Modeling method for the simulation of austenitic weld ultrasonic inspection

realistic prediction of echoes and structural noise in weld inspection

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Introduction

and context

Introduction and context

Industrial context

- Qualification and performance demonstration of NDE in nuclear industry
- Many welds to inspect in primary and secondary circuit

Physical issues

- Anisotropy and heterogeneity ➔ perturbations of the ultrasonic beam

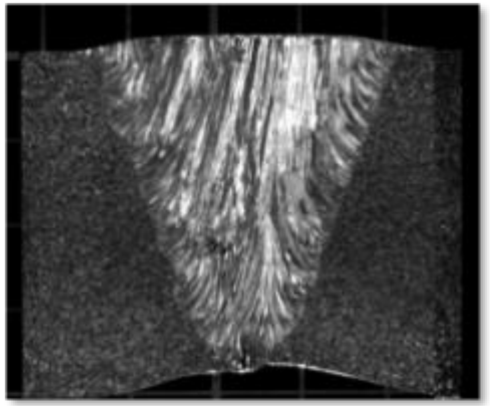
Current approach

- Intensive use of numerical modeling for performances demonstration

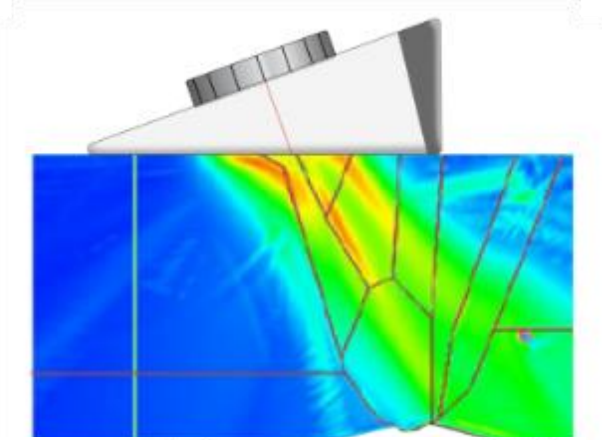
<u>Objective</u>

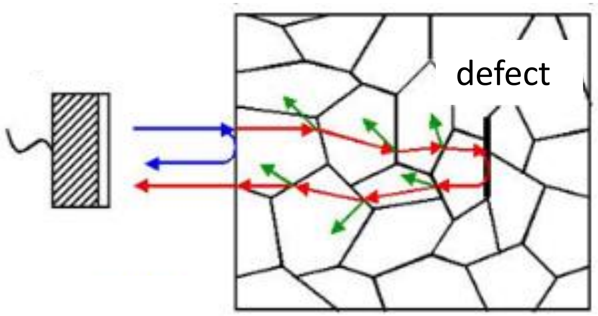
Improvement in the prediction of noise level and complex / spurirous echoes occurrence and intensity in weld ultrasonic inspection

- ➢ Include microstructure in FE modeling
- ➢ Predict the phenomena related to grain scattering



Presurizer surge line weld (Chassignole et al, 4th ICNDE)



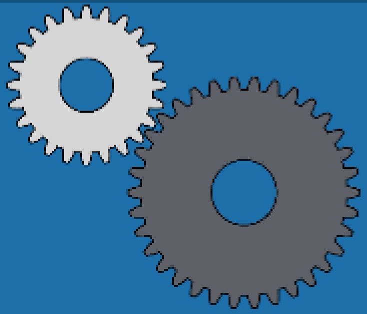


Modeling approach

Modeling approch

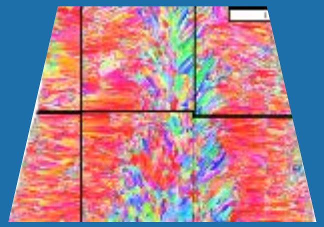
- Coupling Finite Elements modeling with fine description of the weld microstructure

Finite Elements code



\+

Weld microstructure



Introduction

Modeling approach

Applications

Conclusion

The FE Codes – ATHENA 2D and A3D-CND

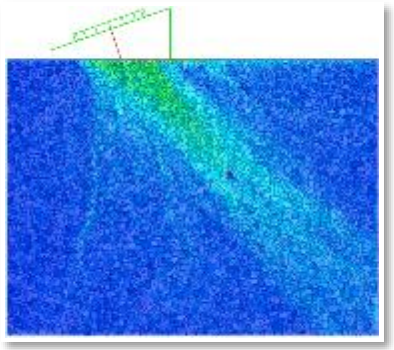
- Finite Elements code developped by EDF
- Computes the elastodynamic propagation in heterogeneous, anisotropic materials
- Manages various type of probes (contact, immersion, tofd, tandem, phased array)
- Equiped with a NDT dedicated interface

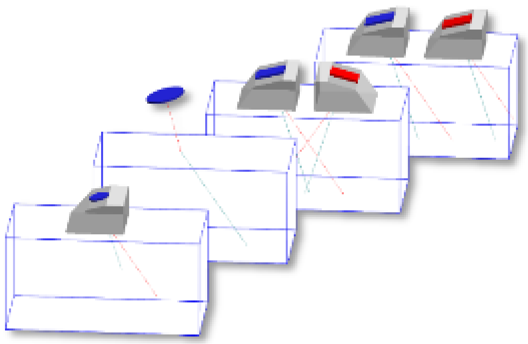
ATHENA 2D (since 2002)

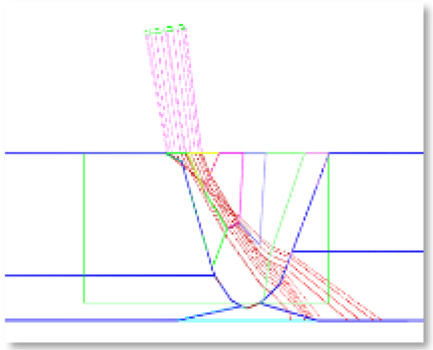
- 2D Version on regular mesh
- Complex defects managed with the fictitious domain method
- Available in CIVA (module)

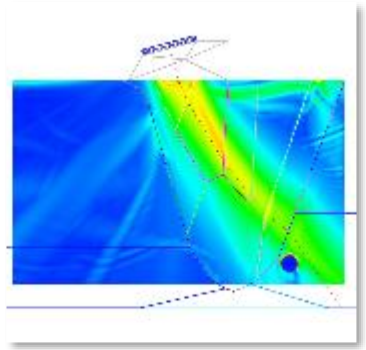
A3D-CND (since 2018)

- 3D Version on tetrahedron
- Prototype under developpment and validation









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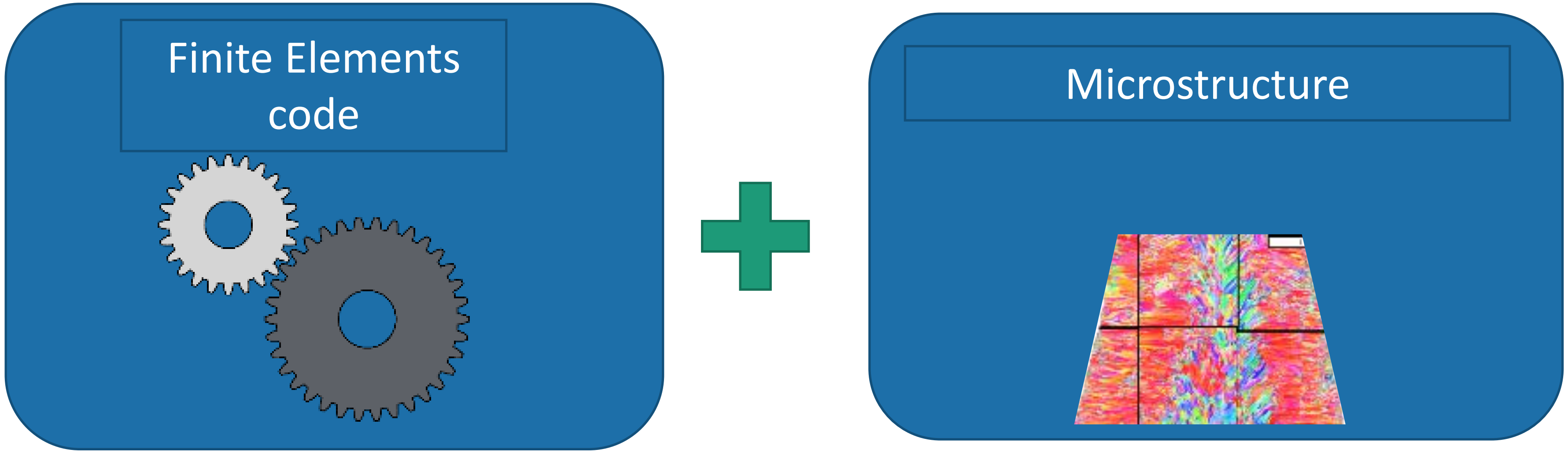
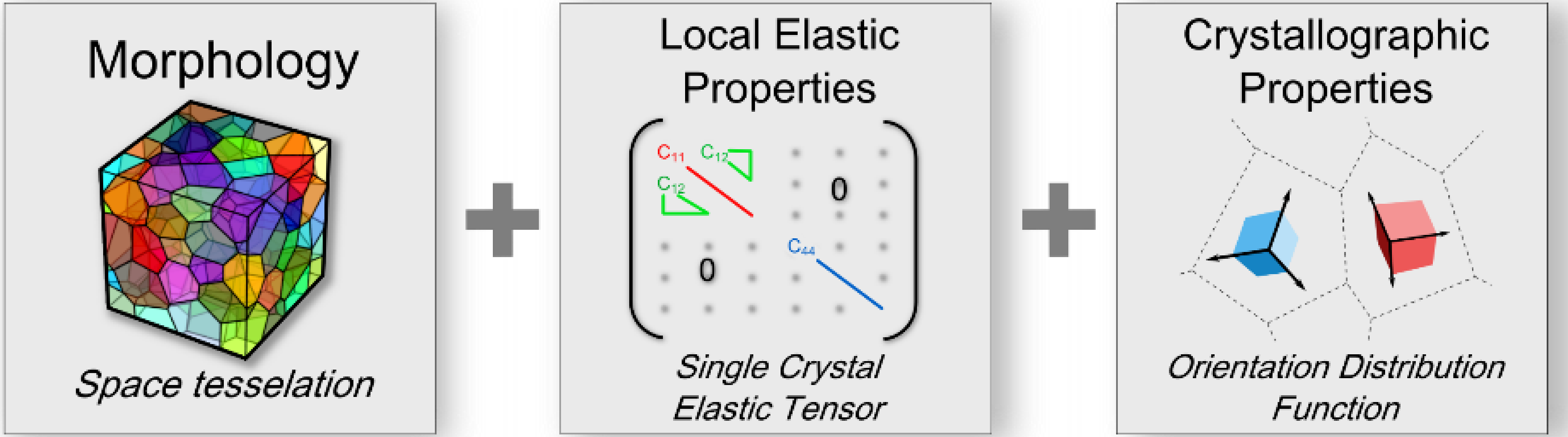
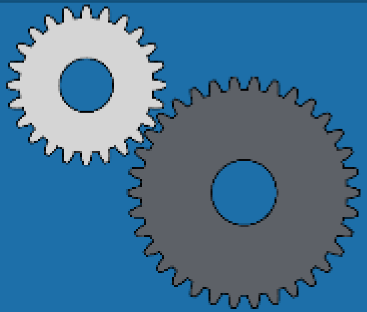


Microstructure

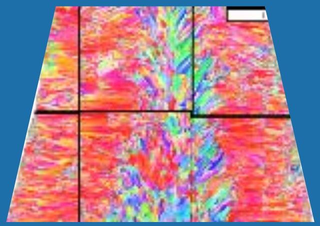


Applications

Finite Elements code



Microstructure



1. 3D simulation of ultrasonic attenuation homogeneous weld
2. 2D simulation of the US inspection of dissimilar weld
3. 3D simulation and coupling with numerical simulation of welding (CAFE)

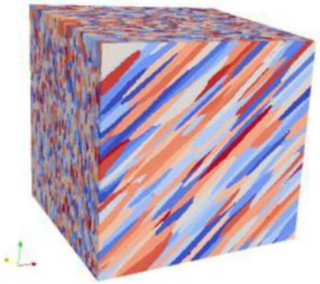
Preliminary study

Application 1

3D simulation of ultrasonic attenuation in homogeneous weld

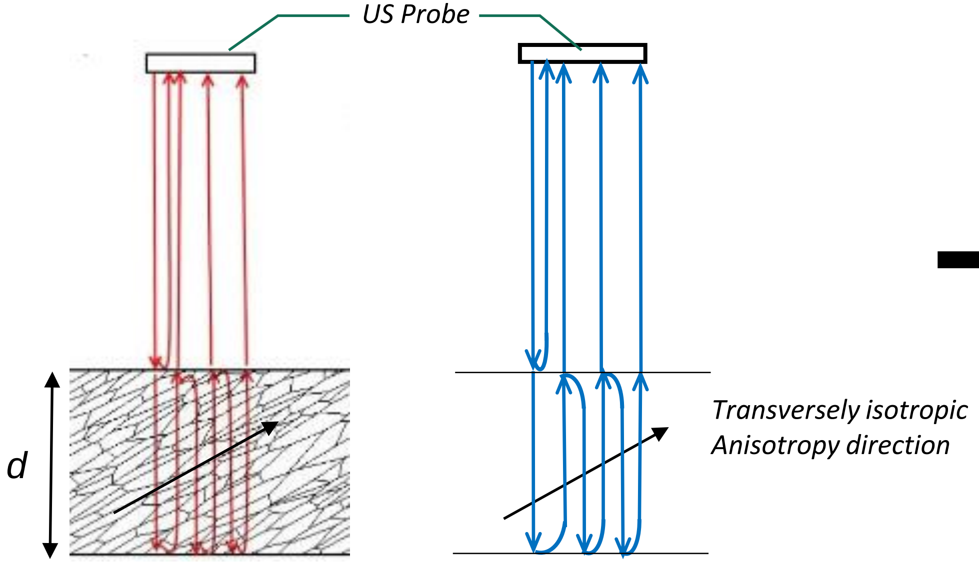
3D simulation - Attenuation prediction

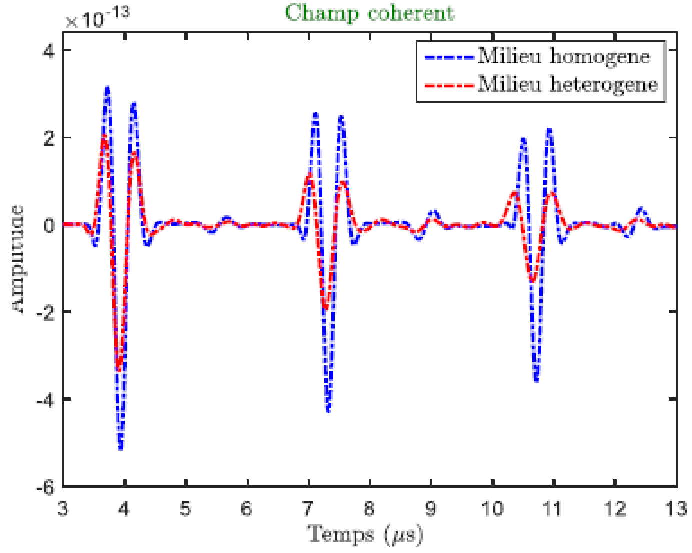
DREAM3D Weld microstructure



- 3D homogeneous weld microstructure with DREAM3D
- Computation of the apparent attenuation
- Divergence correction with homogeneous media

$$\alpha_{diffusion}(w) = \alpha_{het}(w) - \alpha_{hom}(w)$$

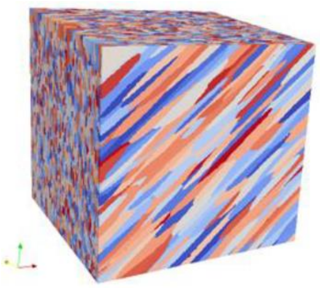




3D simulation - Attenuation prediction

- 3D homogeneous weld microstructure with DREAM3D
- Computation of the apparent attenuation
- Divergence correction with homogeneous media
- Nominal grain size 5*0.25 mm

DREAM3D Weld microstructure



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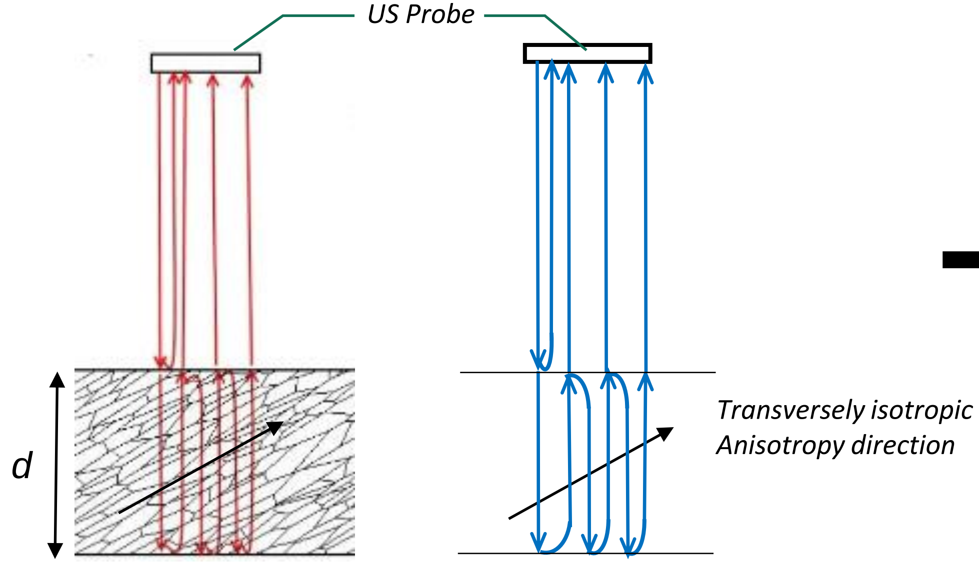
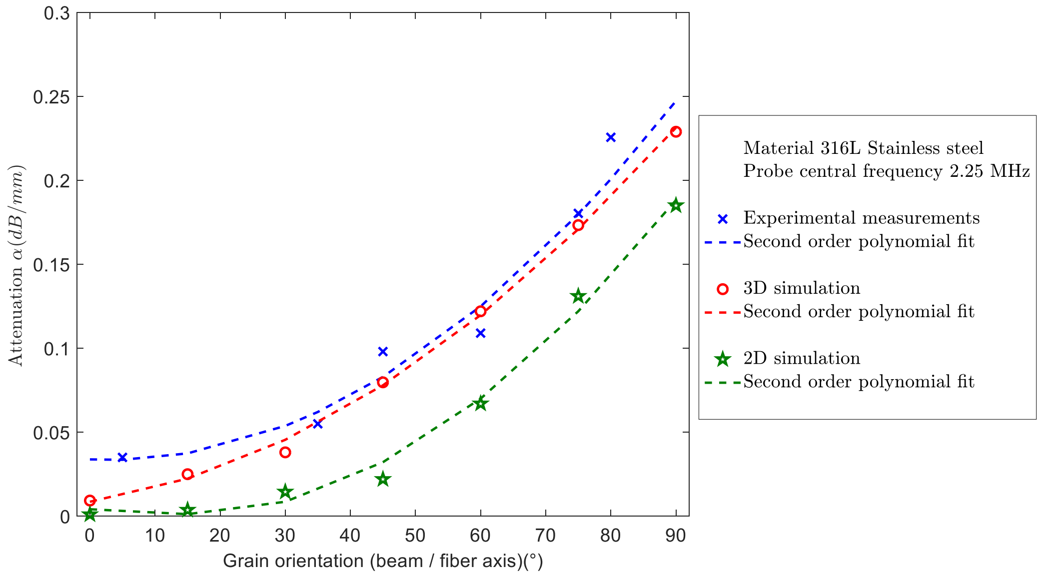


Comparison with experimental data



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3D simulation - Attenuation prediction

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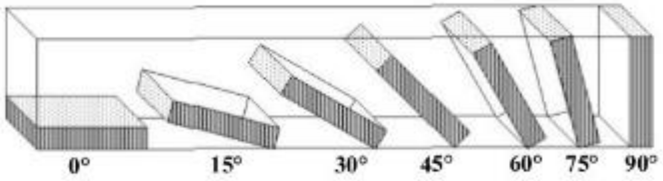
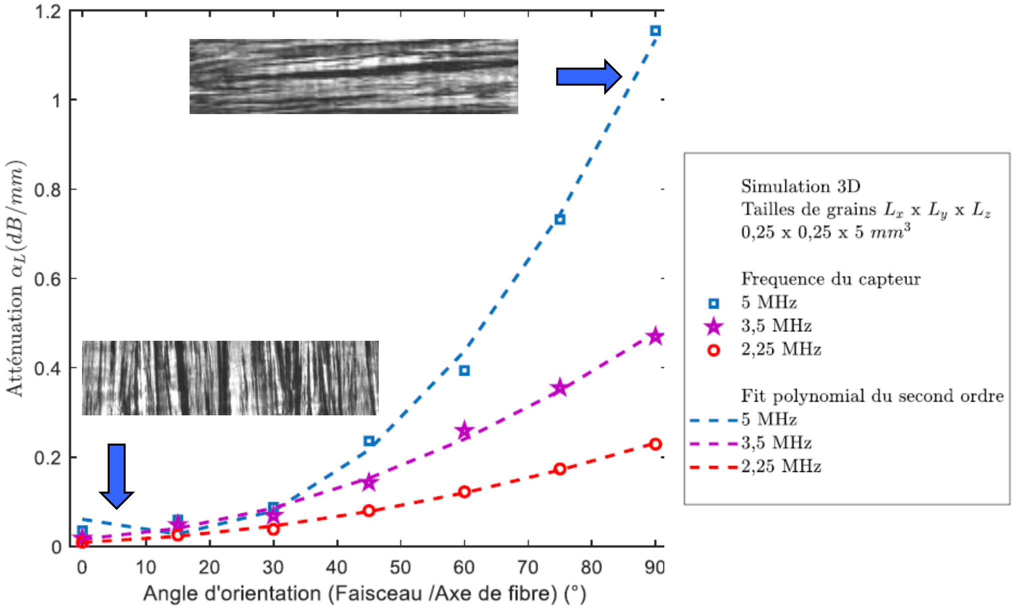
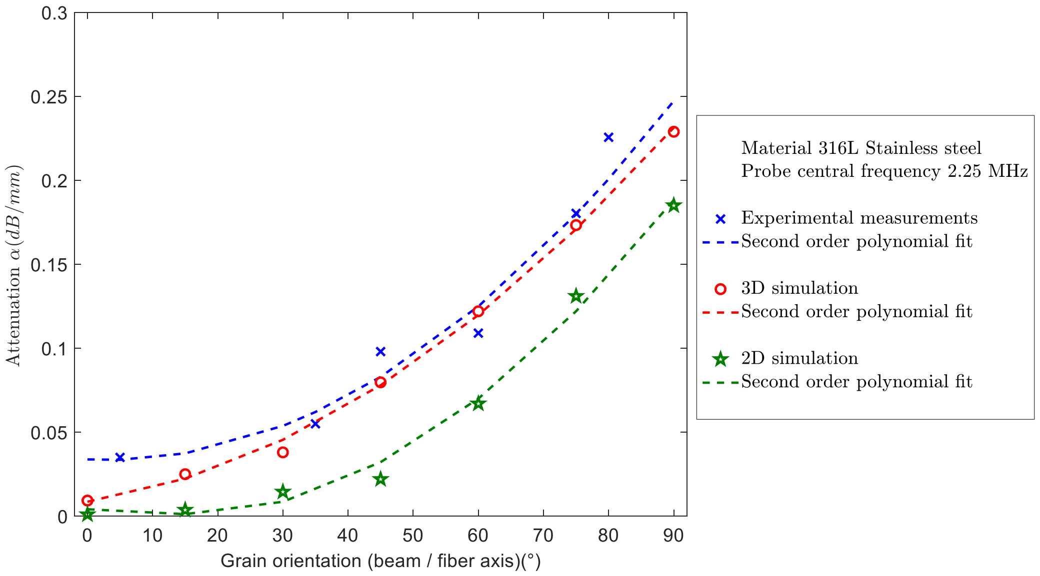


Samples of various orientation taken in a very large weld mold



Comparison with experimental data

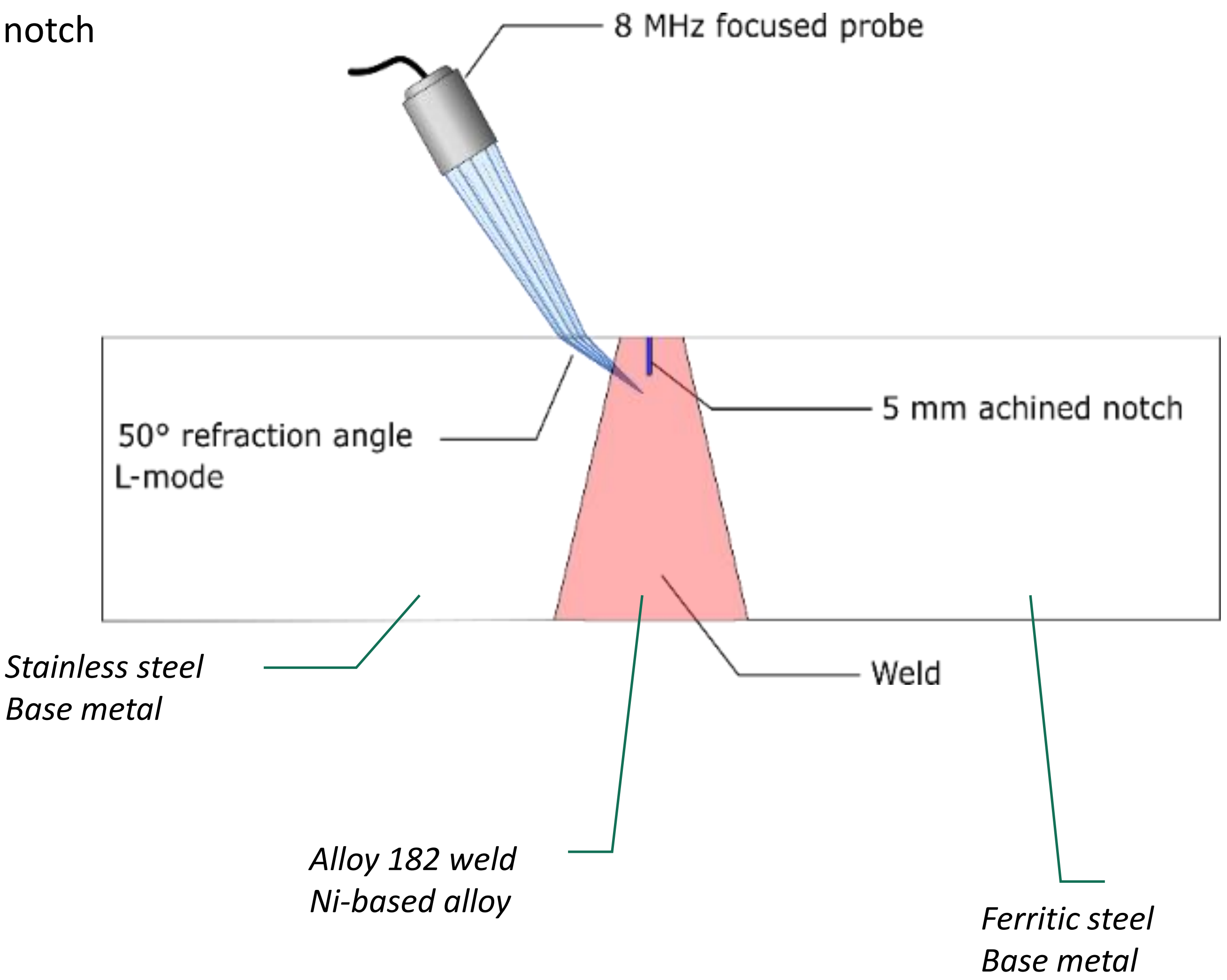


Application 2

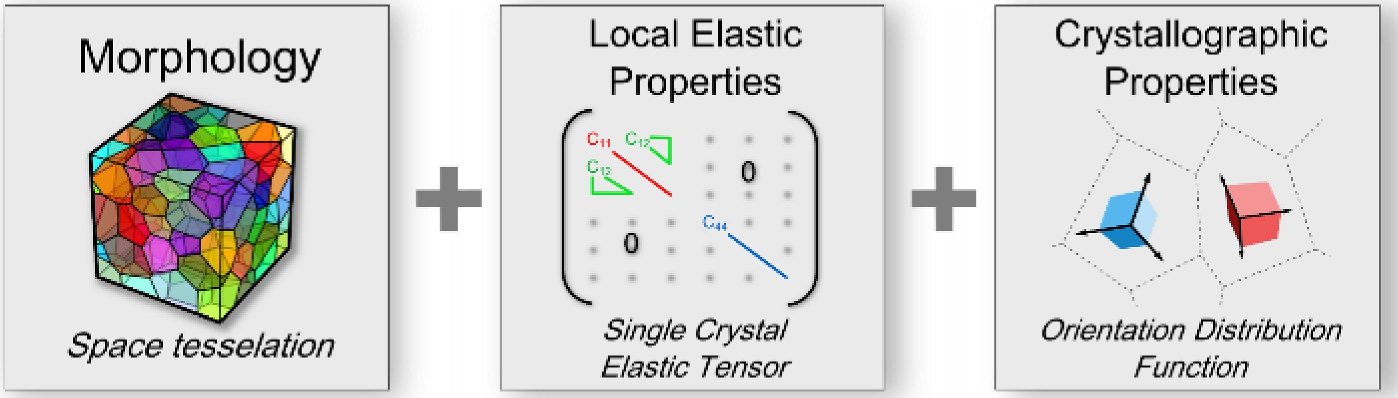
2D simulation of the US inspection of dissimilar weld

Inspection configuration

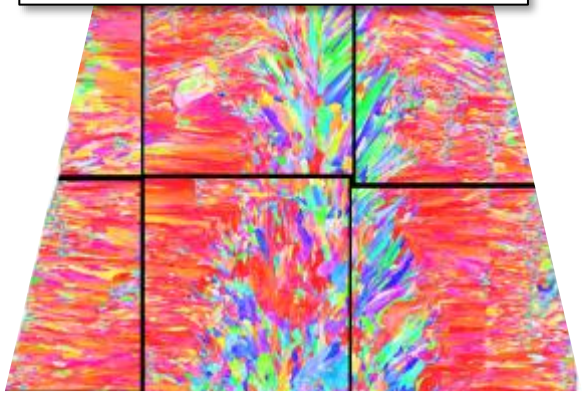
- Inspection of a Nibased alloy weld root
- Seek for a 5mm surface-breaking machined notch
- Focused US probe at 8 MHz
- Bscan inspection
- L-mode 50° (nominal refraction angle)



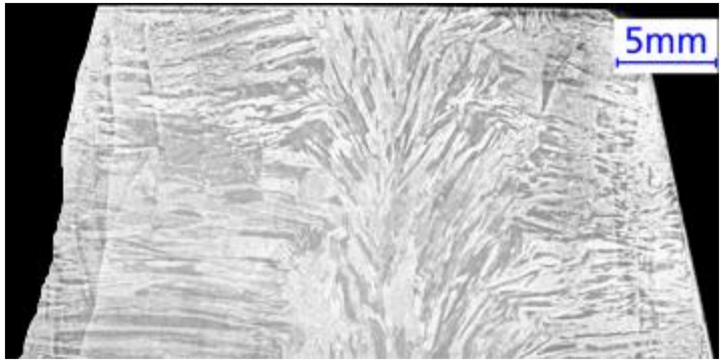
Microstructure creation



Reference for validation

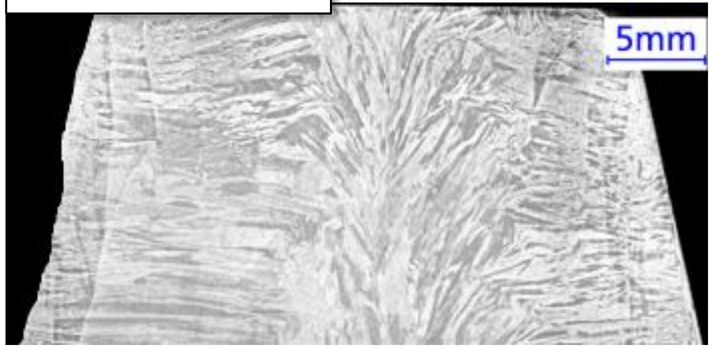


Input



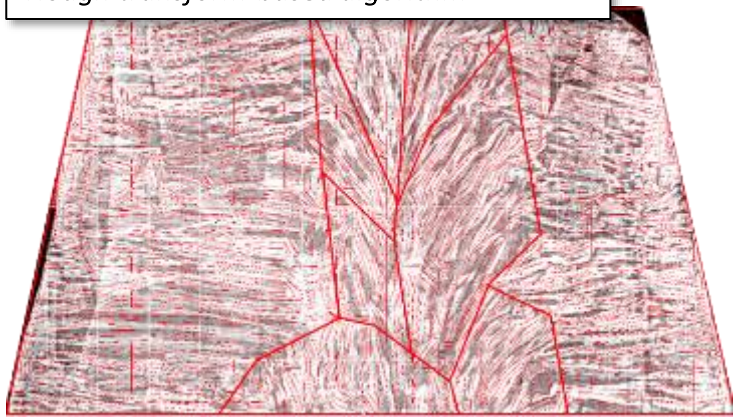
Microstructure model - Workflow

1 Metallography

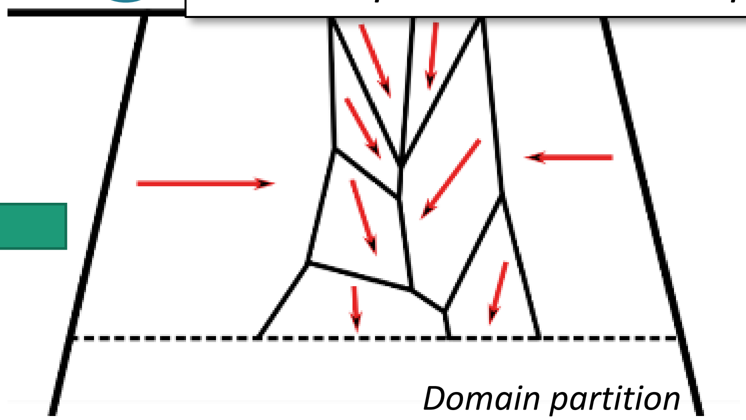


2 *Local orientation*

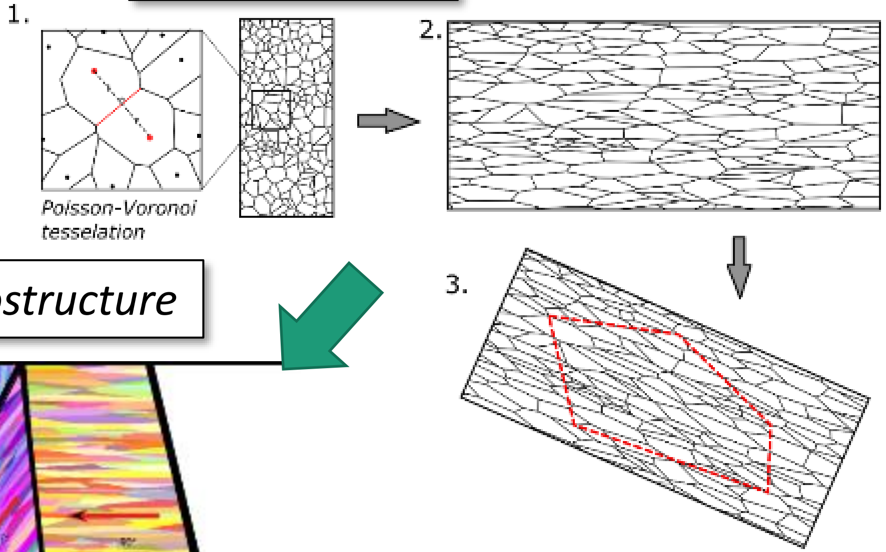
Hough transform-based algorithm



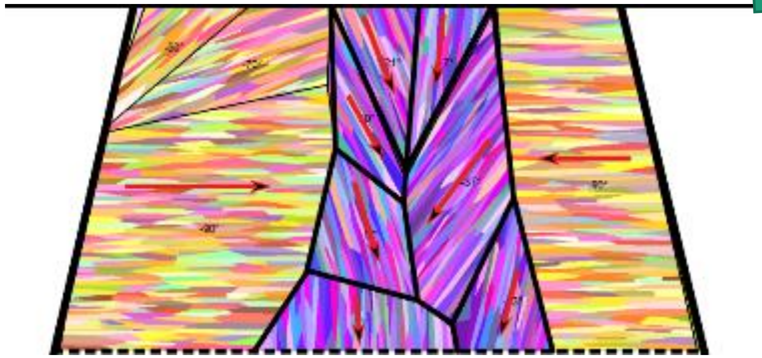
3 *Mesoscopic orientation map*



4 *Grain partition*



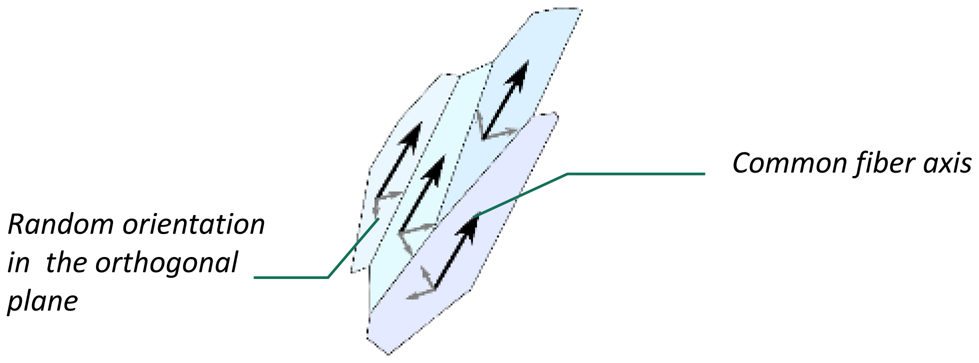
5 *Realistic final microstructure*



Microstructure model – Cristallography and elastic properties

Attribution of grain orientation

- Local orientations in sub-domain
  ➔ locally transversely isotropic cristallographic symetry



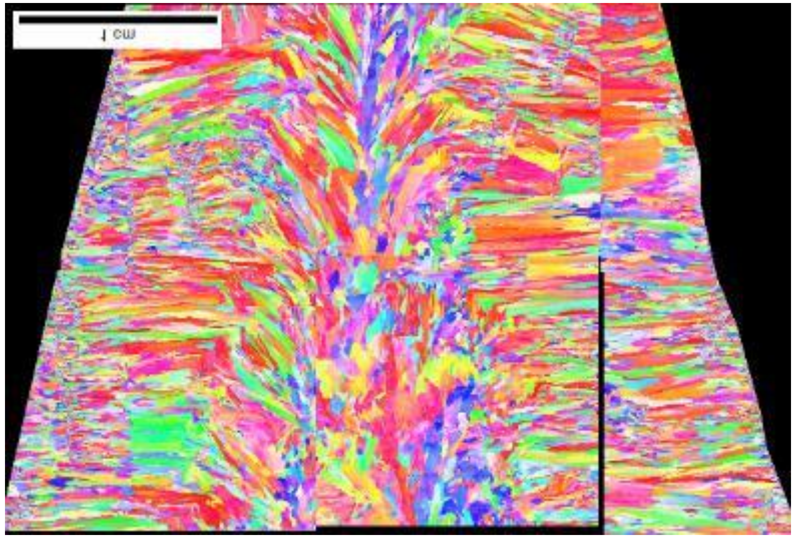
Individual grain elastic properties

235	145	145			
145	235	145			
145	145	235			
			126		
				126	
					126

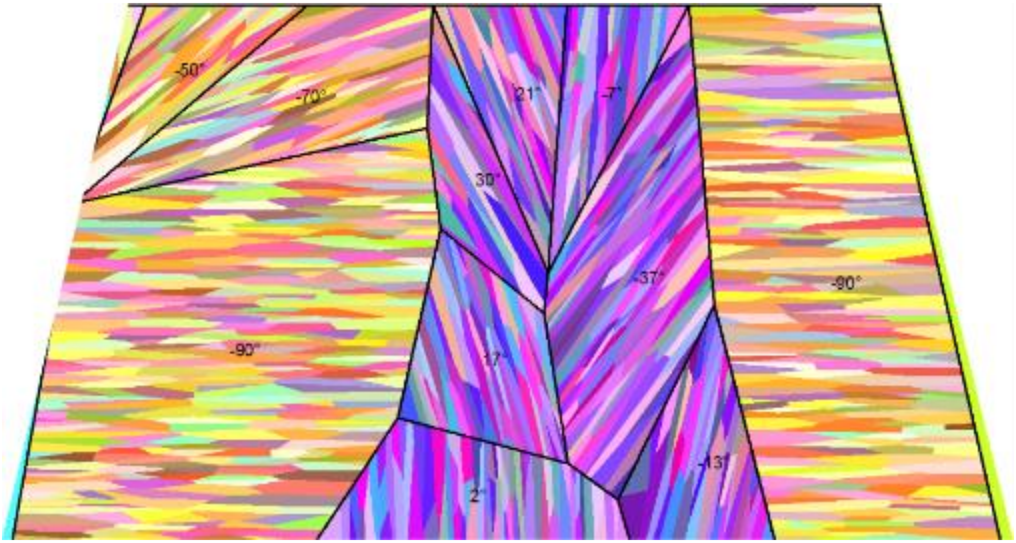
Ni_based alloy
Cubic Single crystal
elastic properties

Microstructure model

Real microstructure

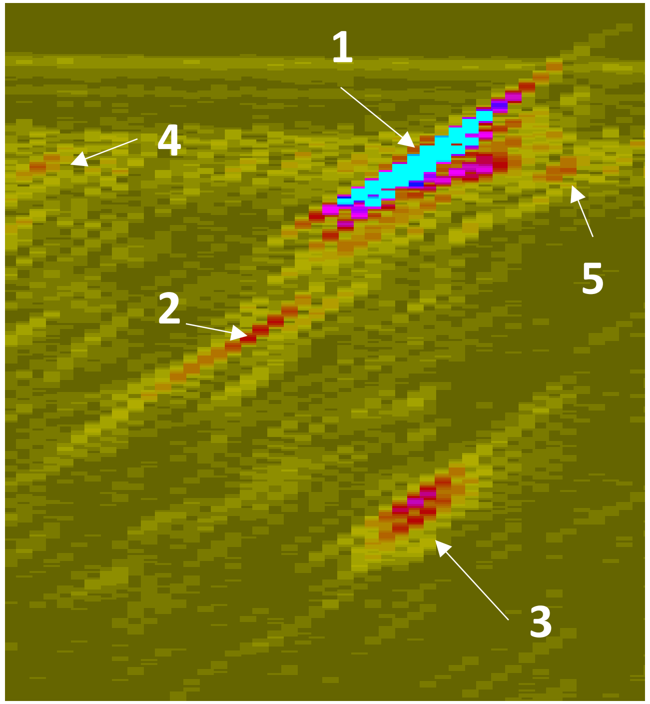


Synthetic microstructure



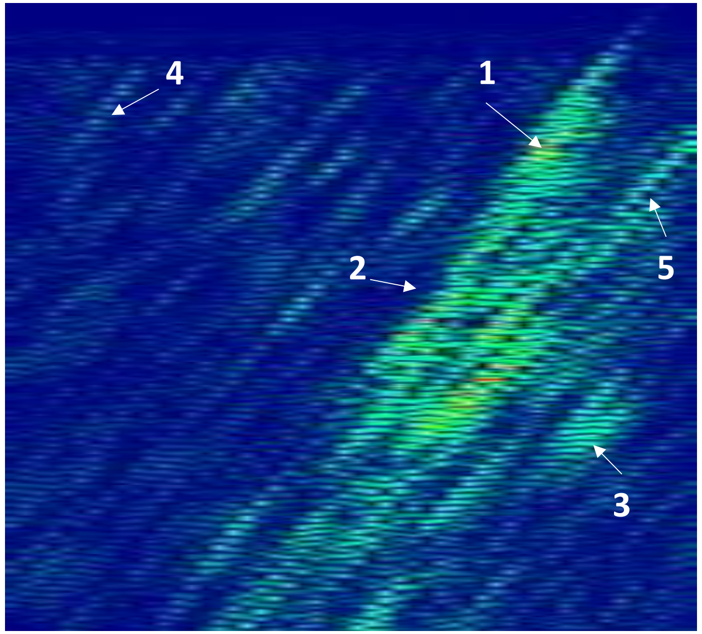
Simulation results - Bscan

Experimetal bscan



1. *Notch surface breaking echo*
2. *Notch tip diffraction echo (direct L-mode)*
3. *Mode converted L-T mode echo*
4. *Weld chamfer spurious echo*
5. *Complex weld / notch interaction echo*

Simulated bscan



- Qualititatively : Identification of 5 different characteristic echoes, visible on both experiments and simulation
- Quantitatively : reasonably good prediction of main echoes intensity

Echo	Expe vs simu discrepancy
Notch tip diffraction	+3,8 dB
Weld structural noise	- 1,6 dB

Application 3

3D simulation and coupling with numerical simulation of welding (CAFE)

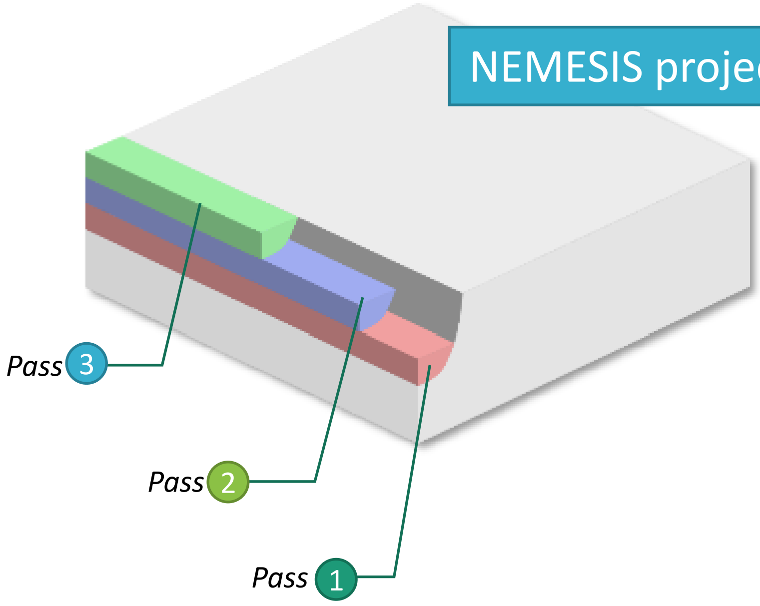
NEMESIS project

Weld configuration and model

NEMESIS project

- Multi-layer TIG weld ➔ 3 passes in a weld groove
- 316L stainless steel
- Numerical modeling of welding with the CAFE model

  Cellular Automaton Finite Elements



Grain structure modeling in fusion welding processes using a coupled CAFE approach - Application in NDT methods, C. Xue, G. Guillemot, C.-A. Gandin, M. Bellet, LUS4METALS 2022

Tomorrow 11h

Weld configuration and model

NEMESIS project

- Multi-layer TIG weld ➔ 3 passes in a weld groove
- 316L stainless steel
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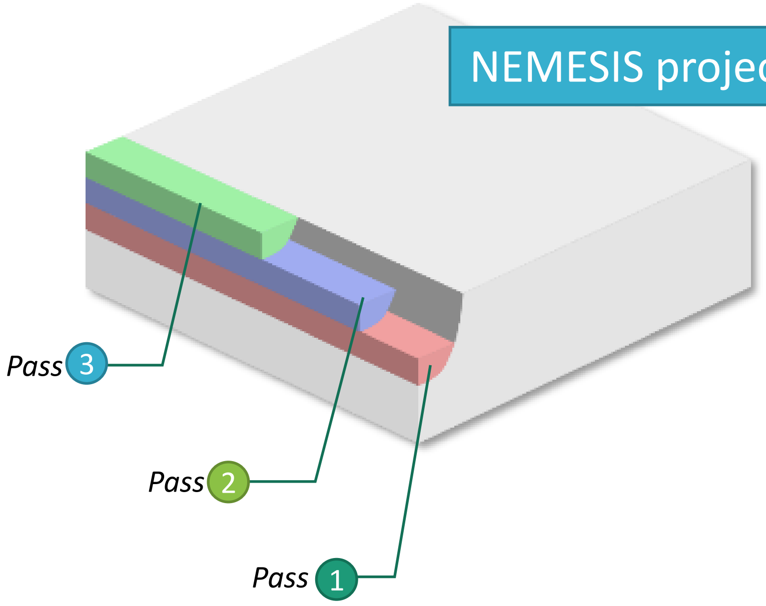
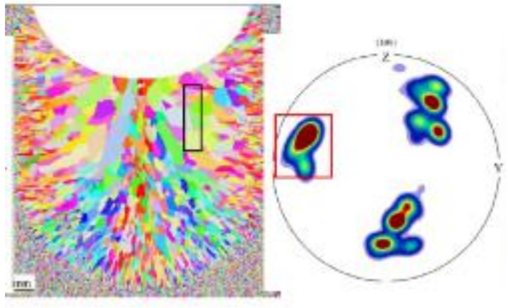


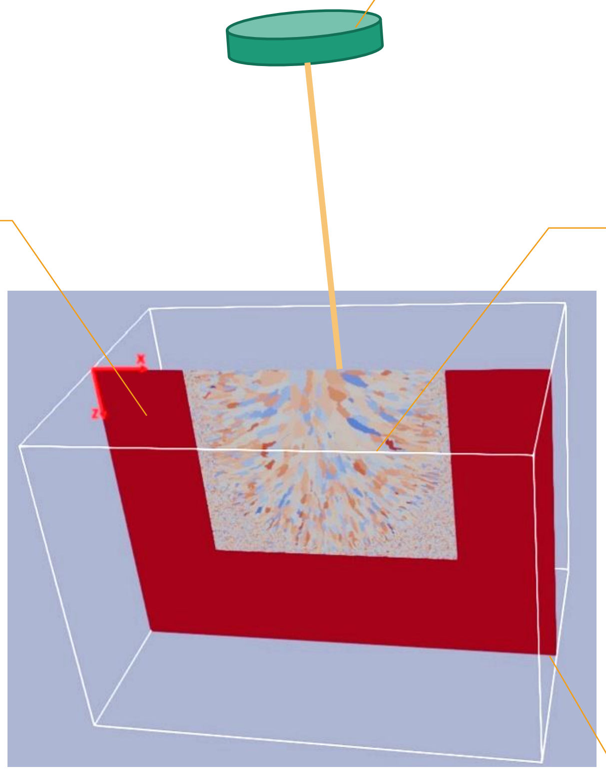


Weld configuration

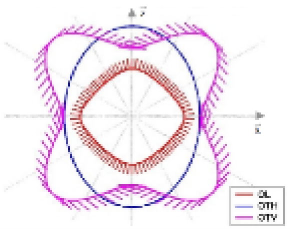
- 3D moding configuration

US transducer
Normal incidence
Phi 12,7 mm

Isotropic base metal



CAFE simulation zone
Material = austenite single cristal



206	133	133			
	206	133			
		206			
			119		
				119	
					119

+3 Euler angles for each grain

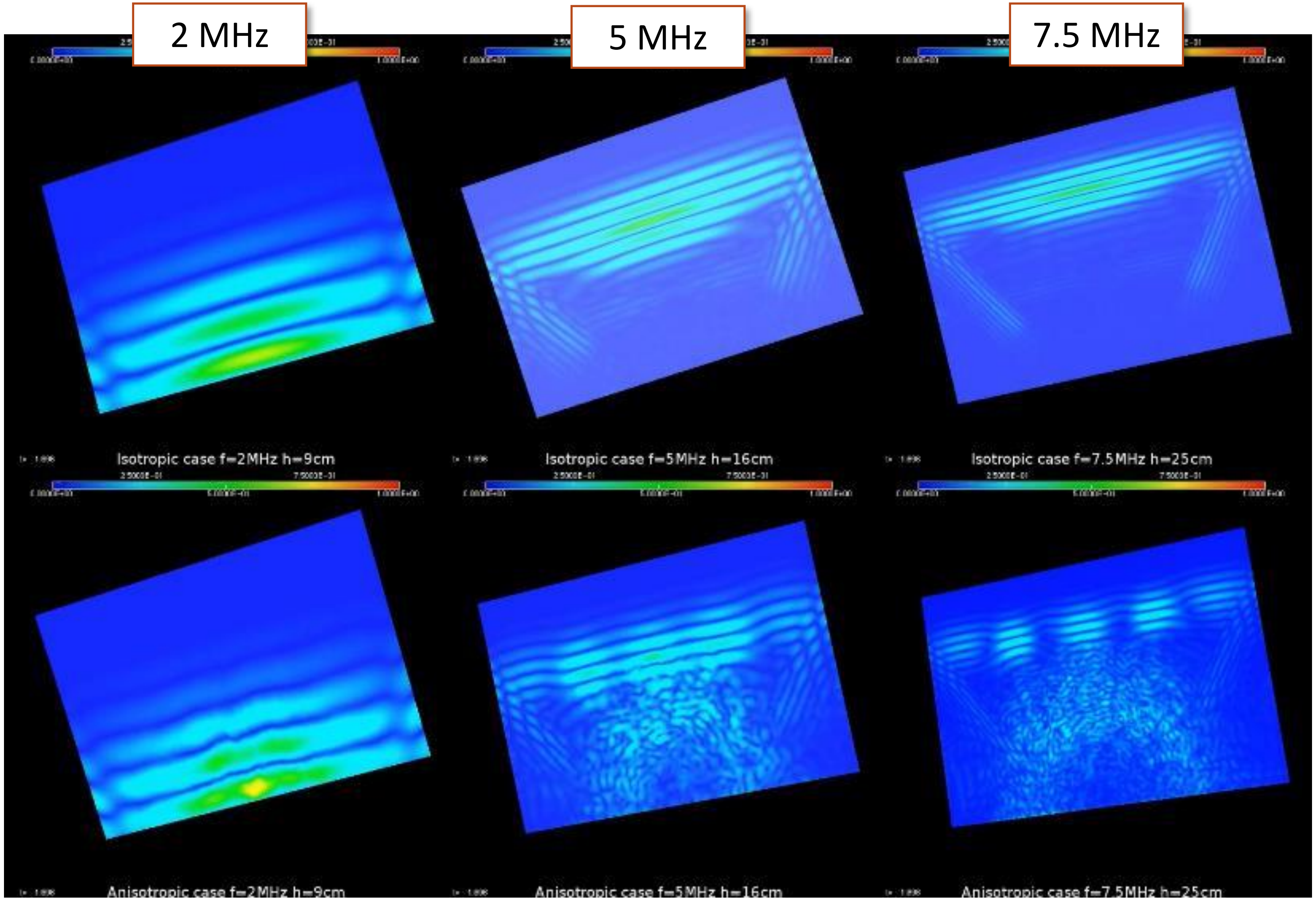
Rho = 7925, VL= 6184, VTmin = 2292

Visualisation plane (x,z)

Computation performances

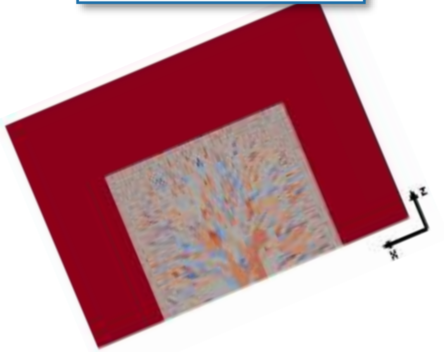
- Dimension : (14mm)x(10mm)x(10mm)
- Number of tetrahadron : 1 000 000 000
- DoF : 175 000 000
- Simulated time : tf = 6,4µs
- RAM : 340 Go
- Computation time : 5h30mn

Numerical results



Isotropic config

Weld config



Time t =1,696µs

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may 5th 2022

Introduction

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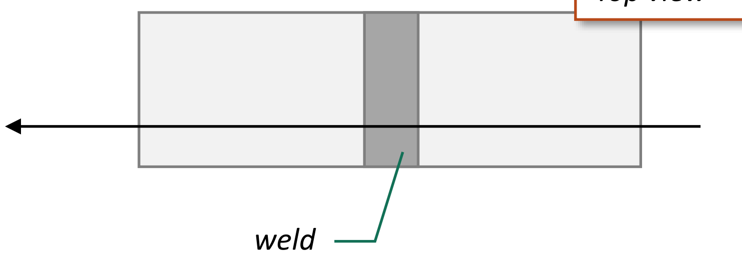
Future work

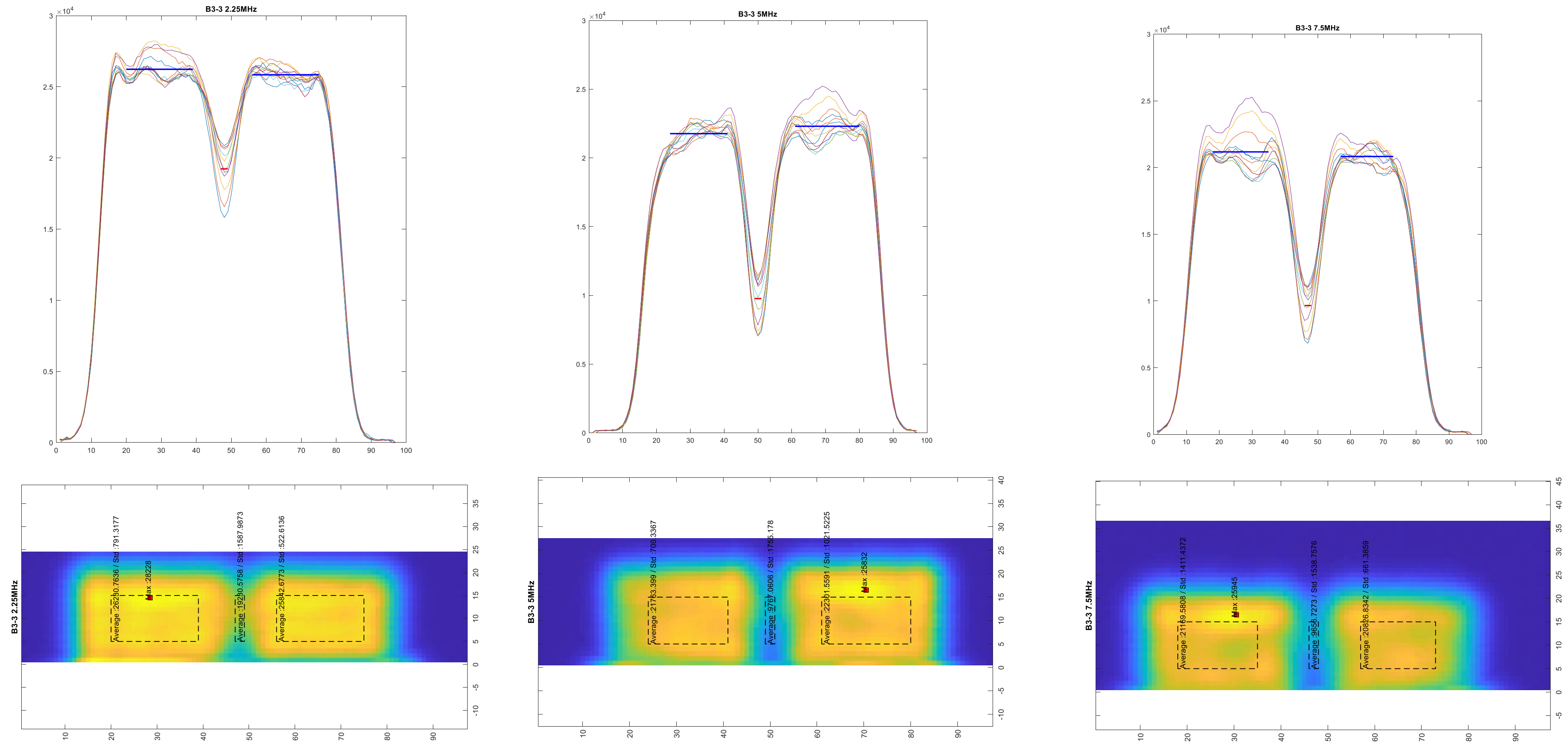


- Comparison with experimental data

2 MHz

5 MHz

7.5 MHz



Amplitude profile Perpenticular to weld direction

Cscan

Summary & Conclusion

Method

- Coupling FE modeling of US propagation with virtual microstructure model

Applications

- 3D simulation of ultrasonic attenuation homogeneous weld
- 2D simulation of the US inspection of dissimilar weld
- 3D simulation and coupling with numerical simulation of welding (CAFE)

Results, acheivement

- Enable to predict complex phenomena : attenuation, structural noise, spurious echos
- Reasonbly good agreement of echo amplitude prediction (2D) ➔ ~2 to 4 dB max
- Proof of concept of a fully numerical workflow ➔ CAFE weld model + A3D-CND

To be compared with experimental data

Limits

- Require a high knowledge of the microstructure, or the manufacturing conditions
- Require high computing ressources (only available on High Performance Computer clusters)

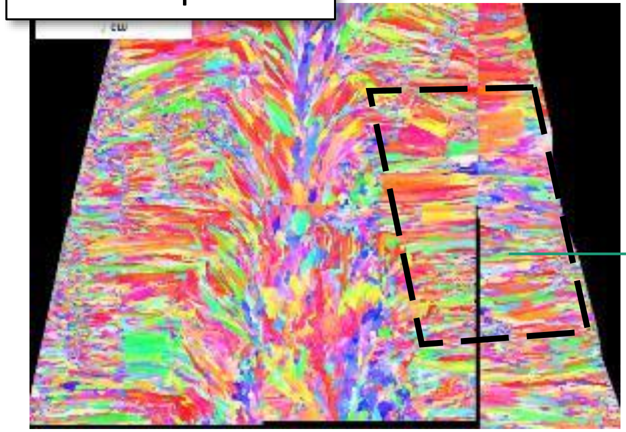
Thank you for your attention

Annex

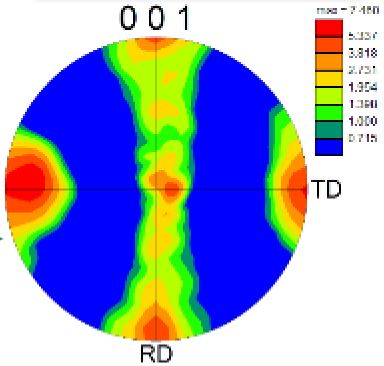
Microstructure model – Cristallography and elastic properties

- Hypothesis confirmed by EBSD measurement and previous studies

EBSD map



Local pole figure



Exhibits local transversely isotropic distribution of crystallographic orientations