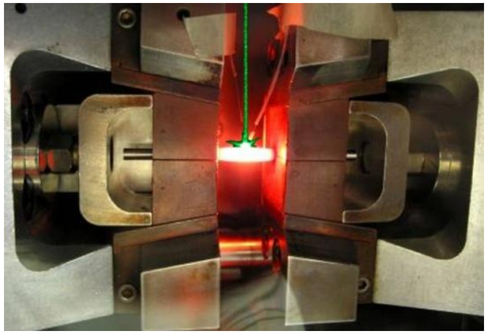
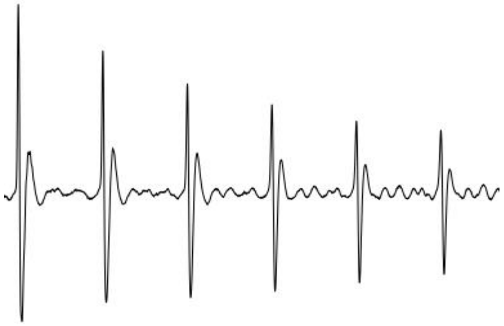
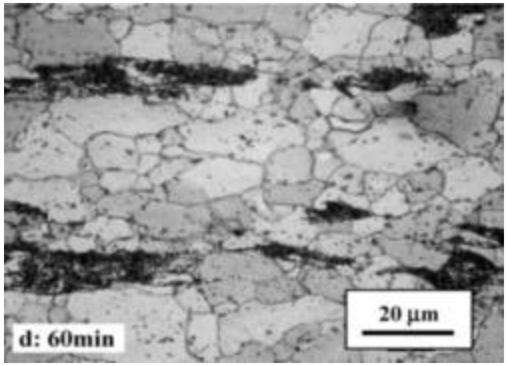




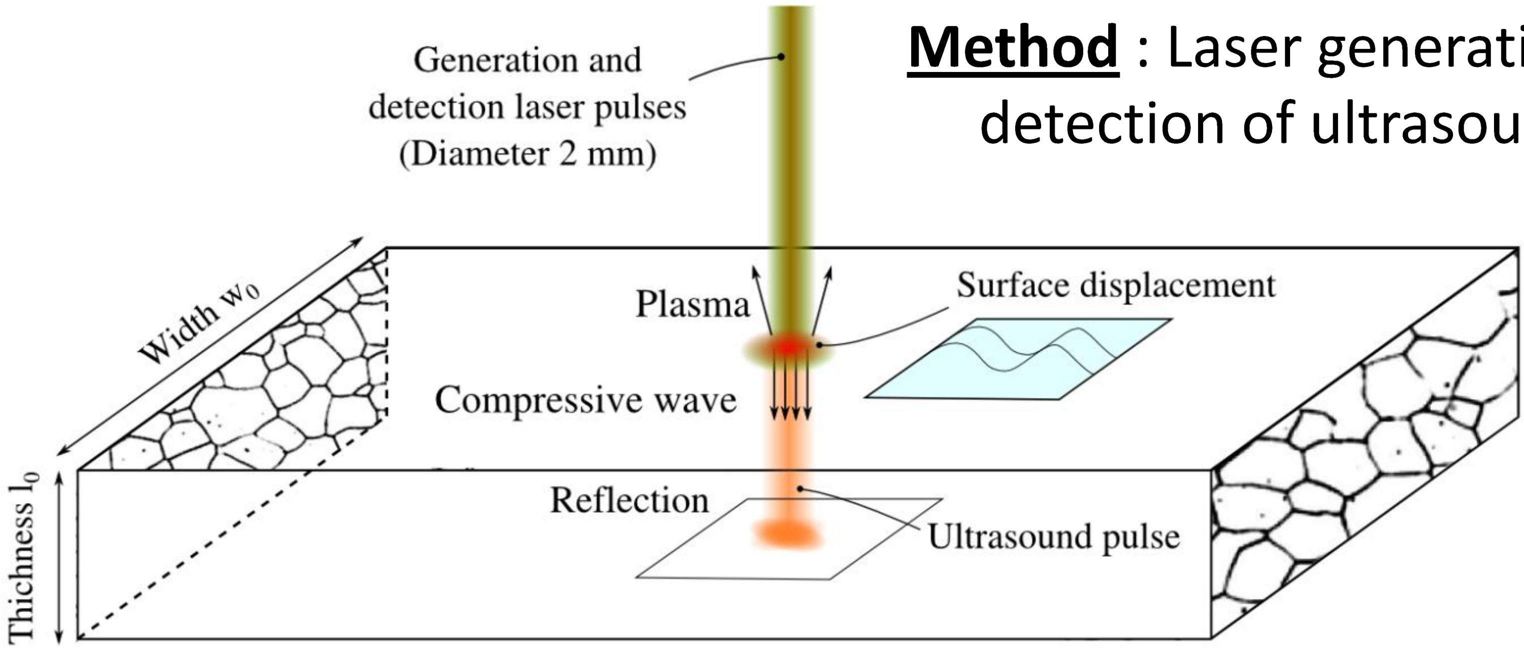


Laser Ultrasonics for Steel Characterization

Thomas Garcin[1], Matthias Militzer[1], Andre Moreau[2], Warren J. Poole[1]

[1]The Centre for Metallurgical Process Engineering, The University of British Columbia, Vancouver, BC, Canada
[2]Industrial Materials Institute, National Research Council of Canada,
Boucherville, QC, Canada

Description of the technique

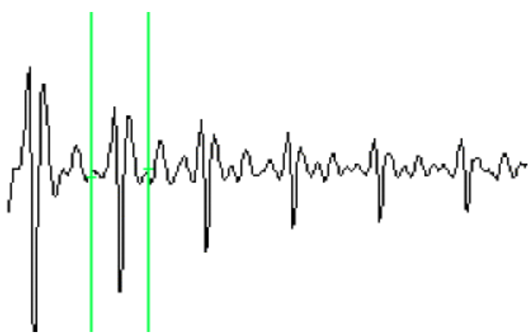


Method : Laser generation and detection of ultrasounds

Parameters :

1- Velocity = Elasticity, density

2- Attenuation = Grain size, …



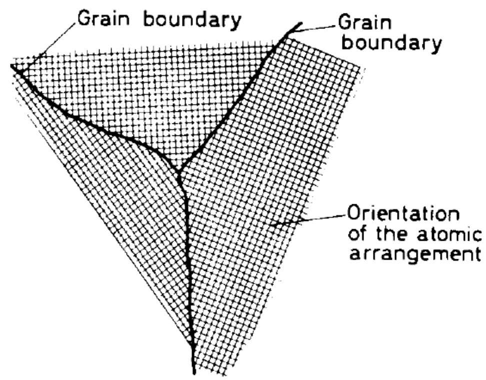
Ultrasonic wave propagation

SINGLE CRYSTAL

Anisotropy ratio at 600ºC

Iron $r = 3.0$

Aluminum $r = 1.2$



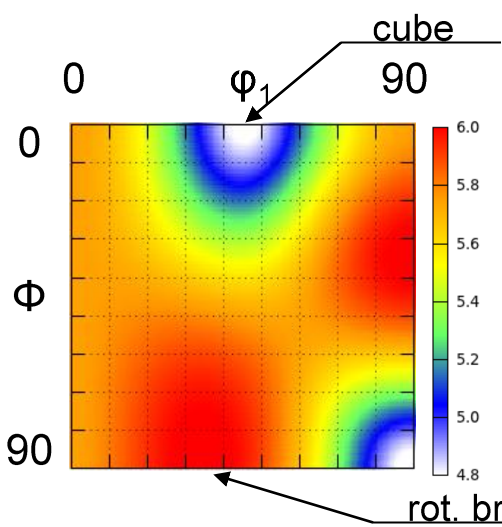
POLYCRYSTAL

Elastic mismatch between grain causes scattering

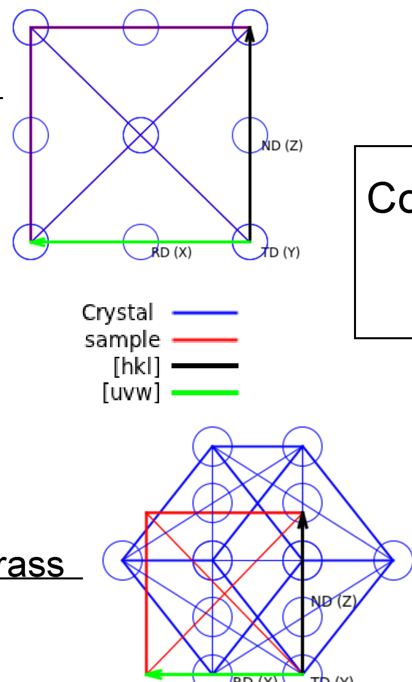
At frequency constant

$$f = v/\lambda$$

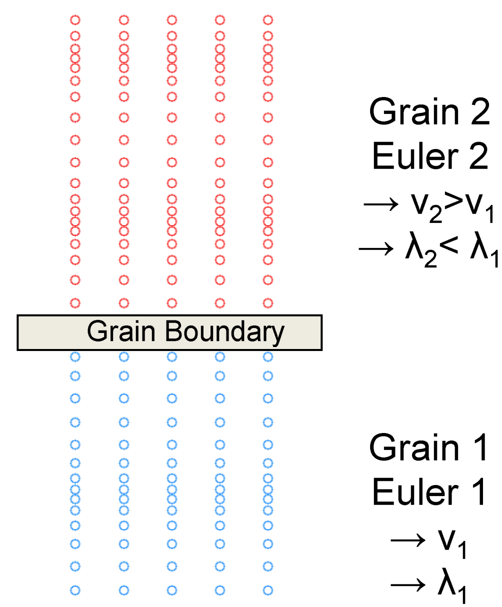
Velocity of a compressive wave propagating along X direction



$\varphi_2 = 45°$



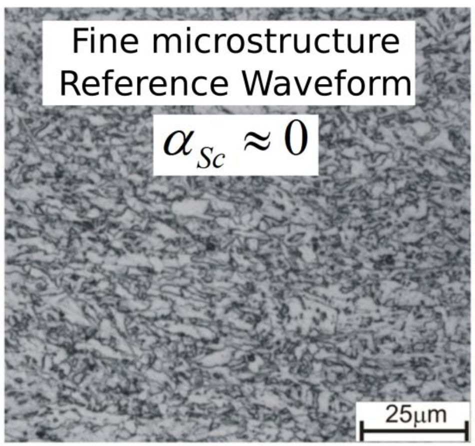
Compressive wave Propagation // Polarization

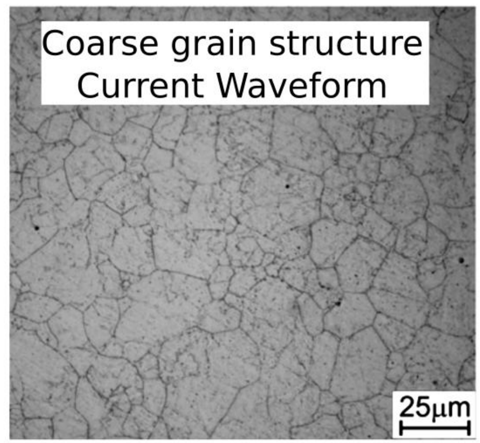


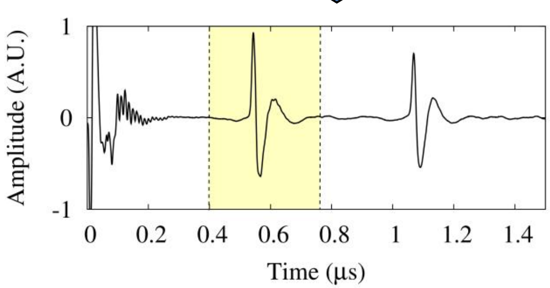
From grain scattering to grain size

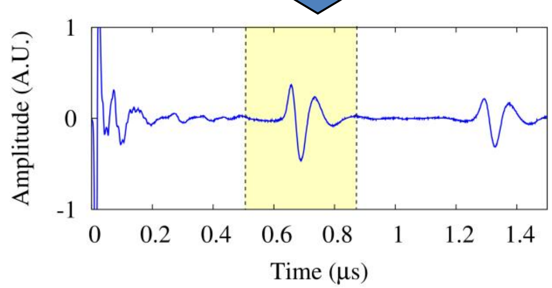
Grain size measurement from ultrasonic attenuation

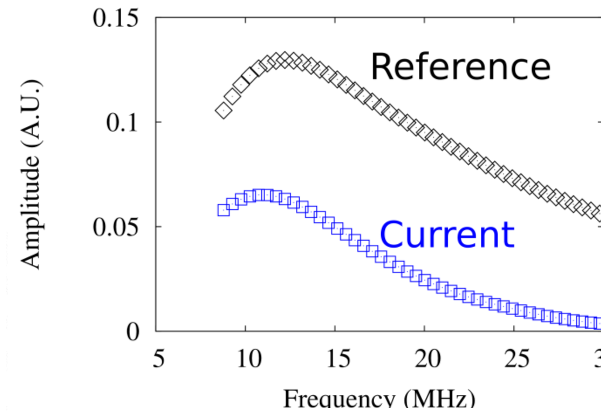
$$\alpha = \alpha_D + \alpha_{Sc}$$



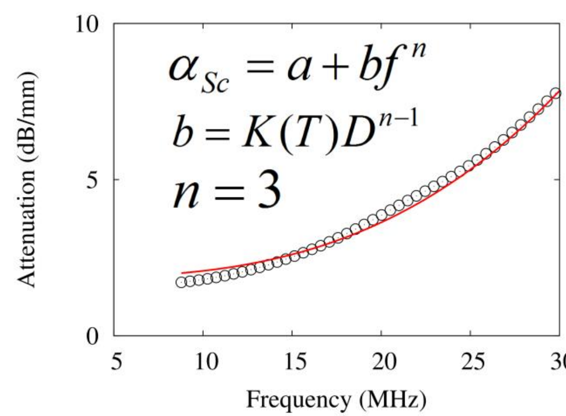








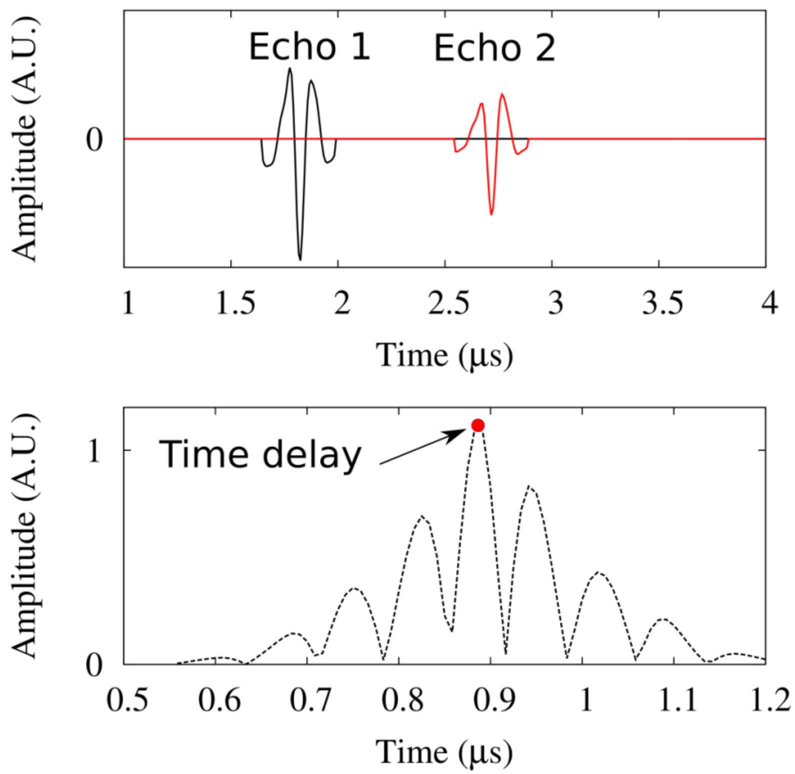
$$\alpha_{sc} = -\frac{20}{2e}\log 10\left(\frac{A_{Current}}{A_{Reference}}\right)$$



Calibration available for austenite in low alloy steel : S.E. Kruger et al., Iron Steel Technol, (2005), 2(10),25

From velocity to texture information

$$v_L = \frac{2(e+\varepsilon)}{delay}$$



Propagation distance :

Thickness + Thermal expansion

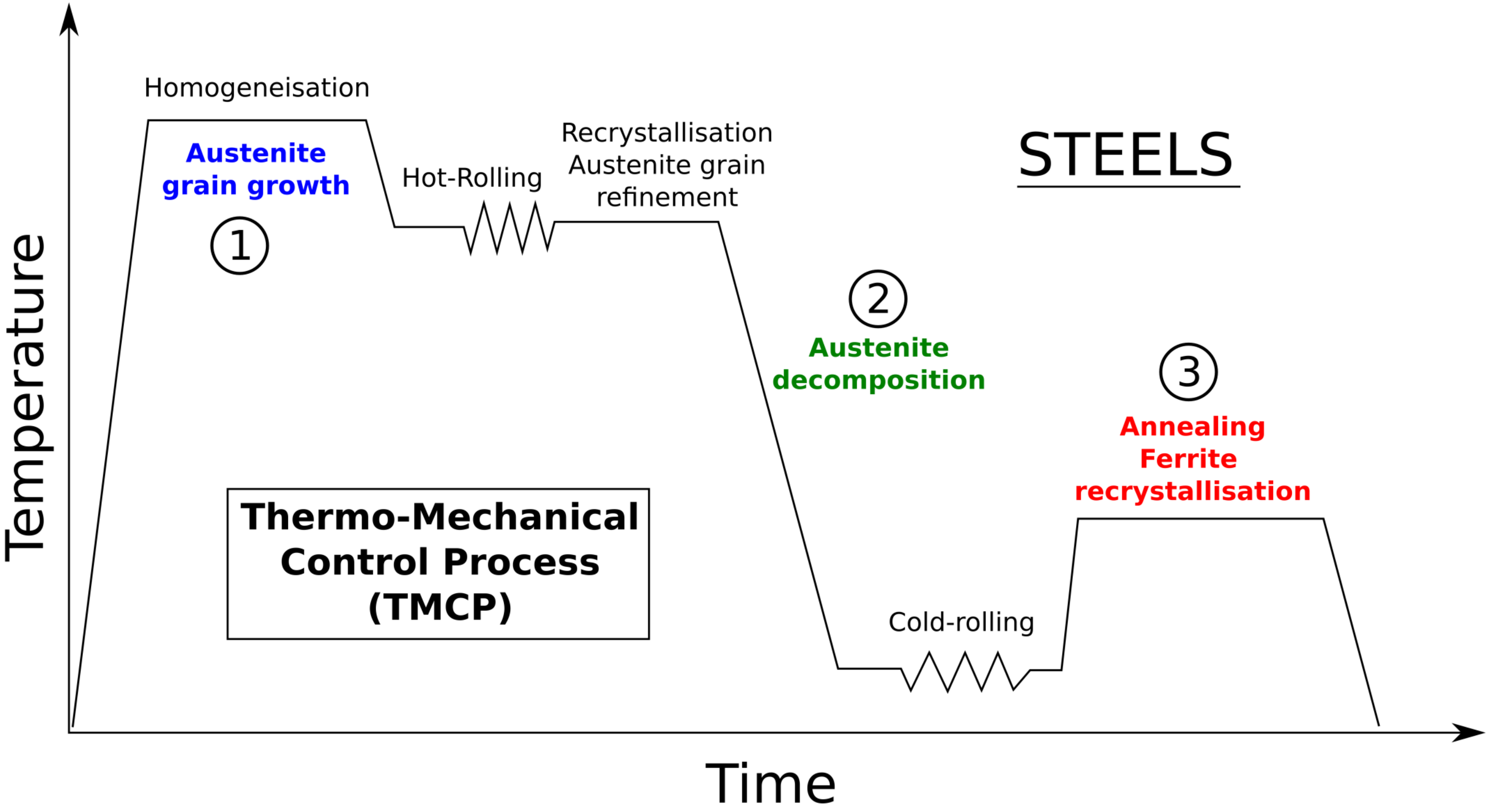
Time delay :

Phase shift between two successive echoes by cross-correlation method

Velocity is proportional to the elastic properties in the propagation direction

$$v_L = \sqrt{\frac{\lambda + 2\mu + f(W_{400})}{\rho}}$$

Contents


Homogeneisation
Austenite
grain growth
1
Hot-Rolling
Recrystallisation
Austenite grain
refinement
STEELS
2
Austenite
decomposition
3
Annealing
Ferrite
recrystallisation
Thermo-Mechanical
Control Process
(TMCP)
Cold-rolling
Temperature
Time

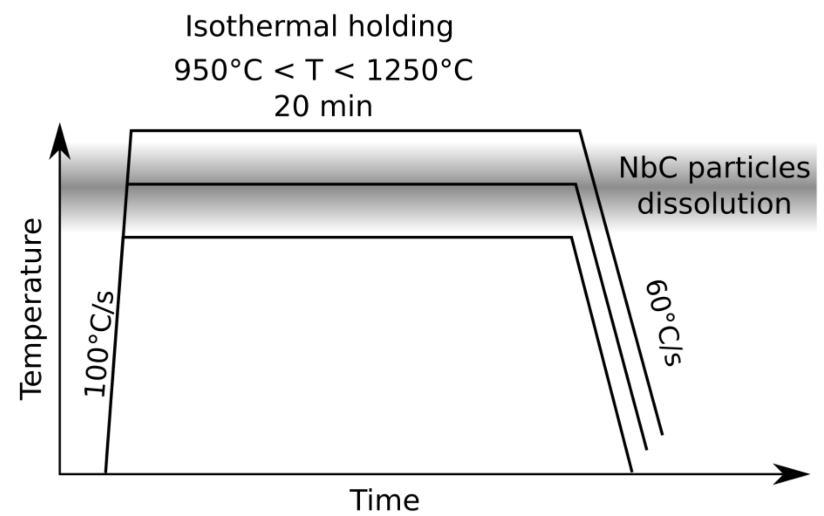
Austenite Grain size evolution

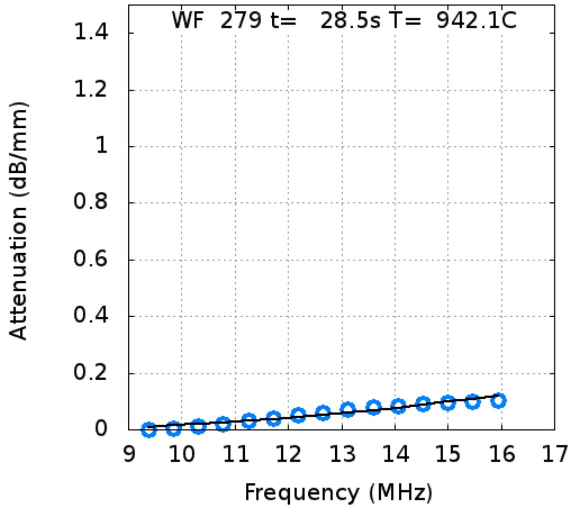
Linepipe Steel (X80)

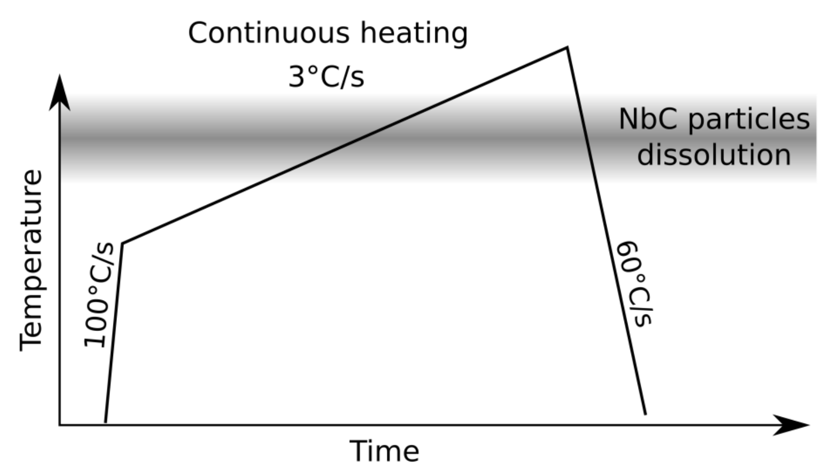
Key elements(wt%)

C	Mn	Mo	Nb	Ti	N
0.06	1.65	0.24	0.034	0.012	0.005

- Competition between grain boundary curvature and particles pinning

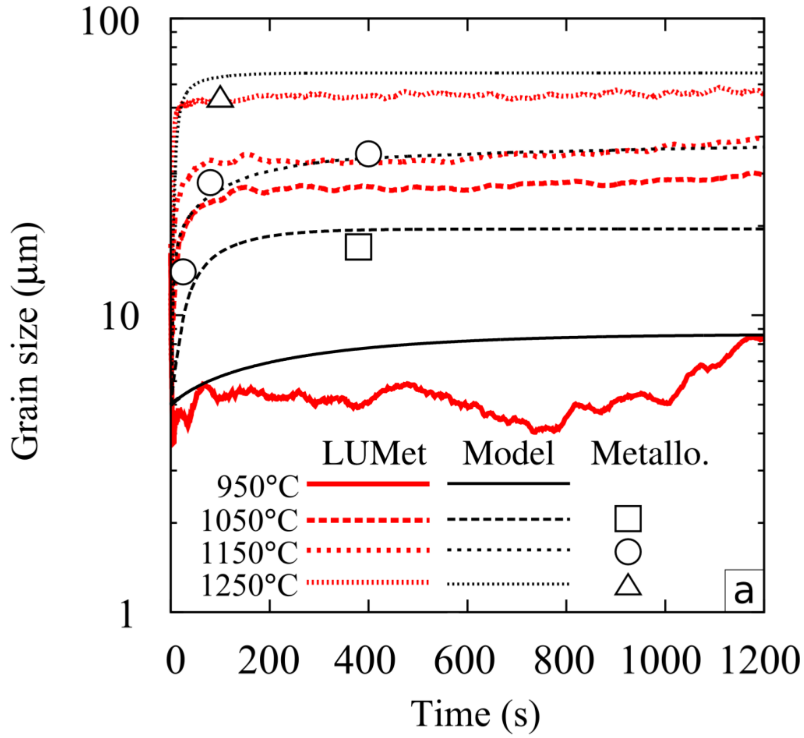




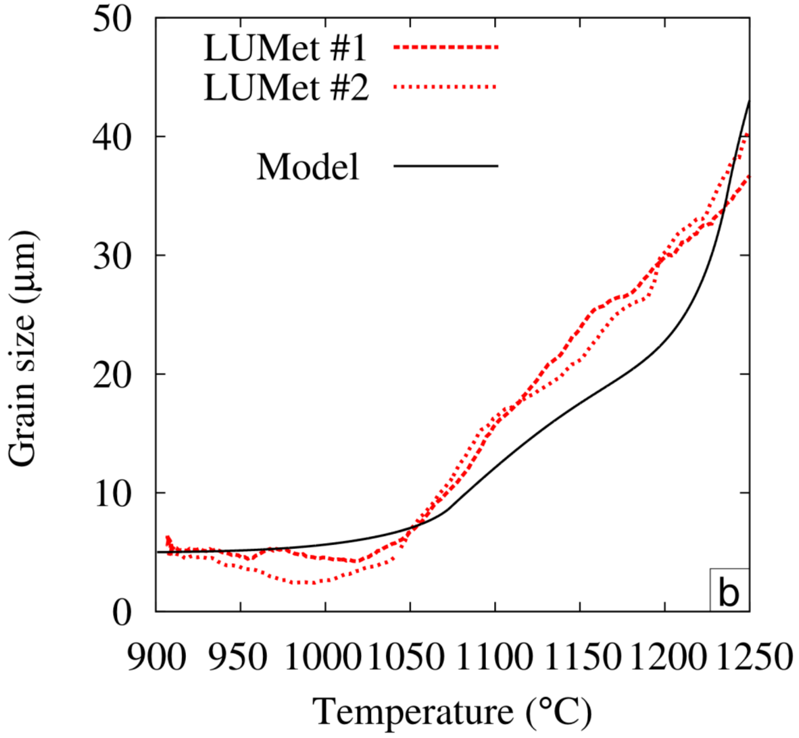


Results

Isothermal holding



Continuous heating



How can we measure grain sizes in materials in which it is impossible to acquire a reference in a fine grain structure?

Can we distinguish normal and abnormal grain growth ?

What is a good estimation of the errors bars ?

Austenite Decomposition

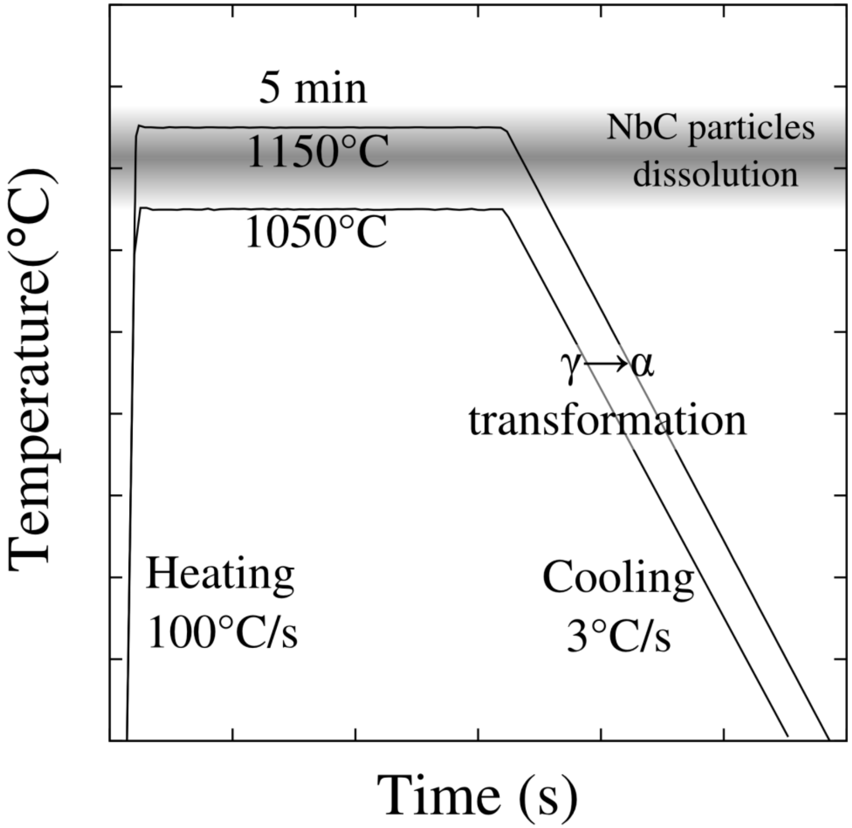
Low-Alloyed Steel

Key elements(wt%)

C	Mn	Si	Nb	Ti	N
0.047	1.49	0.200	0.047	0.001	0.010

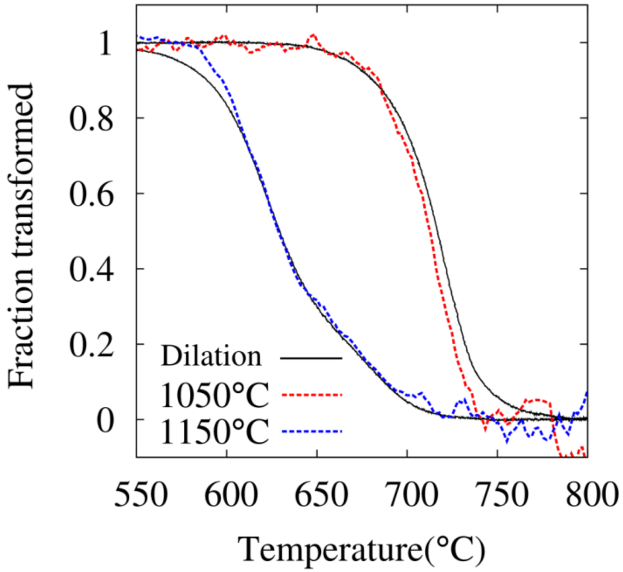
- Ultrasonic velocity measurements during austenite decomposition

	600ºC	900ºC
Velocity in ferrite	**5.496**	5.045
Velocity in austenite	**4.905**	4.956

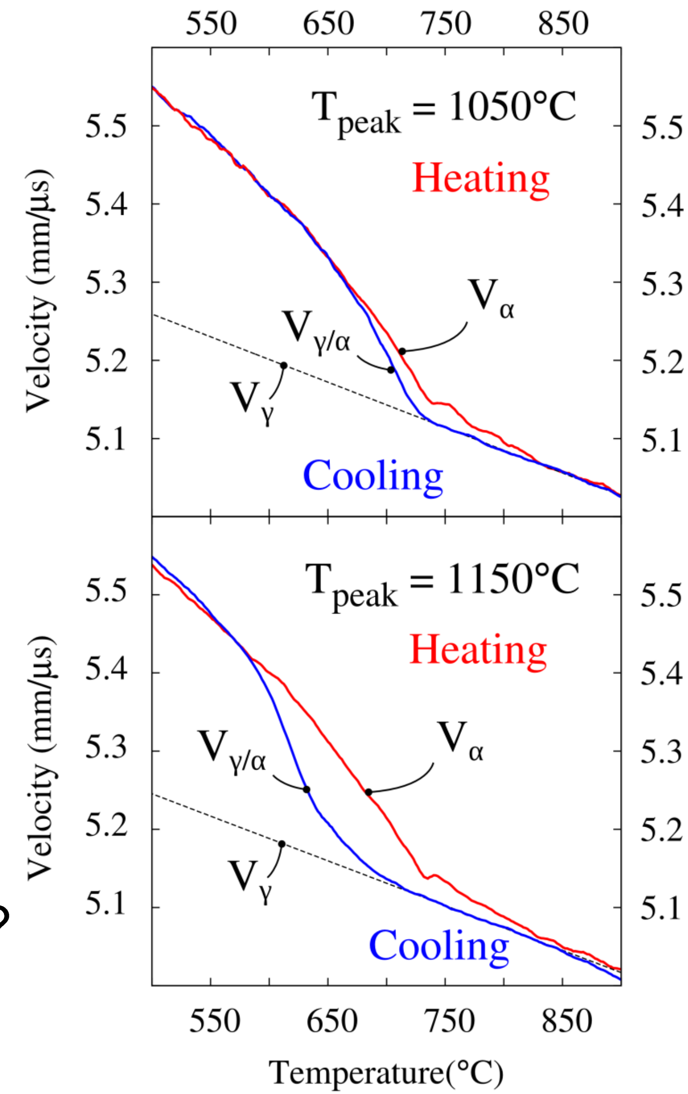


Velocity measurements

- Velocity difference between ferrite and austenite
- Application of the lever-rule method on ultrasonic velocity



$$f_\alpha = \frac{v_\gamma - v_{\gamma/\alpha}}{v_\gamma - v_\alpha}$$



What if the initial and final velocity are different ?
Is there measurable differences between velocity in ferrite, bainite, martensite ?

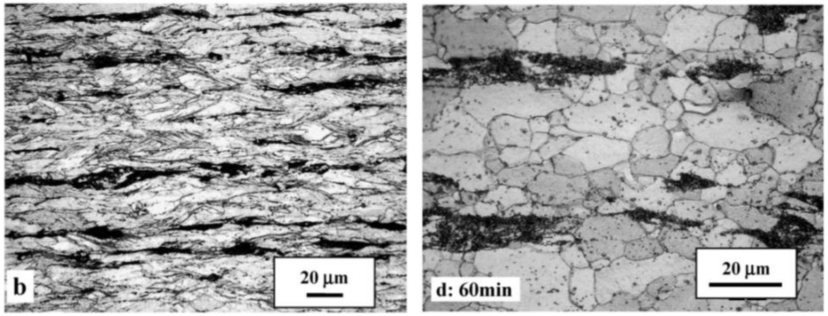
Ferrite recrystallization

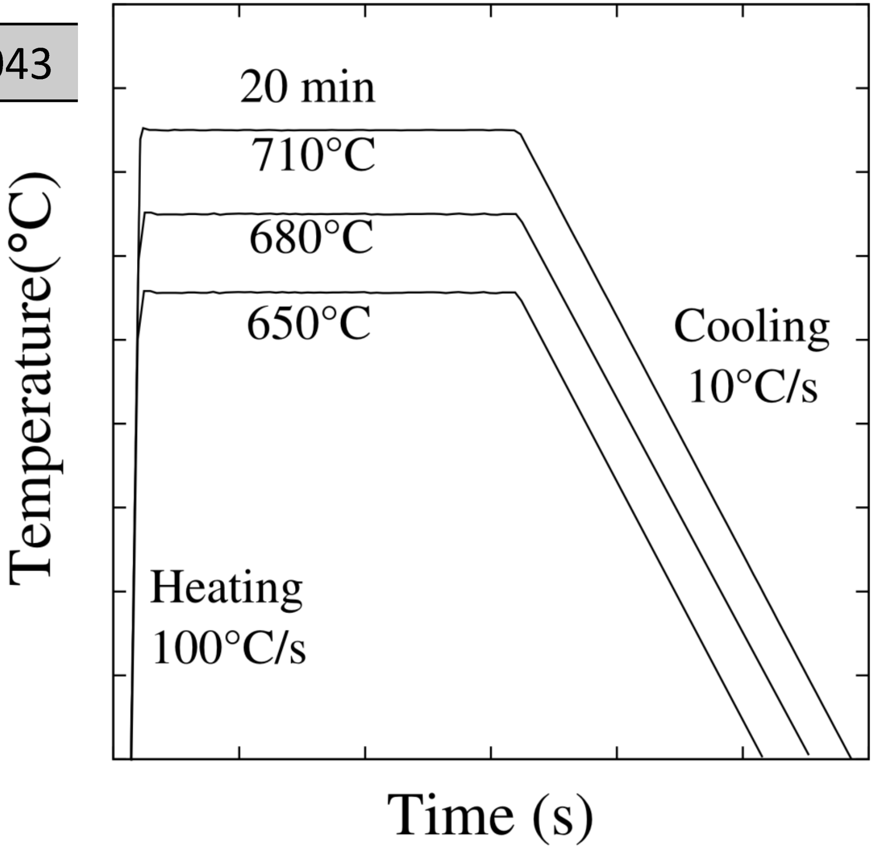
Dual Phase Steel 55% Cold Rolled

Key elements(wt%)

C	Mn	Si	Mo	Cr	Ni	Al
0.06	1.86	0.077	0.155	0.048	0.014	0.043

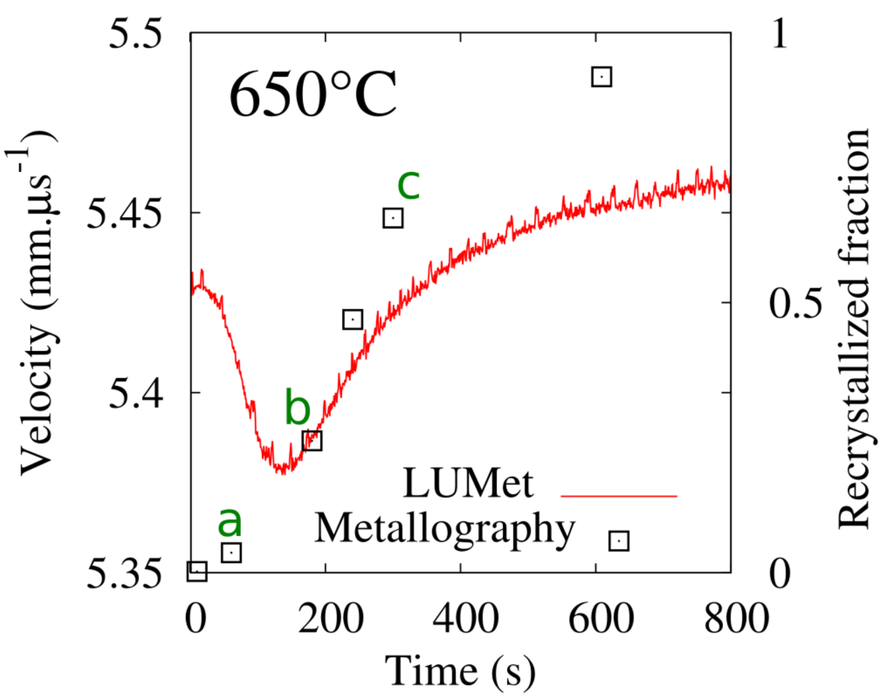
As Cold Rolled Recrystallized

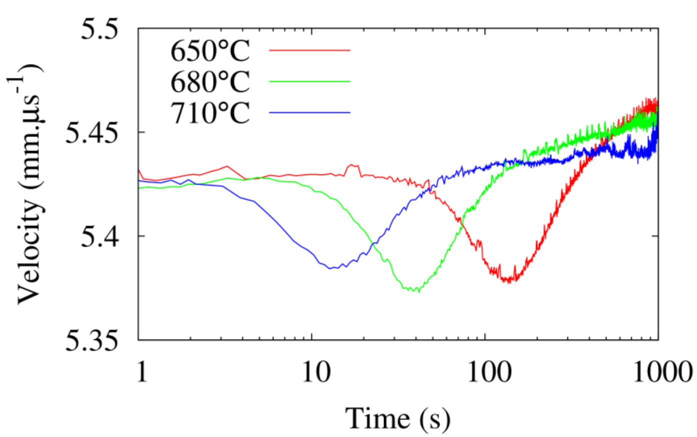




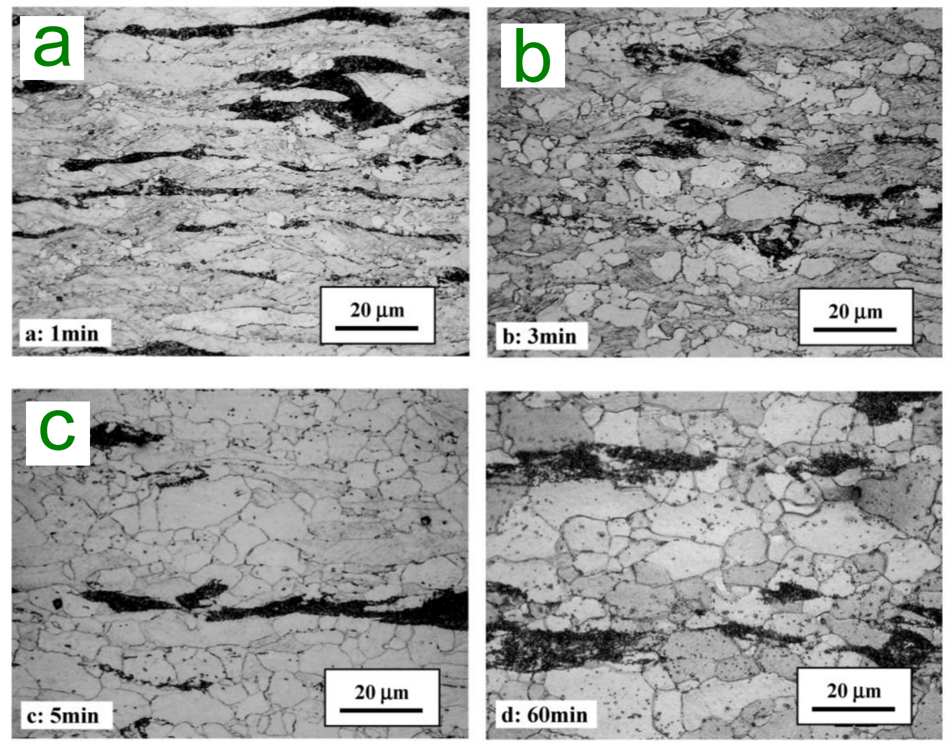
- Ultrasonic velocity measurements in Normal Direction during isothermal annealing

Velocity / Hardness measurements





Interrupt treatment at 650ºC



Why the velocity evolve in two steps during the recrystallization process ?
Is it the case for all steel compositions ?

Lever Rule Method

Segmentation of the velocity

↓

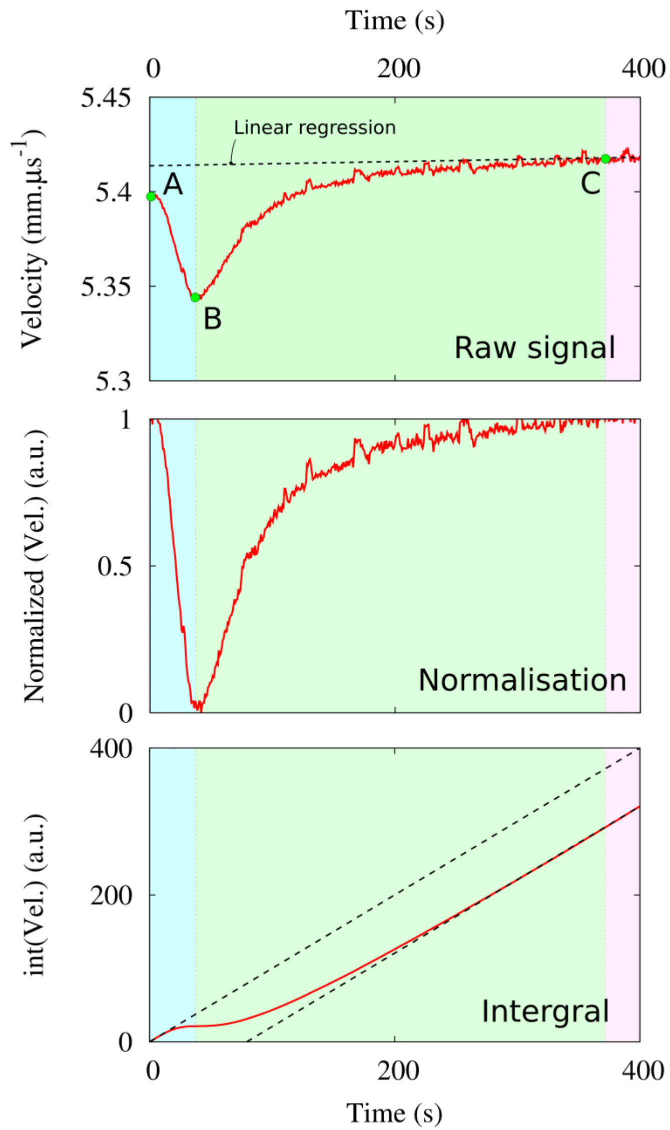
Normalisation of individual segment

↓

Integration of the normalized signal

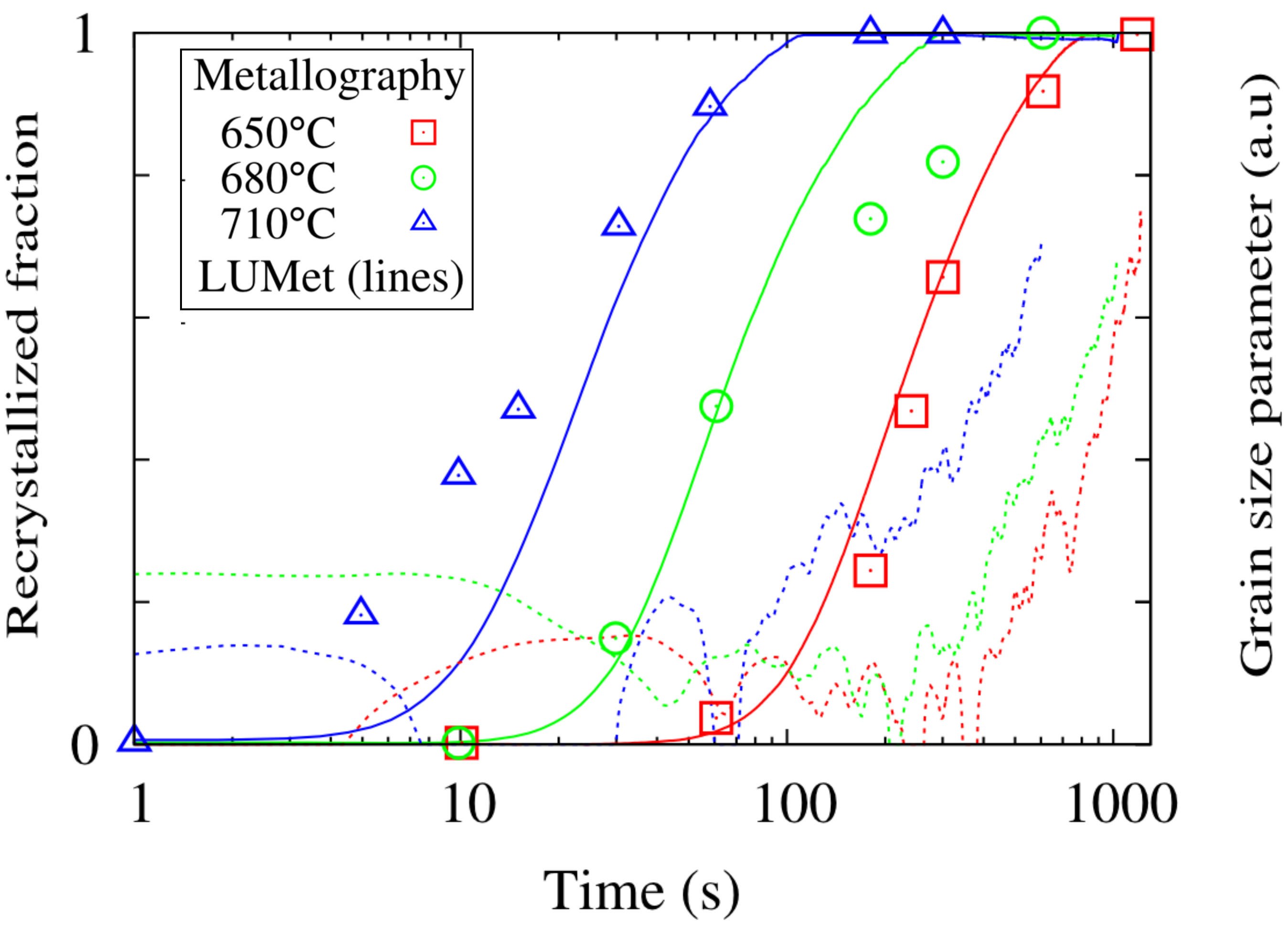
↓

Application of the lever rule



Fraction recrystallized
Grain size change

Continuous lines = Recrystallized fraction
Dotted lines = Grain size parameter



Conclusions & Perspectives

- Austenite static recrystallization, grain refinement
- Dynamic recrystallization, transformation, precipitation
- Other materials : Nickel base Super alloys, Aluminum alloys, HCP