard deviation of the different parameters and diagrams were produced using MS Excel. MS Excel was also used for reporting data to the SICADA database. Data are traceable in SICADA by the activity plan number.

4.5 Analyses and interpretation

In the shear tests, the normal stress σ_N and shear stress σ_S are defined as

$$\sigma_N = \frac{F_N}{A} \quad \text{and} \quad \sigma_S = \frac{F_S}{A}$$

where F_N is the normal force and F_S is the shear force acting on the joint and A is the joint area. The shear strength σ_{SS} of the sealed joint, the peak value σ_{SP} and the residual value σ_{SR} of the shear stress σ_S on each of the three shear cycles on the broken joint are determined. The peak value is defined as the maximum value during the whole shear cycle. The residual value is defined as the mean value of the shear stress of the last 0.5 mm of the shear cycle before the unloading of the shear stress for the 0.5 and 5 MPa normal stress levels and the last 1 mm for the 20 MPa normal stress level. In some cases the actual shear force is fluctuating up and down caused by a stick-slip response that is achieved during the shear process due to the uneven surfaces in the joints. The shear stress used when the residual value is evaluated is defined as the envelope obtained by interconnecting the sub-peaks obtained during shearing. The distance between the sampled sub-peak points during the tests is quite coarse which makes the mean value calculation less accurate. New data points are therefore added in the interval for the mean value calculation with a linear interpolation, if the distance in the shear direction between the sampled sub-peaks is less than 0.01 mm. The new points are equidistantly distributed and the number of new points that are created are determined with the criterion that the distance of the added points should be just less or equal to 0.01 mm.

The shear deformation δ_S is represented by the relative displacement between the shear boxes in the horizontal (shear) direction measured by one LVDT. The normal deformation δ_N is defined as the average value of four LVDTs used to measure the vertical (normal) displacement between the two shear boxes.

A part of the normal deformations and shear deformations measured in the shear tests belong to the deformations in the epoxy, in the holders and shear boxes and in the contact surfaces between the specimen holders and the shear boxes. However, the system deformations during the shear tests are of less significance for the results and no correction is made.

4.6 Nonconformities

The testing was conducted according to the method description with no departures. Due to considerable irregular shape of the joints, specimens KLX13A-117-2a–c and KLX13A-117-4a–c were replaced by specimens KLX13A-117-5a–c and KLX13A-117-7a–c.

5 Results

The test results of the individual specimens are presented in Section 5.1, and a summary of the results is given in Section 5.2. The reported parameters are based both on unprocessed raw data obtained from the testing and processed data and were reported to the SICADA database. These data together with the digital photographs of the individual specimens were handed over to SKB. The handling of the results follows routine SDP-508 (SKB internal controlling document) in general.

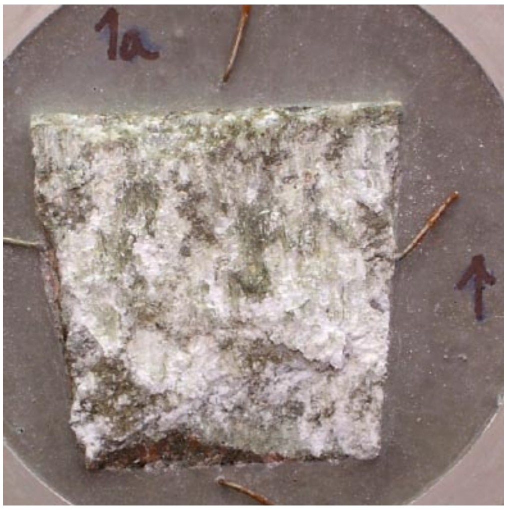
5.1 Description and presentation of the specimens

The specimens and joints before casting and after testing are shown on photos. Comments on observations appeared during the testing are reported. The results from the four shear tests are shown in the two diagrams. The results from the shear test on the sealed joint are displayed in magenta and the results from the shear tests on the open joint for the three normal stress levels are displayed in black (0.5 MPa), green (5 MPa) and blue (20 MPa), respectively. Furthermore, the red triangle markers show the peak shear stresses and the red square markers indicate the residual stresses. Moreover, the dilatancy in the joints is derived from the shearing part of the four shear tests.

Specimen ID: KLX13A-117-1a

Before mechanical test

After mechanical test

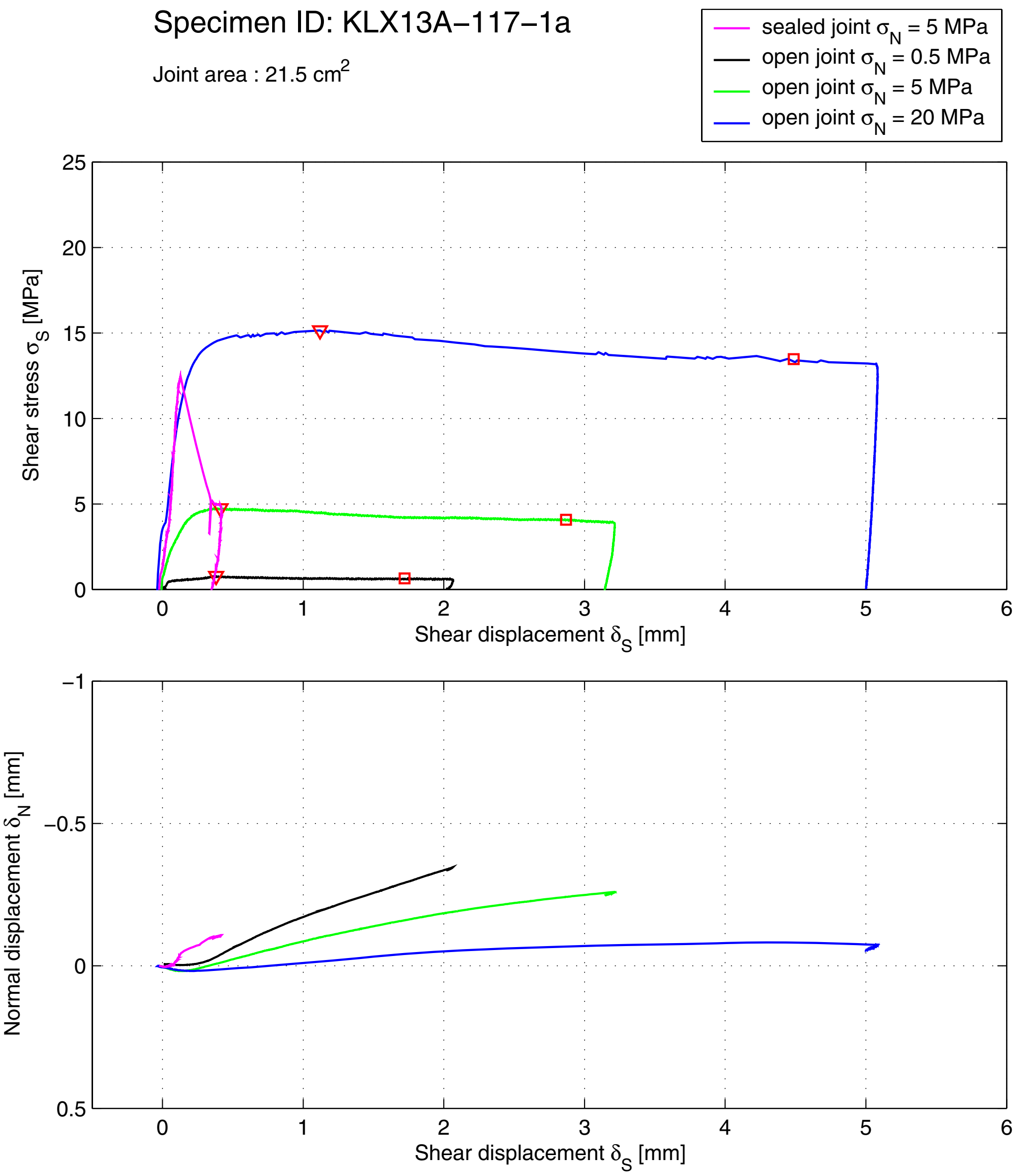


Comments

The shear failure occurred in the sealed joint.

Upper half: At the rear end of the specimen, small pieces have spalled off.

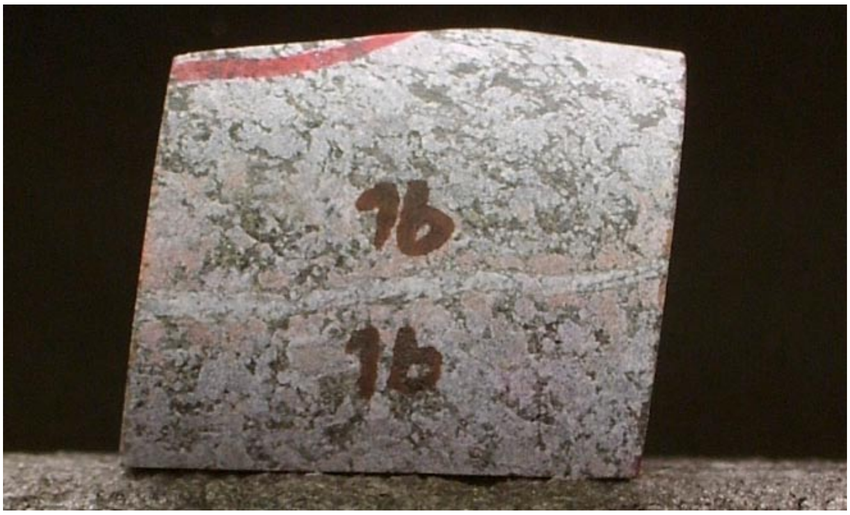
Lower half: At the rear end of the specimen, small pieces have spalled off.



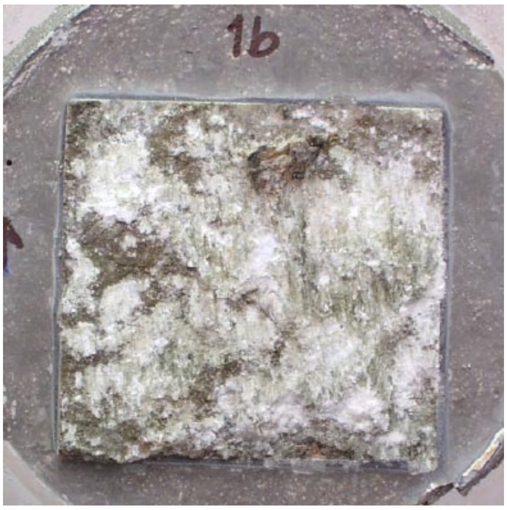
Specimen ID: KLX13A−117−1a
Joint area : 21.5 cm2
sealed joint σN = 5 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]
Shear displacement δS [mm]

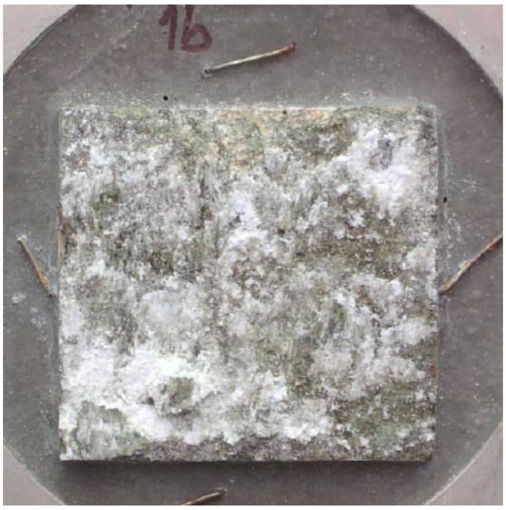
Specimen ID: KLX13A-117-1b

Before mechanical test

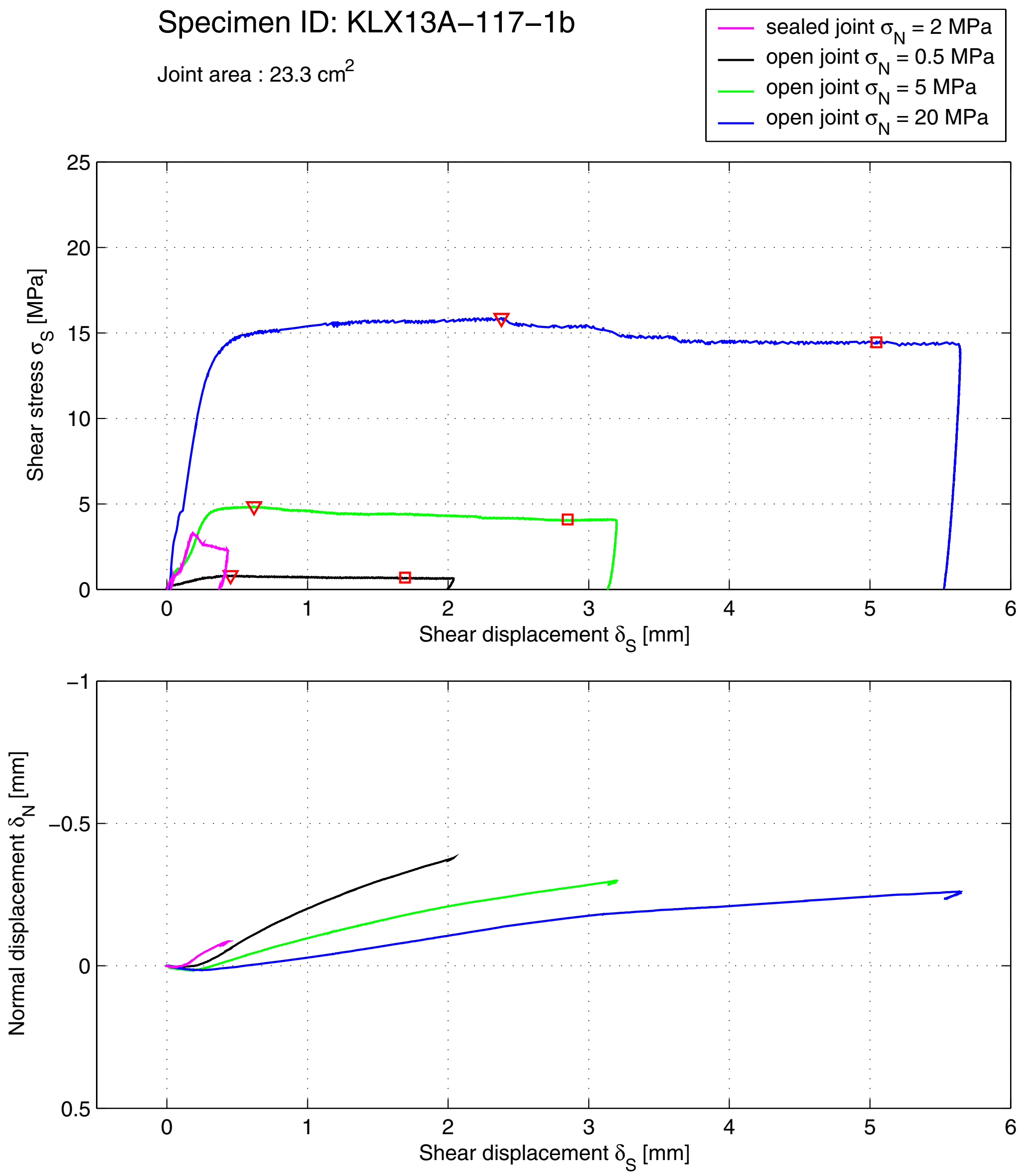


After mechanical test





Comments The shear failure occurred in the sealed joint.
Upper half: At the rear end of the specimen, small pieces have spalled off.
Lower half: At the rear end of the specimen, small pieces have spalled off.

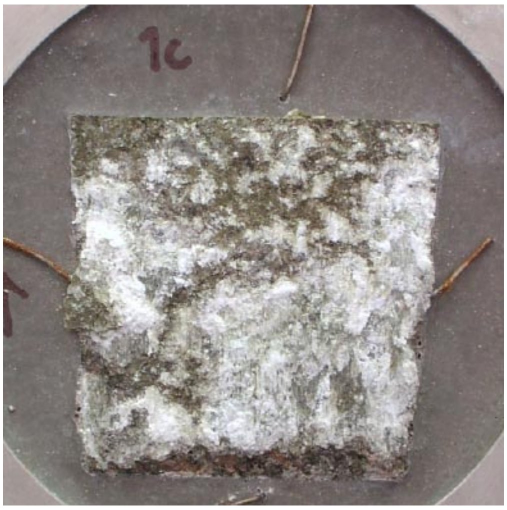


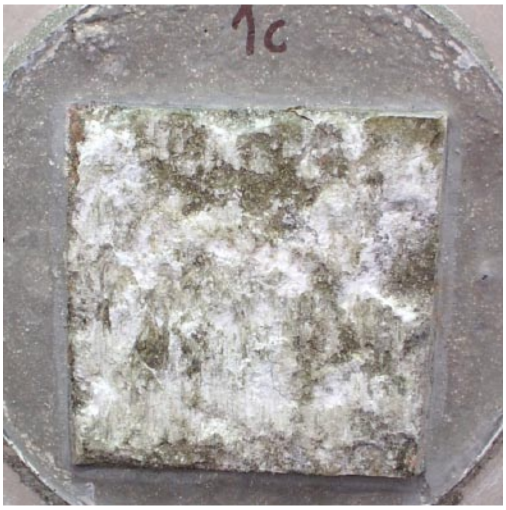
Specimen ID: KLX13A−117−1b
Joint area : 23.3 cm2
sealed joint σN = 2 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]
Shear displacement δS [mm]

Specimen ID: KLX13A-117-1c

Before mechanical test

After mechanical test



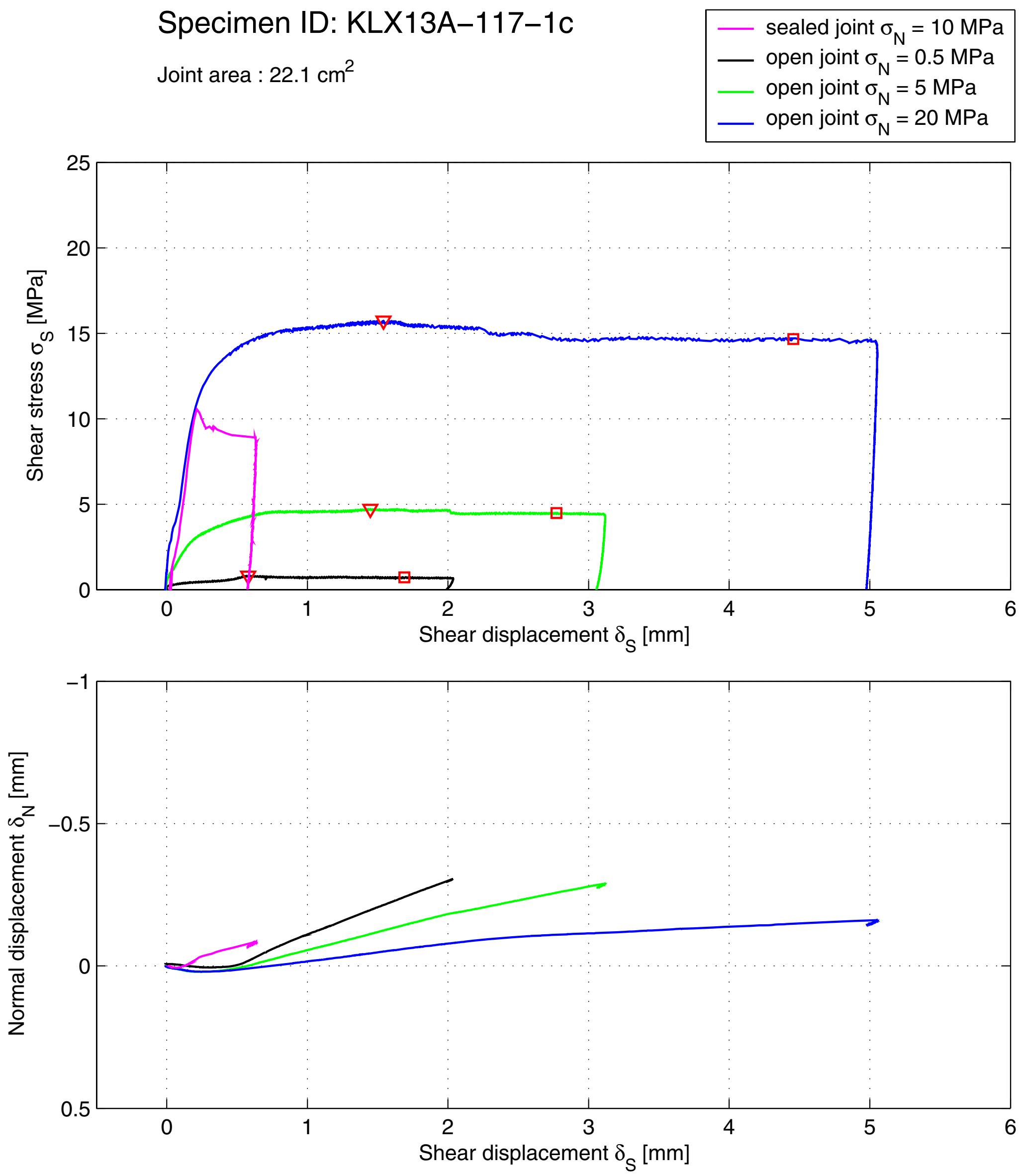


Comments

The shear failure occurred in the sealed joint.

Upper half: At the rear end of the specimen, small pieces have spalled off.

Lower half: At the rear end of the specimen, small pieces have spalled off.

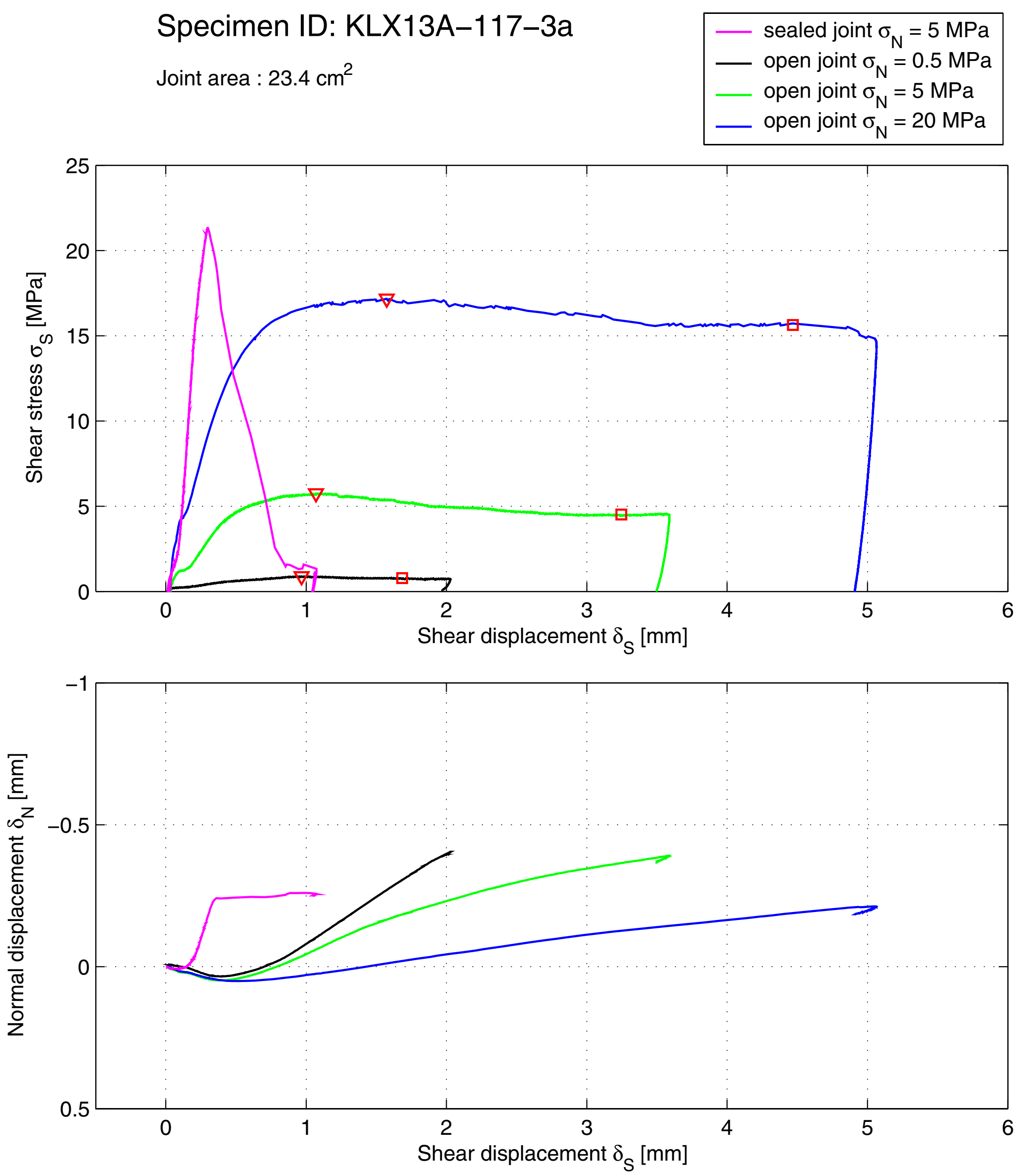

Specimen ID: KLX13A−117−1c
Joint area : 22.1 cm2
sealed joint σN = 10 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]

Specimen ID: KLX13A-117-3a

Before mechanical test

After mechanical test

Comments	The shear failure occurred in the sealed joint. Upper half: At the rear end of the specimen, small pieces have spalled off. Lower half: At the rear end of the specimen, small pieces have spalled off.

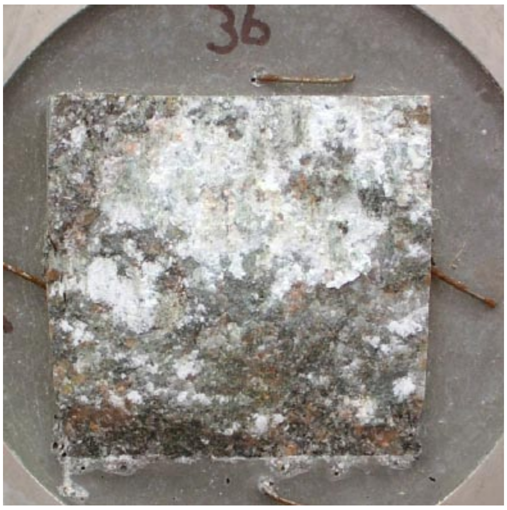


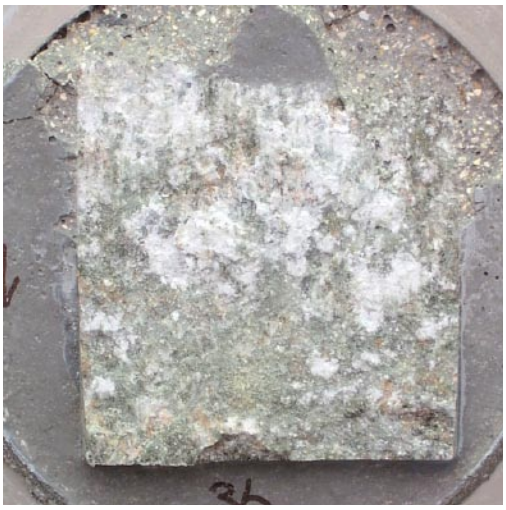
Specimen ID: KLX13A–117–3a
Joint area : 23.4 cm²
sealed joint σN = 5 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]

Specimen ID: KLX13A-117-3b

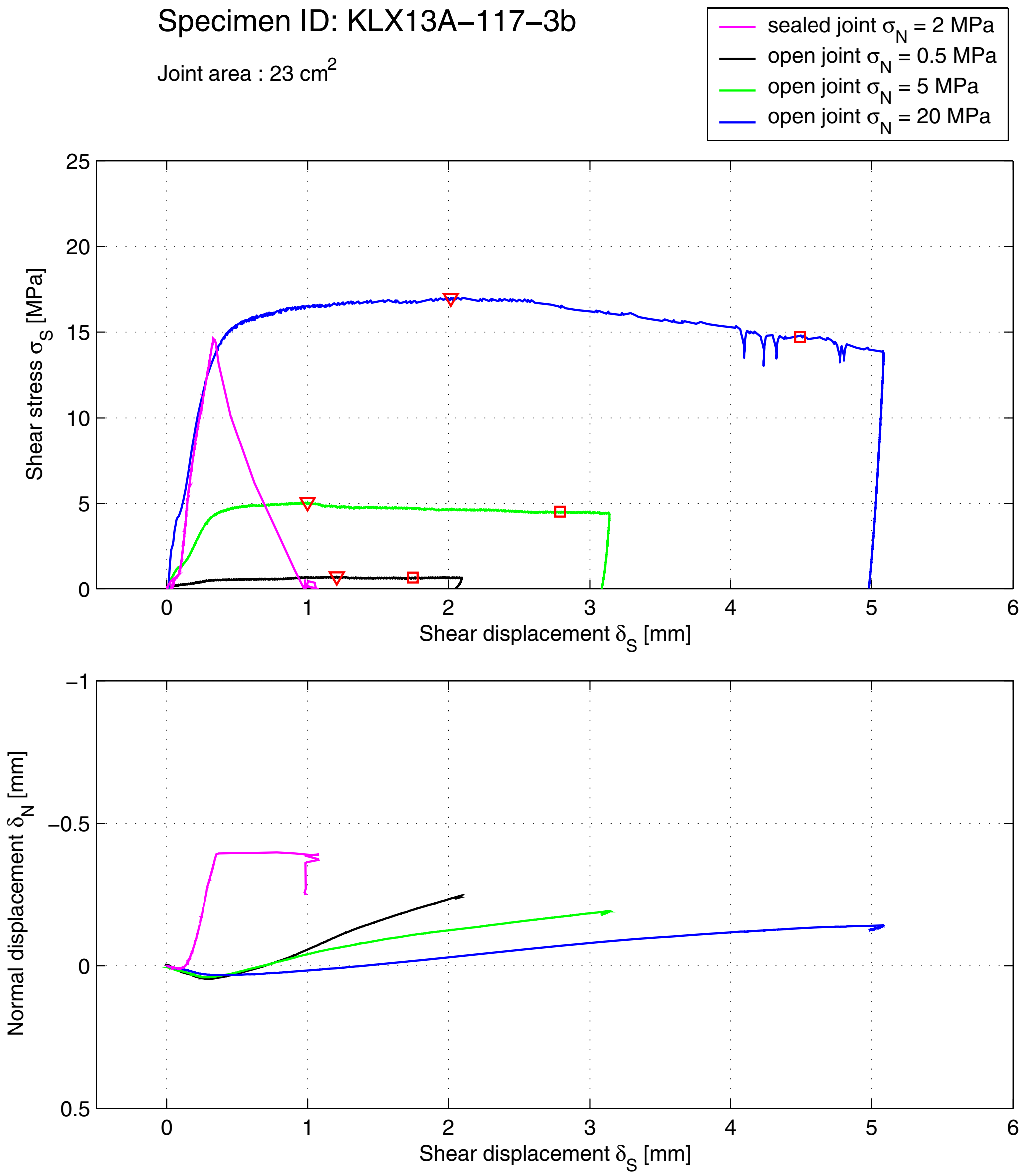
Before mechanical test

After mechanical test





Comments	The shear failure occurred in the sealed joint. Upper half: At the rear end of the specimen, small pieces have spalled off. Lower half: At the rear end of the specimen, small pieces have spalled off.

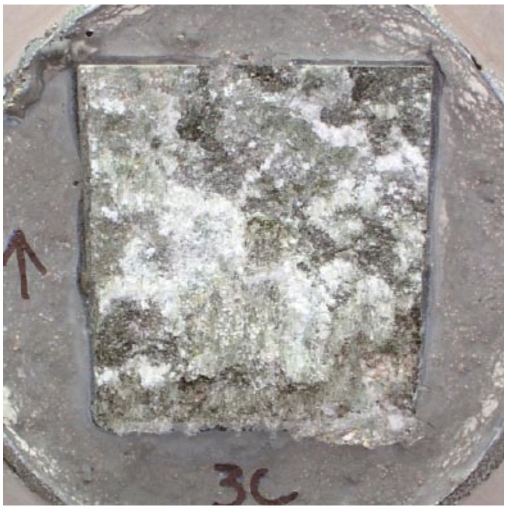


Specimen ID: KLX13A−117−3b
Joint area : 23 cm²
sealed joint σN = 2 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]

Specimen ID: KLX13A-117-3c

Before mechanical test

After mechanical test

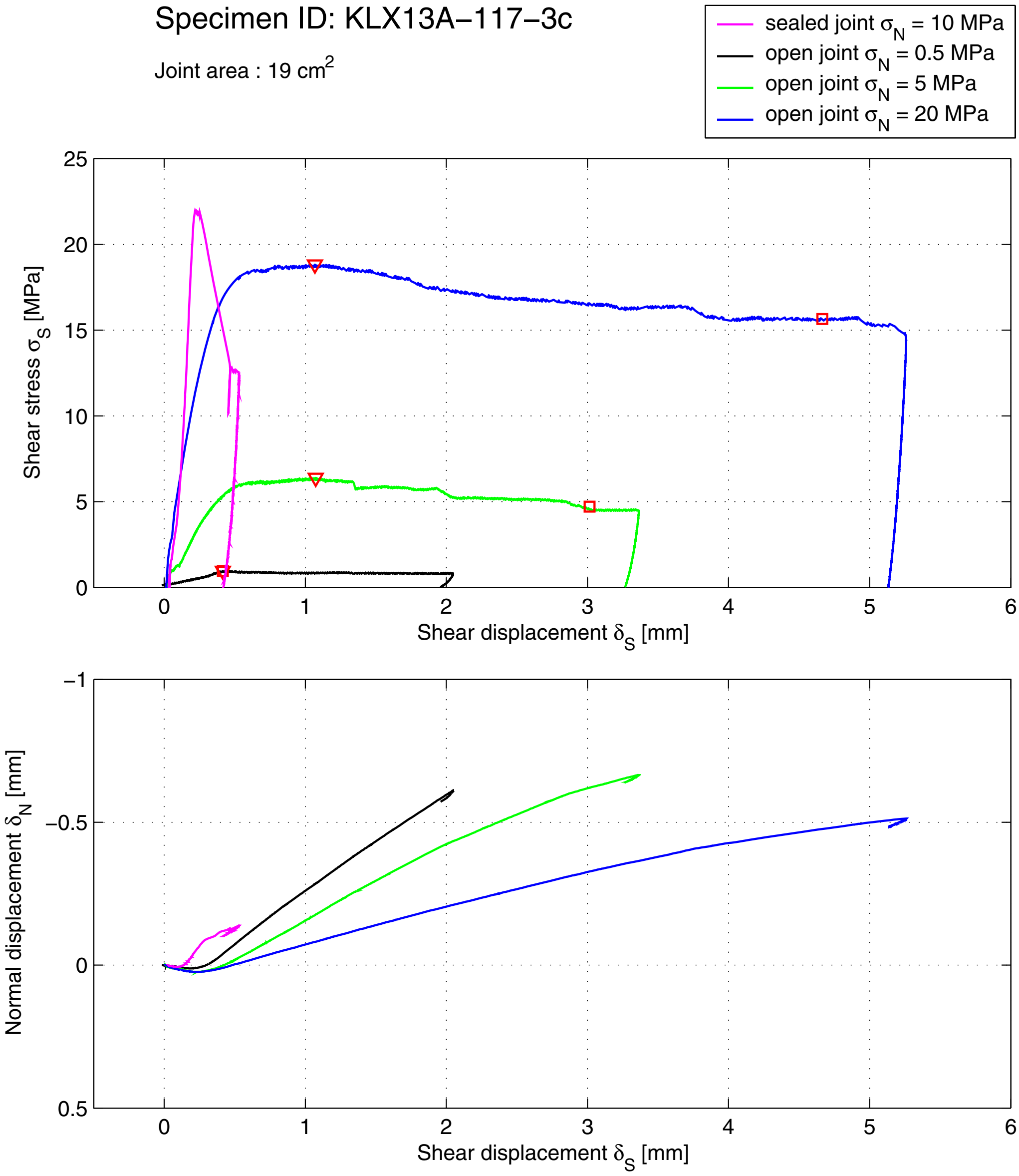


Comments

The shear failure occurred in the sealed joint.

Upper half: At the rear end of the specimen, small pieces have spalled off.

Lower half: At the rear end of the specimen, small pieces have spalled off.

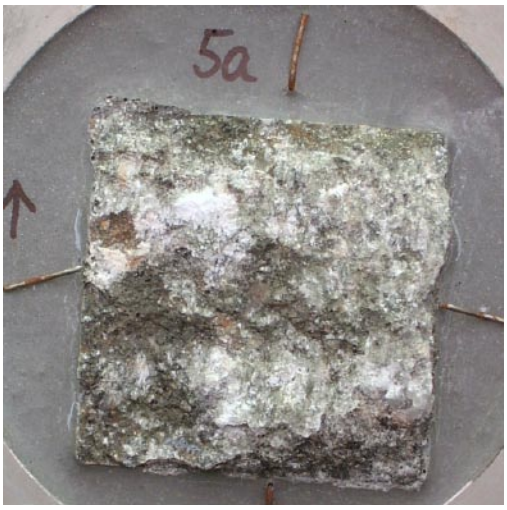


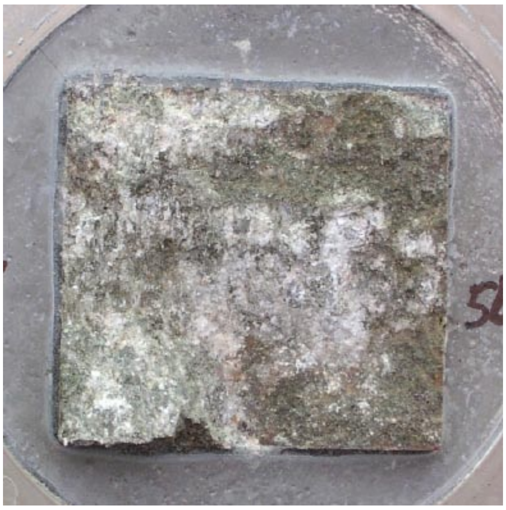
Specimen ID: KLX13A−117−3c
Joint area : 19 cm2
sealed joint σN = 10 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]
Shear displacement δS [mm]

Specimen ID: KLX13A-117-5a

Before mechanical test

After mechanical test

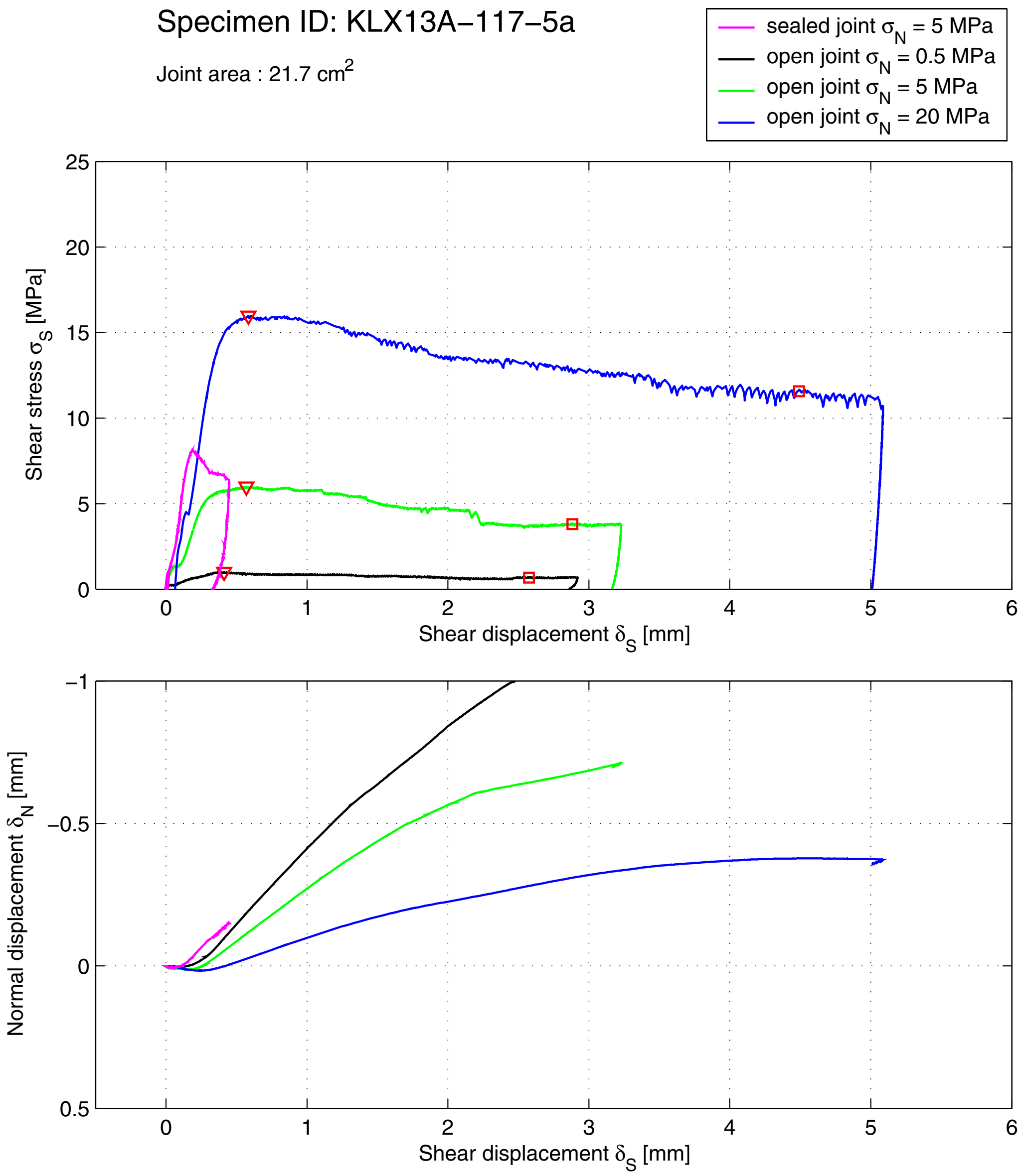




Comments The shear failure occurred in the sealed joint.

Upper half: At the rear end of the specimen, small pieces have spalled off.

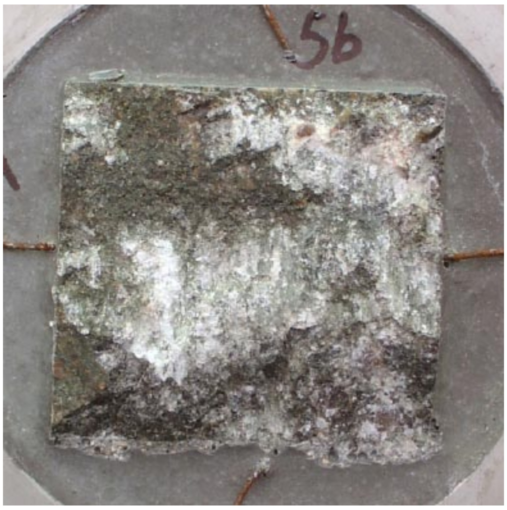
Lower half: At the rear end of the specimen, small pieces have spalled off.

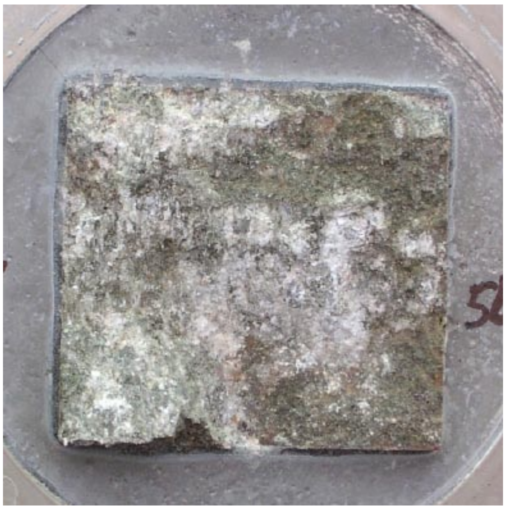

Specimen ID: KLX13A–117–5a
Joint area : 21.7 cm²
sealed joint σN = 5 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]
Shear displacement δS [mm]

Specimen ID: KLX13A-117-5b

Before mechanical test

After mechanical test

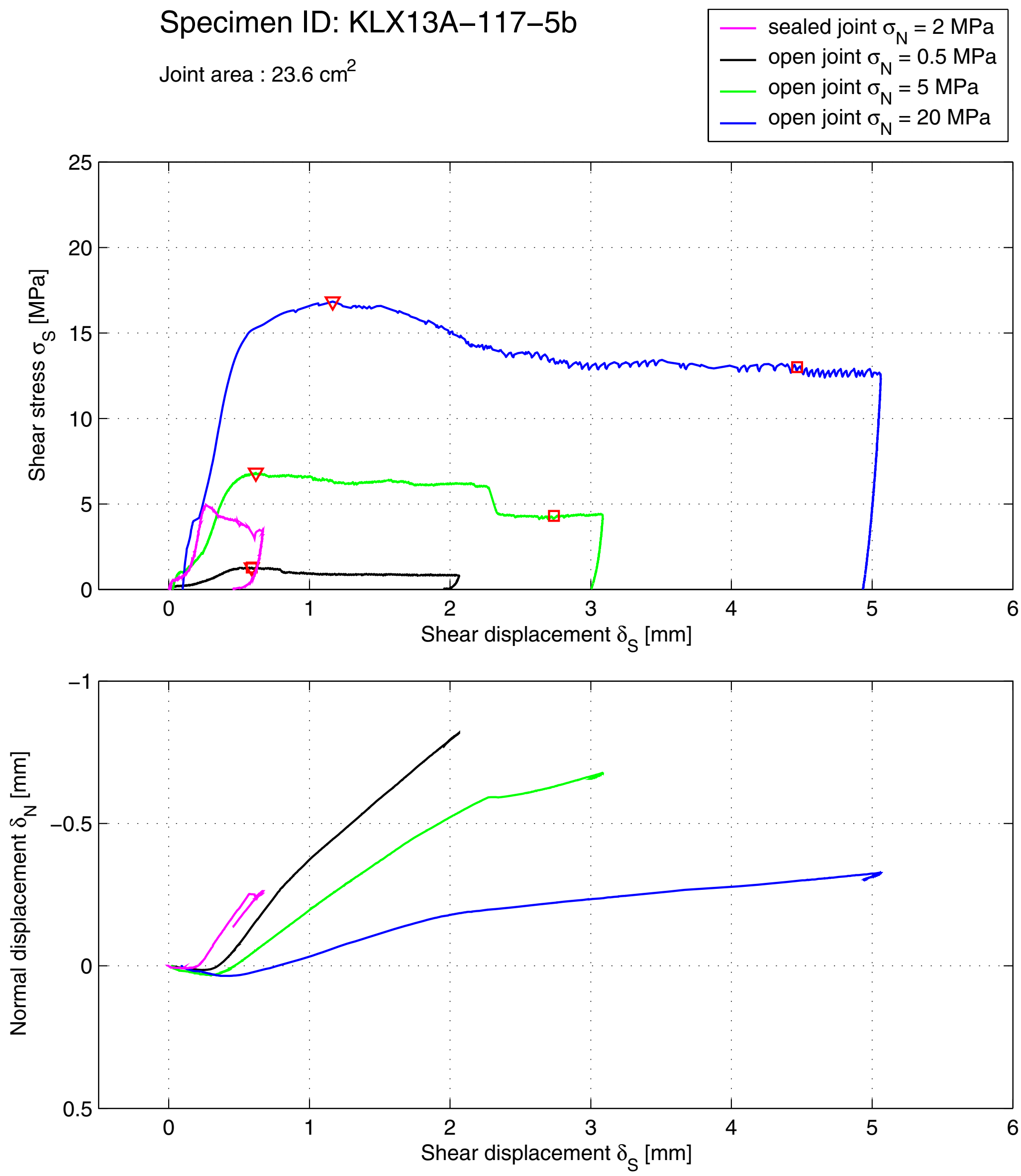




Comments The shear failure occurred mainly in the sealed joint.

Upper half: At the rear end of the specimen, pieces have spalled off.

Lower half: At the rear end of the specimen, pieces have spalled off.


Specimen ID: KLX13A−117−5b
Joint area : 23.6 cm2
sealed joint σN = 2 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]
25
20
15
10
5
0
−1
−0.5
0.5
1
2
3
4
6

Specimen ID: KLX13A-117-5c

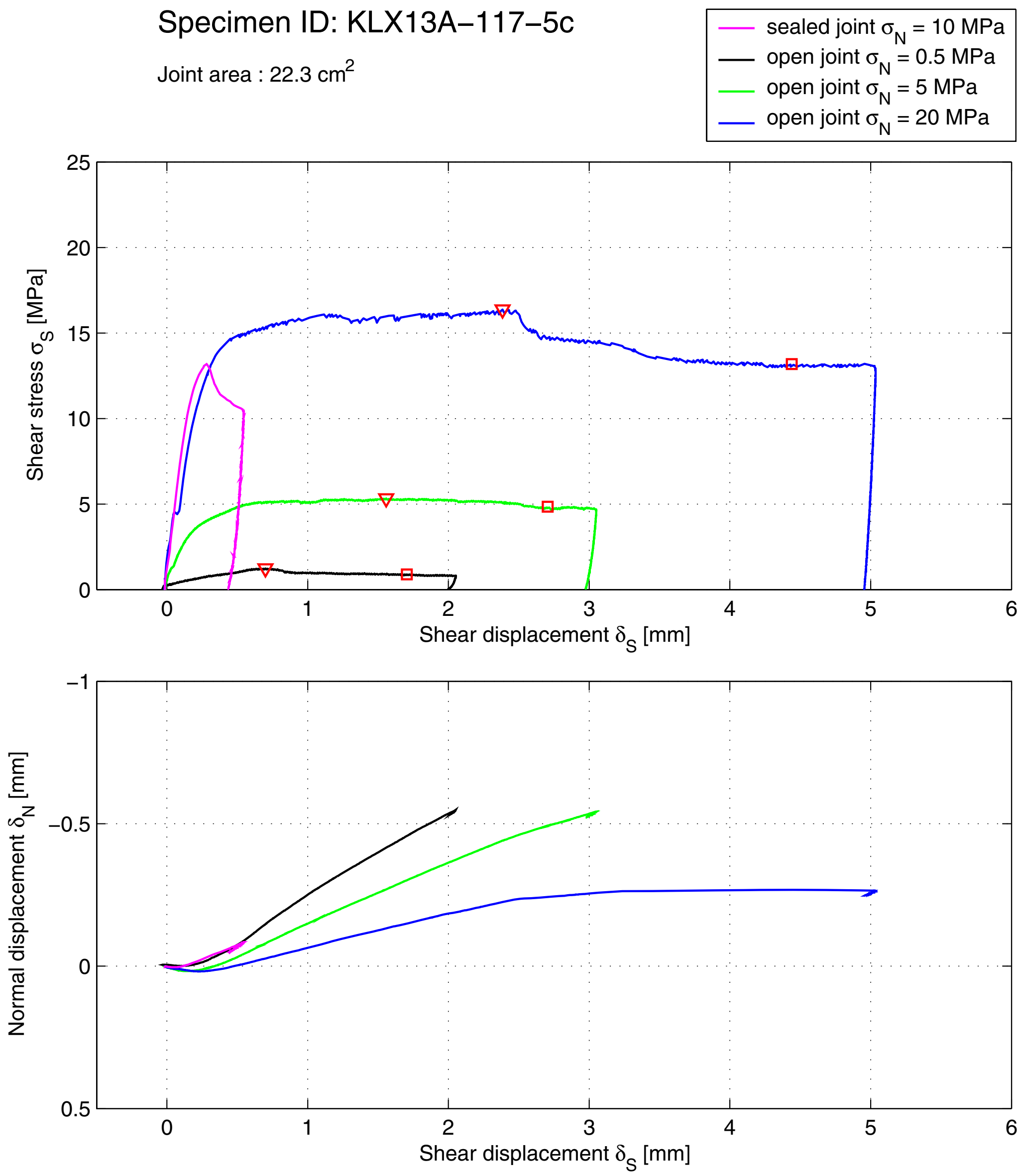
Before mechanical test

After mechanical test

Comments The shear failure occurred in the sealed joint.

Upper half: At the rear end of the specimen, pieces have spalled off.

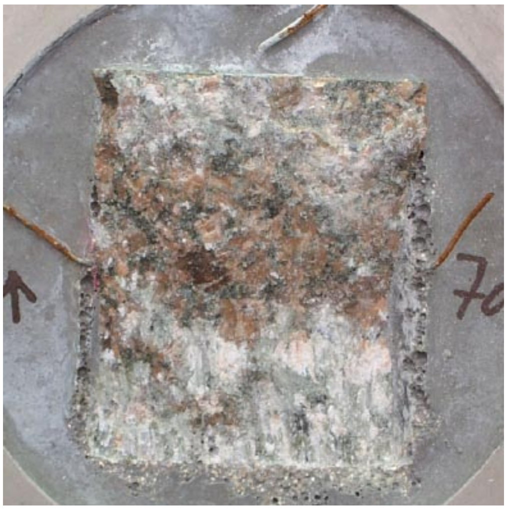
Lower half: At the rear end of the specimen, pieces have spalled off.


Specimen ID: KLX13A–117–5c
Joint area : 22.3 cm2
sealed joint σN = 10 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]
Shear displacement δS [mm]

Specimen ID: KLX13A-117-7a

Before mechanical test

After mechanical test

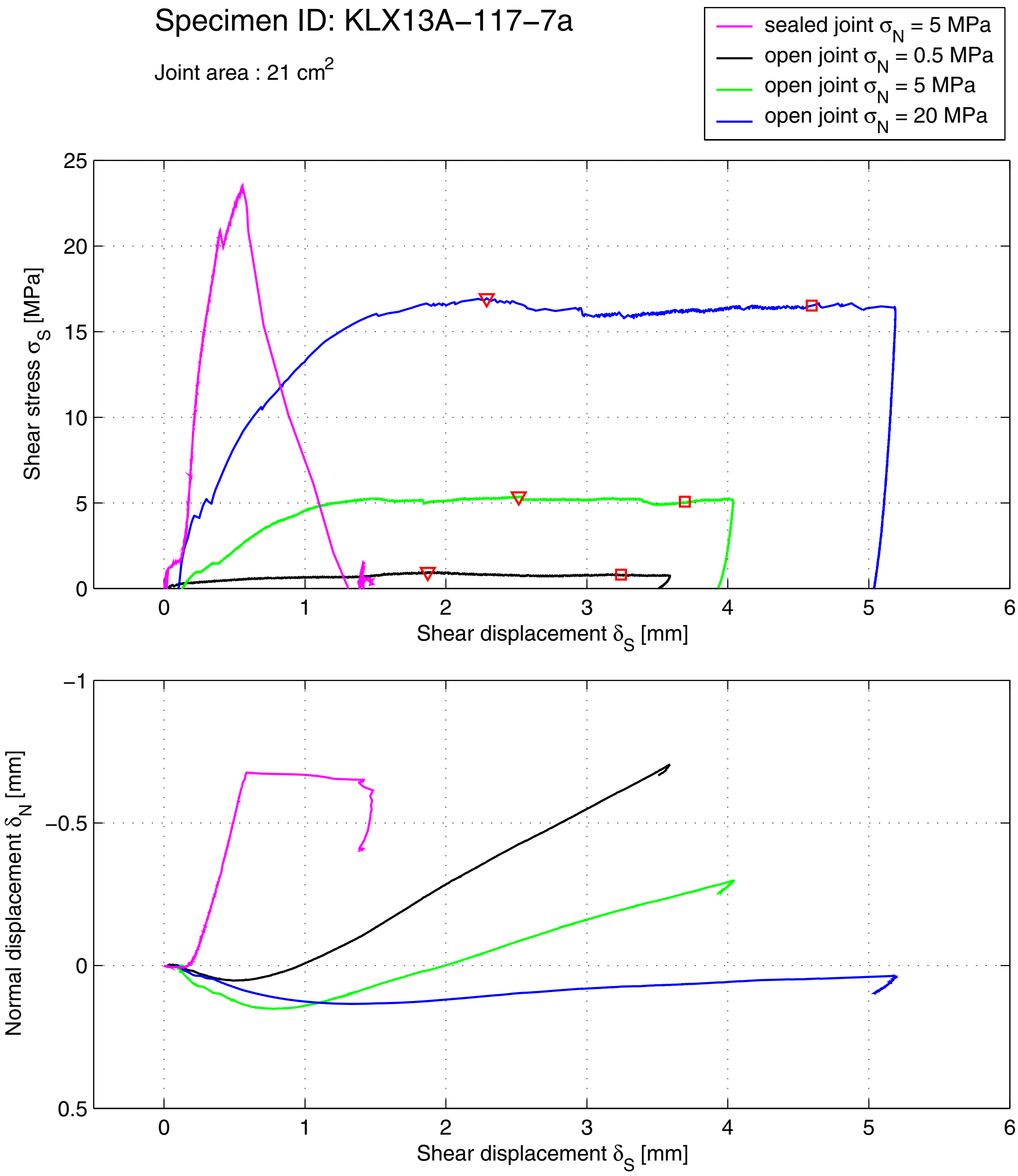


Comments

The shear failure occurred mainly in the sealed joint.

Upper half: At the rear end of the specimen, pieces have spalled off.

Lower half: At the rear end of the specimen, pieces have spalled off.

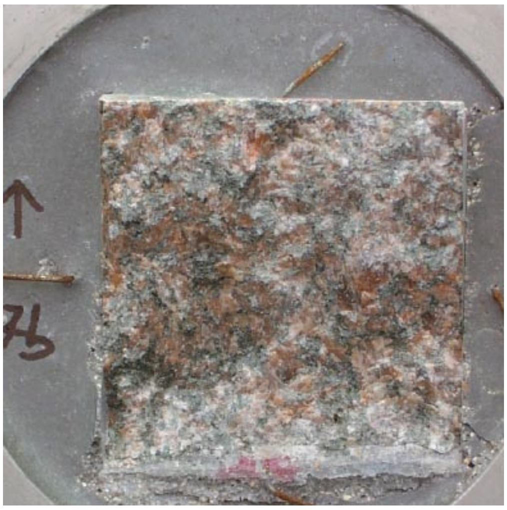


Specimen ID: KLX13A−117−7a
Joint area : 21 cm2
sealed joint σN = 5 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]
Shear displacement δS [mm]

Specimen ID: KLX13A-117-7b

Before mechanical test

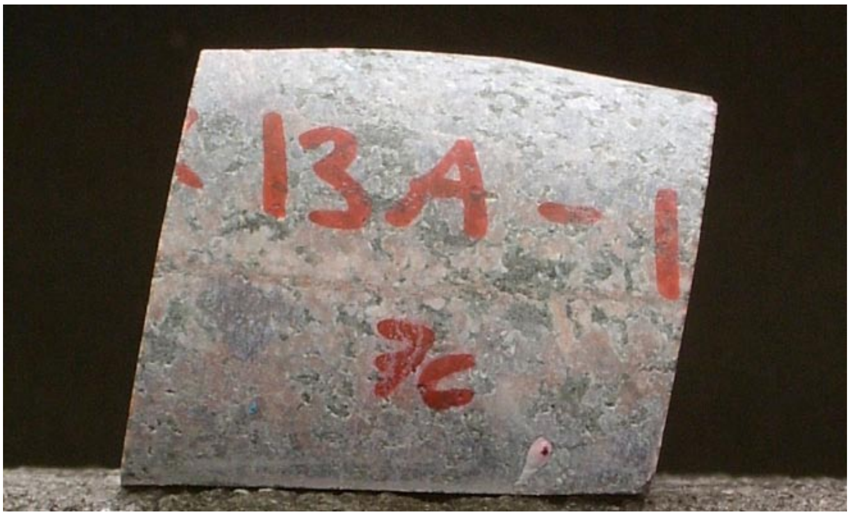
After mechanical test



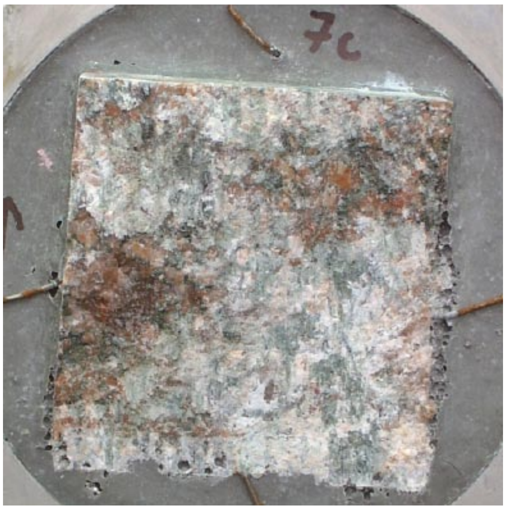
Comments Failure in the grout, during test.

Specimen ID: KLX13A-117-7c

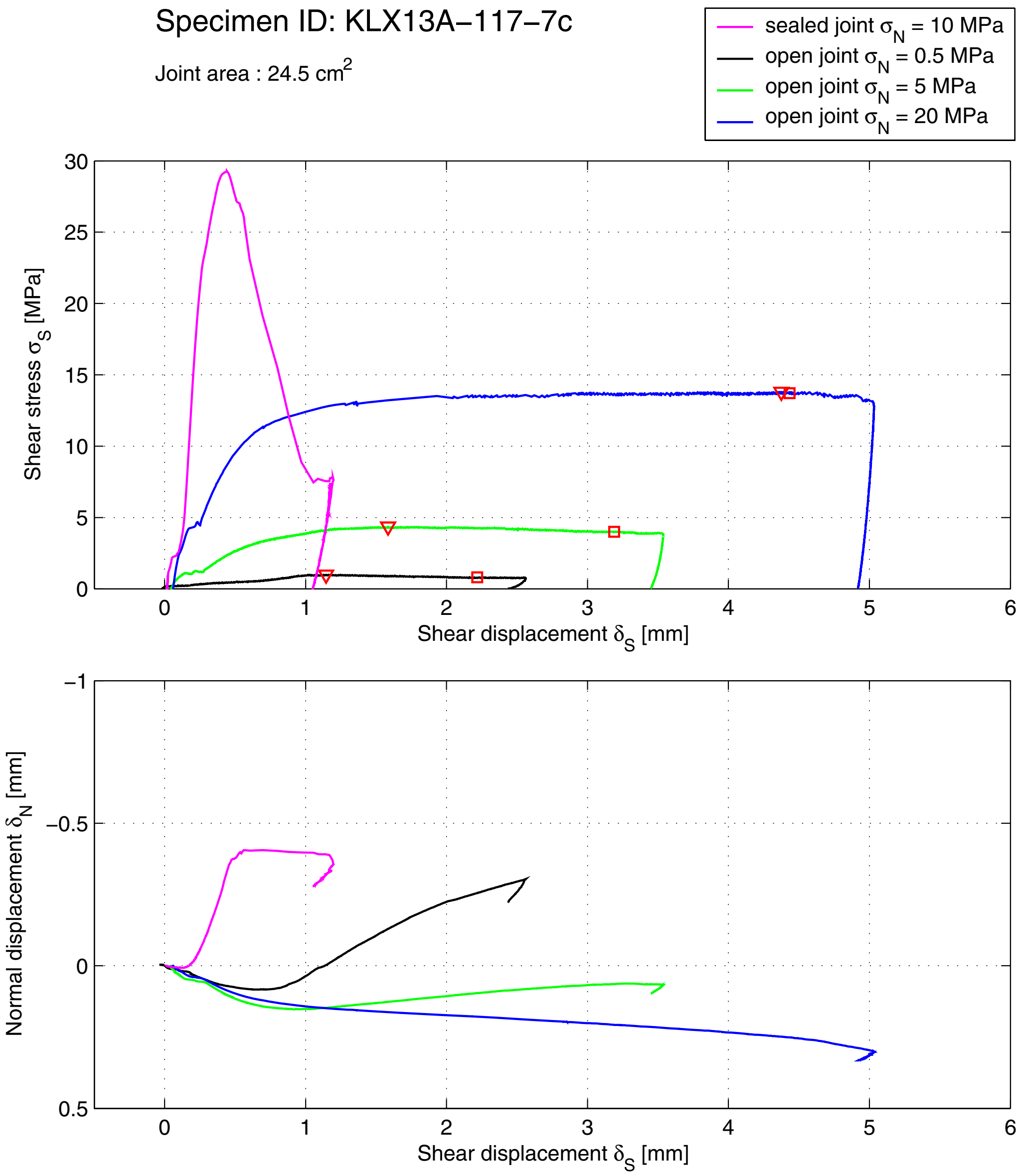
Before mechanical test



After mechanical test



Comments	The shear failure occurred mainly in the sealed joint.
	Upper half: At the rear end of the specimen, small pieces have spalled off.
	Lower half: At the rear end of the specimen, small pieces have spalled off.


Specimen ID: KLX13A−117−7c
Joint area : 24.5 cm2
sealed joint σN = 10 MPa
open joint σN = 0.5 MPa
open joint σN = 5 MPa
open joint σN = 20 MPa
Shear stress σS [MPa]
Shear displacement δS [mm]
Normal displacement δN [mm]
Shear displacement δS [mm]

5.2 Results for the entire test series

A summary of the test results is shown in Tables 5-1 and 5-2.

Table 5-1. Summary of results.

Identification	Area [cm²]	Normal stress[1] [MPa]	Shear strength [MPa]	Peak 05 [MPa]	Resid 05 [MPa]	Peak 5 [MPa]	Resid 5 [MPa]	Peak 20 [MPa]	Resid 20 [MPa]	Comments
KLX13A-117-1a	21.5	5	12.47	0.77	0.64	4.74	4.07	15.14	13.46	
KLX13A-117-1b	23.3	2	3.28	0.82	0.68	4.86	4.09	15.86	14.45	
KLX13A-117-1c	22.1	10	10.55	0.81	0.72	4.72	4.48	15.73	14.67	
KLX13A-117-3a	23.4	5	21.37	0.89	0.78	5.75	4.51	17.16	15.62	
KLX13A-117-3b	23.0	2	14.62	0.73	0.68	5.05	4.50	16.99	14.70	
KLX13A-117-3c	19.0	10	21.97	0.96	0.96	6.37	4.70	18.81	15.64	
KLX13A-117-5a	21.7	5	8.13	1.01	0.68	5.99	3.79	15.97	11.56	
KLX13A-117-5b	23.6	2	4.94	1.27	1.27	6.82	4.30	16.83	13.00	
KLX13A-117-5c	22.3	10	13.17	1.23	0.88	5.32	4.84	16.37	13.18	
KLX13A-117-7a	21.0	5	23.43	0.96	0.80	5.37	5.07	16.95	16.52	
KLX13A-117-7b	22.8	2	–	–	–	–	–	–	–	Failure in the grout, during test
KLX13A-117-7c	24.5	10	29.28	1.00	0.81	4.37	4.00	13.81	13.71	

[1] The constant normal stress used in the initial shear test of the sealed crack.

Table 5-2. Calculated mean values and standard deviation (Std dev).

	Peak 05 [MPa]	Resid 05 [MPa]	Peak 5 [MPa]	Resid 5 [MPa]	Peak 20 [MPa]	Resid 20 [MPa]
Mean value (all specimens)	0.95	0.81	5.40	4.40	16.33	14.23
Std dev (all specimens)	0.18	0.18	0.76	0.39	1.28	1.42

References

/1/ **SKB, 2001.** Site investigations. Investigation methods and general execution programme. SKB TR-01-29, Svensk Kärnbränslehantering AB.

/2/ **ISRM 1974.** Suggested methods for determining shear strength. Part 2: Suggested method for laboratory determination of direct shear strength. Final draft.

/3/ **Jacobsson L, Flansbjer M, 2006.** Oskarshamn site investigation, Borehole KLX07A, Shear tests on sealed joints, SKB-P05-209, Svensk Kärnbränslehantering AB.

/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.

/5/ **MATLAB, 2002.** The Language of Technical computing, Version 6.5, MathWorks Inc.