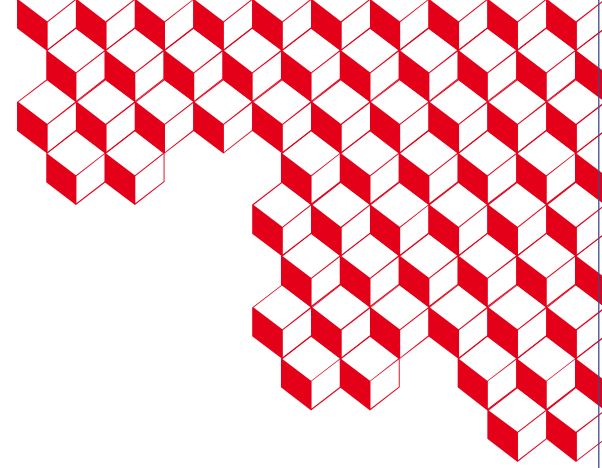




list



Multi-modal characterization of ultrasonic bulk wave properties in heterogeneous textured media through finite element computations

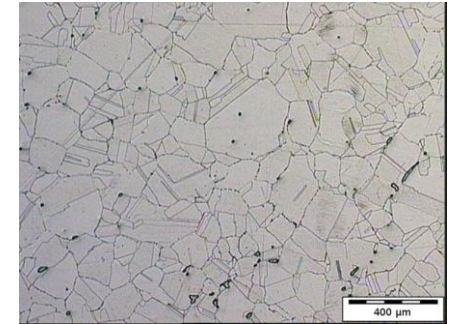
Vincent Dorval, Nicolas Leymarie, Alexandre Impériale, Edouard Demaldent
Université Paris-Saclay, CEA, List

Contact : vincent.dorval@cea.fr

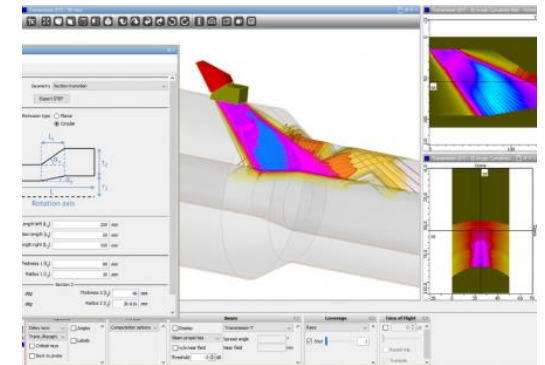
Context

Simulation of ultrasonic non-destructive testing of heterogeneous materials

- Multiscale problem
 - Propagation at the scale of the inspected component
 - Interactions at microstructure scale
- Several simulations approaches
 - Semi-analytical (rays): fast but poorly suited for heterogeneous materials
 - Finite Elements: accurate but costly for large volumes



Microstructure (steel)



Ray-based simulation

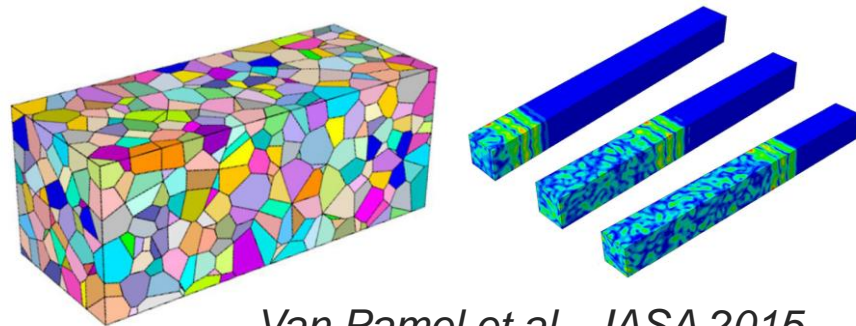


Finite Elements characterization of Representative Elementary Volumes, providing input for ray-based simulations

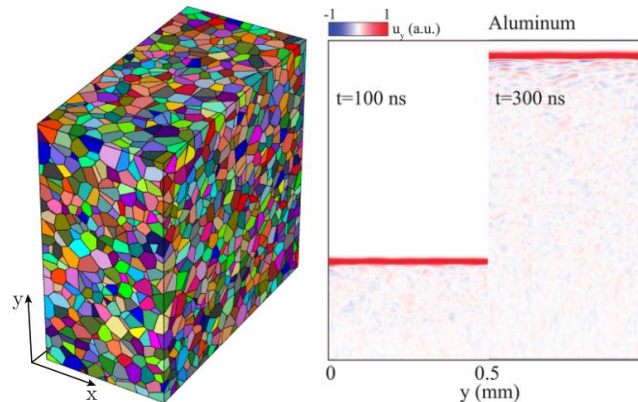
Finite Elements characterization

Simulation of plane waves propagation through heterogeneous material samples

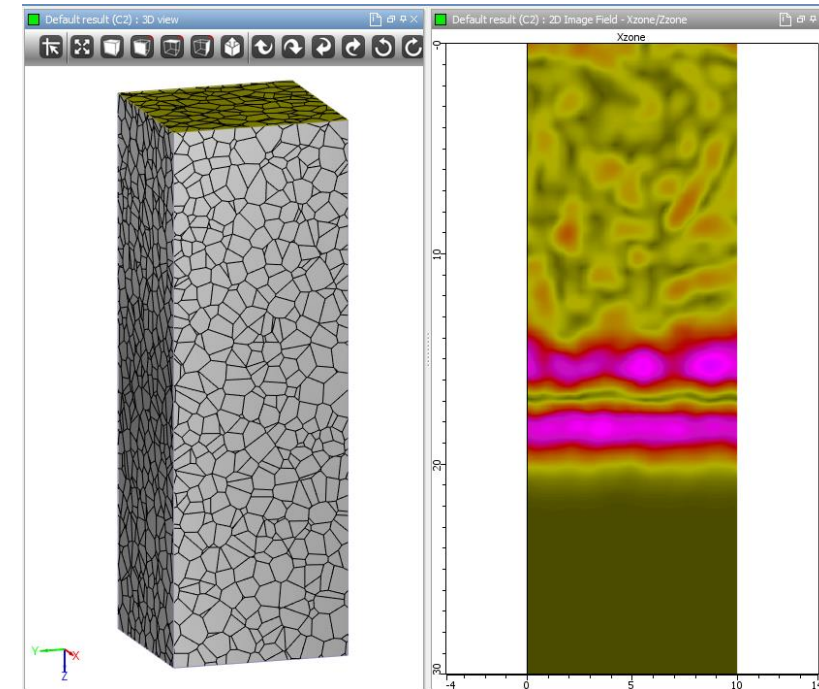
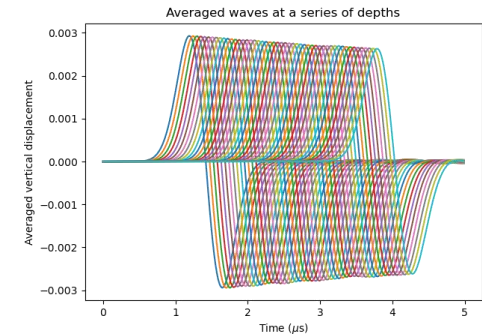
- Random generation of polycrystalline samples (Voronoi tessellations)
- Finite element computation with incident plane wave
- Averaging of the computed field at different propagation distances
- Behavior of the averaged wave (in the frequency domain):
 - Phase shift \rightarrow velocity
 - Amplitude loss \rightarrow attenuation



Van Pamel et al., JASA 2015



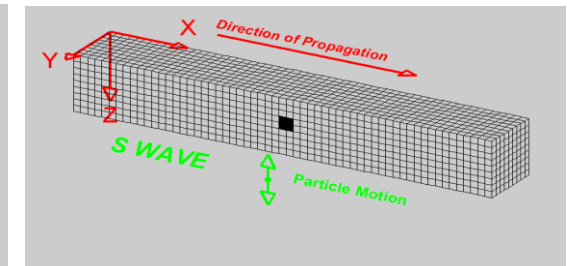
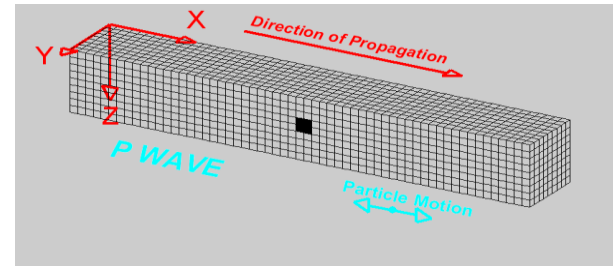
Ryzy et al., JASA 2018



Dorval et al., ECNDT 2023

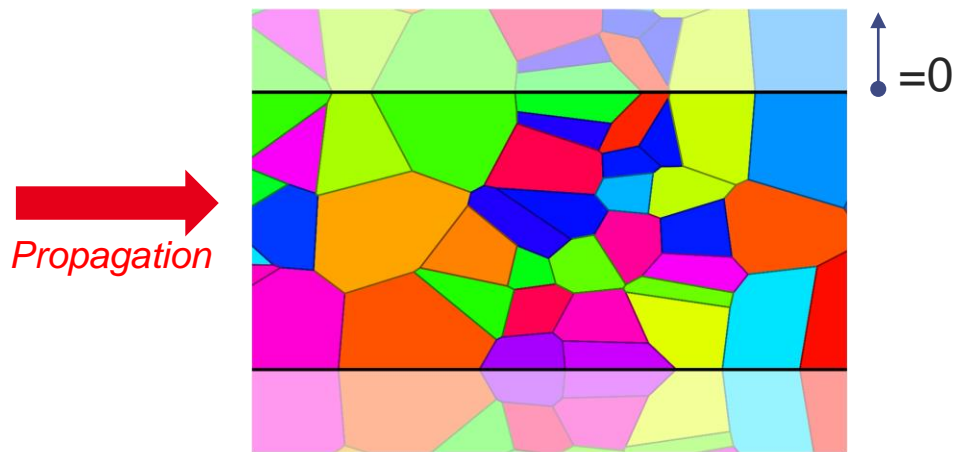
Wave modes and boundary conditions

- In most existing works:
 - Focus on longitudinal waves
 - Symmetric boundary conditions are used
- Interest for periodic boundary conditions:
 - Allows for compressional AND shear waves
 - Also avoids large symmetric grains at boundaries

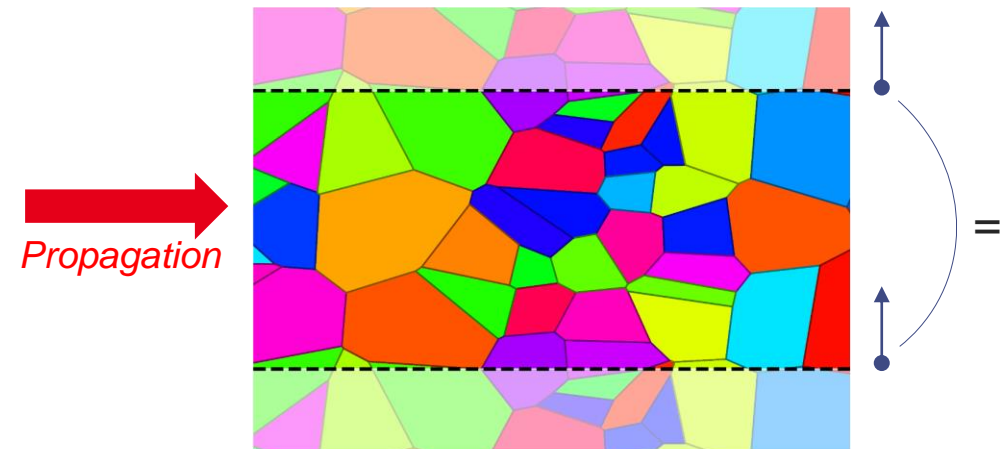


Longitudinal and shear waves

<http://web.ics.purdue.edu/~braile/edumod/waves/WaveDemo.htm>

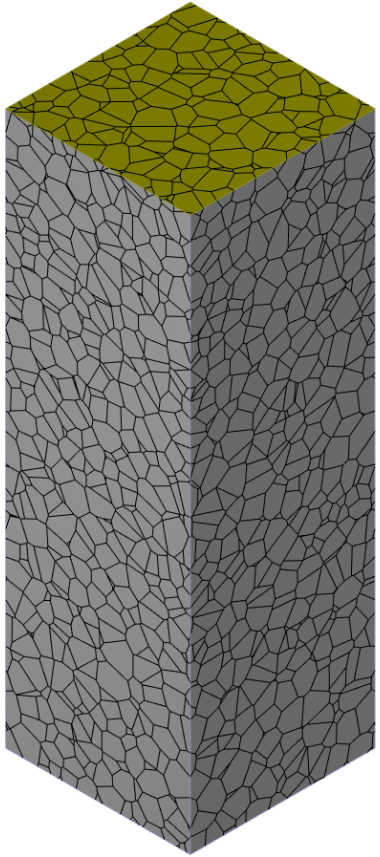


Symmetric boundary conditions

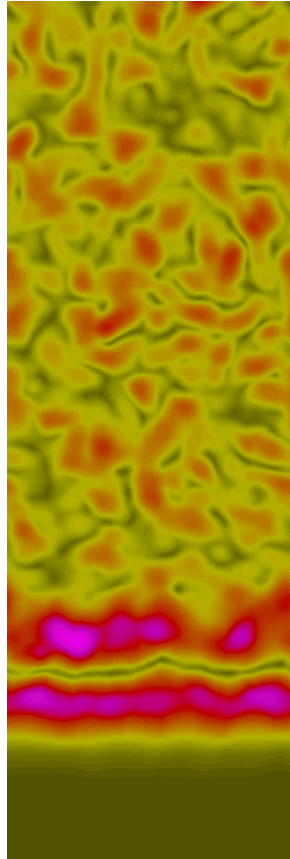


Periodic boundary conditions

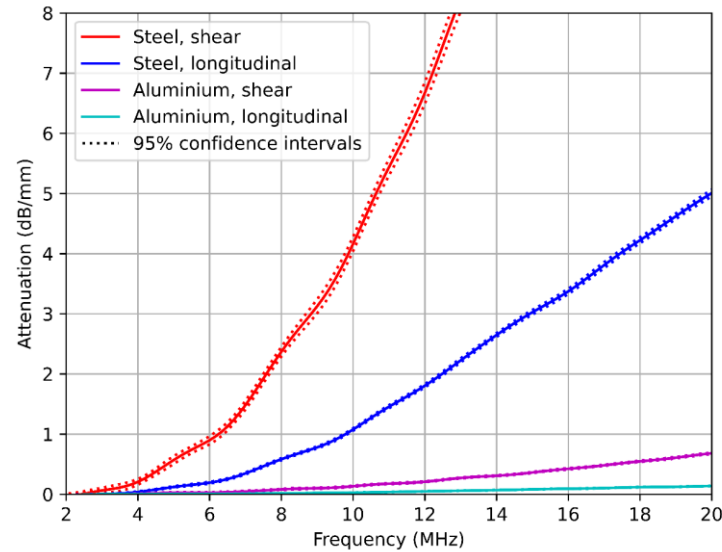
Examples of results



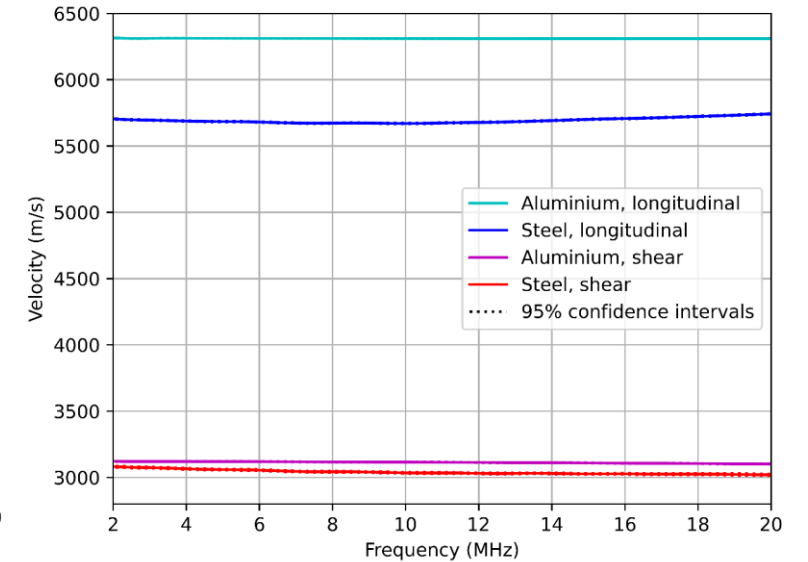
Sample



Longitudinal wave simulation (steel)



Attenuation

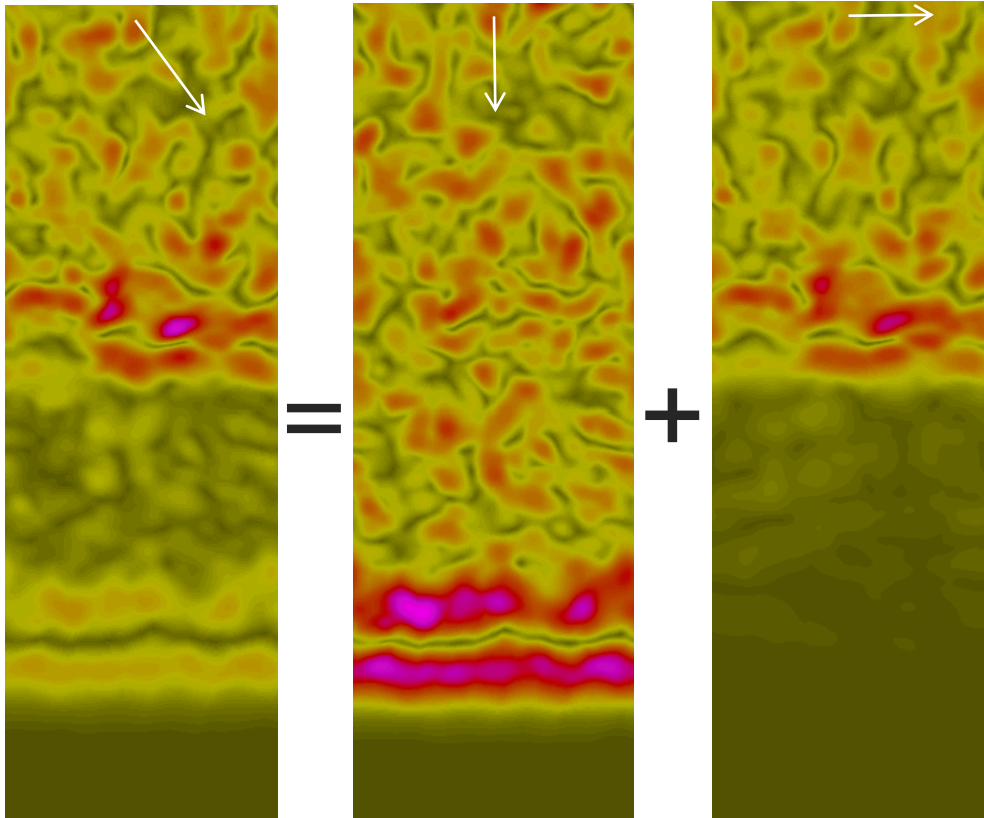


Velocity

- Comparisons of steel (strongly anisotropic) and aluminium (weakly anisotropic) for the same grain size
- 50 simulations for each material and each mode (longitudinal and shear)
- Results are consistent with expectations
- 5 hours on a laptop for a set of 50 simulations

Simultaneous characterization of both modes

- With appropriate loading, longitudinal and shear waves can be included in a single simulation
- They are easily separated in post-processing due to their different polarization directions

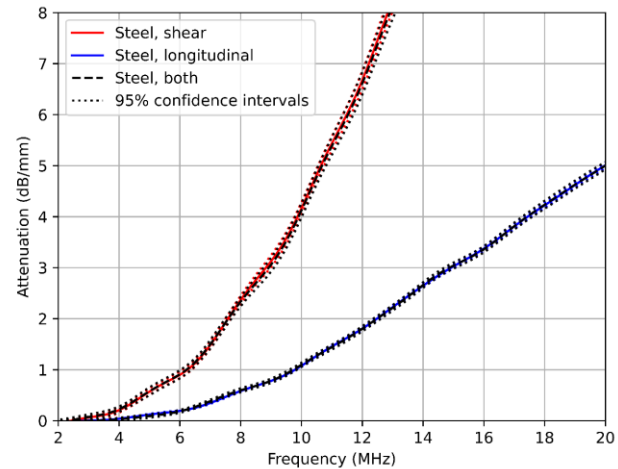


Both waves

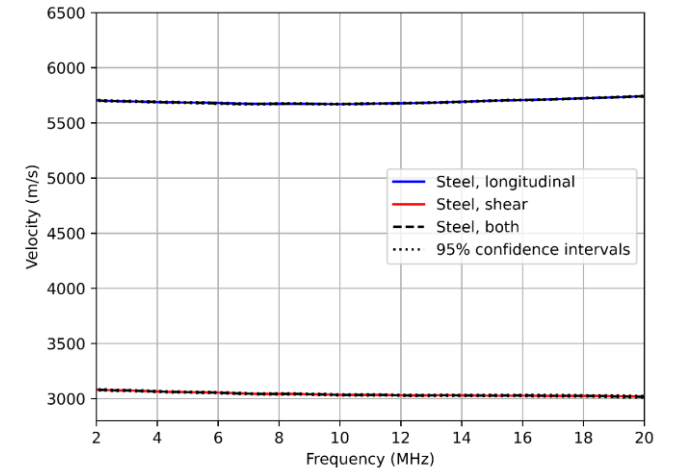
Only longitudinal

Only shear

(modulus of displacement)



Attenuation

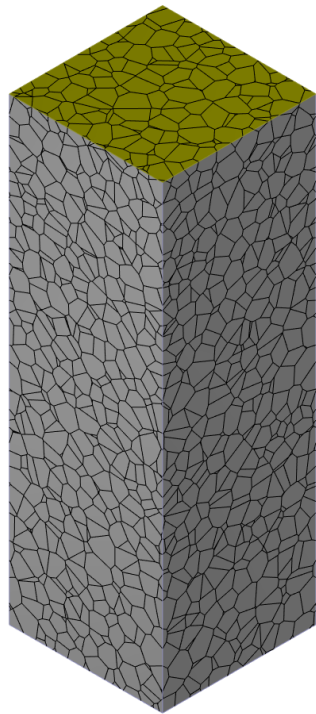


Velocity

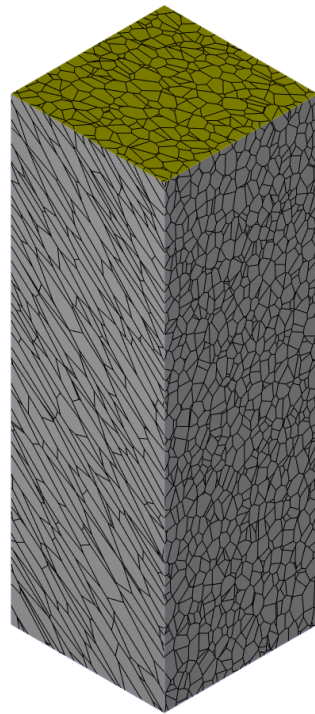
- Results with both modes agree with previous results
- Potential gains in computation times
- Interesting strategy for anisotropic materials

Anisotropic materials

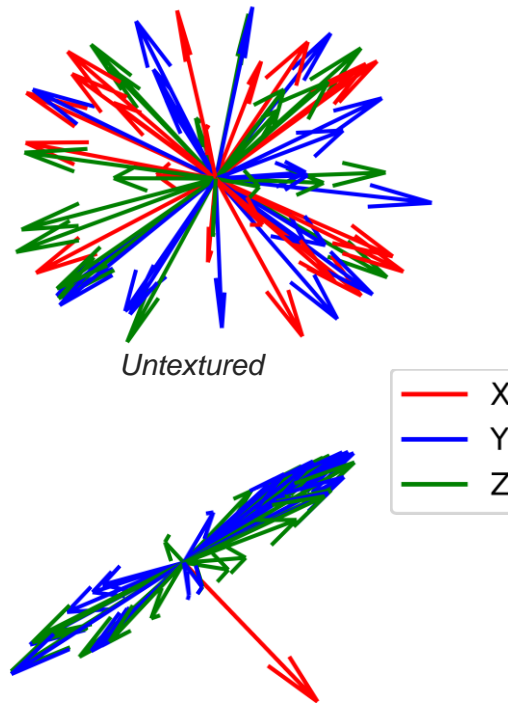
- Elongated grains and texture can be found in welds or additive manufacturing samples
- Anisotropic behaviour: one quasi-longitudinal and two quasi-shear waves with different properties



Equiaxed



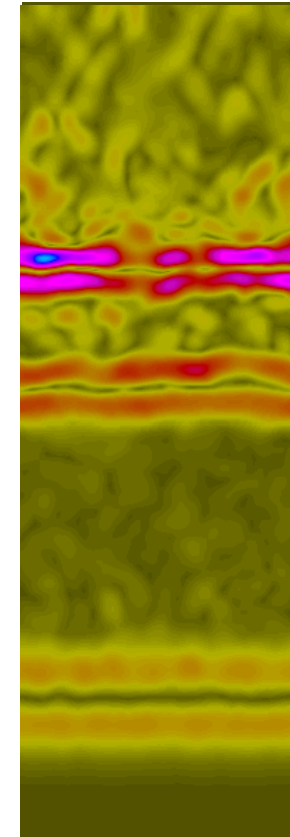
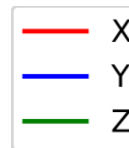
Elongated



Untextured

Textured

Crystallographic orientations



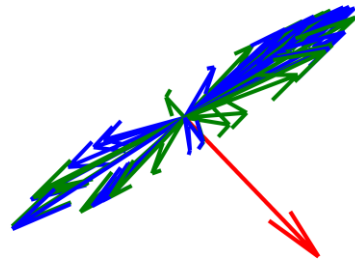
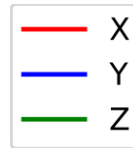
Simulated field in a textured and elongated sample

Separating modes in anisotropic materials



$$\begin{bmatrix} 207 & 133 & 133 & 0 & 0 & 0 \\ 133 & 237 & 103 & 0 & 0 & 0 \\ 133 & 103 & 237 & 0 & 0 & 0 \\ 0 & 0 & 0 & 67 & 0 & 0 \\ 0 & 0 & 0 & 0 & 117 & 0 \\ 0 & 0 & 0 & 0 & 0 & 117 \end{bmatrix}$$

Elongation



Texture

- Problem: separate mode contributions
- Proposed solution: project the field on expected polarization directions
- Strategy: use an approximated homogenization (Hill average) of the material to obtain modal polarizations

$$\begin{bmatrix} 207 & 133 & 133 & 0 & 0 & 0 \\ 133 & 207 & 133 & 0 & 0 & 0 \\ 133 & 133 & 207 & 0 & 0 & 0 \\ 0 & 0 & 0 & 117 & 0 & 0 \\ 0 & 0 & 0 & 0 & 117 & 0 \\ 0 & 0 & 0 & 0 & 0 & 117 \end{bmatrix}$$

Elastic constants of monocrystal (Gpa)



$$\begin{bmatrix} 207 & 133 & 133 & 0 & 0 & 0 \\ 133 & 237 & 103 & 0 & 0 & 0 \\ 133 & 103 & 237 & 0 & 0 & 0 \\ 0 & 0 & 0 & 67 & 0 & 0 \\ 0 & 0 & 0 & 0 & 117 & 0 \\ 0 & 0 & 0 & 0 & 0 & 117 \end{bmatrix}$$

Anisotropic Hill average (Gpa)

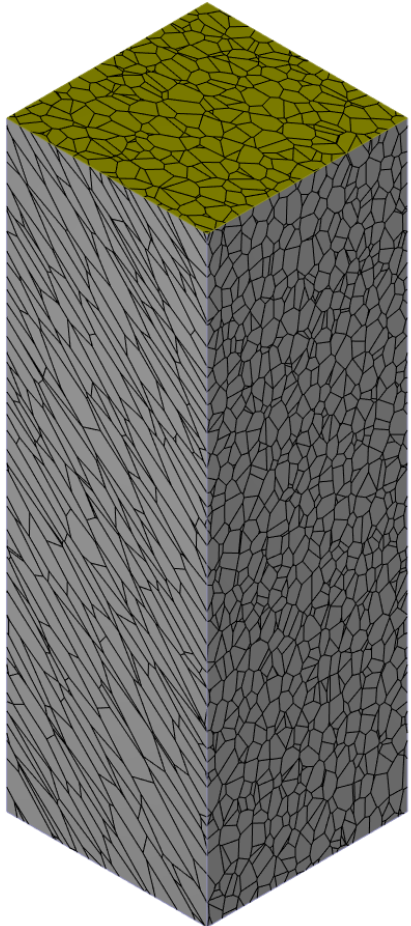


Christoffel equation for propagation direction

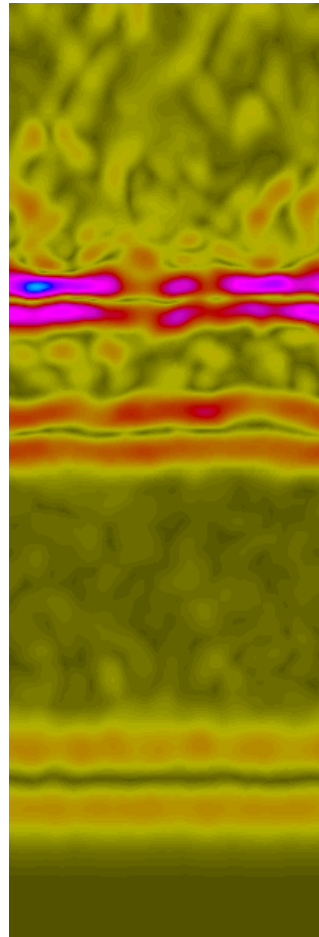


Estimation of polarizations for the 3 modes

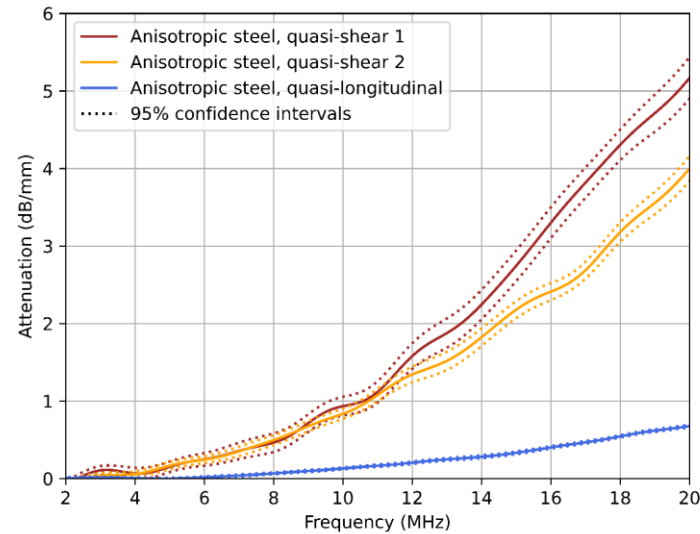
Results for anisotropic materials



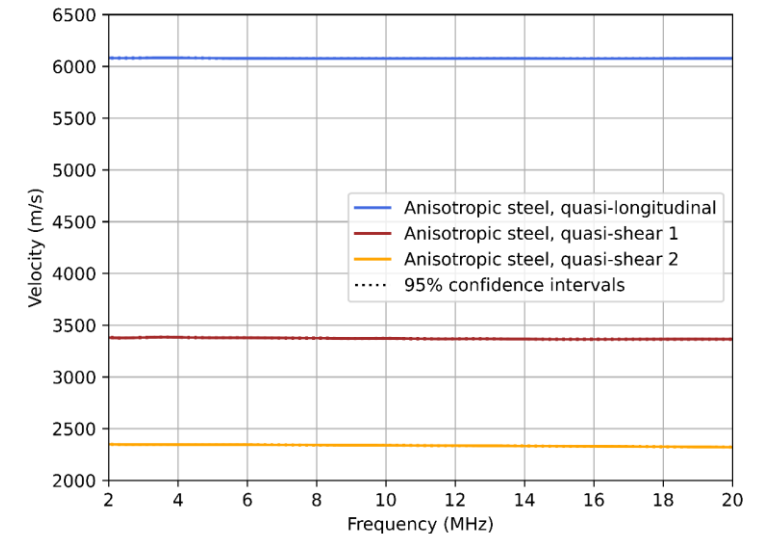
Sample



Simulated field



Attenuation



Velocity

- The three modes are successfully separated, and their characteristics can be obtained
- Results depend on the angle between propagation direction and elongation/texture axis
- A full characterization of the material requires simulations at various angles

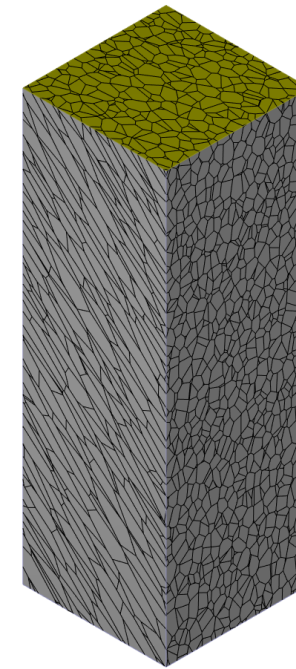
Conclusions

Characterization of wave properties in polycrystalline materials

- Adaptation of an established approach based on Finite Elements
- Use of periodic properties to study all bulk wave modes
- Simultaneous characterization of modes
- Extension to anisotropic material

Perspectives

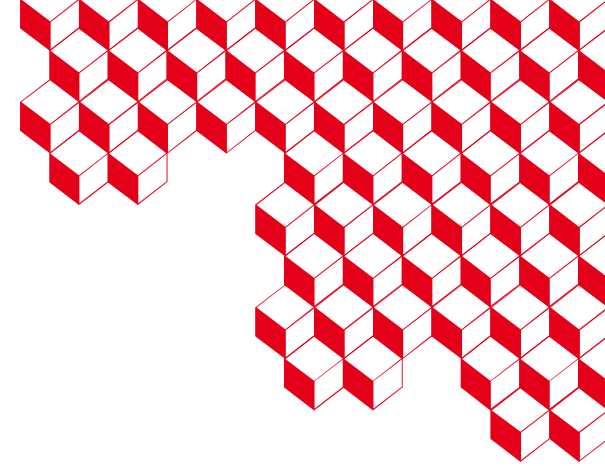
- Using micro-scale characterization results in macro-scale simulations
- Practical application to anisotropic components (welds, wire arc additive manufacturing...)
- Characterization of structural noise properties
- Release of the simulation tools in a future commercial version of CIVA



Virtual sample



Weld microstructure (EDF)



Thank you for your attention

Contact: vincent.dorval@cea.fr