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Modelling the microstructure of austenitic thick welds to improve their ultrasonic testing

Marie-Aude PLOIX, Cécile GUEUDRÉ, Joseph MOYSAN, Gilles CORNELOUP

marie-aude.ploix@univ-amu.fr



laboratoire «mécanique» «acoustique»

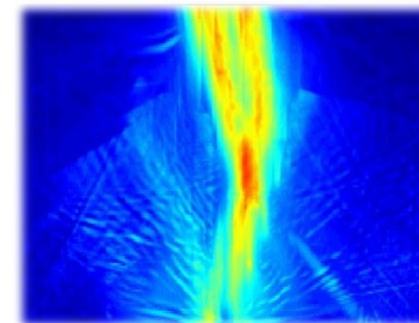
<http://www.lma.cnrs-mrs.fr/>



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ITPA ITER

Octobre 2022

<http://www.lma.cnrs-mrs.fr/>

- **LMA** = Research Unit of **CNRS** (UMR 7031)
attached to Aix-Marseille University (**AMU**), and the Ecole Centrale de Marseille (**ECM**)
- About **130 people**:
 - ⇒ 90 permanent staff (researchers, lecturers, engineers, assistant engineers and technicians)
 - ⇒ About 40 doctoral students



2 sites: Marseille & Aix-en-Provence

Brief overview of the laboratory and the NDT issue

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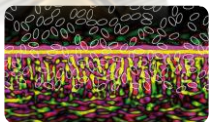
- Divided in **3 teams**:



⇒ Materials and Structures



⇒ Sounds



⇒ **Waves and Imaging** →

Medical US

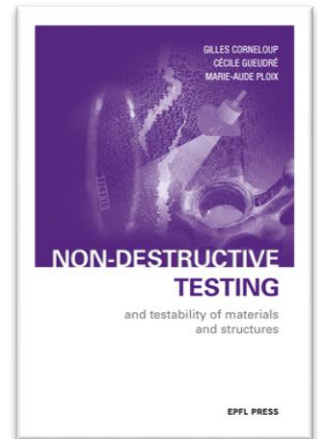
Seismic

*NDT&E
in aeronautics*

*NDT&E
in civil engineering*

*NDT&E
in nuclear industry*

Underwater acoustics

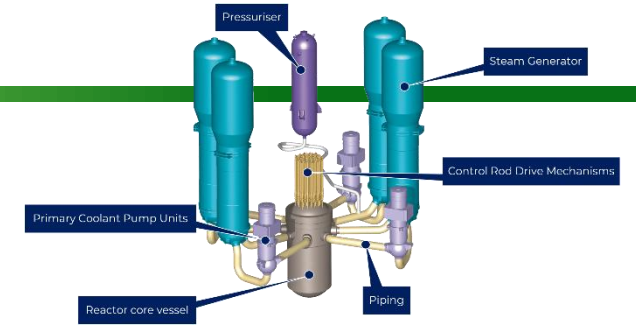


US, EC, RX etc.

Non-Destructive Testing and Evaluation issue

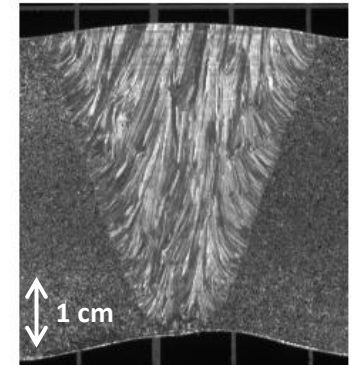
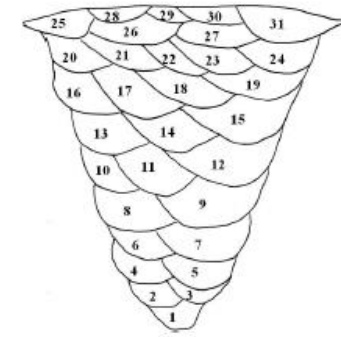
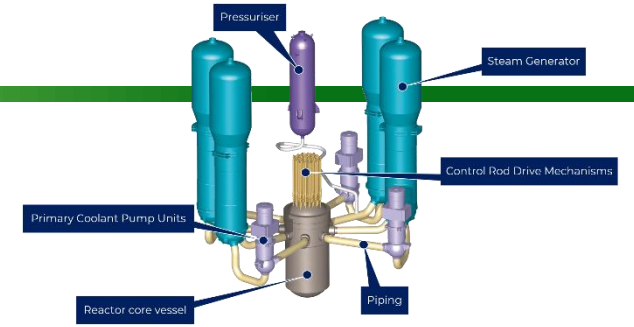
Context of austenitic thick welds

- Non-Destructive Testing (**NDT**) by **ultrasonic** method of piping in current generation nuclear power plants (REP and EPR) and future ones (RNR-Na etc.)
- Industrial objective: **detect and characterize potential defects**



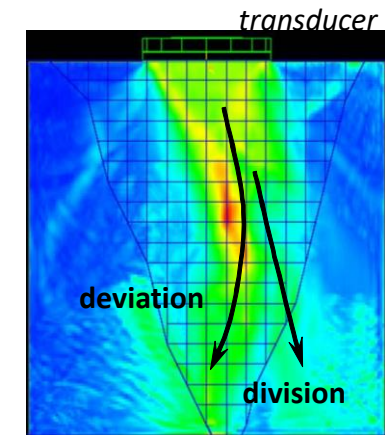
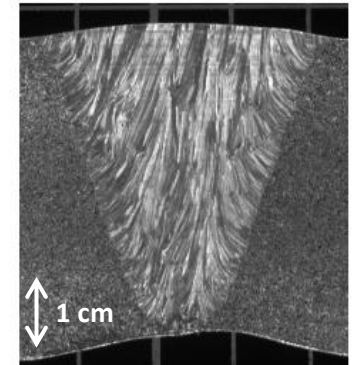
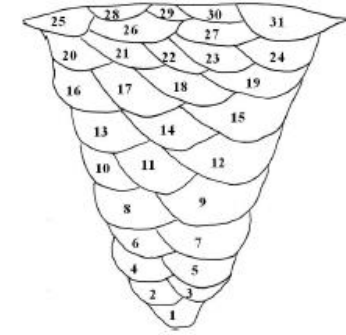
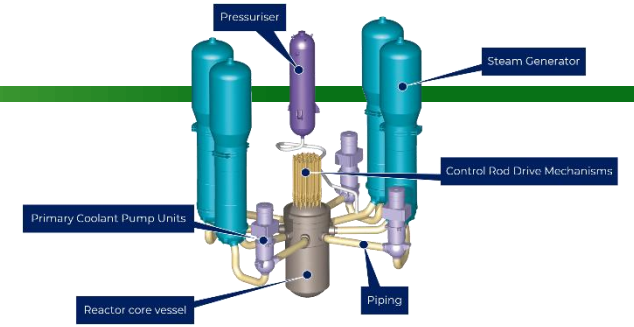
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 - ⇒ **Anisotropic and heterogeneous** structures



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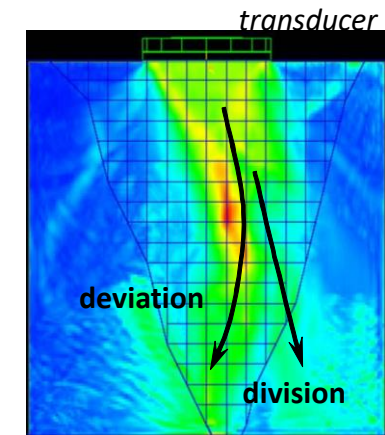
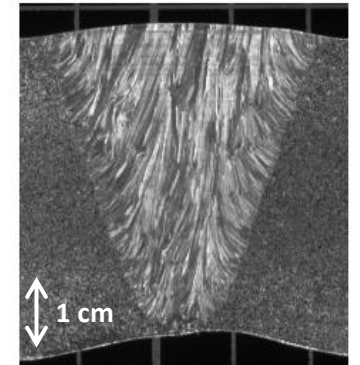
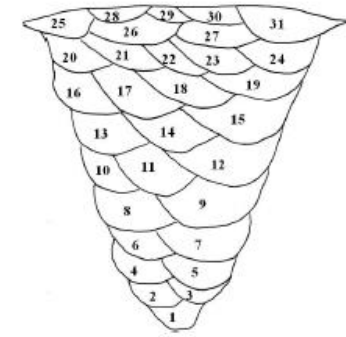
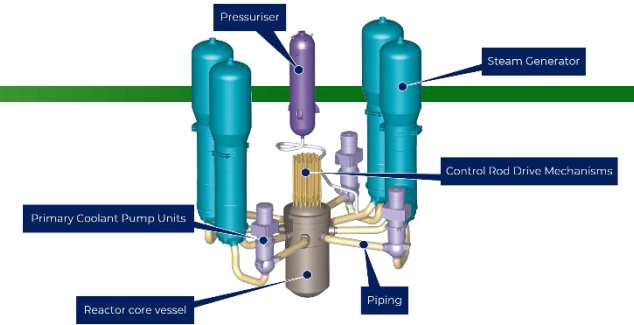
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 - ⇒ **Columnar grains**, with thermal-dependent growth
 - ⇒ **Anisotropic and heterogeneous** structures
- Complex ultrasonic propagation: **beam deviation, splitting and attenuation**
- **Difficult interpretation and therefore difficult diagnostic**

⇒ **Need to model the microstructure, to predict the propagation thus make the testing and diagnostic reliable**

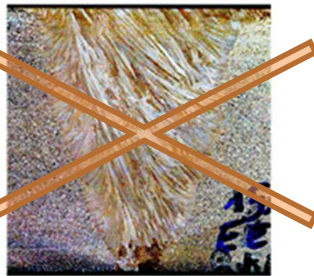


- MINA: Modelling anisotropy from Notebook of Arc welding

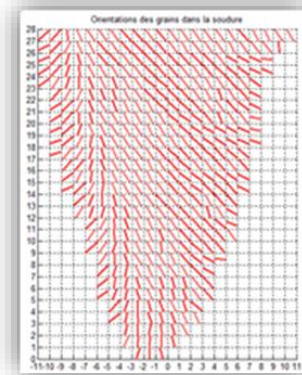
Developed since the 2000s, initially with EDF and Naval Group, and more recently with CEA

Phenomenological modeling providing a **realistic description of the microstructure** from the available data, written in the **welding notebook**

Destructive characterization (cutting and etching)



Knowledge of the crystalline structure



MINA modelling

human-machine interface

Définition complète de la soudure et des paramètres du modèle
 Visualisation du résumé de la géométrie et de la description des couches de la soudure
 Lancement du calcul
 Sauvegardes et exportations du résultat
 Comparaison du résultat avec une autre matrice d'orientation de grains (issue de MINA, ou d'une micrographie...)
 Visualisation du résultat en terme d'orientations des grains dans la soudure



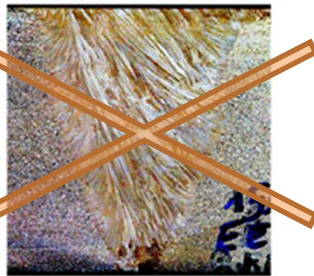
Provided solution: MINA model

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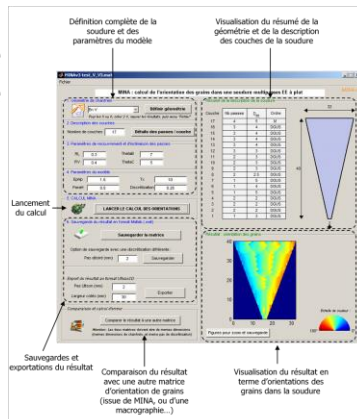
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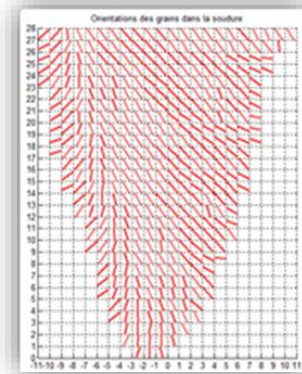
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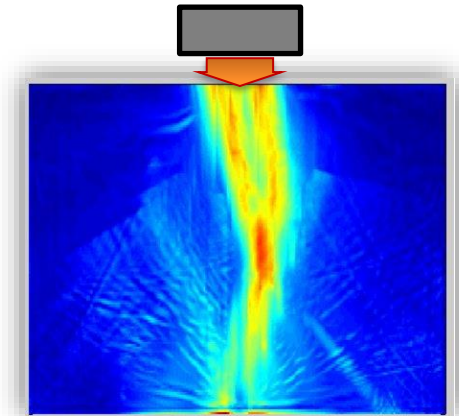
MINA modelling



Knowledge of the crystalline structure



Modelling of the ultrasonic propagation



+ 4 elasticity constants C_{ij}
(orthotropic 2D, and rotation of the matrix in each mesh)

with any propagation code (finite elements, ray tracing etc.)

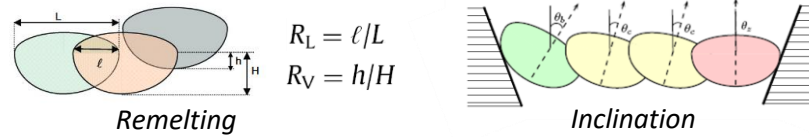
Here: EDF finite element code named ATHENA

human-machine interface

Principle of MINA model (developed for SMAW and GTAW processes)

- Input data:

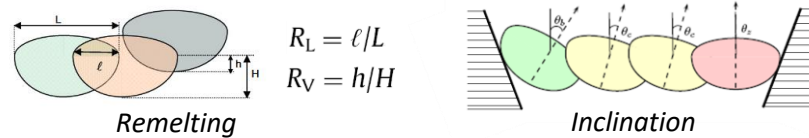
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- ✓ Solidification parameters specific to the process



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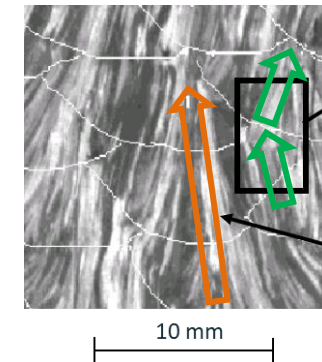
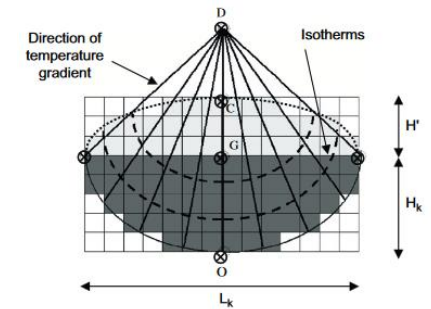
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Algorithm:

- ✓ Calculation of the local direction of the temperature gradient
- ✓ Solidification mechanisms: epitaxy and selective growth



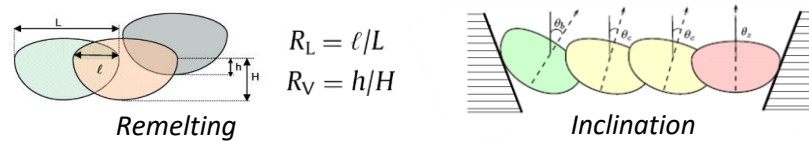
abrupt change of orientation

grain going through several passes

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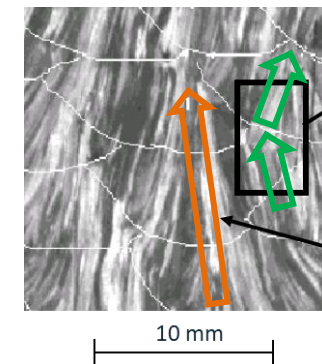
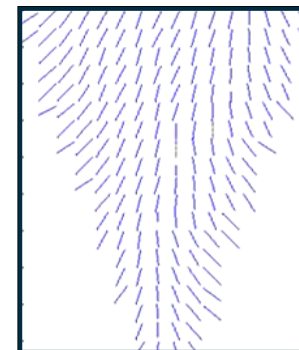


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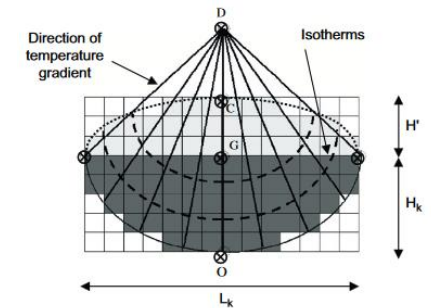
Output data:

- ✓ **Local orientation of the grains, with a mesh size smaller than one pass**



abrupt change of orientation

grain going through several passes



Determination of C_{ij} for ultrasonic modelling

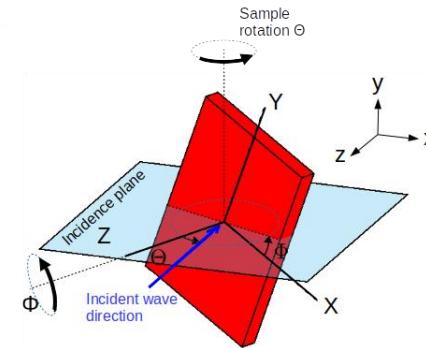
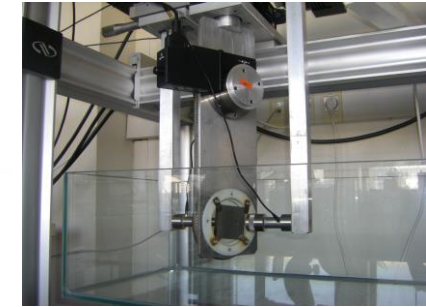
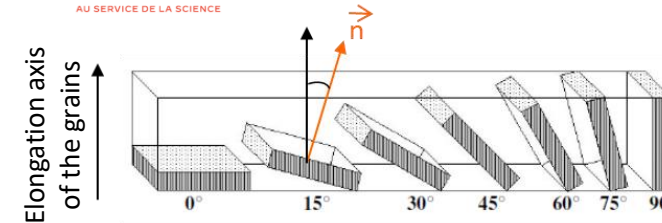
- Two possibilities :
 - ⇒ Take values from the **literature**
 - ⇒ **Measurement**



Determination of C_{ij} for ultrasonic modelling

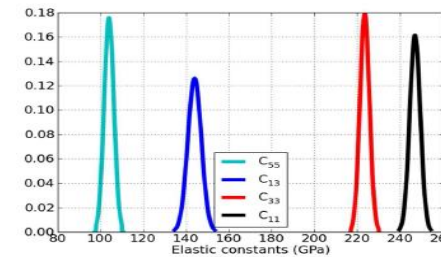
Two possibilities :

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- ⇒ **Measurement** (performed by P. Guy, LVA, INSA Lyon):
 - ✓ 7 homogeneous and orthotropic samples
 - ✓ Velocity measurements of longitudinal and shear waves, in \neq planes, with \neq incidences
 - ✓ Determination of the real (and imaginary) parts of C_{ij} through inversion method



	C_{11}	C_{33}	C_{13}	C_{55}
Mean value	242.9	230.9	142.9	110
Standard deviation	18.2	8.2	6.2	5.5

(GPa)



Optimized procedure ⇒ weak uncertainties

Determination of C_{ij} for ultrasonic modelling

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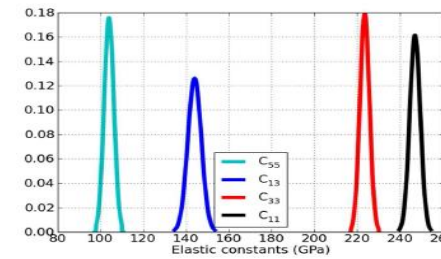
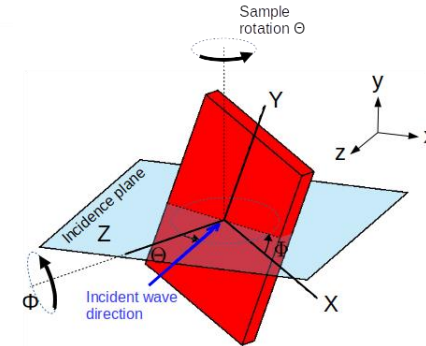
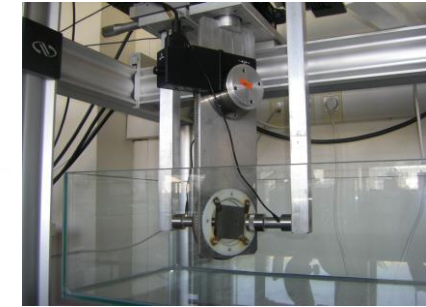
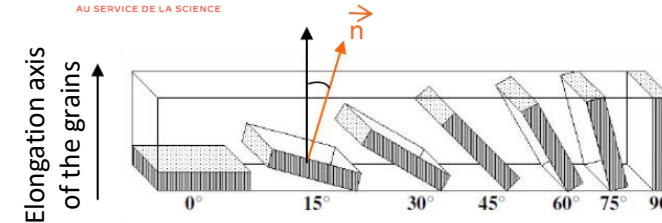
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Optimized procedure ⇒ weak uncertainties

- Whatever the chosen option, values present **uncertainties**

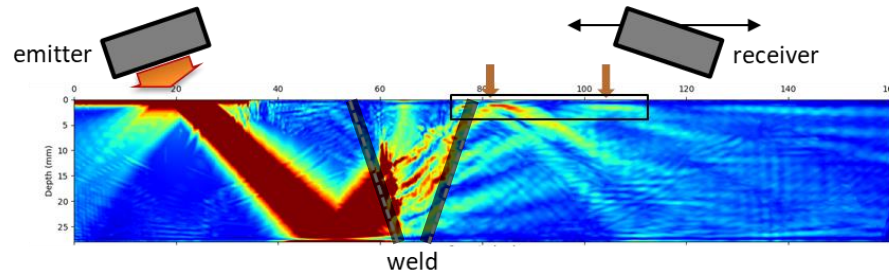


Influence on ultrasonic simulation?

- Examples of significant results:

(industrial configuration: tandem mode with oblique incidence)

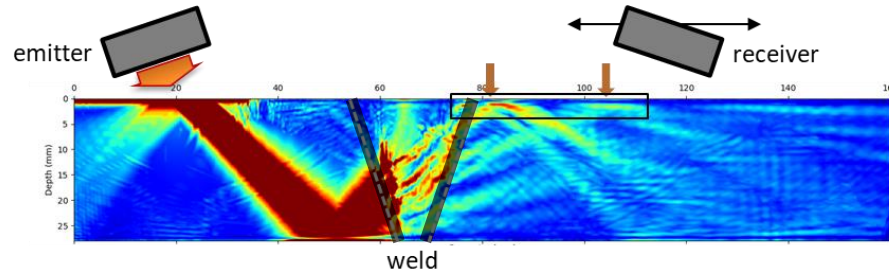
- 1 A C_{ij} variation of a few % can strongly modify the position of the amplitude maximum (beam splitting + weak variation of amplitude \Rightarrow jump of maximum position)



Influence of the Cij uncertainties on the ultrasonic modelling

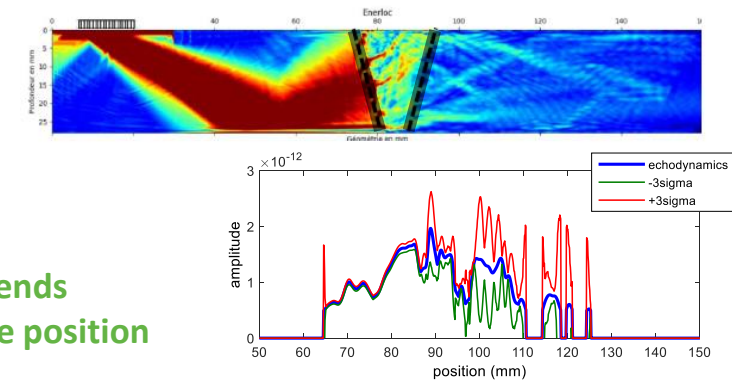
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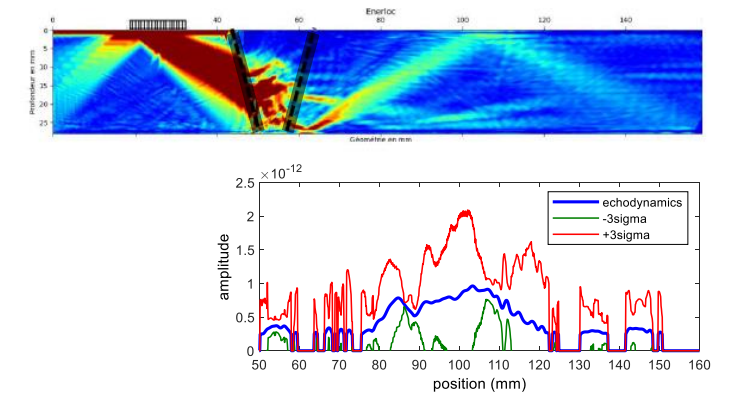


② The impact on modeling depends strongly on the position of the emitter

Emitter at 75mm from the weld axis



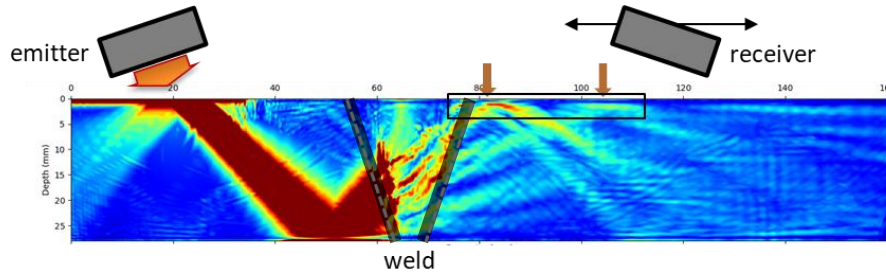
Emitter at 30mm from the weld axis



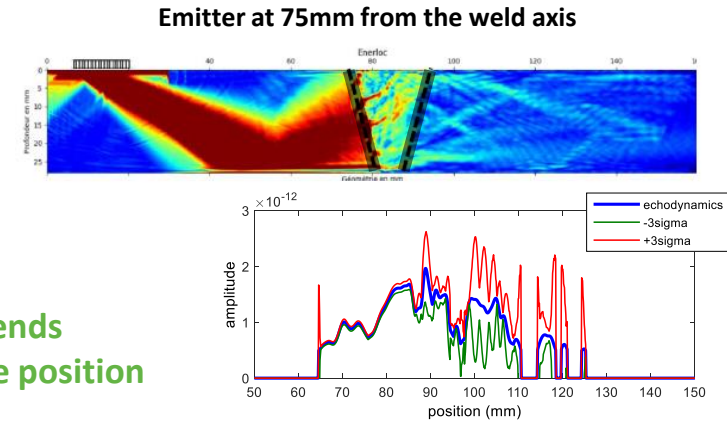
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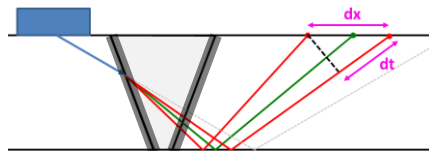
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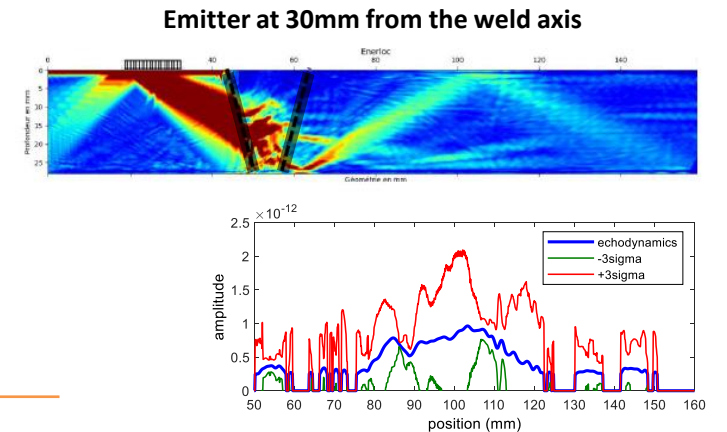
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③ The impact on modeling depends strongly on the testing configuration: as expected, L waves are less sensitive to Cij uncertainties than S waves



Configuration	S60	S45	L45 / LL	L45 / LS
dx maxi	35 mm	30 mm	4 mm	10 mm
dt maxi	11 μ s	8 μ s	0,3 μ s	1,3 μ s



⇒ Developed tool allows to anticipate and choose the best NDT configuration (position, angle etc.)

- Work for about twenty years to **improve knowledge of thick welds** with the purpose of **improving their Non-Destructive Testing: detect, localize and size defects**

Some references :

Moysan et al., 2003, "Modelling the grain orientation of austenitic stainless steel multipass welds to improve ultrasonic assessment of structural integrity", *Int. J. Press. Vess. Pip.*, [10.1016/S0308-0161\(03\)00024-3](https://doi.org/10.1016/S0308-0161(03)00024-3)

Gueudré et al., 2009, "Direct model optimisation for data inversion. Application to ultrasonic characterisation of heterogeneous welds", *NDT&E Int.*, [10.1016/j.ndteint.2008.07.003](https://doi.org/10.1016/j.ndteint.2008.07.003)

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Chassignole et al., 2011, "Application of Modelling for Enhanced Ultrasonic Inspection of stainless steel welds", *Weld World*, [10.1007/BF03321310](https://doi.org/10.1007/BF03321310)

Ye et al., 2012, "Influence of welding passes on grain orientation - The example of a multi-pass V-weld", *Int. J. Press. Vess. Pip.*, [10.1016/j.ijpvp.2012.02.007](https://doi.org/10.1016/j.ijpvp.2012.02.007)

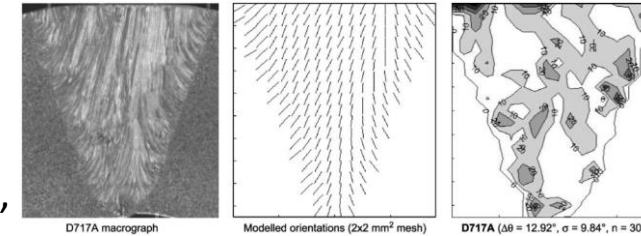
Ploix et al., 2014, "Measurement of ultrasonic scattering attenuation in austenitic stainless steel welds: Realistic input data for NDT numerical modeling", *Ultrasonics*, [10.1016/j.ultras.2014.04.005](https://doi.org/10.1016/j.ultras.2014.04.005)

Gueudré et al., 2019, "Influence of the uncertainty of elastic constants on the modelling of ultrasound propagation through multi-pass austenitic welds. Impact on non-destructive testing", *Int. J. Press. Vess. Pip.*, [10.1016/j.ijpvp.2019.02.011](https://doi.org/10.1016/j.ijpvp.2019.02.011)

Marsac et al., 2020, "Realistic model to predict the macrostructure of GTAW welds for the simulation of ultrasonic non destructive testing", *J. Nondestruct. Eval.*, [10.1007/s10921-020-00724-y](https://doi.org/10.1007/s10921-020-00724-y)

Corneloup et al., 2021, "Non-Destructive Testing and testability of materials and structures", 320 p., EPFL Press, ISBN 9782889154401

- Work for about twenty years to **improve knowledge of thick welds** with the purpose of **improving their Non-Destructive Testing: detect, localize and size defects**
- MINA SMAW** validated, used in the literature, and soon by industrials through CIVA platform, already commonly used by EDF



Some references :

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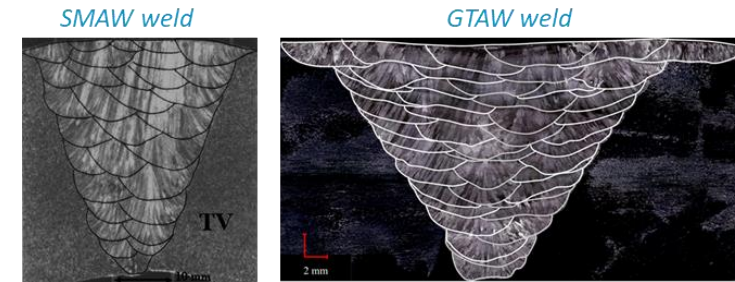
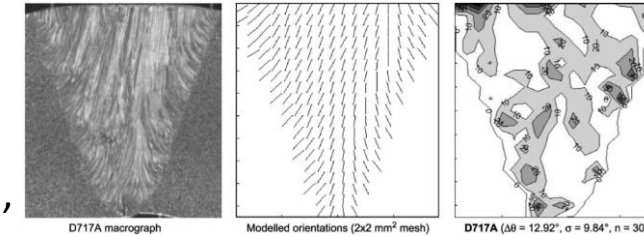
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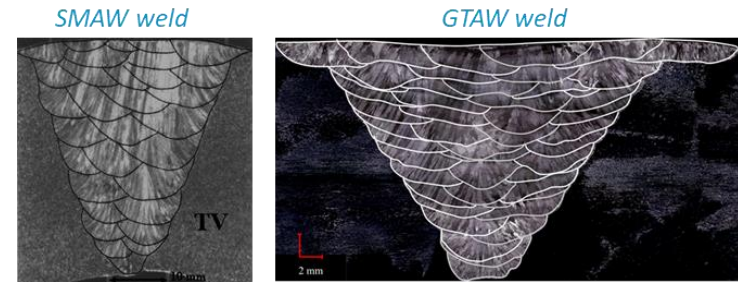
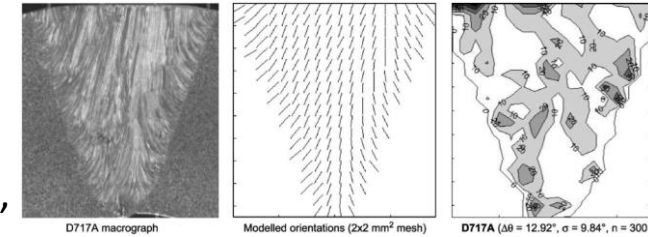
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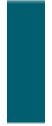
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- Complete modelling MINA + ATHENA**: efficient (with importance to take uncertainties on Cij input data into account)



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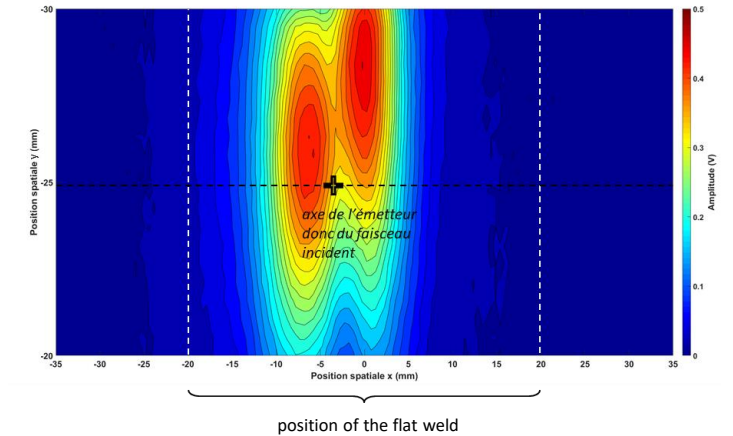
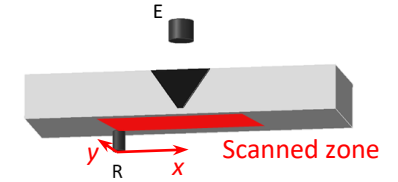
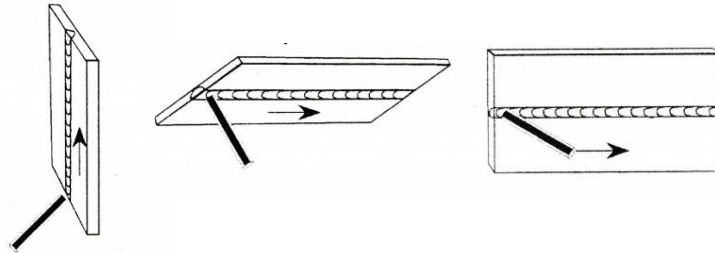
- Feedback following the integration of MINA in the CIVA platform



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- MINA 3D:**
 - 2D assumption not always sufficient in flat welding
 - position (vertical, ceiling etc.) and orbital welding

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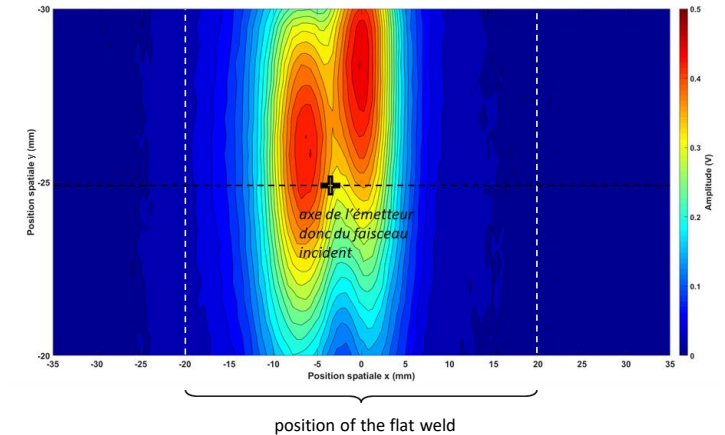
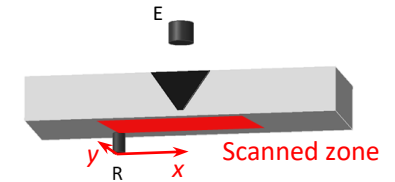
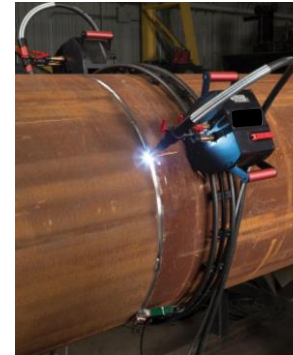
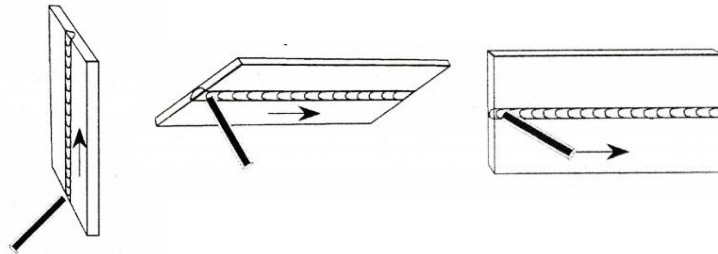
Project being
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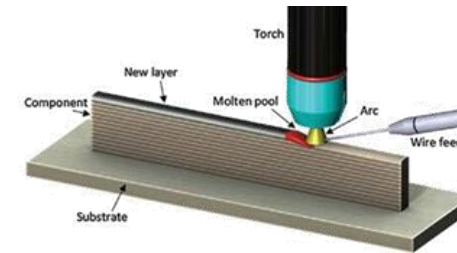
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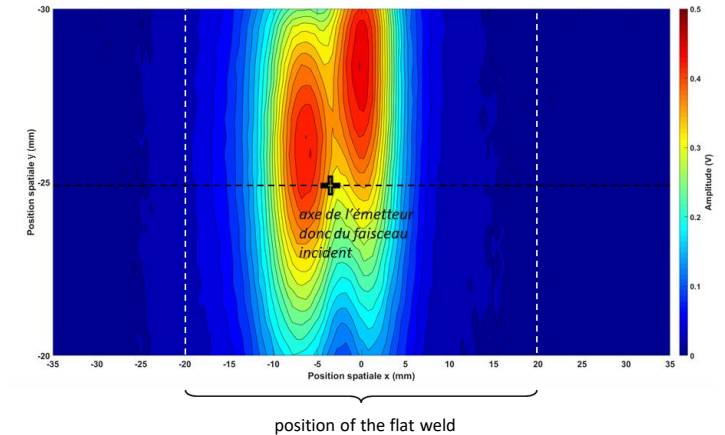
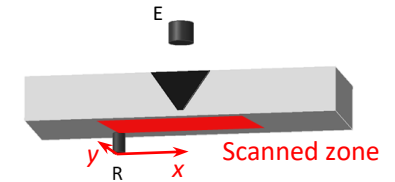
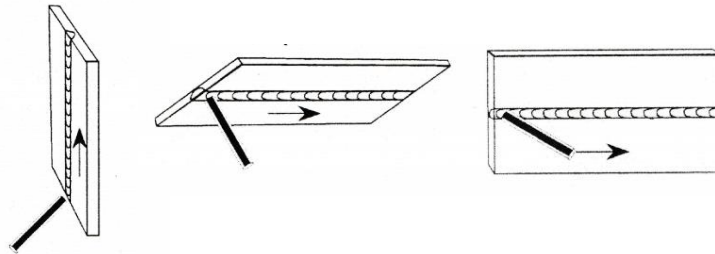


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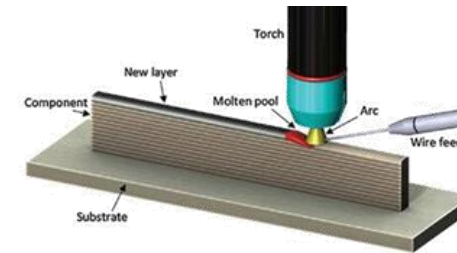
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- Notion of **“testability”** : “drive” the microstructure (prior specification) to improve and optimize the future testing



*No funding for
the moment*

Modelling the microstructure of austenitic thick welds to improve their ultrasonic testing

Marie-Aude PLOIX, Cécile GUEUDRÉ, Joseph MOYSAN, Gilles CORNELOUP

marie-aude.ploix@univ-amu.fr



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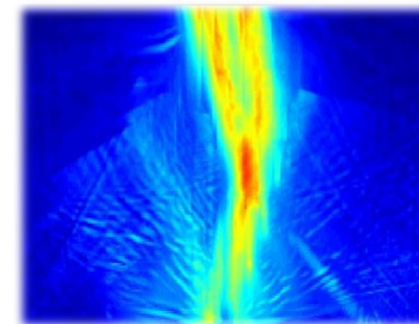
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