Modelling the $\alpha \rightarrow \gamma$ transformation of a low carbon martensitic stainless steel.

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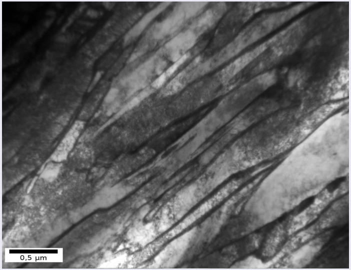
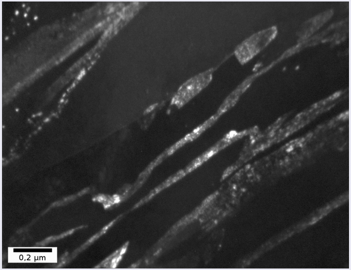
AℓEMI - June 24-25th 2013- Delft

Context and challenges

The material :

- Good yield strength, without Hardening Precipitation (welding and aging) and good resilience.



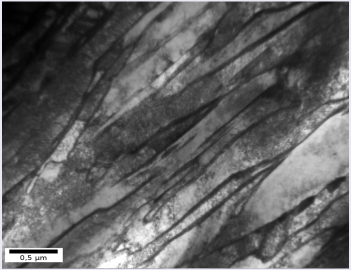


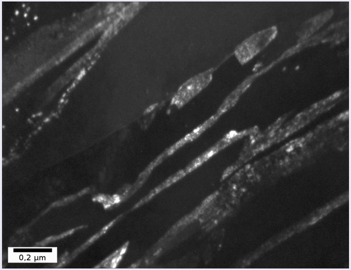
Context and challenges

The material : X4CrNiMo16.5.1 or APX4

- Good yield strength, without Hardening Precipitation (welding and aging) and good resilience.

  $\Rightarrow$ Due to lamellar residual austenite





During welding

$\Rightarrow$ Stability of residual austenite ?

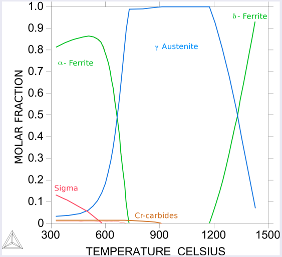
Outline...

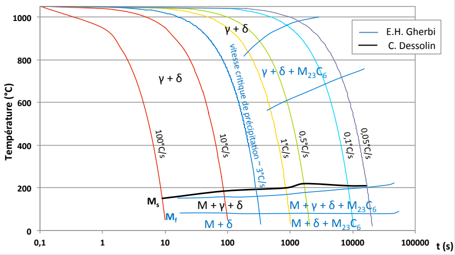
The material : APX4

Chemical composition

Element	Cr	Ni	Mo	Mn	Cu	Si	C	N	P	S
wt%	15.5	4.75	0.97	0.93	0.1	0.24	0.06	0.04	0.017	0.001
at%	16.5	4.48	0.56	0.94	0.09	0.47	0.28	0.16	0.024	0.002

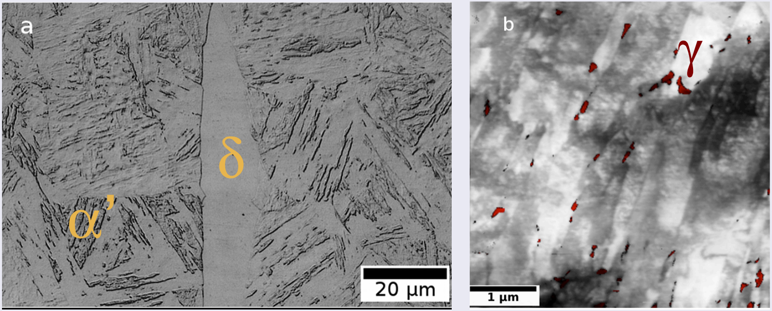
Phase diagram and TRC





The material : APX4

Microstructure : martensitic matrix



- 3% vol. delta
- 6% vol. γ (Morphology by ASTAR [a])

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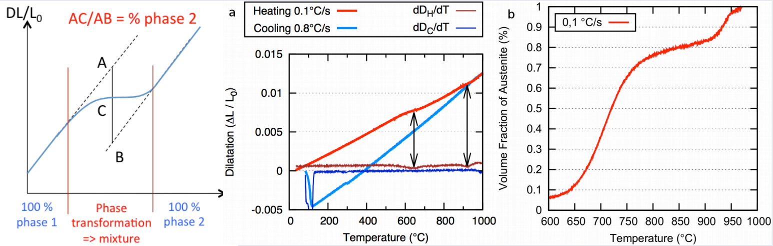
a. Courtesy of M. Veron, Grenoble INP

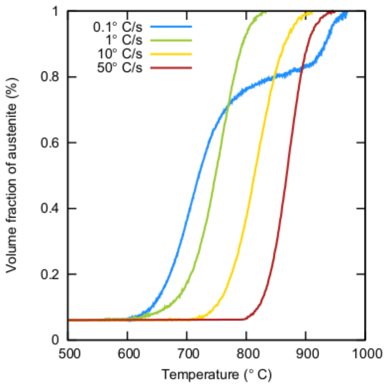
Experimental characterization

Austenite fraction during heating

- Adamel-Lhomargy DT1000 quench dilatometer (CEA Saclay/SRMA)
- Continuous Heating : 0.1, 1, 10 and 50°C/s, $T_{max} = 1050°C$
- Samples : as-quenched state, $L = 10$ mm ; $s = 1$ mm^2
- Lever rule to determine % γ :



Austenite fraction *vs* heating rate



"To win a race, the swiftness of a dart. Availeth not without a timely start" [a]

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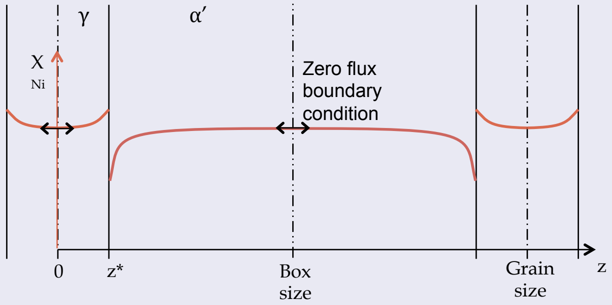
a. J. de La Fontaine, 1688

The model

Hypothesis

- Interface motion is driven by nickel diffusion
- LE for Ni and full equilibrium for C
- linear 1D problem

Geometry



The model

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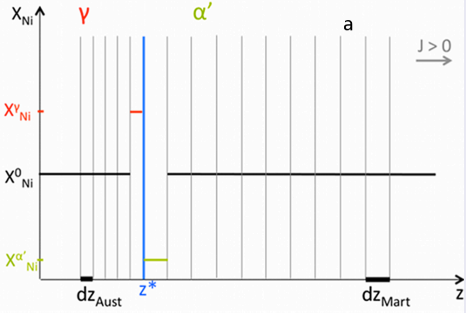


The model

Kinetics equations

- Flux between adjacent layers

$$J = -D\frac{\partial C}{dx}$$

- mass balance on a layer of surface S

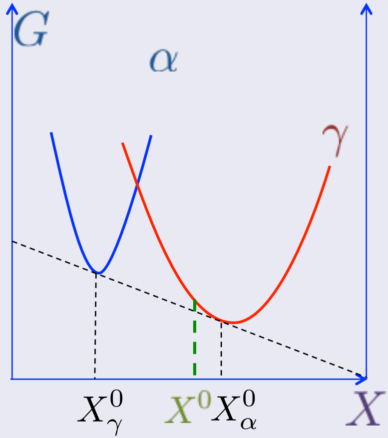
$$(-J^{\alpha} + J^{\gamma})Sdt = (C^{\gamma} - C^{\alpha})Sdx$$

- interface velocity

$$v = \frac{dx}{dt} = \frac{J^{\gamma} - J^{\alpha}}{C^{\gamma} - C^{\alpha}}$$

The model

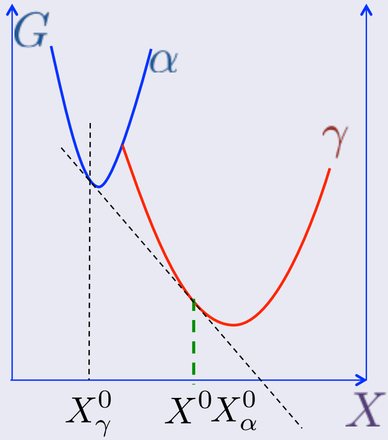
Interfacial compositions : T_1



- Two interface compositions

The model

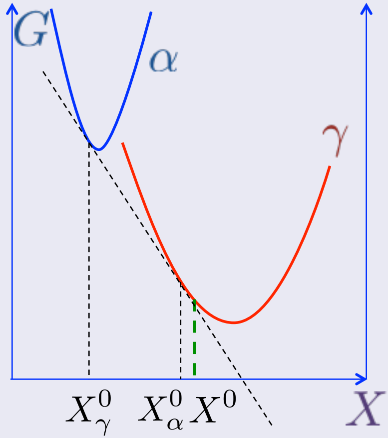
Interfacial compositions : $T_2 > T_1$



- Two interface compositions (limiting case)

The model

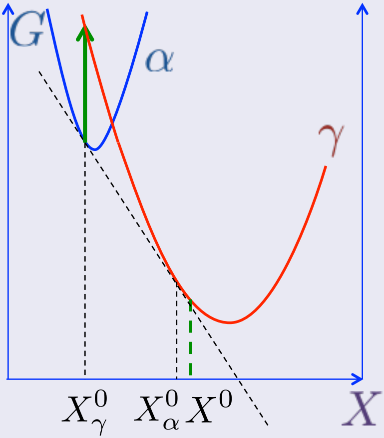
Interfacial compositions : $T_3 > T_2 > T_1$



- Only one phase !

The model

Interfacial compositions : $T_3 > T_2 > T_1$

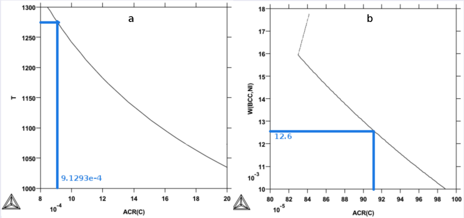


- Massive transformation : impossible !

The model

Interfacial composition : the idea

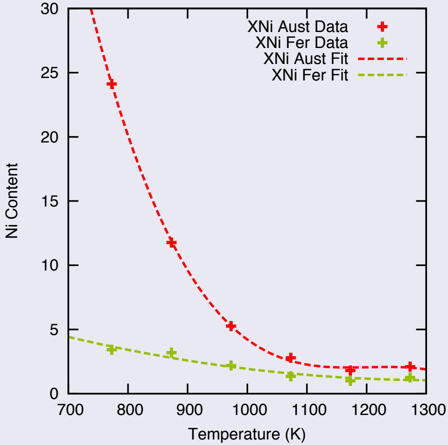
- Activity of carbon remains the same between LE and FE



1. at a given T, calculate activity of C with FE conditions
2. calculate the composition of α (constrained LE)
3. calculate the composition of γ(constrained LE)

The model

Interfacial composition : results



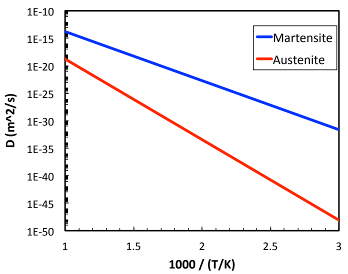
The model

Parameters

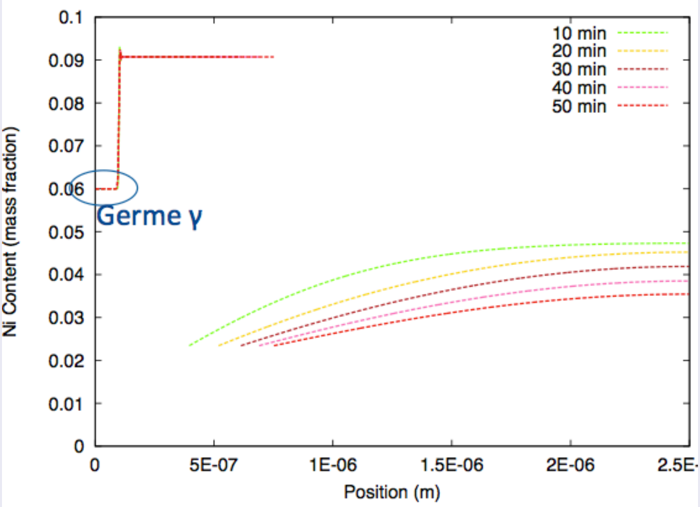
- Diffusion of Ni in martensite ?

$$D^{\alpha'} = D^{\alpha} A \exp\left[Q/(RT)\right]$$

- $A = 0.1$ and $Q = 75kJ/mol$
- Diffusion of Ni in martensite and austenite

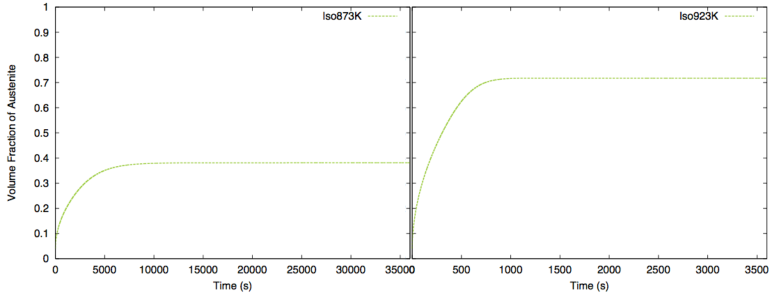


Isothermal


Ni Content (mass fraction)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
10 min
20 min
30 min
40 min
50 min
Germe γ
0
5E-07
1E-06
1.5E-06
2E-06
Position (m)

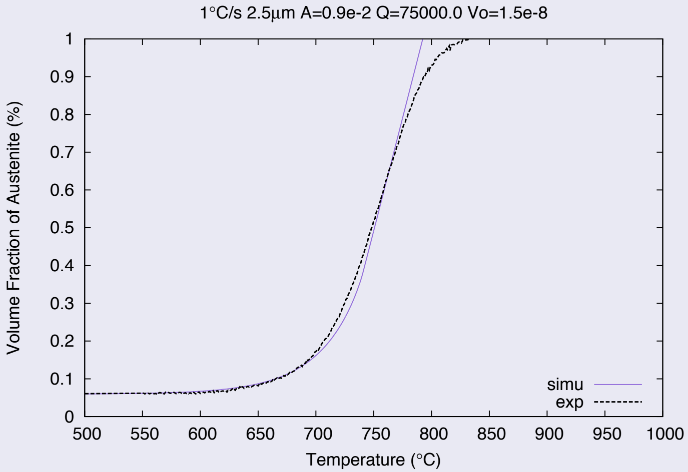
Results

Isothermal

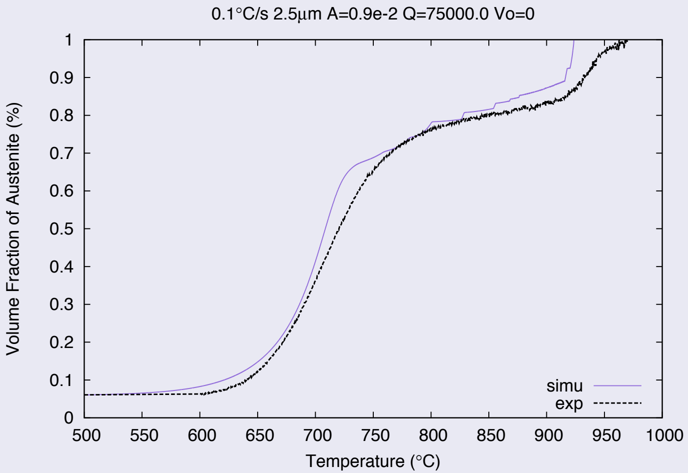


Results

High heating rate



Low heating rate : the explanation !



Conclusions and outlook

Conclusions

- Simple LE model
- Interface motion limited by Ni diffusion
- Needs for thermodynamical data
- Explanation of the two regimes for interface migration
- low temperature austenite acts as Ni reservoir

Outlook

- Transition between diffusion limited and interface limited migration
- Massive transformation during couling