Influence of the initial damage on fracture toughness and subcritical crack growth in a granite rock.

Salvatore D'Urso[1], Lucas Xan Pimienta[1], François Passelègue[1], Federica Sandrone[1], Sergio Vinciguerra[2] and Marie Violay[1]

[1] Laboratory of Experimental Rock Mechanics, École Polytechnique Fédérale de Lausanne
[2] Dipartimento di Scienze della Terra, Università di Torino

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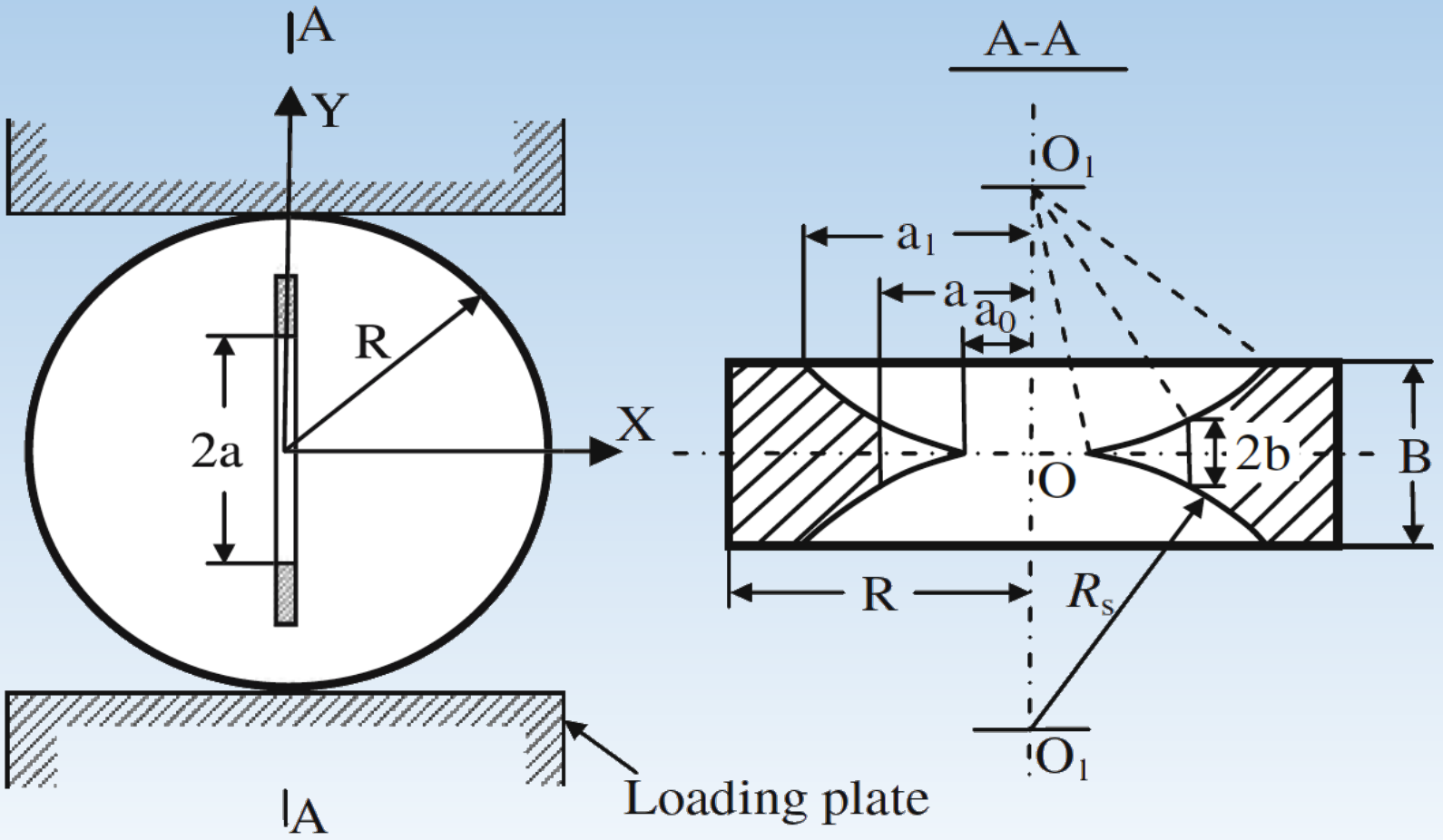
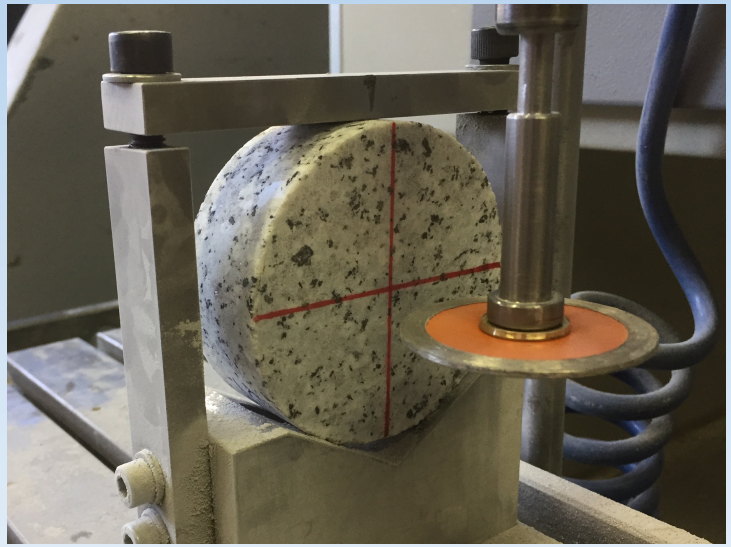
Crack Chevron Notched Brazilian Disc (CCNBD)



Picture from R. J. Fowell, C. Xu, and P. A. Dowd, "An update on the fracture toughness testing methods related to the cracked Chevron-notched Brazilian disk (CCNBD) specimen".

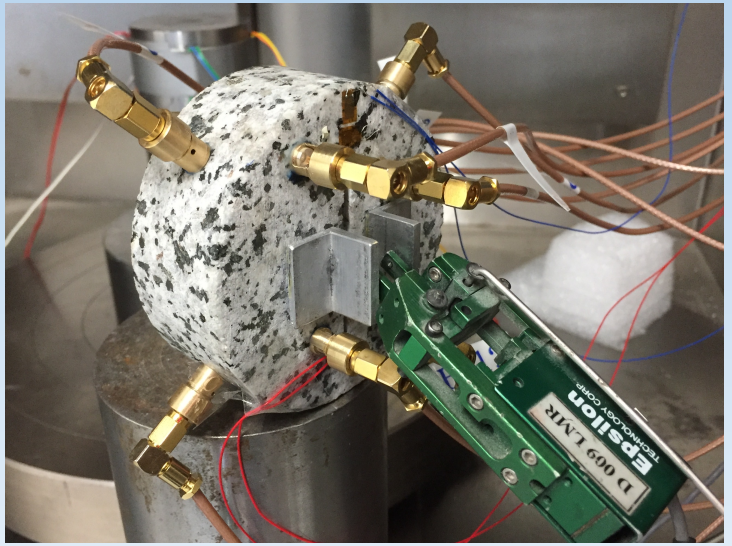
Sample Preparation



Cutting phase

Thermal treatment:

- 100° C;
- 200° C;
- 300° C;
- 400° C.



Sensors positioning:

- Strain gauges;
- CMOD sensor;
- AE recorders.

Mode I Fracture Toughness

Three types of test have been performed in order to investigate the mechanical behaviour of the granite:

- Test under displacement control until failure, with the purpose of calculating the mode I fracture toughness;
- Test under force control by applying a constant ratio K_I/K_{IC} until failure, with the aim of studying the creep behaviour and the subcritical crack growth on the 200°C thermally treated samples;
- Stress-stepping creep tests by applying an increasing ratio K_I/K_{IC} until failure with the aim of studying the subcritical crack growth on all different thermally treated samples;

Mode I Fracture Toughness

$$K_{IC} = \frac{P_{max}}{B\sqrt{R}} Y^*_{min}$$

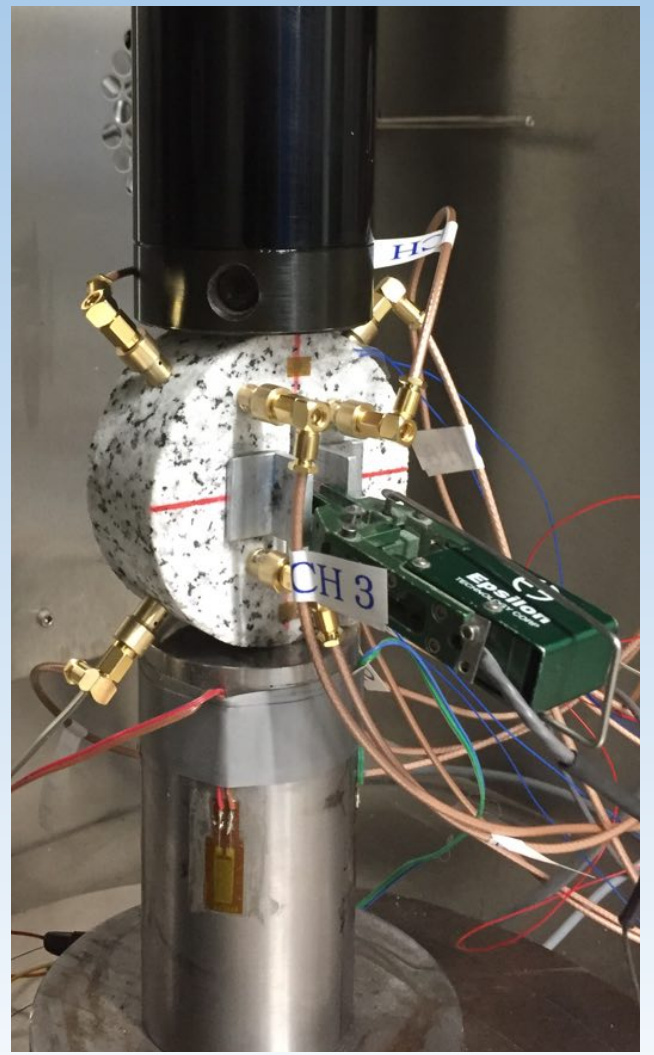
where,

P_{max} is the maximum load at the failure;

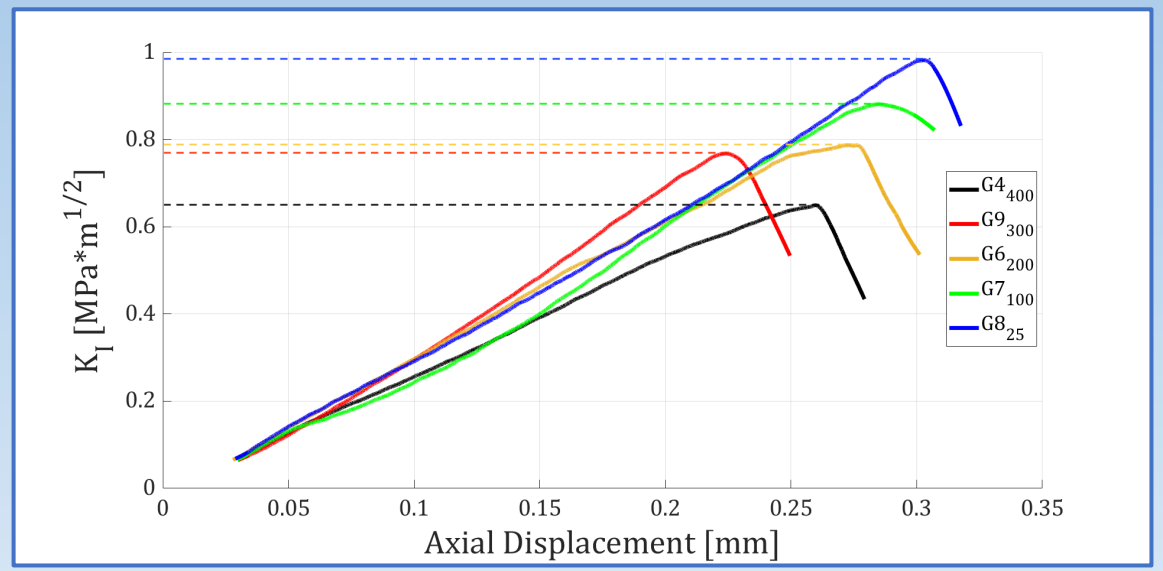
R is the radius of the disc;

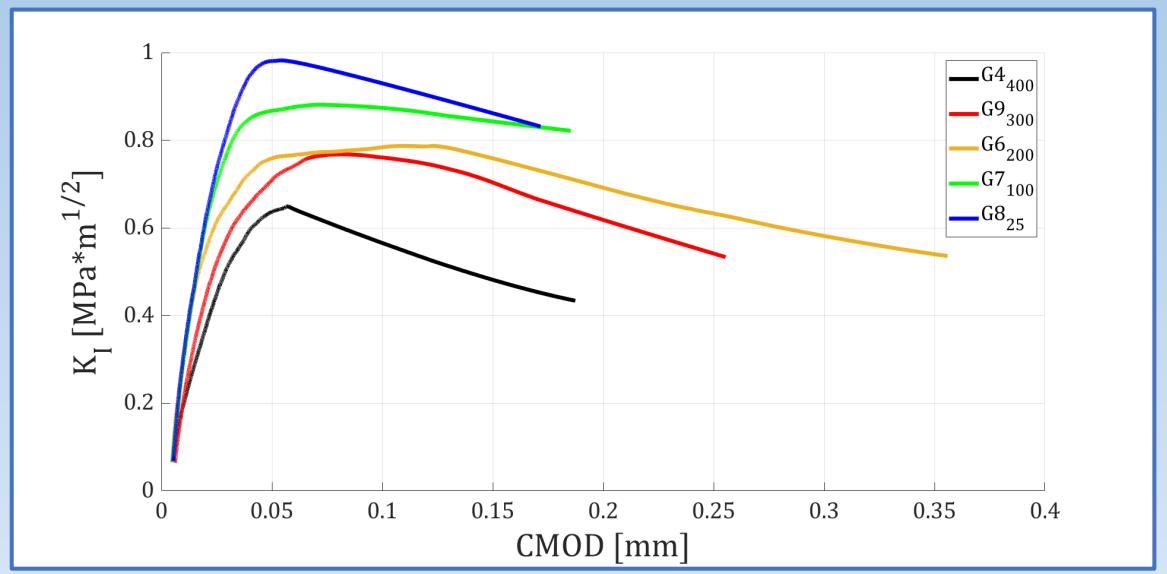
B is the thickness of the disc;

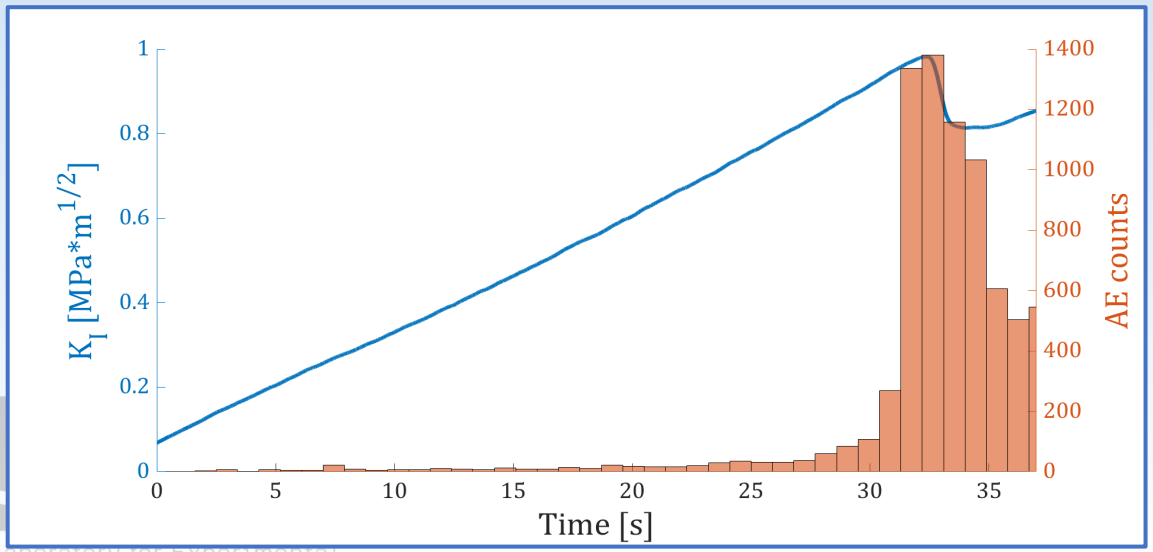
Y^*_{min} is the critical dimensionless stress intensity factor.



Mode I Fracture Toughness (increasing load)

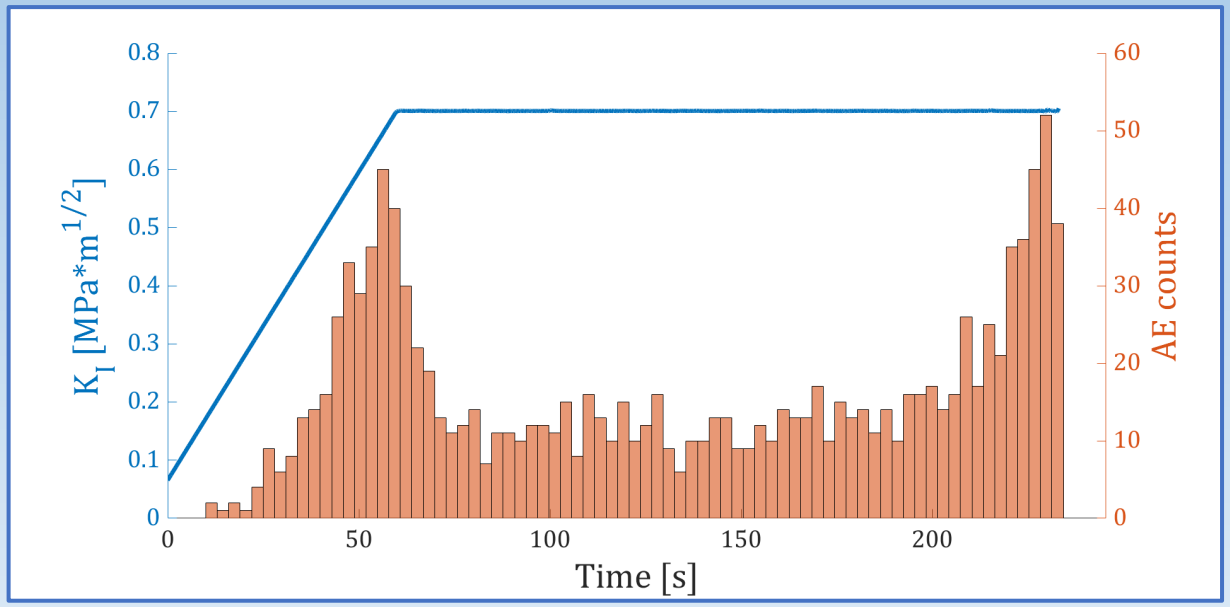


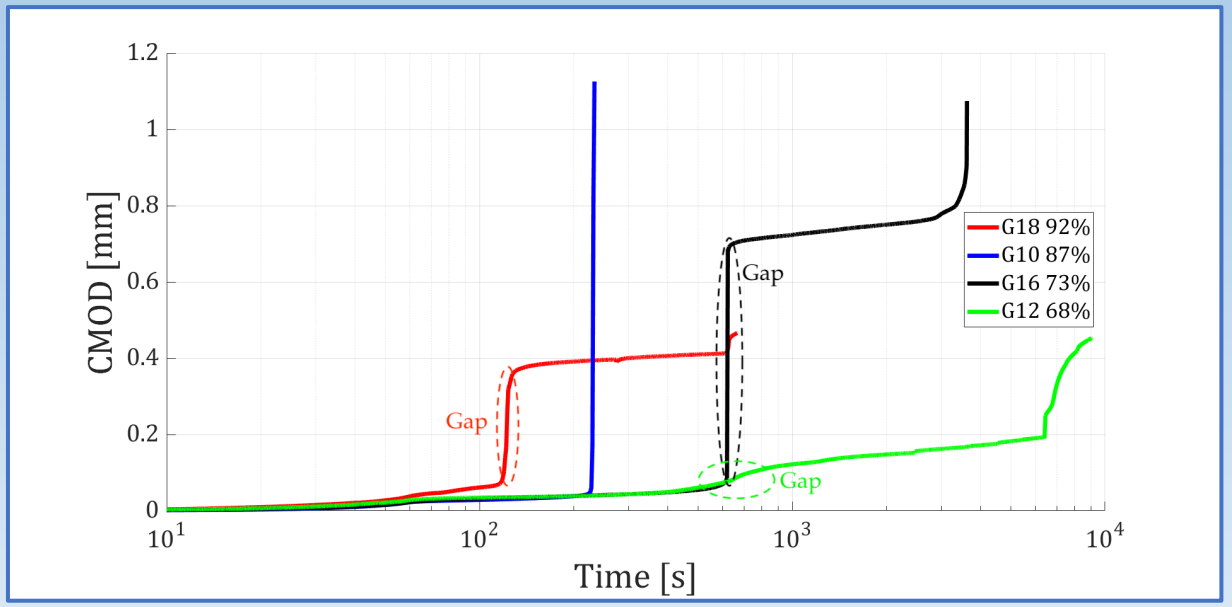




Sample	Thermal treatment	P_{max} $[kN]$	K_{IC} $[MPa\sqrt{m}]$	$K_{IC}/K_{IC,25}$ [%]
G4	400° C	4.93	0.65	65.6
G9	300° C	6.13	0.77	77.7
G6	200° C	6.09	0.79	79.8
G7	100° C	7.01	0.88	88.9
G8	none	7.93	0.99	100

Mode I Fracture Toughness (creep) of $200°\ C$ thermally treated samples





Sample	$K_I\ [MPa\sqrt{m}]$	K_I/K_{IC} [%]	Time 1^{st} crack propagation $[s]$
G18	0.73	92	120
G10	0,69	87	230
G16	0,58	73	622
G12	0,54	68	700

Subcritical Crack Growth Parameters A and n

From the Charles power-law

$$v = A\left(\frac{K_I}{K_{IC}}\right)^n$$

where,

v is the subcritical crack growth velocity;

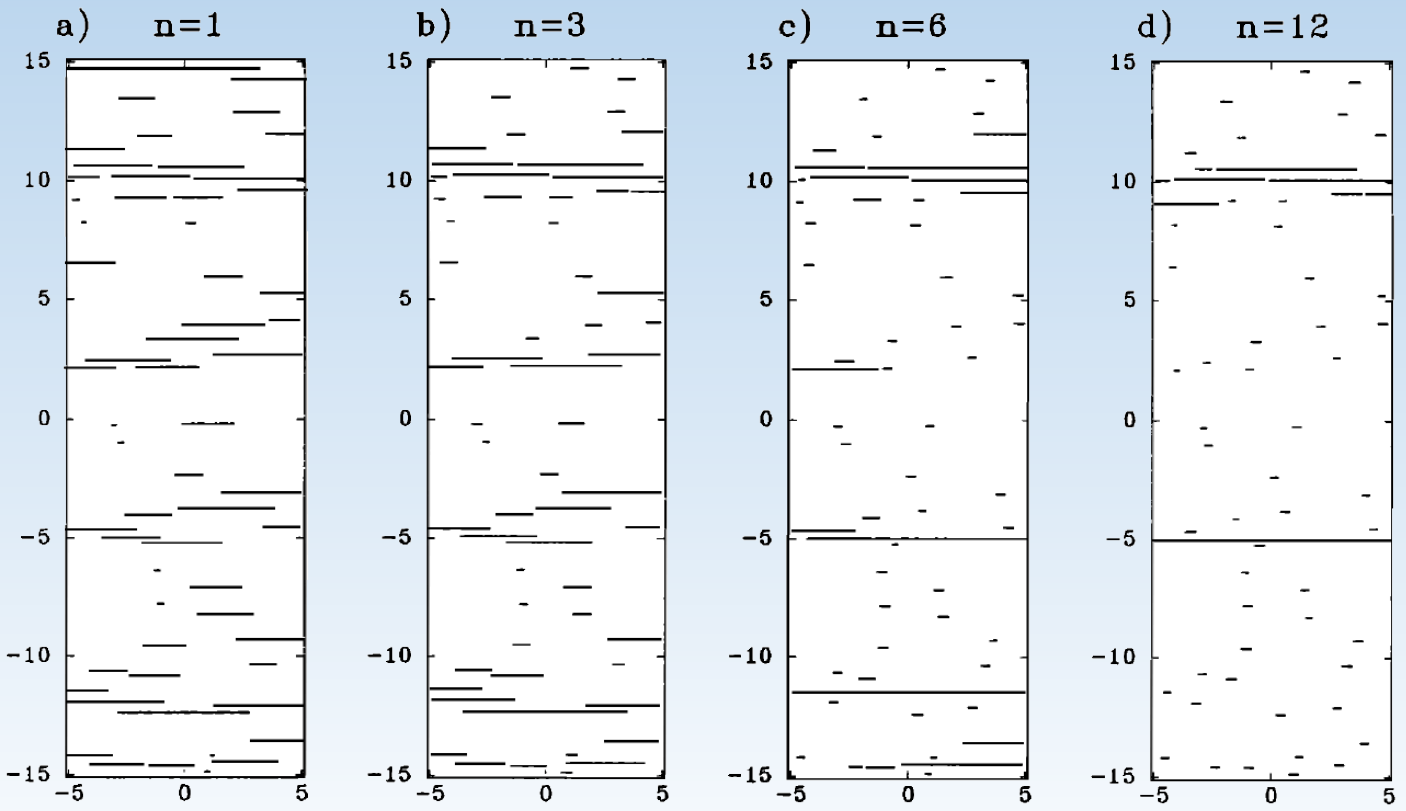
K_I is the mode I stress intensity factor;

K_{IC} is the mode I fracture toughness;

A is the crack propagation velocity when $K_I = K_{IC}$;

n is an index of the internal damage.

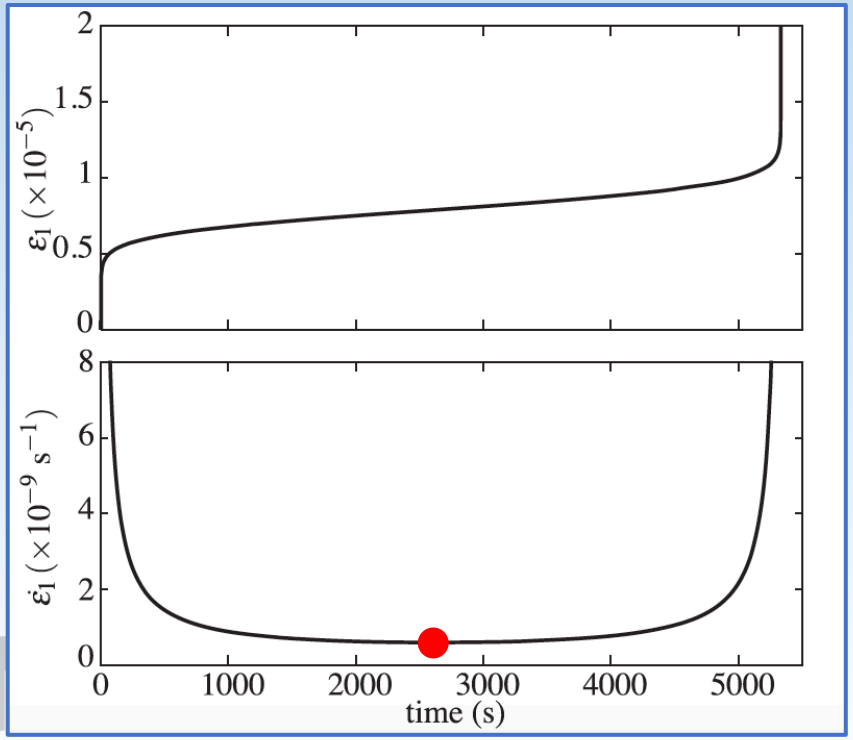
Increasing internal damage



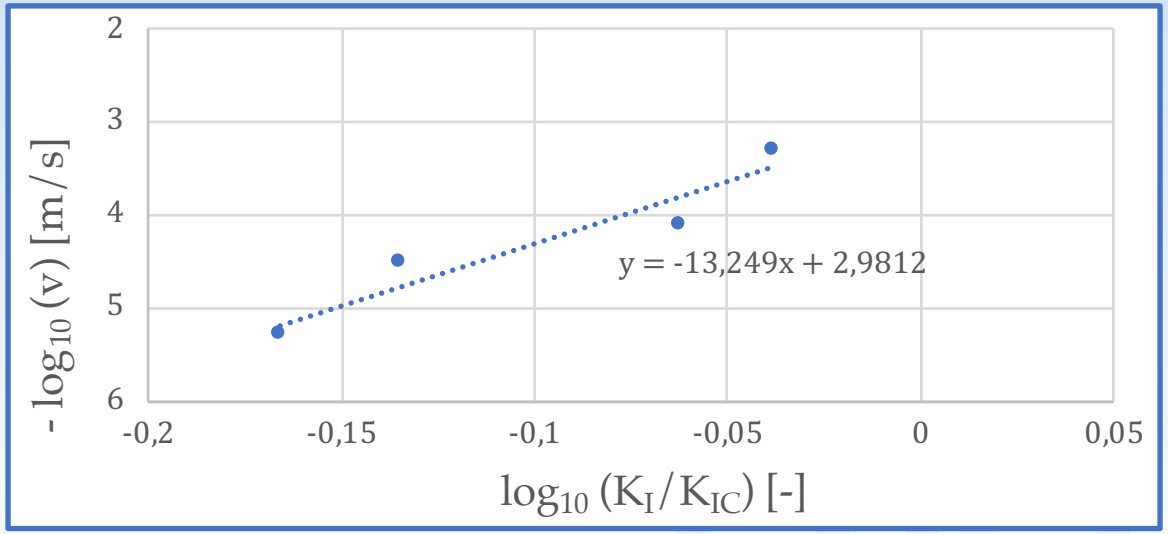
Subcritical Crack Growth Parameters A and n

$$v = A\left(\frac{K_I}{K_{IC}}\right)^n \quad \Longrightarrow \quad \log(v) = \log(A) + n\log\left(\frac{K_I}{K_{IC}}\right)$$

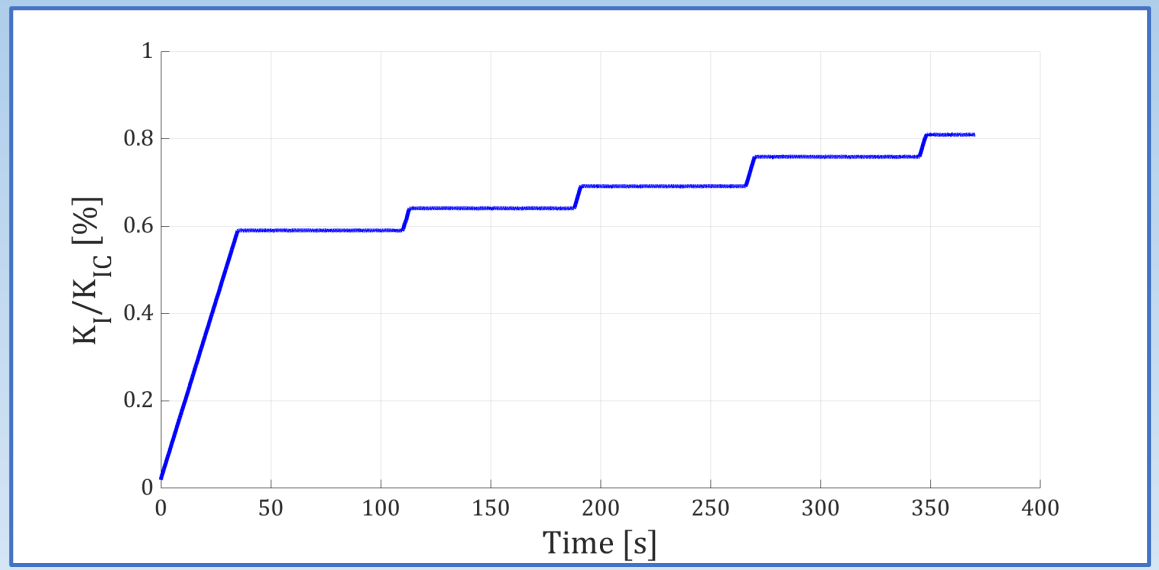
Subcritical crack growth velocities calculated through the derivative of the crack mouth opening displacement (CMOD)

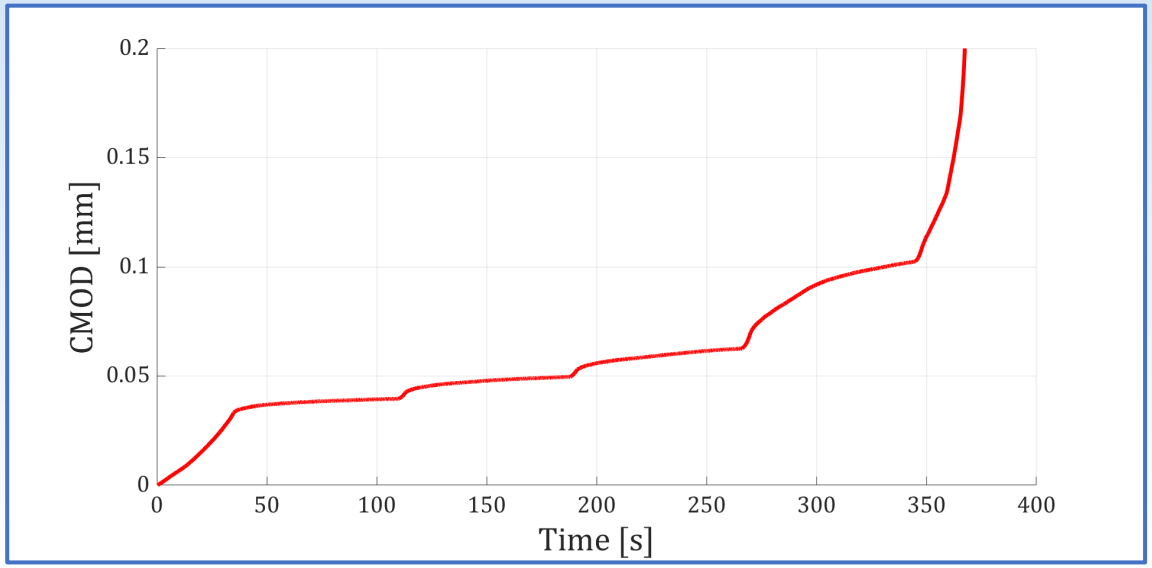


Sample	Thermal treatment	K_I/K_{IC} [%]	Subcritical crack growth velocity $[mm/s]$
G18	200° C	92	$5 \cdot 10^{-4}$
G10	200° C	87	$8 \cdot 10^{-5}$
G16	200° C	73.5	$3 \cdot 10^{-5}$
G12	200° C	68	$5 \cdot 10^{-6}$

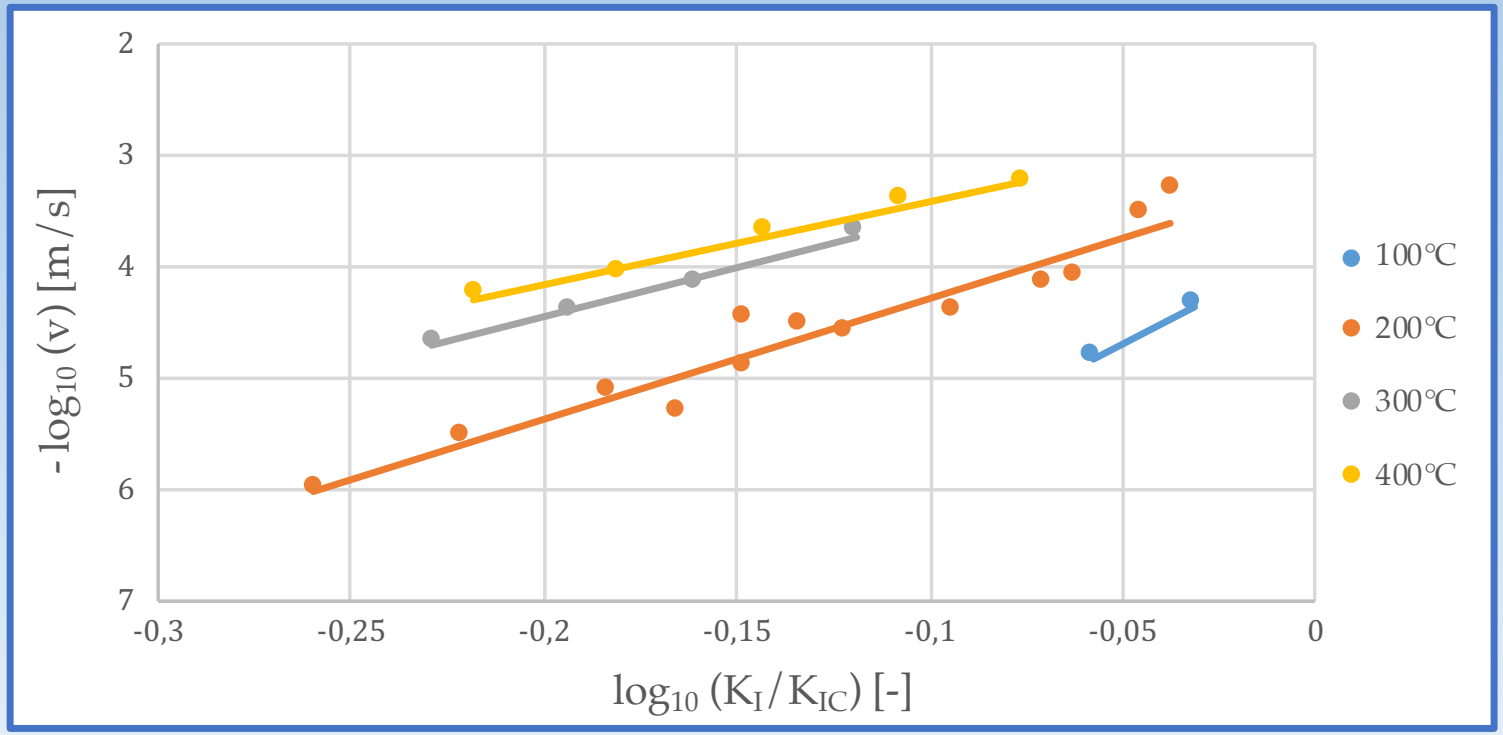


Stress-stepping creep tests





Influence of the initial damage on subcritical crack growth parameters



	$100°\,C$	$200°\,C$	$300°\,C$	$400°\,C$
n [–]	18	13.2	9	7.5
A $[mm/s]$	$1.5 \cdot 10^{-4}$	$1 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$

References

- R. J. Charles, "Dynamic fatigue of glass," *J. Appl. Phys.*, vol. 29, no. 12, pp. 1657–1662, 1958.
- R. J. Fowell, et al. "Suggested method for determining mode I fracture toughness using cracked chevron notched Brazilian disc (CCNBD) specimens." *International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts*, vol. 7, no. 32, 1995.
- R. J. Fowell, C. Xu, and P. A. Dowd, "An update on the fracture toughness testing methods related to the cracked Chevron-notched Brazilian disk (CCNBD) specimen," *Pure Appl. Geophys.*, vol. 163, no. 5–6, pp. 1047–1057, 2006.
- J. E. Olson, "Joint pattern development: Effects of subcritical crack growth and mechanical crack interaction," *J. Geophys. Res. Solid Earth*, vol. 98, no. B7, pp. 12251–12265, 1993.
- B. K. Atkinson, "Subcritical Crack Growth in Geological Materials," *J. Geophys. Res.*, vol. 89, no. 10, pp. 4077–4114, 1984.
- P. G. Meredith and B. K. Atkinson, "Fracture toughness and subcritical crack growth during high-temperature tensile deformation of Westerly granite and Black gabbro," *Phys. Earth Planet. Inter.*, vol. 39, no. 1, pp. 33–51, 1985.