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AGENCE NATIONALE DE LA RECHERCHE ANR

Validation of simulation tools for ultrasonic inspection of austenitic welds in the framework of the MOSAICS project

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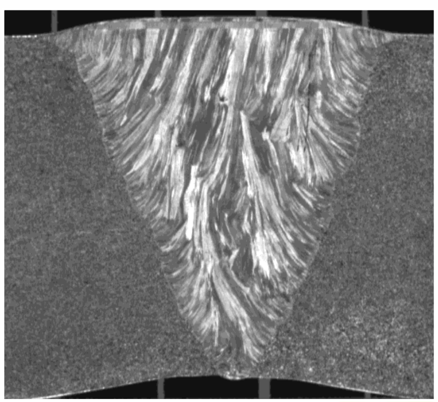
Outline

- Context
- The MOSAICS project
- The CIVA dynamic ray tracing model : “CIVA weld”
- The 3D ATHENA code
- Ultrasonic inspection: comparison between experimental and modelling results
- Modelling influential parameters
- Conclusion

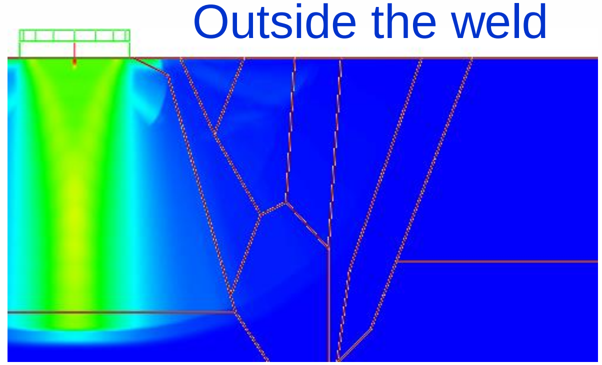
Context

- Use of robust NDT numerical models:
  - Understanding of complex physical phenomena
  - Parametric studies in order to determine the performances and limitations of a NDT process (impact of influential parameters, qualification of UT processes)

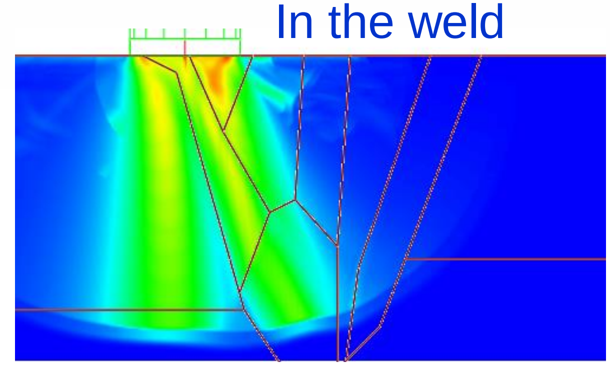
- Limitations for the UT inspection of austenitic welds in piping of primary circuit of EDF PWR plants and DCNS structures:
  - Anisotropic, heterogeneous and coarse grain structures highly disturbing UT propagation
  - Beam deviation, division and attenuation



Outside the weld



In the weld



The MOSAICS project

- Duration: 10/2011 – 01/2015
- Supported by French National Research Agency
- 6 partners : EDF – DCNS – CEA – EXTENDE – Aix-Marseille University– INSA de Lyon

- Objective: development and validation of numerical codes to predict the ultrasonic propagation in austenitic welds for a reliable NDT diagnosis

  → Development and validation of modelling tools used for ultrasonic testing of austenitic welds in 3D configurations

    - Finite element code ATHENA 3D

    - CIVA semi-analytical models : continuously varying model

The CIVA dynamic ray tracing model

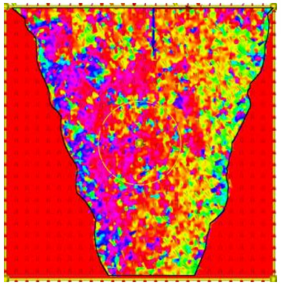
- Method of paraxial rays in an anisotropic and gently inhomogeneous medium

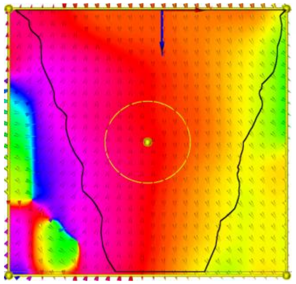
- Weld described as a grain orientation mapping
  - Obtained with the Orientation J plug-in of the Image J software (EPFL)
  - Determines the orientation of every pixel of an image
  - Orientation imaging displayed on [−90°, 90°] interval

- Smoothing filter (Gaussian function) characterized by its standard deviation σ associated with the wavelength λ
- Spatial decimation can be performed to reduce the loading time of the mapping

To be defined before calculation

Before smoothing and decimation

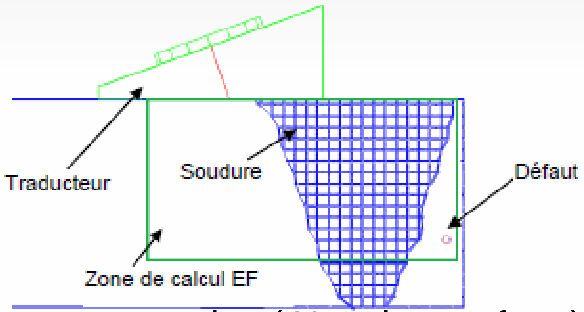




After smoothing and decimation

The ATHENA code

- FE code based on solving elastodynamic equation in the calculation zone expressed in terms of stress and velocities of displacements
- Modelling of the entire ultrasonic testing chain: specimen, probe, and defect
- Discretization:
  - Calculation domain: Cartesian regular 3D mesh
  - Defects : fictitious domains method (separate mesh)



- Grain orientation mapping:
  - Grid made of 2mm side squares
  - Measurements of columnar grain orientations by macrograph image processing (Hough transform)
- Attenuation problem reflecting the phenomenon of grain boundary scattering implemented in 2D and development for the 3D version; in progress
- 3D version validated in isotropic and homogeneous medium *(C. Rose, ATHENA 3D : A finite element code for ultrasonic wave propagation*, *IOP Publishing, Journal of Physics: Conference Series 498 (2014)*)

Objective of the study

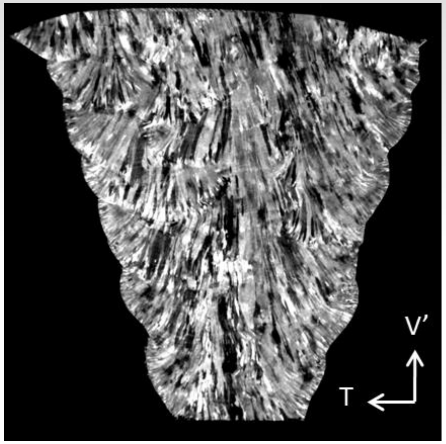
- Validation of CIVA dynamic ray tracing model and of the ATHENA 3D code
  - Analysis of the amplitude before and after weld crossing for different calibration defects:
    - Side Drilled Holes (SDH)
    - Backwall breaking notches

- 2 application cases :
  - EDF application: anisotropic V-shape weld with orthotropic symmetry
  - DCNS application: primary safety valve nozzle (not presented today)

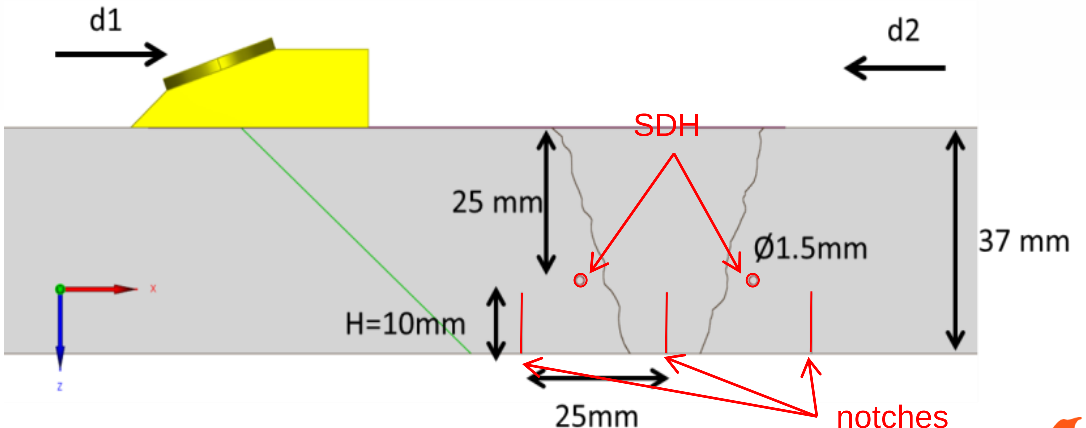
EDF application case: V-shaped weld

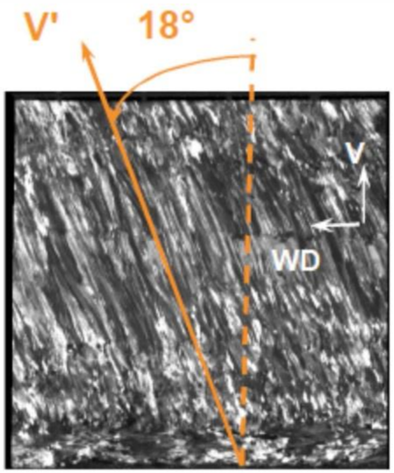
- Austenitic stainless steel grade 316 L weld realized with SMAW in vertically upward position
- Anisotropic material with orthotropic symmetry :

$$\rho = 7.85.10^3\ kg.m^{-3}\ \ et\ \ C_{ij} = \begin{pmatrix} 247 & 110 & 148 & 0 & 0 & 0 \\ 110 & 247 & 148 & 0 & 0 & 0 \\ 148 & 148 & 218 & 0 & 0 & 0 \\ 0 & 0 & 0 & 105 & 0 & 0 \\ 0 & 0 & 0 & 0 & 105 & 0 \\ 0 & 0 & 0 & 0 & 0 & 80 \end{pmatrix}$$



- V bevel of 37 mm thickness
- Average grain tilt estimated to 18° along the welding direction (WD axis)





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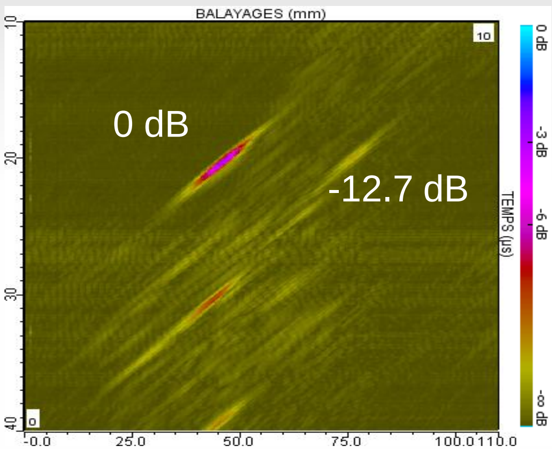
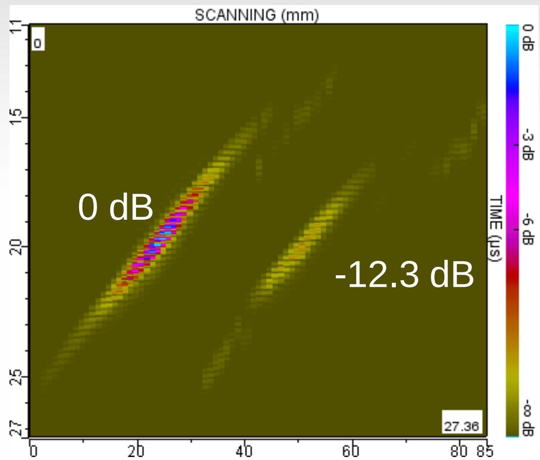
SDH validation results

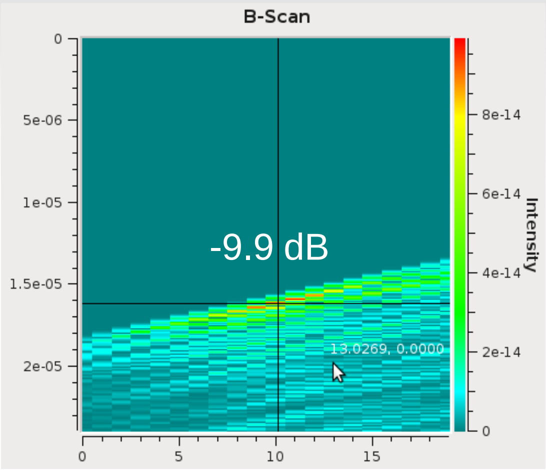
Experiment



CIVA CV (with attenuation)



ATHENA 3D



σ = 4 mm
Decimation = 3 mm

Values chosen in order to minimize the discrepancy between experimental and modelling results in d1 and d2 directions for SDH defects.

	Experiment (dB)	Civa (dB)	ATHENA 3D (dB)
Direction d1	-12.7 ± 0.6	-12.3	-9.9
Direction d2	-9.3 ± 0.7	-8.1	-3.8

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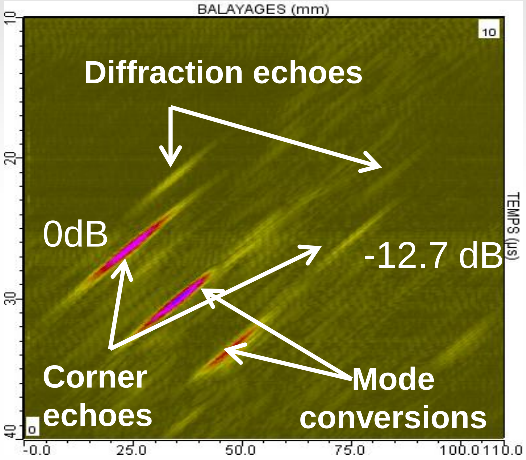
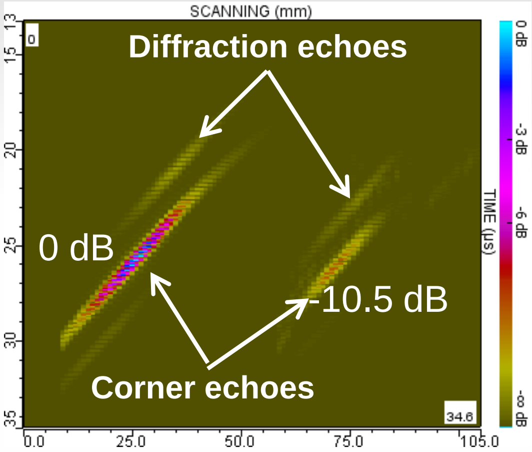
Validation results on notches

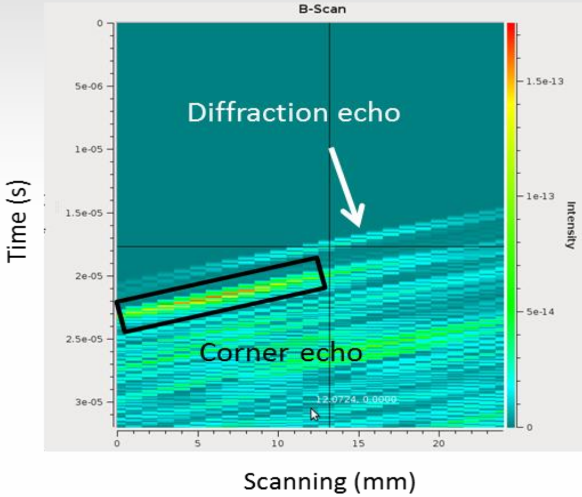
Experiment



CIVA CV (with attenuation)



ATHENA 3D



σ = 4 mm
Décimation = 3 mm

	Experiment (dB)	Civa (dB)	ATHENA 3D (dB)
Direction d1	-12.7 ± 0.6	-10.5	-7.9
Direction d2	-10.6 ± 0.9	-7.8	-5.9

- CIVA : simulated results in good agreement with experimental ones
- ATHENA :
  - Prediction of scattering at each domain interface but underestimation of attenuation and overestimation of noise
  - New calculations with 3D attenuation model using INSA characterization work to be performed
  - Specific study to be carried out on the reproduction of coarse grain noise

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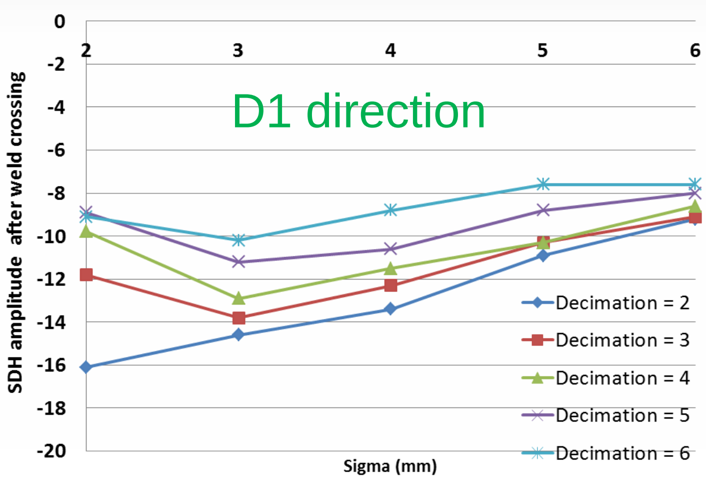
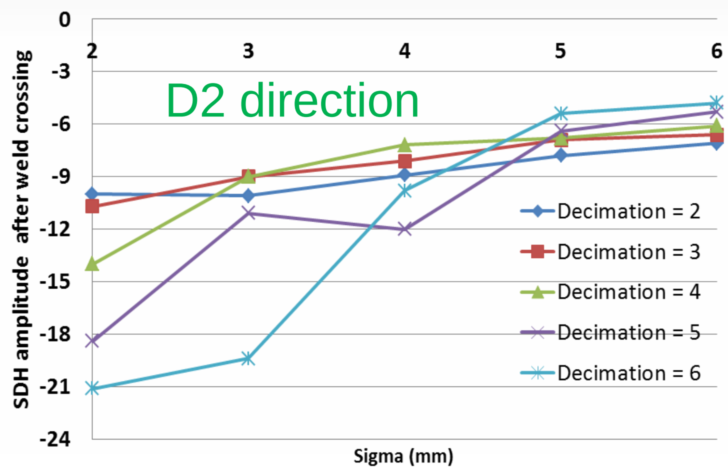
CIVA influential parameters

- In CIVA_CV : 2 variables to specify before calculation
  - The size of the Gaussian window used as smoothing filter (σ)
  - The decimation parameter

Empirical values definition





- ❑ The SDH echoes amplitude converges when σ value increases
- ❑ Amplitude not equal the one measured experimentally

- ❑ The curve evolution changes according to the direction studied
- ❑ High sensitivity of the results with the 2 parameters

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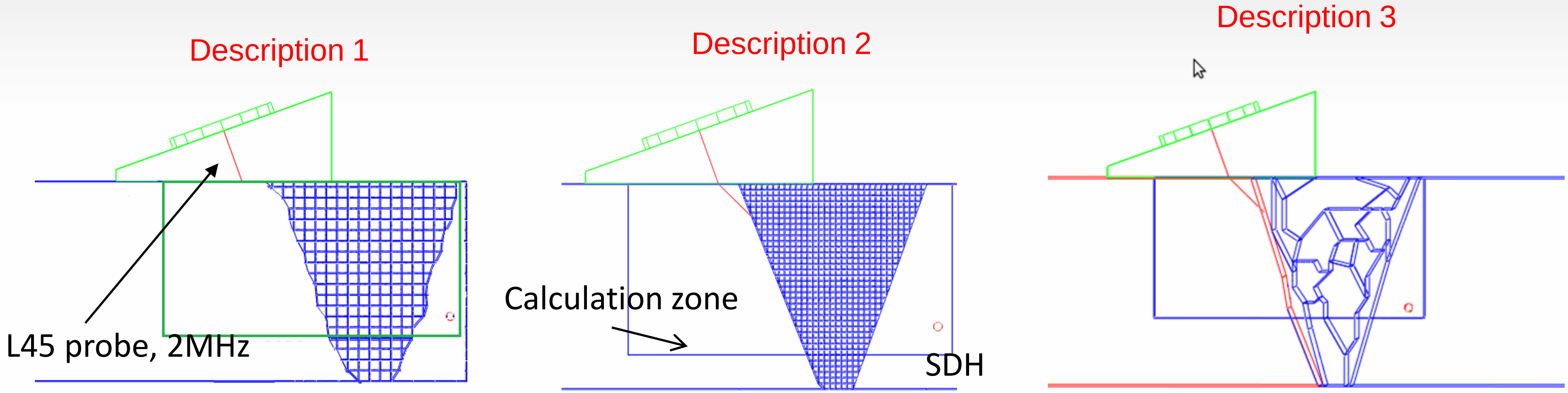
ATHENA3D influential parameters
influence of the weld grid description

- Key parameter for the UT modelling with ATHENA
- Comparison of 3 grid descriptions



	Experiment	Description 1 (2 mm grid)	Description 2 (1 mm grid)	Description 3
Defect echo amplitude (dB)	-12.5	-11.0	-7.0	-3.5
Structural Noise amplitude (dB)	-23.0	-11.0	-12.0	-18.0
SNR (dB)	11.5	0.0	5.0	14.5

Significant influence of the weld description on the FE modelling results in terms of echo amplitudes and noise level

ATHENA3D influential parameters
influence of C_{ij} elastic constants

- C_{ij} coefficients describe the anisotropy degree of the weld
- Difficult to measure accurately
- Comparison of 2 sets of anisotropic constants with 2mm-square grid

	C_{11}	C_{22}	C_{33}	C_{23}	C_{13}	C_{12}	C_{44}	C_{55}	C_{66}
Set 1	247	247	218	148	148	110	110	110	80
Set 2	250	255	230	137	127	112	102	123	60

	Set 1	Set 2
Amplitude (dB)	-11.0	-8.5
SNR (dB)	0.0	4.0

Little changes on the C_{ij} coefficients have an impact on the amplitude and SNR.

The second set of C_{ij} describe a less anisotropic tensor.

Conclusion and outlook

- MOSAICS progress :
  - Development of simulation codes adapted to 3D configurations (any kind of anisotropy, probe, flaw)
  - CIVA_CV: No more limitations associated to highly heterogeneous structures
  - ATHENA3D: allows to deal with configurations impossible in the 2D version
  - Experiment validation
    - Different configurations of weld and defects have been evaluated with L waves only
    - Disturbances (attenuation, deviation) and influence of the structure dissymmetry predictions

- Outlook :
  - Other kind of welds and propagation modes
  - 3D attenuation model (complex elasticity constants)
  - Study on the influence of the material input data (scale of weld description, elastic constant values,…)

Thank you for your attention !