Laser ultrasonics as a new research tool for the in-situ characterization of metallurgical processes

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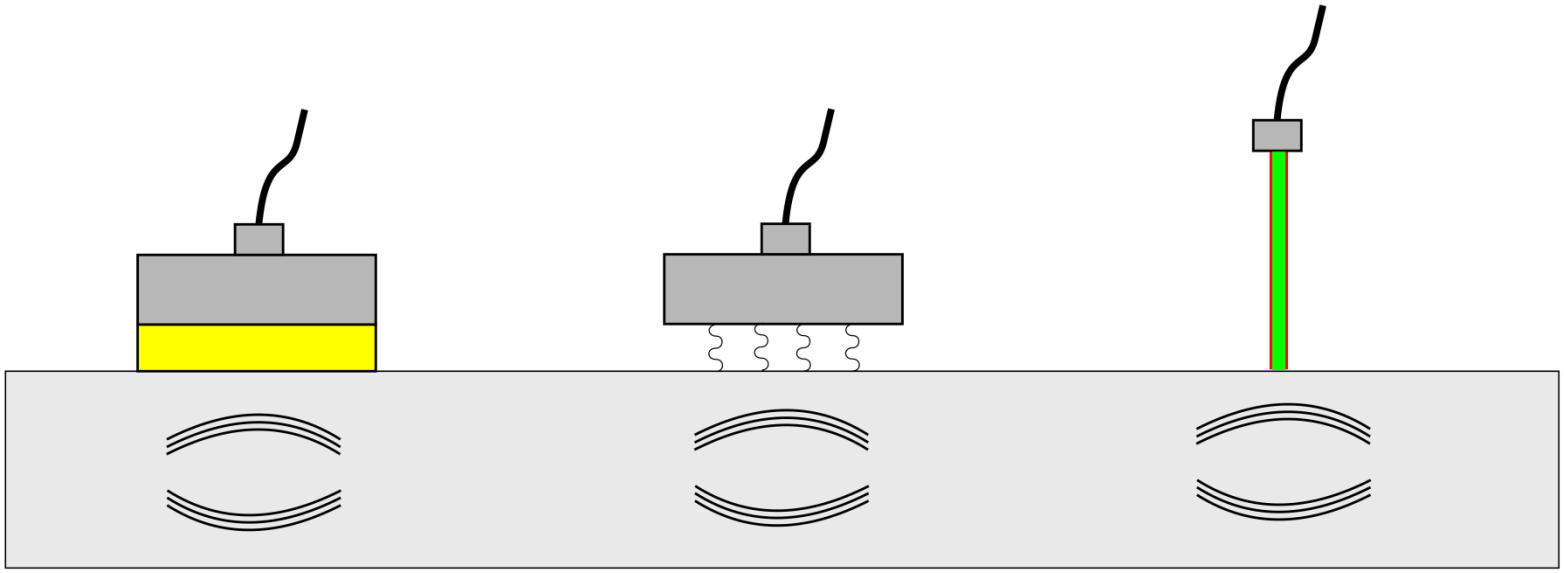
Evolution of ultrasonic sensors

Ultrasounds inspection of materials properties

Various class of sensors



Piezo-acoustic

Non-destructive

EMAT

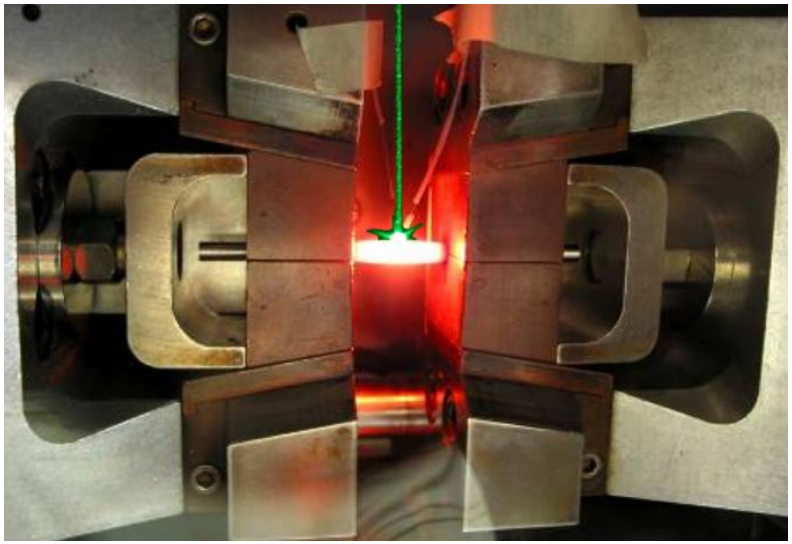
Non-contact

Laser ultrasonics

Remote

Introduction and Motivation

- Properties of ultrasonic waves depend on microstructure characteristics
- Laser ultrasonics measurement during thermo-mechanical simulation



NRC·CNRC Industrial Materials Institute

UBC

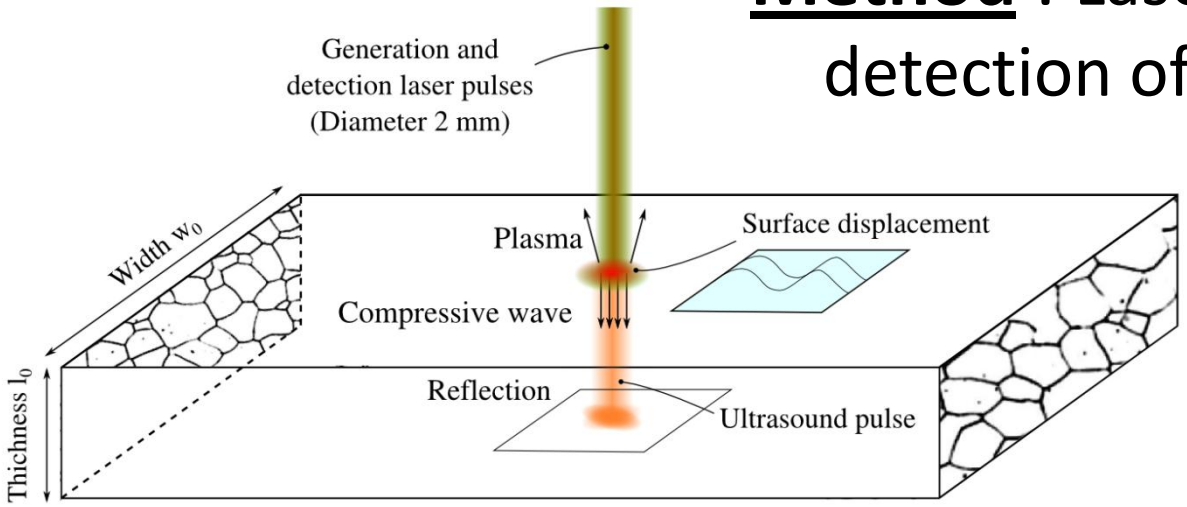
DSI® Dynamic Systems Inc.

TECNAR

Gleeble 3500
LUMet

Description of the technique

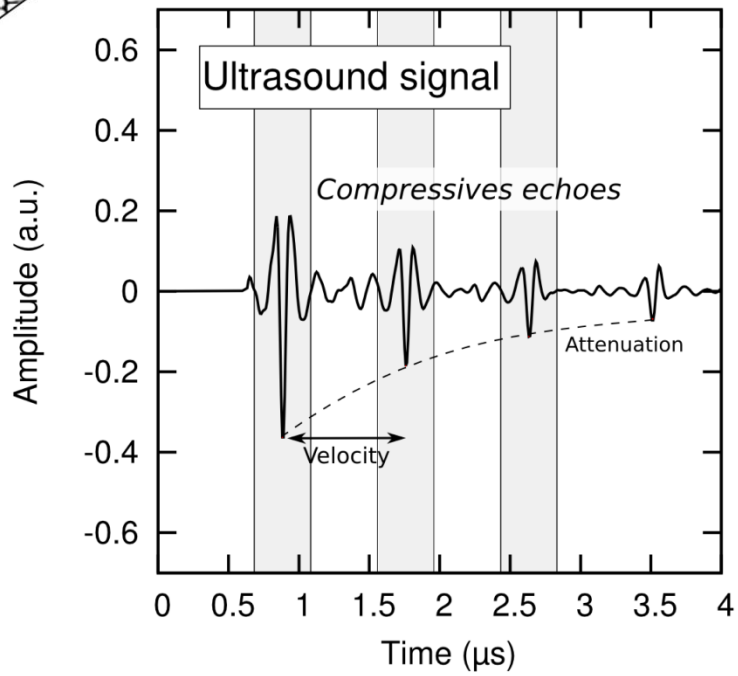
Method : Laser generation and detection of ultrasounds



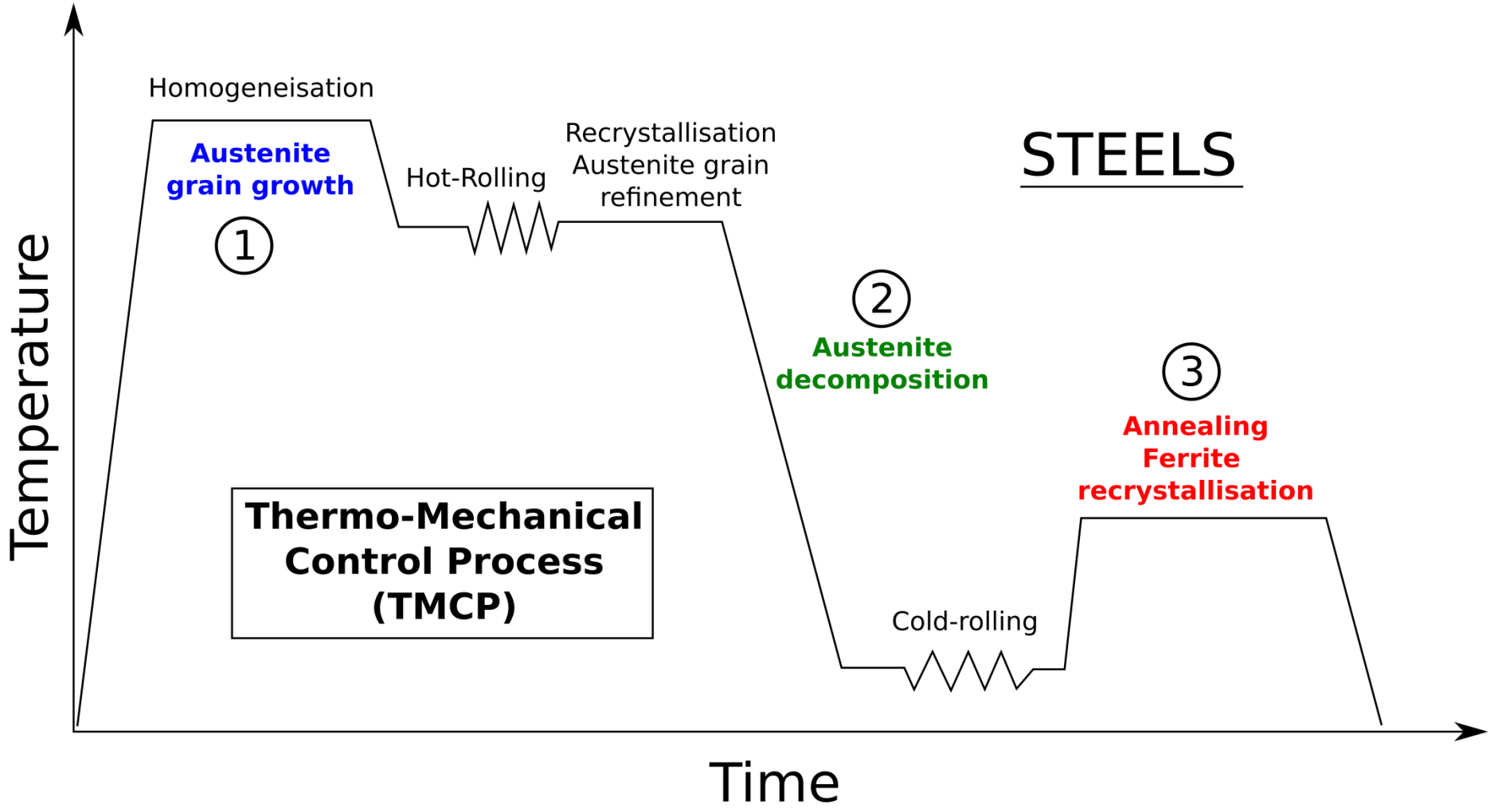
Parameters :

1- Velocity = Elasticity, density

2- Attenuation = Grain size, …



Contents


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

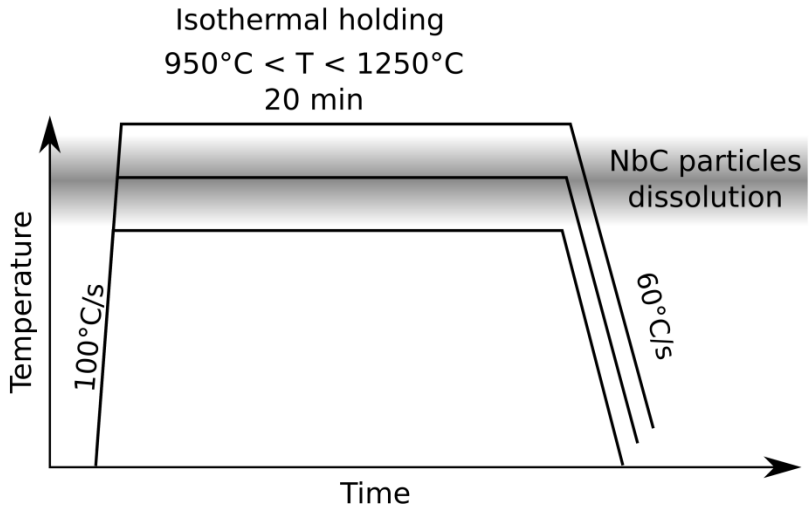
Austenite Grain size evolution

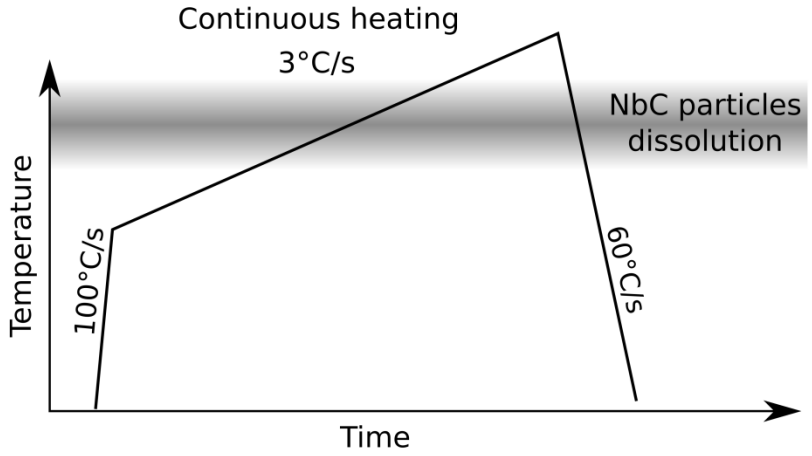
Linepipe Steel (X80)

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
- **Ultrasonic attenuation** measurements during austenite grain growth

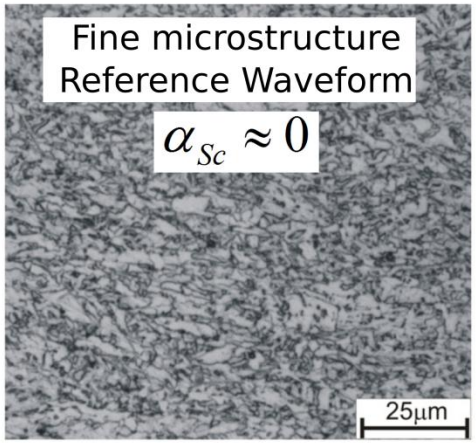


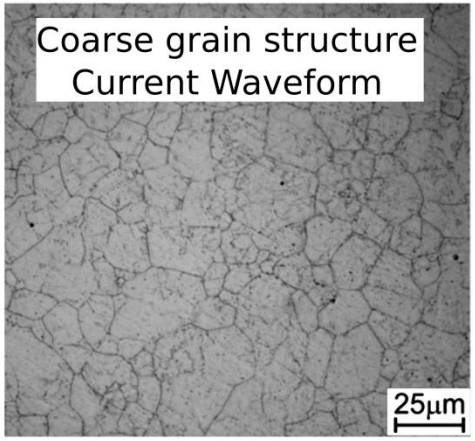


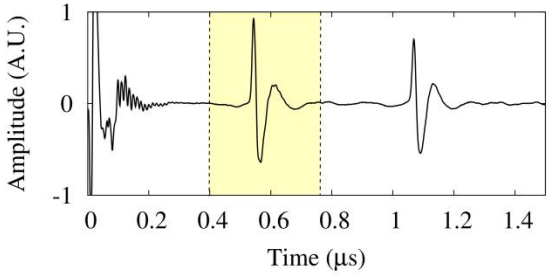
Method

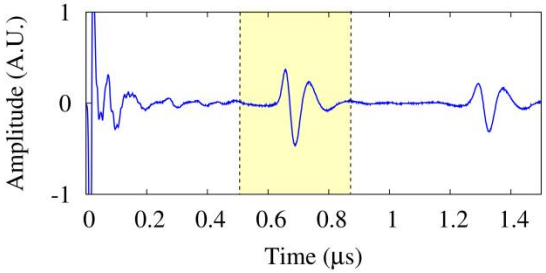
Grain size measurement from ultrasonic attenuation

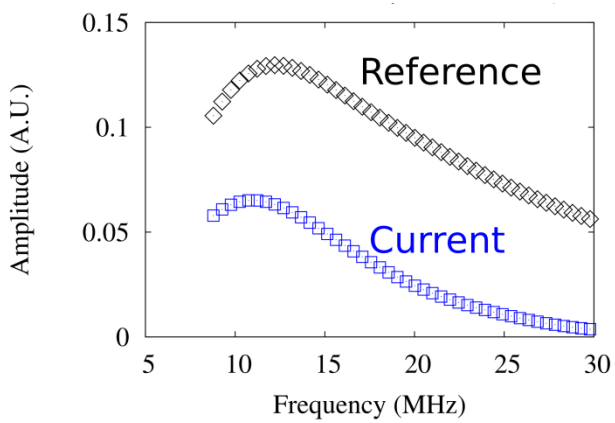
$$\alpha = \alpha_D + \alpha_{Sc}$$



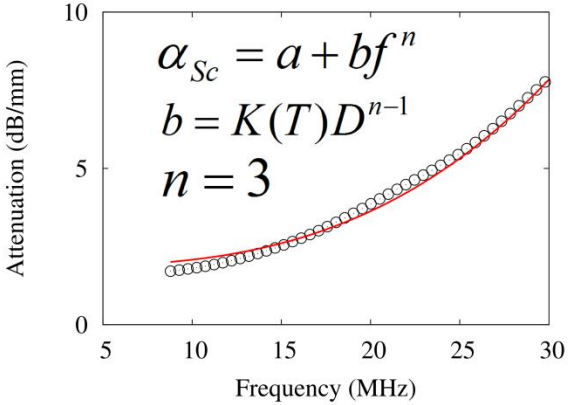








$$\alpha_{Sc} = \frac{20}{2e}\log\left(\frac{A_{Current}}{A_{Reference}}\right)$$

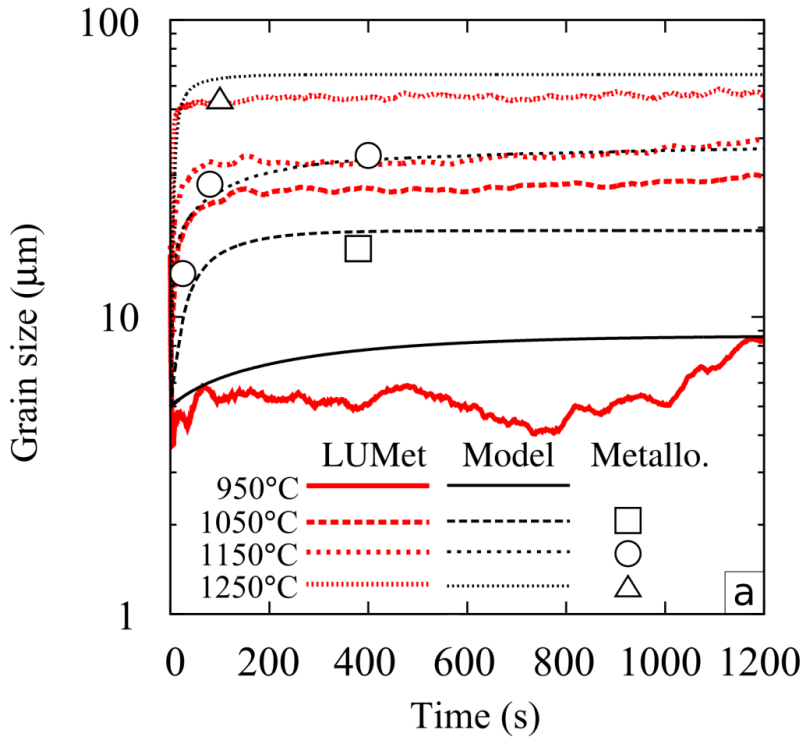


Calibration available for austenite in low alloy steel : S.E. Kruger et al., Iron Steel Technol, (2005), 2(10),25

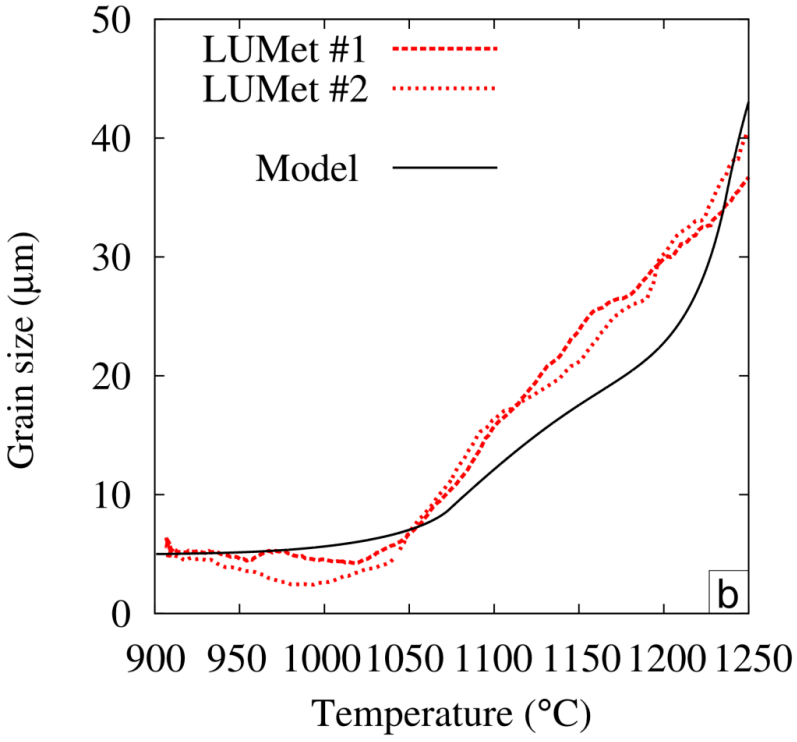
Results

Change in growth rate at the temperature where NbC precipitates begin to dissolve

Isothermal holding



Continuous heating



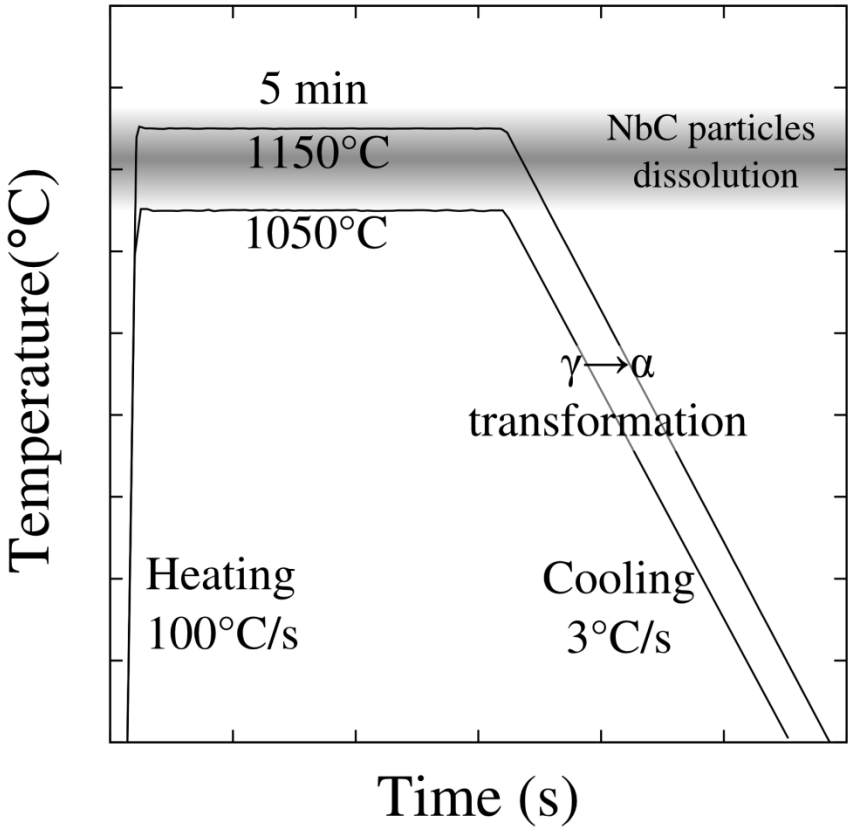
Austenite Decomposition

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



Method

Determination of ultrasonic velocity

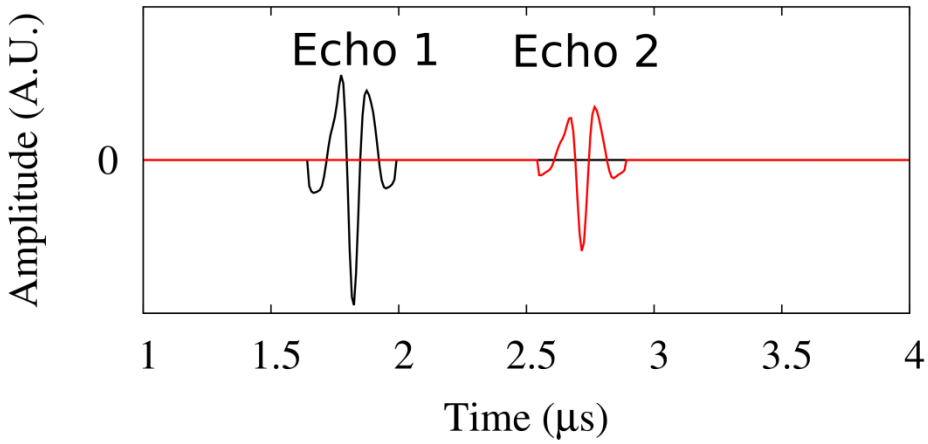
$$v_L = \frac{2(e+\varepsilon)}{delay}$$

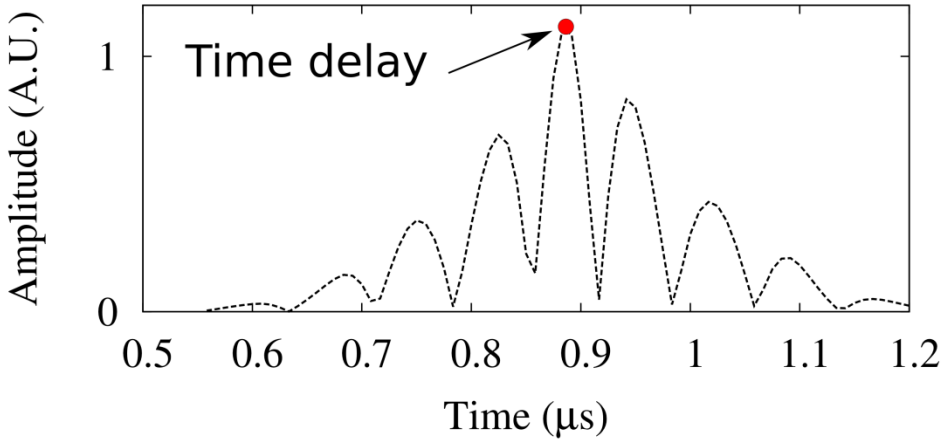
Propagation distance :

Thickness + Thermal expansion

Time delay :

Phase shift between two successive echoes by cross-correlation method





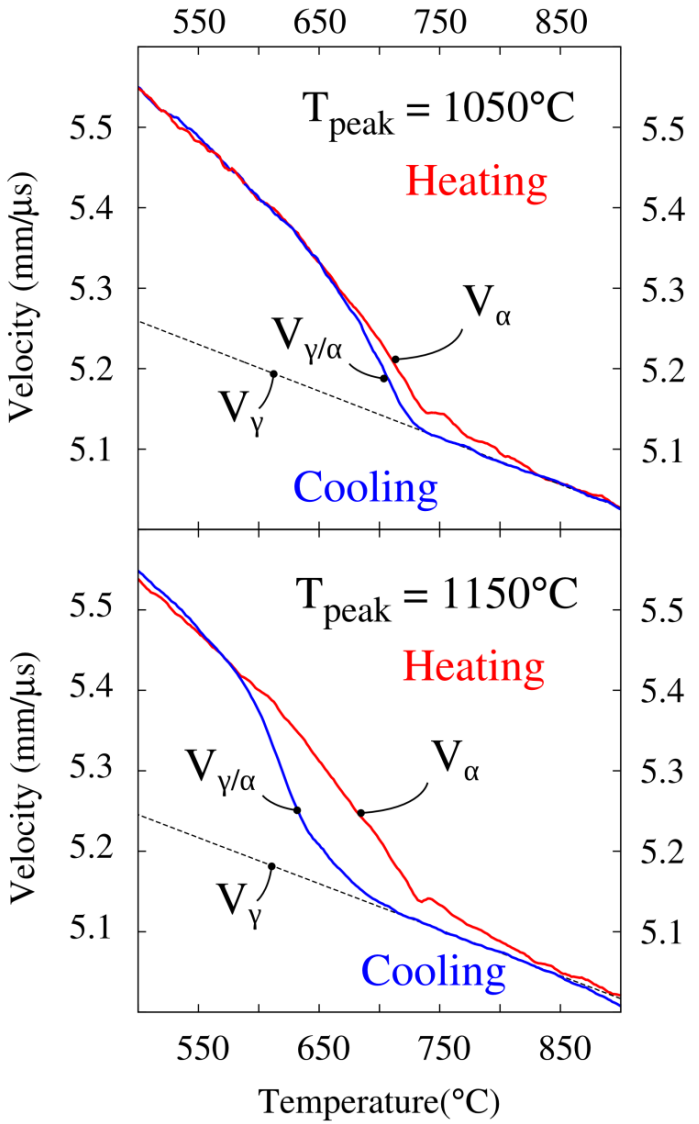
Velocity measurements

- Velocity difference between ferrite and austenite

$$v \cong \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

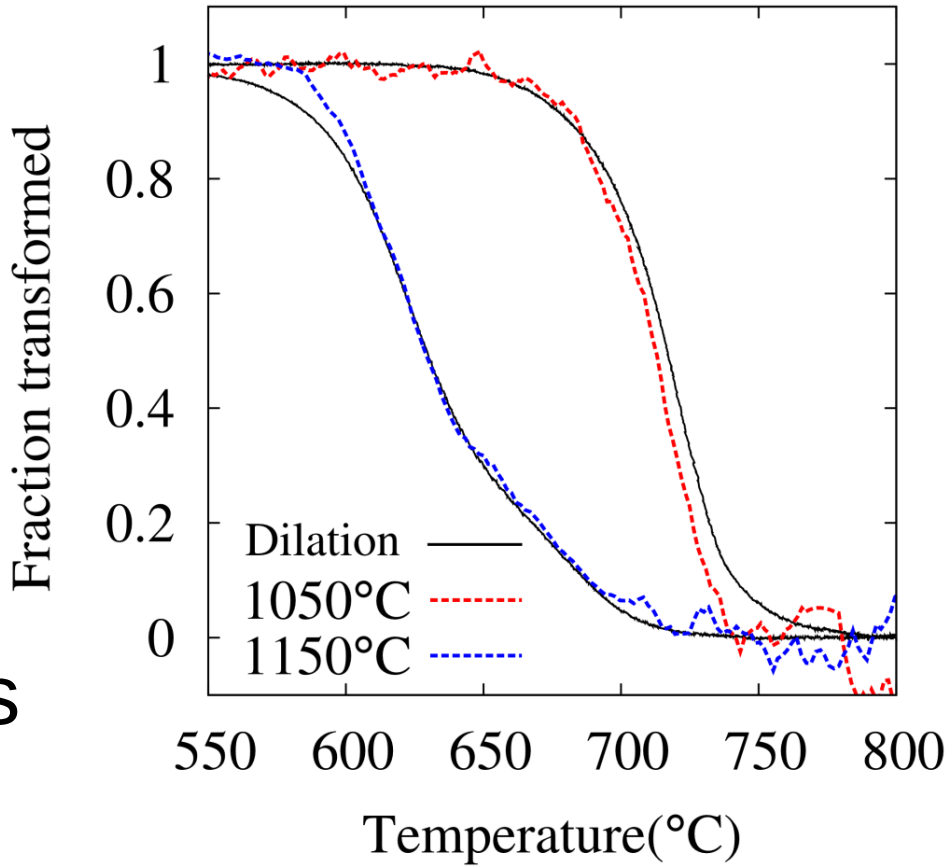
- Application of the lever-rule method on ultrasonic velocity

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



Fraction transformed

- Comparison of dilatometric and ultrasonic method
- Influence of Nb and prior austenite grain structure on transformation kinetics



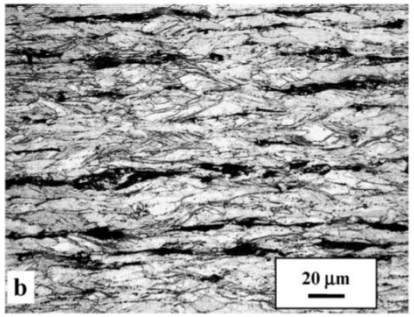
Ferrite recrystallization

Dual Phase Steel 55% Cold Rolled

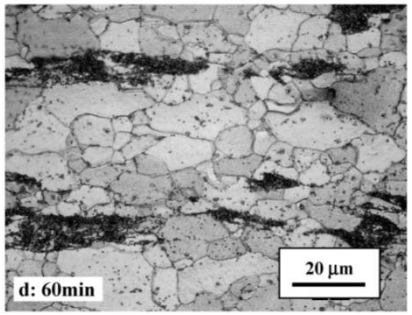
Key elements(wt%)

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

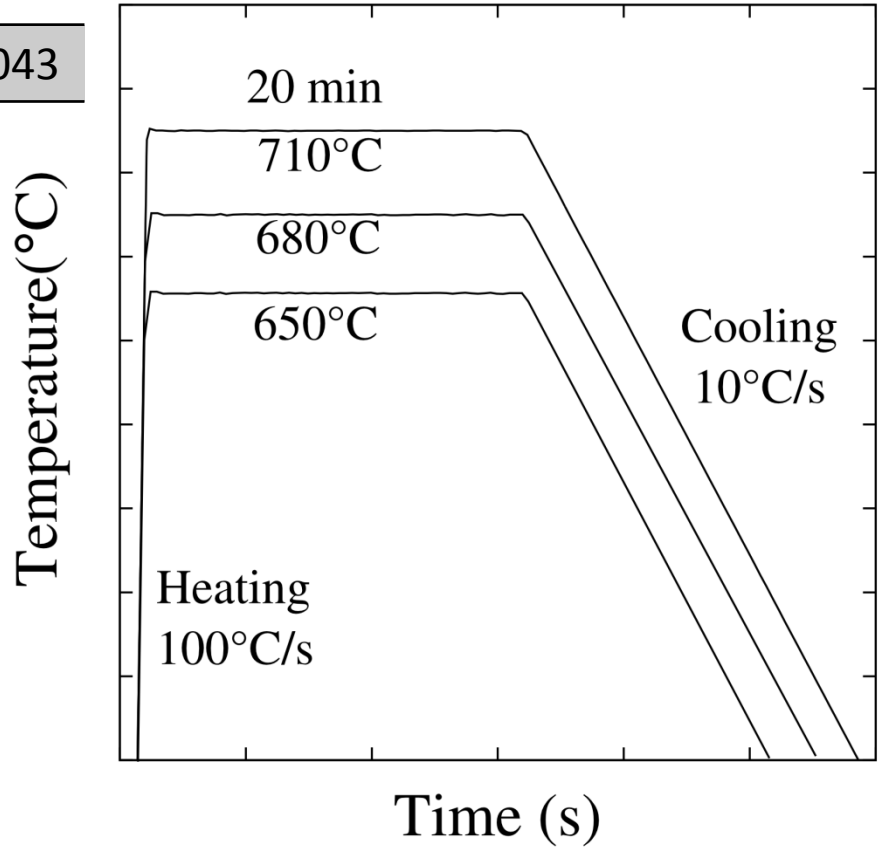
As Cold Rolled



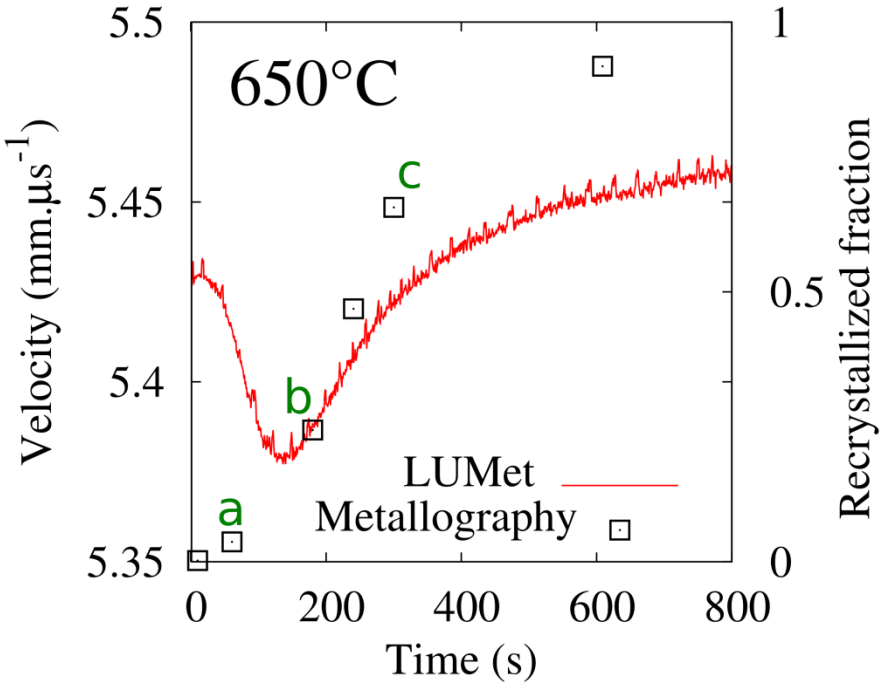
Recrystallized

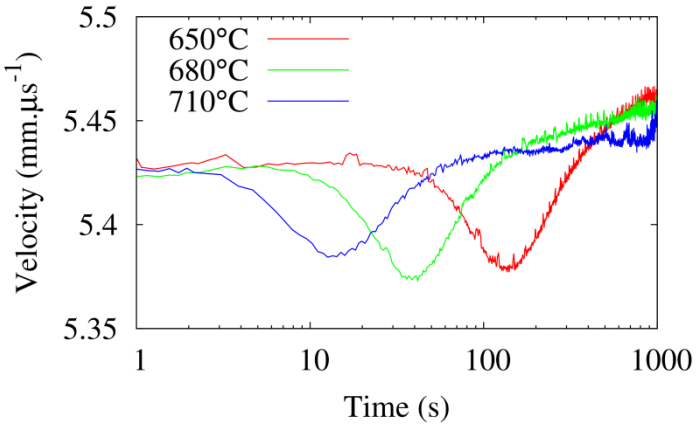


- Ultrasonic velocity measurements in Normal Direction during isothermal annealing

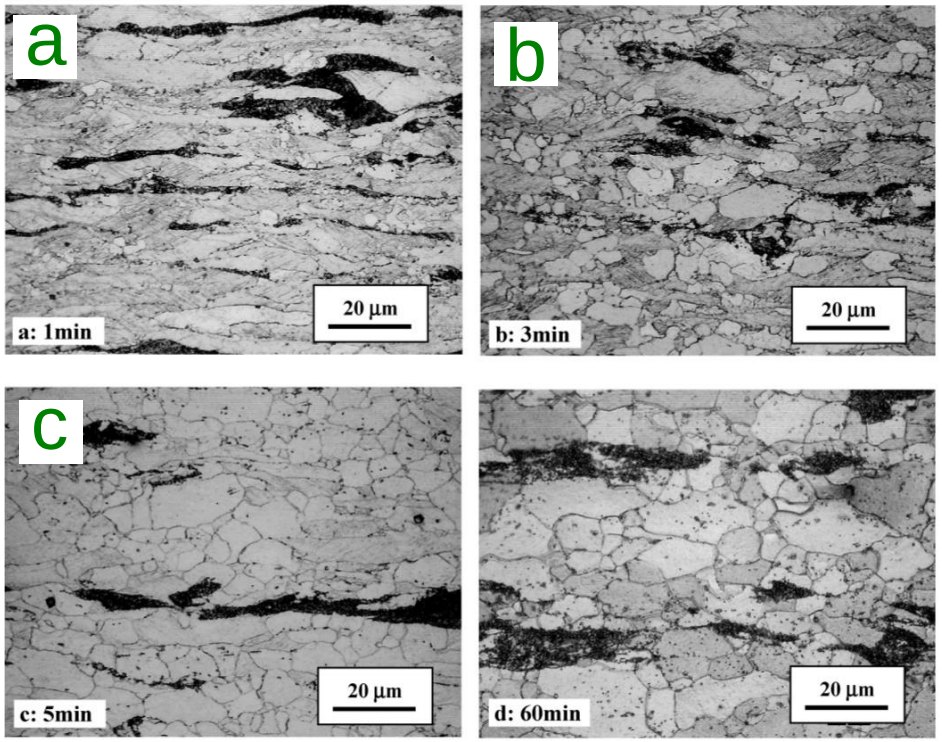


Velocity / Hardness measurements





Interrupt treatment at 650ºC



J. Huang et al. Metall. Mater. Trans. A, (2004), 35, 3363

Modification of the lever rule method for the evaluation of the recrystallization fraction

Lever Rule Method

Segmentation of the velocity

↓

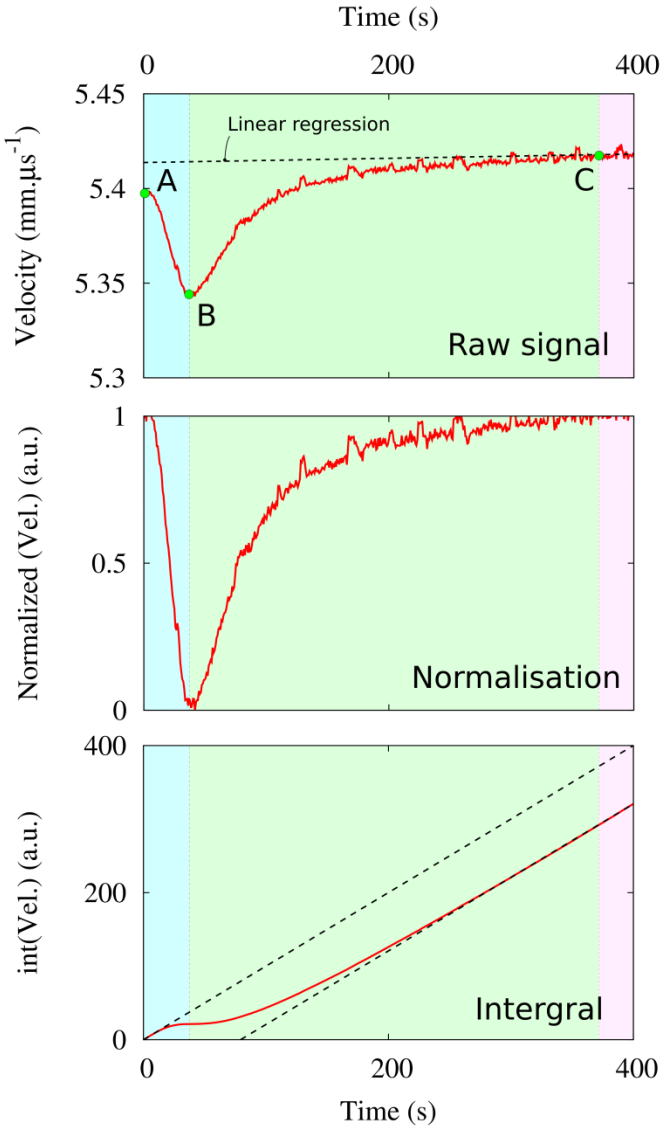
Normalisation of individual segment

↓

Integration of the normalized signal

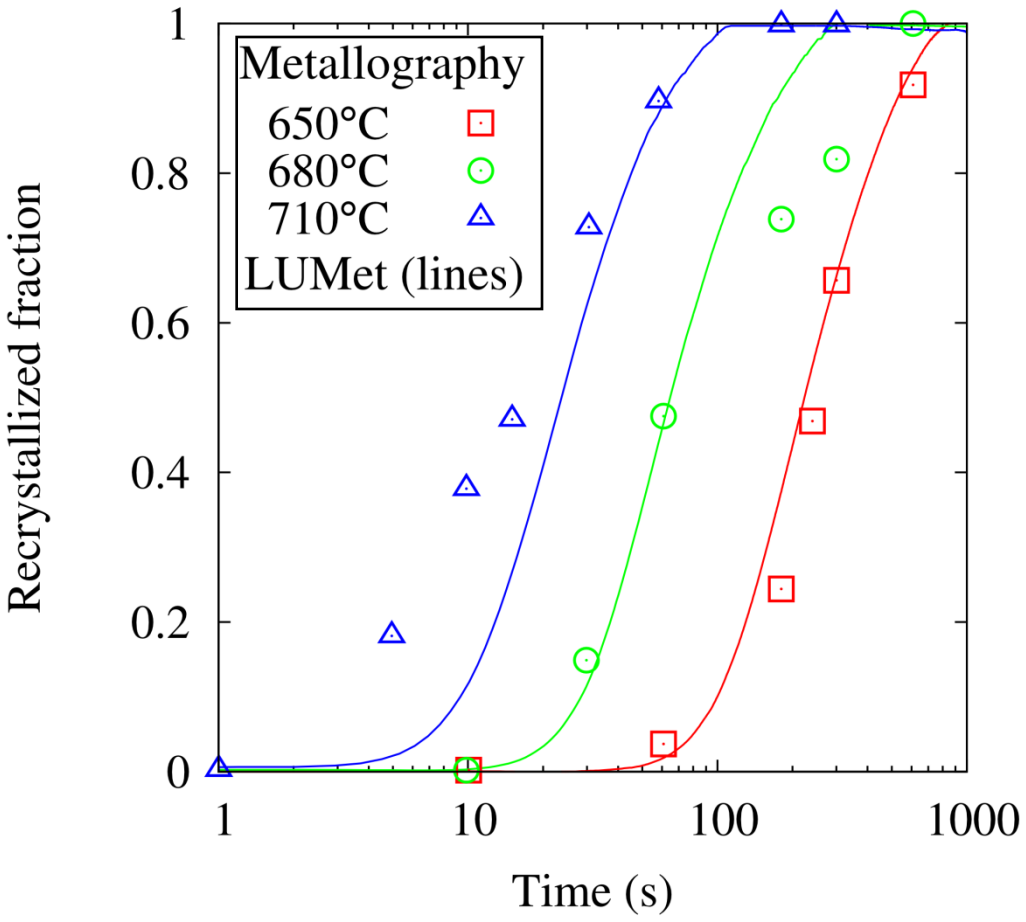
↓

Application of the lever rule



Results

- Characterization of ferrite recrystallization at various temperatures
- Measured evolution of the recrystallized fraction validated with metallographic observations



Conclusions

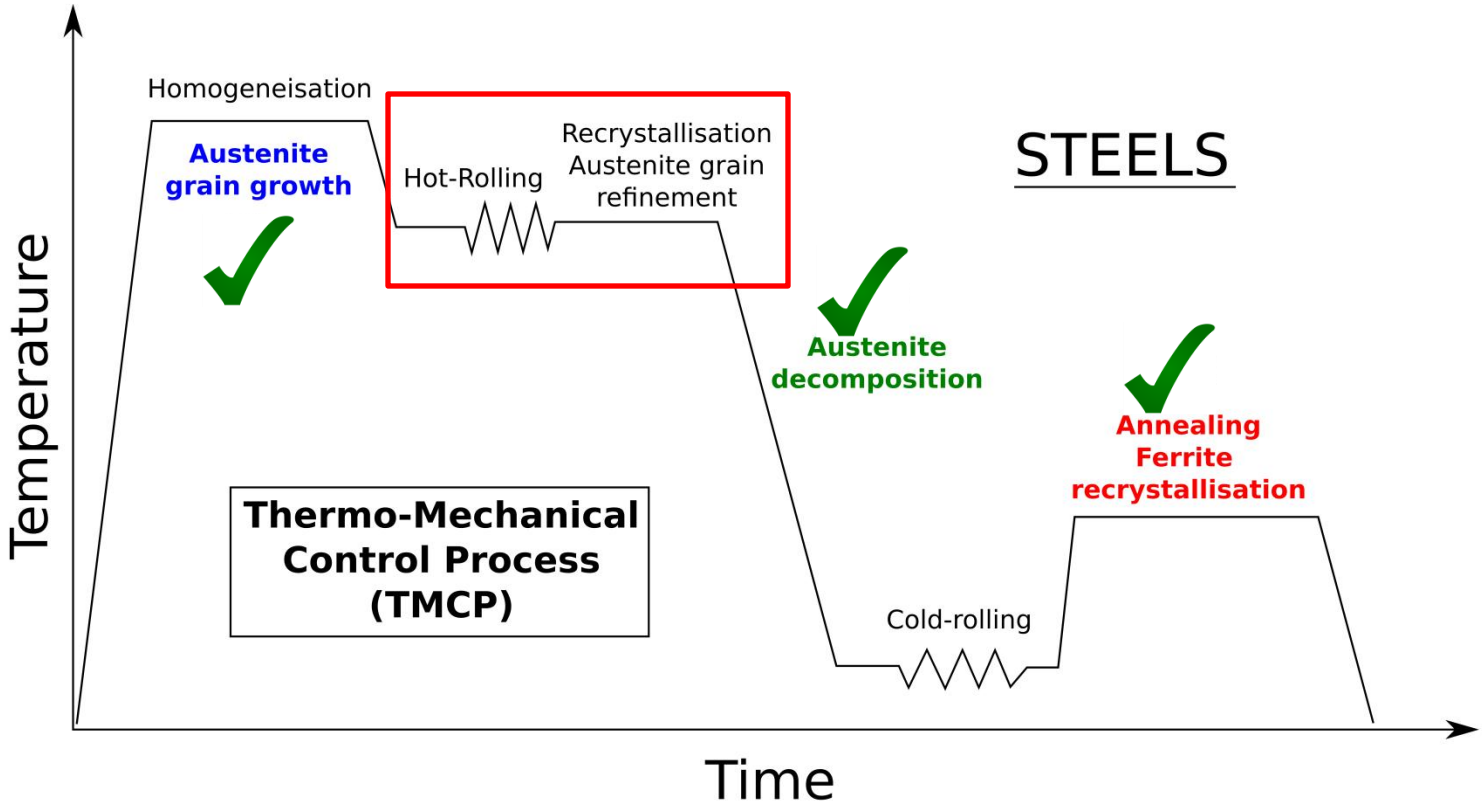
- New laser ultrasonics sensor LUMet attached to the Gleeble 3500
- Good measures of austenite grain size evolution as long as the grain structure correctly described by the average grain size
- Austenite decomposition kinetics remotely monitored when transformation lower than about 750ºC
- Ferrite recrystallization kinetics monitored using adapted lever rule method.

Perspectives

- Austenite static recrystallization, grain refinement

S. Sarkar et al. Metall. Mater. Trans. A (2008),39, 897

- Dynamic recrystallization, transformation, precipitation
- Other materials : Aluminum alloys, Nickel base Super alloys, HCP



Acknowledgments

Microstructure analysis and microstructure modelling

F. Fazeli, K. Banerjee, M. Maalekian, R. Radis, R. Tafteh, J. Huang

Ultrasound analysis

Andre Moreau, Industrial Materials Institute, National Research Council Canada

Financial support

Natural Sciences and Engineering Research Council (NSERC) of Canada

Canada Foundation for Innovation

Evraz Inc. NA

TransCanada Pipelines Ltd