Short story on how loading scenario influence failure of solid material under stretching

W. Dębski

Inst. Geophys. PAS

28.10.2022

History ...

- 2019, S. Pradhan, J.T. Kjelstadli, A. Hansen

  Variation of elastic energy shows reliable signal of upcoming catastrophic failure

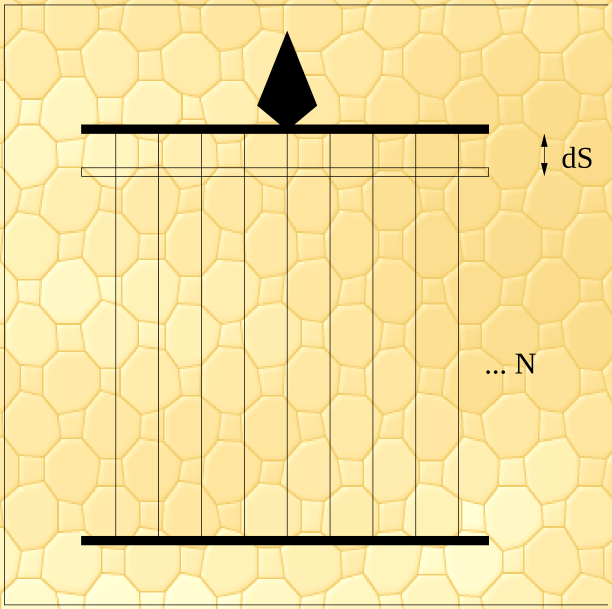
  Frontiers in Phys., doi:10.3389/fphy.2019.00106

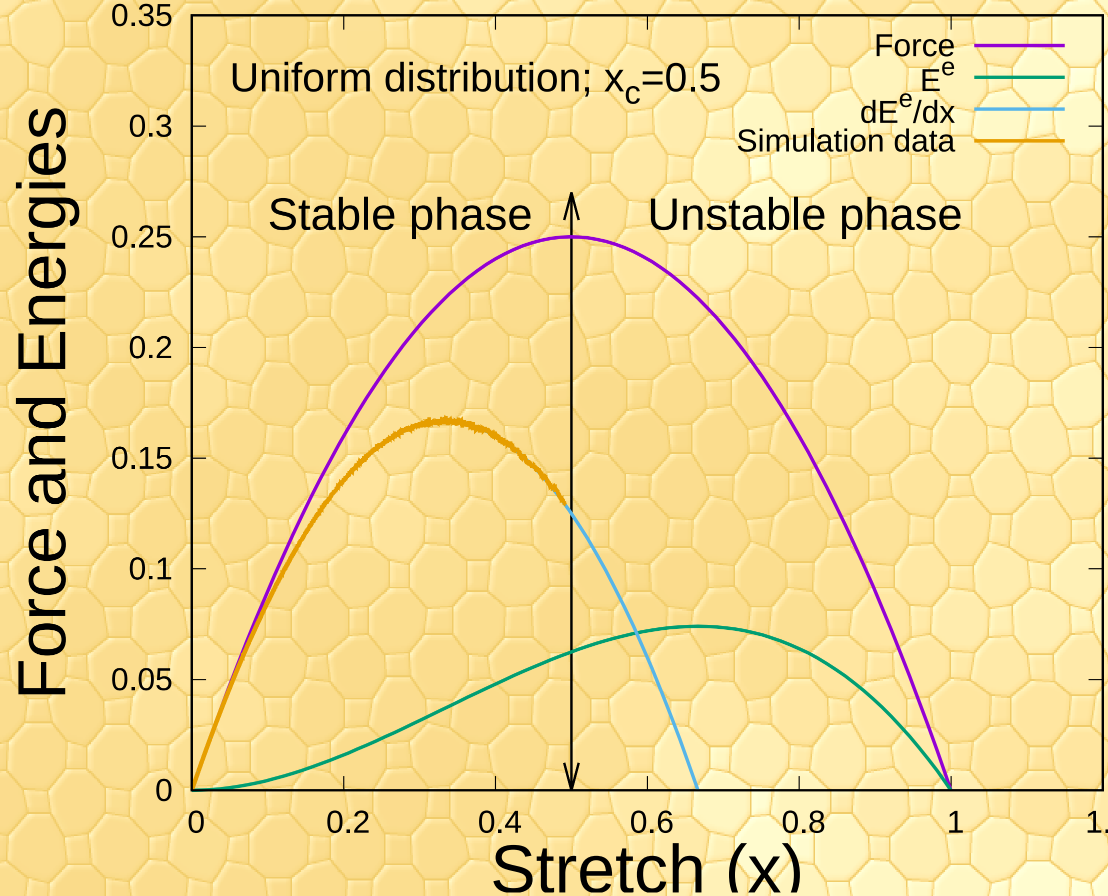
- 2021, W. Debski, S. Pradhan, A. Hansen

  Criterion for Imminent Failure During Loading - Discrete Element Method Analysis

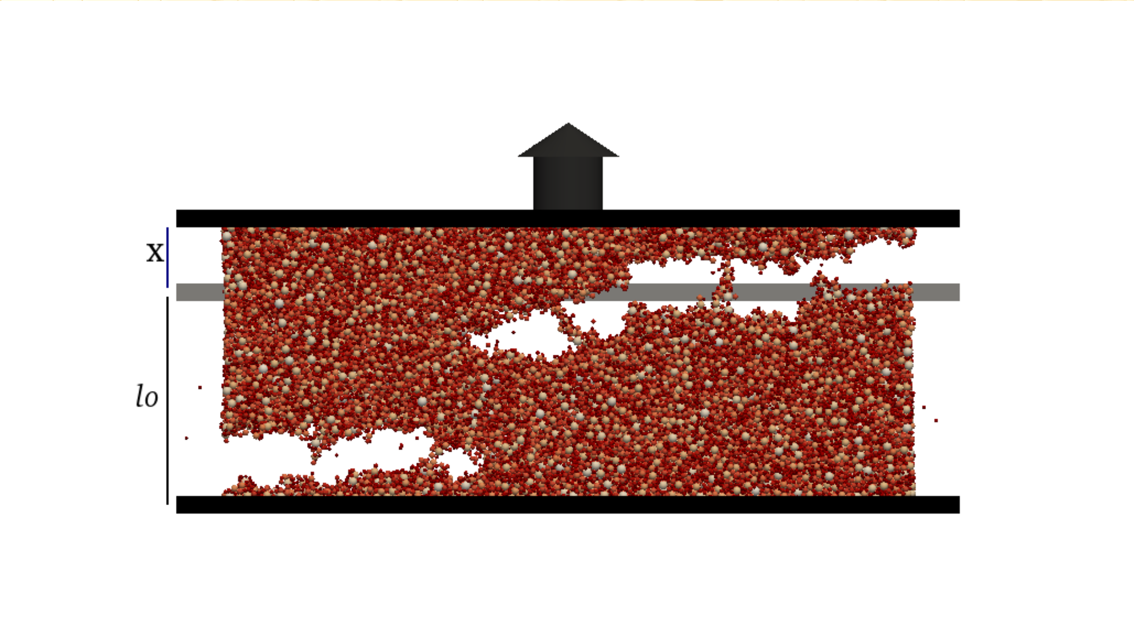
  Frontiers in Phys., doi:10.3389/fphy.2021.675309

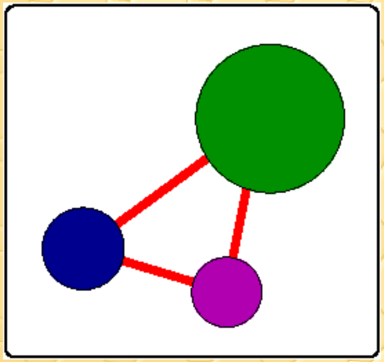
Fiber Bundle Model

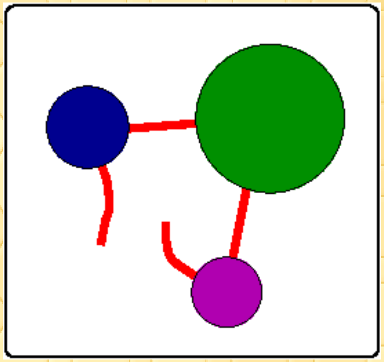


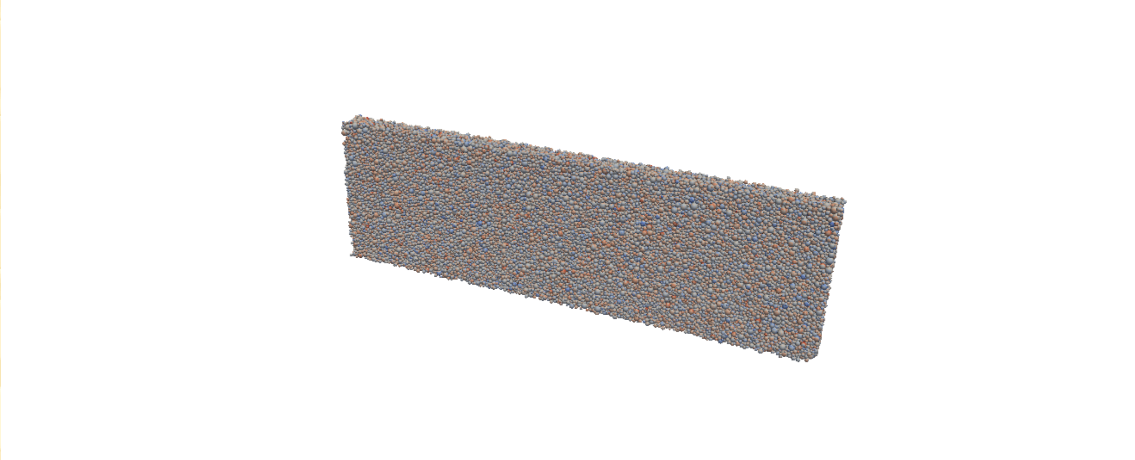


Discrete Element Method (DEM)

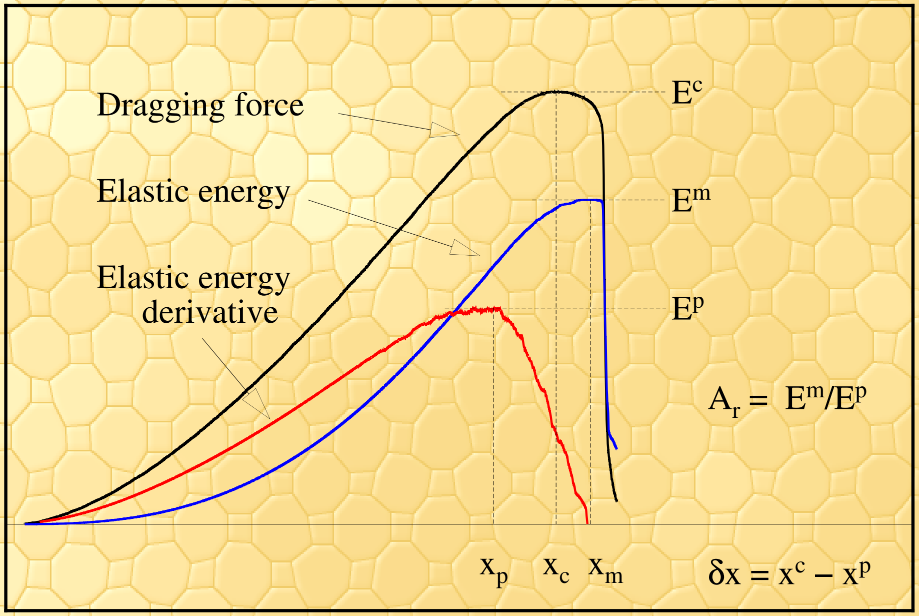


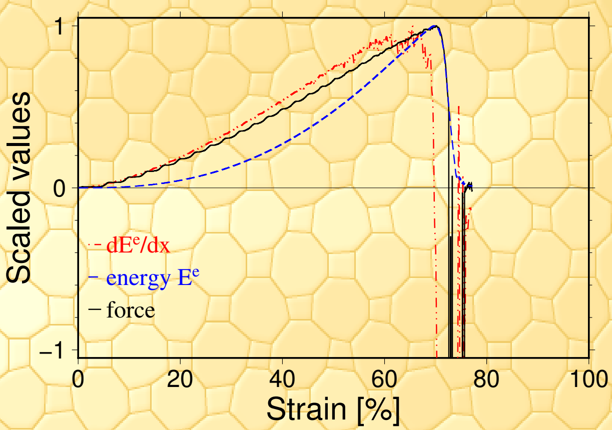


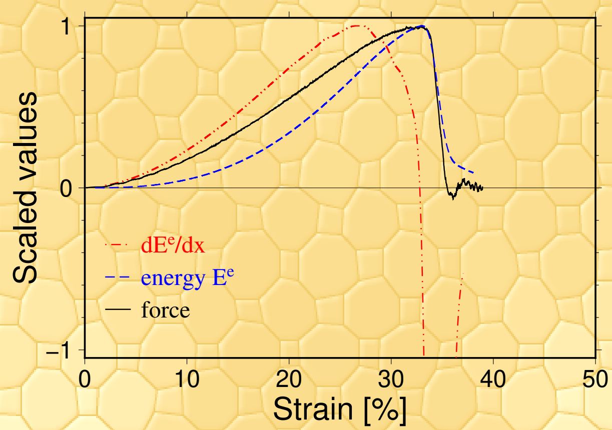


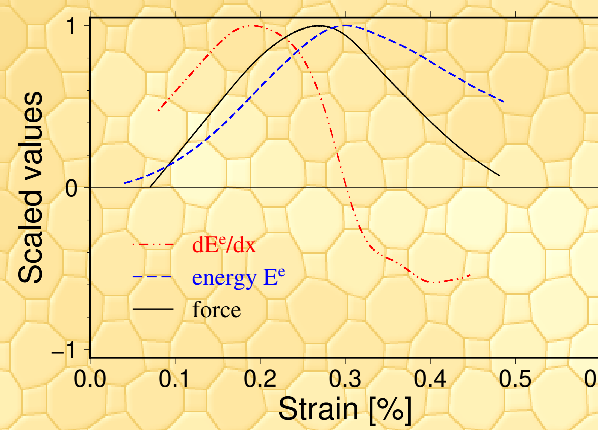


DEM simulations

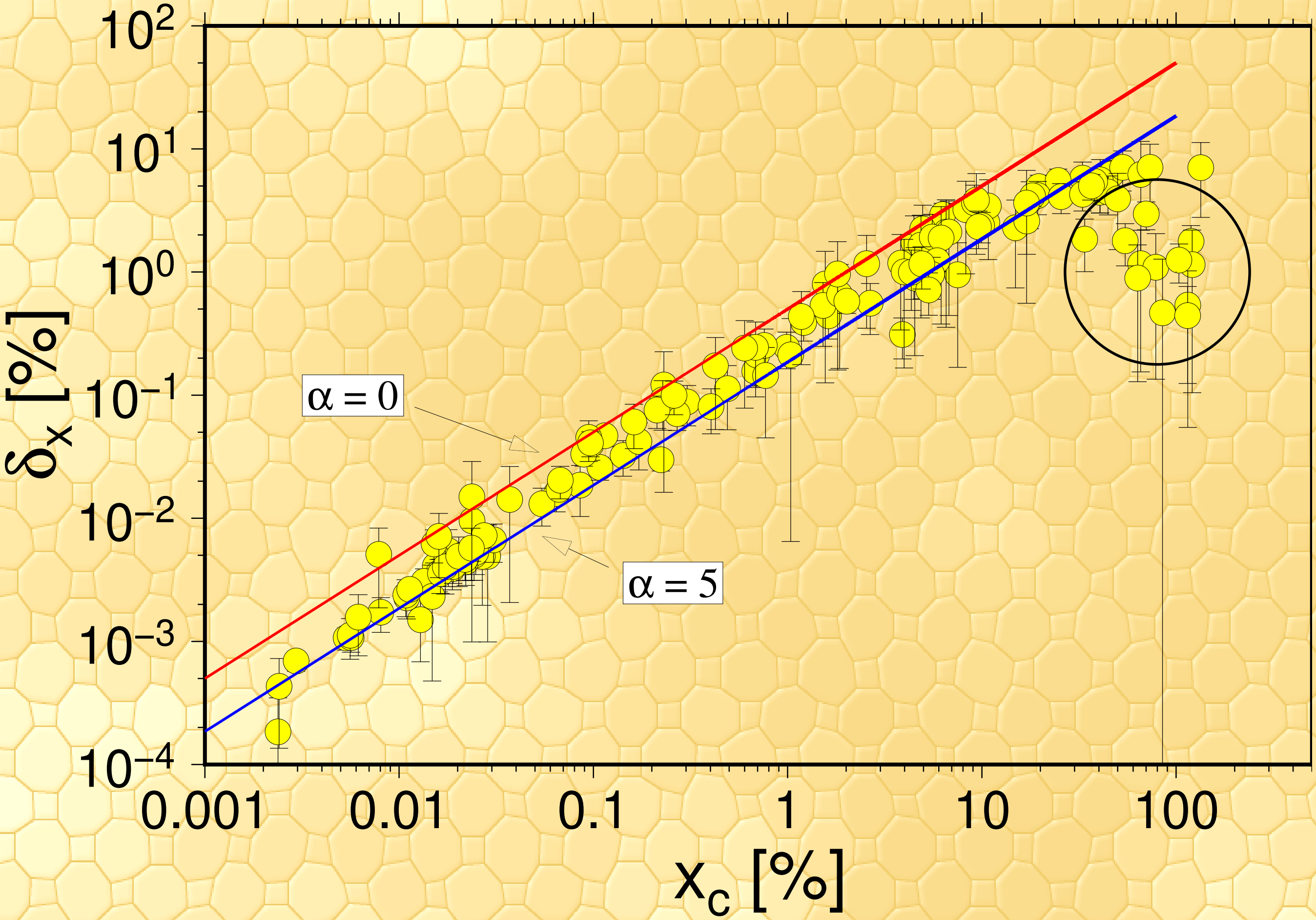




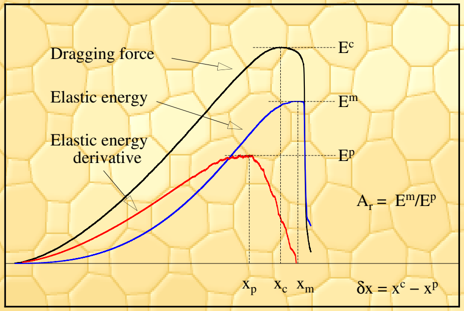




Results (1)

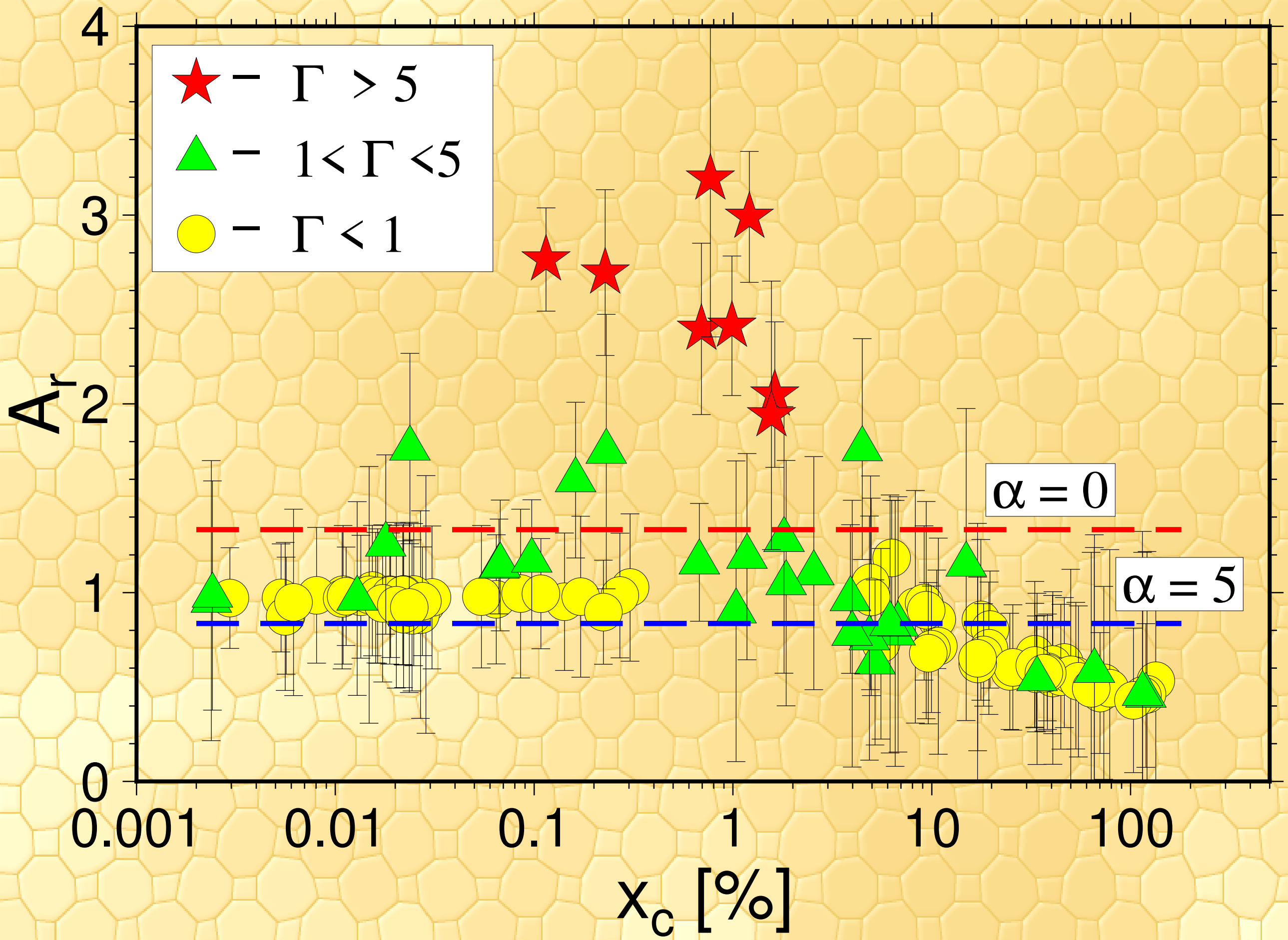


10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
δx [%]
α = 0
α = 5
0.001
0.01
0.1
1
10
100
xc [%]

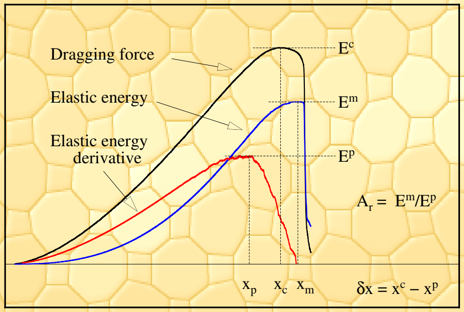


Dragging force
Elastic energy
Elastic energy derivative
Ec
Em
Ep
Ar = Em/Ep
xp
xc
xm
δx = xc − xp

Results (2)



A_r
0
1
2
3
4
0.001
0.01
0.1
1
10
100
x_c [%]
– Γ > 5
– 1< Γ <5
– Γ < 1
α = 0
α = 5



Dragging force
Elastic energy
Elastic energy derivative
E^c
E^m
E^p
$A_r = E^m/E^p$
x_p x_c x_m
$\delta x = x^c - x^p$

Experimental confirmation

Damage evolution in specimens made with quasi-brittle materials: Experimental verification using Acoustic Emission technique

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1) Department of Mechanical Engineering, UFRGS, Porto Alegre, RS/Brazil.
2) Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Turin, Italy.
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Keywords: Acoustic Emission, Damage Process, Failure Precursors.

ABSTRACT: Composites, both natural and engineered, present complex failure behaviour due to their heterogeneous nature. The localisation interaction among a cluster of micro-cracks and the size effect are some of the phenomena that govern the damage process. When dealing with systems composed of such materials, the Acoustic Emission (AE) technique is an excellent strategy to obtain information that allows us to understand and characterize the system's behaviour. The present work tested a pre-cracked prismatic basalt specimen until its complete fracture. The AE technique was employed, and the resulting signals were processed considering different acoustic emission global parameters endorsed in the specialized bibliography as precursors of the local/global collapse failure. Moreover, a measure of the temporal elastic energy derivative was computed from the data obtained in the experimental tests. The preliminary results showed that all of the obtained global evolution parameters performed well as failure precursors.

Experimental confirmation

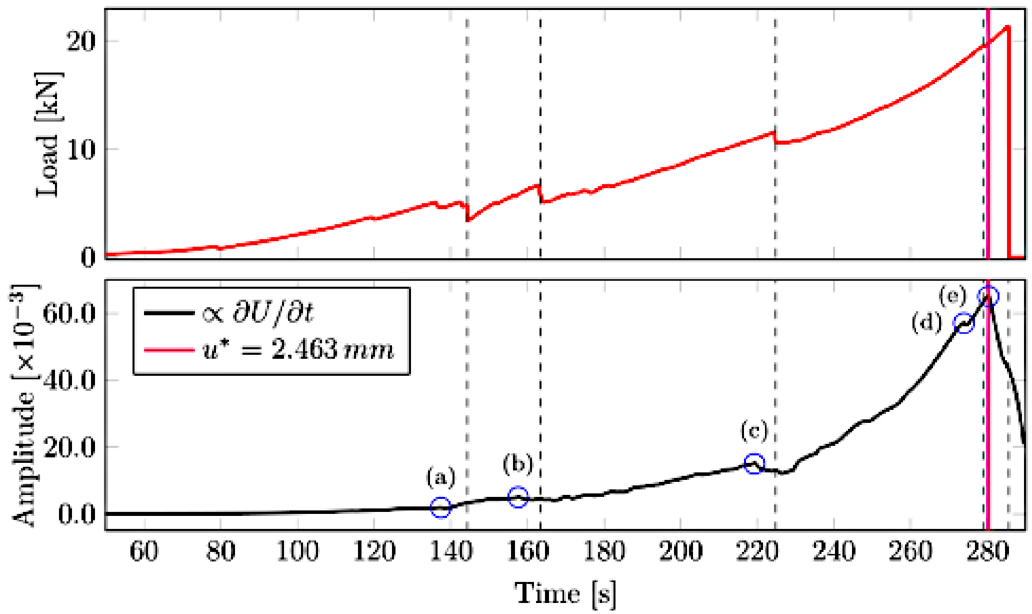


Figure 4: Load vs. time, and derivative of elastic energy.

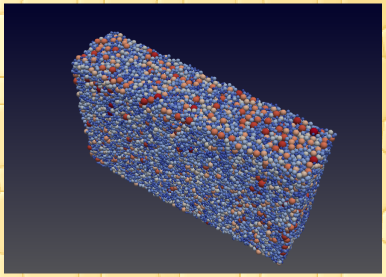
In Table 1, the times where the elastic energy derivative presents a local maximum were computed (t_n), together with the moments where the local drops of the global load vs. time is registered (t_j), and the ratio between the two values. (t_n/t_j). From this table it is possible to see that the values of (t_n/t_j) doesn't change significantly. Debski et al. [1] discussed how (t_n/t_j) changes. This aspect will be further explored as a continuity of the present work.

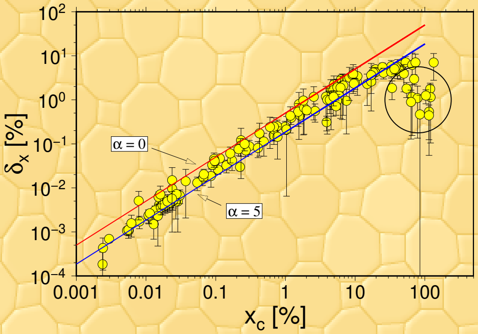
Table 1: Collapse prediction time relationship with elastic energy delta.

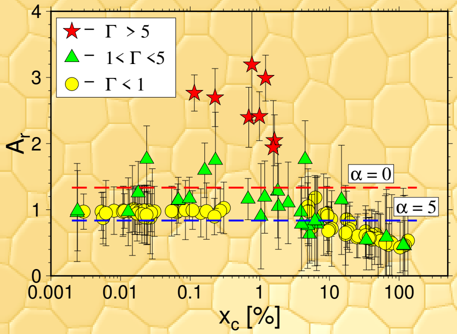
	(a)	(b)	(c)	(d)	(e)
t_n [s]	137.44	157.59	219.23	273.91	280.31
t_j [s]	144.42	163.51	224.83	278.94	285.56
t_n/t_j [%]	95.17	96.38	97.51	98.20	98.16

Question:

What are limits of FBM/DEM ?







what should we look for ?

Discrete Element Method

- PP interactions
  - central forces
  - no internal PP-friction
  - bonds braking condition
- geometry of the sample
- internal structure of the sample

Fiber Bundle Model

- deals with deformation dynamics (x) only
  - massless theory
  - ★ no kinetic energy (variation)
  - ★ no time evolution (no time scale)
- no space scale (only in ELS models)
- no thermodynamics (???)

What should we look for ?

no time scale

$\Downarrow$

loading independence

$\Downarrow$

DEM: search for dependences on loading velocity

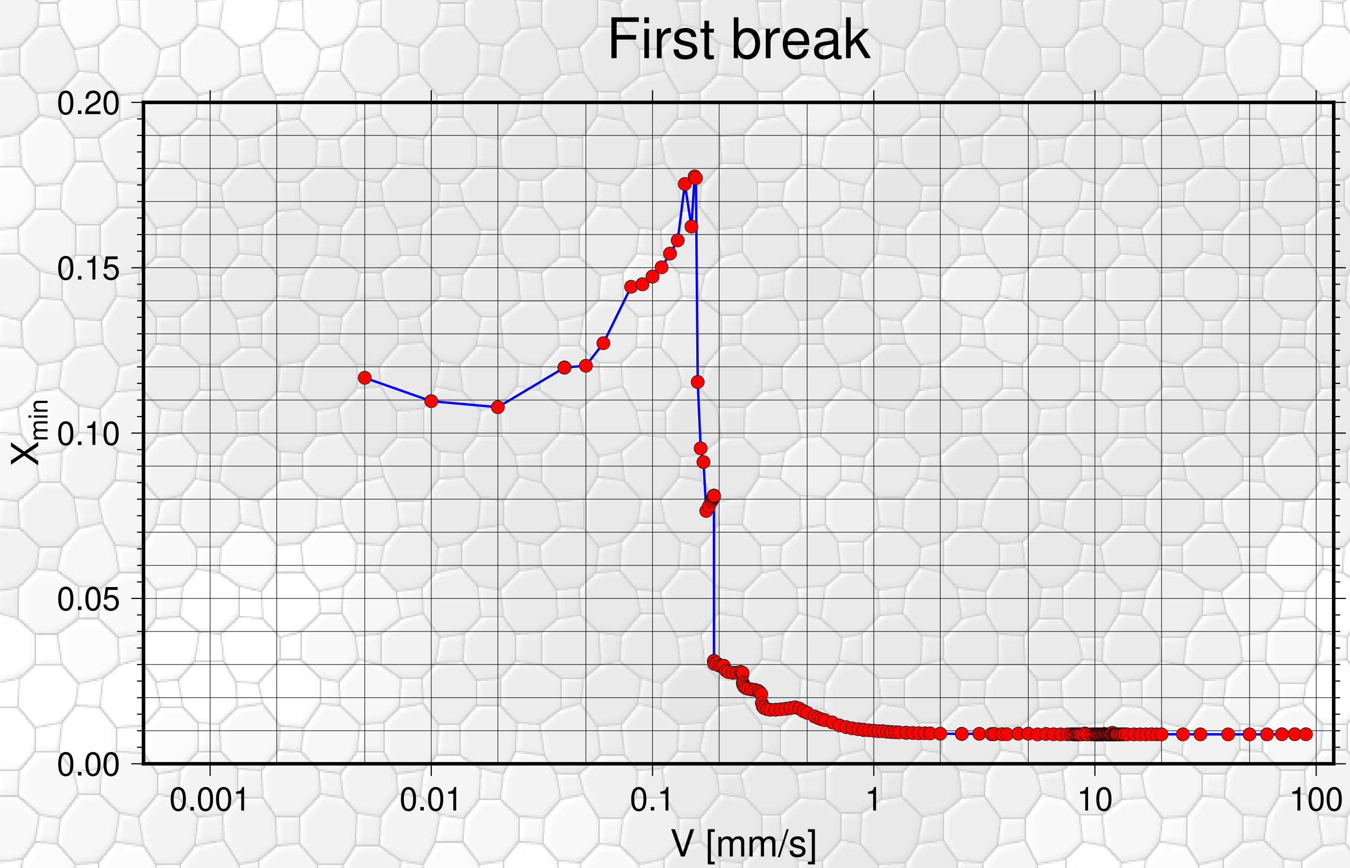
DEM: pay attention on kinetic energy variation

Perform simulation with different velocity of moving plate !

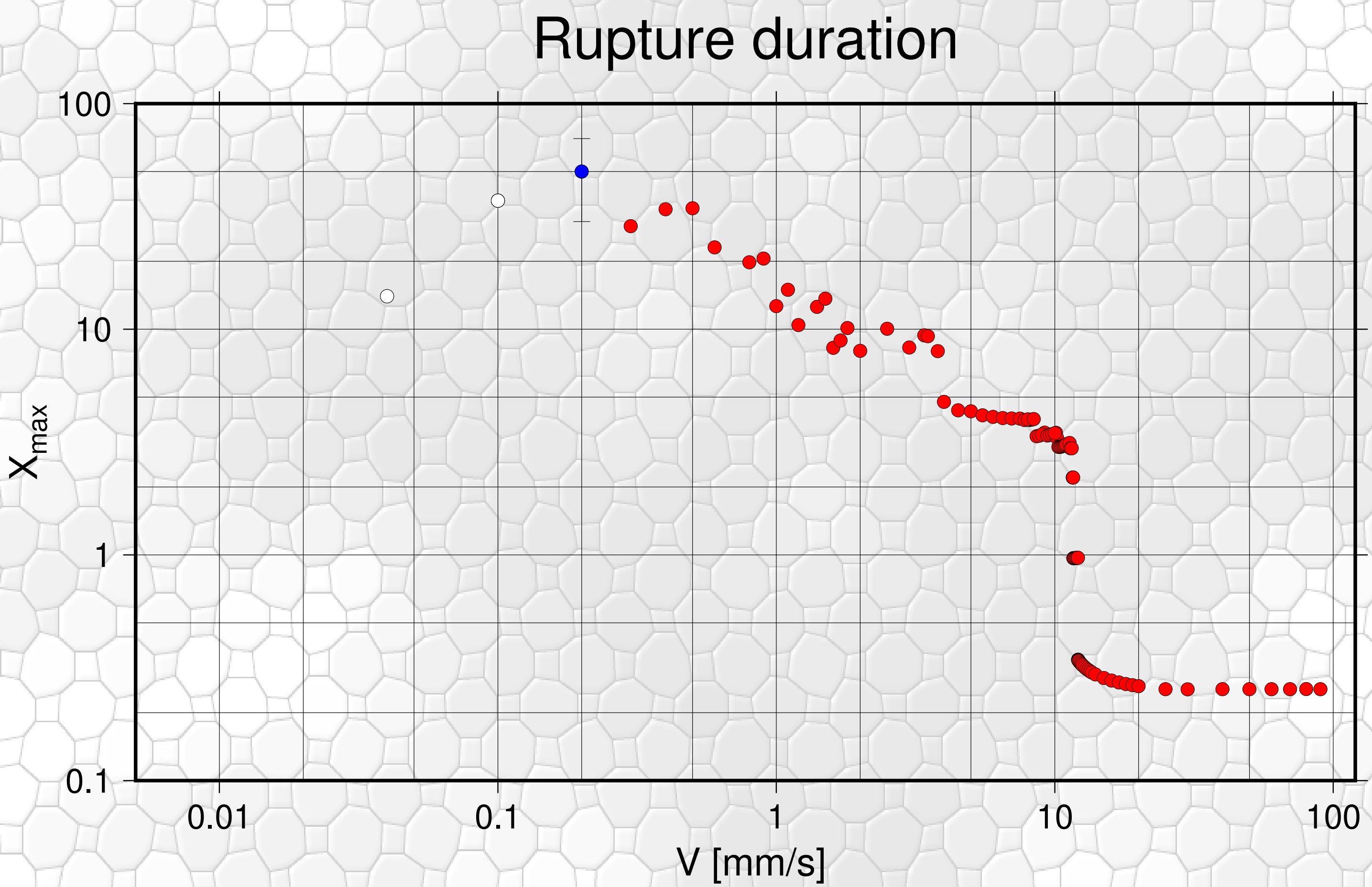
Analysis of velocity dependences

- x_{min} - extension when first PP bonds break
- x_{max} - extension when sample splits off
- $E_p(x)$ - total elastic energy
- $\Delta Nb(x)$ - dynamics of bonds breaking

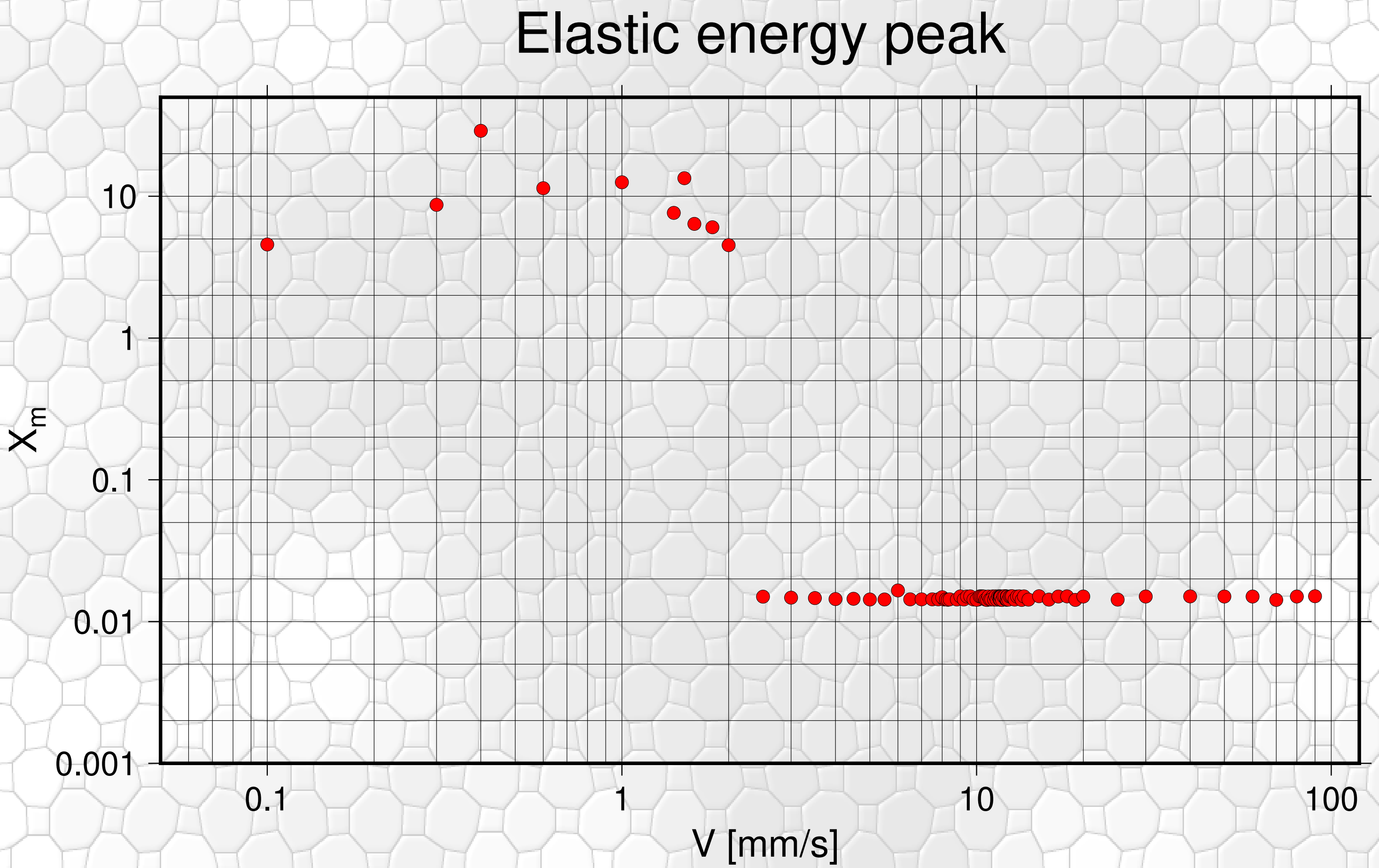
Begining of fracturing



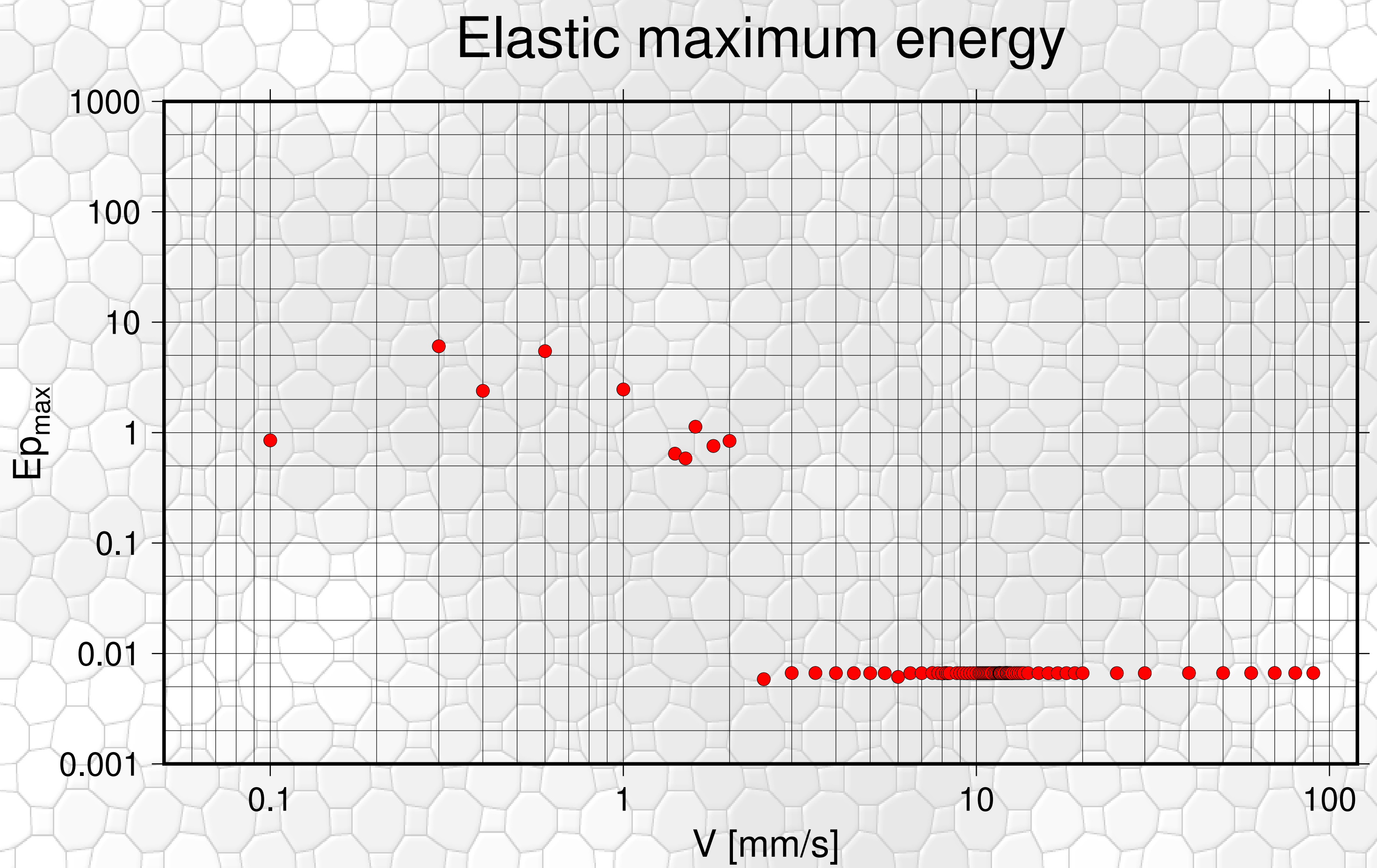
Collaps of sample



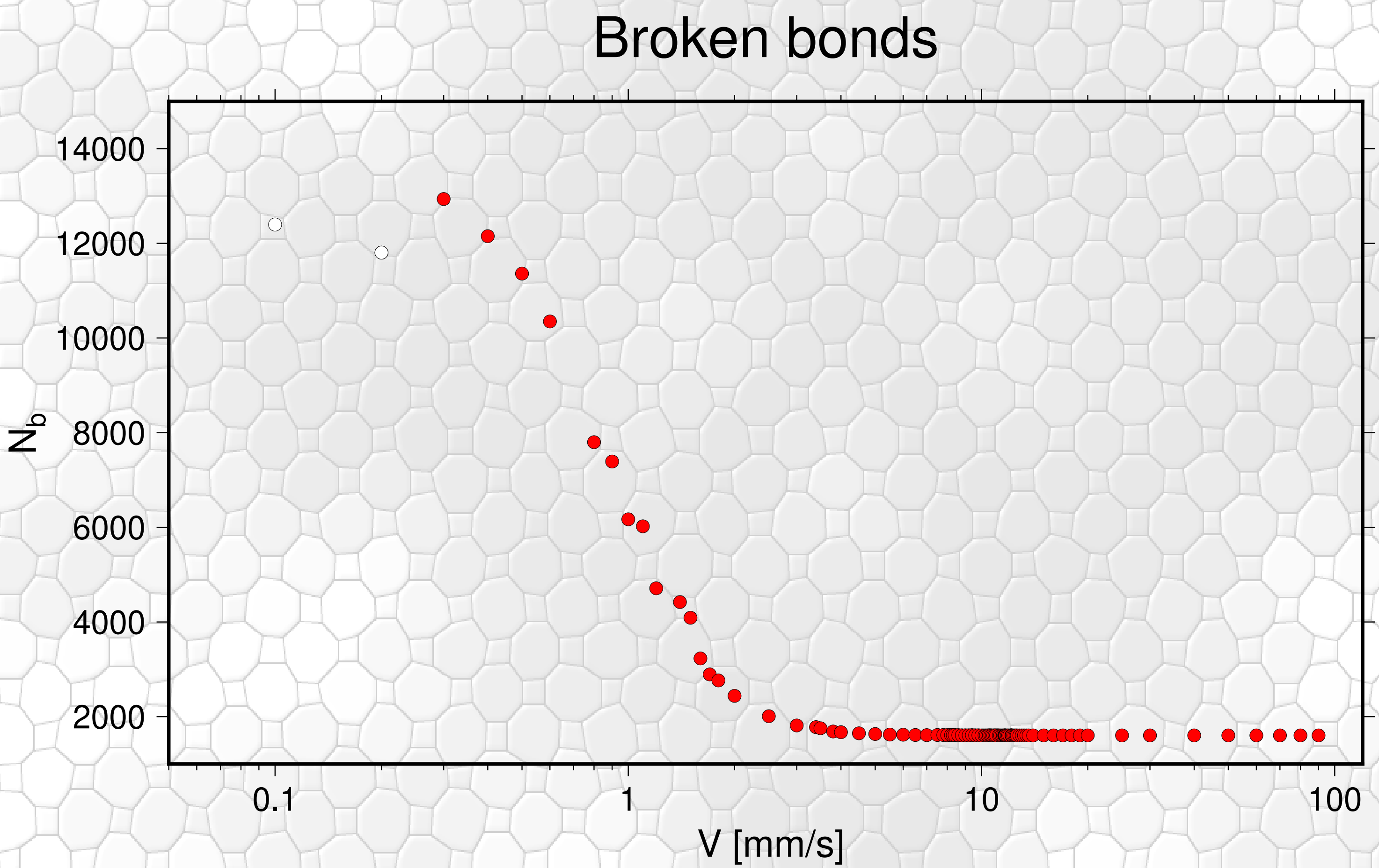
Elastic energy



Elastic energy



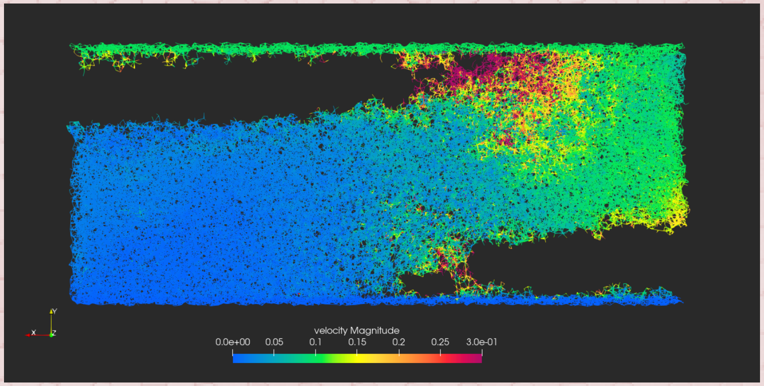
Broken bonds

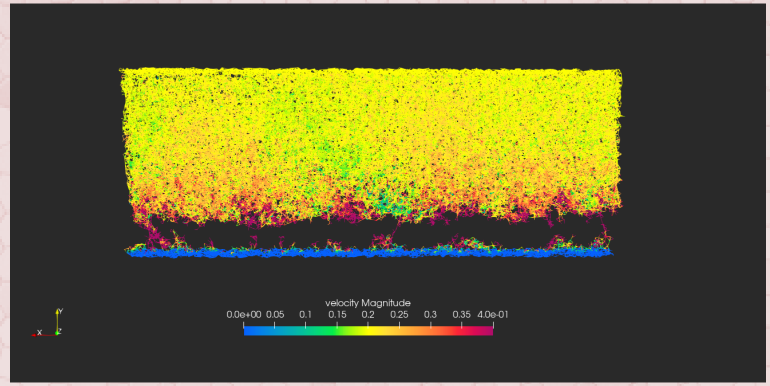


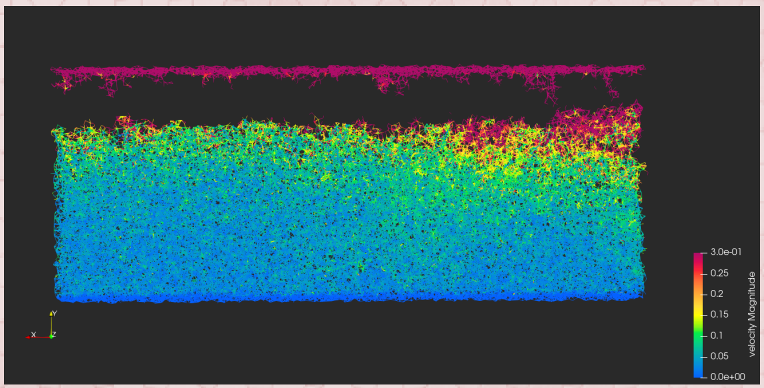
Partial conclusions

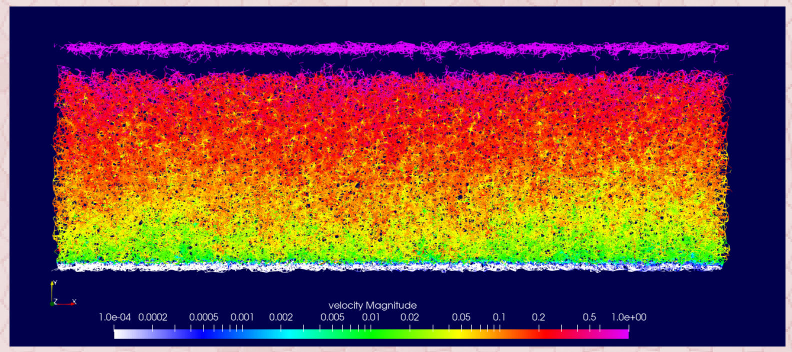
- apparently visible dependences on V
- high-, and low - velocity breaking modes
- FBM - appropriate for high velocity mode

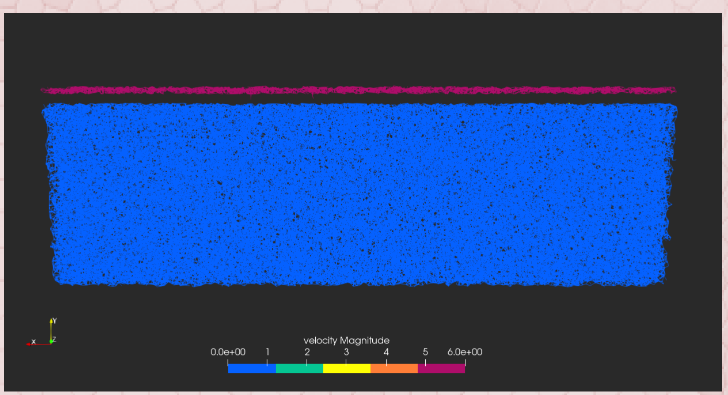
Fragmentation dynamics

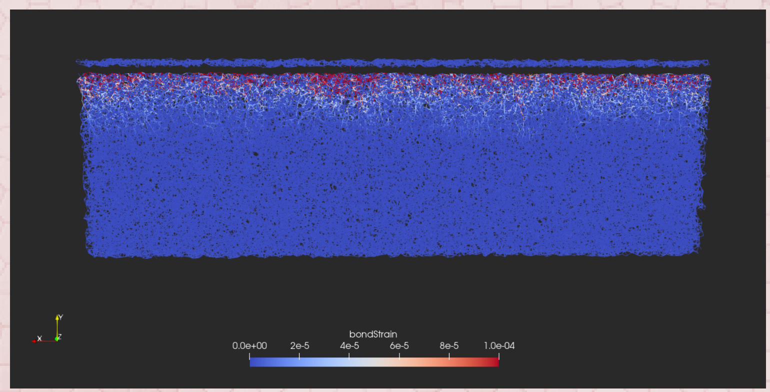




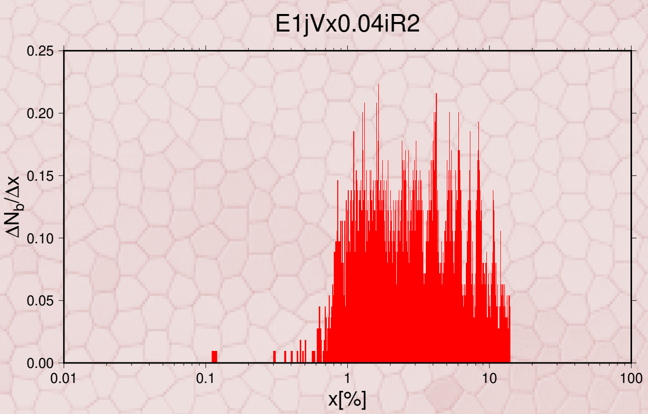


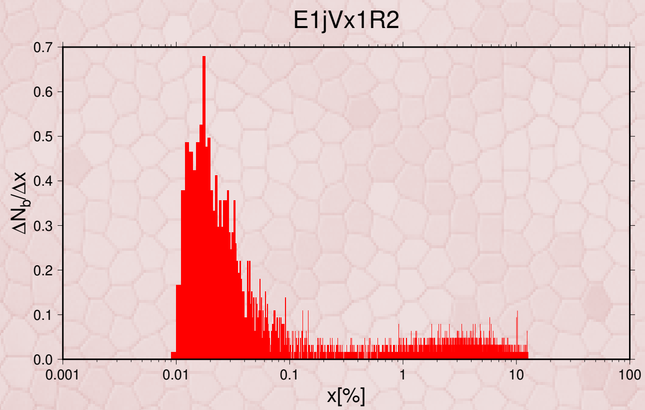


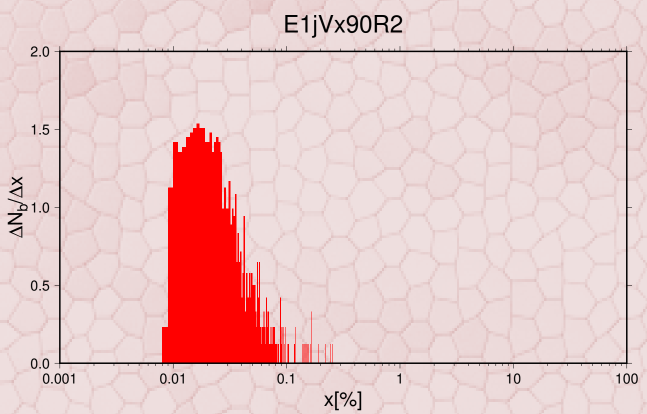




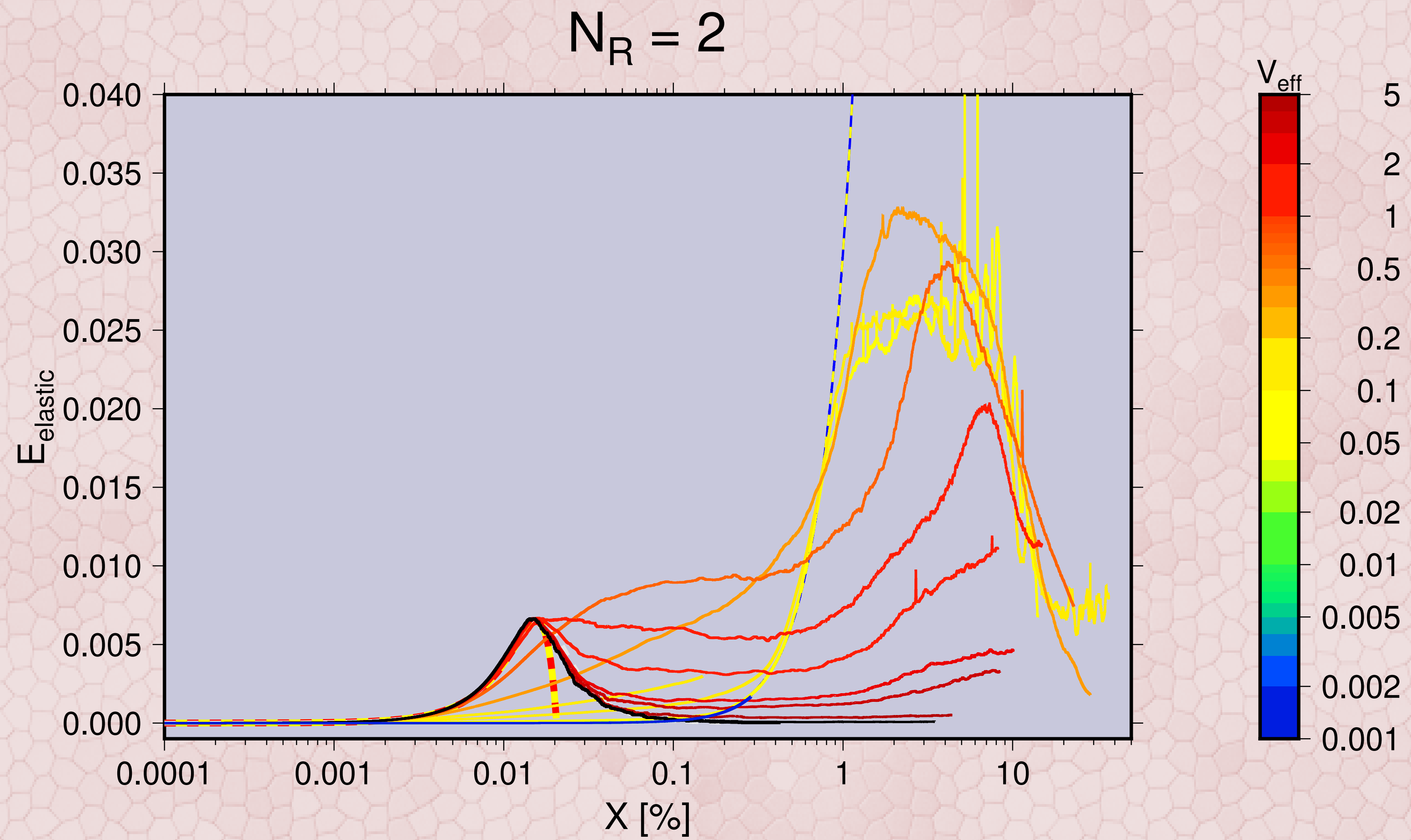
Fragmentation dynamics



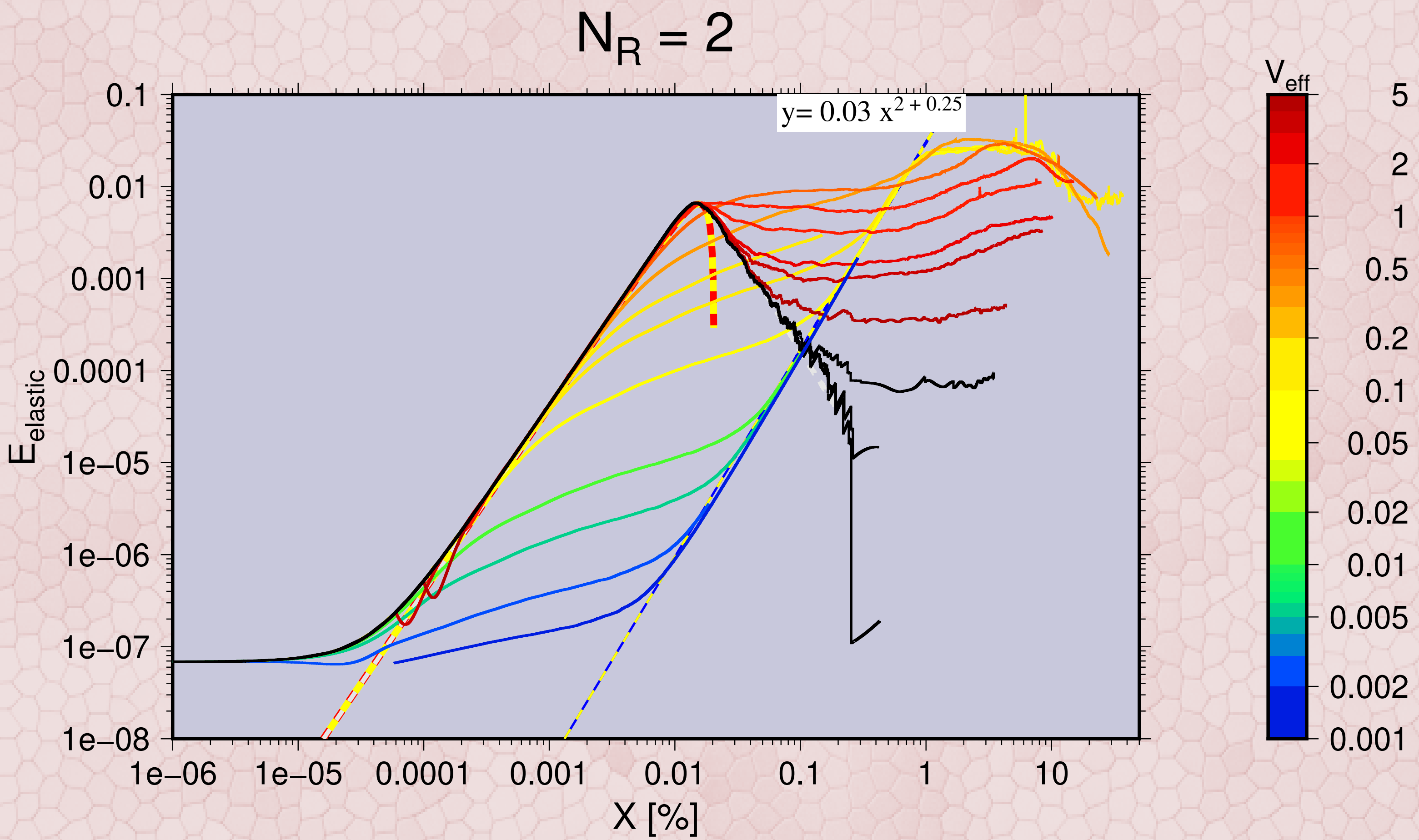




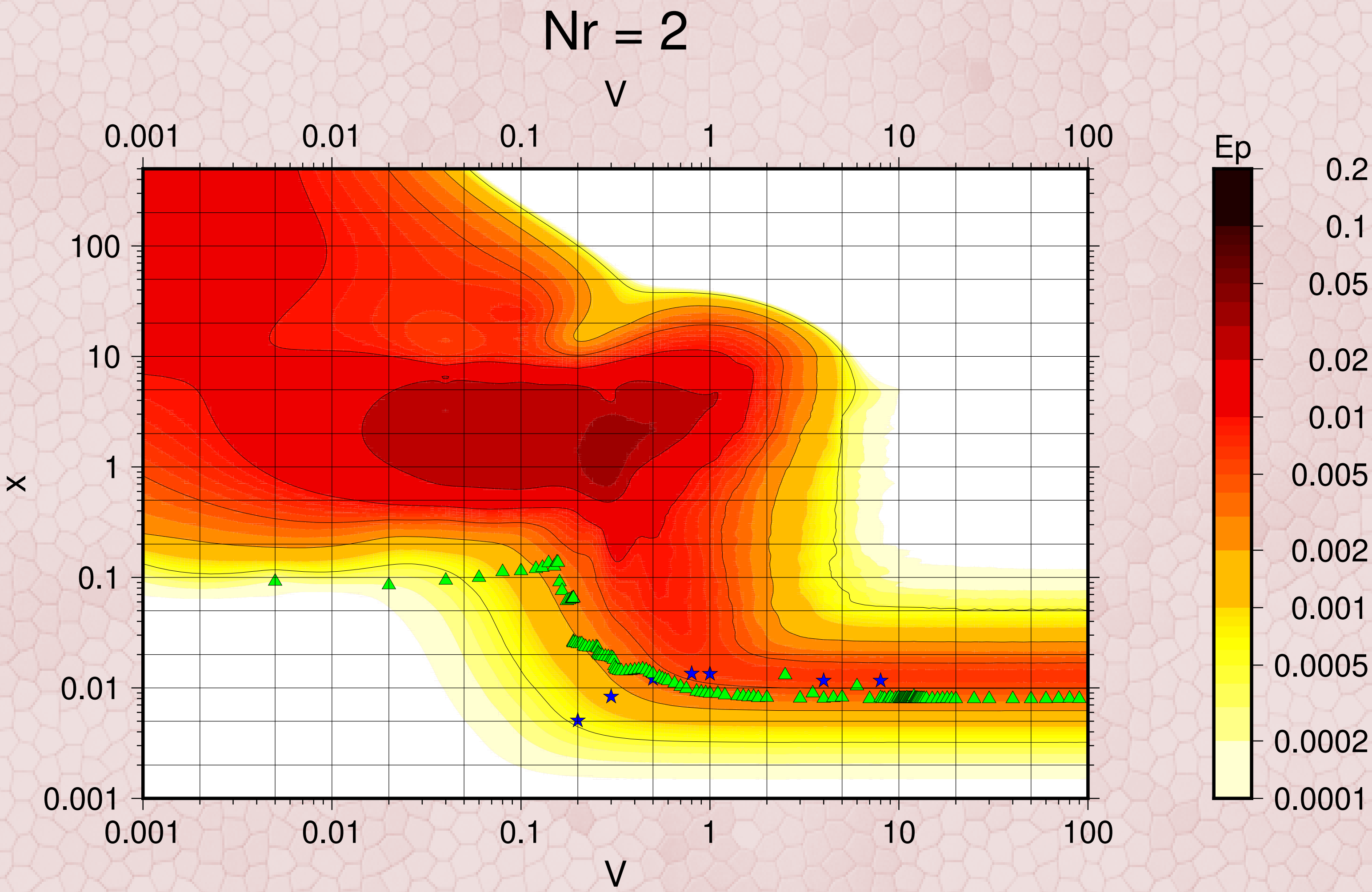
Fragmentation dynamics



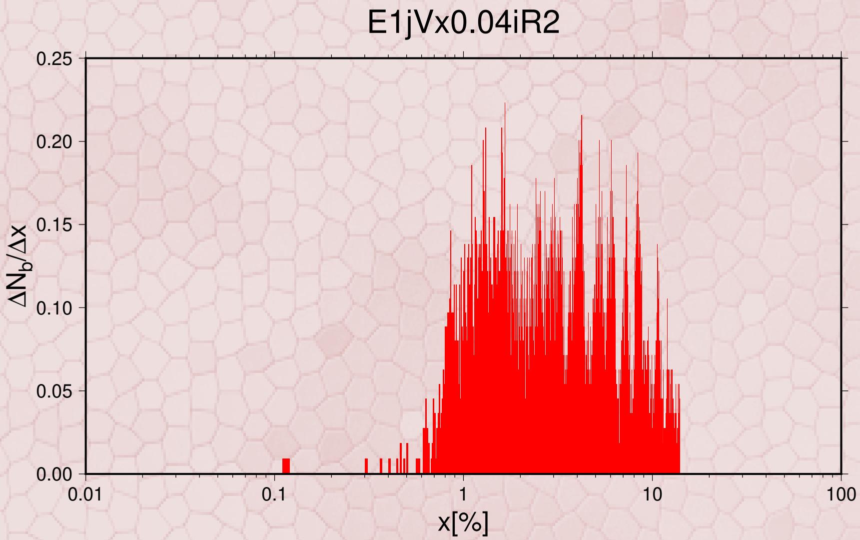
Fragmentation dynamics



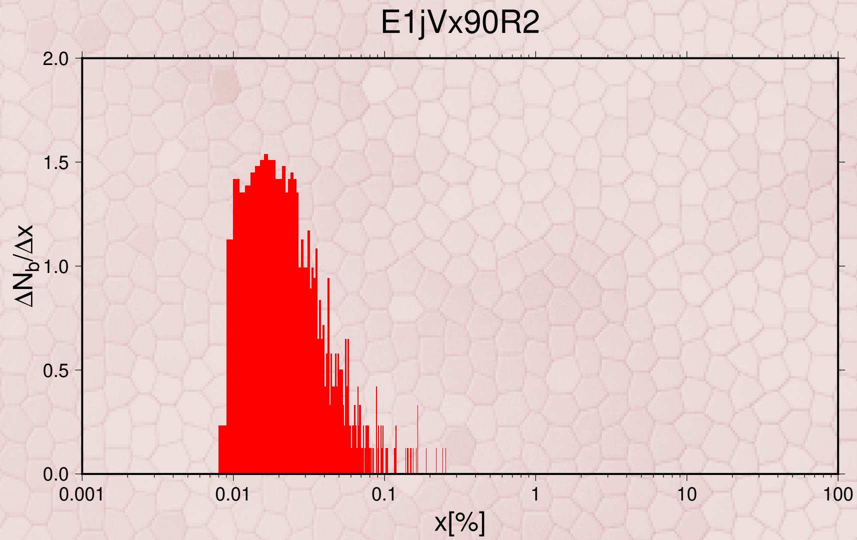
Fragmentation dynamics



Two breaking modes

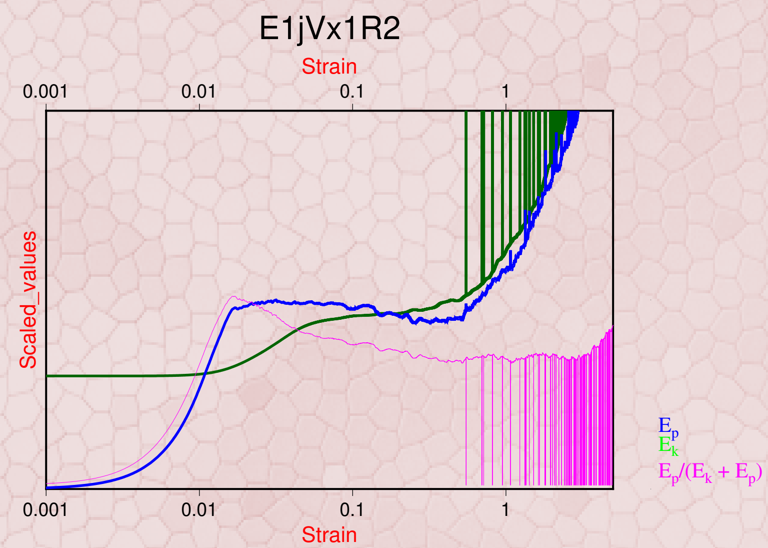


“random”

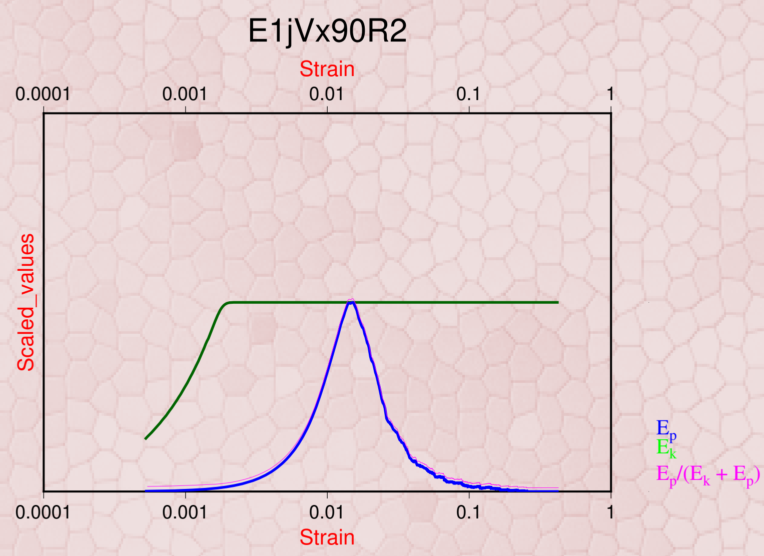


“cooperative ”

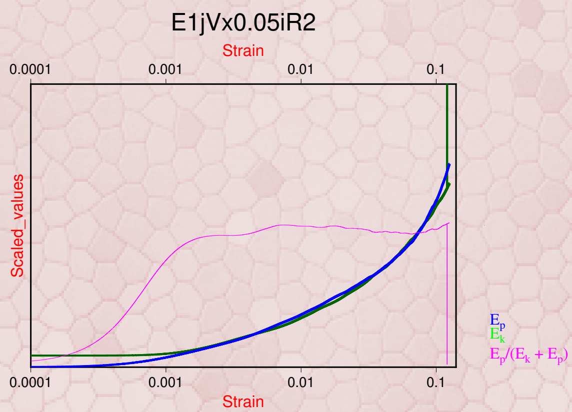
Why ....



E1jVx1R2
Strain
0.001
0.01
0.1
1
Scaled_values
0.001
0.01
0.1
1
Strain
E_p
E_k
$E_p/(E_k + E_p)$

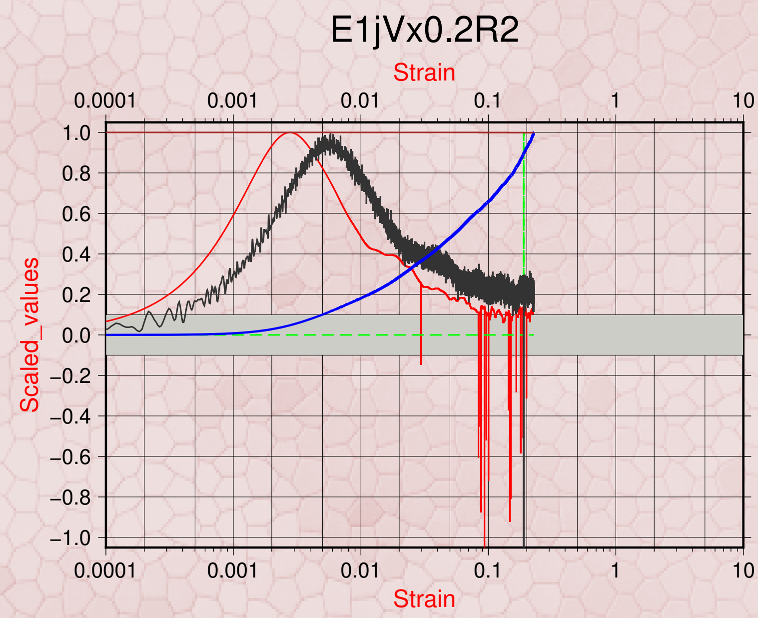


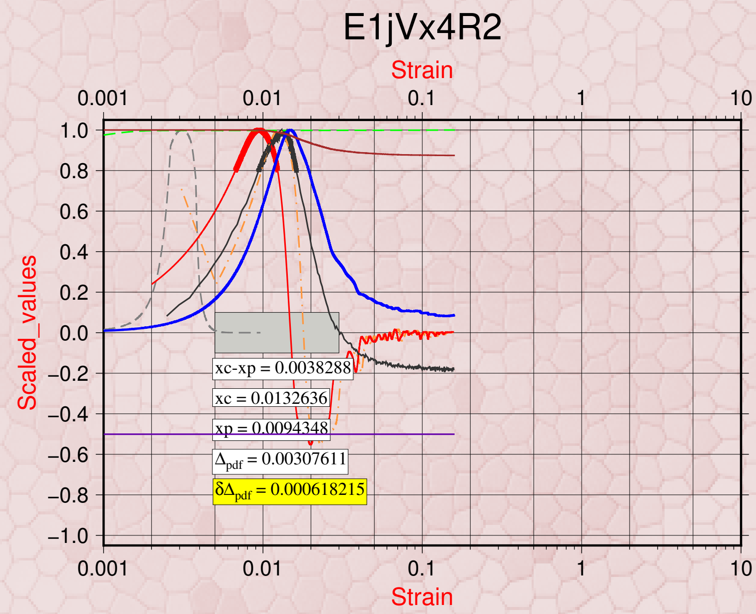
E1jVx90R2
Strain
0.0001
0.001
0.01
0.1
1
Scaled_values
0.0001
0.001
0.01
0.1
1
Strain
E_p
E_k
$E_p/(E_k + E_p)$



E1jVx0.05iR2
Strain
0.0001
0.001
0.01
0.1
Scaled_values
0.0001
0.001
0.01
0.1
Strain
E_p
E_k
$E_p/(E_k + E_p)$

What about "precursor" at low V ?





Final conclusions

- high-, and low - velocity breaking modes
- FBM - appropriate for high velocity (???)
- more advanced DEM simulation model needed

"local reality" problem

$\Downarrow$

Nobel Prize in circa 2120 ???