Presentation of *Code_Aster* ® platform

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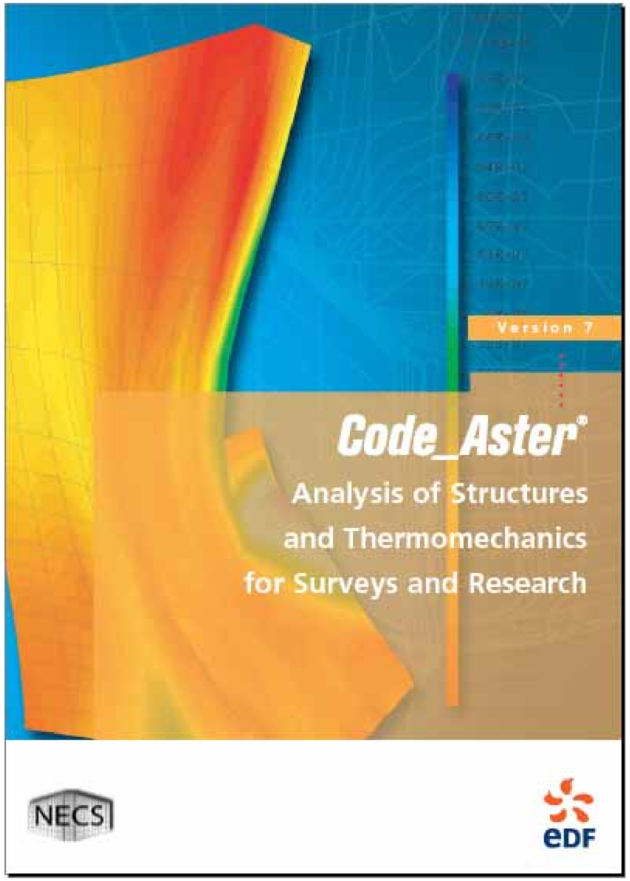

Courtesy of EDR R&D AMA department for slides

SIMDI
GÖTEBORG 2006

Features of *Code_Aster* ®

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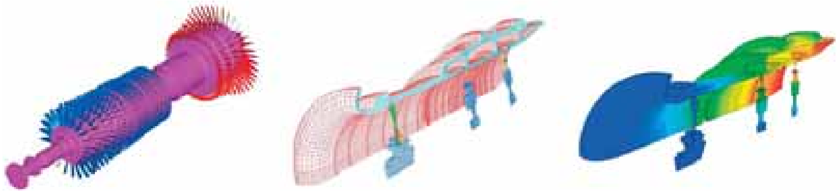
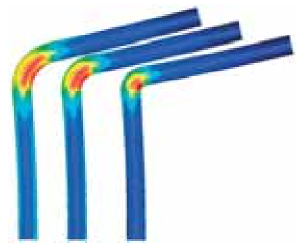
Analyses :

- Thermal mechanics
- Linear and non Linear 3D
- Static and dynamics
- Pressure instruments
- Machines
- Civil Engineering
- Porous media

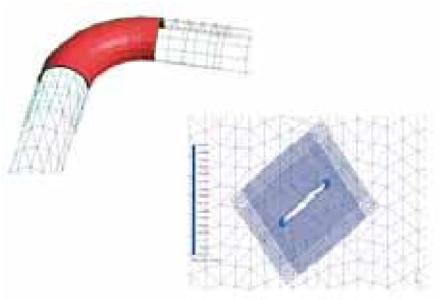


Nonlinear thermomechanical calculation of a combustion turbine compressor : bladed rotor and quartercompressor.



Optimizing the bending radius of an elbow by Gmsh-Code_Aster chaining.

RRA circuit elbow : damage calculation by the Dang Van criterion and thermal crazing.



Arlequin : connection of 3D-shell modelling on an elbow ; patch of a crack block on a healthy structure.

Code_Saturne/Code_Aster chaining on an Alstom-Velan glove valve : mesh and internal fluid pressure field.

Download and services

How to obtain the program

Official Code_Aster® website www.code-aster.org
(documents, sources, Linux GPL version, forum)

NECS website www.necs.fr
(Windows distribution, training, assistance, expertise)

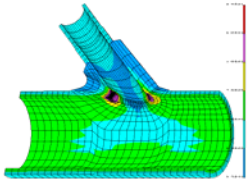
Thermal analysis

Summary

- **From welding to residual stresses :**
  - → **Which physical phenomena need to be taken into account ?**
  - → **Scheme of a thermal metallurgical mechanical analysis using *Code_Aster***
- **Functionalities for thermal computations**
  - → ***An example of a thermal analysis :***
    - o **Simulating the welding of an adapter for vessel cover**
    - o **Simulating a two layer TIG welding on plates**
- **Functionalities for thermo - metallurgical analysis**
  - → ***An example of a metallurgical analysis :***
    - o **Quench of a steel (16MND5) cylinder**
- **Functionalities for thermo – metallo – mechanical analysis**
  - → ***An example of a thermal metallurgical mechanical analysis***
    - o **Numerical simulation of a multilayer (13) welding on tube**

The origin of thermo – metallo - mechanical analysis with Code_Aster

RESIDUAL STRESSES IN FRACTURE MECHANICS OR FATIGUE



↓

DETERMINATION OF THE RESIDUAL STRESSES FOR WELDING

↓

THERMO – MECHANICAL BEHAVIOUR FOR STEEL DURING WELDING

↓

LIMITS OF THERMO - MECHANICAL ANALYSIS AND NEEDS FOR METTALURGICAL CONSIDERATIONS

Welding simulation :
Phenomena taken into account

HEAT FLOW

THERMAL LOADING and EXCHANGES
NON LINEAR BEHAVIOUR
LIQUID / SOLID STATE CHANGE
WELD POOL MOTION
Surface tension (Marangoni effect)
Electromagnetic effect

METALLURGY

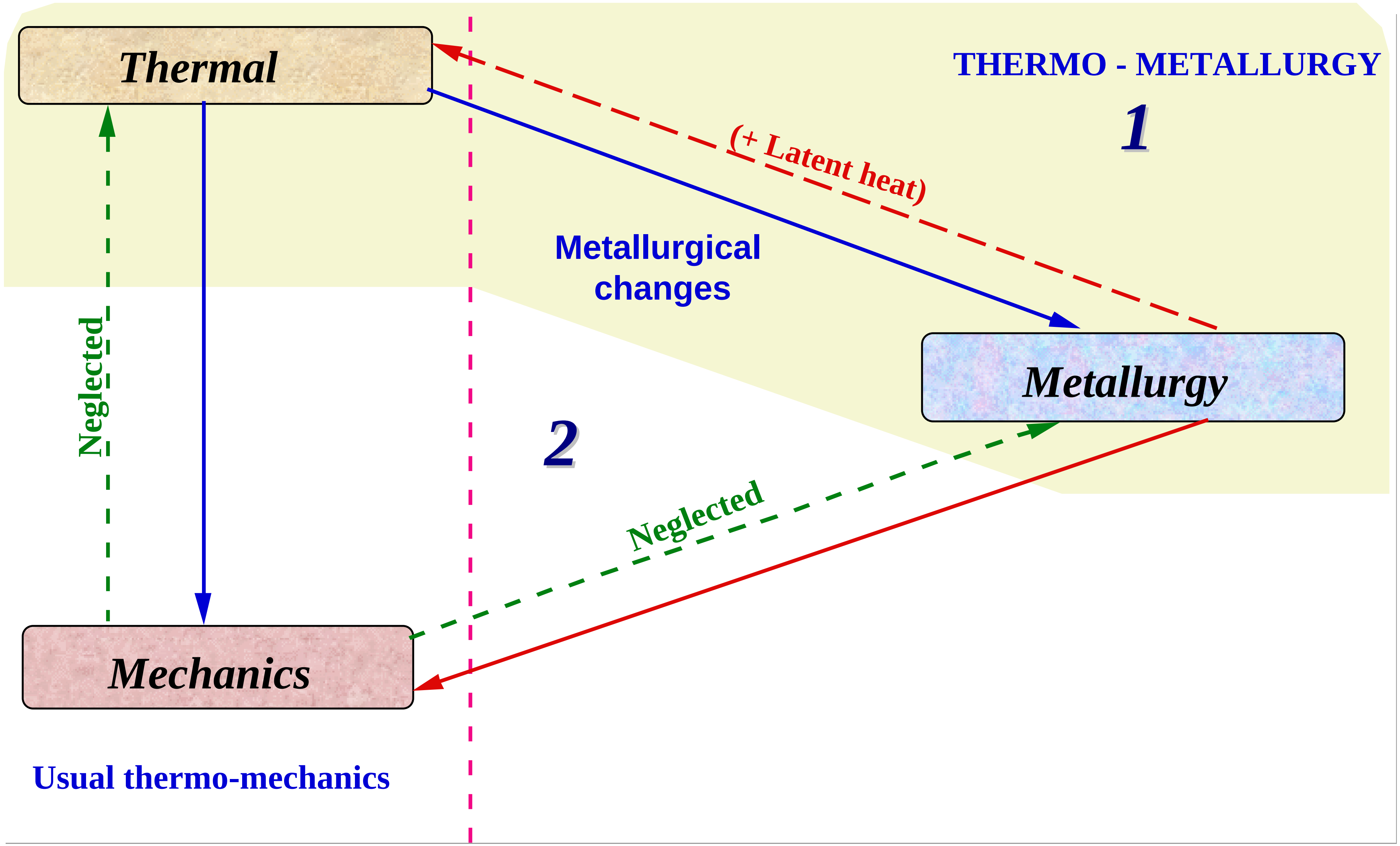
SOLID / SOLID PHASE CHANGE
(HARDNESS)
Austenitic Grain Size
Precipitation - Tempering
Carbon and Hydrogen Diffusion

Base and Deposit
Metals dilution

MECHANICS

PHASE CHANGE STRAIN
MULTIPHASED BEHAVIOUR
TRANSFORMATION PLASTICITY
METALLURGICAL HARDENING RECOVERY
CREEP and VISCOPLASTICITY
WELD POOL BEHAVIOUR

Scheme of a thermo – metallo - mechanical computation using Code_Aster



Welding simulation using Code_Aster

In a simplified way, two main phenomena need to be considered for welding:

→ **Those related to the welding process :**

- **Initiation and propagation**
  - **- of an electric arc, of a plasma of arc (welding by fusion)**
  - **- of laser rays or electrons (welding by radiation)**
- **Welding by friction - mixing (welding by pressure, STIR Welding)**

Outside the piece to be welded

→ **Those related to the effects on welded pieces :**

- **Study of the mechanical consequences**
  - ⇨ *Modelling of a simple heat (or matter) supply*

Inside the piece to be welded on the boundary

Thermal analysis

Using Code_Aster ⇨ Resolution of the heat equation only on the structures to be welded

Volumetric enthalpy

Conductivity

Volumetric heat supply from the medium

Primitive of $\rho C p \dot{T}$

$$\dot{\beta}(T) - \mathrm{div}(\lambda(T)\nabla T) = r$$

$$-\lambda \frac{\partial T}{\partial n} = \phi(T) \quad \text{ou} \quad T = T^i$$

On the boundary

Surface heat flow received by the structure

Transient analysis (linear, non linear or in a moving reference) with a steady condition

Functionalities for thermal computations

THERMAL phenomena

Material and heat supply
Solid – liquid state change
Movement of the weld pool
Electromagnetic effects
Surface tension

→ $\Delta\varphi$ *LIQUID / SOLID* : **NON LINÉARITY ON $\beta(T)$**

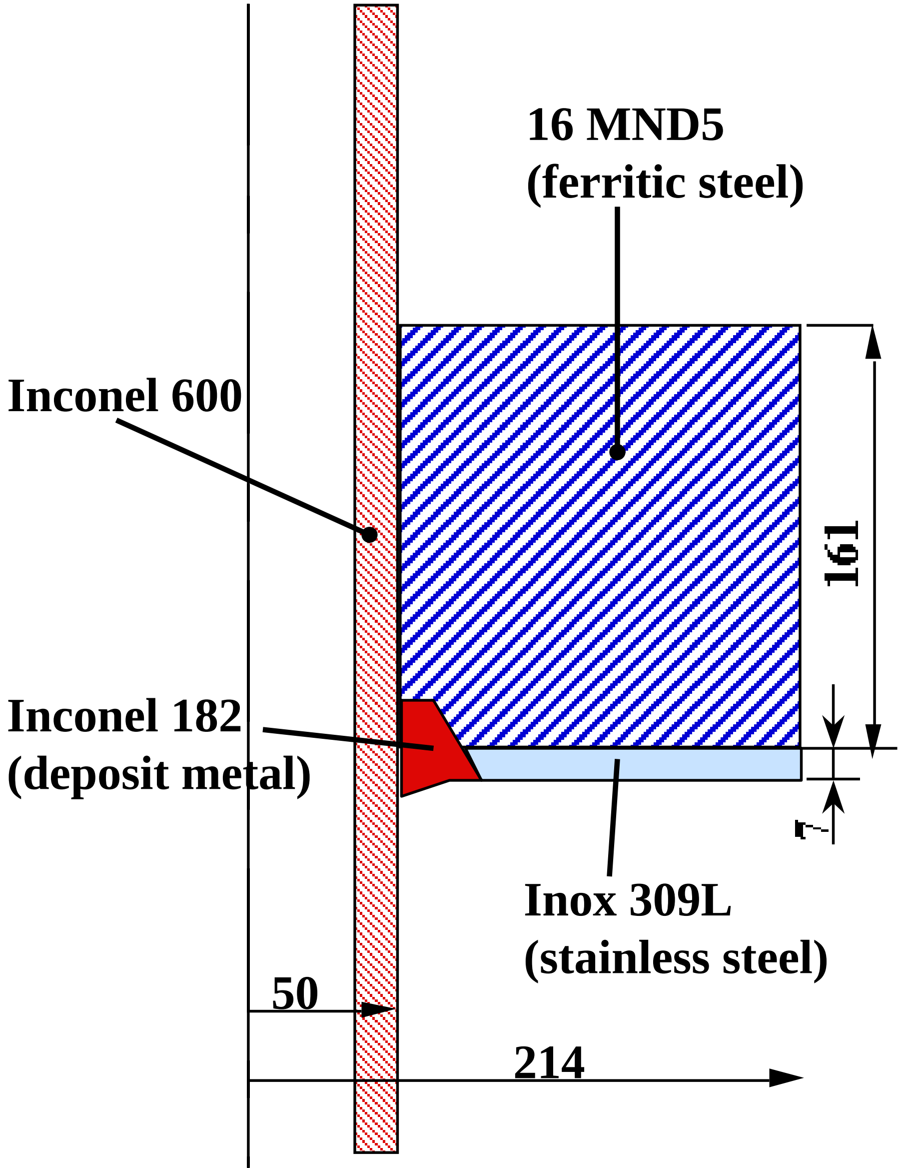
→ *WELD POOL CONVECTION :* **INCREASE OF λ OVER Tf**

→ *HEAT SUPPLY :* **JOULE EFFECT** (heat production inside the bond)
SURFACE FLOW (Φ) (arc contact at the bond surface)
VOLUME SOURCE (r)
SUBSTANCE DEPOSIT (imposed temperature = experimental one)

→ *KINEMATIC EFFECTS :*

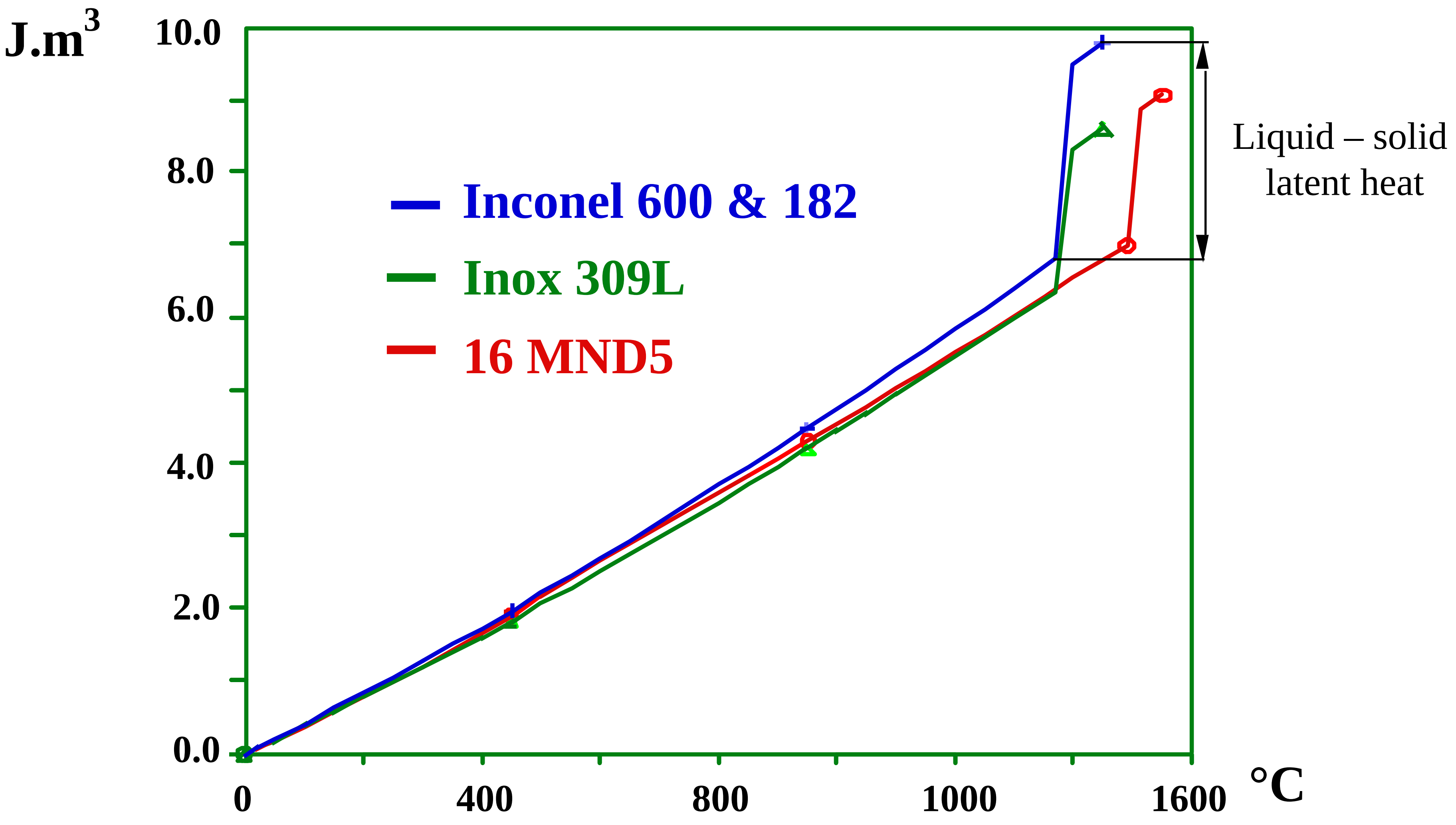
- *ϕ (t) and r(t)*
- ***BY REPRESENTING THE SUCCESSIVE DEPOSITS***
- ***STEADY NON LINEAR RESOLUTION IN A REFERENCE RELATED TO THE SOURCE***

Welding simulation of an adapter of the vessel cover

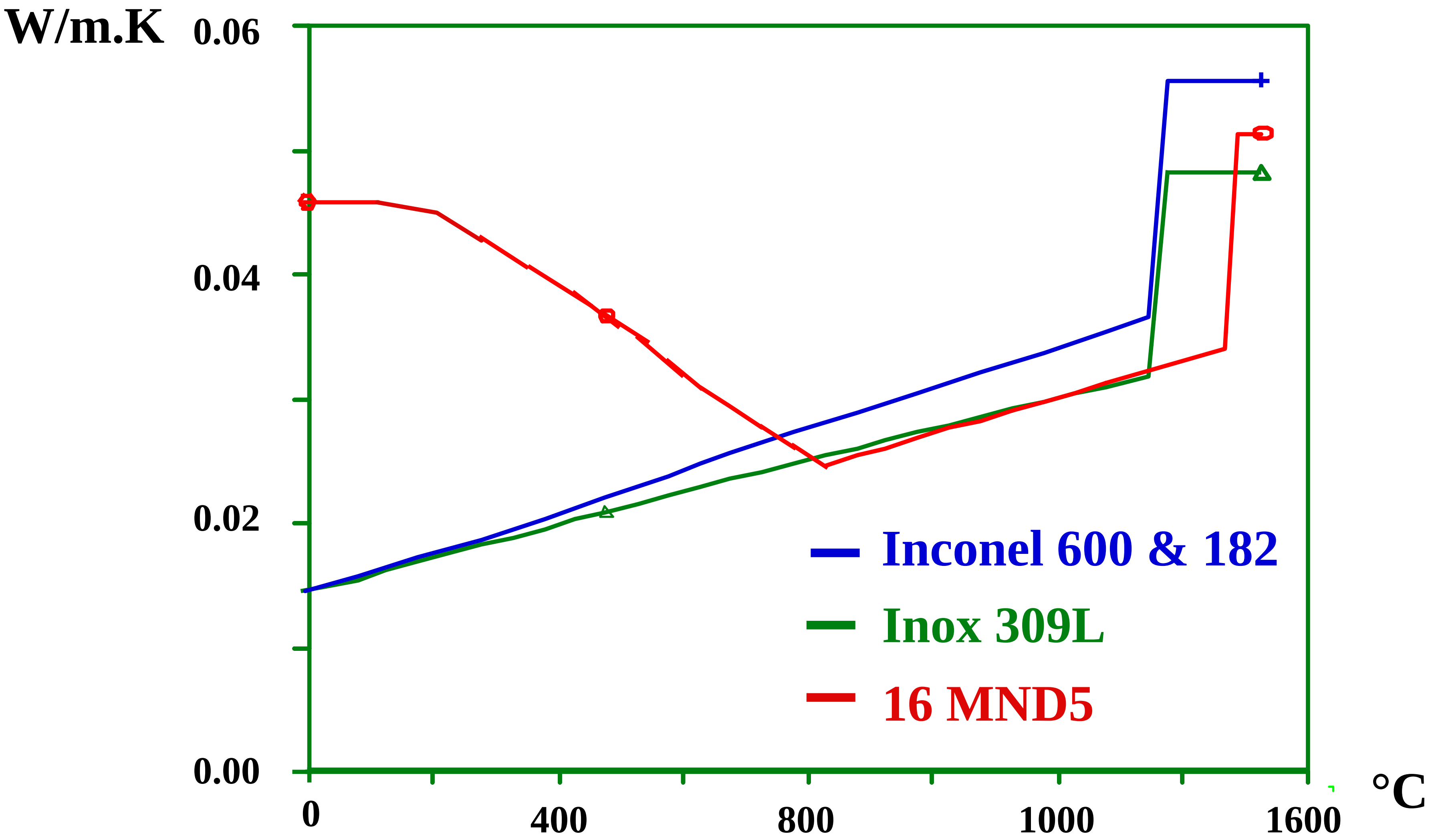


- *axisymmetric simulation*
- *1 welding layer*
- *Loading : temperature of the metal deposit (heating) imposed*
- *Non linear thermal analysis with :*
  - *liquid solid latent heat ;*
  - *«Weld pool movement » ;*
  - *Material properties = function (T°) ;*
  - *Transfer conditions : convection and radiation ;*
- *Metallurgical changes for ferritic steel during cooling and heating ;*

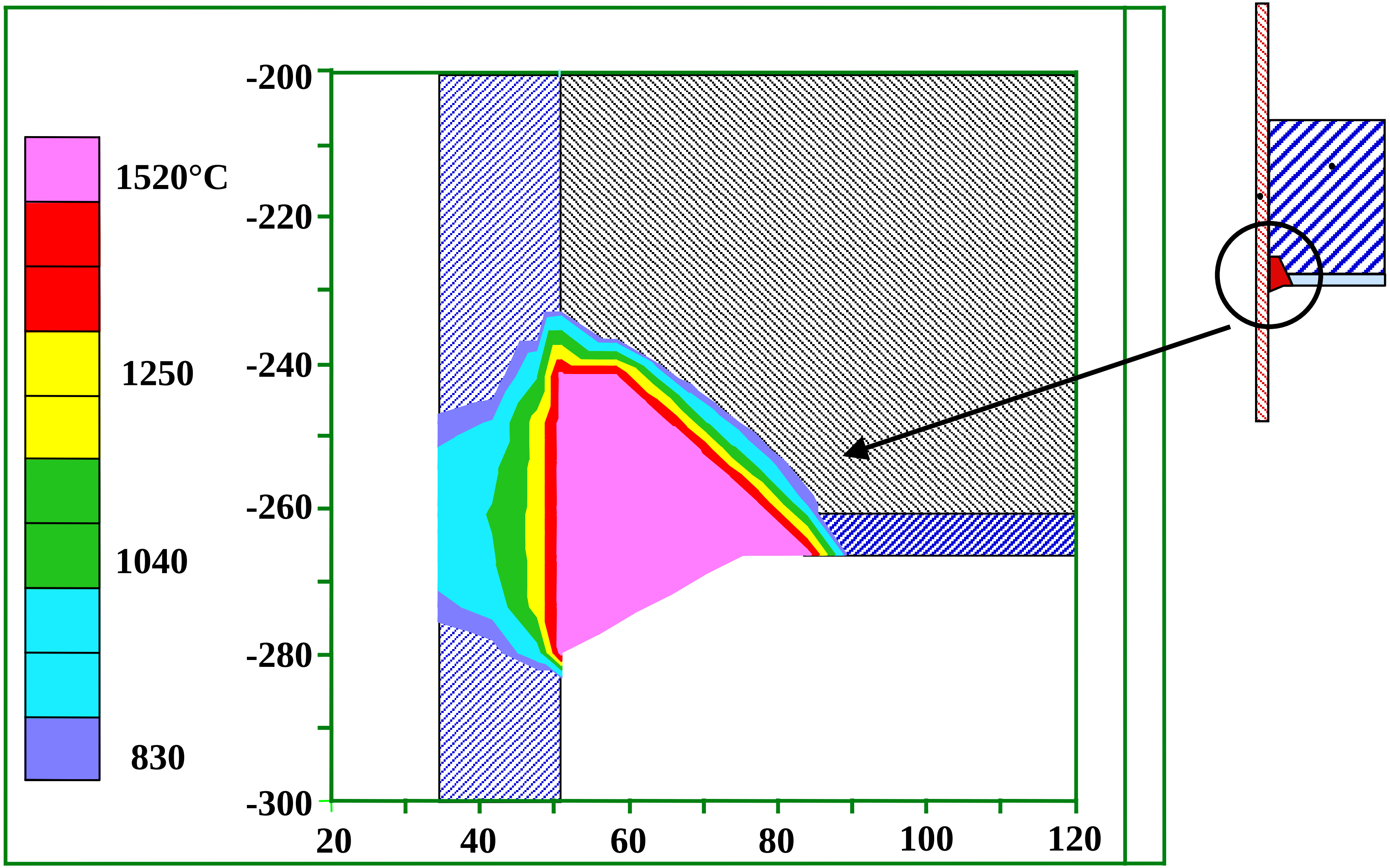
Material properties : volume enthalpy as a function of T°



Material properties : thermal conductivity as a function of T°



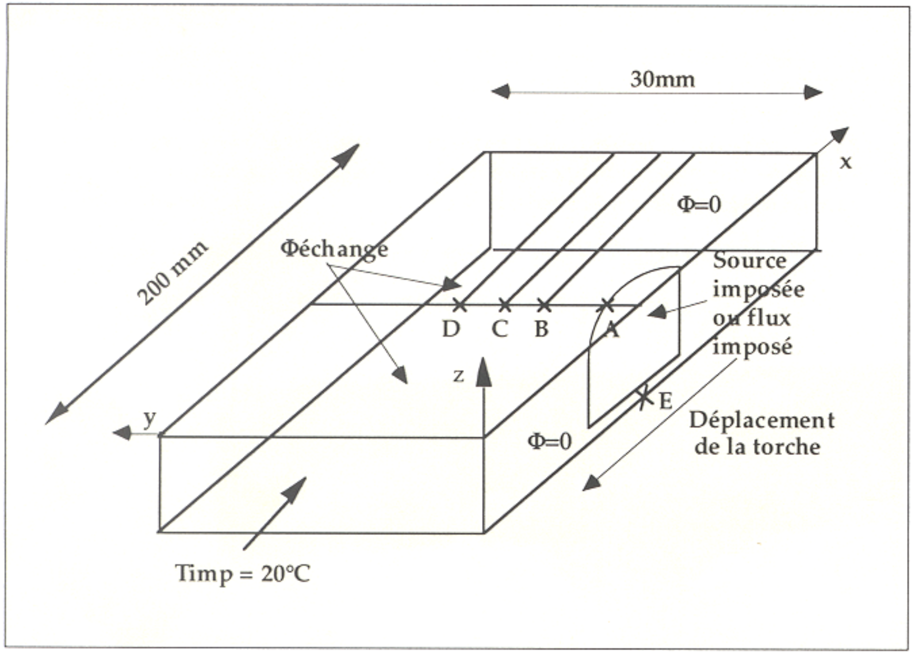
Thermally influenced zone (Tmax > 830°)



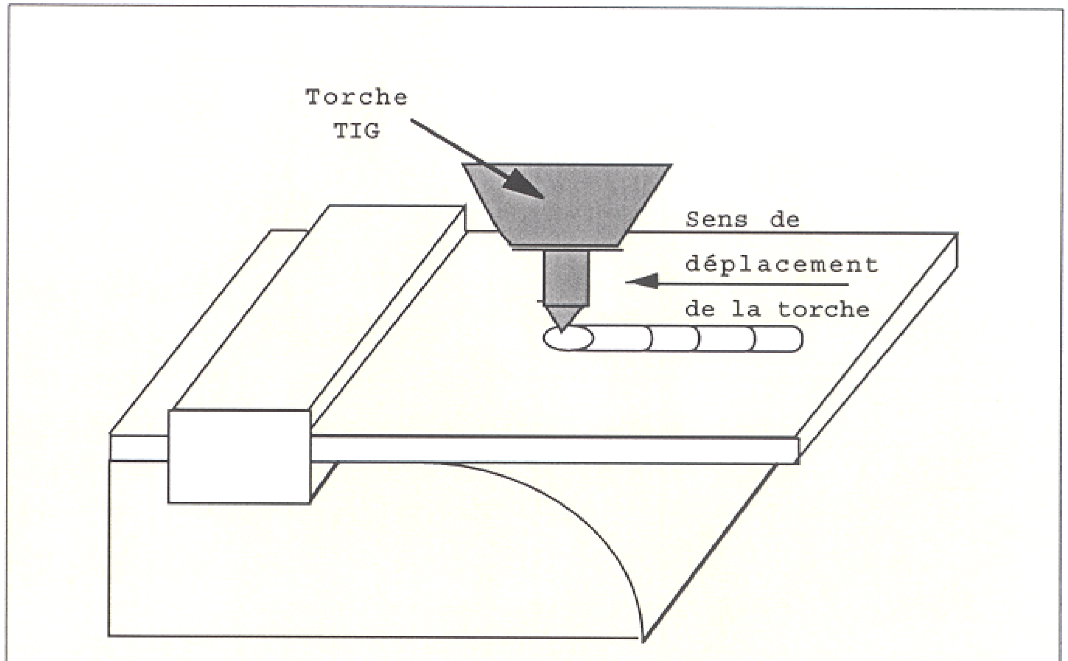
Simulation with a moving heat source (moving reference)

Weldability test ⇨ hot crack resistance of the material

Thermal problem formulated in the reference related to the source



Boundary conditions and loading



1 Essai Varestraint

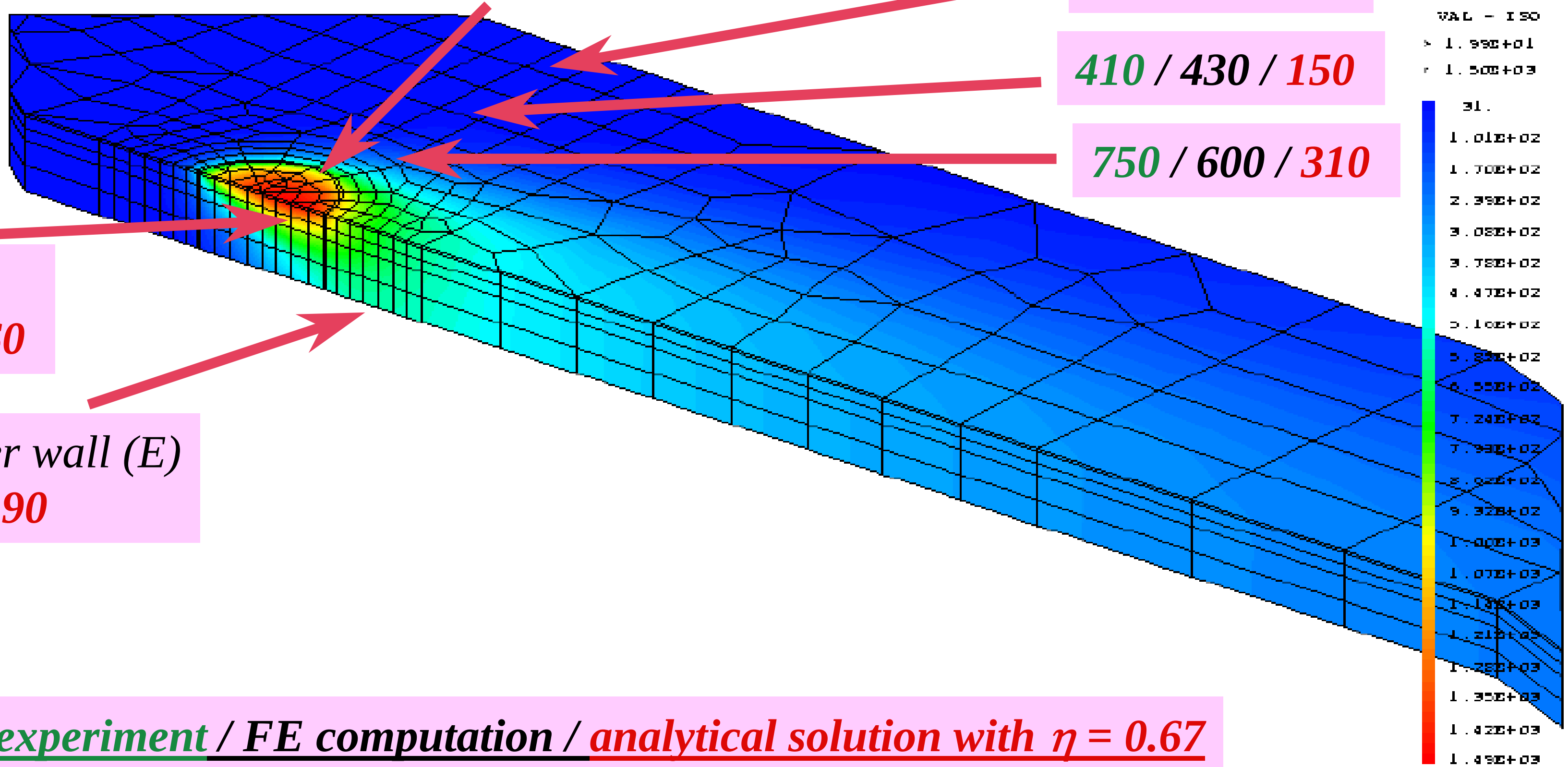
Specimen = moulding of the supplied material used for the welding

Moving heat source calculation (moving reference)

3D Computation in a moving reference with a Gaussian flow

Width ZF (A)
1370 / **1400** / *1010*

Temperature - upper wall (B, C, D)
370 / **400** / *90*
410 / **430** / *150*
750 / **600** / *310*

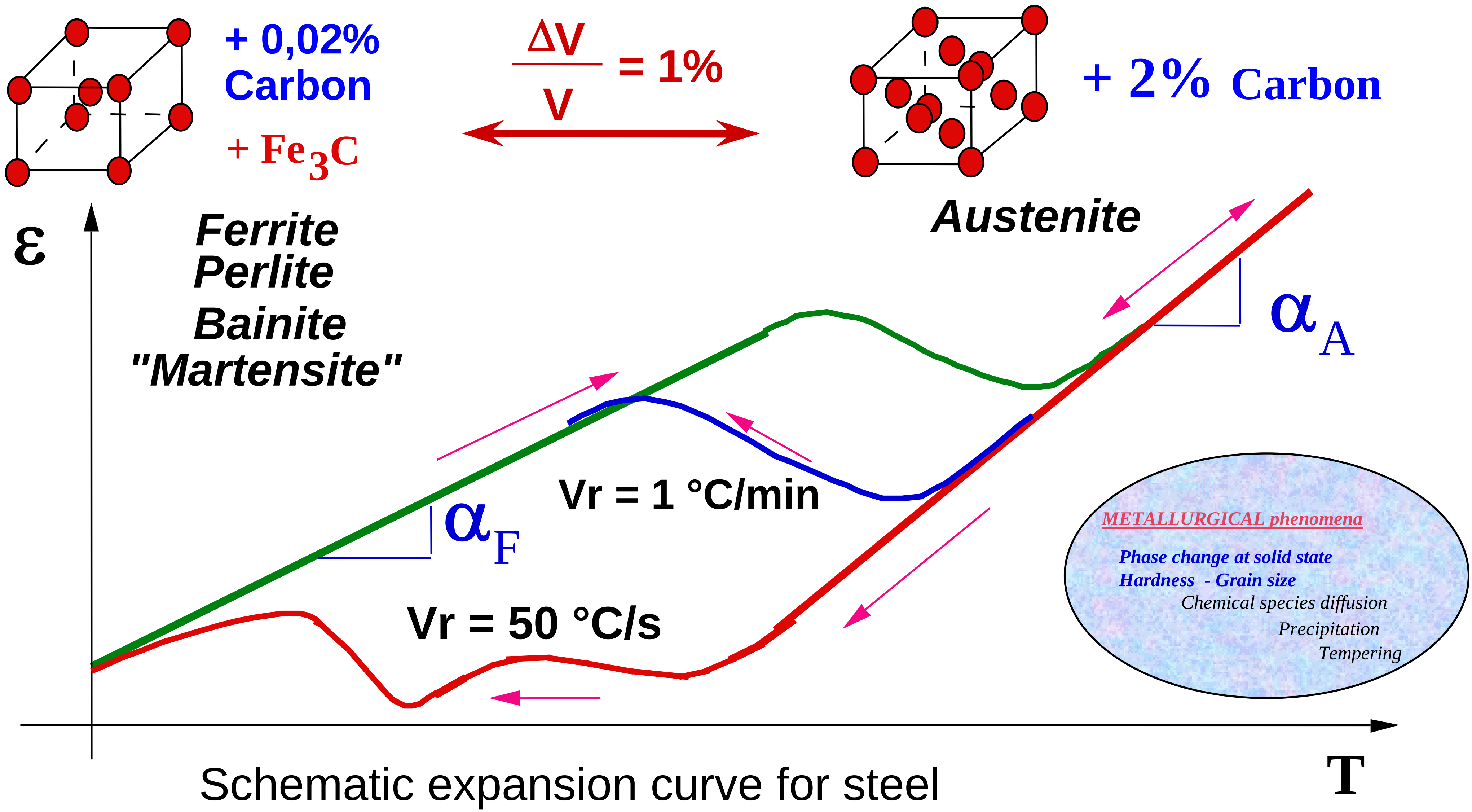


Depth ZF
1370 / **1340** / *1560*

Temperature - inner wall (E)
1030 / **400** / *90*

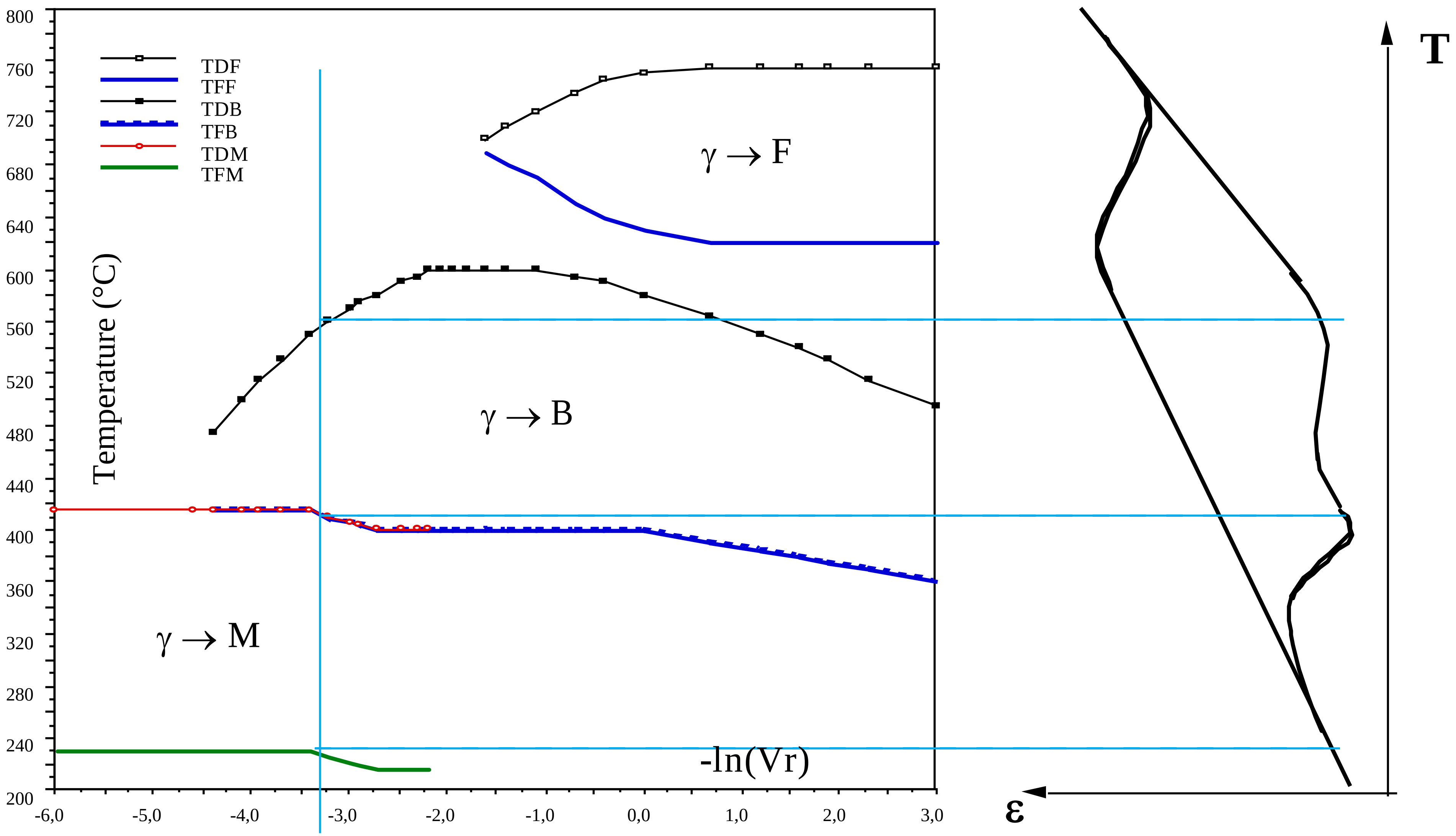
Comparison : experiment / **FE computation** / *analytical solution with $\eta = 0.67$*

Structural changes
Need for metallurgical considerations



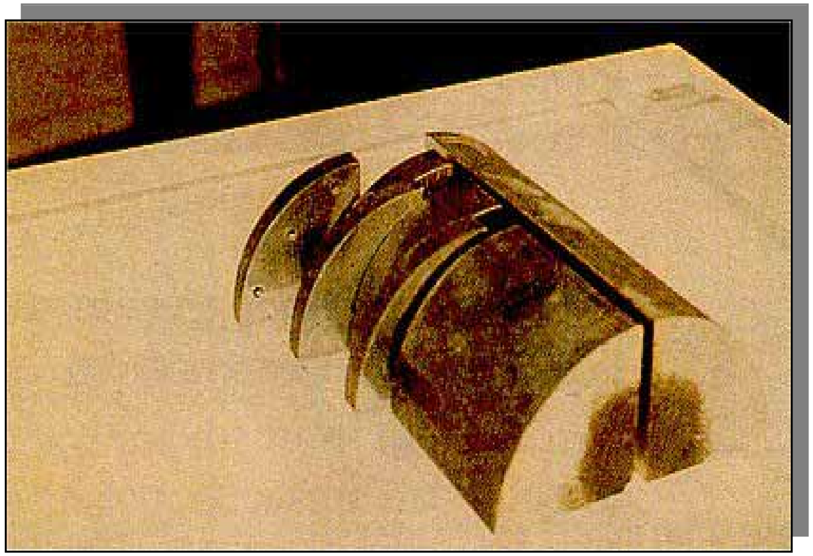
Schematic expansion curve for steel

Experimental characterization of metallurgical changes

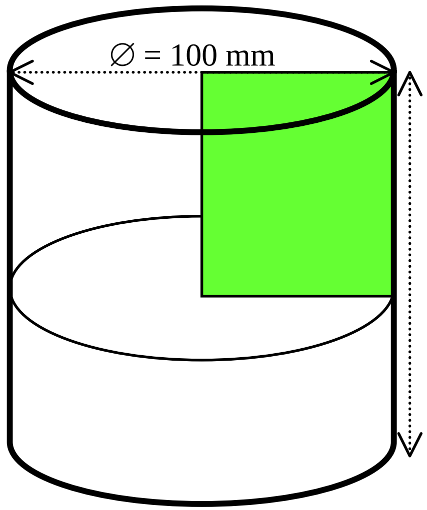


Austenitized 16MND5 steel (5 min at 900 °C) (data from ENSAM & EDF)

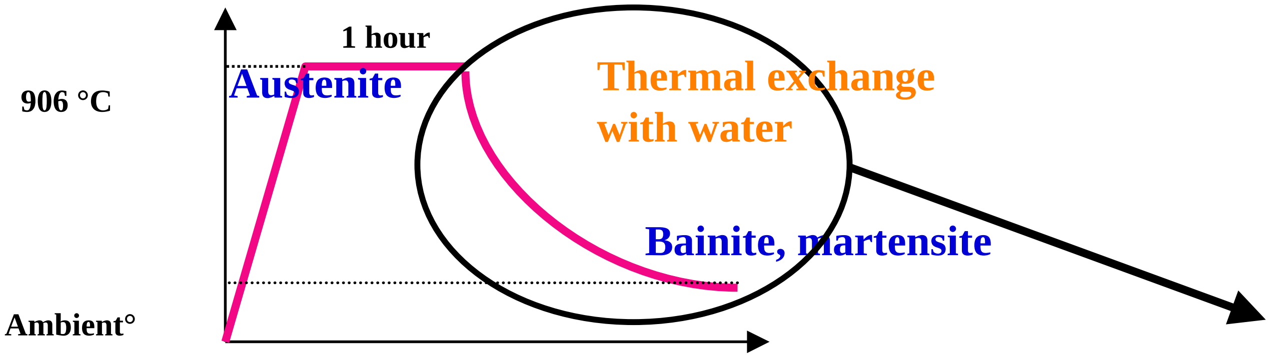
Metallurgical models : quench simulation



Axisymmetric model



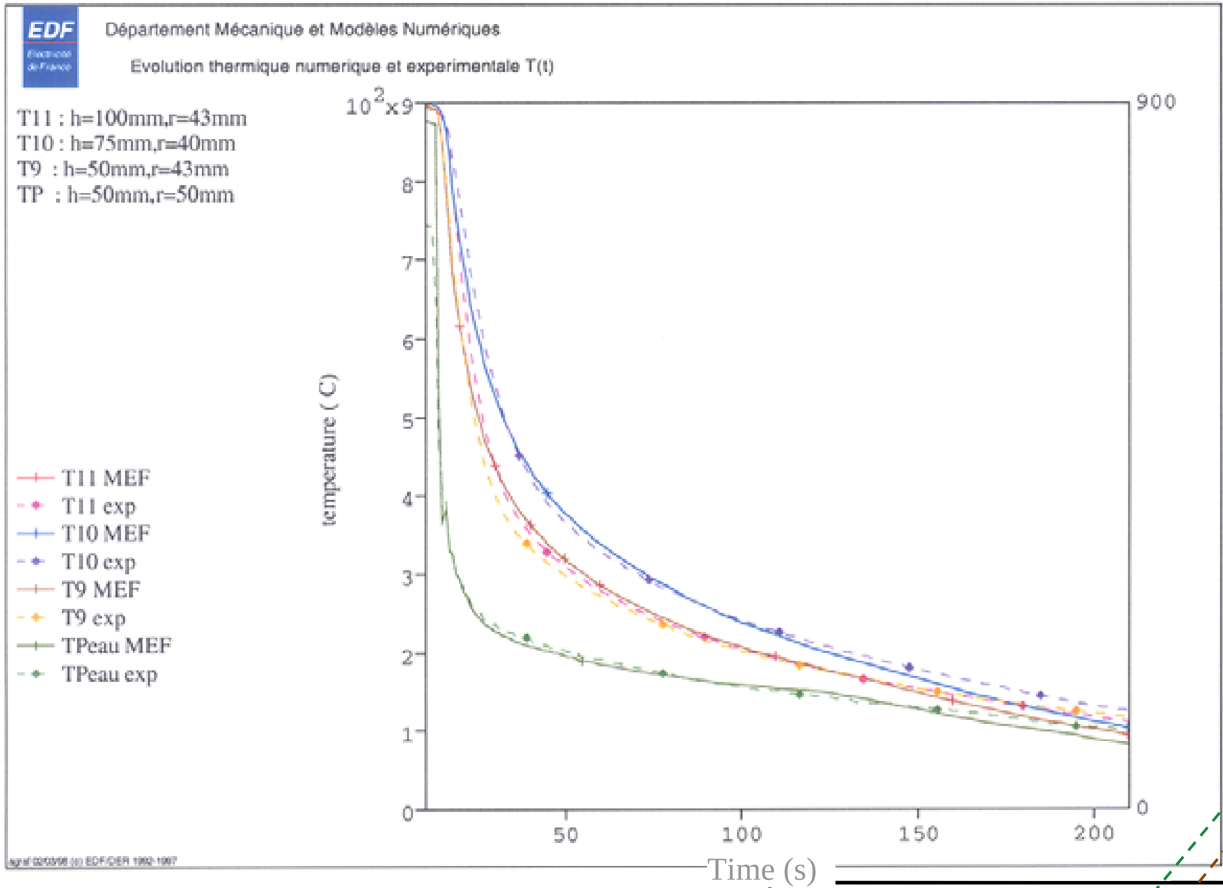
Structural changes



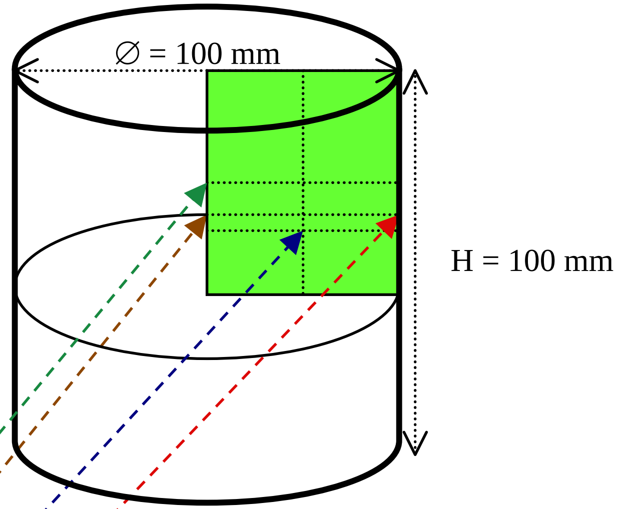
Cooling = Non linear thermal

λ = function of (T°) β = function of (T°)

Metallurgical models : quench simulation

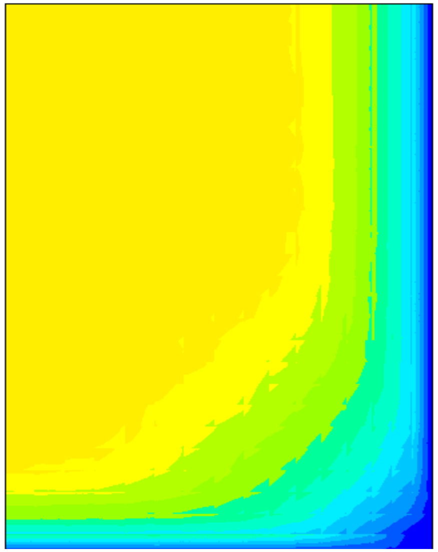


Thermal fitting

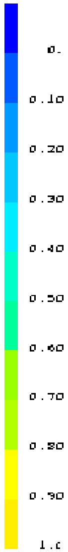


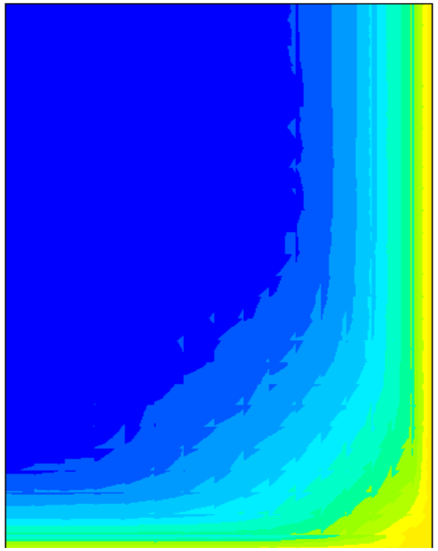
Thermocouple	height h (mm)	Radius r (mm)
Tp	50	50
T9	50	43
T10	75	40
T11	100	43

Metallurgical models : quench simulation

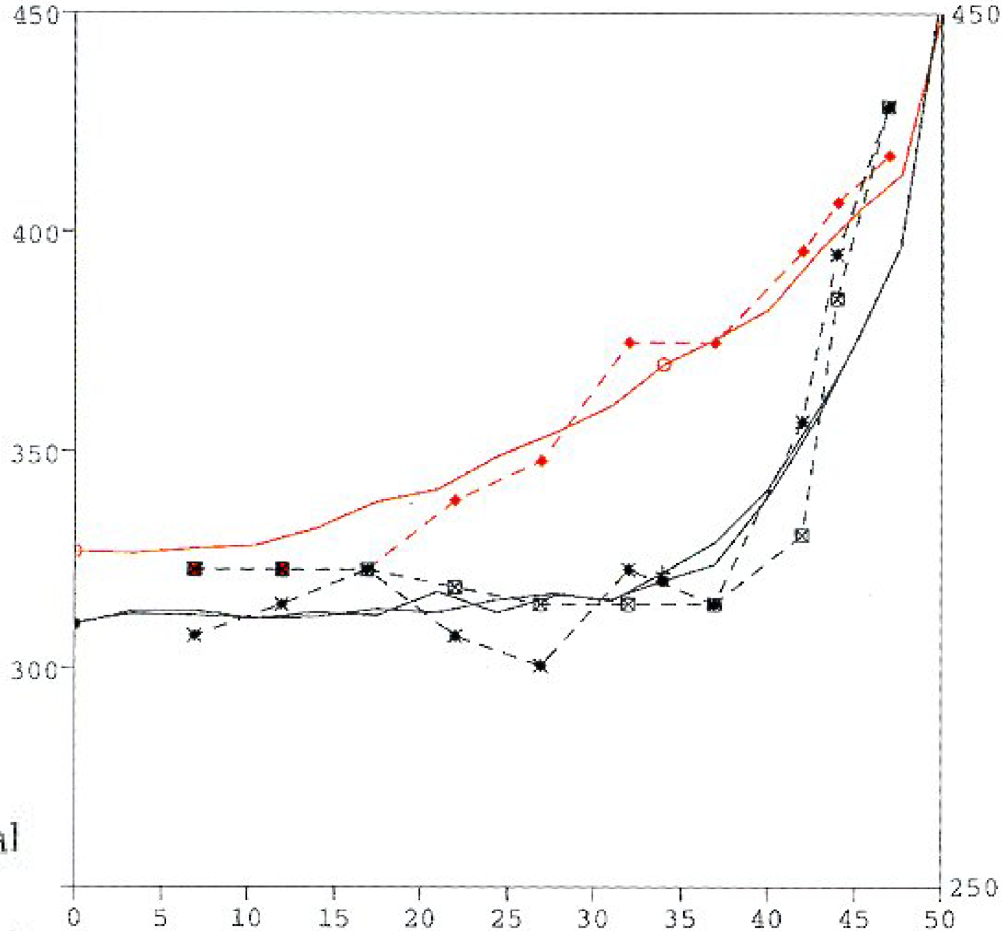


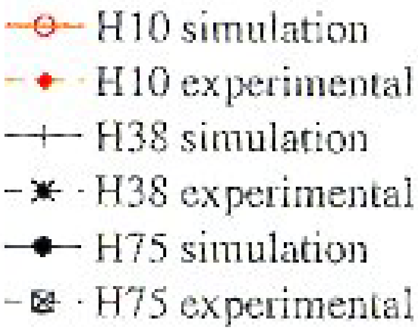
Bainite iso-proportion





Martensite iso-proportion



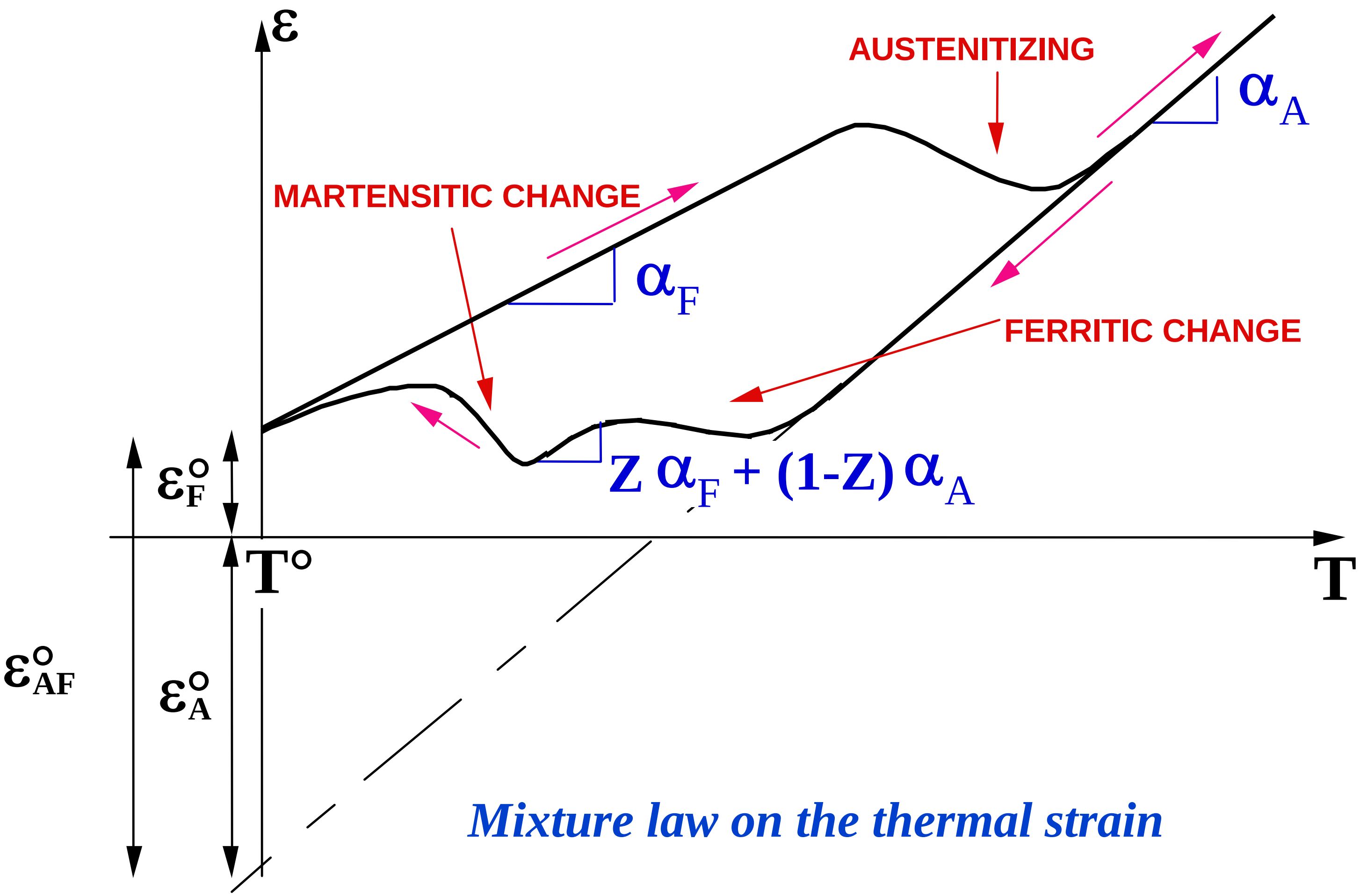


Radius (mm)

Vickers hardness

Mechanical effects of the structural changes

Thermal strain of a multiphase material

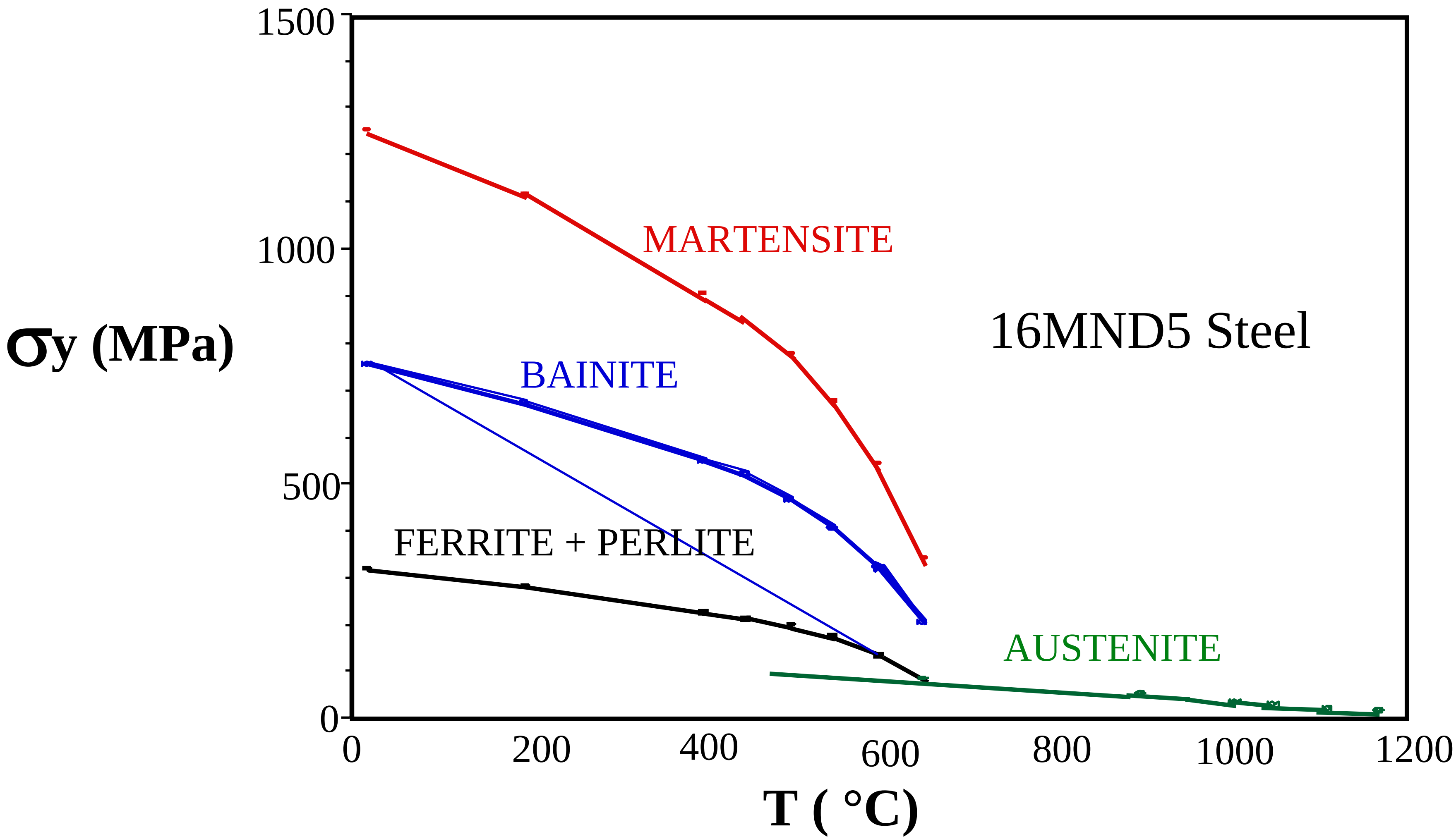


Mixture law on the thermal strain

$$\varepsilon^{th} = Z\,\{\,\alpha_F(T-T^\circ) + \varepsilon^\circ_F\,\} + (1-Z)\,\{\,\alpha_A(T-T^\circ) + \varepsilon^\circ_A\,\}$$

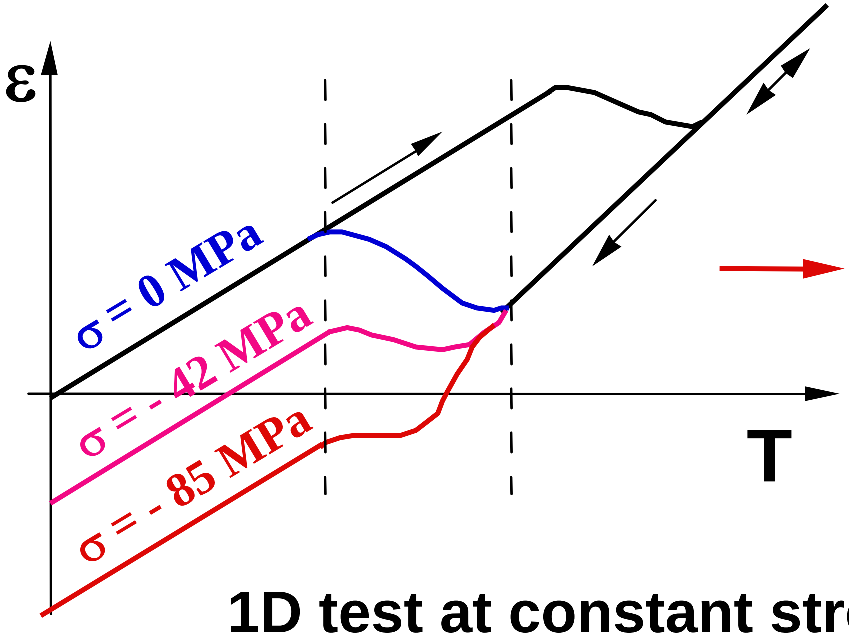
Mechanical effects of the structural changes

Elastic limit of a multiphased material



Mechanical effects of the structural changes

Modelling of the transformation plasticity



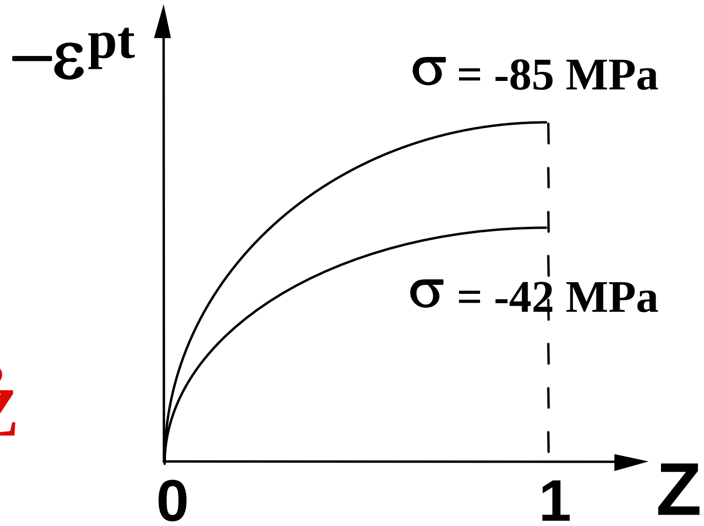
$\varepsilon^{pt} = \Phi(\sigma,Z)$ et $\dot{Z} = 0 \Rightarrow \dot{\varepsilon}^{pt} = 0$

1D test at constant stress

⇒ 1D phenomenological model

$$\varepsilon^{pt} = k.\varphi(Z).\sigma$$

- **Generalization :** $\dot{\varepsilon}^{pt} = K\ \varphi'(Z)\sigma^{D}\dot{Z}$



STRAIN DECOMPOSITION : $\sigma = \Lambda.(\varepsilon - \varepsilon^{th} - \varepsilon^{vp} - \varepsilon^{pt})$

MULTIPHASE BEHAVIOUR
THERMO-METALLURGICAL STRAIN
TRANSFORMATION PLASTICITY
HARDENENING RECOVERY
(VISCOUS AND METALLURGICAL)
CREEP AND VISCOPLASTICITY
WELD POOL BEHAVIOUR
EFFECT OF THE TEMPERING

THERMO - METALLURGICAL STRAIN

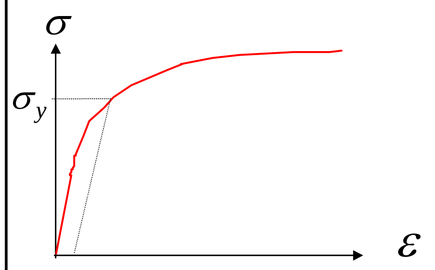
Linear mixture law for the thermal strains of each phase

$$\varepsilon^{th}(T, Z) = \alpha(T, Z).(T - T^{r}) + Z . \Delta \varepsilon^{r}_{\alpha\gamma}$$

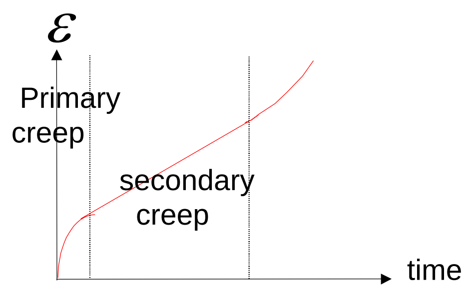
TRANSFORMATION PLASTICITY

Micro plasticity between phases : $\dot{\varepsilon}^{pt} = k.\Phi'(Z).\tilde{\sigma}.\dot{Z}$

MODELLING OF THE VISCOUS RELAXATION DUE TO WELDING STRESS RELIEVING TREATMENTS



- **Usual plastic behaviour for low temperature (T<Tf/3)**
- **Hardening viscoplastic behaviour with viscous hardening recovery for high temperatures**
- **Viscous type behaviour for T° > Tf**
- **Compatible with the metallurgical effects**



Summary…

- **Over 750°C a ferritic steel changes its crystalline structure into austenite**

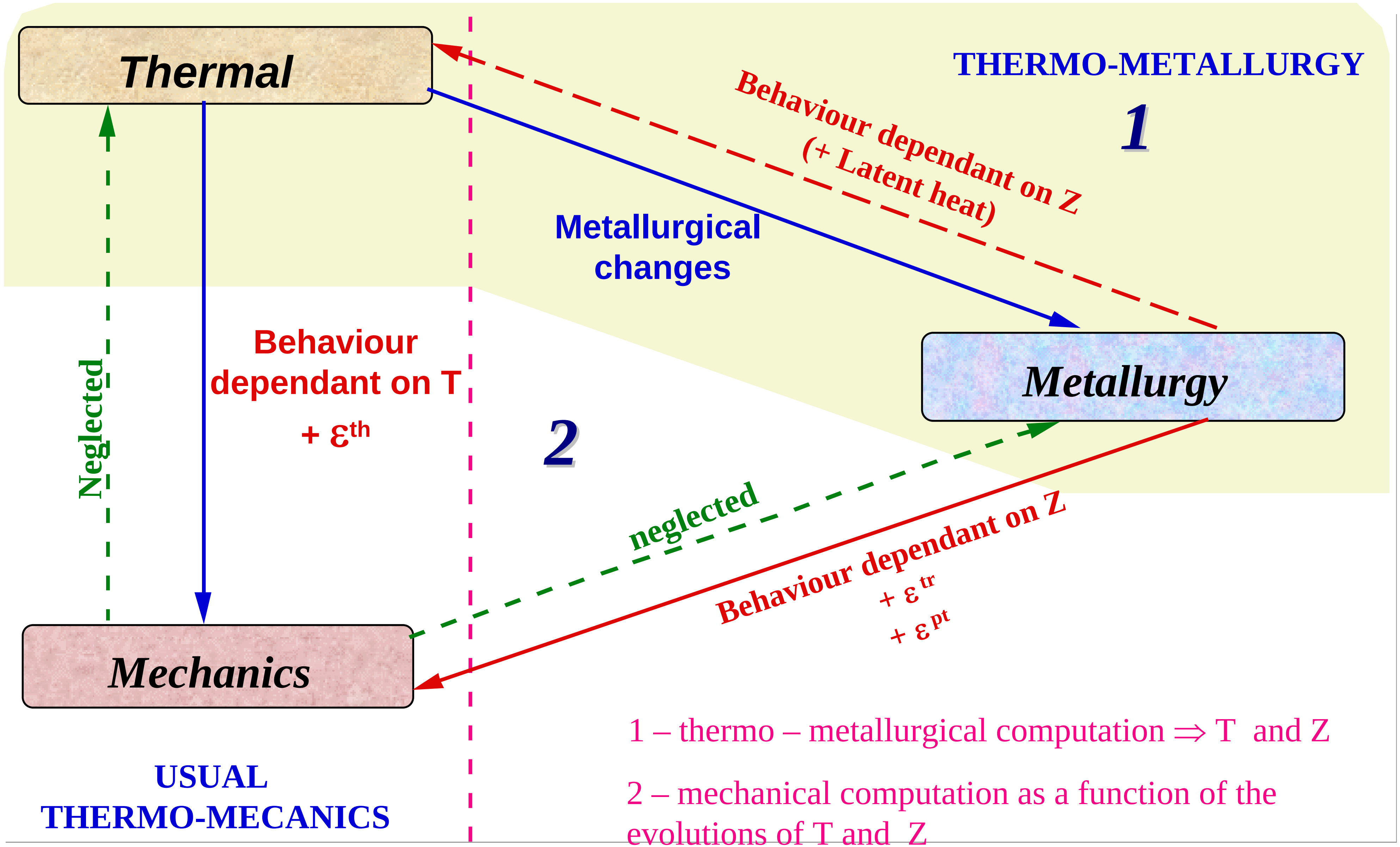
- **During cooling, austenite breaks up, more or less totally, into several phases with different mechanical properties**

- **The <u>nature</u> and <u>kinematics</u> of changes are determined from the thermal time evolution T(t)**

- **« Averaged » microscopic « phenomena »"**
  $\Rightarrow$ transformation plasticity

- **Modelling scale : with Z = { Zf, Zp, Zb, Zm }the proportions of each phase at the material point**
  ⟶ Mixture law for the mechanical properties of the material point

Scheme of a « thermo-metallo-mechanical » computation using Code_Aster

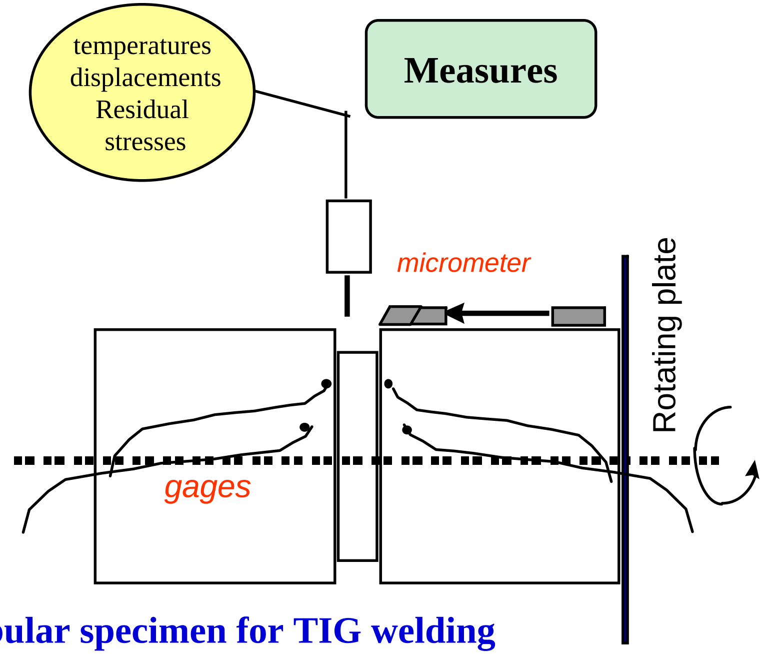


1 – thermo – metallurgical computation ⇒ T and Z

2 – mechanical computation as a function of the evolutions of T and Z

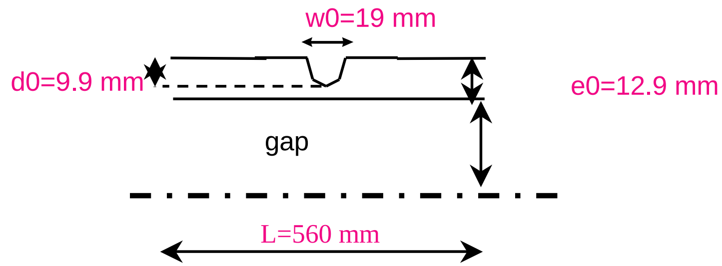
Numerical simulation of a multi layer (13) welding test on tube

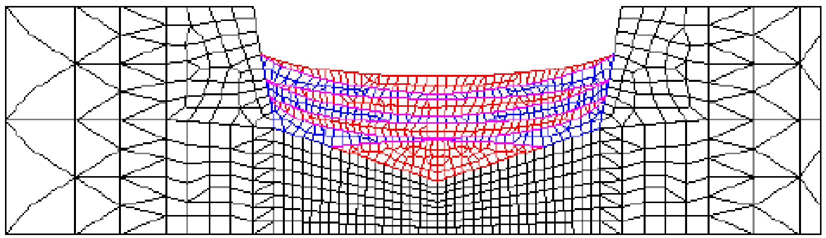
EDF - CEA - FRAMATOME



Tubular specimen for TIG welding

Tubular experimental device





Mesh of the welding lines in the gap

Non linear thermal with refitting

Thermal stresses, material properties f(T)

Non linear mechanical computation

Axisymmetric geometry
Mesh : tube + welding lines
(volume and shape
from macrography)

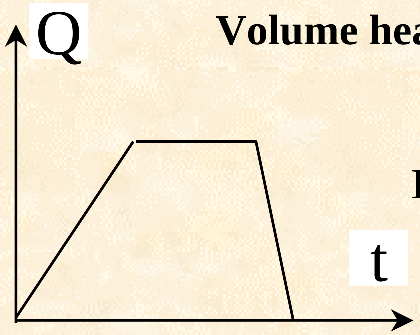
Numerical simulation of a multi layer (13) welding test on tube

THERMAL **: transient non linear computation, layer by layer**

Properties function of (T°)

convection + radiation on the external surface

Liquid – solid latent heat

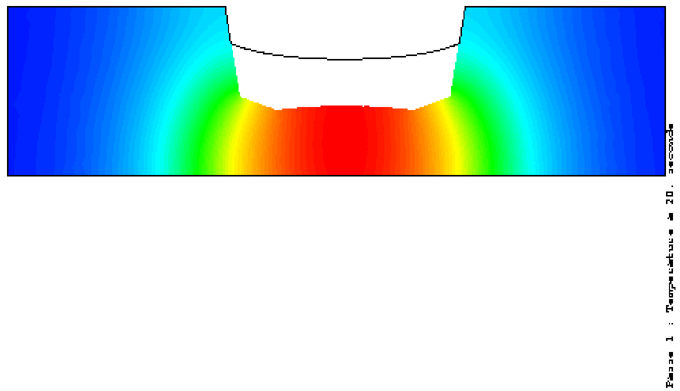


Volume heat source Q(t) in the metal deposit

Inter-layer time~ 2000S

nested thermal models

Temperature End of layer 1



Numerical simulation of a multi layer (13) welding test on tube

MECHANICS : non linear computation layer by layer

loading : **thermal cycle**

*Behaviour law : **ELASTO-VISCO-PLASTIC***

Non linear isotropic hardening

Boundary conditions : **unilateral capping** of the tube in expansion

Geometry updating at the end of each layer