Caractérisation de l'endommagement du béton polymère par émission acoustique

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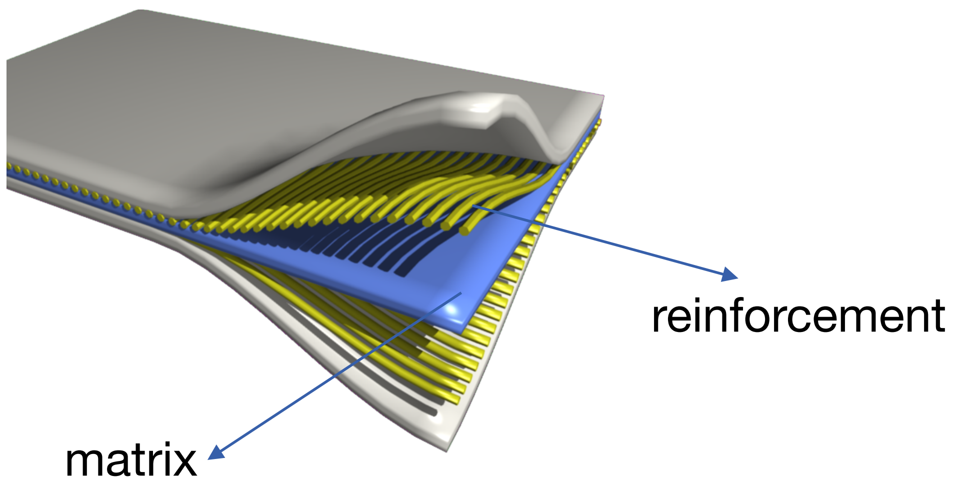
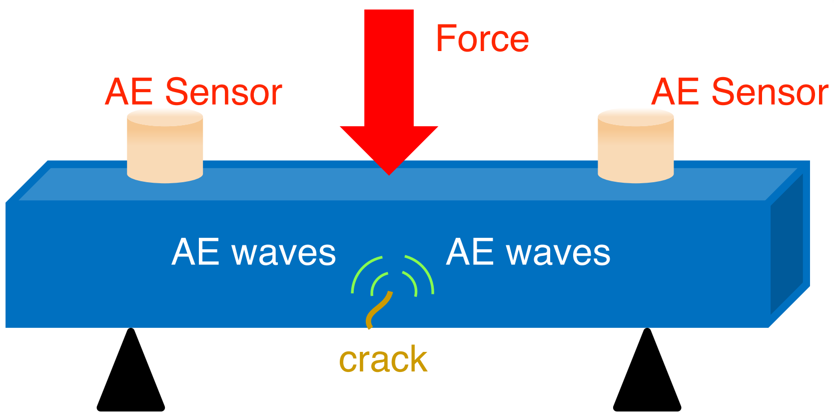
Contexte and introduction

- **Composite Materials**
  - **Composite materials:** matrix + reinforcement
  - **Advantage :** High strength to weight ratio
  - **Applications**
    - Carbon fiber composite : aerospace…
    - Glass fiber composite : automobile…
    - Polymer concrete : civil engineering…



Need to monitor the health of composite materials

- **Acoustic Emission (AE)**
  - **Advantage** : monitoring the damage in time
  - **But : Material was damaged**



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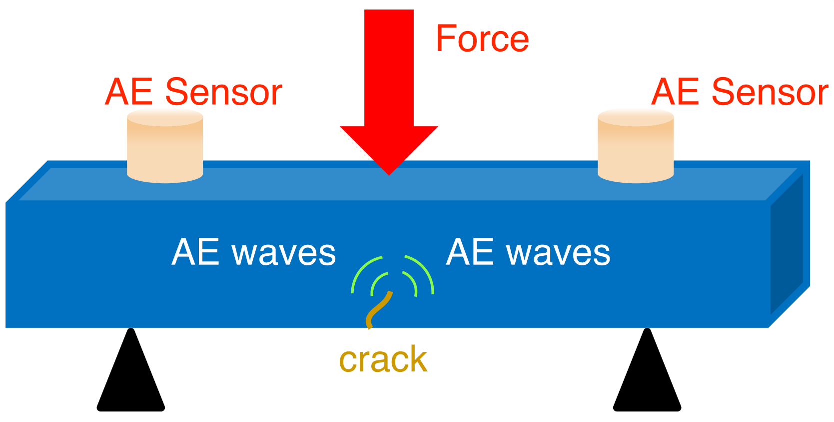

When a composite material is already cracked

How can we checking the cracks by AE without destroying this material ?

Contexte and introduction

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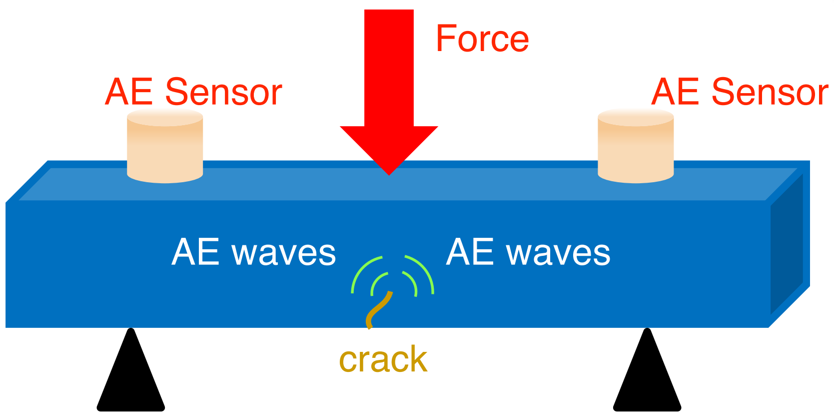


When a composite material is already cracked

How can we checking the cracks by AE without destroying this material ?

Dynamic acoustic emission
Nonlinear regime of material + monitoring the acoustic activity with AE

Planning

- **Studied Specimen and characterization**
- **Mechanical test monitored with Acoustic Emission**
- **Dynamic Acoustic Emission**
- **Results and discussion**
- **Conclusion and outlook**

Studied Specimen

- **Polymer concrete**

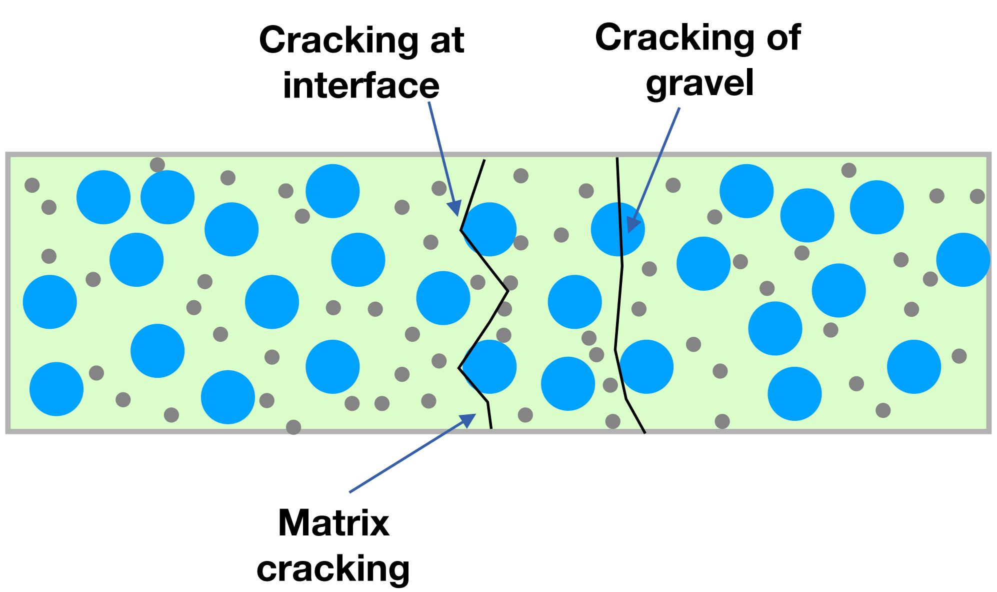
- **Constituents :**

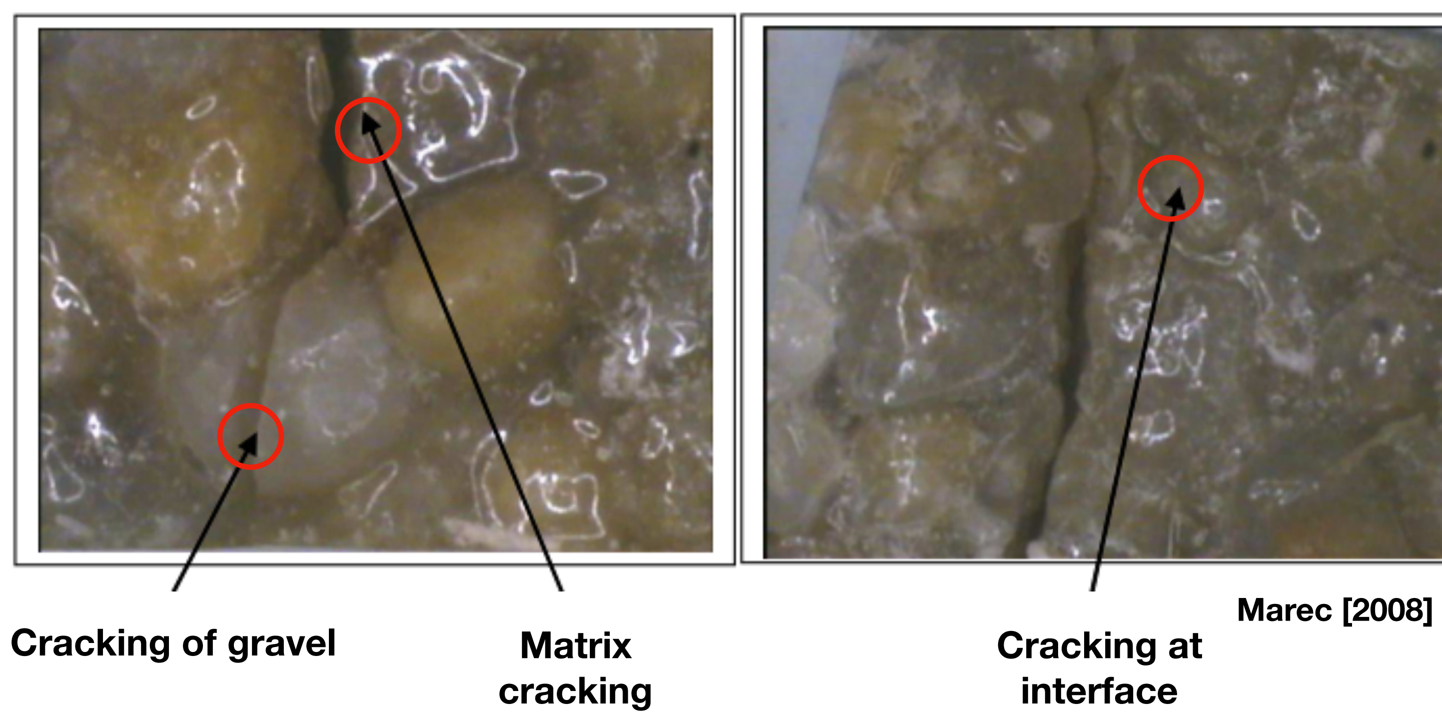
Epoxy resin, sand : 0.4 mm, gravel : 2 mm

	resin	gravel	sand
Sample I	40%	30%	30%
Sample II	40%	60%	0%

- **Dimension :** 200 X 40 X 40 (mm^3)

- **Damage mechanisms**





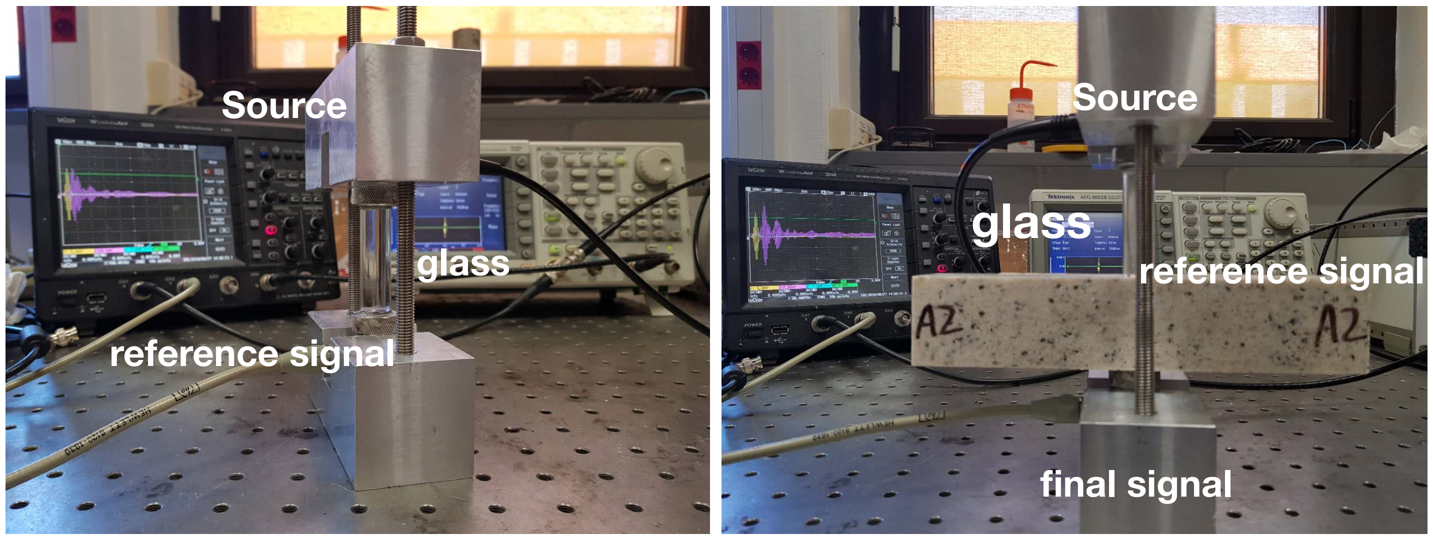
Marec [2008]

A quasi-static test monitored with AE ==> The damage mechanisms

Characterization of samples

- **Attenuation of samples**

- **Experimental set-up of attenuation measurement**



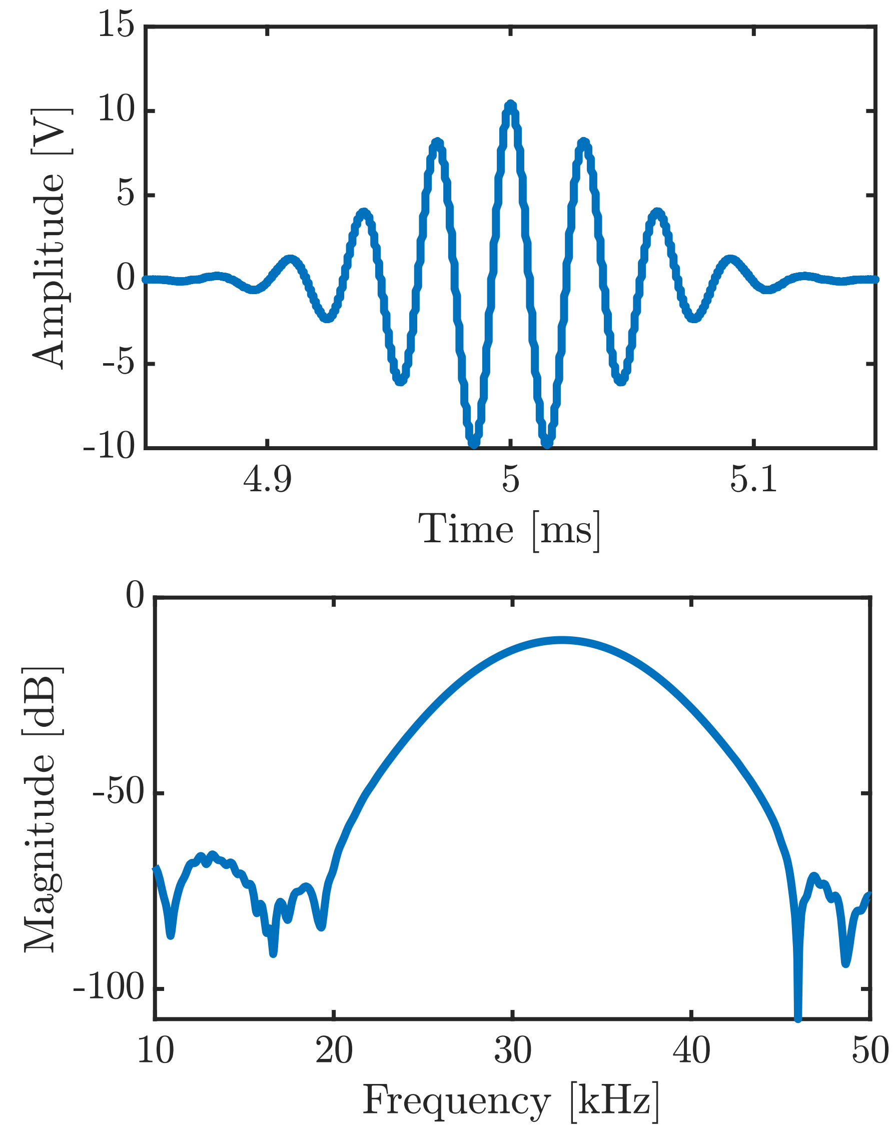
*Exemple of **sample I** under measurement with 2 protocoles*

- 2 sensors of 1MHz
- One glass to mesure the reference signal
- **Protocole :**
  - 1. mesure references signals
  - 2. mesure finals signals
  - 3. Compare their FFT, calculate attenuation

- **Why use references signals**

==> To avoid the changement of wave forme in source sensor

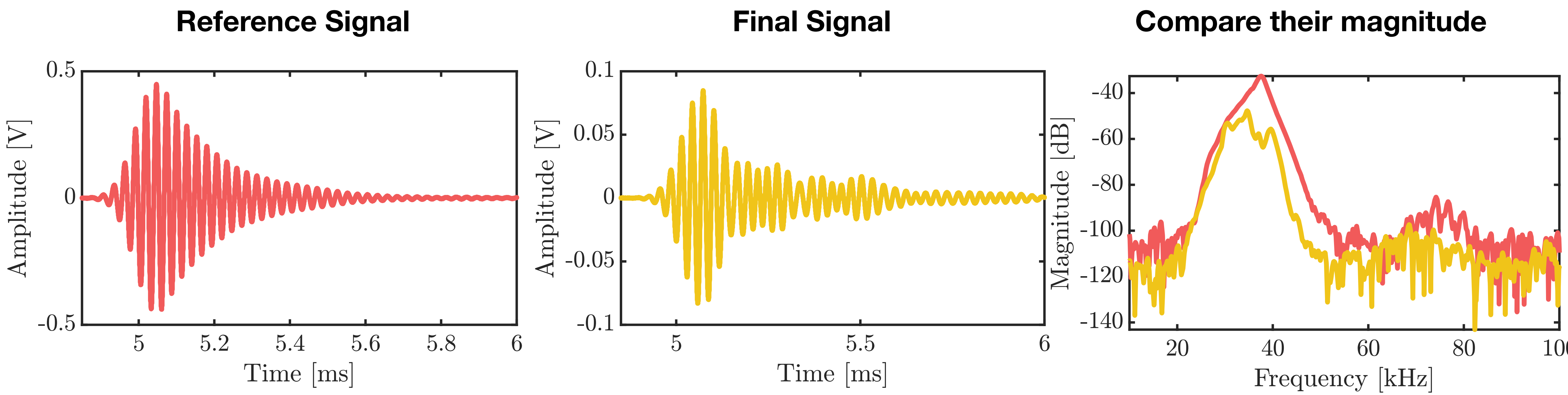
- **Source :**
  - **Amplitude : 20 Vpp**
  - **Frequency : 35 - 600 kHz**



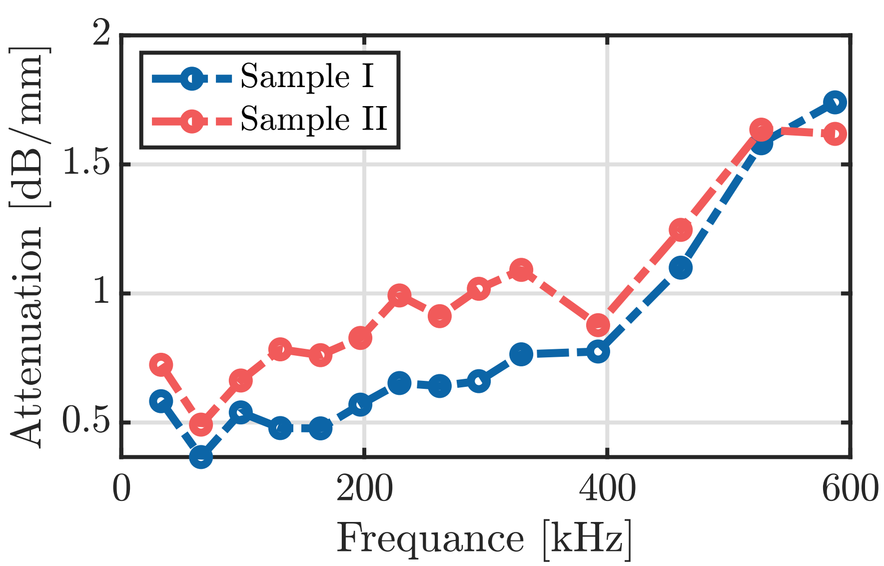
Exemple of source at 35kHz and its FFT

Characterization of samples

- **Attenuation of samples**



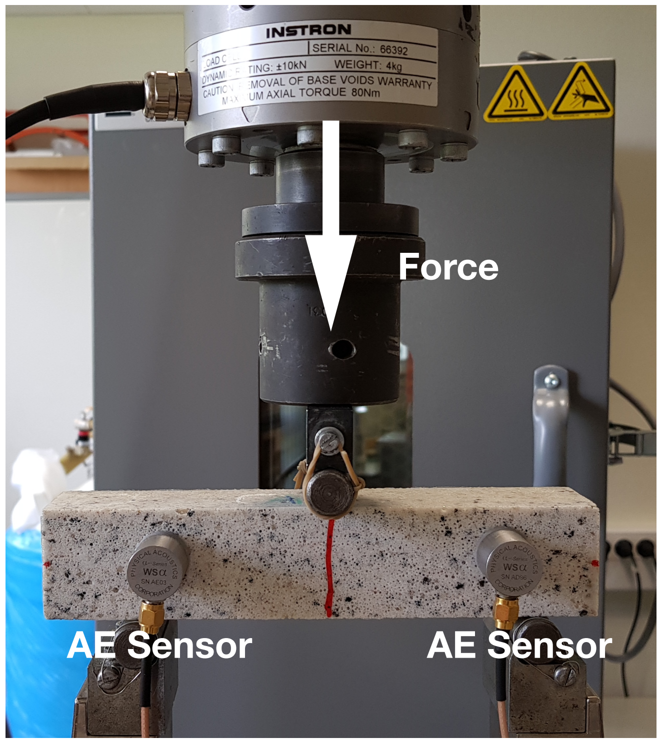
- **Results**



	resin	gravel	sand
Sample I	40%	30%	30%
Sample II	40%	60%	0%

- **Attenuation increases in frequency**
- **The gravel increased attenuation at 35 and 400 kHz**

- **The three point bending test monitored with AE**



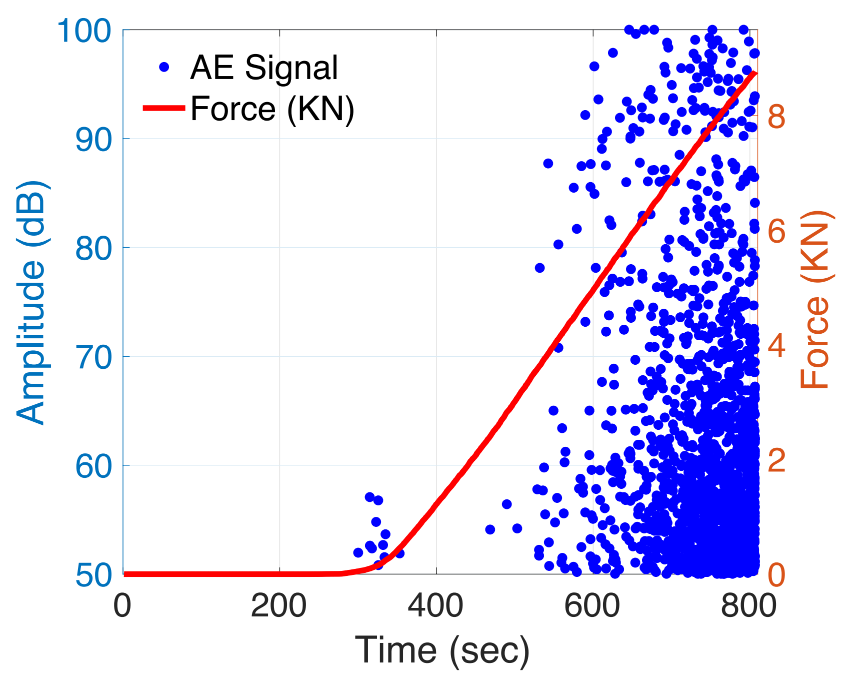
Quasi-static mechanical test (Sample I)

- **AE System :** Mistras PIC-2

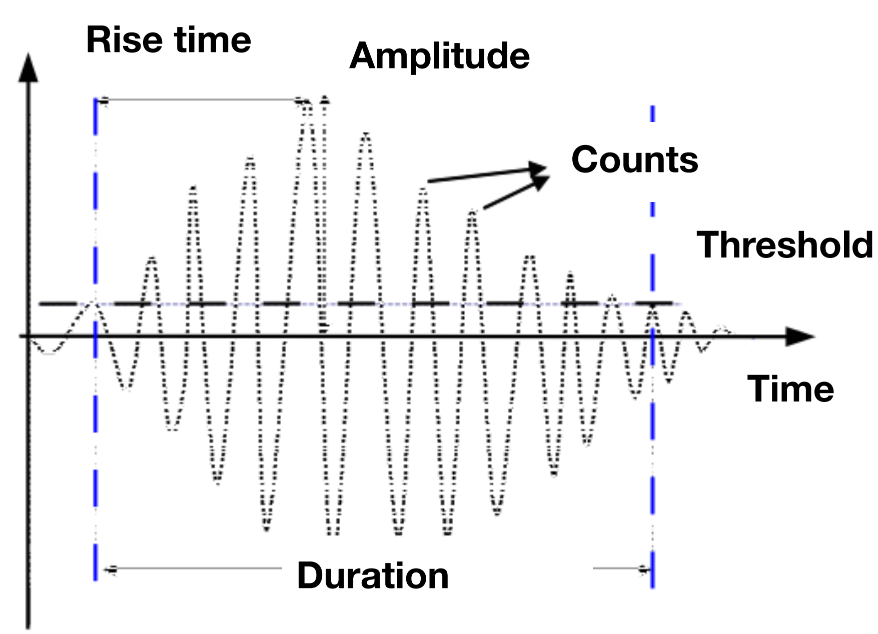
- **2 types of samples**

	resin	gravel	sand
Sample I	40%	30%	30%
Sample II	40%	60%	0%

- **Force— AE hits (Sample I)**

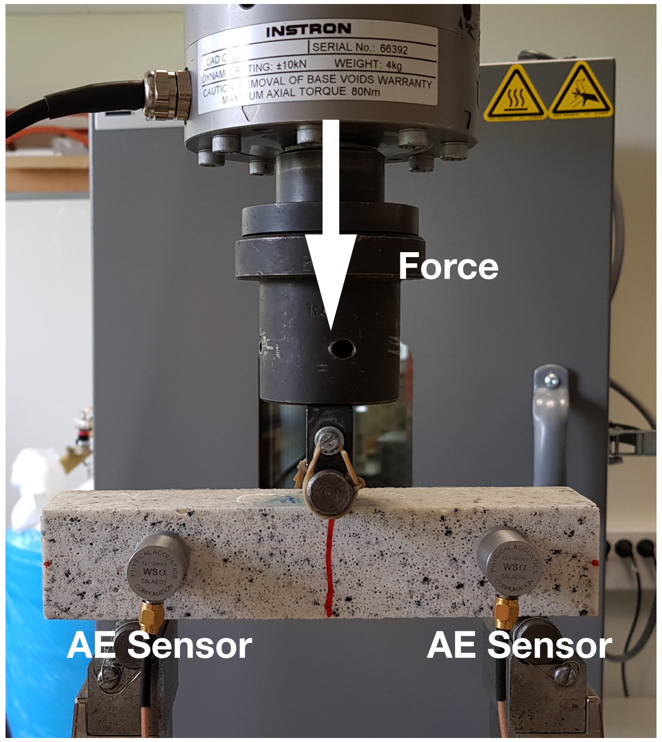


- **An AE signal and its temporal features**



Mechanical test monitored with AE

- **The three point bending test monitored with AE**



Quasi-static mechanical test

- **AE System :** Mistras PIC-2
- **2 types of samples**

	resin	gravel	sand
Sample I	40%	30%	30%
Sample II	40%	60%	0%

- **The temporal and spectral features**

Property	Dimension
Amplitude (PA)	dB
Duration (D)	micro second
Rise time (RT)	micro second
RA (RT/PA)	micro second/V
Counts (CNT)	
Energy (E)	aJ
Frequency centroid (FC)	**kHz**
Peak frequency (PF)	**kHz**

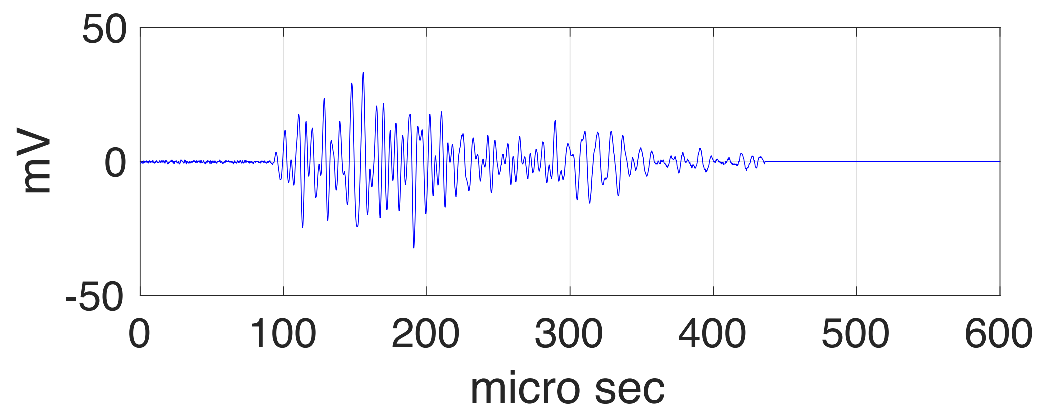
Common temporal features

New frequency-based feature

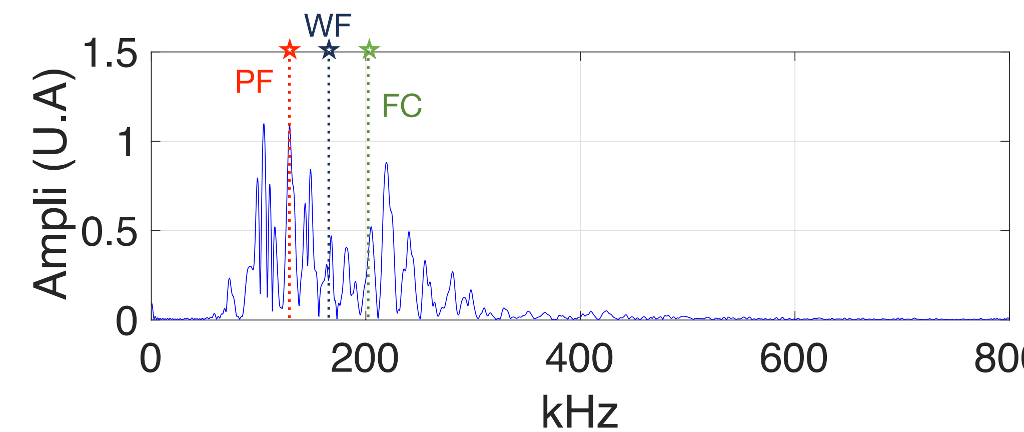
$$\mathrm{WF} = \sqrt{\mathrm{FP}^2 + \mathrm{FC}^2}$$

Mechanical test monitored with AE

- **Relation between PF FC and WF**



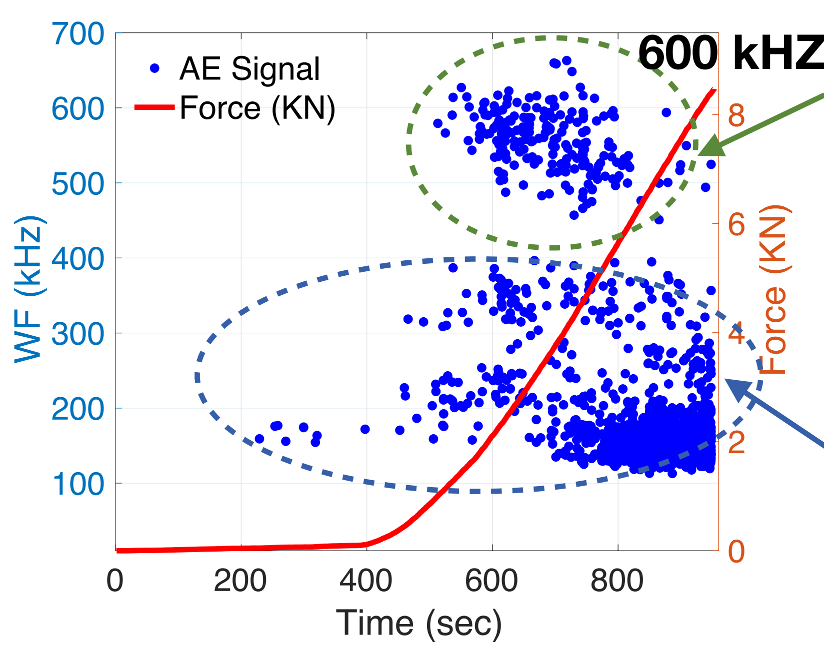
FFT



- **Comparison of two samples by WF**

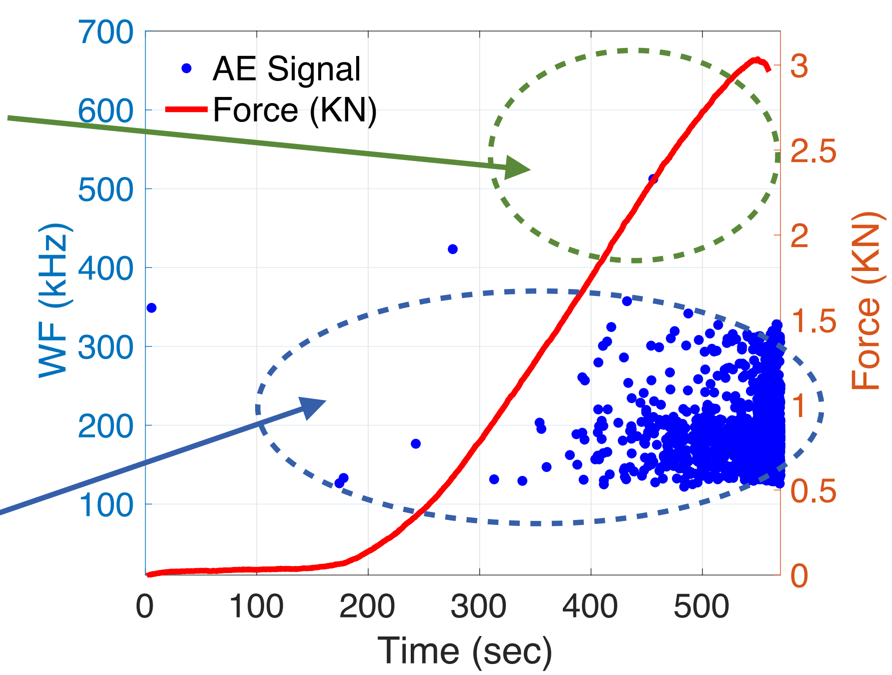
	resin	gravel	sand
Sample I	40%	30%	30%

	resin	gravel	sand
Sample II	40%	60%	0%



Debonding between sand and resin

Other mechanisms



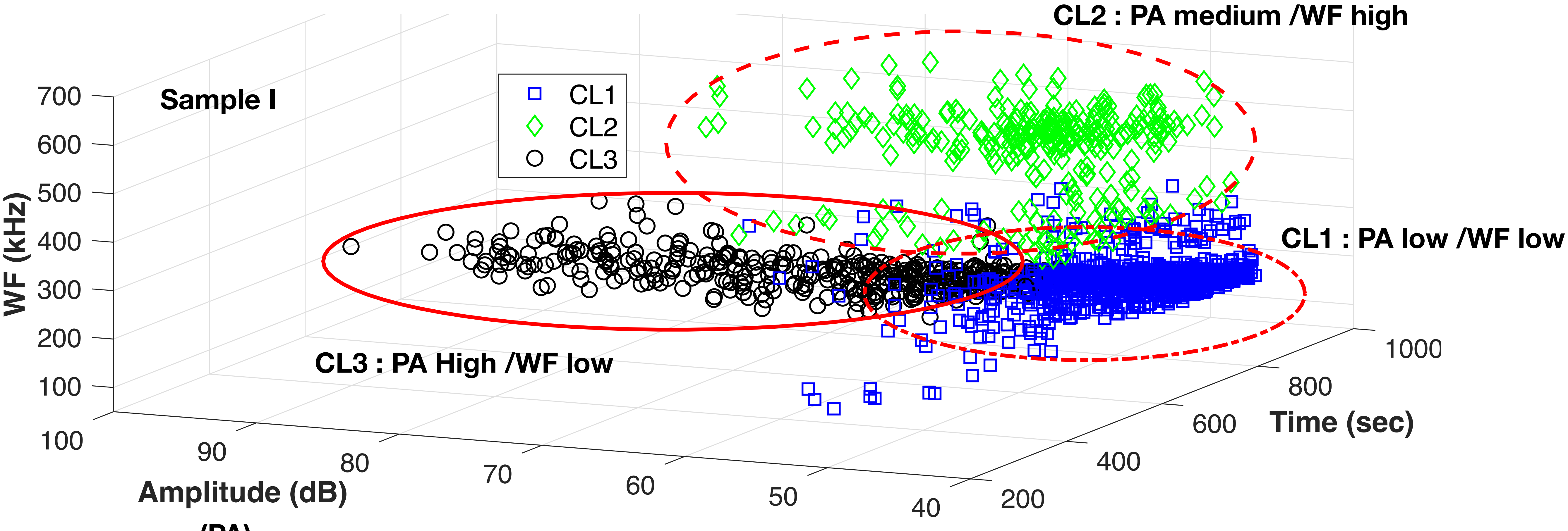
Other mechanisms to be separated by K-means

K-means classification of AE hits

- **Classification by k-means**
  - **Principal Component Analysis reduced the number of features from 7 to 4**
  - **Then, the classification is made using k-means analysis**

	resin	gravel	sand
Sample I	40%	30%	30%

- **Three classes of AE signals**

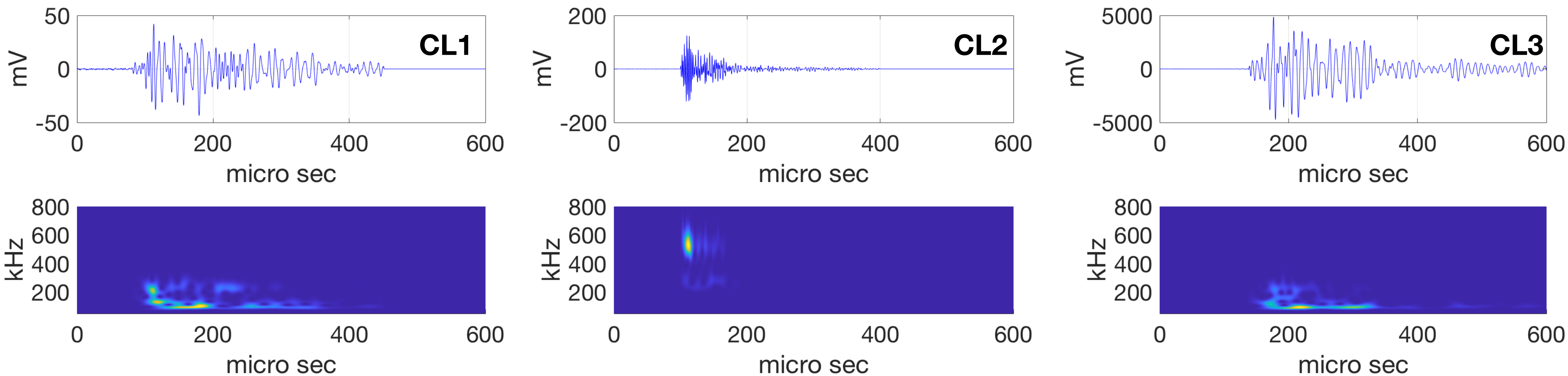


Evolution of classes according to the mechanical test

Results of the test

- **Three classes of AE signals**

	resin	gravel	sand
Sample I	40%	30%	30%

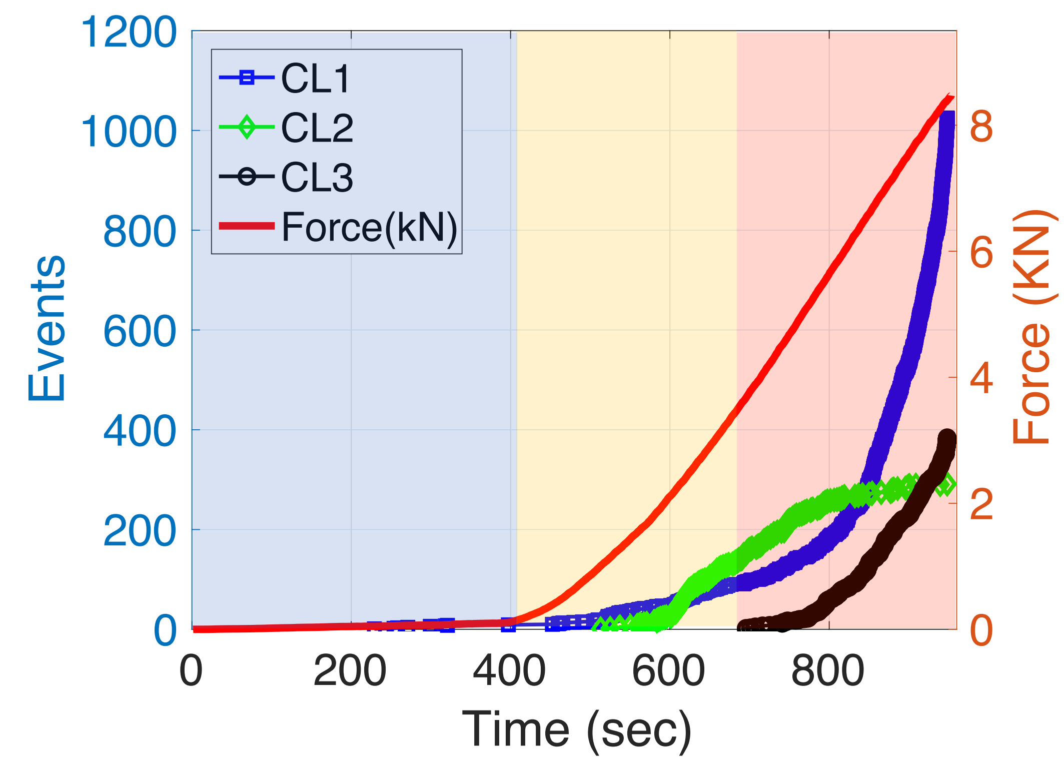


- **Résultats de la classification**

CL1 : Matrix cracking

CL2 : Debonding between sand and resin

CL3 : Gravel failure/ Debonding between gravel and resin



General Observations

- **AE hits were recorded during the damage process of materiel**

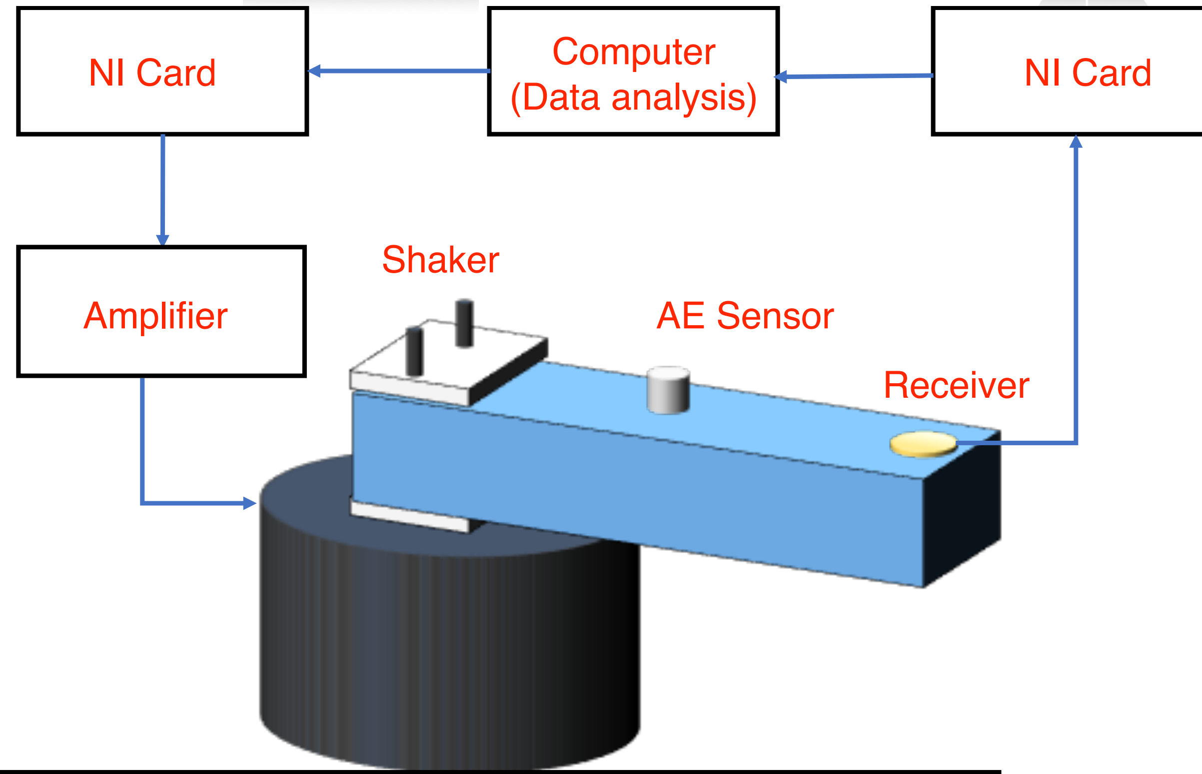
- **Why should we damage the materiel in order to get AE hits ?**

→ What we propose is :

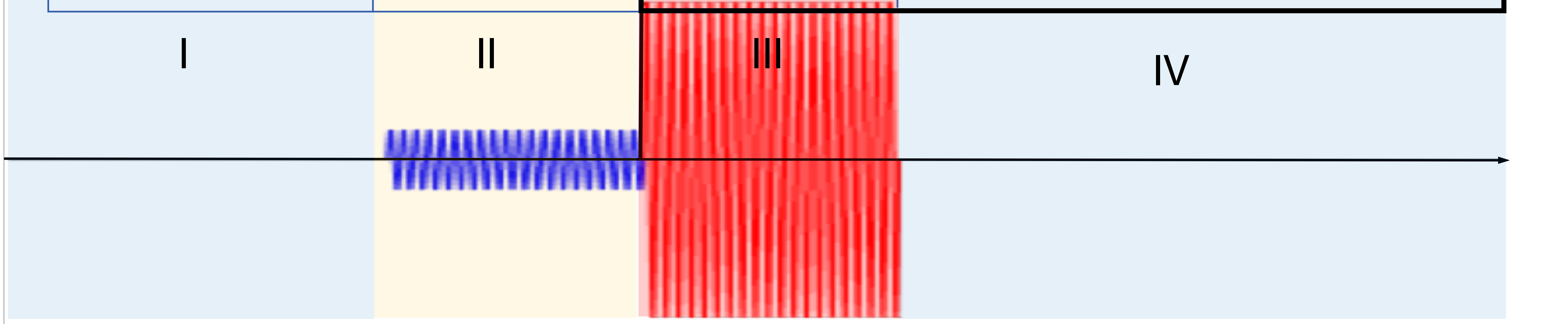
Develop dynamic AE measurements as NDT&E technique to link macroscopic observations to the excited micro-mechanisms

Dynamic acoustic emission

- **Dynamic acoustic emission**
  - **Micro-cracked polymer concrete**
  - Excitation around **the bending mode** (240 Hz)
  - **Four steps in the protocol**
  - Test monitored with AE



		Dynamics AE	
No excitation	Linear vibration	Conditioning	Passive relaxation
0 V	50 mv	2 V	0 V
2 hours	9 minutes	9 minutes	16 hours

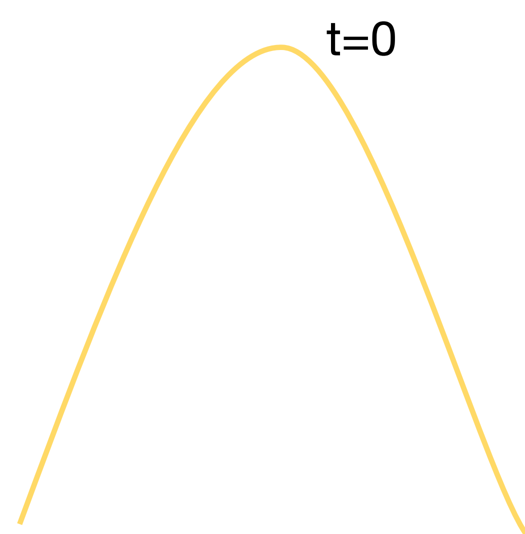


No AE signal **AE signals appear**

Protocole of Dynamic Acoustic Emission

Dynamic acoustic emission

- **Slow Dynamics** **Ruyer [1999] TenCate [2008] Remillieux [2016]**
  - **Conditioning**
    - A high level of constant excitation around a resonance mode of the material
    - During conditioning time : **Johnson [2005] Scalerandi [2017]**
      - Quality factor decreases ==> **Increase in attenuation**
      - Resonance frequency decreases ==> **Decrease of the elastic modulus (softening)**
  - **Relaxation**
    - Material **recovers to its original property** after $10^3 - 10^5$ s
    - **Relaxation time:** monitoring the health state of the material **Bentahar [2009]**



Beginning of conditioning

Step III : Conditioning

Dynamic acoustic emission

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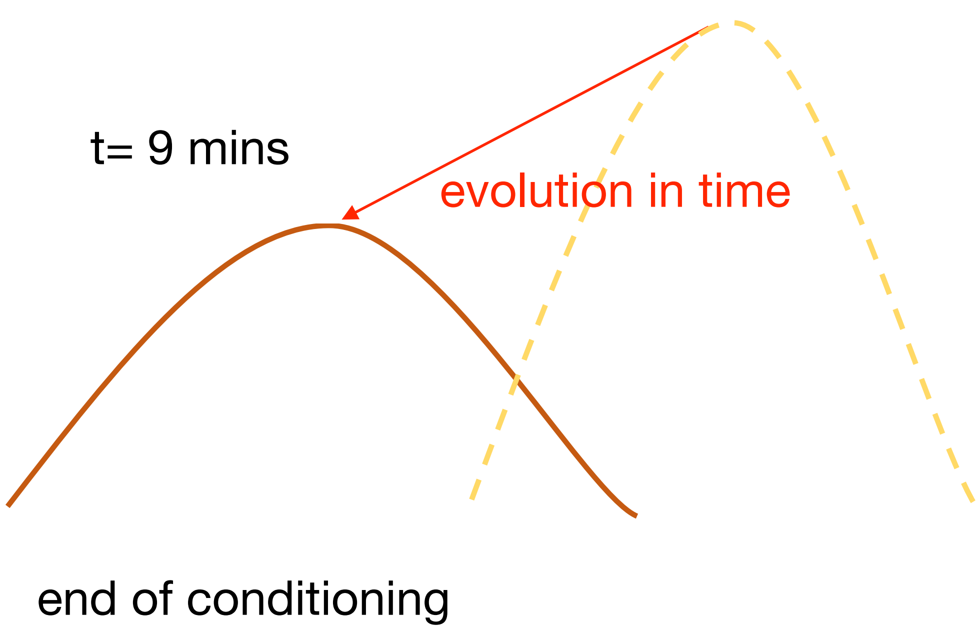

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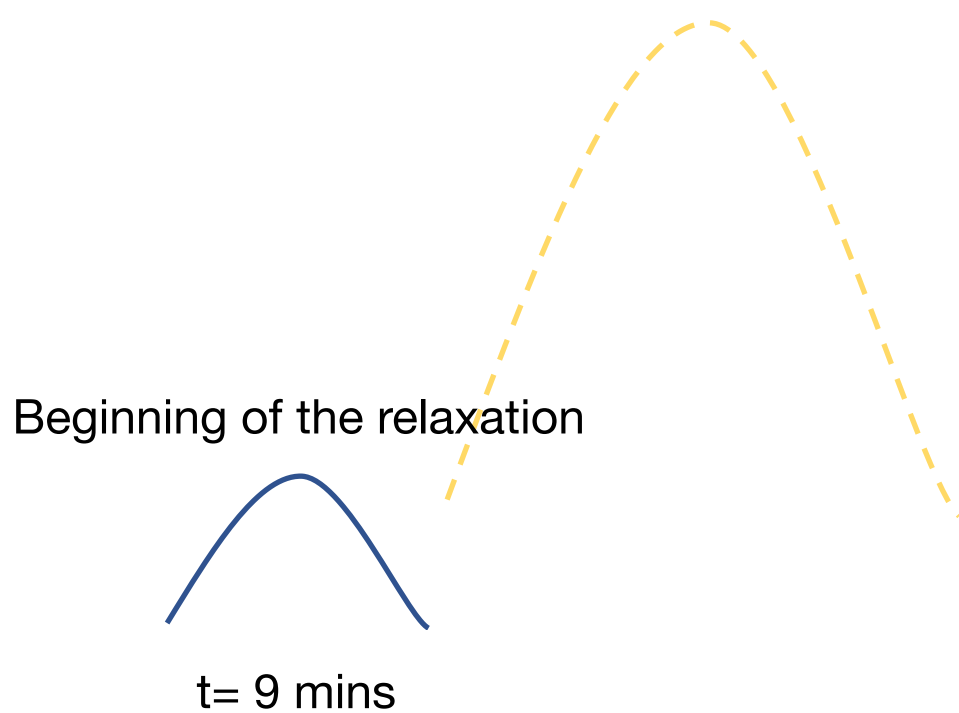

Step IV : Relaxation

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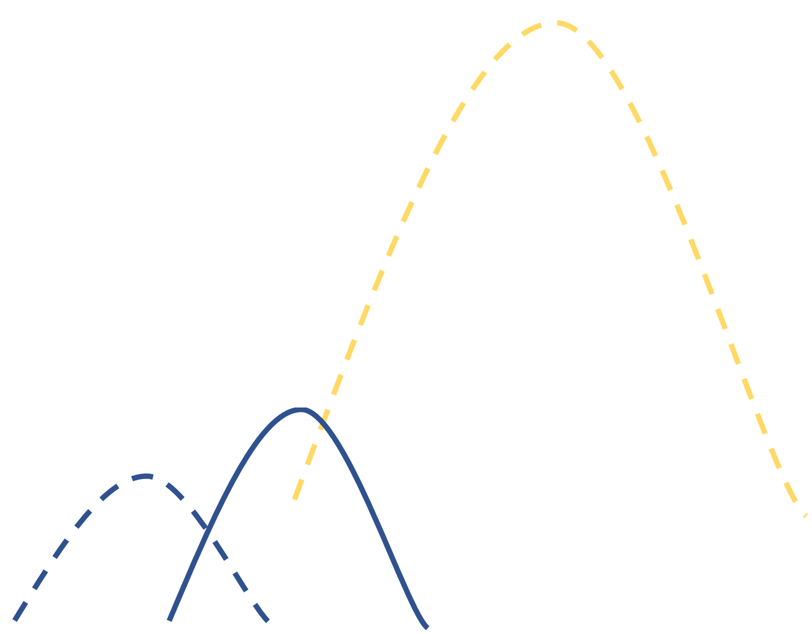

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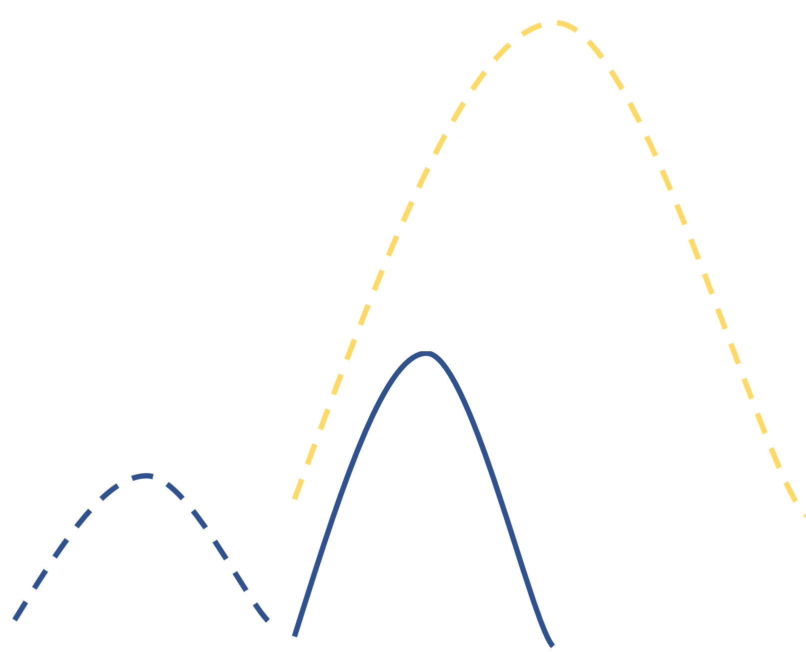

Step IV : Relaxation

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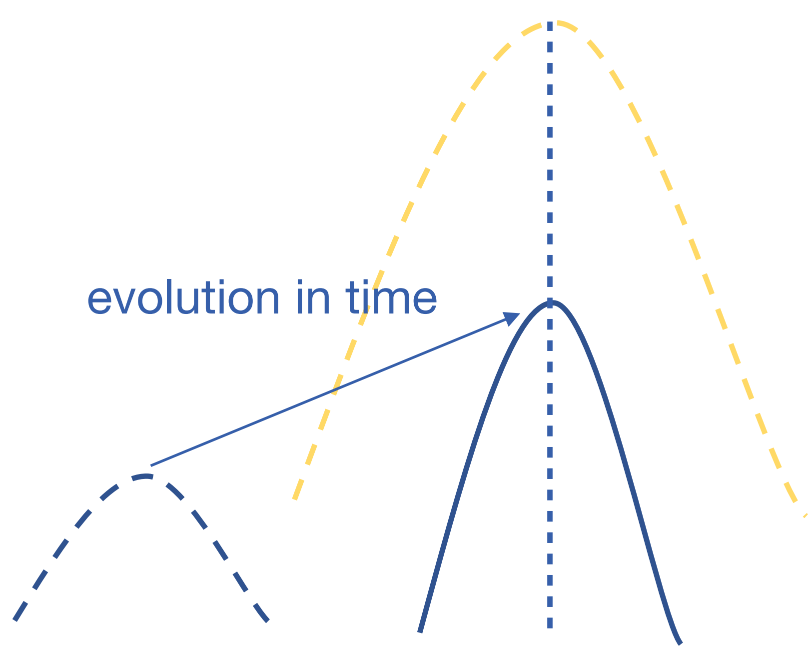

End of the relaxation

Step IV : Relaxation

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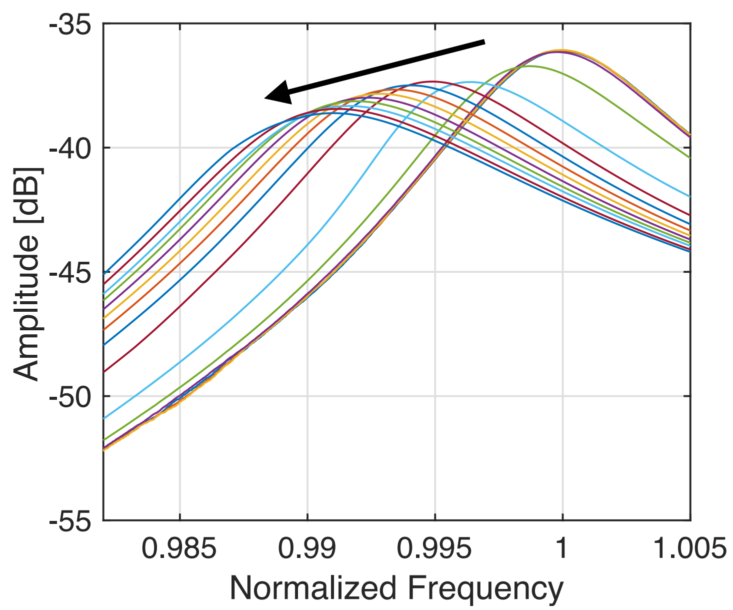
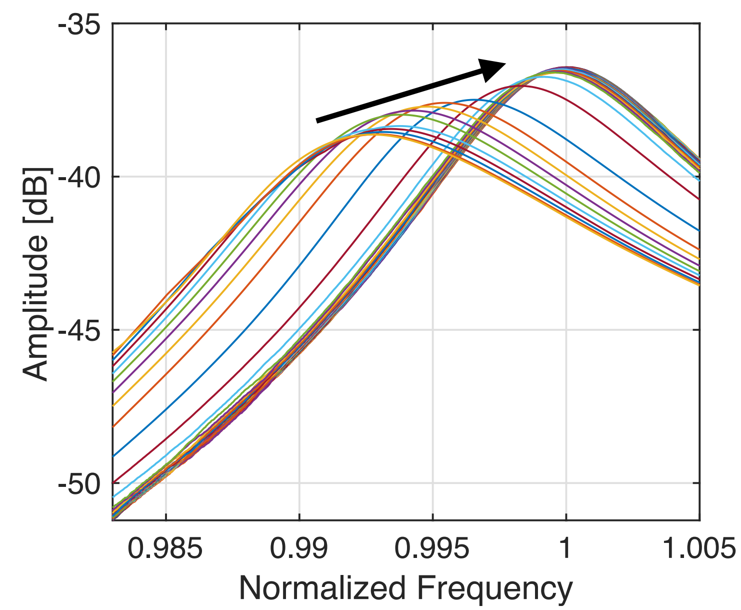


Conditioning

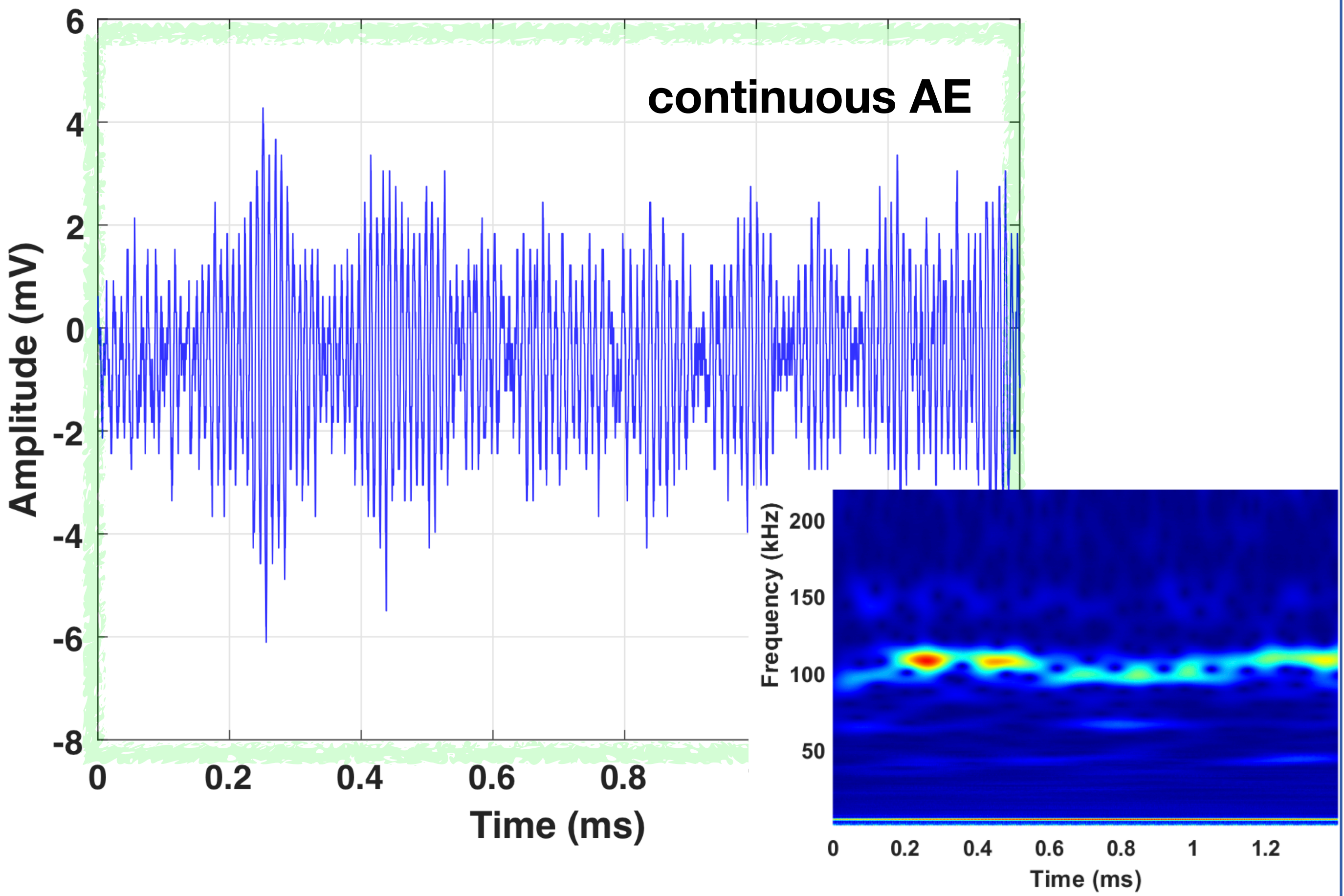


Relaxation

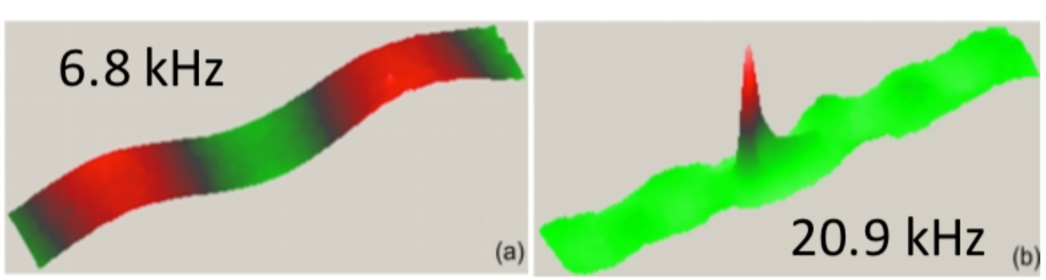
Results and discussion

- **AE signal during the test**

  - **Conditioning**



Conditioning at <u>240 Hz</u>, continuous AE around <u>110 kHz</u>

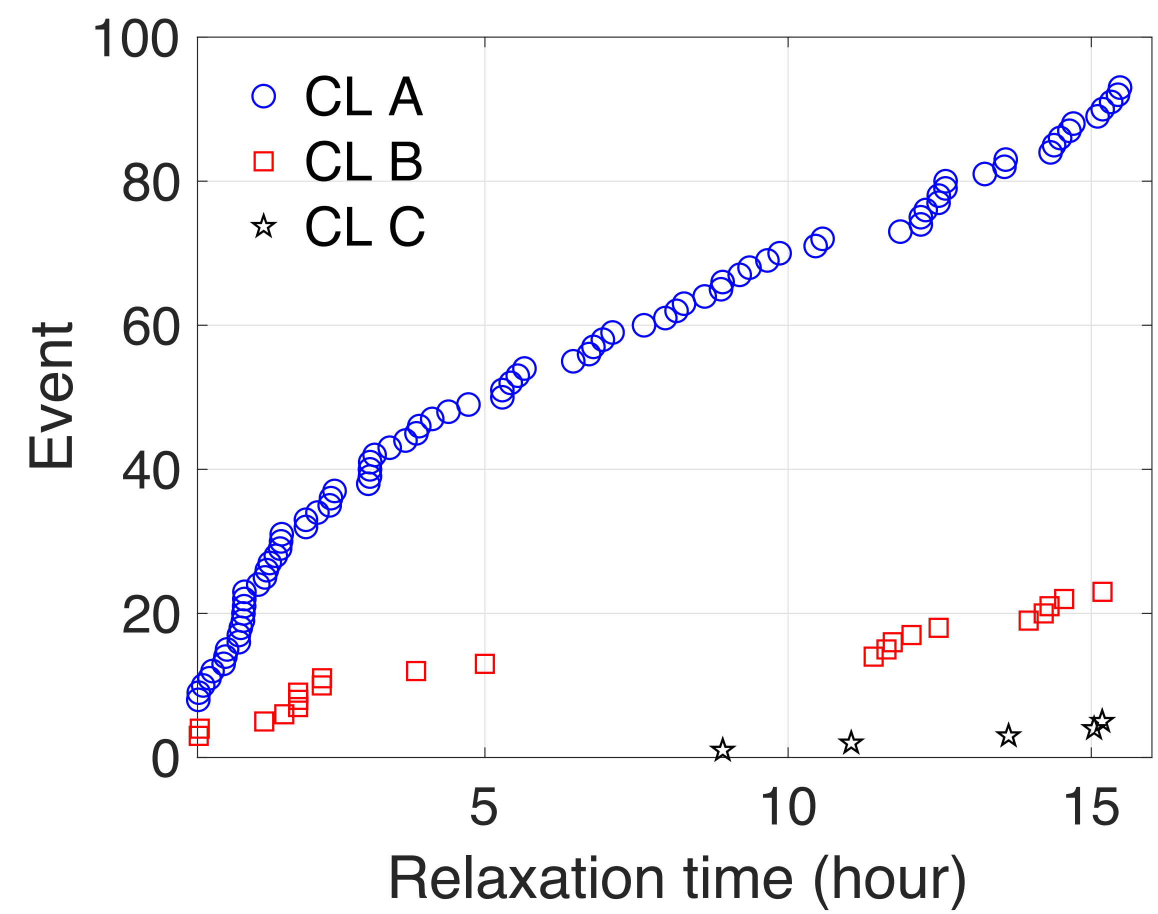


Solodov [2011]

Local resonance effect in a composite plate with delamination

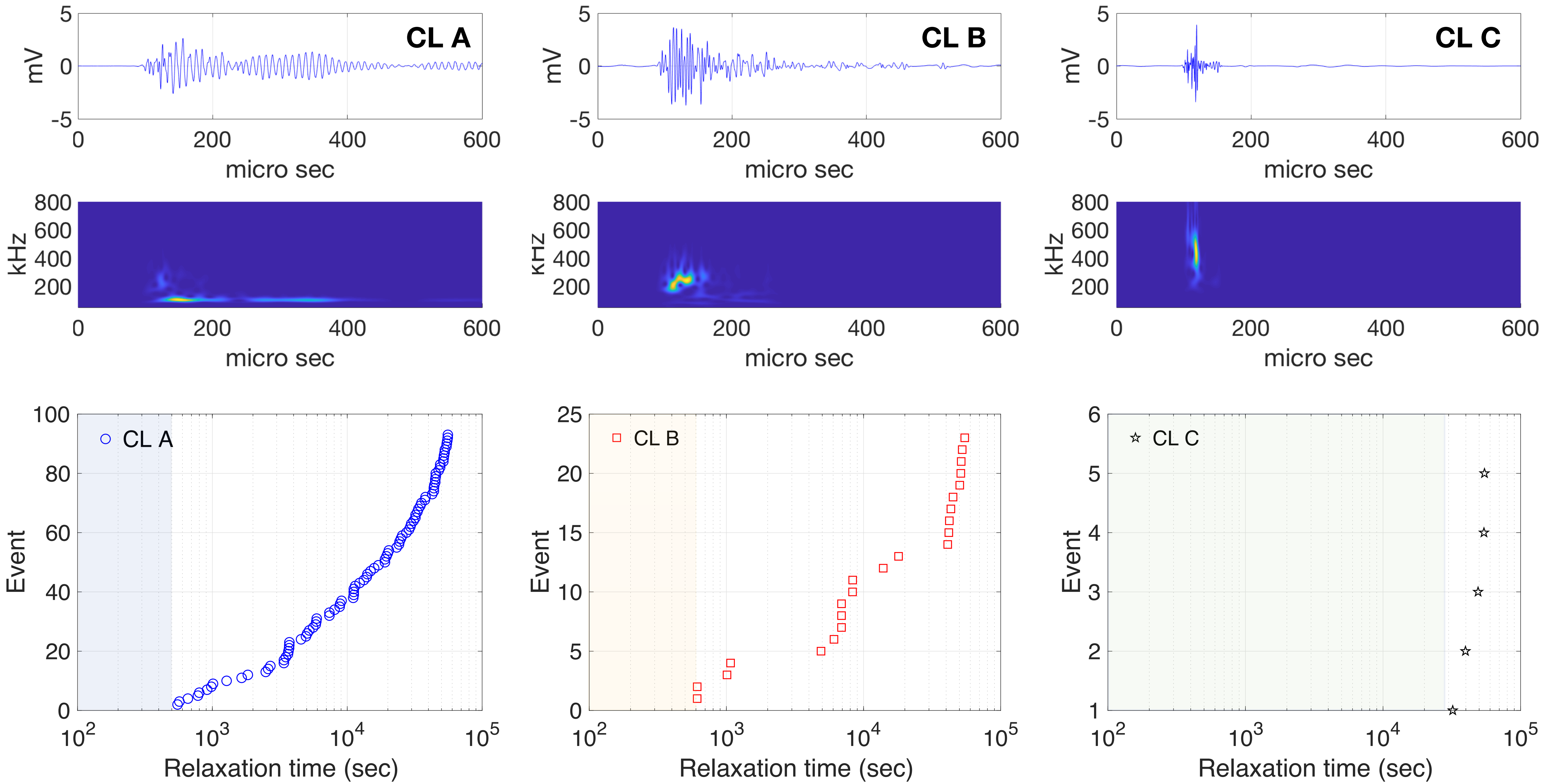
<u>Local resonances may be the source of AE signals</u>

- **Passive relaxation (3 classes of AE signal)**



Evolution of the number of AE signals during relaxation (in three classes)

- **Three classes of AE signals during passive relaxation**

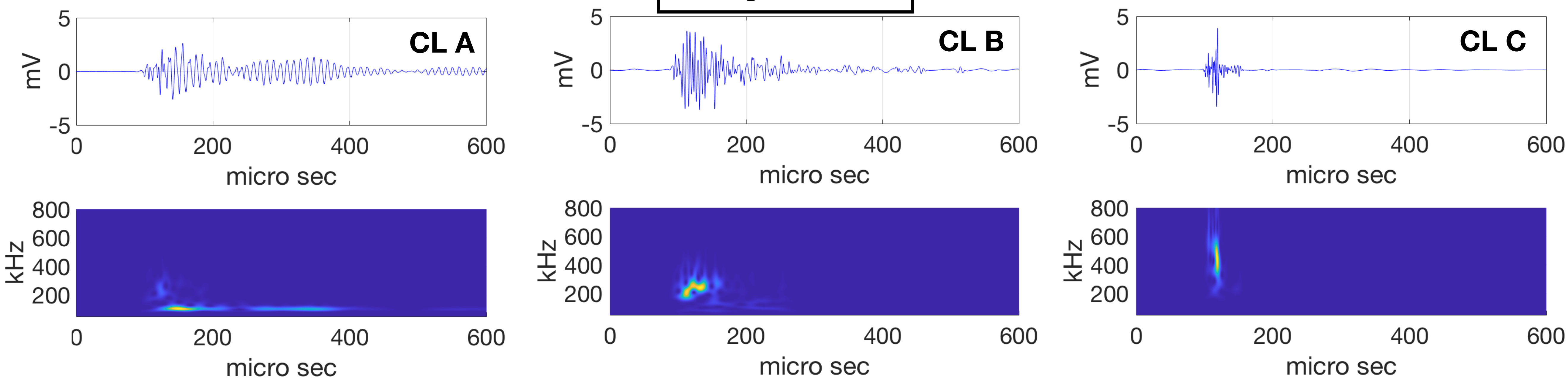


'The silence' at the beginning of relaxation

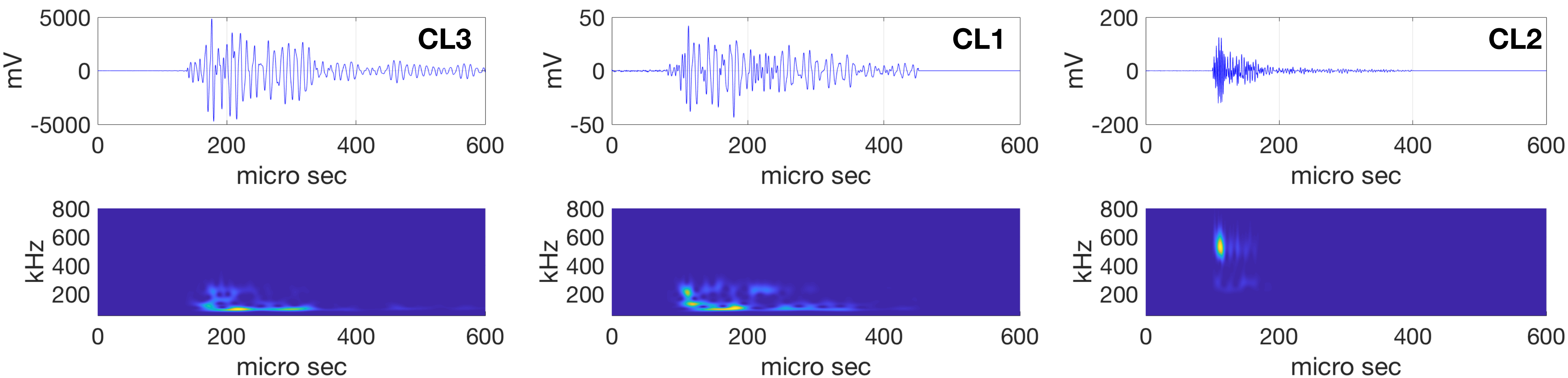
Different kinds of damages have different relaxation rates

Results and discussion

During relaxation



<u>They have strong similarity with signal during quasi-static test</u>



During quasi-static test

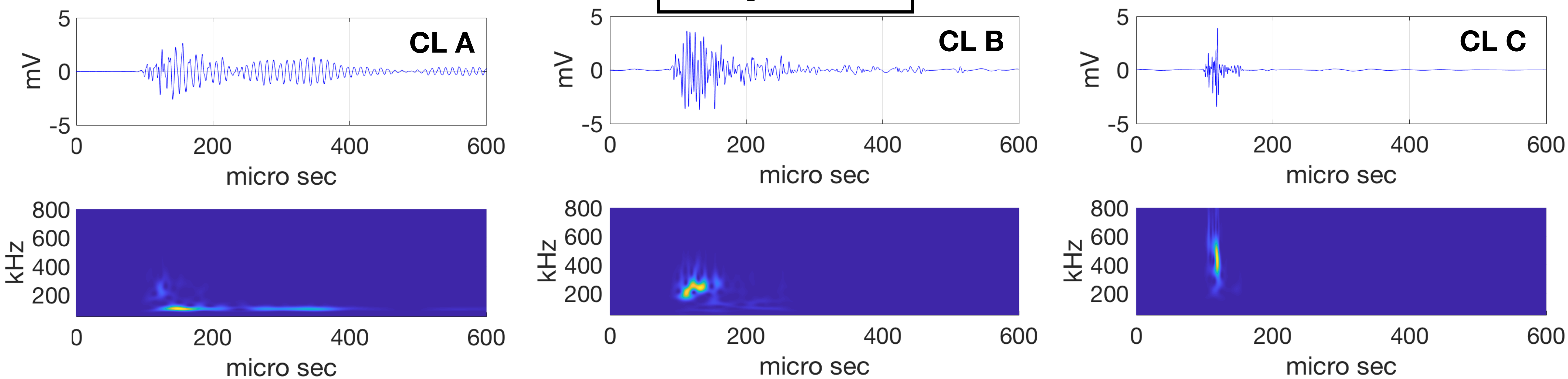
Conclusion

- **Mechanical test followed by AE :**
  - **Three classes of AE signal distinguished**
  - **High amplitude signals during final crack : need a relevant criterion for the separation of events**

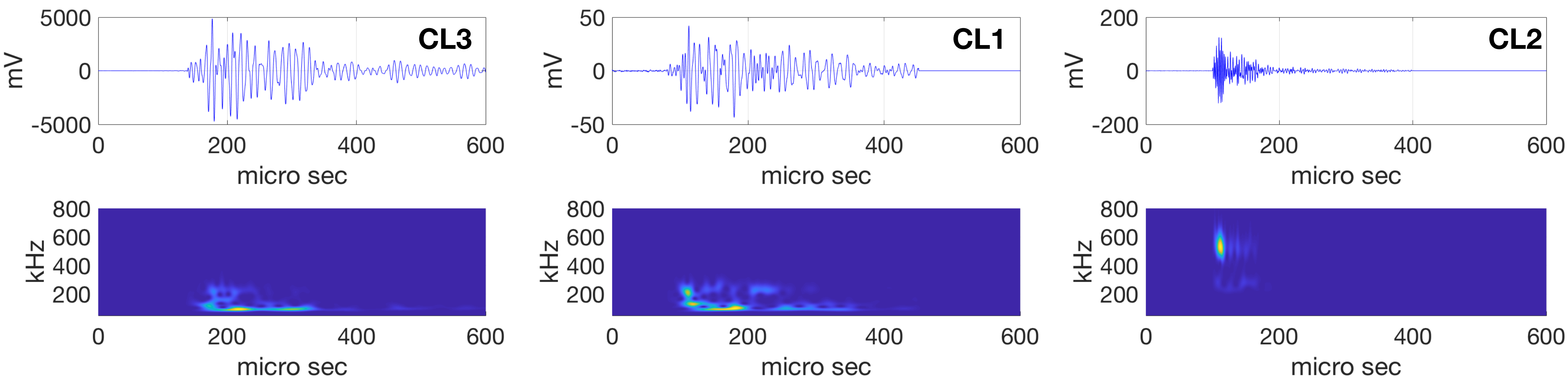
- **Dynamic acoustic emission**
  - **A non-destructive testing technique (defect detection)**
  - **No crack ==> No AE signal during dynamic AE**
  - **A link between damage mechanisms and non-linear behavior**
  - **Conditioning: continuous signals (local resonances of the defect)**
  - **Relaxation: AE signals appear; strong similarity with signals cracking matrix and Debonding of interface**

Works to do…

During relaxation

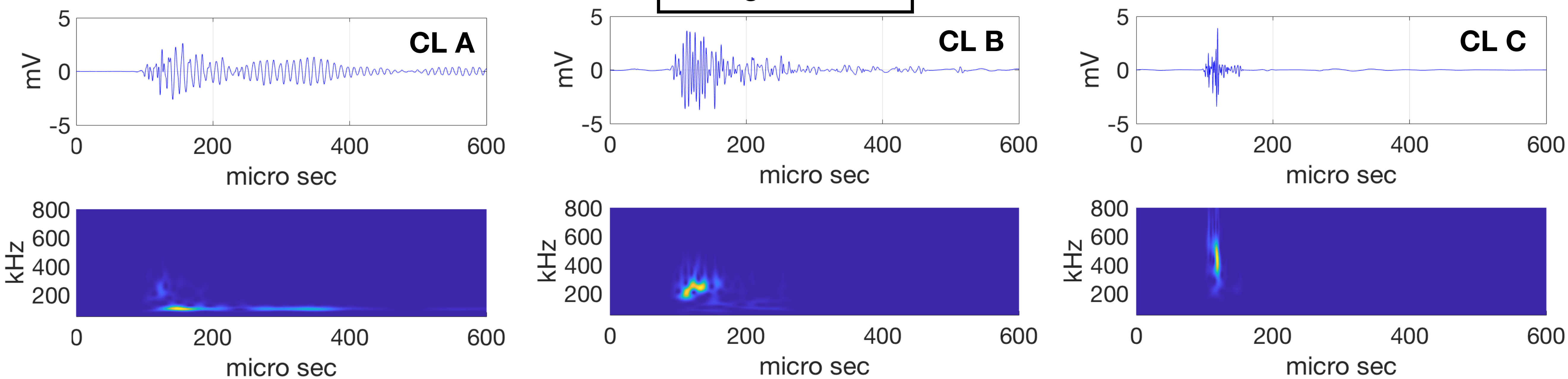


<u>The link between quasi-static test and dynamic AE</u>

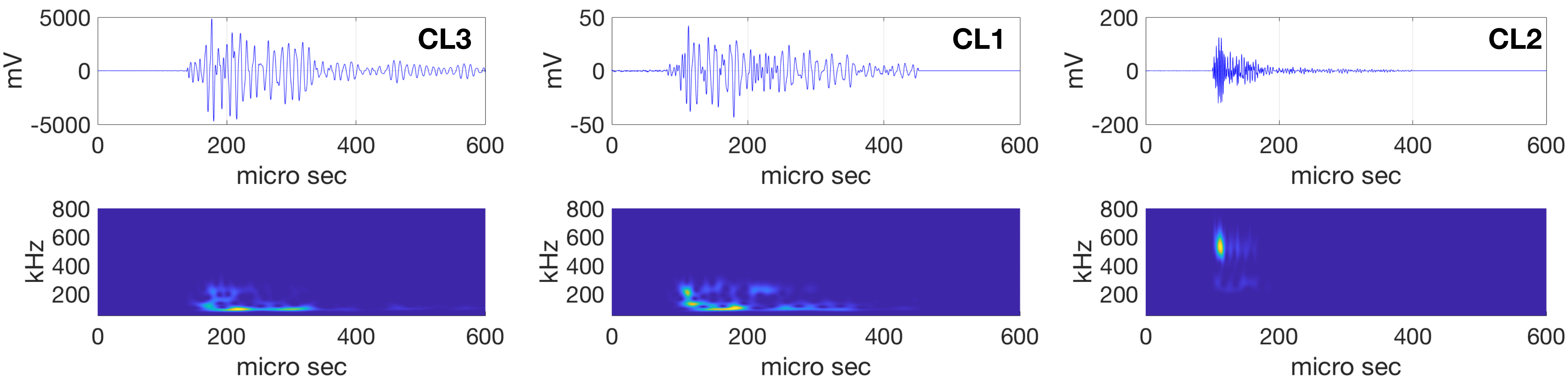


During quasi-static test

During relaxation



Thank you !!



During quasi-static test