P-05-06

Oskarshamn site investigation

Drill hole KSH01A

Normal loading and shear tests on joints

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May 2005

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Keywords: Rock mechanics, Joint test, Normal stiffness, Shear stiffness, Shear strength, Deformation.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author and do not necessarily coincide with those of the client.

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Abstract

Normal loading tests and shear tests on joints on 17 rock specimens from borehole KSH01A in Simpevarp has been carried out. The specimens were taken at four depth levels ranging between 302–312 m, 399–413 m, 479–495 m and 703–706 m. The rock types were Quartz monzodiorite (302–312 m and 703–706 m) and Fine-grained dioritoid (399–413 m and 479–495 m).

Two load cycles with a normal loading to 10 MPa were conducted in the normal loading tests on each specimen in order to investigate the joint stiffness in the normal direction. Moreover, three shear cycles were conducted in the shear tests on each specimen; at 0.5 MPa, 5 MPa and 20 MPa constant normal stress level. The peak and residual shear stresses were deduced from the tests. The specimens were photographed before and after the mechanical tests.

The mean value for the peak shear stress and the residual stress were 0.75 MPa and 0.54 MPa respectively for the 0.5 MPa normal stress level and 3.84 MPa and 3.53 MPa respectively for the 5 MPa normal stress level and 12.91 MPa and 12.14 MPa respectively for the 20 MPa stress level.

Sammanfattning

Normalbelastnings- och skjuvförsök har genomförts på 17 stycken naturliga sprickor i bergprov från borrhål KSH01A i Simpevarp. Proven har tagits från borrkärnor vid fyra djupnivåer 302–312 m, 399–413 m, 479–495 m och 703–706 m. Bergtypen vid dessa nivåer var kvarts monzodiorit (302–312 m och 703–706 m) och finkornig dioritoid (399–413 m och 479–495 m).

Sprickorna belastades med två lastcykler i normalriktningen med en belastning upp till 10 MPa i normalbelastningsförsöken. Vidare genomfördes tre skjuvcykler på sprickorna under skjuvförsöken där en konstant normalspänning på respektive 0,5 MPa, 5 MPa och 20 MPa användes. Toppvärdet och residualvärdet på skjuvspänningen vid de olika normalspänningsnivåerna bestämdes ur dessa försök. Provobjekten fotograferades före och efter de mekaniska proven.

Medelvärdena för toppvärdet och residualvärdet hos skjuvspänningen i de olika skjuvförsöken låg på respektive 0,75 MPa och 0,54 MPa med 0,5 MPa normalspänning, 3,84 MPa och 3,53 MPa med 5 MPa normalspänning och 12,91 MPa och 12,14 MPa med 20 MPa normalspänning.

Contents

1 Introduction

Normal loading and shear tests on joints have been conducted on specimens sampled from borehole KSH01A in Oskarshamn, 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 lead 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 PS 400-03-066 (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 May 2003 and were tested during May 2004. Specimens were cut from cores containing natural fractures and selected based on the preliminary core logging with the strategy to primarily investigate the mechanical properties in joints of the dominant rock types. Two normal loading cycles with loading between 0.5 MPa and 10 MPa was carried out in the normal loading tests in which the normal deformation in the joint was measured. This was followed by three successive shear tests in which the normal stress was kept constant. The normal stress levels were 0.5 MPa, 5 MPa and 20 MPa. 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 tests. The peak and residual shear stress at each shear cycle were determined from the shear tests. No correction of the area due to the shear displacement was made during the shear tests. The specimens were photographed before and after the mechanical testing.

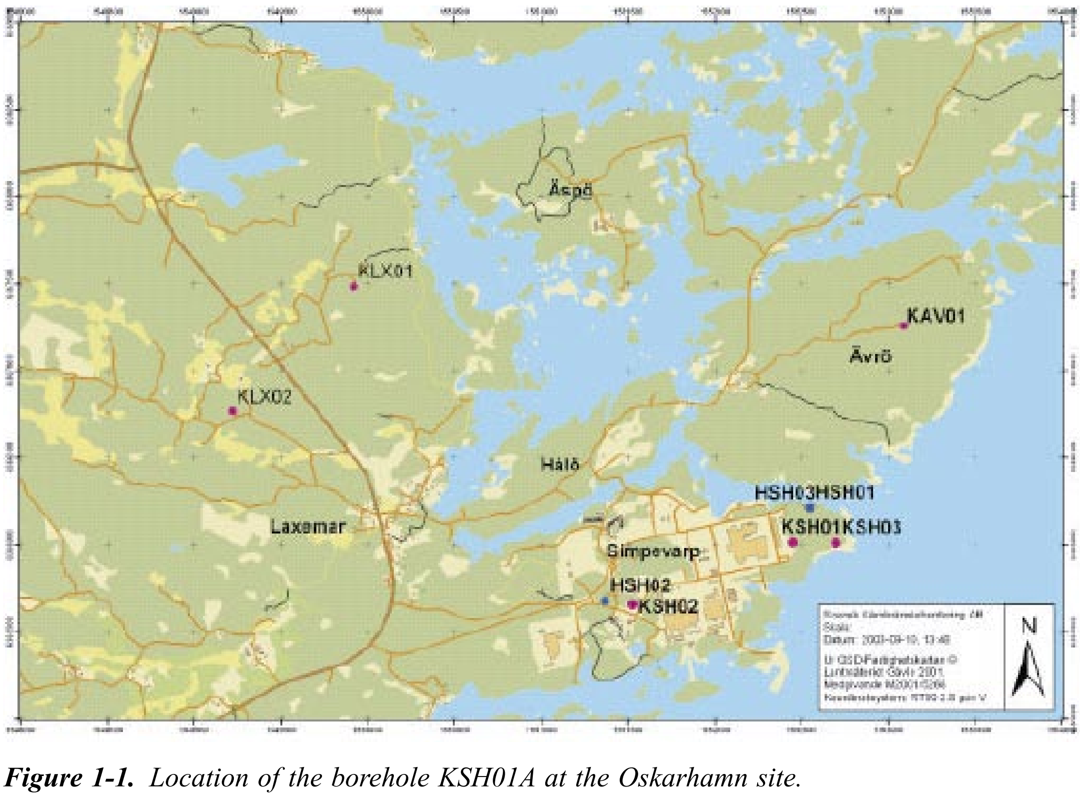


Figure 1-1. *Location of the borehole KSH01A at the Oskarhamn site.*

The method description SKB MD 190.005e, (SKB internal controlling document) was followed for the sampling and for the normal loading and shear tests. The method description is partly based on the ISRM suggested method /1/.

2 Objective and scope

The purpose of the tests in this report is to determine the mechanical properties of natural fractures in rock specimens. The behavior of the joints is investigated during normal loading and shear loading tests. The aim of the normal loading tests is to determine the relation between the normal stress and the normal deformation in the joints. Further, the joint friction represented by the peak and residual shear stresses together with the dilatancy in the joints during shearing at different constant normal stress levels were obtained from the shear tests. The results from the tests are going to be used in the site descriptive the rock mechanics model, which will be established for the candidate area selected for site investigations at Oskarshamn.

The specimens are from the borehole KSH01A, which is a telescope borehole with a bore depth of 1,000 m.

3 Equipment

3.1 Specimen preparation

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

The specimens were cast into steel rings, which serve as specimen holders. A specially designed fixture was used to clamp the two rings in an exact position relative to each other. This is of great importance in order to obtain the correct initial conditions for the tests.

An anchoring grout (cement) was used to cast the specimens. A preliminary test showed that the anchoring grout has a uniaxial compressive strength of about 40–45 MPa.

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 normal loading and shear tests, see Figure 3-1. The machine has two shear boxes, one upper and one lower. The upper box can be moved vertically and the lower can be moved 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 used for the guidance of 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. 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 the four vertical 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, i.e. load frame and digital controller unit.*

4 Execution

The normal loading and shear tests were carried out according to the method description SKB 190.005e, (SKB internal controlling document). The test method follows ISRM Suggested methods for determining shear strength /1/.

4.1 Description of the samples

The rock type characterisation was made according to Stråhle /2/ 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
KSH01A-117-1	302.48	302.59	Quartz monzodiorite
KSH01A-117-2	305.74	305.85	Quartz monzodiorite
KSH01A-117-3	308.58	308.74	Quartz monzodiorite
KSH01A-117-4	311.75	311.86	Quartz monzodiorite
KSH01A-117-5	312.17	312.27	Quartz monzodiorite
KSH01A-117-8	399.58	399.70	Fine-grained dioritoid
KSH01A-117-9	402.21	402.34	Fine-grained dioritoid
KSH01A-117-10	413.31	413.46	Fine-grained dioritoid
KSH01A-117-12	479.37	479.51	Fine-grained dioritoid
KSH01A-117-14	485.65	485.76	Fine-grained dioritoid
KSH01A-117-16	488.37	488.46	Fine-grained dioritoid
KSH01A-117-18	490.32	490.45	Fine-grained dioritoid
KSH01A-117-20	494.06	494.18	Fine-grained dioritoid
KSH01A-117-22	495.45	495.55	Fine-grained dioritoid
KSH01A-117-25	703.97	704.10	Quartz monzodiorite
KSH01A-117-26	705.00	705.08	Quartz monzodiorite
KSH01A-117-27	706.83	706.97	Quartz monzodiorite

4.2 Specimen preparation

The specimens were cut out from rock cores and the dimensions used for the calculation of the joint area was determined and each specimen was photographed.

The specimens were cast in steel holders, which consist of one upper and one lower half, using a fast hardening anchoring grout (cement). The different steps during the casting are displayed in Figure 4-1. The specimen halves are positioned relative to each other such that the two specimen pieces best fit together implying that the fracture or joint is optimally

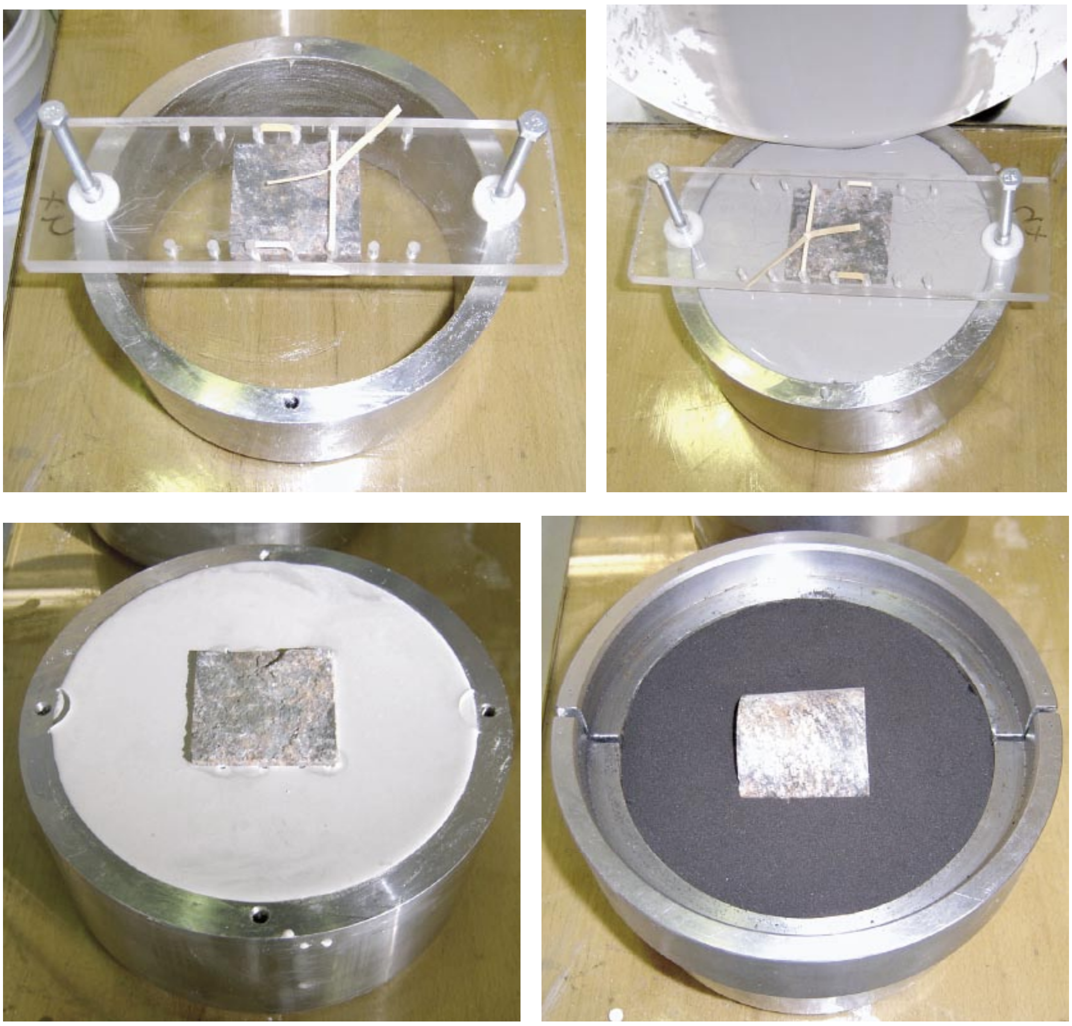


__Figure 4-1.__ Upper left: Specimen holder (steel ring) with the rock specimen. The specimen is fixed in the right level and is ready for casting. Upper right: The cement is poured into the ring. Lower left: After hardening. Lower right: Two joining pieces acting as distance holders and centering device are laid on top of the steel ring. The mating rock piece is put on top of the bottom one and a 10 mm layer of compacted sand is used to fill up the space between the two parts. The second steel ring (not shown) is then mounted on top and the joining pieces clamping the two rings in a fixed position are tightened. The upper ring is finally filled with cement.

closed. This will be termed the zero or the initial position for the shear displacement in conjunction with the shear tests. An overview of the activities during the specimen preparation is shown in the step-by-step description in Table 4-2.

Table 4-2. Activities during the specimen preparation.

Step	Activity
1	Mark the drill cores at the position of the joints that is selected for testing.
2	Cut out the specimens from the cores according to the specified markings.
3	Measure the specimen dimensions and calculate the joint surface area.
4	Take digital photos on each specimen.
5	Cast the specimens into the specimen holders.

4.3 Mechanical testing

The holders containing the cast specimens were mounted in the shear boxes. Two load cycles, with a normal loading between 0.5 MPa and 10 MPa, were conducted in the normal loading tests on each specimen. The normal stress and deformation in the joint were recorded in these tests.

Three successive shear tests at constant normal stress levels, 0.5, 5 and 20 MPa respectively, were carried out directly after the normal loading tests. A shear cycle starts with applying a prescribed level of the normal stress followed by applying a shear deformation with a given deformation rate. The shear loading is stopped when the shear deformation in the actual shear cycle reached a certain value and the shear stress is unloaded. The criterion for ending a shear cycle is to stop the shear deformation when the deformation has reached three times the value that the shear deformation attained at the peak shear stress for the actual shear cycle. If this criterion was not met before the shear deformation reached 5 mm for the particular shear cycle, the shear loading was stopped anyway. If the total shear deformation exceeded 5 mm before the third shear cycle was about to start, the shear box was moved to the original initial position. This was done by first unloading the normal stress to 0.2 MPa whereupon the shear box was repositioned to zero shear deformation. The normal and shear stresses together with the normal and shear deformations were recorded during the test.

A form was filled in for each specimen containing specimen dimensions. Further, the form also contains comments and observations during the different test steps. Moreover, a check-list was filled in during the work in order to confirm that the different specified steps have been carried out. The check-list form is a SP internal quality document.

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

Table 4-3. Activities during the mechanical testing.

Step	Activity
1	Mount the specimen holders in the shear testing machine.
2	Apply 0.5 MPa normal stress and zero the channels for the normal deformation measurement. Perform the normal loading tests with two load cycles. The specified loading/unloading rate is 10 MPa/min.
3	Perform the shear tests at the three constant normal stress levels 0.5 MPa, 5 MPa and 20 MPa:
	a) Apply a normal stress of 0.5 MPa and zero the channels for the deformation measurement.
	b) Increase the normal stress to the prescribed value for the actual shear cycle.
	c) Apply a shear deformation with a rate of 0.5 mm/min until the shear displacement reaches the stop criterion.
	d) Unload the shear stress to zero.
	e) Continue with item b).
	Repeat this for the three shear cycles. Restore the shear deformation to the initial position if the total shear deformation after the second shear cycle is larger than 5 mm.
4	Take out the specimens from the shear boxes.
5	Take digital photos on each specimen.
6	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 /3/. Moreover, MATLAB was used to produce the diagrams shown in Section 5.1 and in Appendix A. The computation of the mean values of the different parameters in Section 5.2 was carried out using MS Excel. MS Excel was also used for reporting data to the SICADA database.

4.5 Analyses and interpretation

As to the definition of the different results parameters we begin with the normal σ_N and shear stresses σ_S which are defined as

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

where F_N is the normal force and F_S force acting on the joint and A is area of the 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 are determined. The peak value is defined as the maximum value during the whole shear cycle and the residual value is defined as the mean value of the last 0.5 mm of the shear cycle before the unloading of the shear stress. The normal and shear displacements are denoted as δ_N and δ_S, respectively.

A part of the measured normal deformation in the normal loading tests and a part of the measured shear deformations in the shear tests belong to the deformations in the in the cement and in the contact surfaces between the specimen holders and the shear boxes. The deformation measured during the normal loading test not belonging to the deformation in the joints is denoted the system deformation $\delta_{N,system}$. By knowing the system deformation, the joint deformation can be obtained as

$$\delta_{N,joint} = \delta_{N,total} - \delta_{N,system} \tag{1}$$

where $\delta_{N,total}$ is the normal displacement registered during the normal loading tests containing the joint displacement $\delta_{N,joint}$. The system deformation in the normal loading test has significance on the obtained results and will be thoroughly discussed below. The system deformation during the shear test is assumed to be negligible for the results.

Two reference tests, where a steel cylinder with 60 mm diameter and 50 mm height was cast in the holders instead of a rock specimen, were conducted in order to determine the magnitude of the deformation in the system (cement and contact areas). The specimen was subjected to normal and shear loading, see Appendix A. The dimensions of the steel cylinder was chosen such that it will represent an average rock specimen with respect to the cross sectional area and casting depth into the specimen holders. The normal loading tests were carried out with loading up to two force levels, approximately 28 and 110 kN. The lower level corresponds to a 10 MPa normal stress for the steel cylinder. The higher load level corresponds to the force that is applied for specimens that have a large joint area. The two normal loading tests were carried out starting with the lower force level followed the higher force level. A shear test was conducted after the normal loading tests with an increasing shear deformation up to and beyond failure.

It is seen that the response during loading and unloading displays a non-linear behaviour. Moreover, a large part of the permanent deformation is developed during the first load cycle. This can be seen both in the reference test and in the tests on joints. The cement deforms and cause residual deformations after unloading. The different contact areas deform as well. The first load cycle can thus be considered as a conditioning load cycle. The residual deformation is only slightly increasing during the second load cycle. The results from the second load cycle are the most suitable for finding an appropriate correction of the results. The results will be corrected according to (1). Further, the results from the second load cycle are most likely most suitable for evaluating the behaviour in the joints as well. We will use the data from the second load cycle in the reference test to account for the system deformations in the joint tests.

The test results will be arranged such that a supposed starting point of the second load cycle starts from zero normal displacement at complete unloading, i.e. $F_N = 0$. In order to do so we first make an assumption that the point at complete unloading before the loading at the second load cycle is obtained as the linear extension of a secant line, which is drawn between the experimentally obtained starting and end points of the loading curve for the second cycle. The normal deformation in the point when $F_N = 0$ is denoted $\delta_{N,0}$. Hence, the data can be shifted by subtracting the value $\delta_{N,0}$ from normal displacement results. The maximum normal displacement during the second load cycle when both the loading and the deformation start from zero is denoted $\delta_{N,max}$.

Normalized normal force and normal deformation are introduced as

$$\overline{F}_{\mathrm{N}} = \frac{F_{\mathrm{N}}}{F_{\mathrm{N,max}}} \text{ and } \overline{\delta}_{\mathrm{N}} = \frac{\delta_{\mathrm{N}}}{\delta_{\mathrm{N,max}}} \tag{2}$$

where $F_{N,max}$ is the maximum normal force for the actual load cycle in the normal loading test and $\delta_{N,max}$ was defined above. The results from the normal loading tests with a steel specimen using the normalized force and normal deformation are shown in Figure 4-2.

The results from the reference test with the two load cycles are divided into four segments: loading 1, unloading 1, loading 2 and unloading 2. It can be noted that the results from second load cycle at the normal loading tests at both load levels are quite similar when the results are displayed with normalized variables. Furthermore, the response during loading at the second load cycle is close to linear and a suitable approximation for this part is

$$\overline{\delta}_{\mathrm{N}} = \overline{F}_{\mathrm{N}} \tag{3}$$

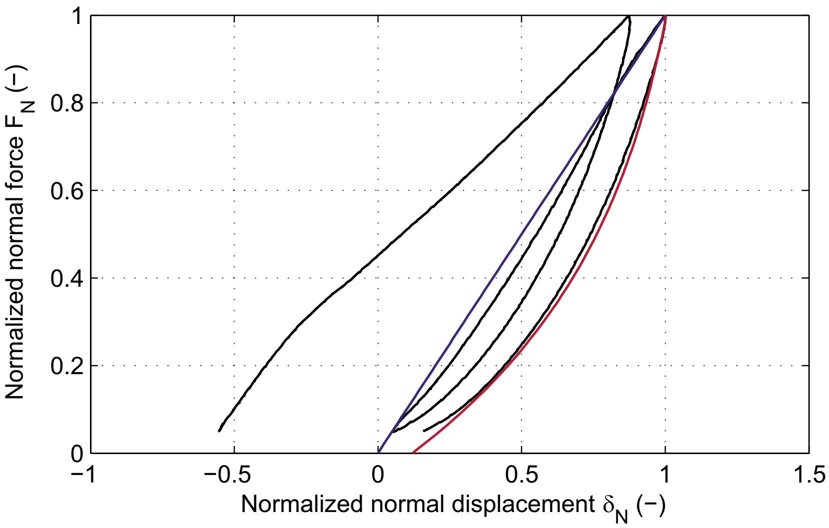
whereas the unloading response displays a non-linear behaviour and can be approximated with an exponential expression according to

$$\overline{\delta}_{\mathrm{N}} = A\left[1 - \exp\left(-B \cdot \overline{F}_{\mathrm{N}}\right)\right] \tag{4}$$

where A and B are constants that are determined from the experiments. It is found that A = 1.03 and B = 1.95 are suitable. The fit of the approximating functions are shown in Figure 4-2. These functions were used to represent the loading and unloading segments of both load cycles for the references tests. Moreover, a relation between $\delta_{N,max}$ and $F_{N,max}$ was found as

$$F_{N,max} = K\ \delta_{N,max}$$

with K = 230 kN/mm as a representative value for the reference tests. The results presented in Section 5 are processed segment-by-segment according to the methodology outlined above using (1) to (4), in order to find the true joint deformations.



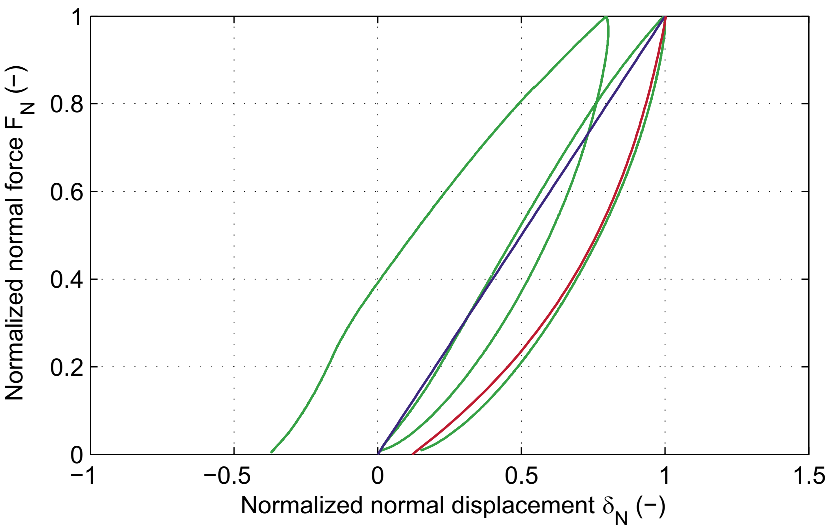


Figure 4-2. *Results from normal loading tests on a steel specimen. The upper diagram is showing the normalized results from the 28 kN normal load cycle (black) and the lower diagram is showing the normalized results from the 110 kN normal load cycle (green). The blue curve is the linear approximation for the loading of the second load cycle and the red curve is the non-linear approximation for the unloading of the second load cycle.*

5 Results

The results of the testing of the 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, FN 96. 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 specimen

The specimens and joints before casting and after testing are shown on pictures. Comments on observations appeared during the testing are reported. The results are shown in diagrams. The upper diagrams show the results from the normal loading tests. The black curve displays the measured data and the red curve displays the adjusted data, cf Section 4.5. The diagrams in the middle show the results from the shear tests and the lower diagrams show the joint dilation during the shear tests.

Two methods were used during the shear tests. The three shear cycles were supposed to be carried out successively without repositioning the shear displacement to the starting position after every cycle. The shear box was repositioned to the starting position before the third shear cycle was conducted in some tests when the shear displacement exceeded about 5 mm after the second load cycle. The green curves show the results from the restarted shear tests. Furthermore, the red triangle markers show the peak shear stresses and the red square markers show the residual stresses.

Specimen ID: KSH01A-117-1

Before mechanical test

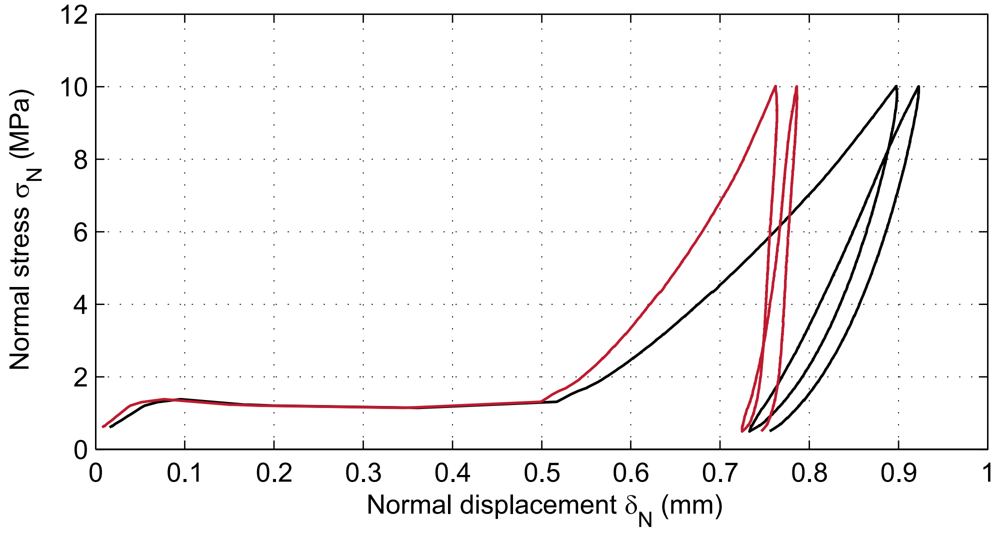
After mechanical test

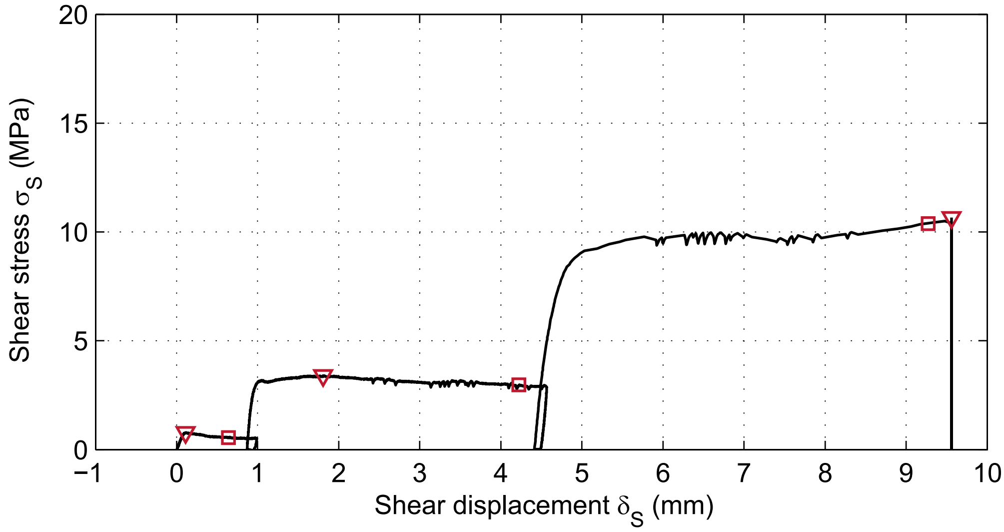
 

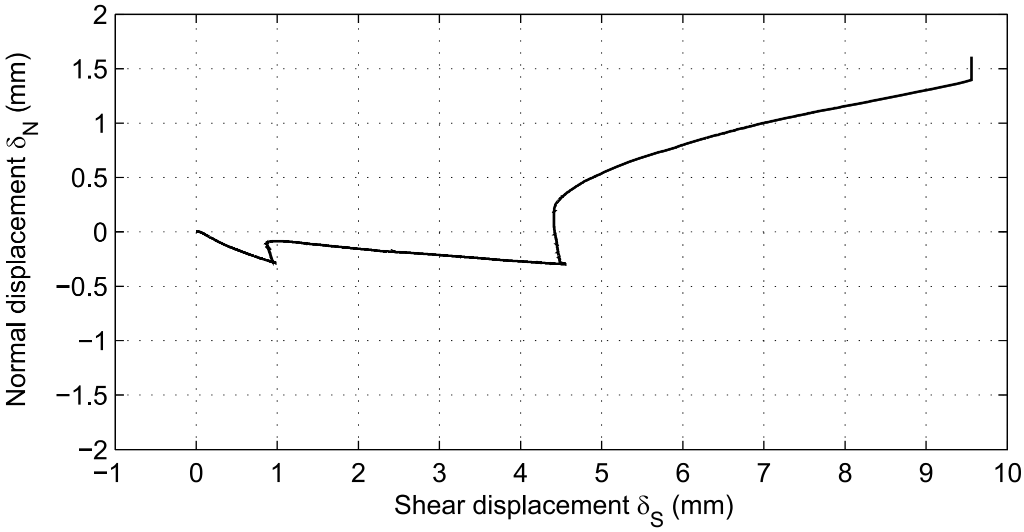
Comments The rock specimen in the upper half has cracked on the edge of the rear end.

Specimen ID: KSH01A−117−01

Shear area : 37.3 cm^2

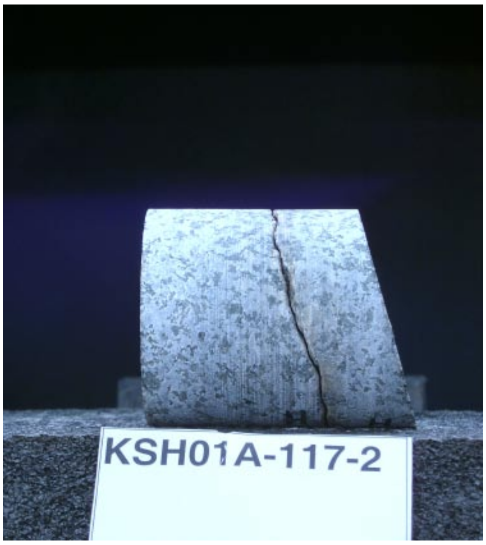


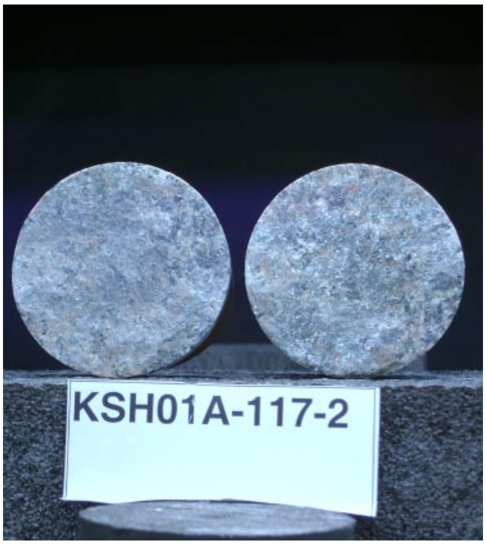




Specimen ID: KSH01A-117-2

Before mechanical test



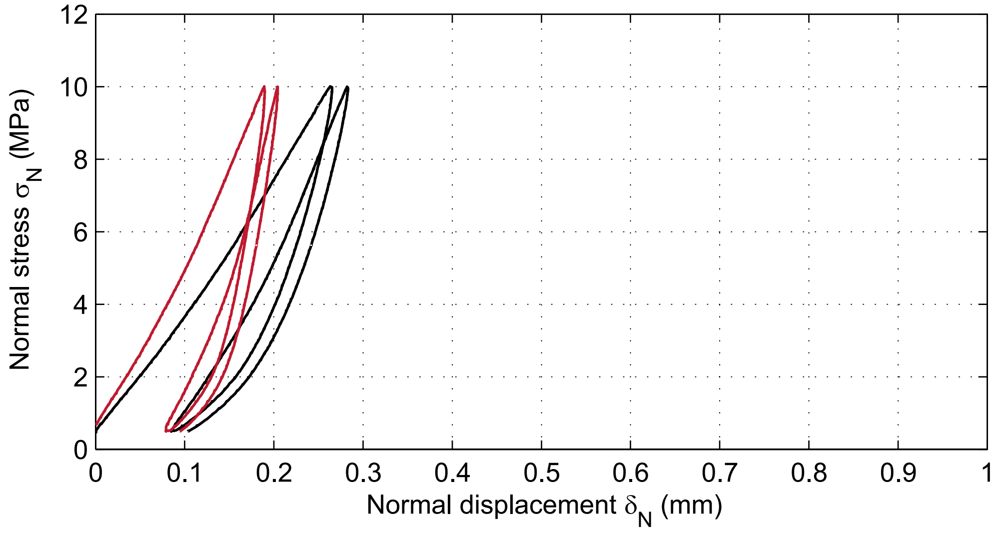


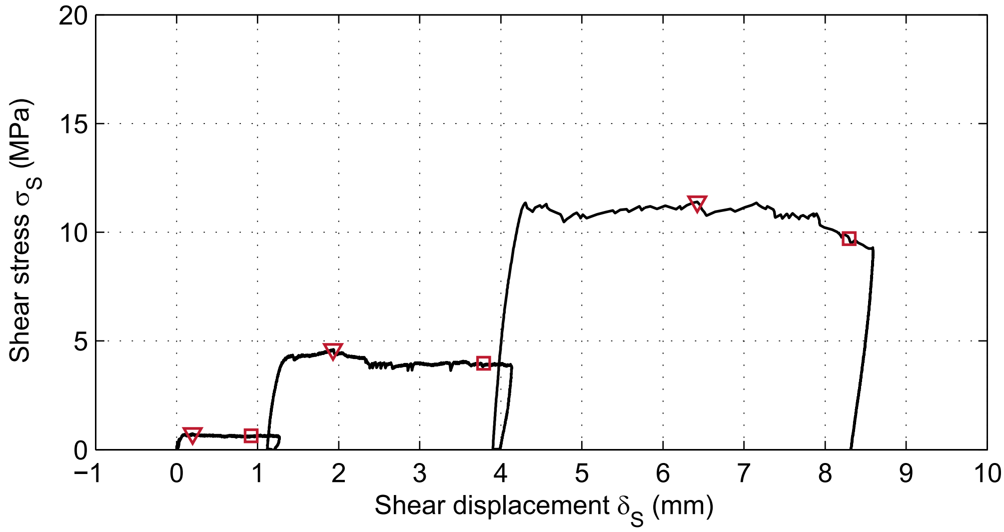
After mechanical test

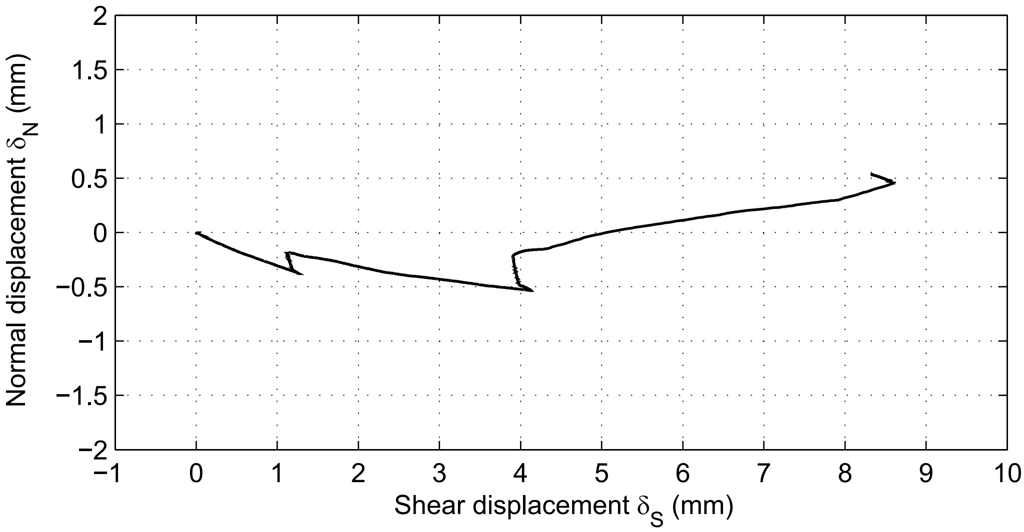
Comments The rock specimen in the upper half has cracked.

Specimen ID: KSH01A−117−02

Shear area : 20.3 cm^2







Specimen ID: KSH01A-117-3

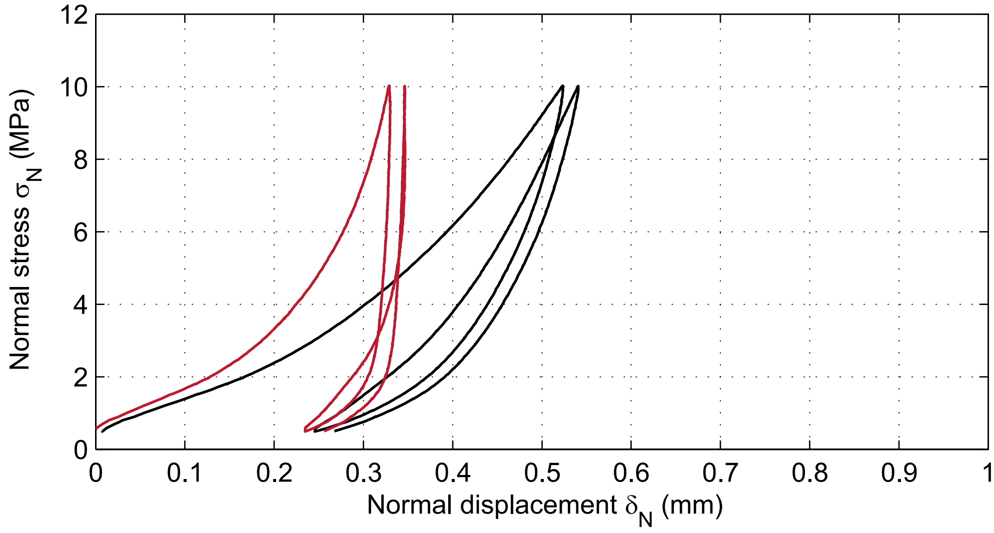
Before mechanical test

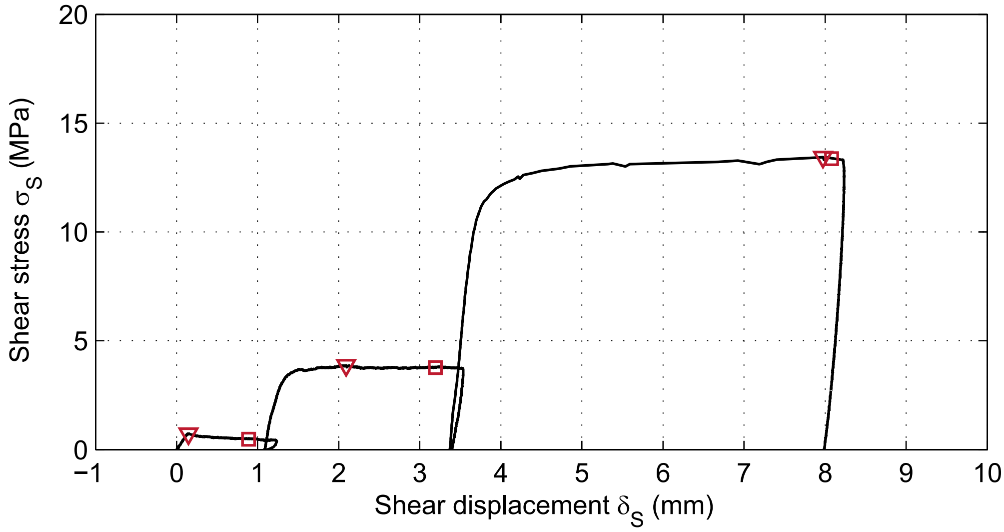
After mechanical test

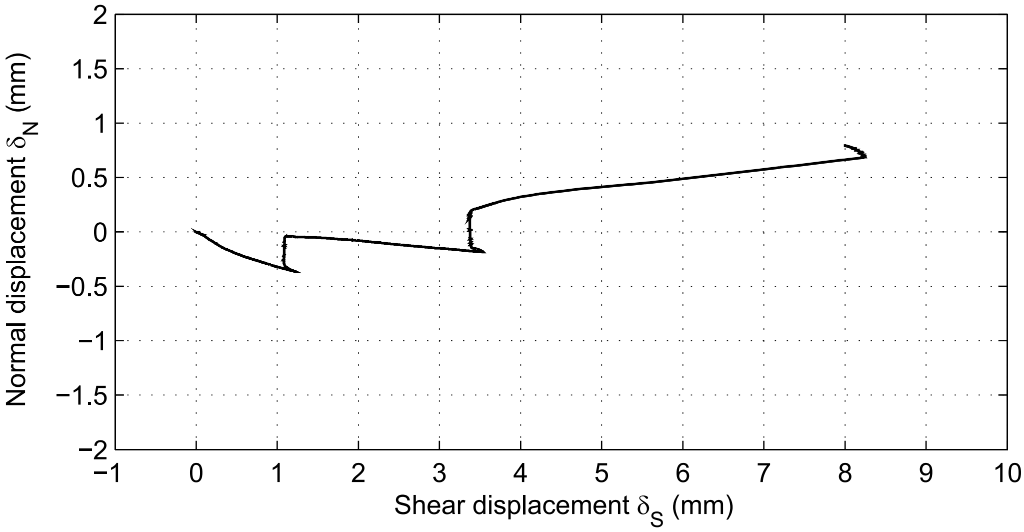
Comments The rock specimen in the lower half has cracked in many places and has lost the attachment to the cement.

Specimen ID: KSH01A−117−03

Shear area : 53.5 cm^2







Specimen ID: KSH01A-117-4

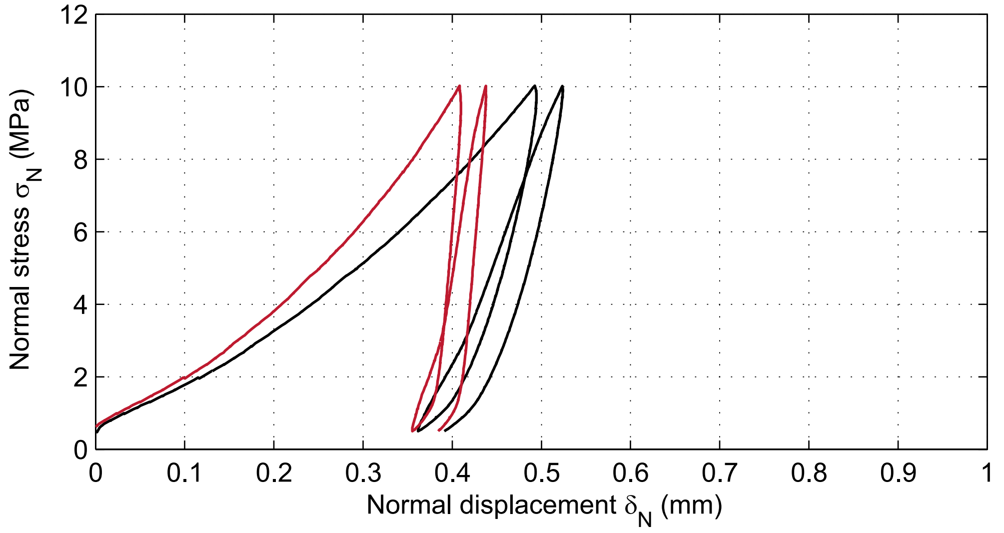
Before mechanical test

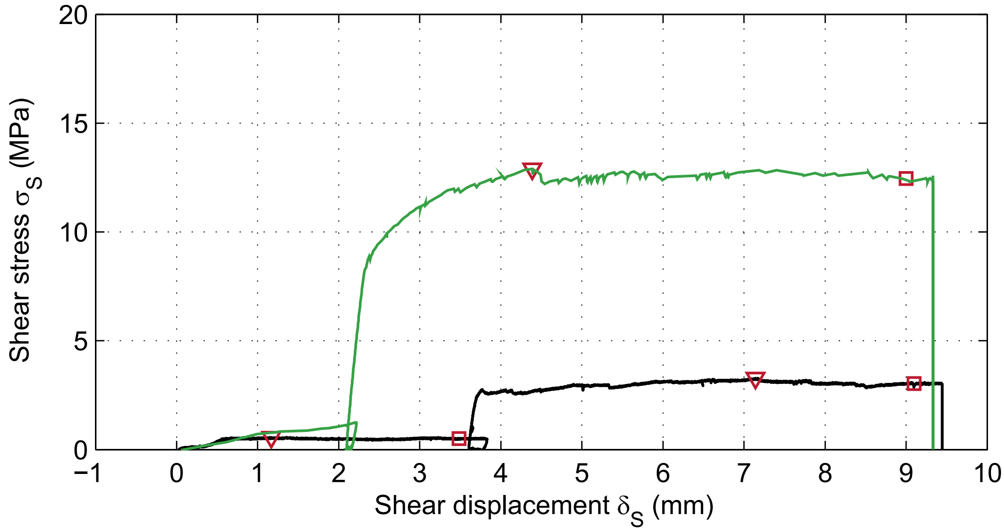

After mechanical test

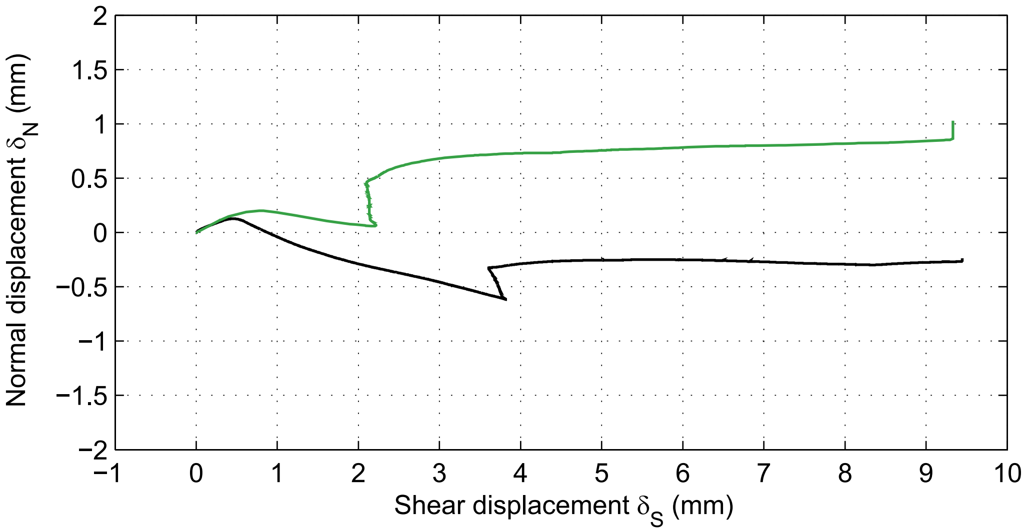

Comments

Specimen ID: KSH01A−117−04

Shear area : 23.2 cm^2







Specimen ID: KSH01A-117-5

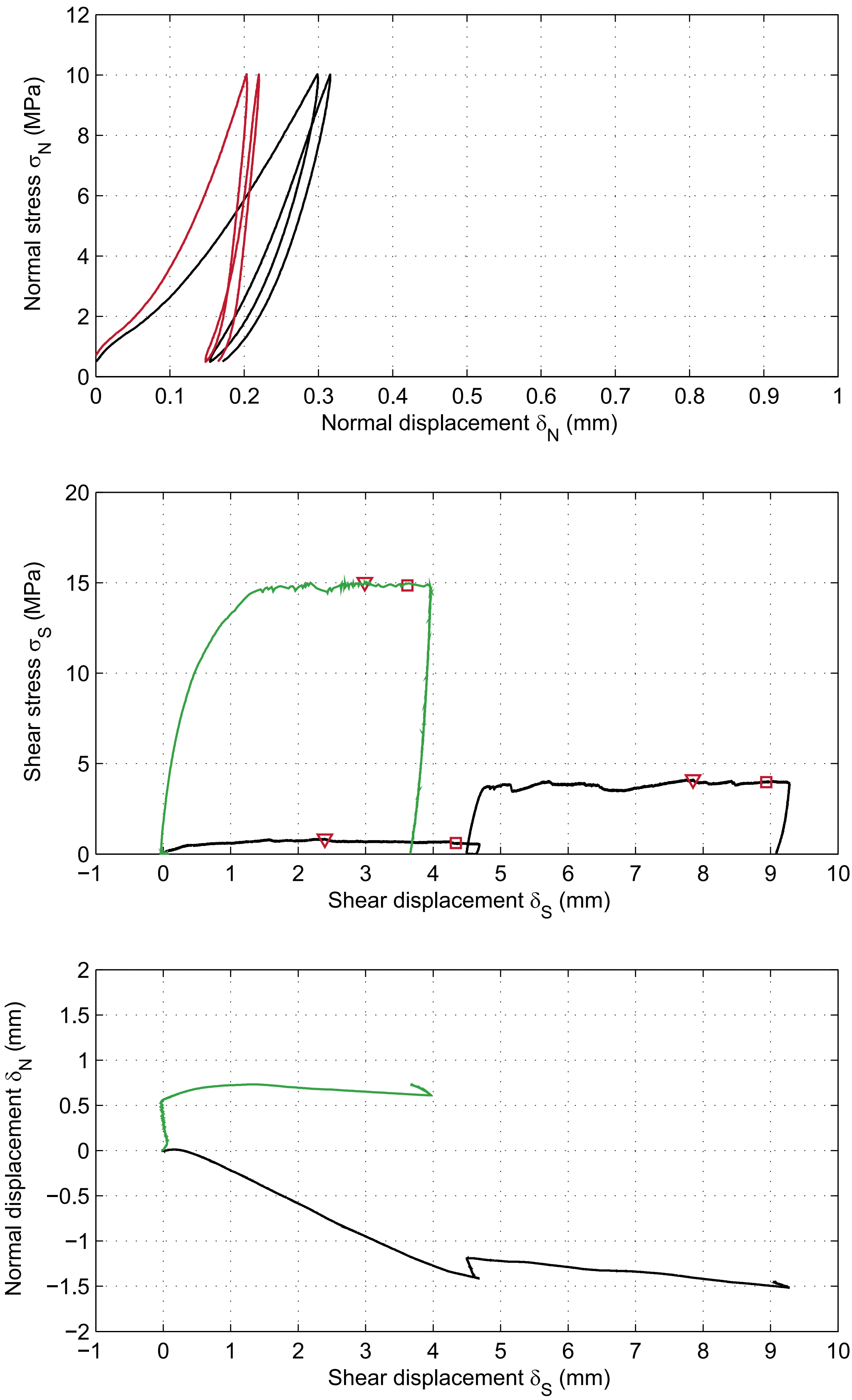
Before mechanical test

After mechanical test

Comments Lower specimen half has cracked in one place. The crack is thin and perpendicular to the shear direction.

Specimen ID: KSH01A−117−05

Shear area : 26.3 cm^2



Specimen ID: KSH01A-117-8

Before mechanical test

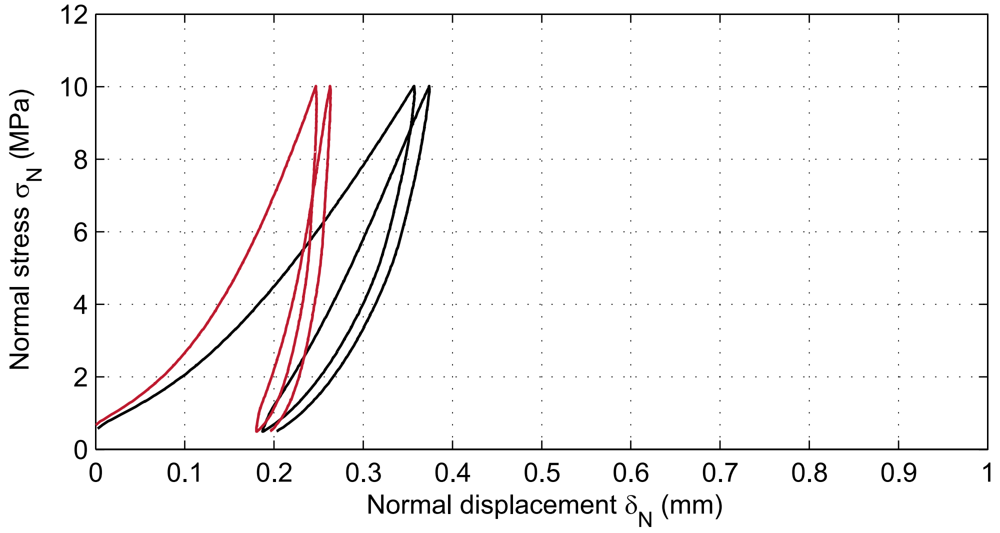
After mechanical test

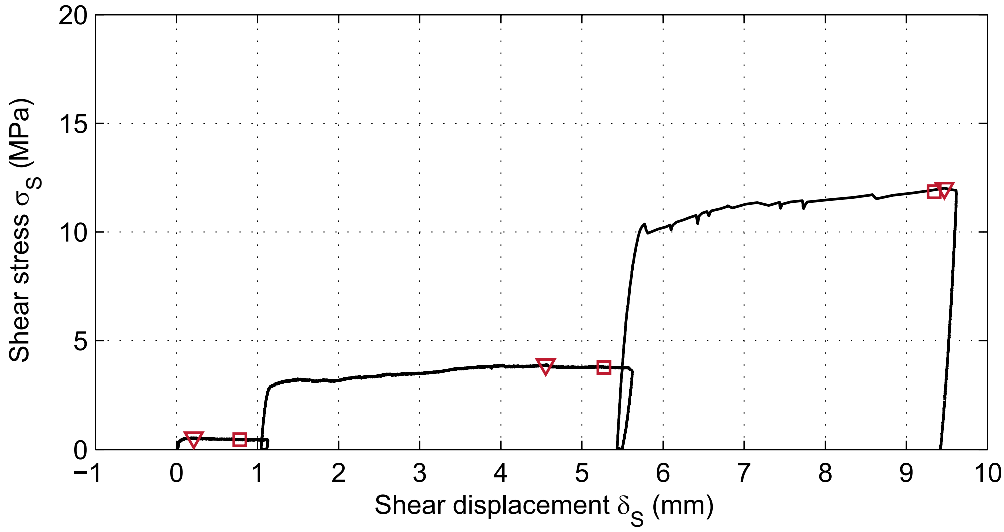
 

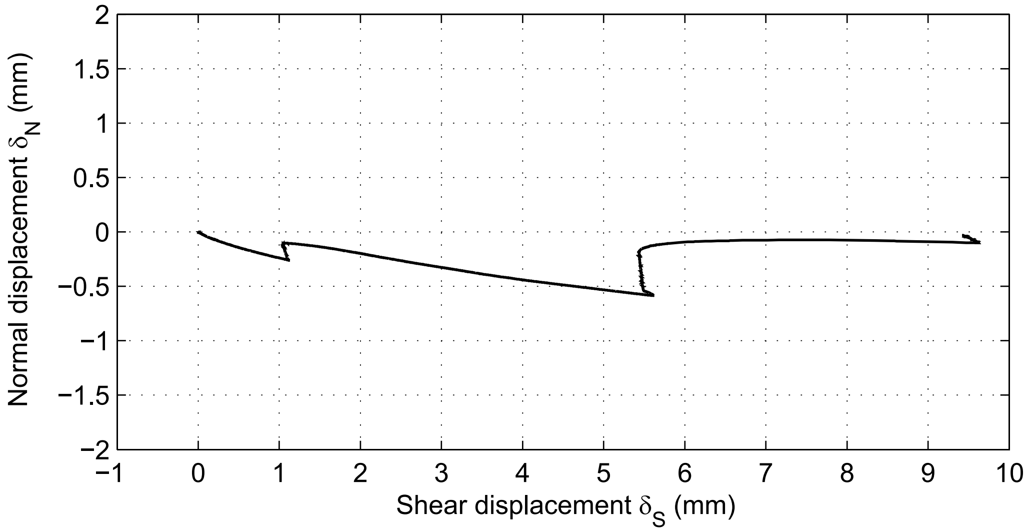
Comments

Specimen ID: KSH01A−117−08

Shear area : 30.3 cm^2



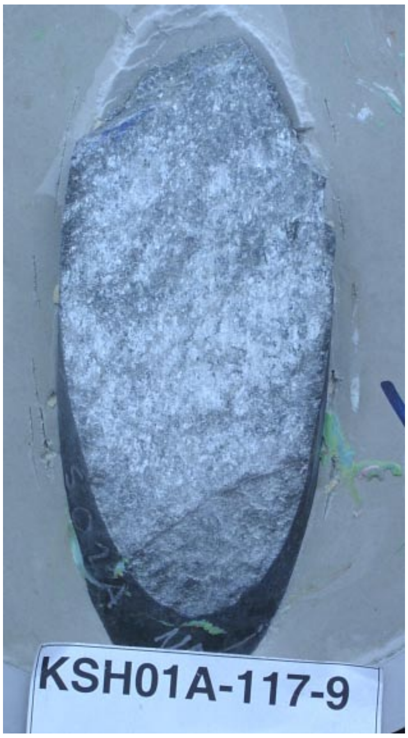




Specimen ID: KSH01A-117-9

Before mechanical test

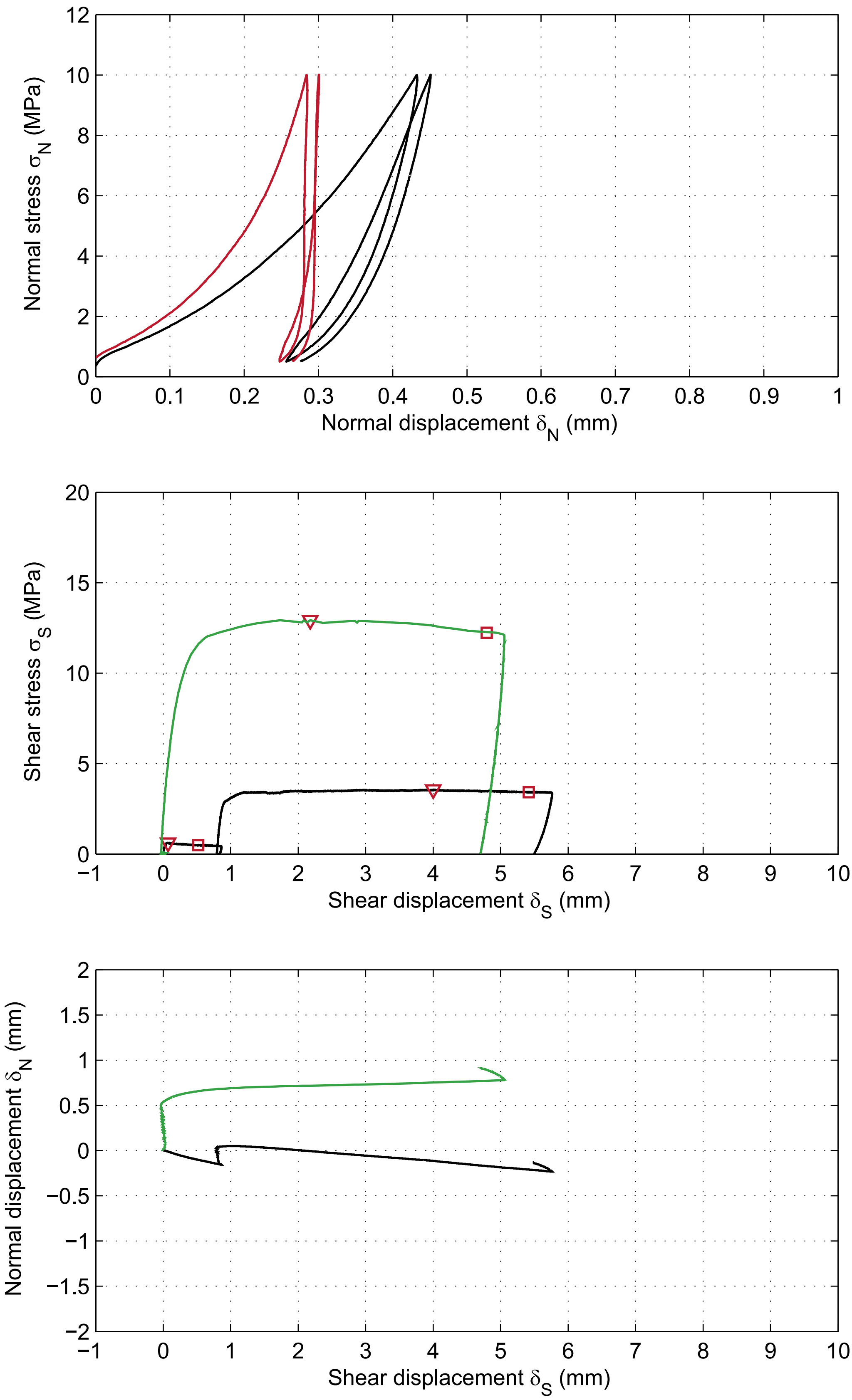

After mechanical test



Comments Lower specimen half has cracked on the edge of the end. Upper half has cracked in many places and lost the attachment to the cement.

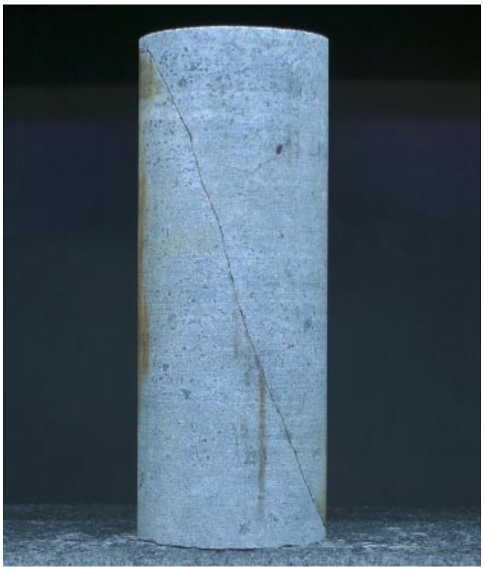
Specimen ID: KSH01A−117−09

Shear area : 41 cm^2



Specimen ID: KSH01A-117-10

Before mechanical test

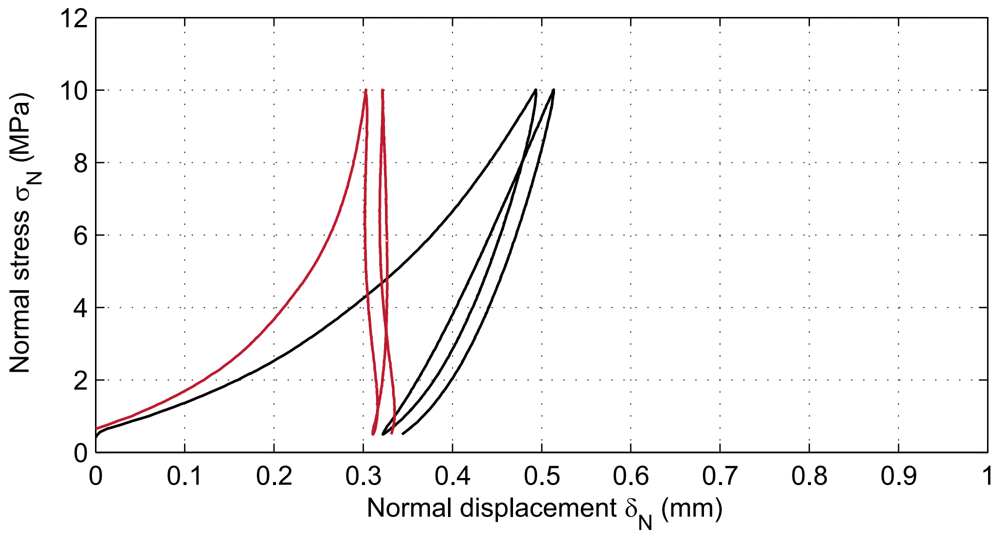


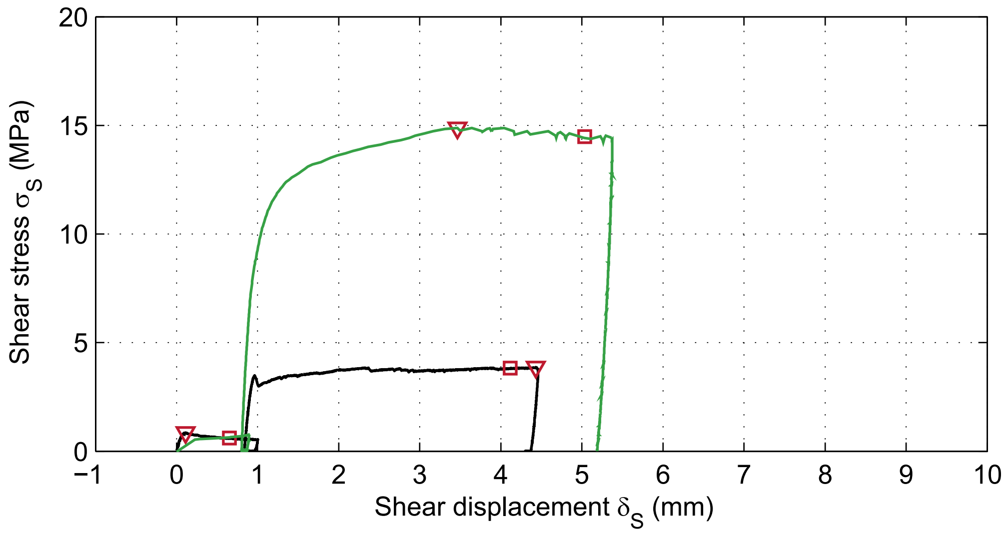
After mechanical test

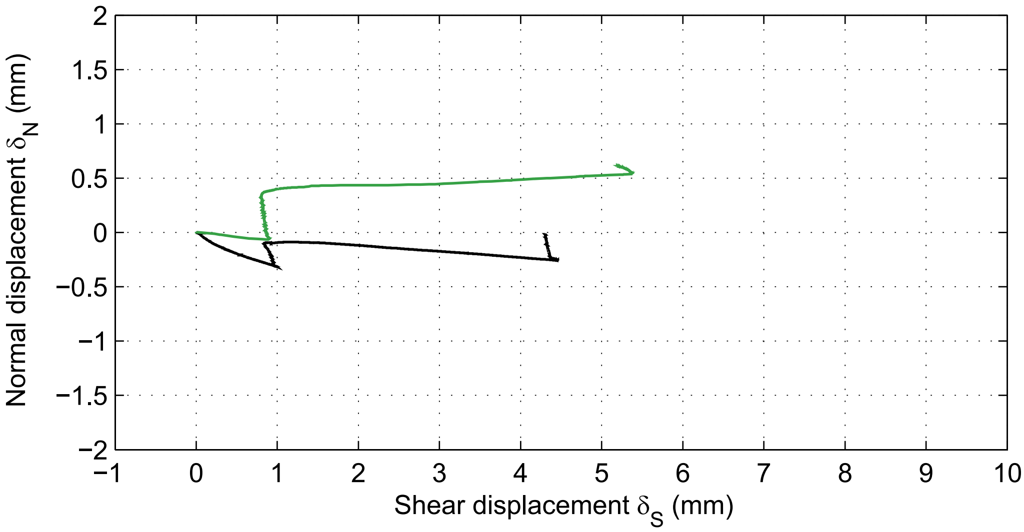
Comments Lower specimen half has cracked on the edge of the end.

Specimen ID: KSH01A−117−10

Shear area : 52.5 cm^2







Specimen ID: KSH01A-117-12

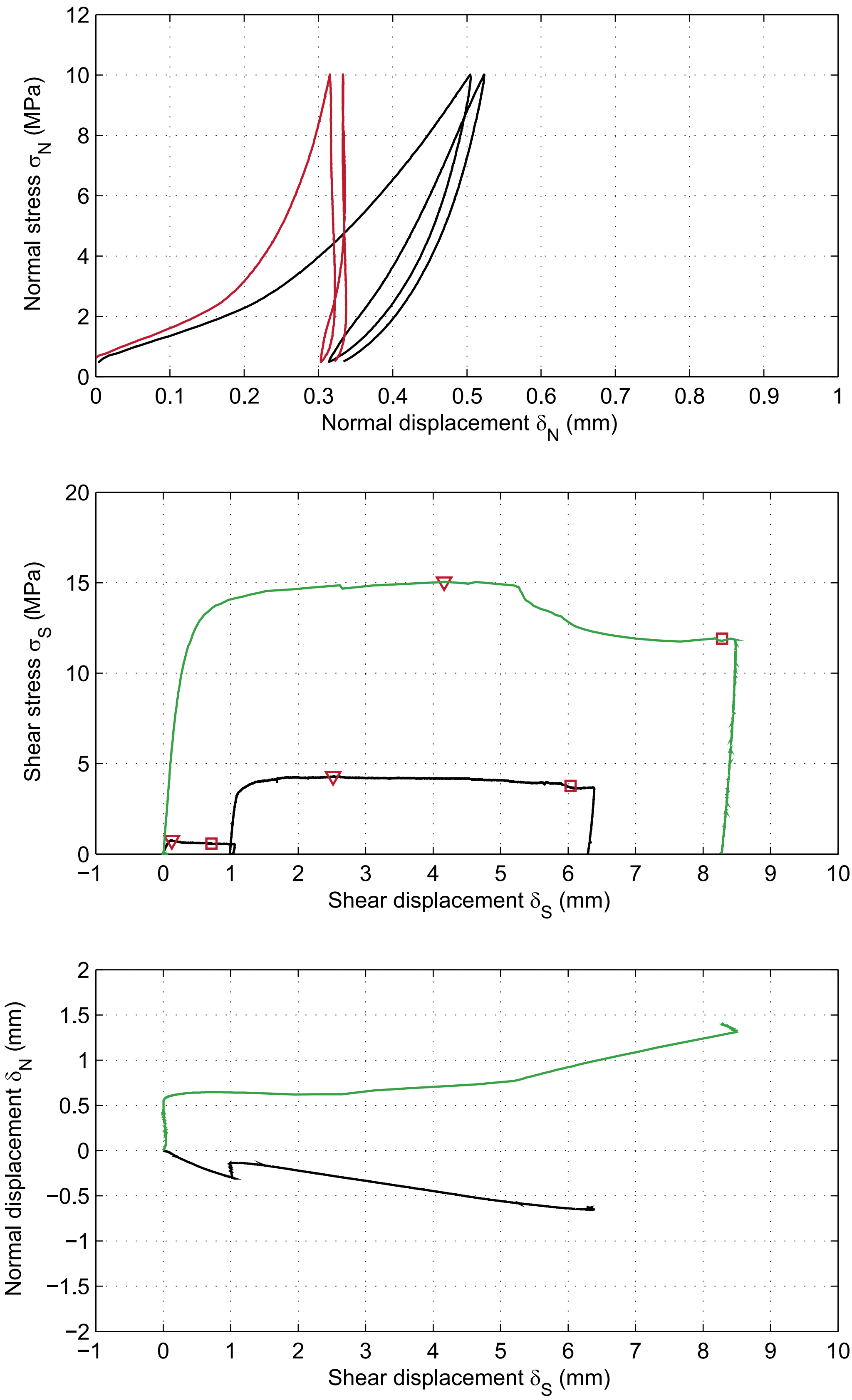
Before mechanical test


After mechanical test


Comments	Upper half: The cement has cracked behind the specimen in the shear direction and the specimen has lost its attachment to the cement.

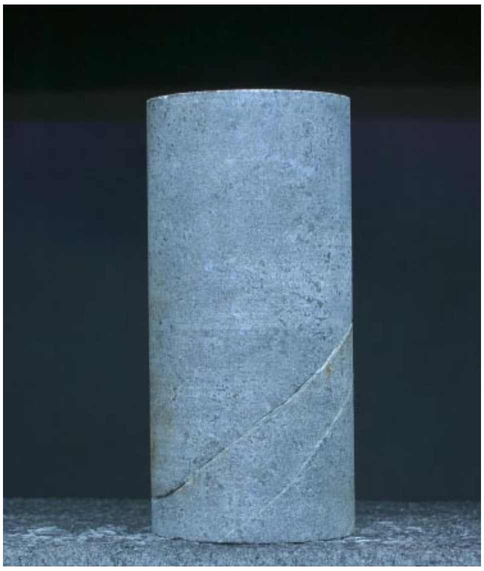
Specimen ID: KSH01A−117−12

Shear area : 52.1 cm^2



Specimen ID: KSH01A-117-14

Before mechanical test

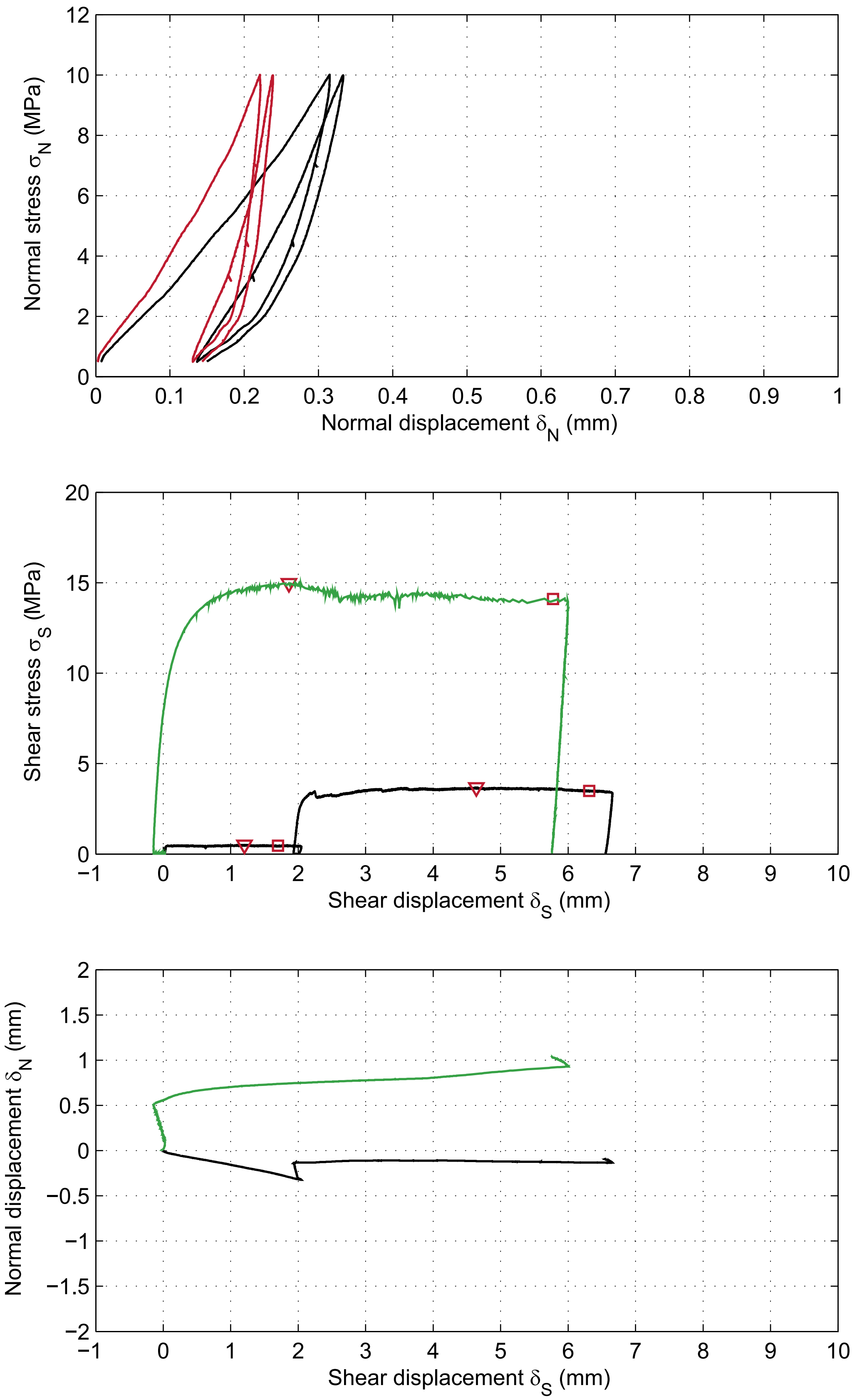


After mechanical test

Comments Lower specimen half has cracked in one place. The crack is thin and perpendicular to the shear direction.

Specimen ID: KSH01A−117−14

Shear area : 25.8 cm^2



Specimen ID: KSH01A-117-16

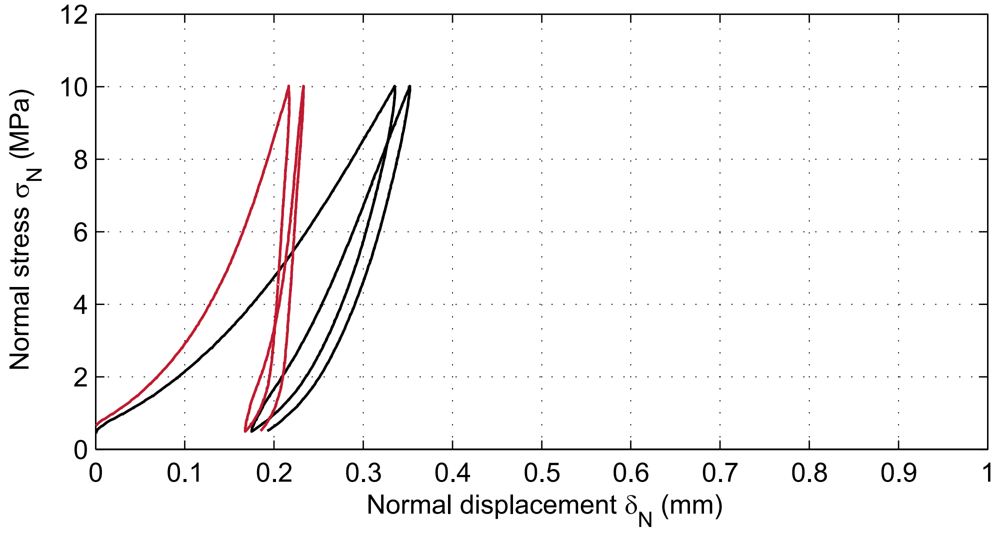
Before mechanical test

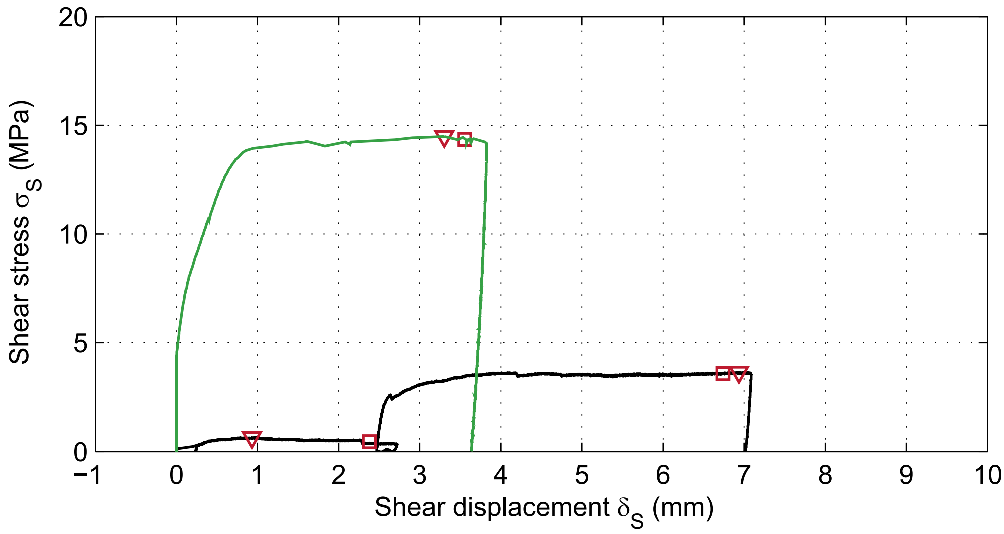
After mechanical test

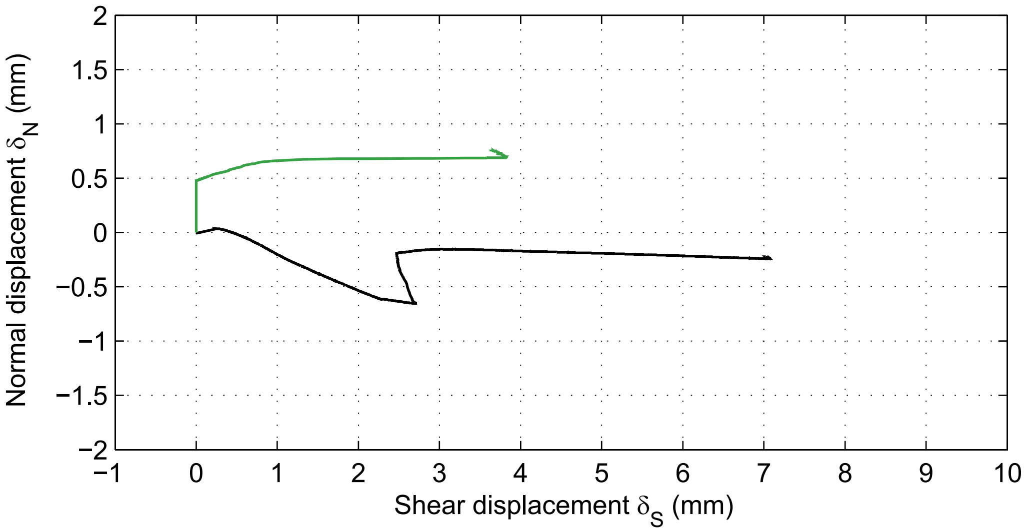
Comments The specimen has small cracks in both upper and lower parts.

Specimen ID: KSH01A−117−16

Shear area : 32.7 cm^2

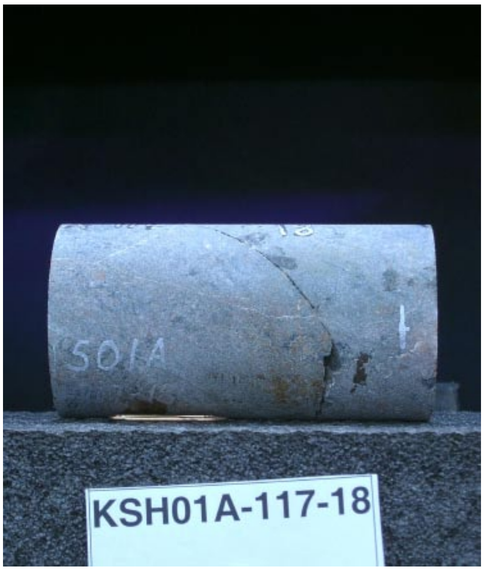






Specimen ID: KSH01A-117-18

Before mechanical test

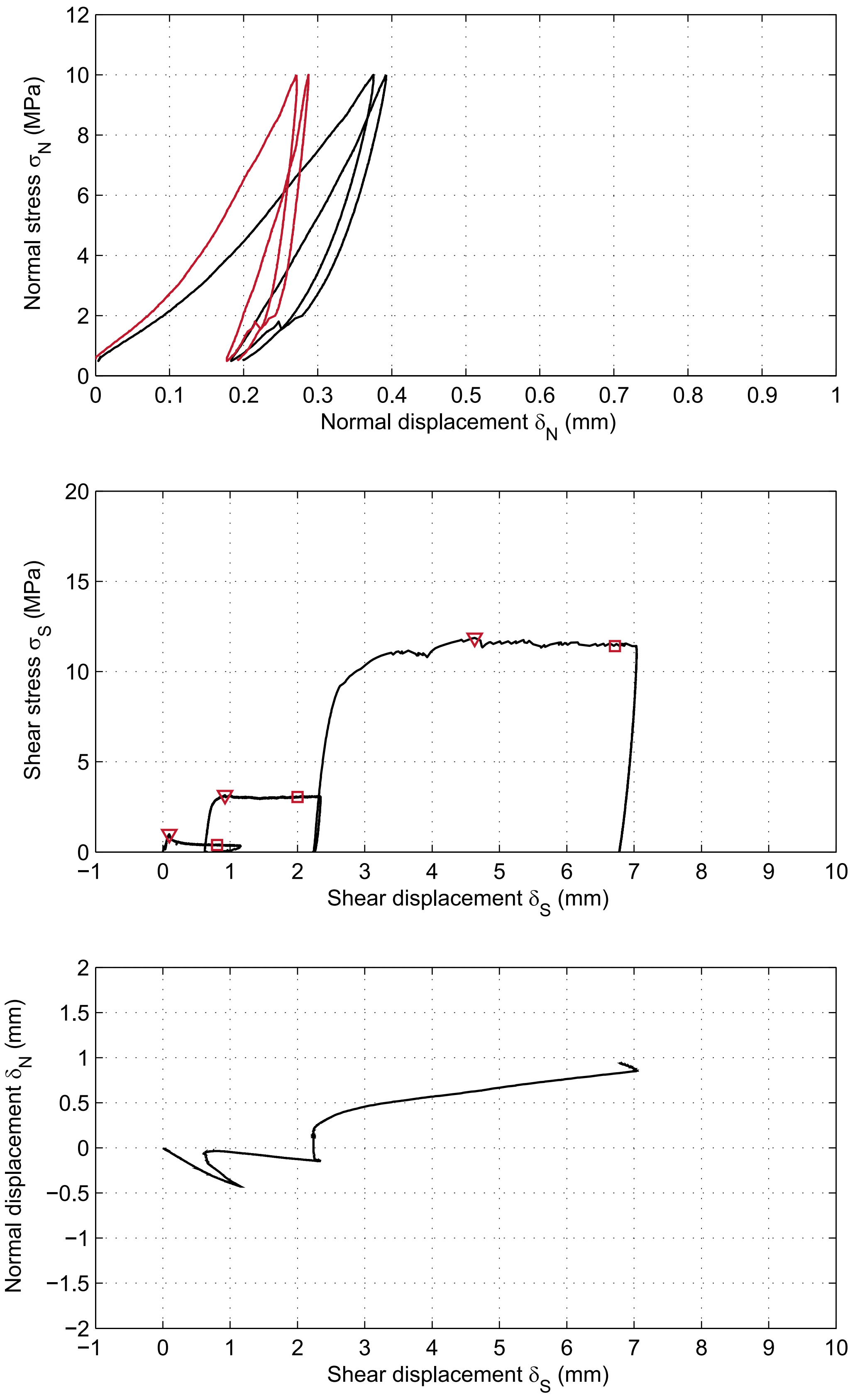


After mechanical test

Comments	Upper half: The specimen has cracked. Lower half: The specimen has cracked on the edge of the end.

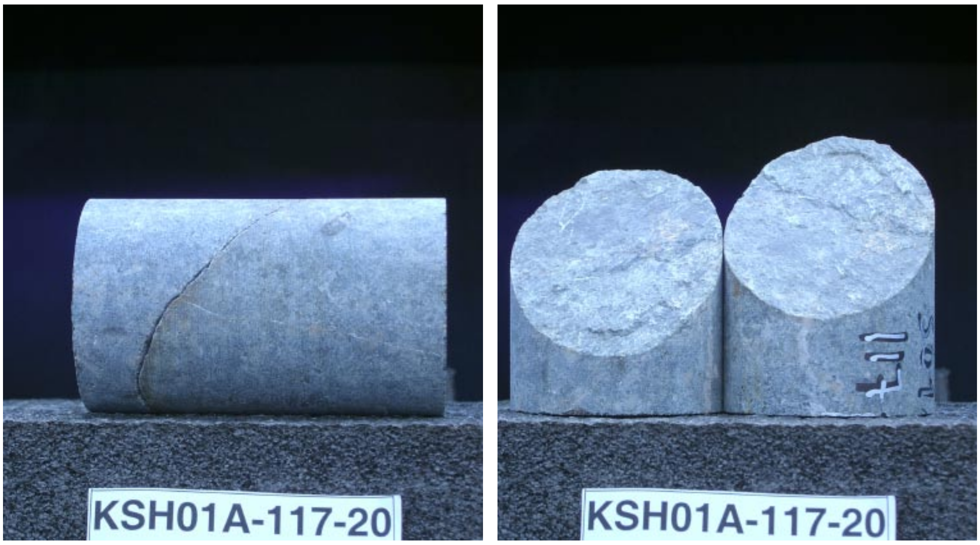
Specimen ID: KSH01A−117−18

Shear area : 28.6 cm^2

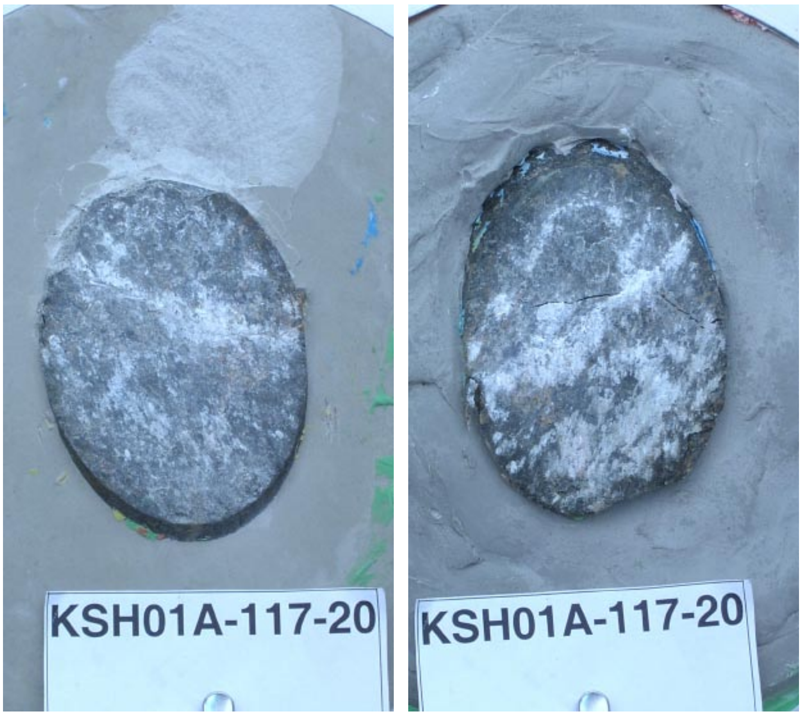


Specimen ID: KSH01A-117-20

Before mechanical test



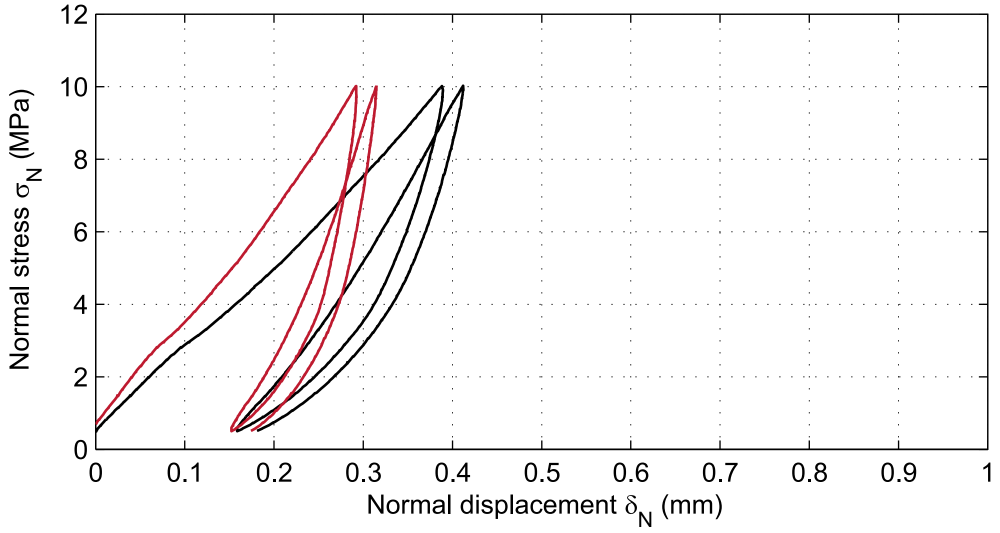
After mechanical test

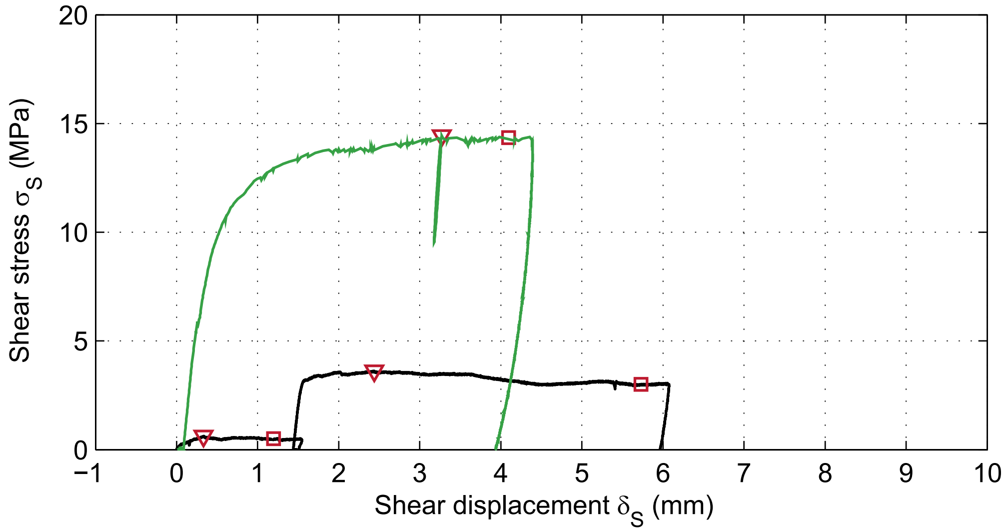


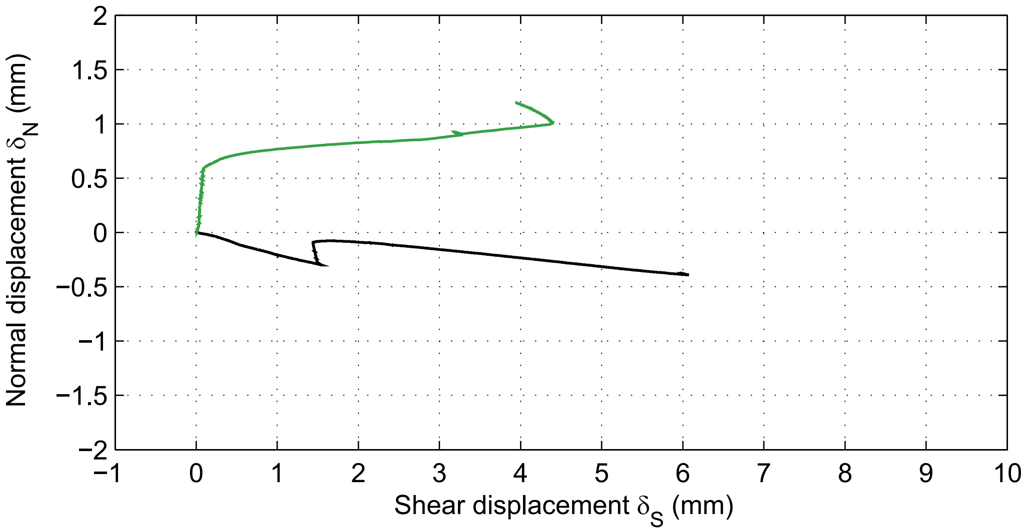
Comments Lower half: The specimen has cracked in many places and a part has lost the attachment to the cement. Upper half: The specimen has cracked in two places.

Specimen ID: KSH01A−117−20

Shear area : 26.6 cm^2







Specimen ID: KSH01A-117-22

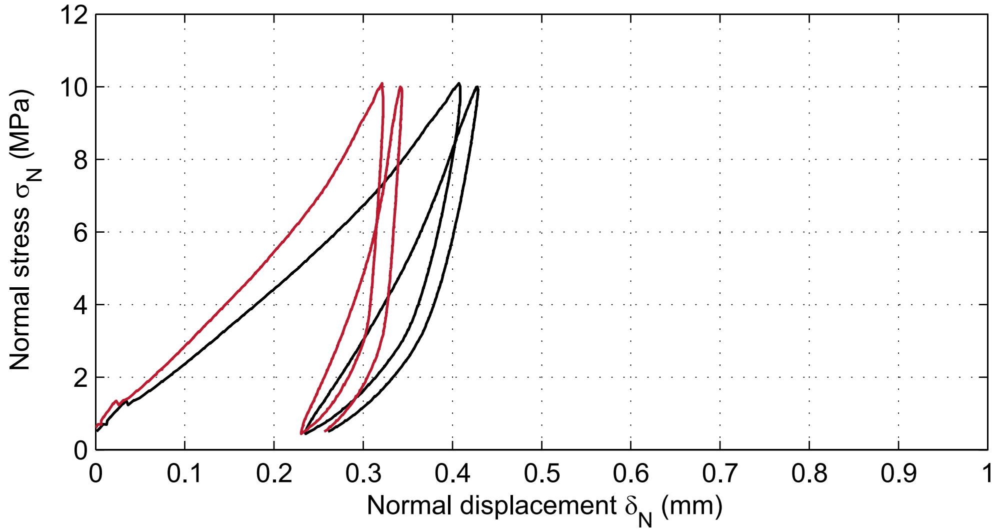
Before mechanical test

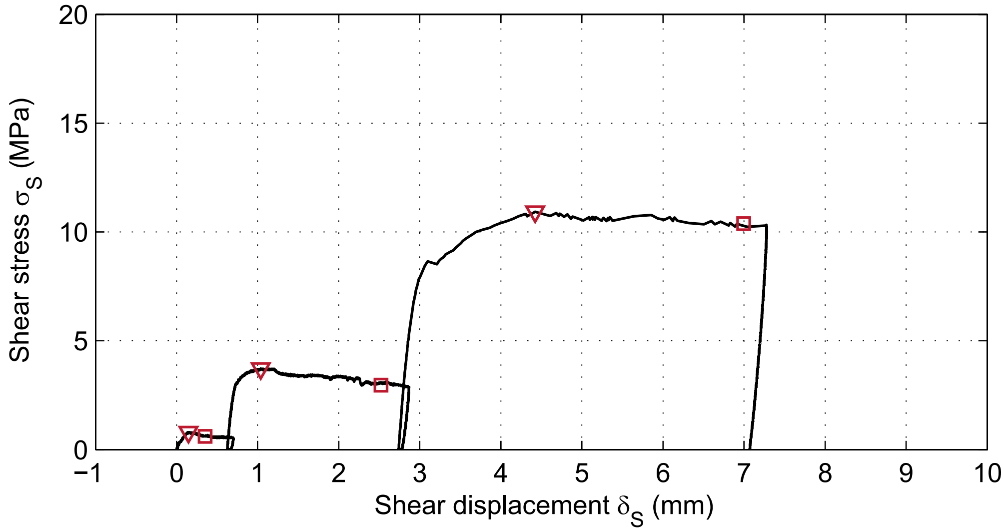
After mechanical test

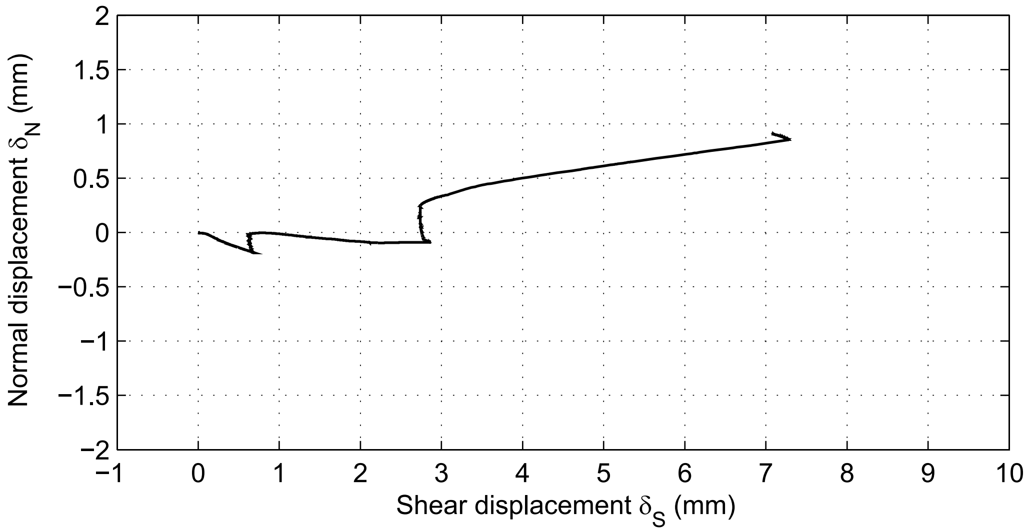
Comments Upper half: The specimen has cracked in many places.

Specimen ID: KSH01A−117−22

Shear area : 23.5 cm^2







Specimen ID: KSH01A-117-25

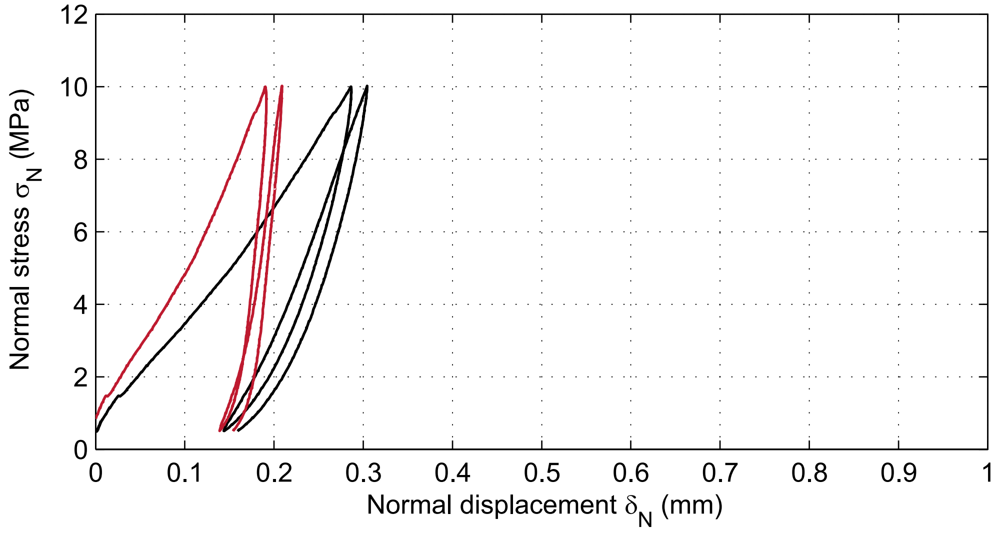
Before mechanical test

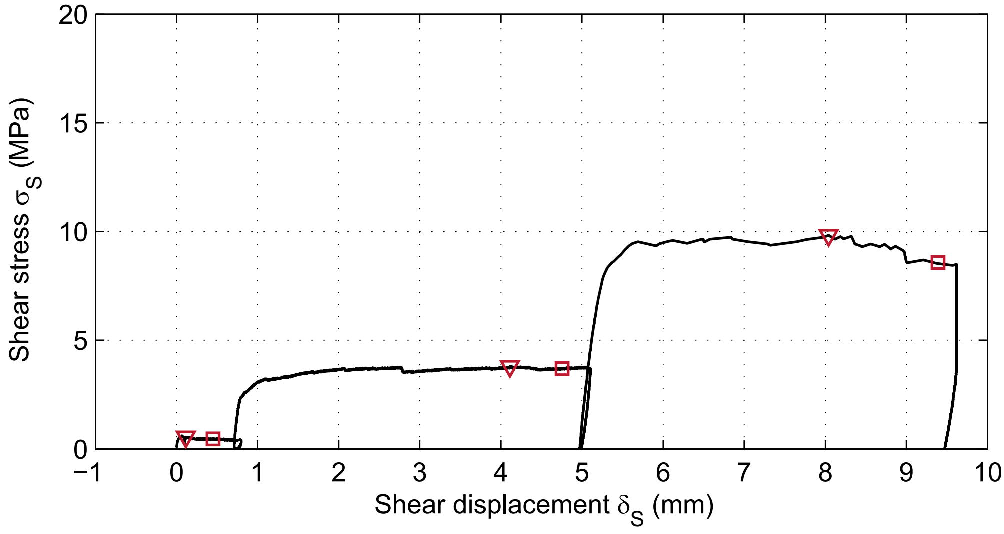
After mechanical test

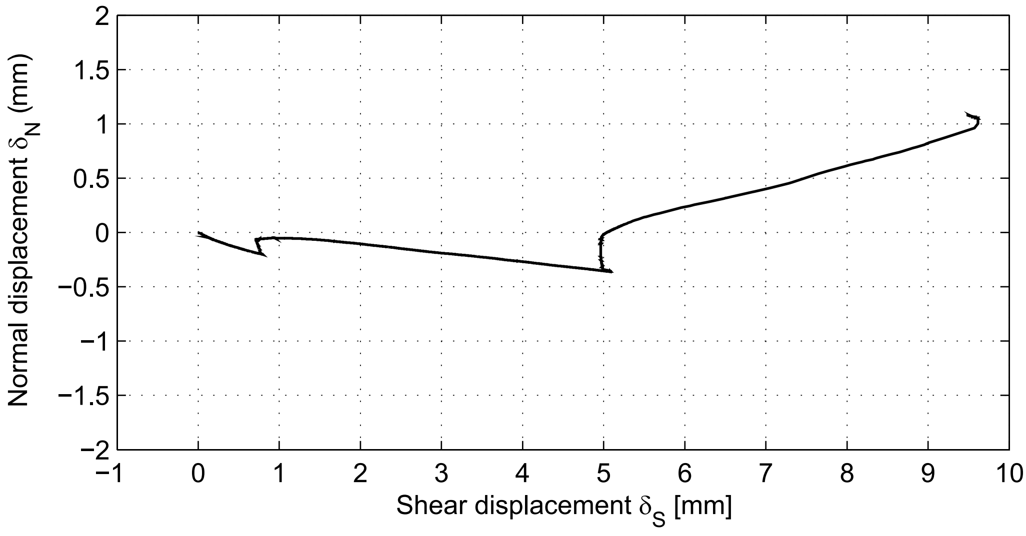
Comments Upper half: A protruding part of specimen has been crushed. Lower half: The specimen has cracked on the edge of the end.

Specimen ID: KSH01A−117−25

Shear area : 26.5 cm^2

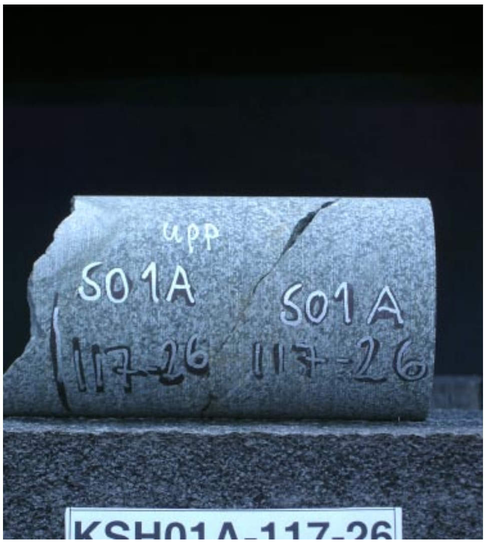


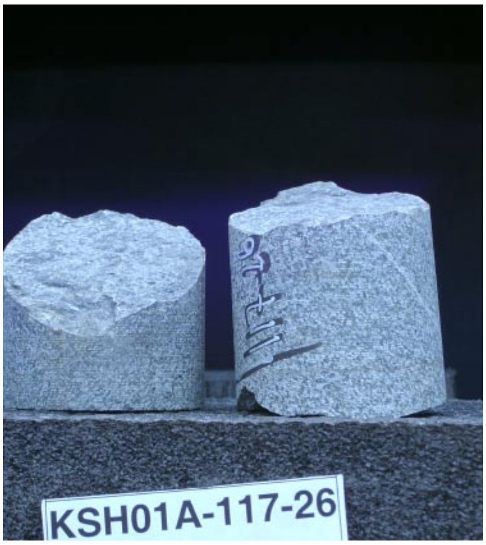




Specimen ID: KSH01A-117-26

Before mechanical test



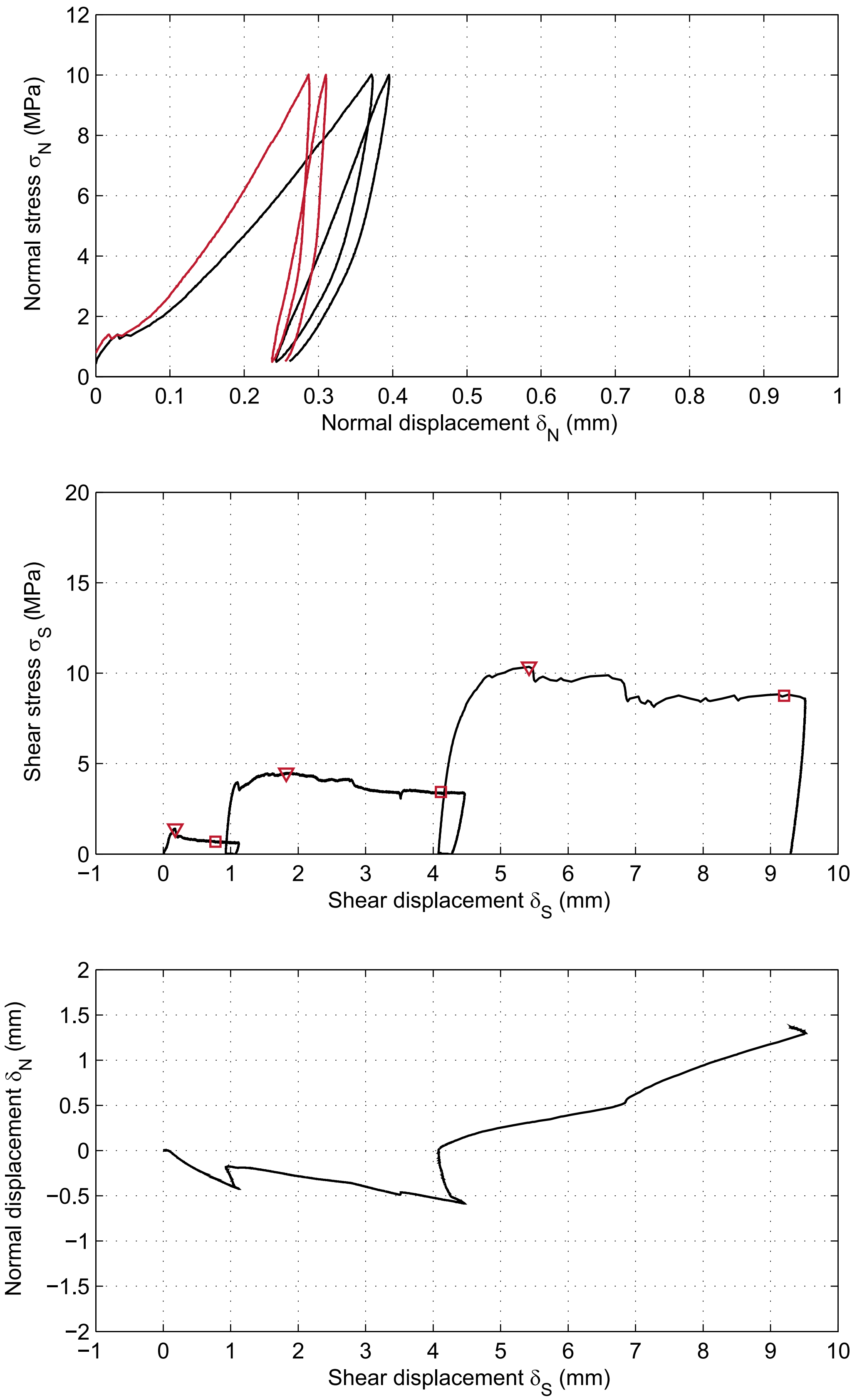


After mechanical test

Comments Upper half: The specimen has cracked in many places in the rear end.

Specimen ID: KSH01A−117−26

Shear area : 23.4 cm^2



Specimen ID: KSH01A-117-27

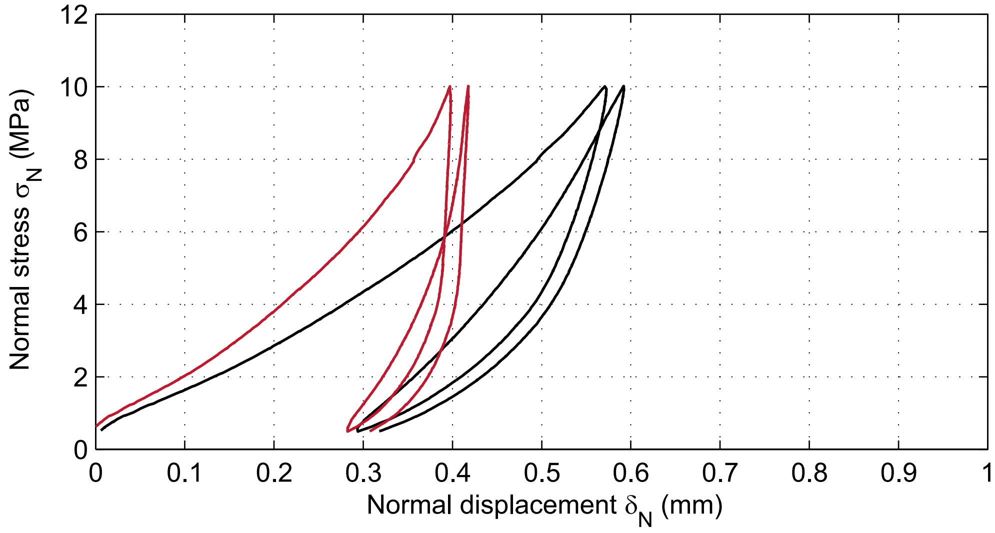
Before mechanical test

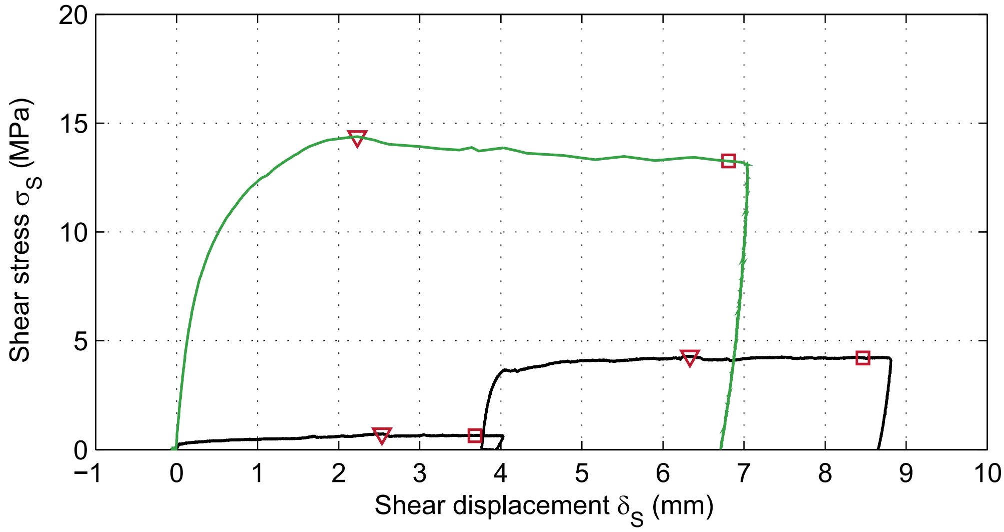
After mechanical test

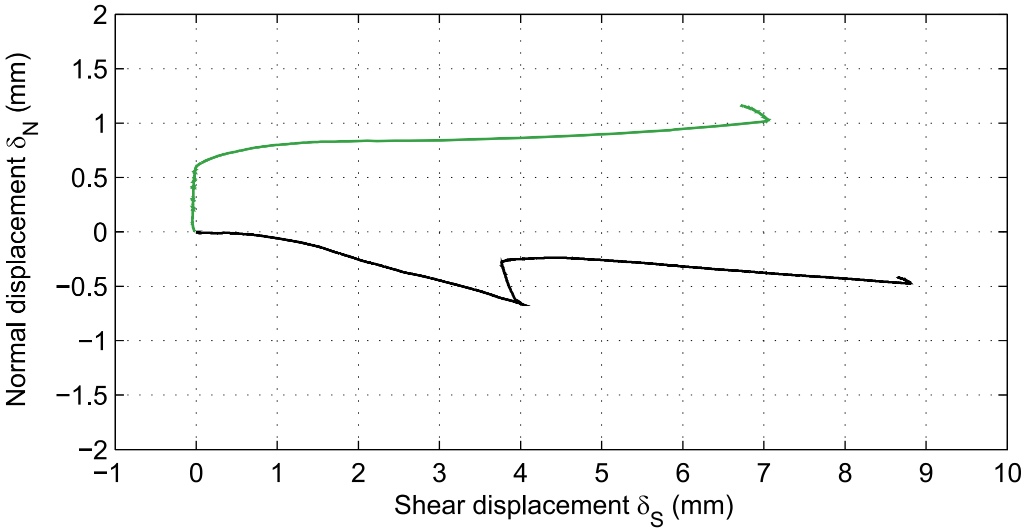

Comments Upper and lower halves: The specimen has thin visible cracks.

Specimen ID: KSH01A−117−27

Shear area : 47.8 cm^2







5.2 Results for the entire test series

A summary of the peak and residual stresses from the shear tests is shown in Tables 5-1 and 5-2.

Table 5-1. Summary of results.

Identification	Area (cm²)	Peak 05 (MPa)	Resid 05 (MPa)	Peak 5 (MPa)	Resid 5 (MPa)	Peak 20 (MPa)	Resid 20 (MPa)	Comments
KSH01A-117-1	37.3	0.78	0.56	3.40	2.97	10.67	10.38	
KSH01A-117-2	20.3	0.74	0.64	4.61	3.98	11.40	9.71	
KSH01A-117-3	53.5	0.73	0.48	3.87	3.77	13.44	13.36	
KSH01A-117-4	23.2	0.57	0.50	3.29	3.03	12.90	12.45	
KSH01A-117-5	26.3	0.84	0.62	4.12	3.97	15.03	14.85	
KSH01A-117-8	30.3	0.54	0.45	3.90	3.77	12.01	11.85	
KSH01A-117-9	41.0	0.63	0.50	3.56	3.42	12.92	12.24	
KSH01A-117-10	52.5	0.86	0.61	3.87	3.83	14.89	14.48	
KSH01A-117-12	52.1	0.75	0.57	4.30	3.77	15.05	11.91	
KSH01A-117-14	25.8	0.51	0.47	3.69	3.48	14.97	14.11	
KSH01A-117-16	32.7	0.64	0.44	3.64	3.58	14.48	14.36	
KSH01A-117-18	28.6	0.99	0.39	3.15	3.05	11.86	11.41	
KSH01A-117-20	26.6	0.63	0.51	3.62	3.01	14.44	14.35	
KSH01A-117-22	23.5	0.81	0.61	3.72	2.97	10.92	10.38	
KSH01A-117-25	26.5	0.61	0.46	3.80	3.69	9.82	8.57	
KSH01A-117-26	23.4	1.40	0.69	4.49	3.43	10.36	8.75	
KSH01A-117-27	47.8	0.73	0.65	4.30	4.21	14.38	13.26	

Table 5-2. Calculated mean values.

	Peak 05 (MPa)	Resid 05 (MPa)	Peak 5 (MPa)	Resid 5 (MPa)	Peak 20 (MPa)	Resid 20 (MPa)
Mean value (all levels)	0.75	0.54	3.84	3.53	12.91	12.14
Mean value (302–312 m)	0.73	0.56	3.86	3.54	12.69	12.15
Mean value (399–413 m)	0.69	0.54	3.74	3.61	13.55	13.17
Mean value (479–495 m)	0.72	0.50	3.69	3.31	13.62	12.75
Mean value (703–706 m)	0.92	0.60	4.20	3.78	11.52	10.19

5.3 Discussion

The tests were conducted according to the method description and the activity plan with no departures.

References

/1/ **ISRM, 1974.** Suggested methods for determining shear strength. Part 2: Suggested method for laboratory determination of direct shear strength. Final draft 1974.

/2/ **Stråhle A, 2001.** Definition och beskrivning av parametrar för geologisk, geofysisk och bergmekanisk kartering av berg, SKB-01-19. In Swedish. Svensk Kärnbränslehantering AB.

/3/ **MATLAB, 2002.** The Language of Technical computing, Version 6.5, MathWorks Inc.

Appendix A

Results from the reference tests with a cast steel specimen are shown below

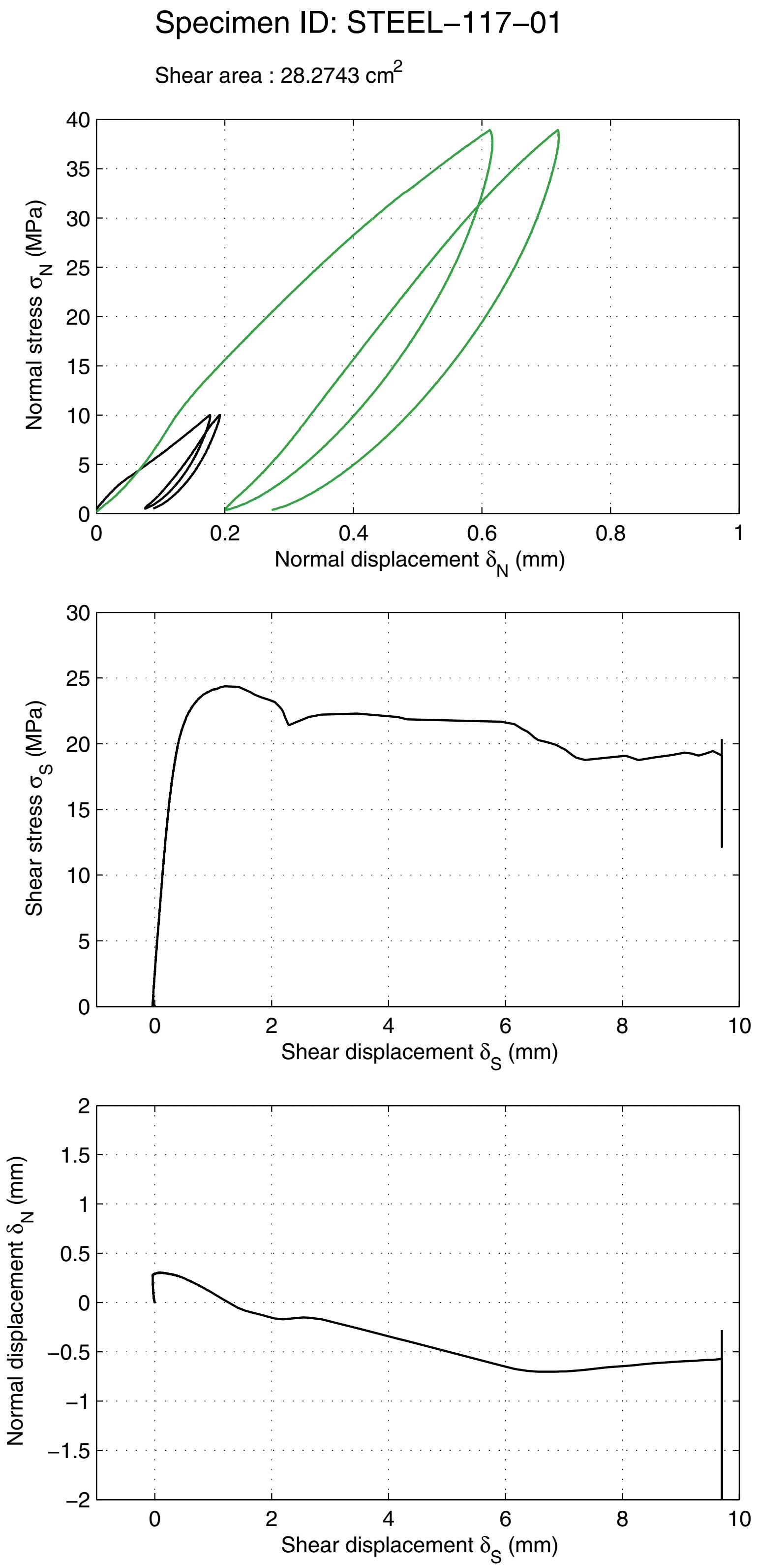


Figure A-1. Results from reference test 1 with a steel specimen cast in concrete.

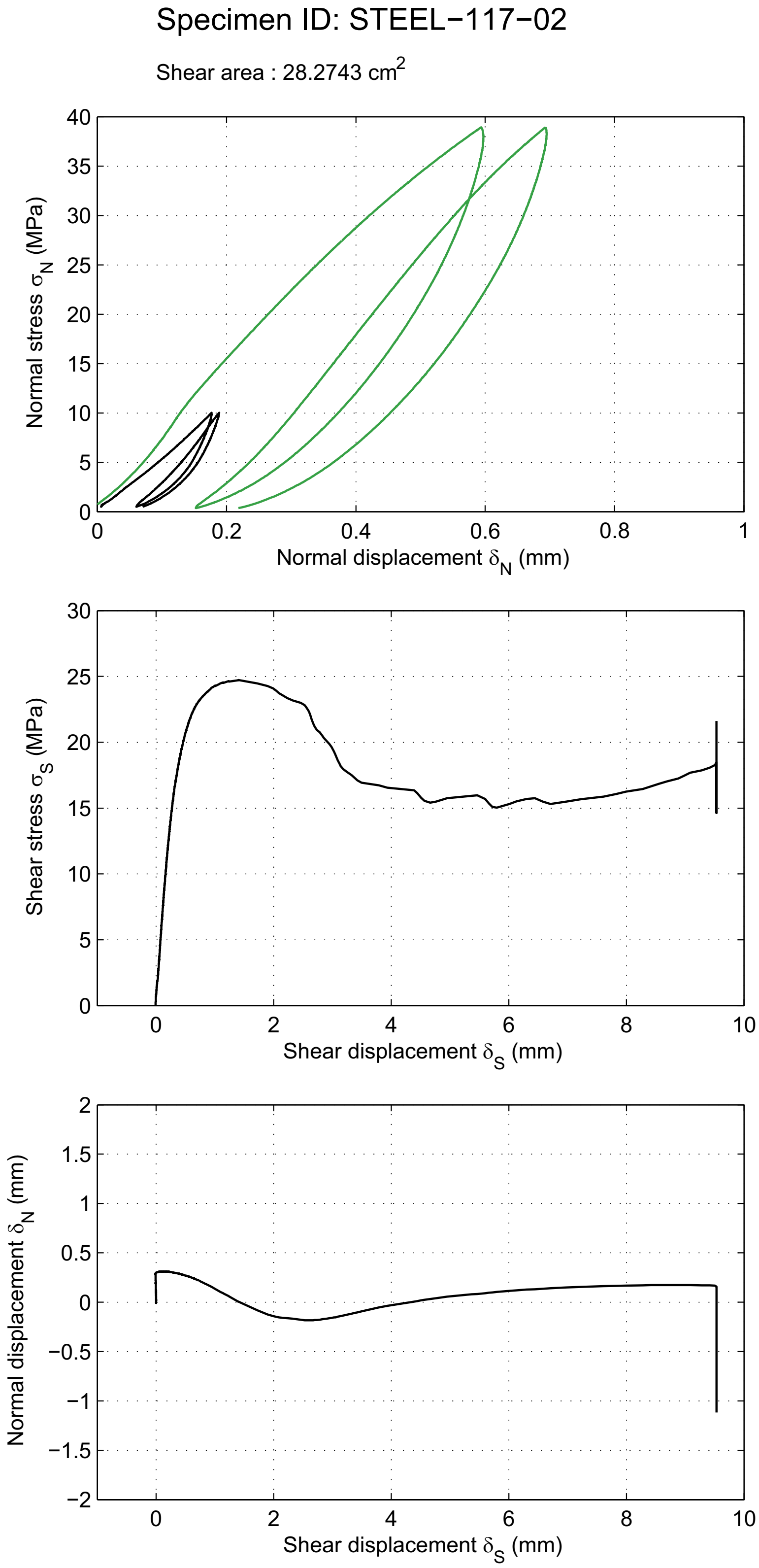


Figure A-2. *Results from reference test 2 with a steel specimen cast in concrete.*