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Enlightening critical details of a standardized procedure used to determine the fracture toughness of brittle structural materials

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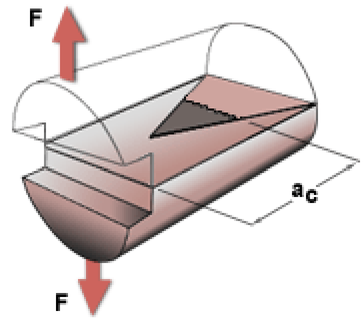
Introduction

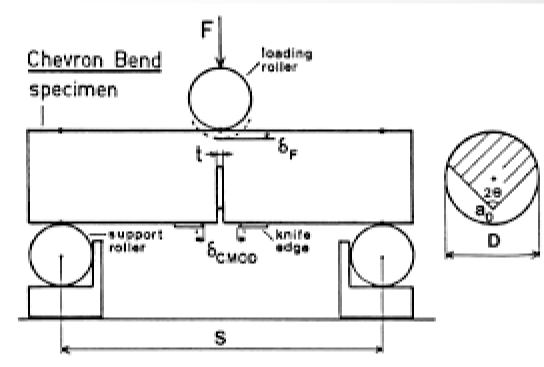
The mode-I fracture toughness (K_{IC}) is a crucial parameter for the design of a large variety of engineering structures, especially for the ones made of brittle geomaterials.

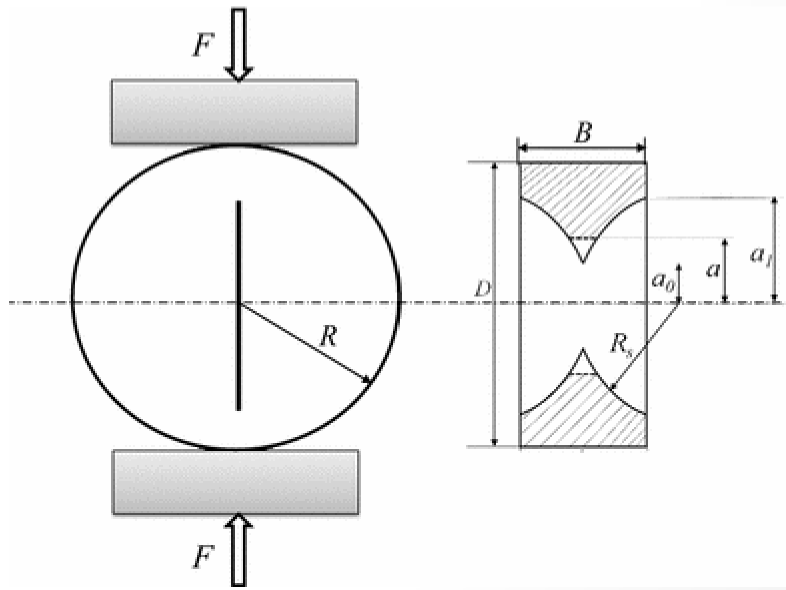
Its experimental determination is already standardized by both ASTM and ISRM.

There are three widely accepted standardized techniques:

- The short rod test
- The Chevron bend test
- The CCNBD test



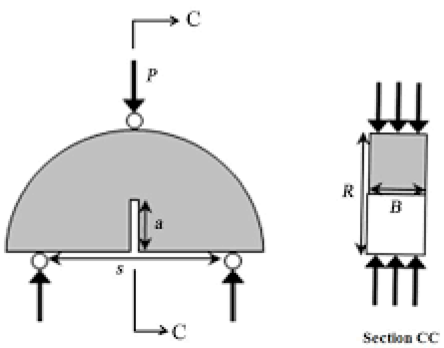


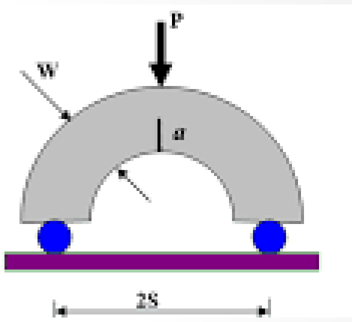


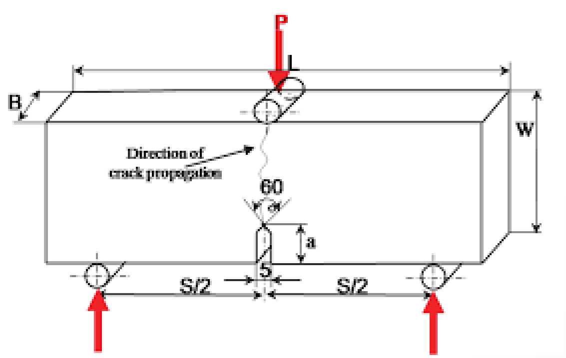
Introduction

Besides the above standardized and widely used techniques, a number of additional ones have been proposed, including:

- The semi-circular notched disc under bending
- The semi-circular notched ring under bending
- The notched beam-shaped specimen under three-point bending





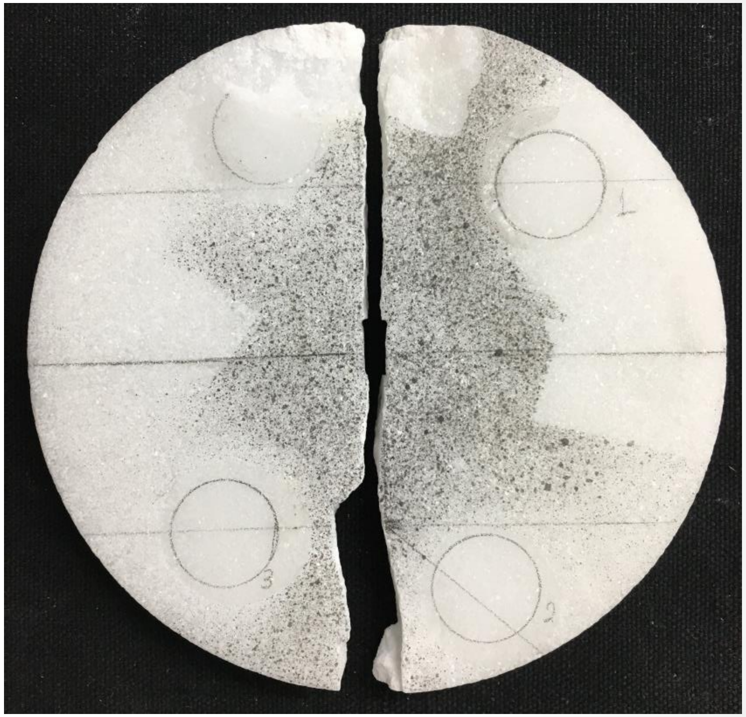


Introduction

The CCNBD test is widely used worldwide, however even today (and in spite of the intensive scientific research) some issues are still open, concerning both its theoretical basis as well as the laboratory implementation.

For the latter, the main issues include:

- The exact shape of the cracks (notches) machined and its role on the stress field developed.
- The role of the boundary conditions along the contact arc developed at the disc-jaw interface.
- The critical load causing propagation of the crack (notch).
- The point from which crack propagation begins.
- The role of secondary fractures and local exfoliations quite often observed, especially for specimens made of materials with increased stiffness.



The geometry

Notched Straight Through Brazilian Discs (NSTBD)

<u>Disc</u>

Diameter (D): 100 mm

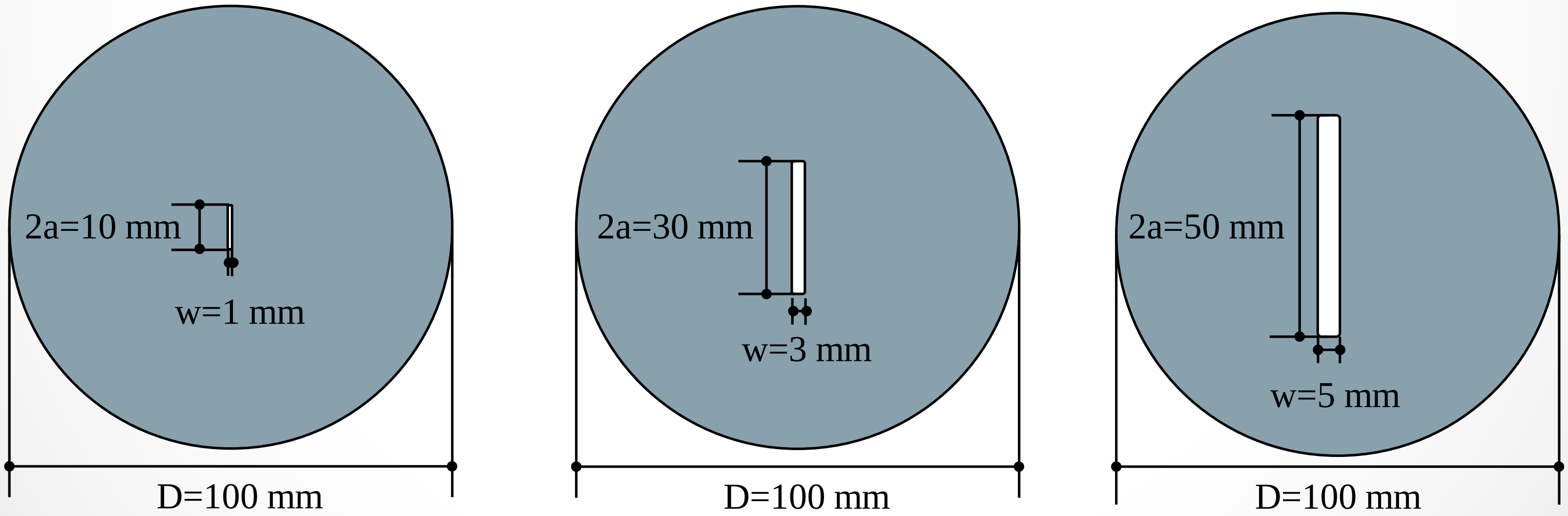
Thickness (t): 10 mm

<u>Central notch</u>

Length (2a): 10, 30, 50 mm

Width (w): 1, 3, 5 mm

w/2a: 1/10



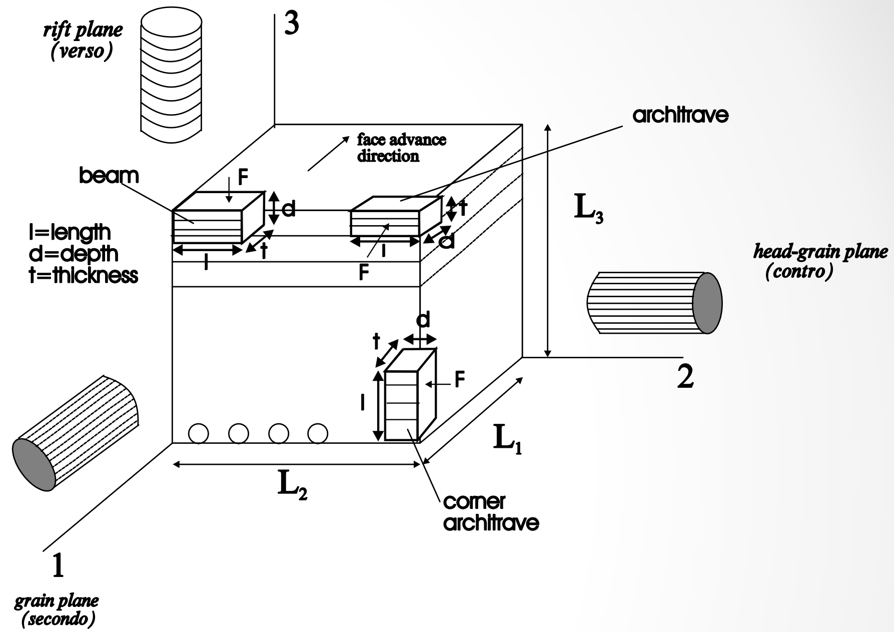
The specimens

Waterjet cutting technology was used to machine the notches.

The material

<u>Dionysos marble</u>

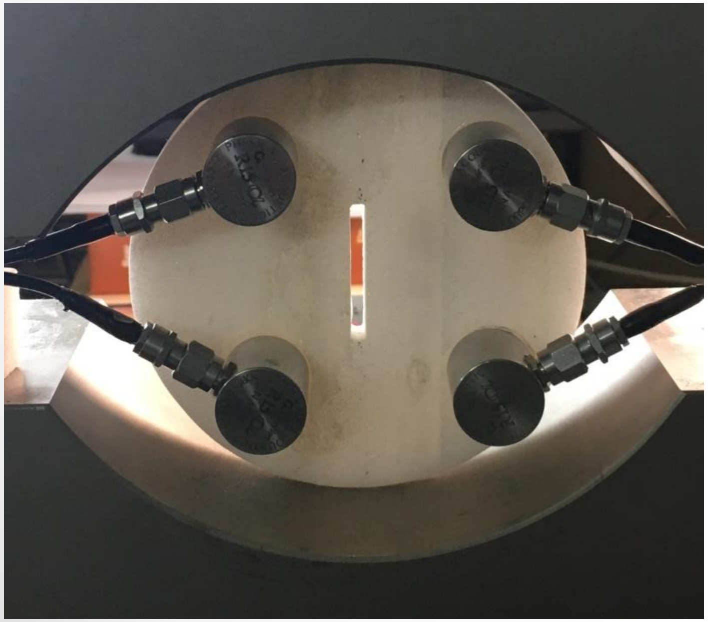
- It is exclusively used as substitute stone in the restoration projects of the monuments of the Athenian Acropolis.
- Transversely isotropic material.

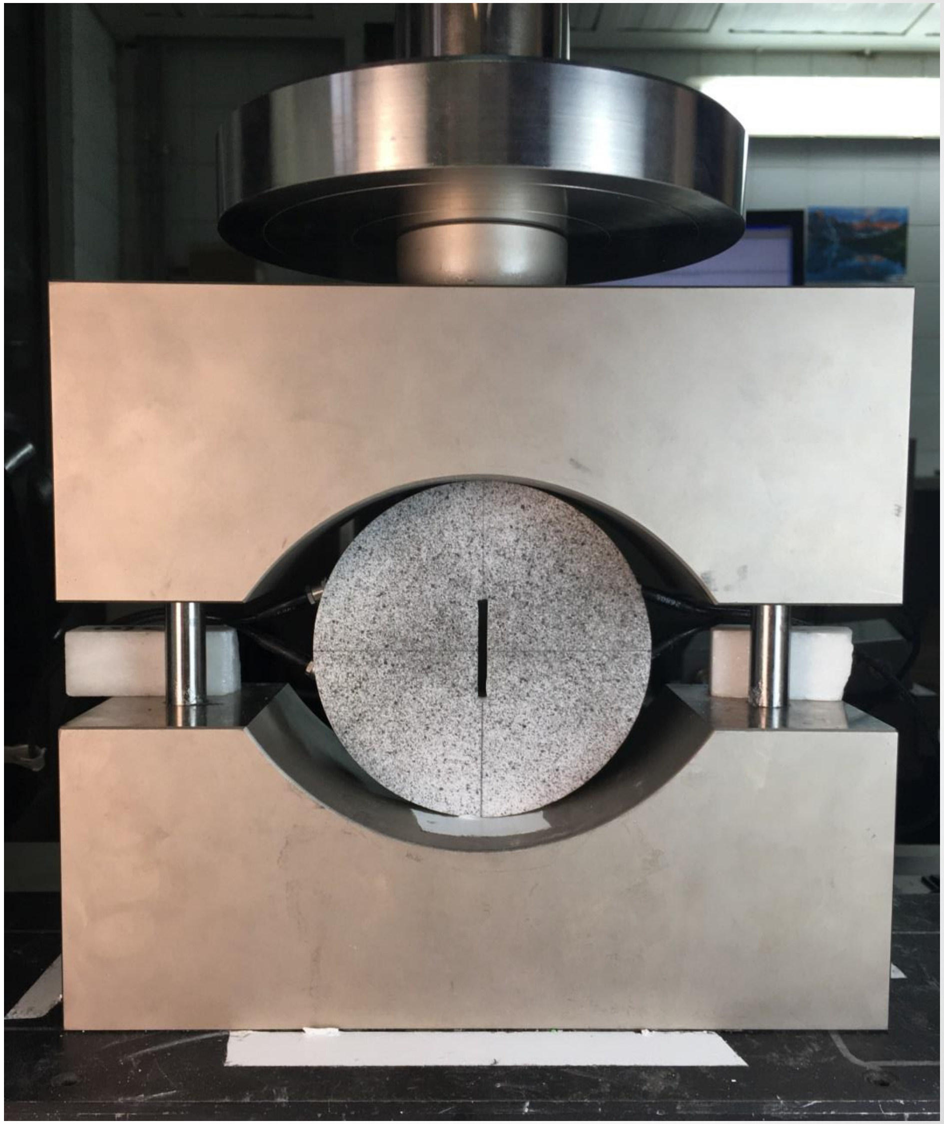


	Modulus of elasticity, E [GPa]	Poisson's ratio, ν [-]	Tensile strength, σ_f [MPa]
Strong direction (1)	84.5	0.26	10.8
Intermediate direction (2)	79.5	0.26	9.5
Weak direction (3)	50.0	0.11	5.3

The experimental set-up

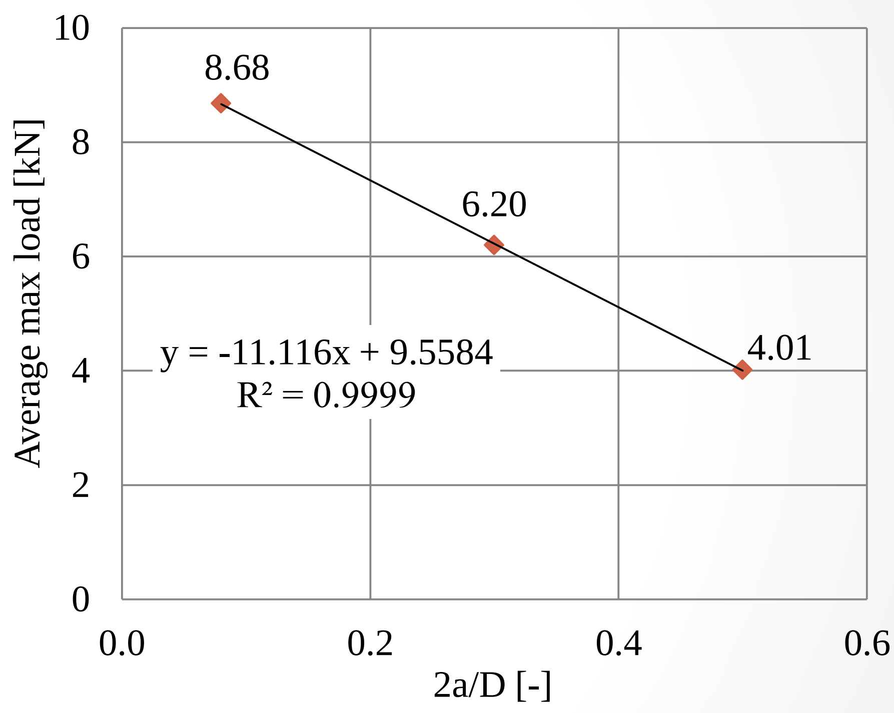
- Curved jaws according to the ISRM standard
- MTS Insight electromechanical loading frame of capacity 10 kN
- Loading rate: 0.02 mm/min
- Two cameras of resolution 1623x1234 pixels (3D DIC technique)
- *Four (4) acoustic sensors R15α*



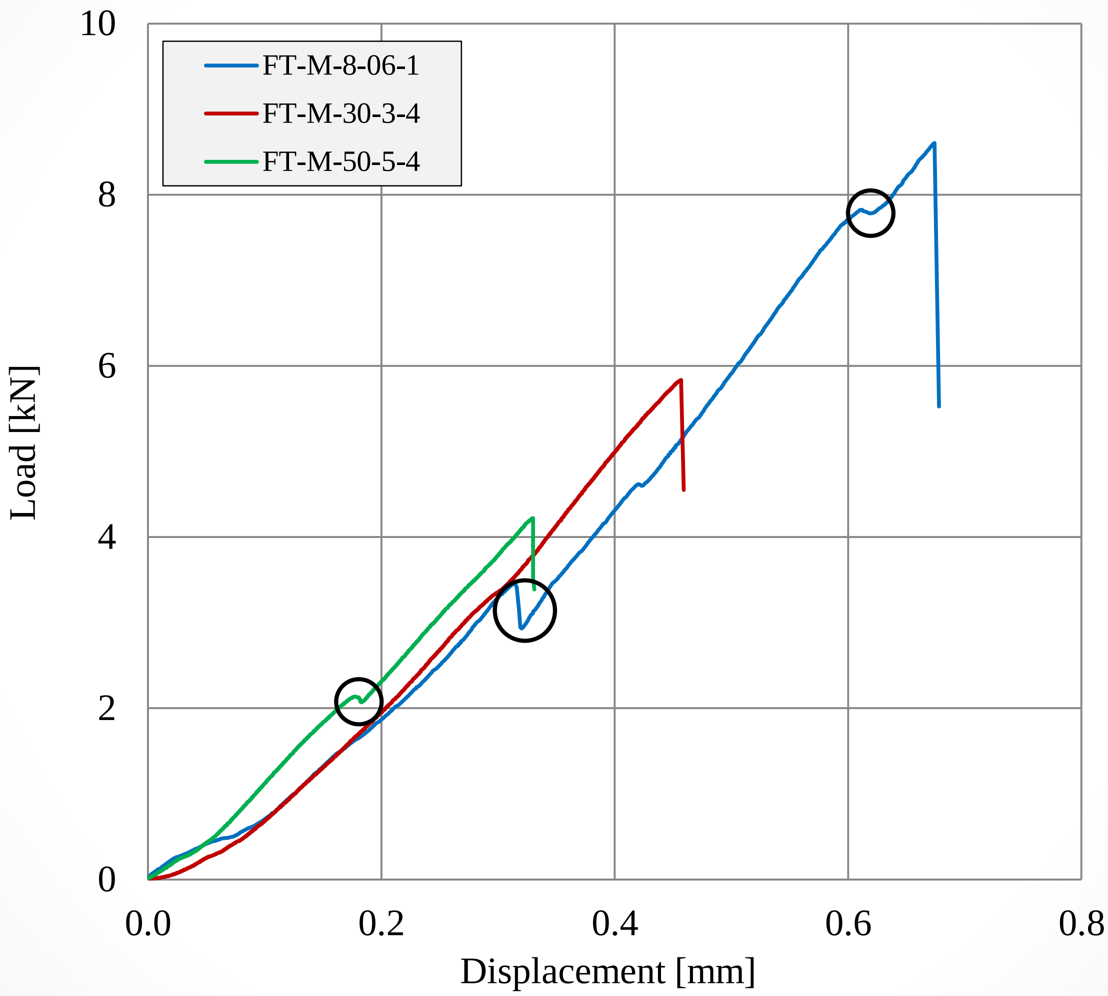


Results

Specimen	Maximum load [kN]
FT-M-8-06-1	8.60
FT-M-8-06-2	8.44
FT-M-8-06-4	9.00
FT-M-30-3-1	5.96
FT-M-30-3-2	6.66
FT-M-30-3-3	6.33
FT-M-30-3-4	5.83
FT-M-50-5-1	4.03
FT-M-50-5-2	3.80
FT-M-50-5-4	4.22

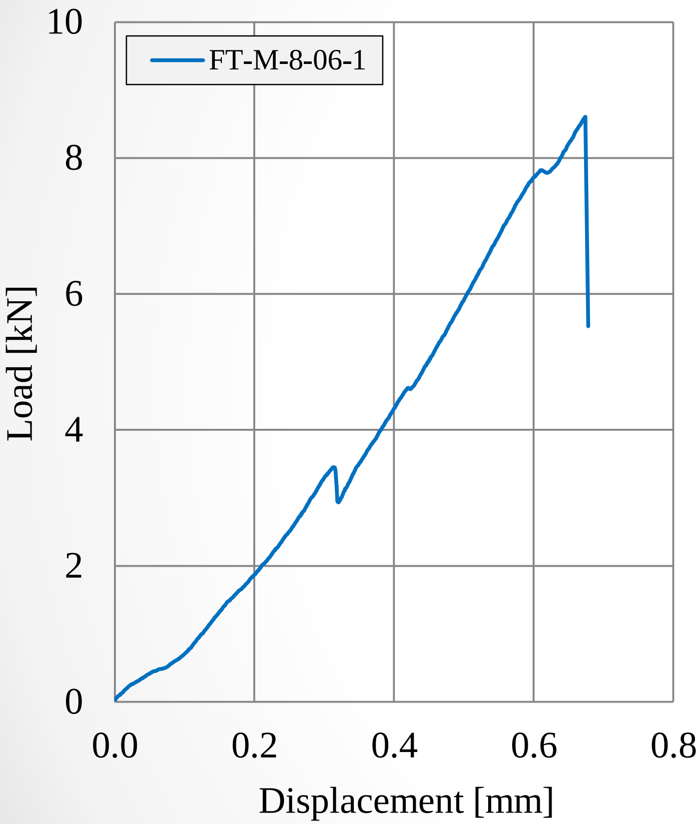


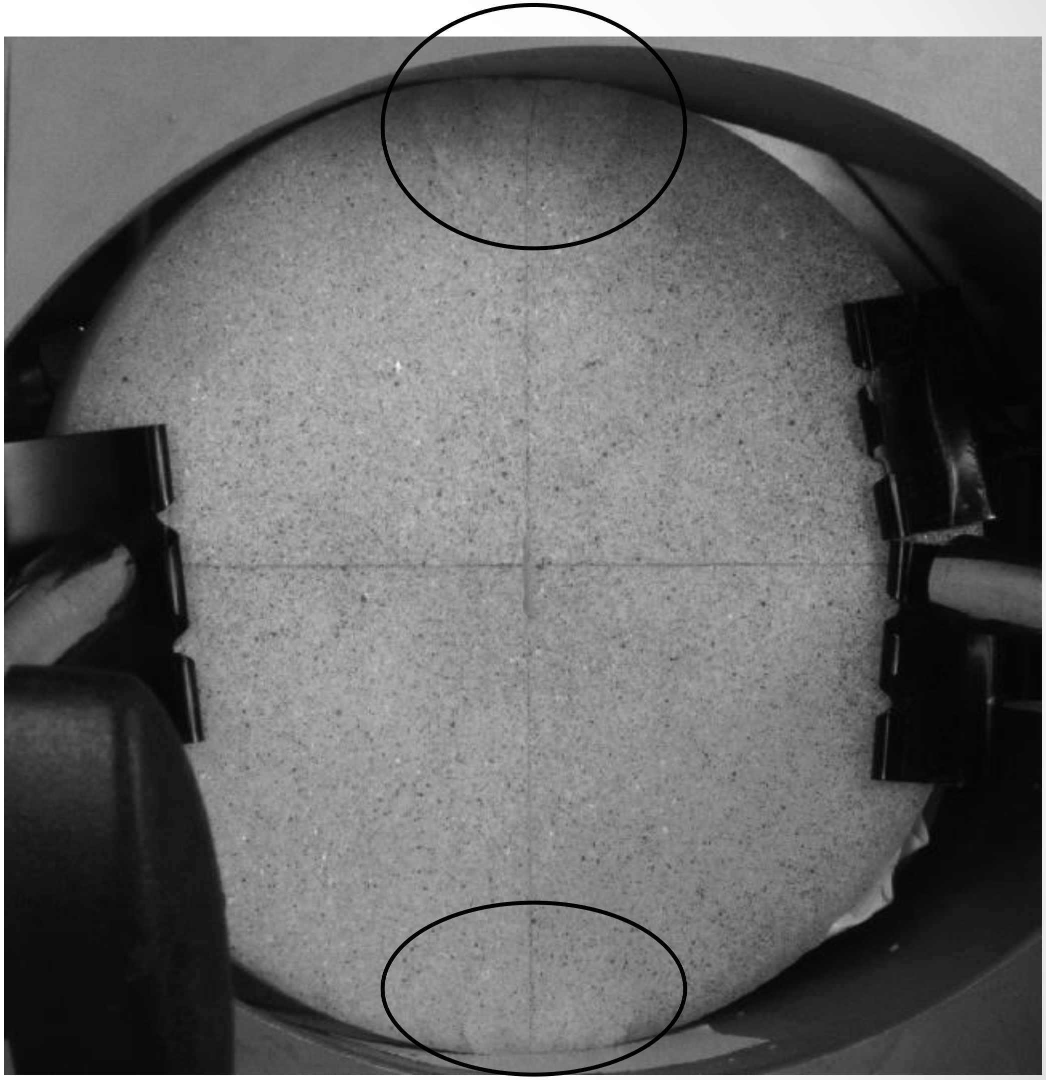
Results



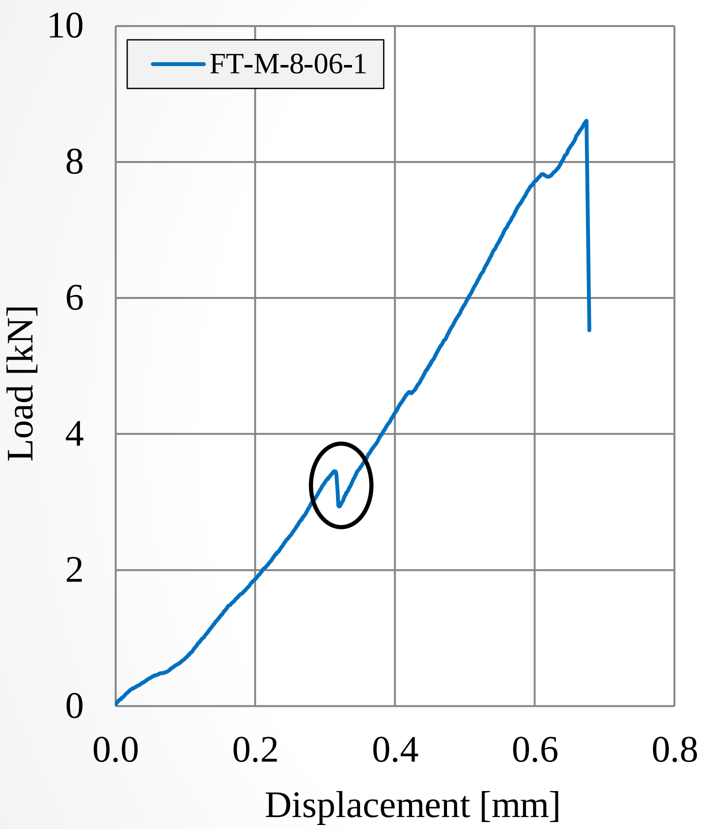
10
8
6
4
2
0
Load [kN]
0.0
0.2
0.4
0.6
0.8
Displacement [mm]
FT-M-8-06-1
FT-M-30-3-4
FT-M-50-5-4

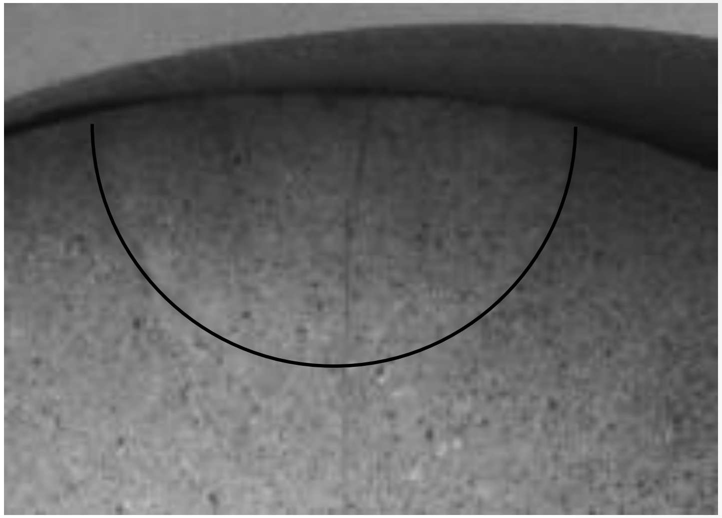
Results

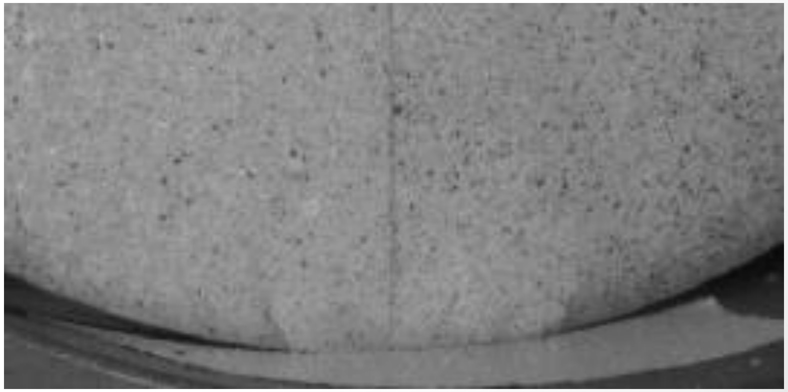




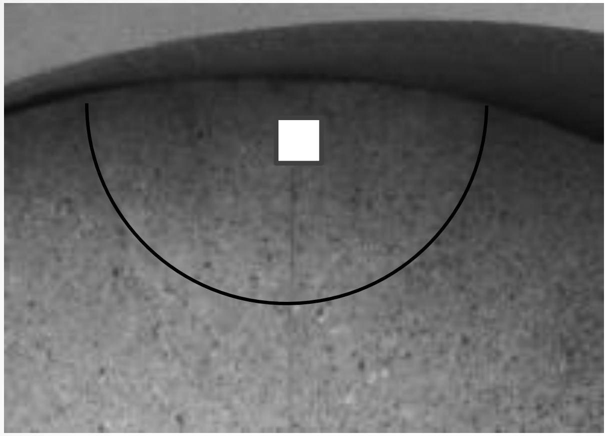
Results

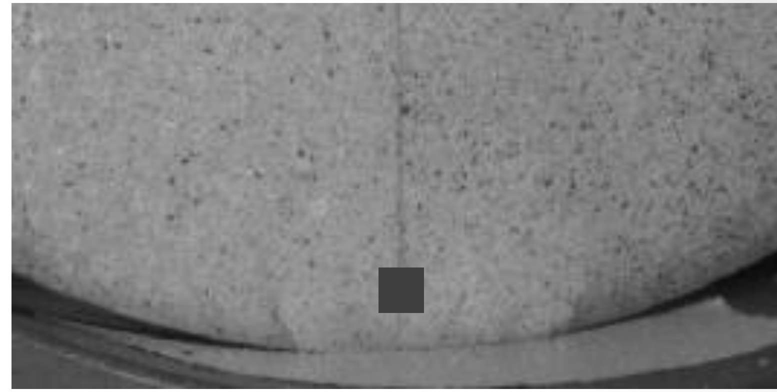


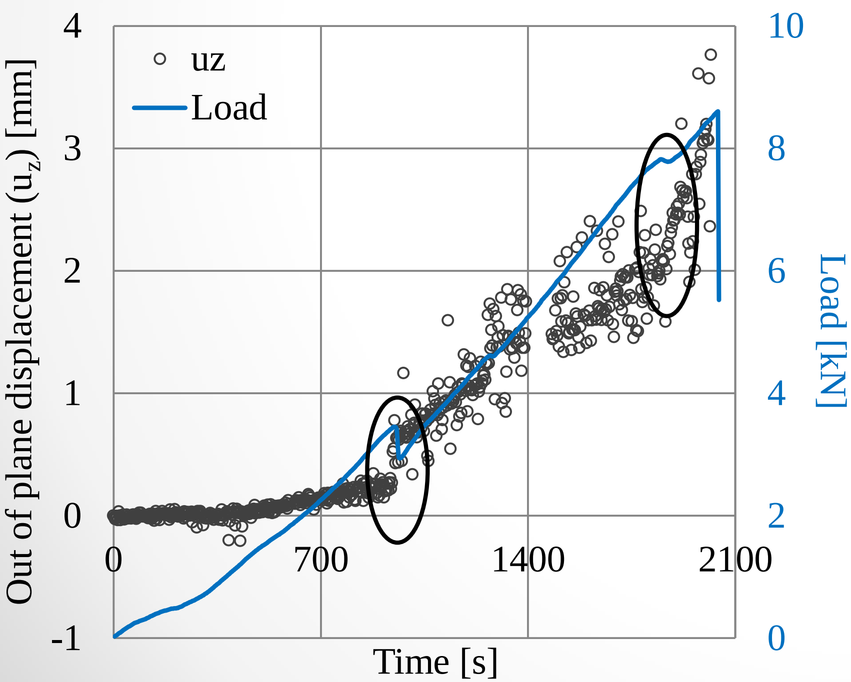




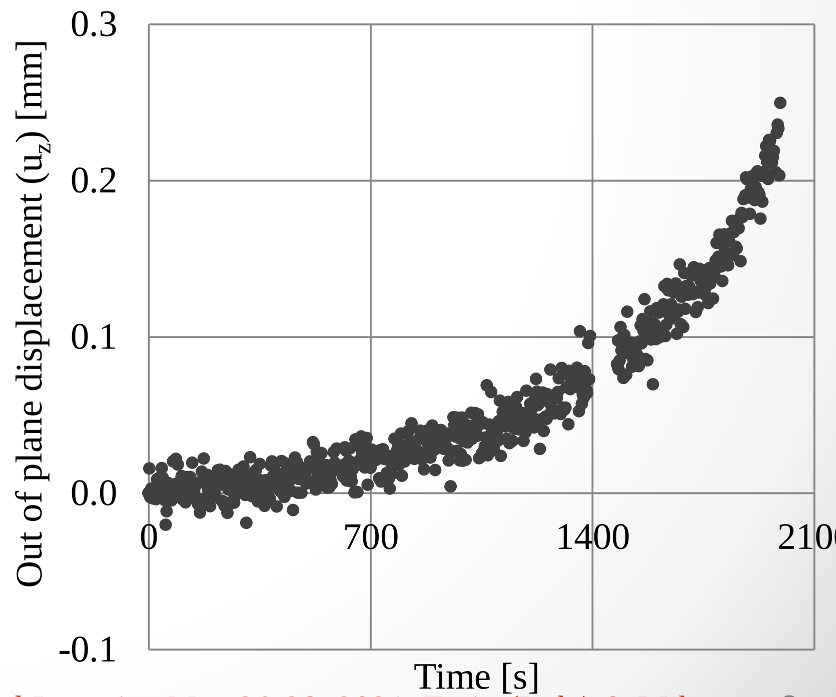
Results





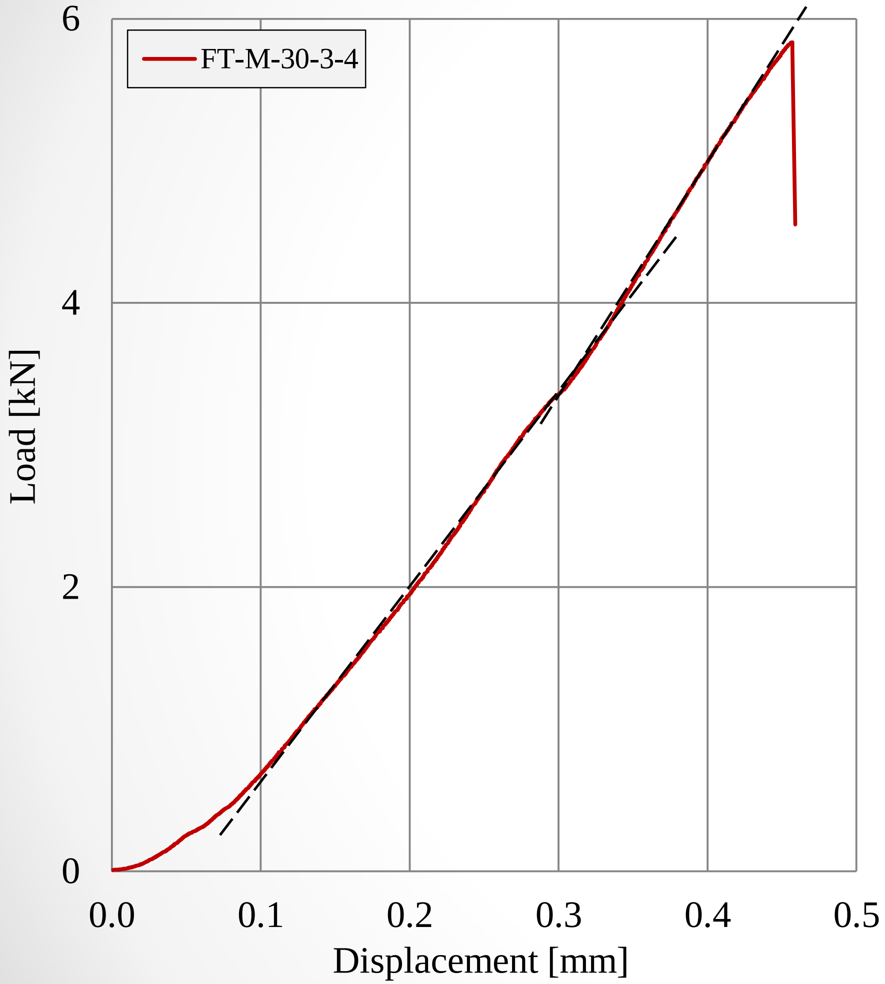


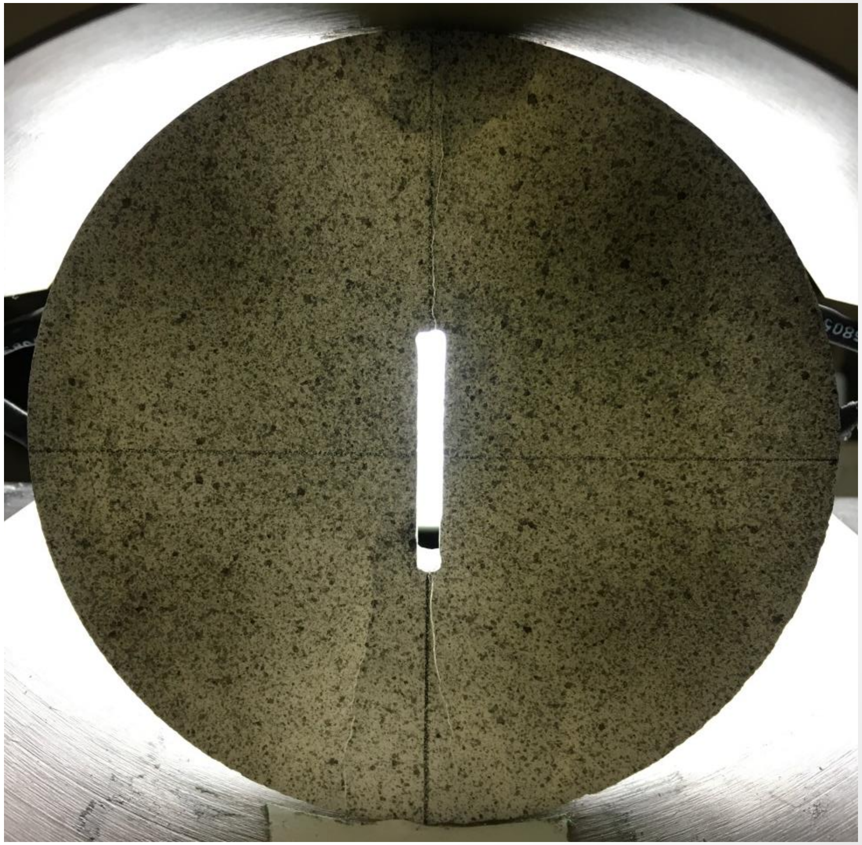
uz
Load
Out of plane displacement (u_z) [mm]
Load [kN]
Time [s]
4
3
2
1
0
-1
10
8
6
4
2
0
0
700
1400
2100



Out of plane displacement (u_z) [mm]
Time [s]
0.3
0.2
0.1
0.0
-0.1
0
700
1400
2100

Results

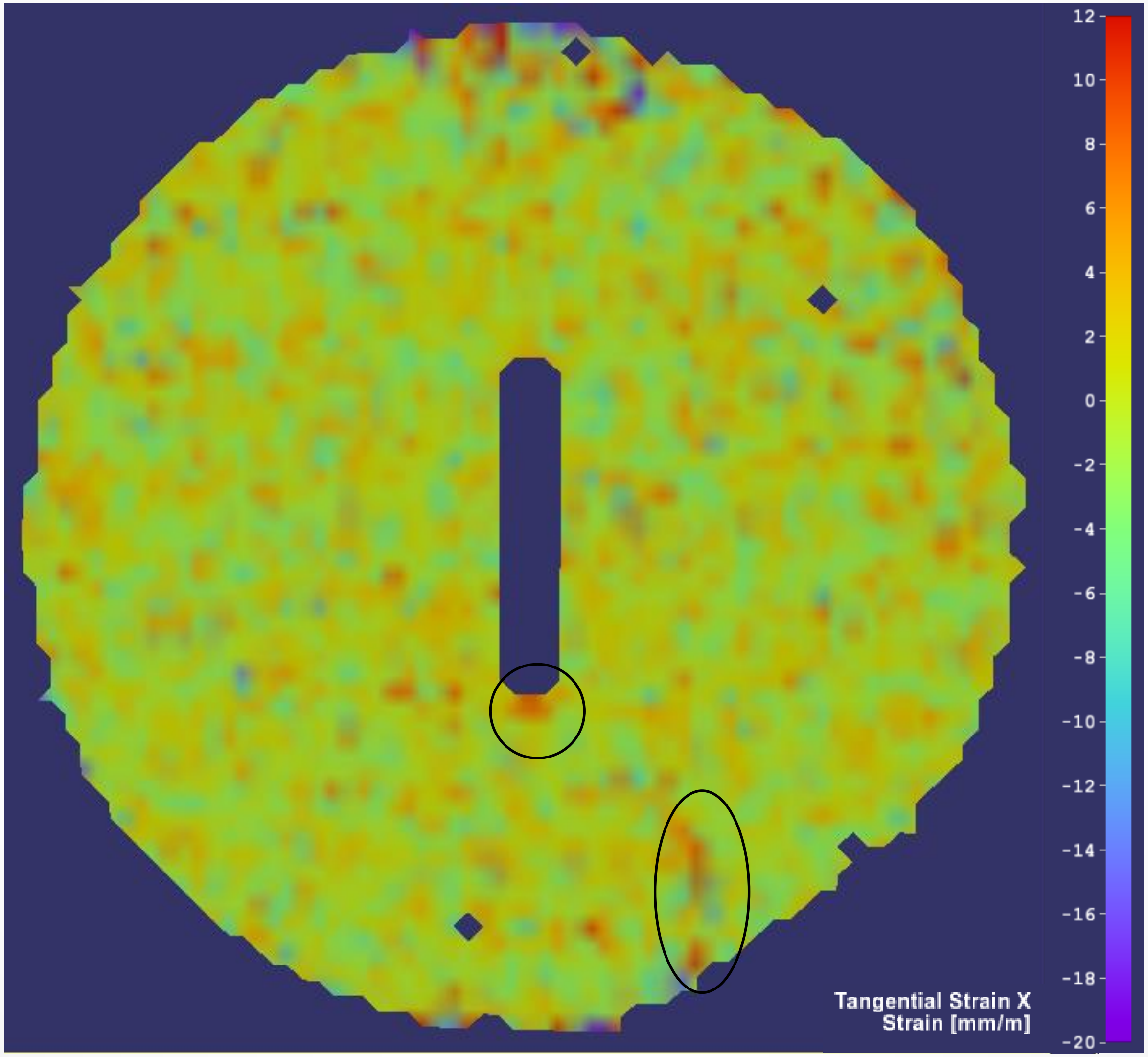




Results

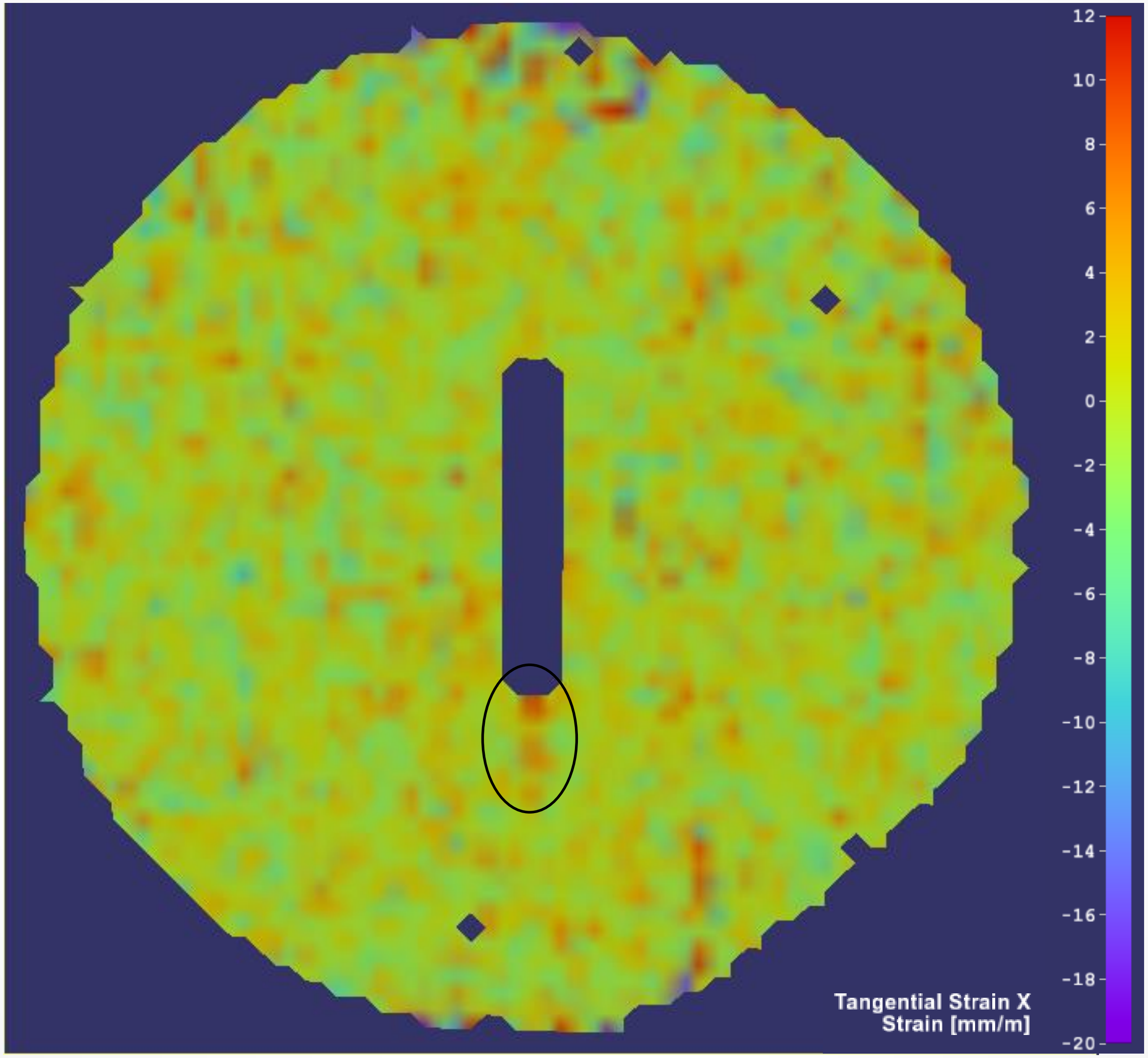
Results

~98% of the maximum load

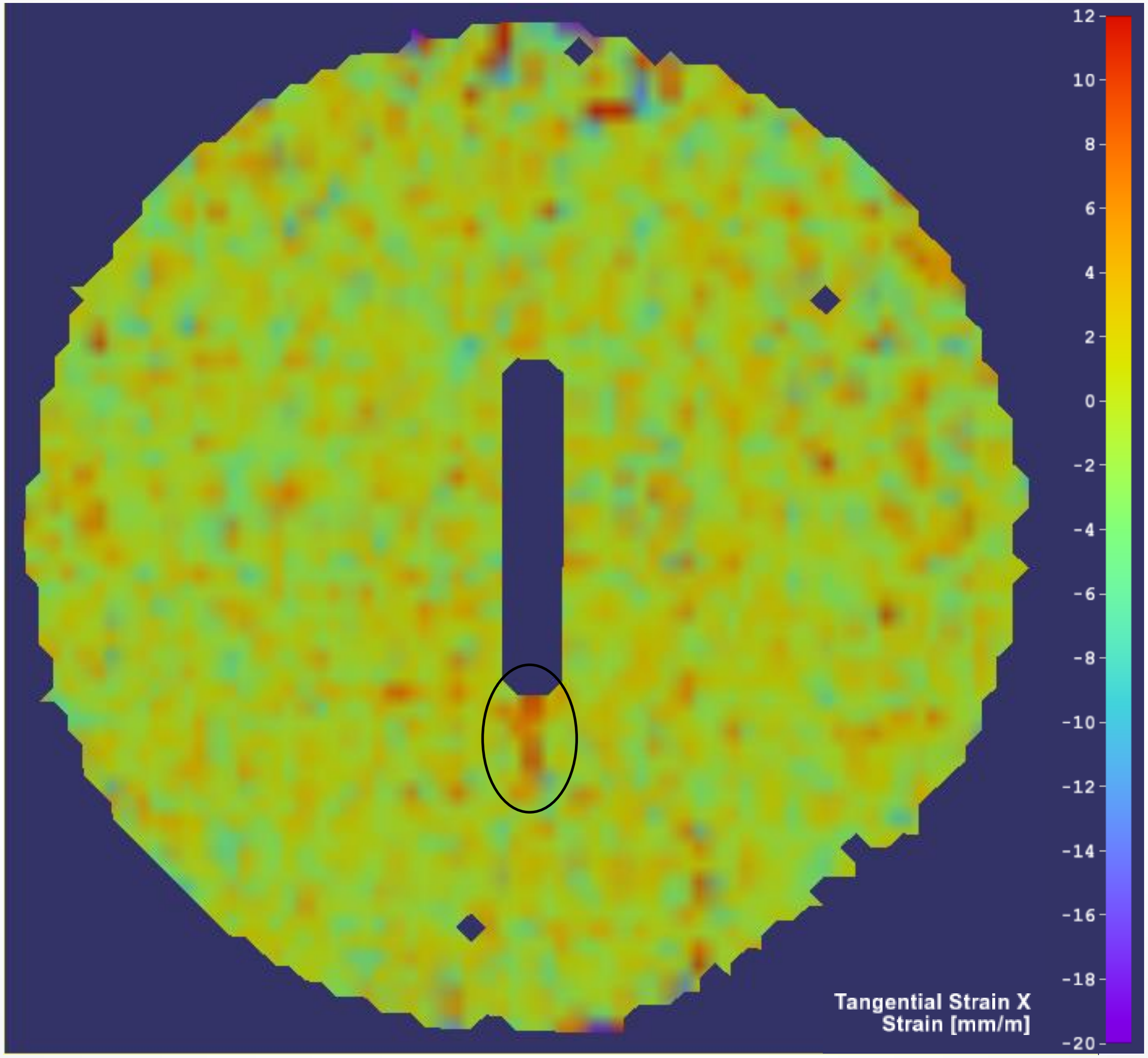


The crack starts from the lower crown of the notch

Results

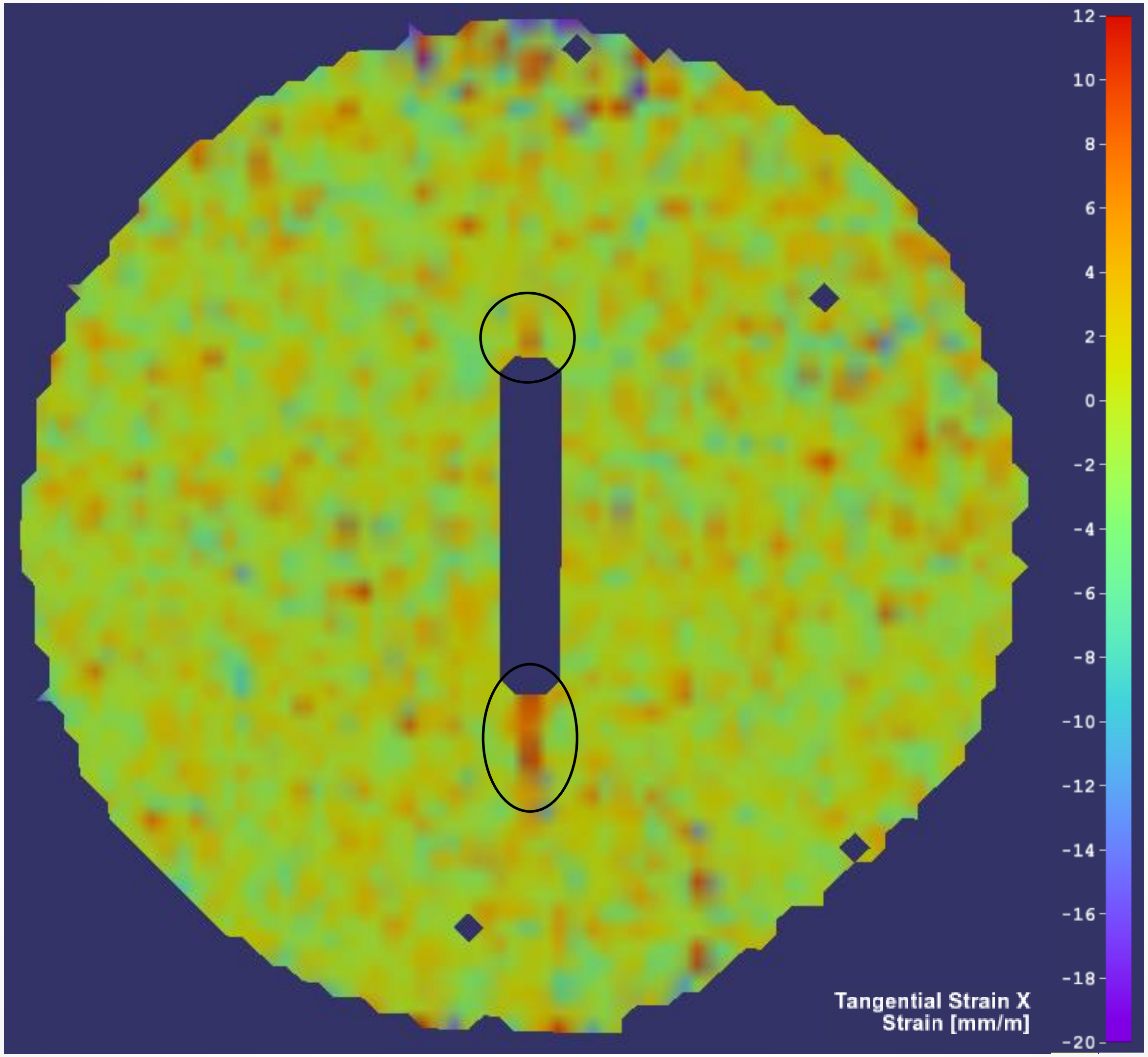

12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Tangential Strain X
Strain [mm/m]

Results

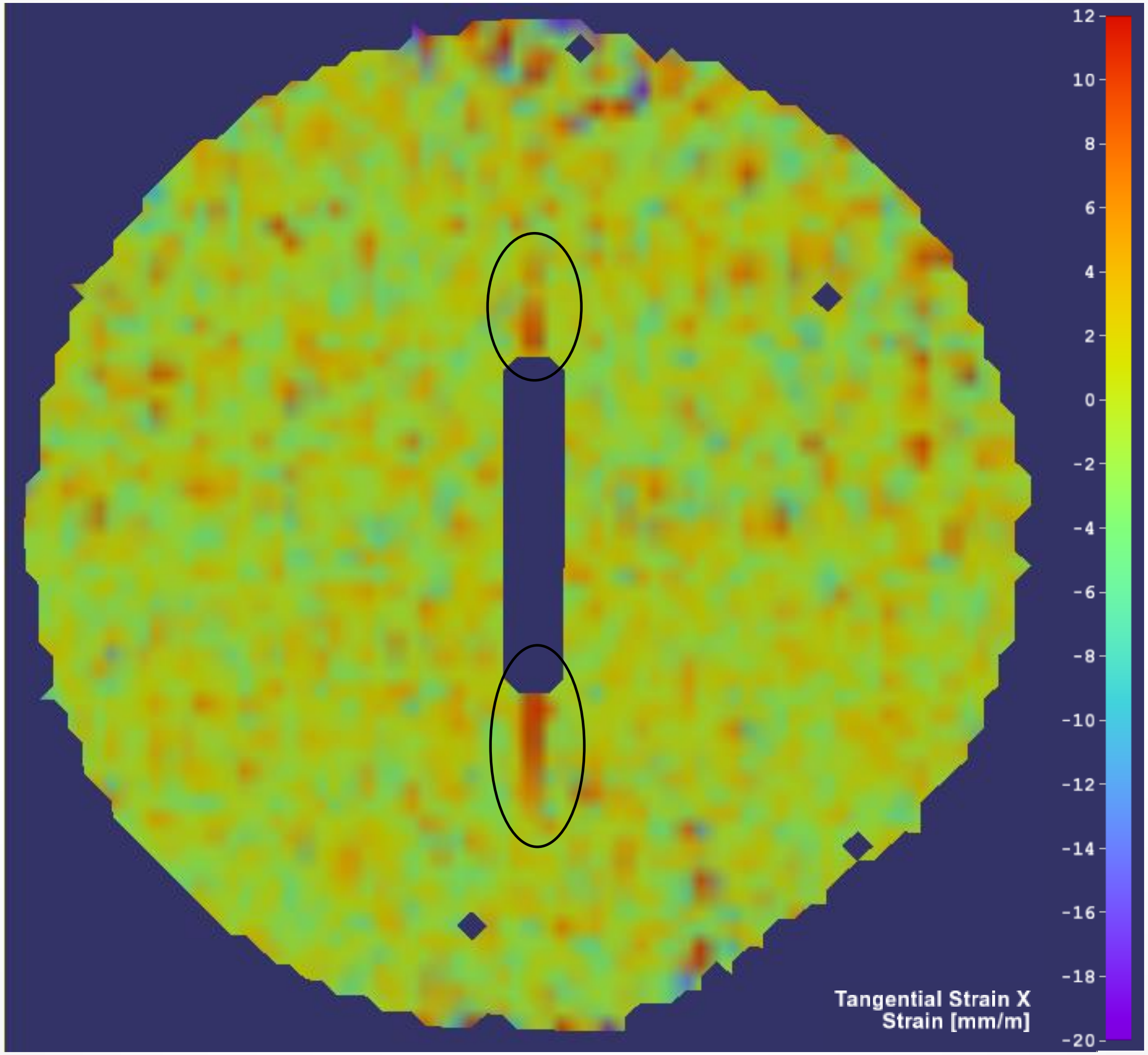

12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Tangential Strain X
Strain [mm/m]

Results

Intense
strain field
appears also
at the upper crown
of the notch



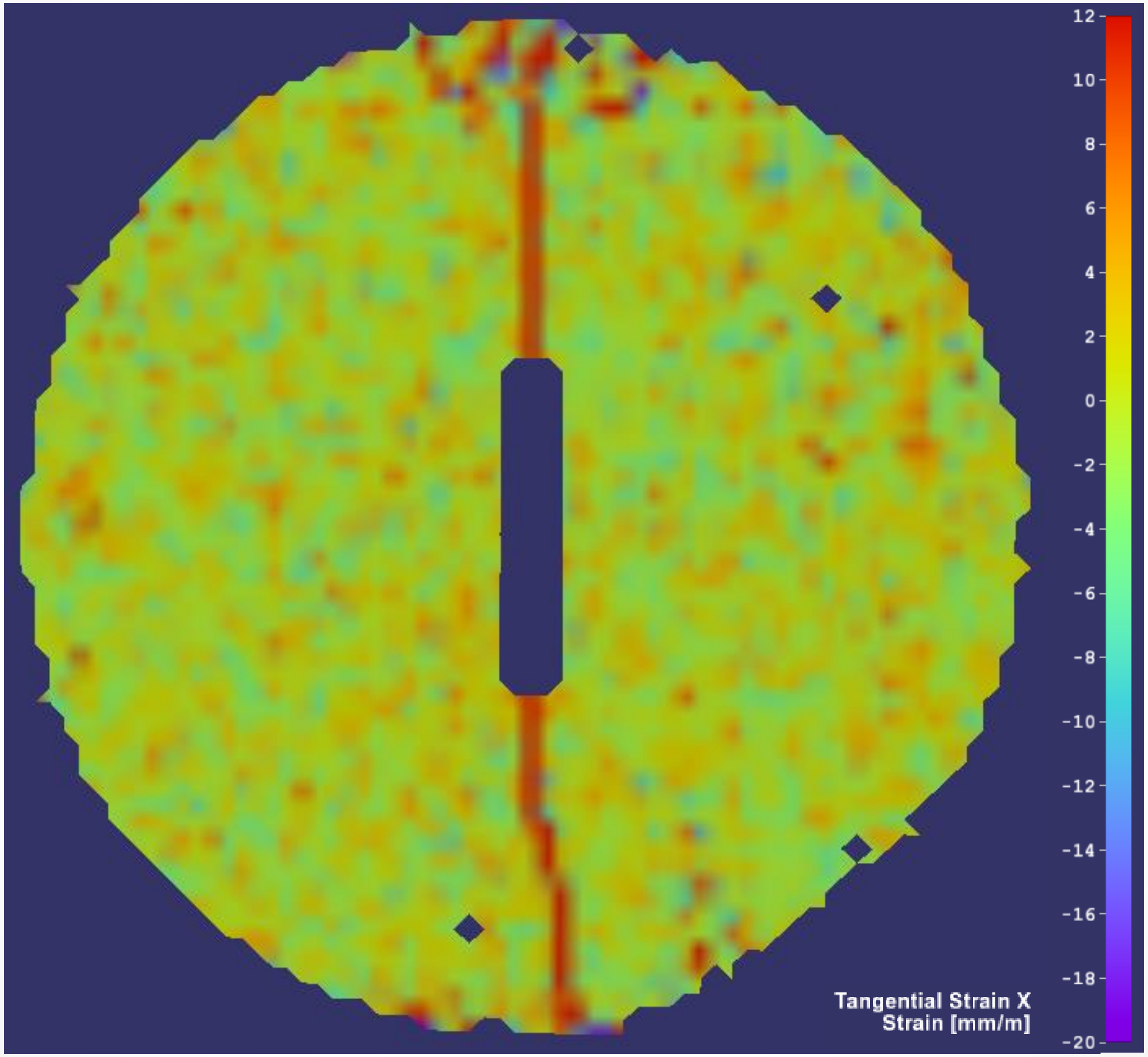
Results



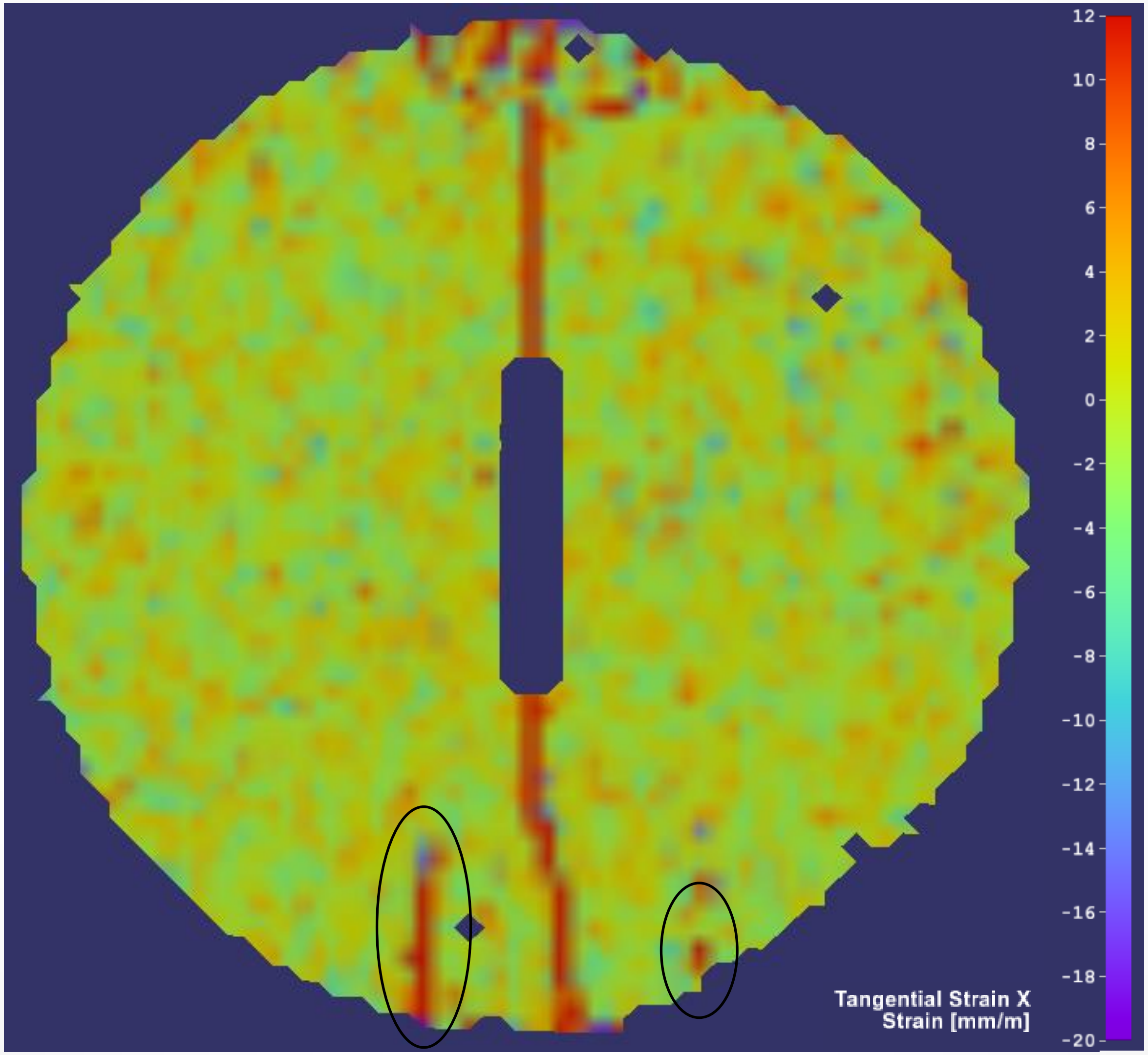
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Tangential Strain X
Strain [mm/m]

Results

Failure of the specimen

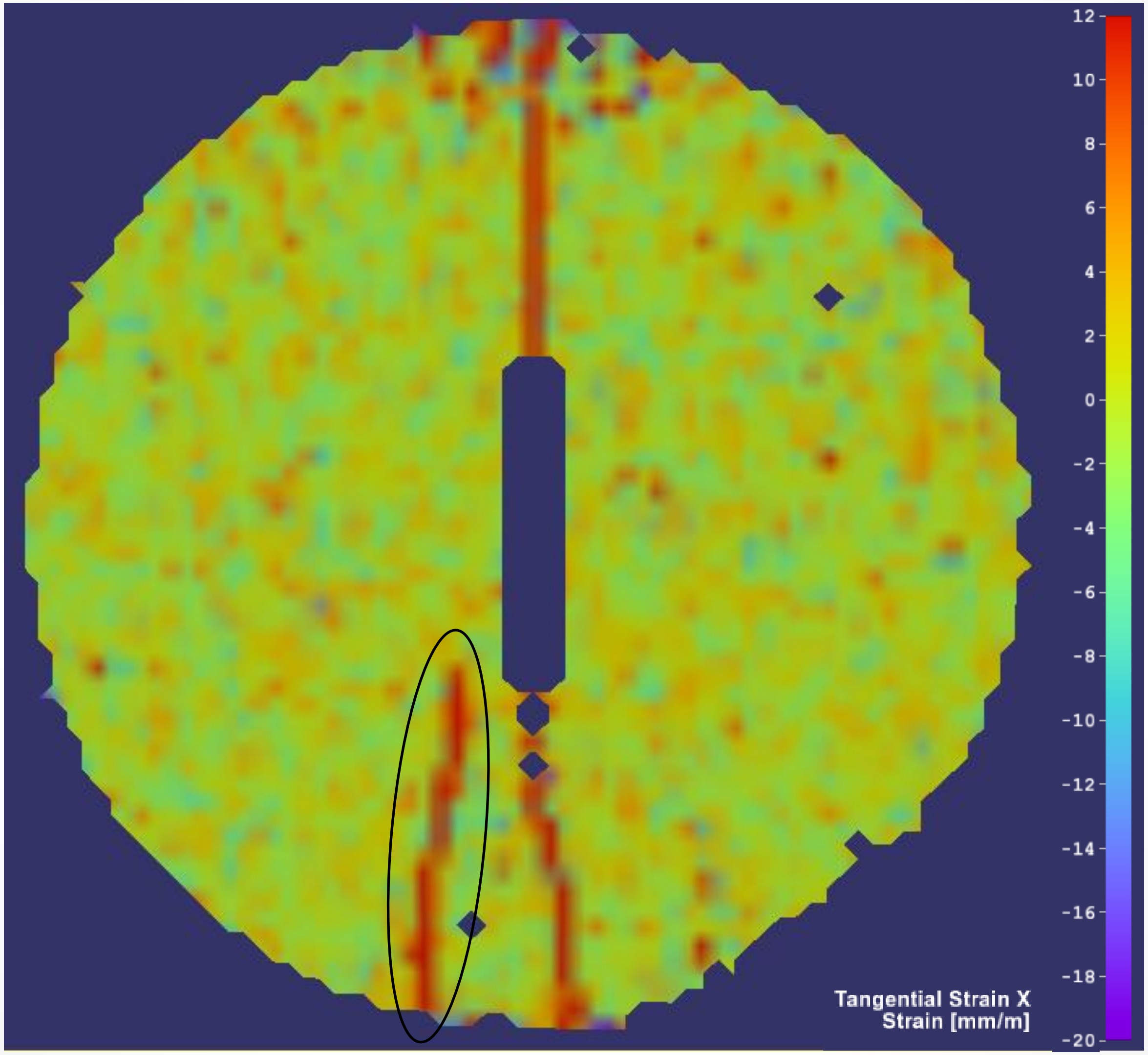


Results



Secondary cracks

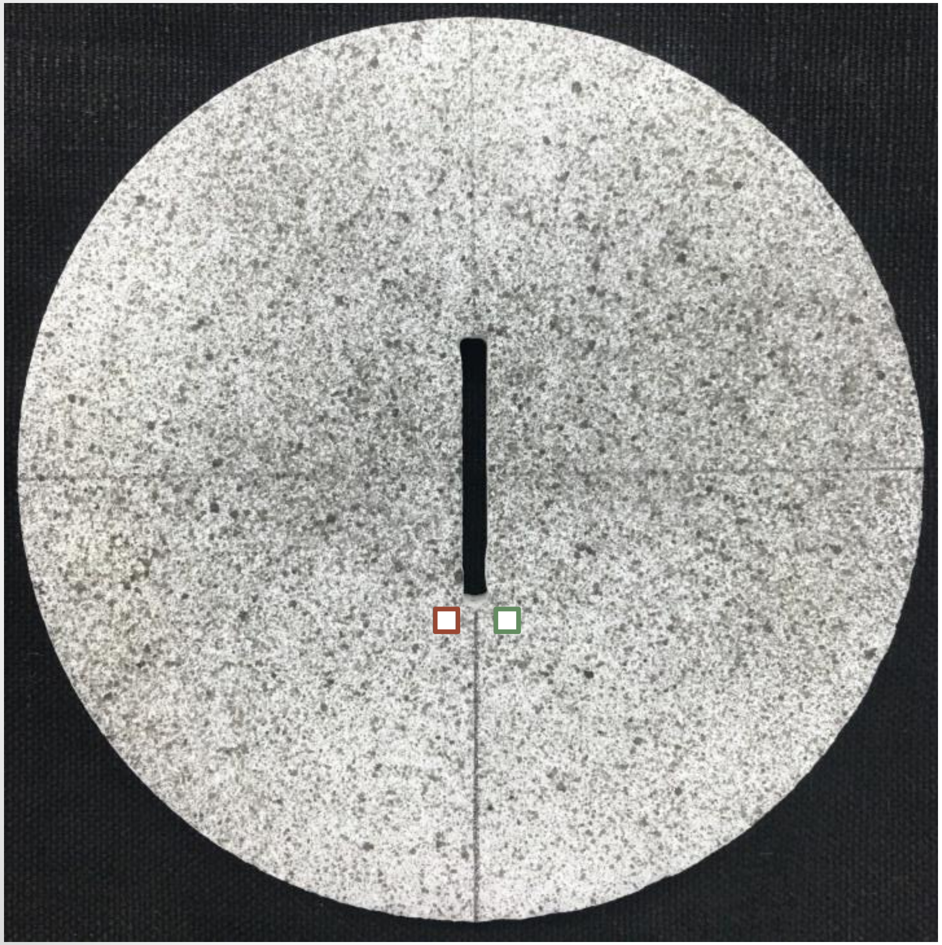
Results

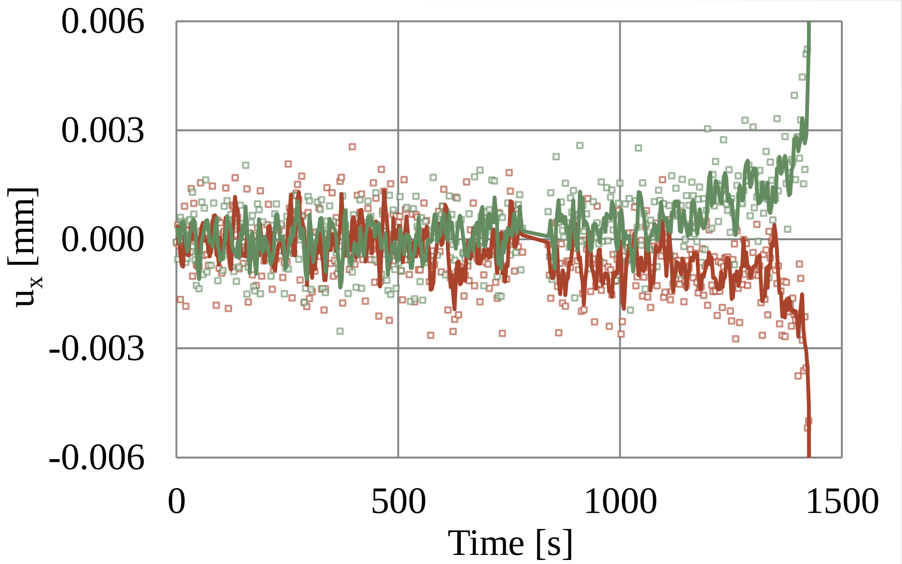


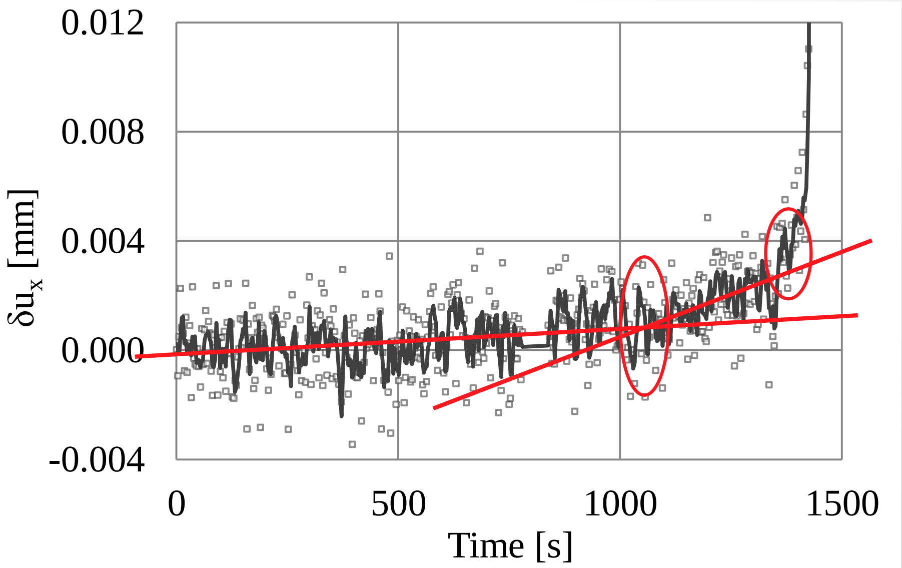
Secondary cracks

Results

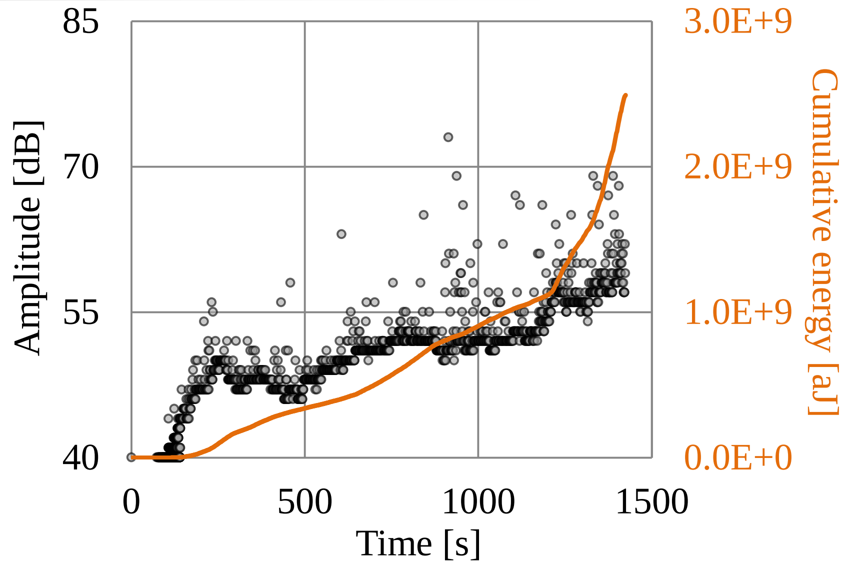
Small areas of the specimen at both sides of the lower crown of the notch are isolated.





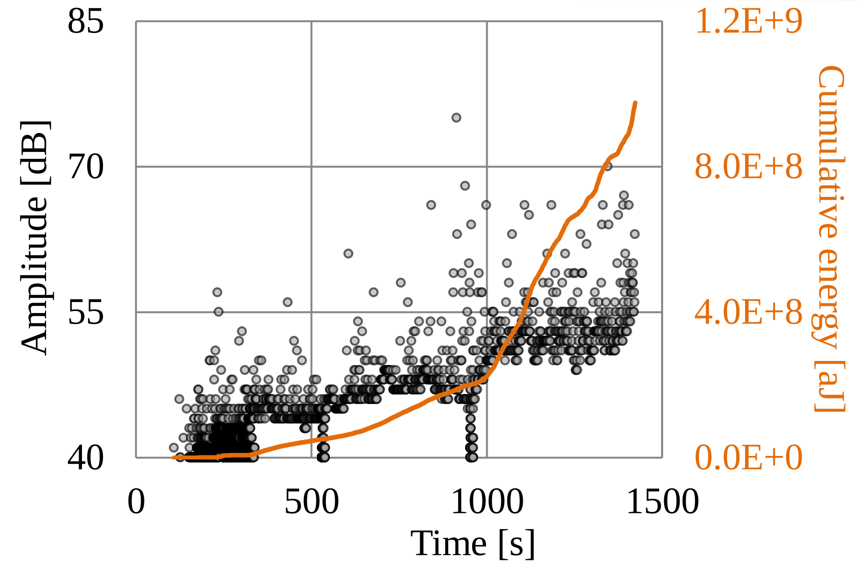


Results



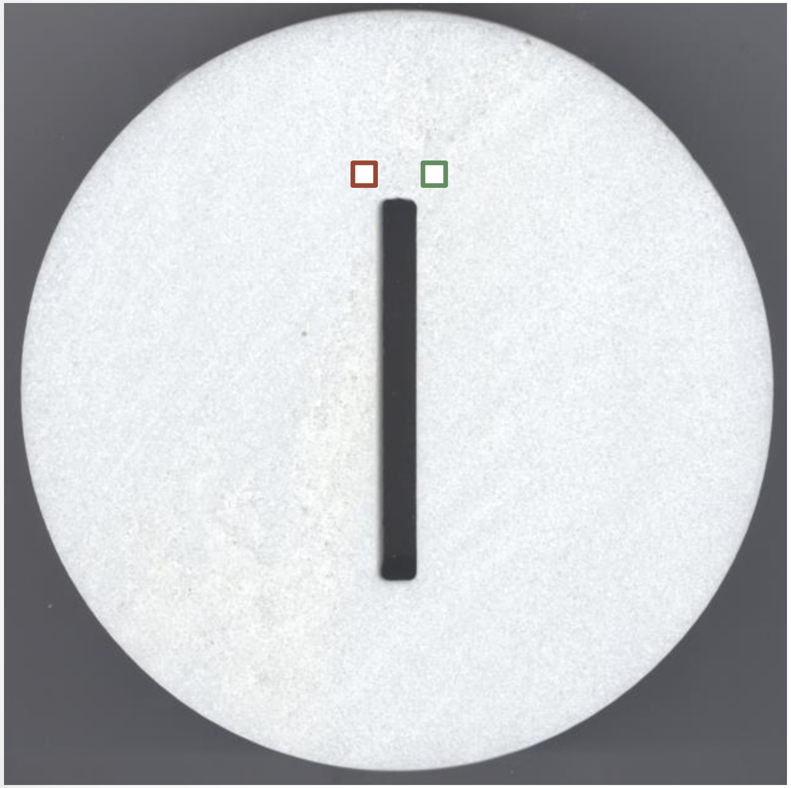
Sensor 4
(upper part of the disc)

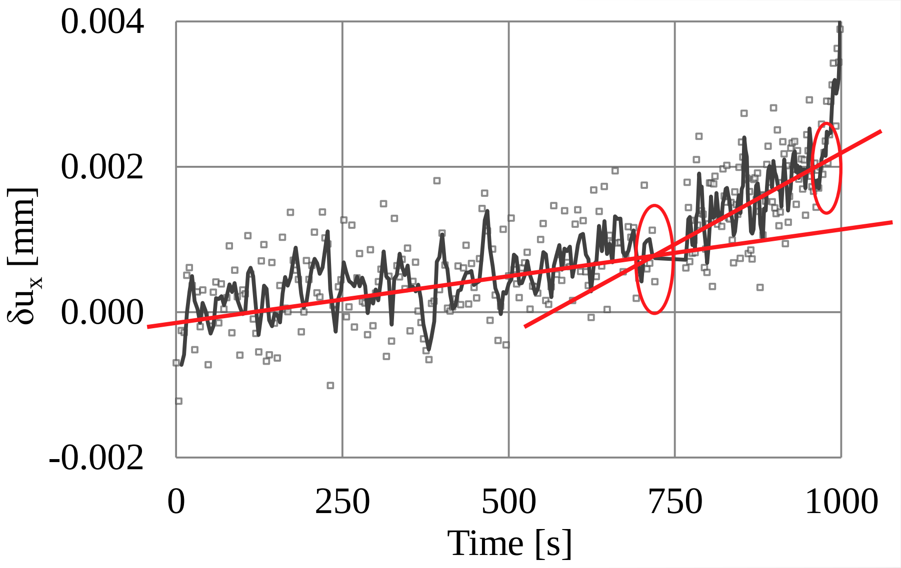
Sensor 2
(lower part of the disc)



Results

FT-M-50-5-4





Conclusions

- The curved jaws of the ISRM standard impose lateral restrictions on the specimen (which are intensified by the action of the inevitable friction forces) and as a result the two parts of the cracked specimen are not divided into two halves rendering naked eye (and also high-speed camera) observations difficult.

- The load at which the specimen fails seems to be smaller than the maximum load recorded and this smaller load should be used for the determination of the fracture toughness.

- DIC technique is an extremely useful tool allowing the researcher to deepen his/her understanding of the fracture process.

- Different experimental techniques offer mutually complementary results and their combined use is highly recommended.

Acknowledgements

"This research is carried out / funded in the context of the project

"Critical assessment and revision of the standard regarding

the determination of the Mode I fracture toughness, K_{IC}*, of brittle building materials*

using a combination of innovative experimental techniques,

numerical simulations and analytical methods" (MIS 5049181)

under the call for proposals

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