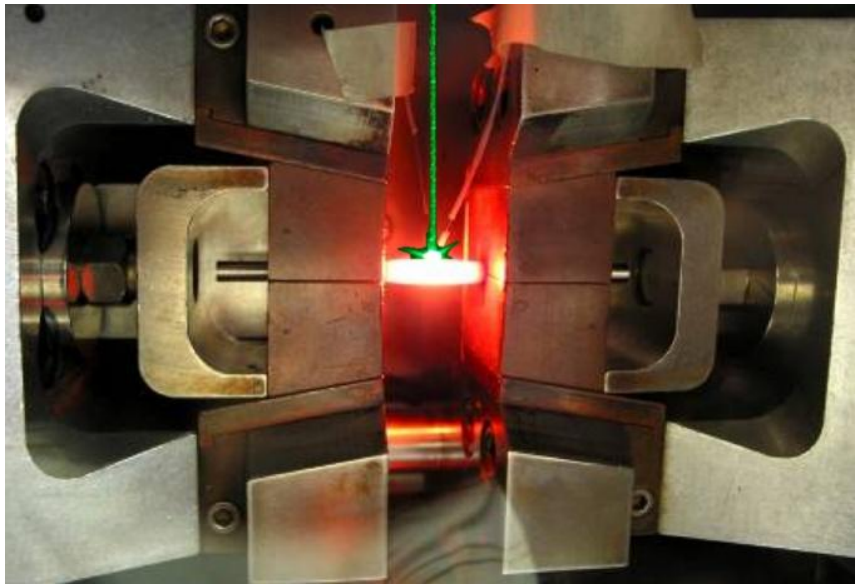
The Application of Laser Ultrasonics to Welding Simulations on a Gleeble 3500

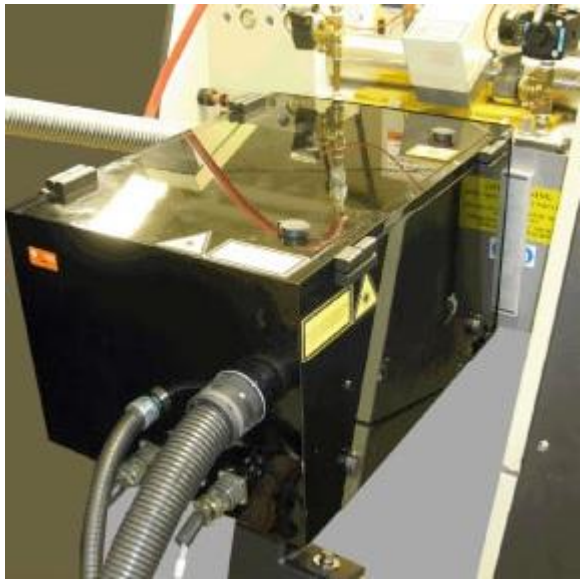
Thomas Garcin[1], Matthias Militzer[1], Warren J. Poole[1]

[1]The Centre for Metallurgical Process Engineering,
The University of British Columbia, Vancouver, BC, Canada

Laser Ultrasonic for Metallurgy (LUMet)

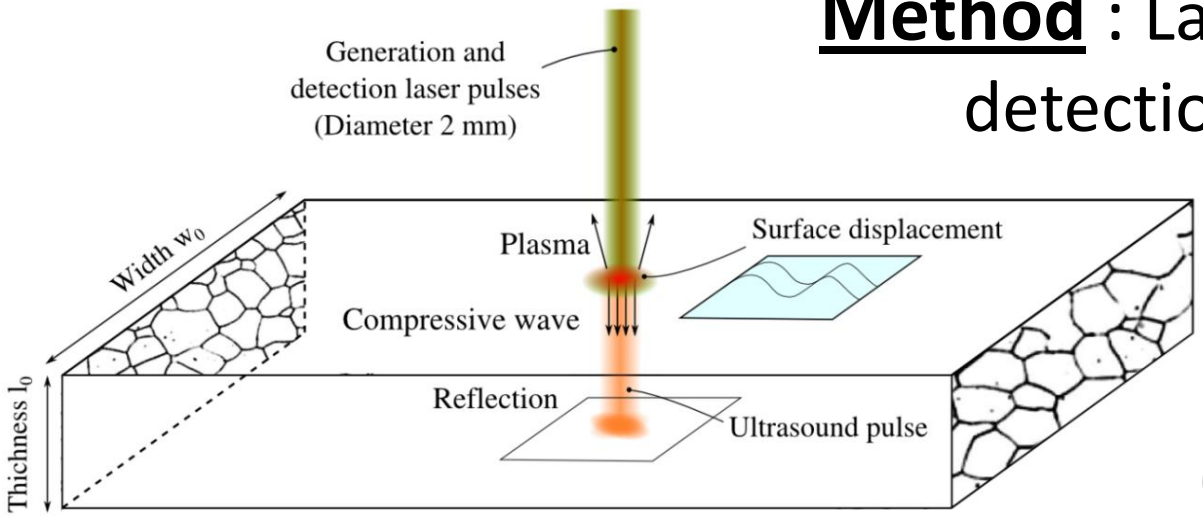
- Properties of ultrasonic waves depend on microstructure characteristics
- Laser ultrasonics measurement during thermo-mechanical simulation





Description of the technique

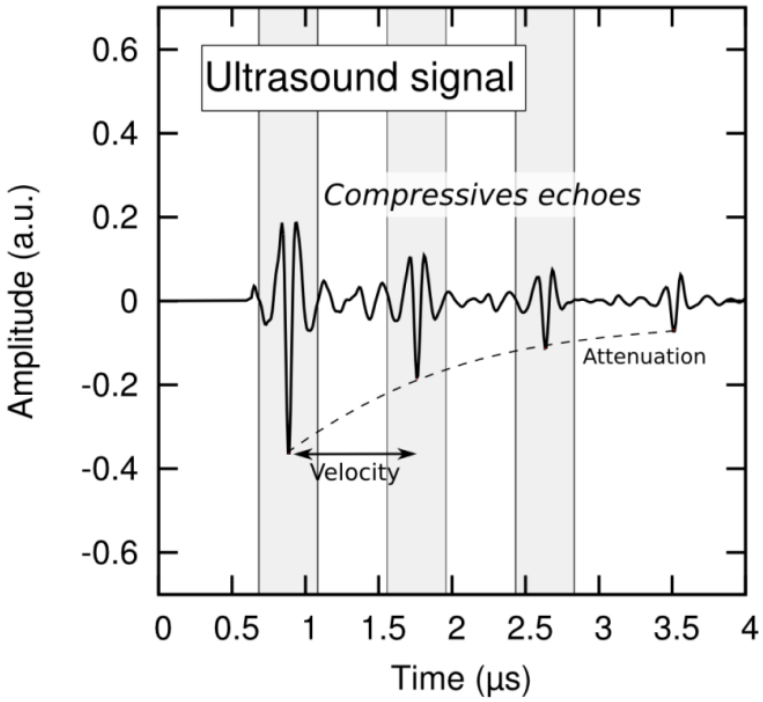
Method : Laser generation and detection of ultrasounds



Parameters :

1- Velocity = Elasticity, density

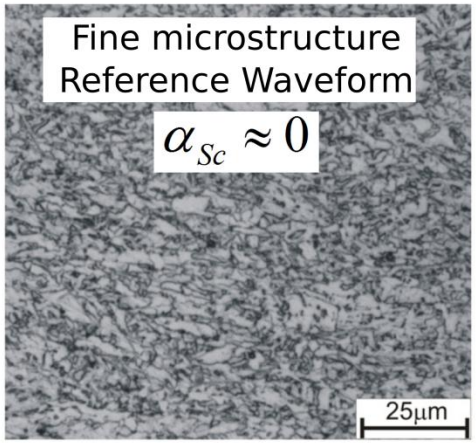
2- Attenuation = Grain size, …

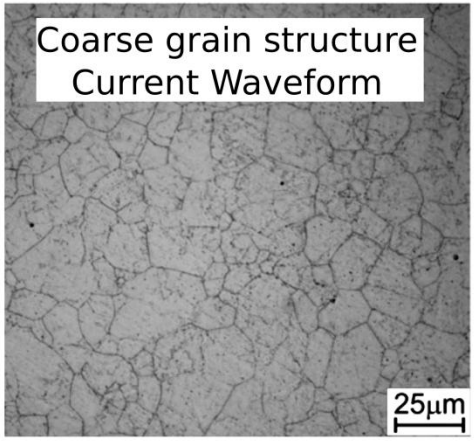


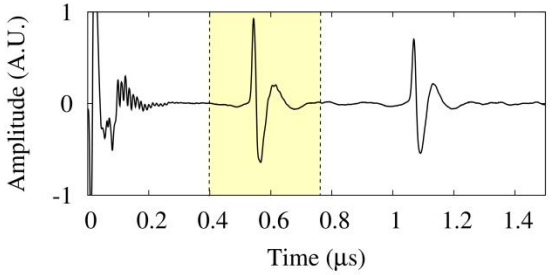
Method

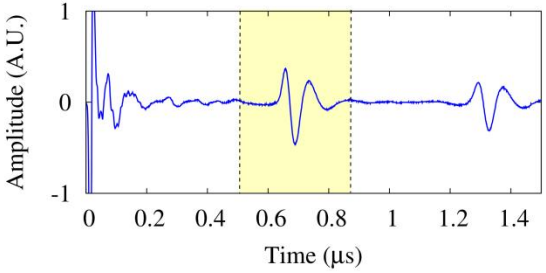
Grain size measurement from ultrasonic attenuation

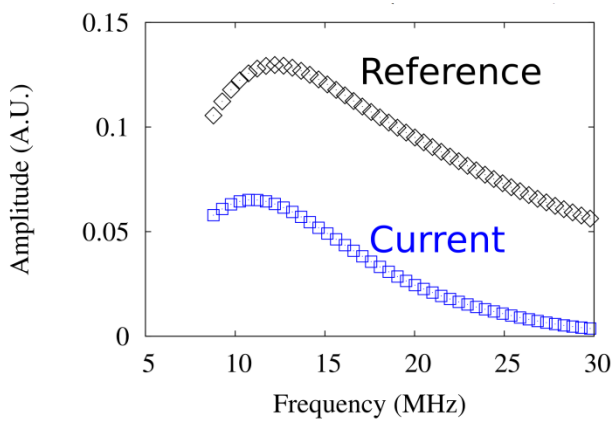
$$\alpha = \alpha_D + \alpha_{Sc}$$



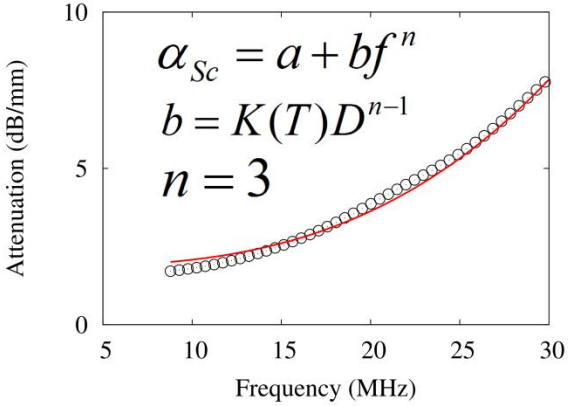








$$\alpha_{Sc} = \frac{20}{2e}\log\left(\frac{A_{Current}}{A_{Reference}}\right)$$



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

Method

Determination of ultrasonic velocity

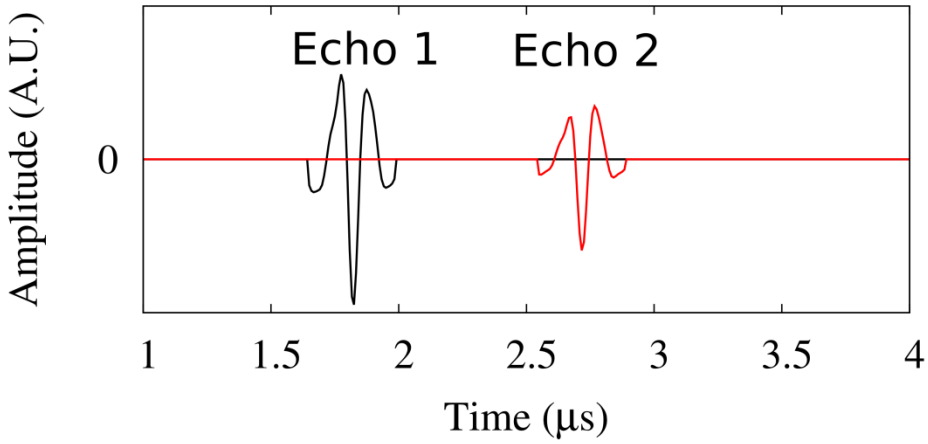
$$v_L = \frac{2(e+\varepsilon)}{delay}$$

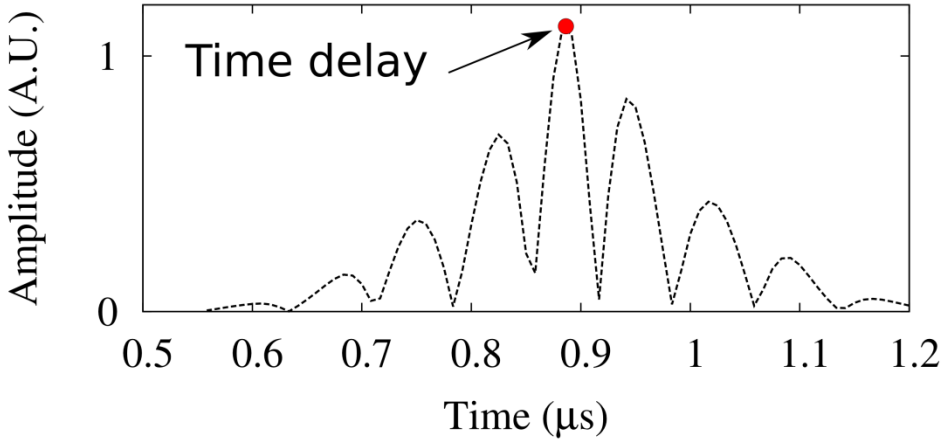
Propagation distance :

Thickness + Thermal expansion

Time delay :

Phase shift between two successive echoes by cross-correlation method





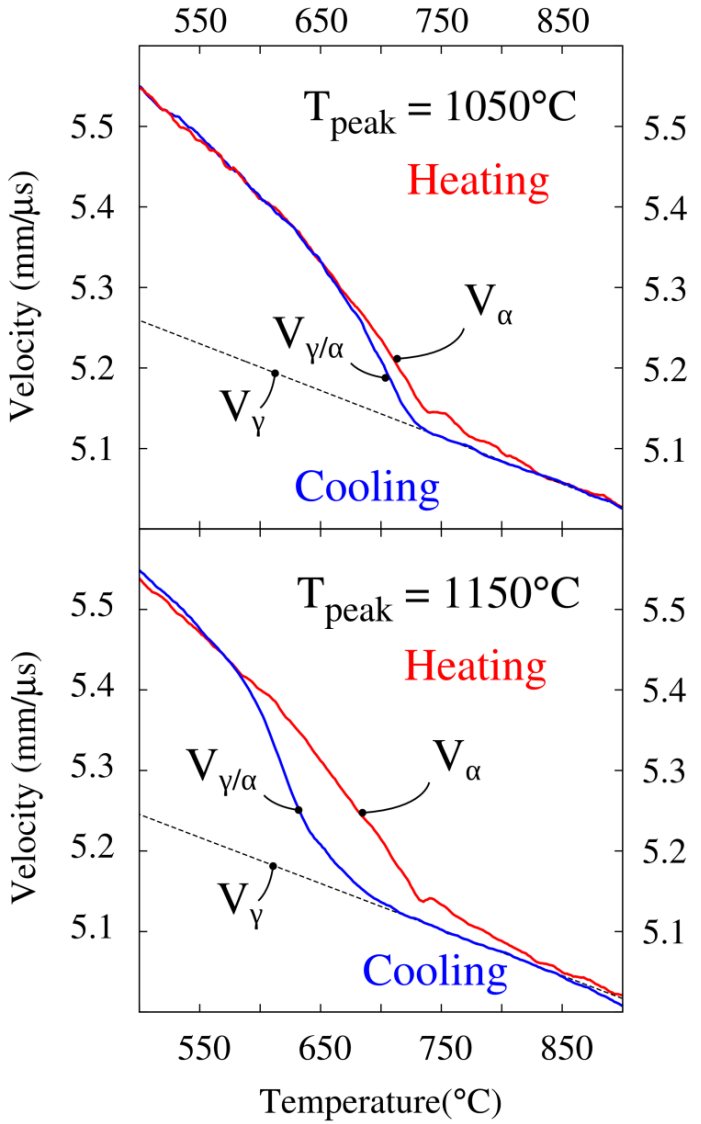
Velocity measurements

- Velocity difference between ferrite and austenite

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

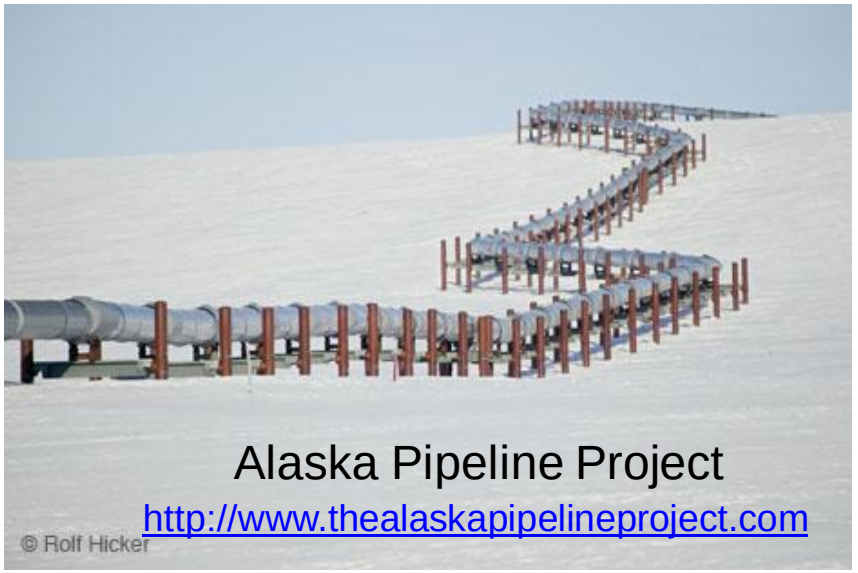
- Application of the lever-rule method on ultrasonic velocity

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

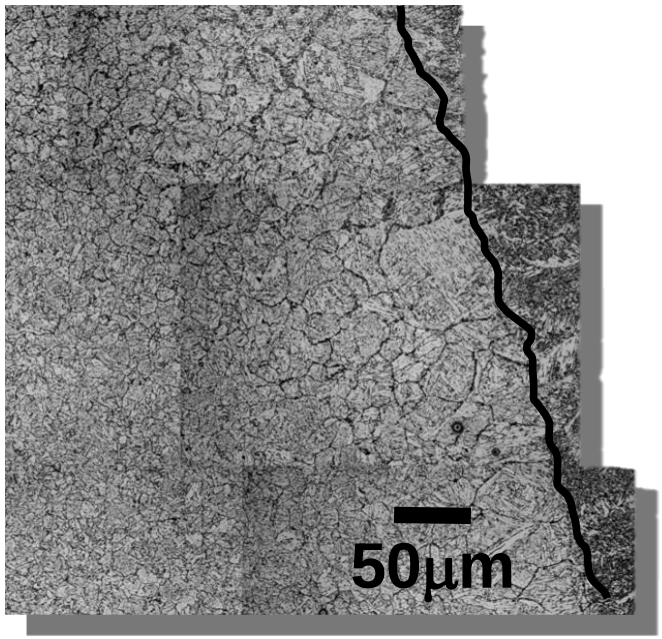


Application to welding simulation

- Advance High Strength Steels for pipeline construction
- Joining of pipes leads to HAZ with weaker mechanical properties.
- LUMet+Gleeble : Highly accelerate the development of microstructure modeling tools

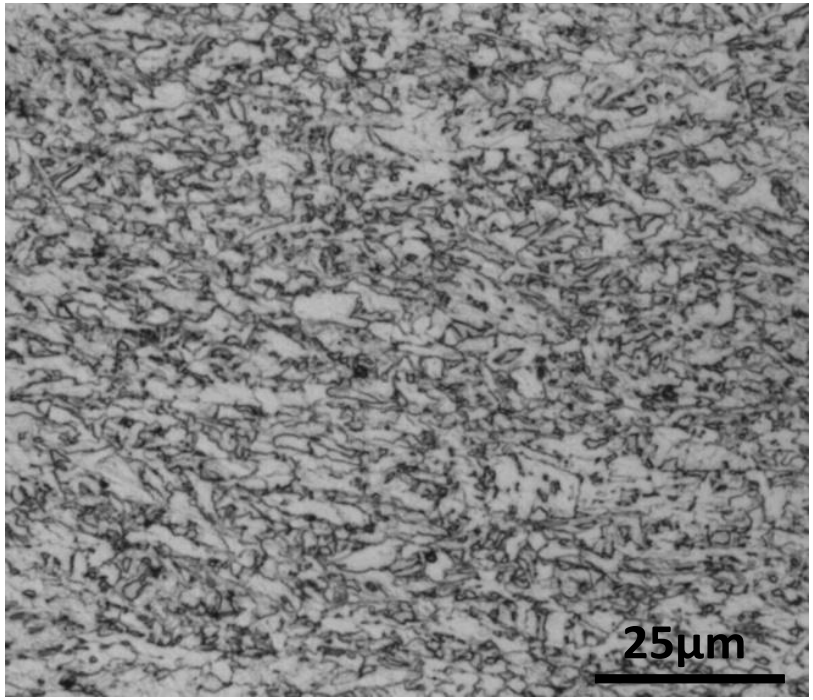


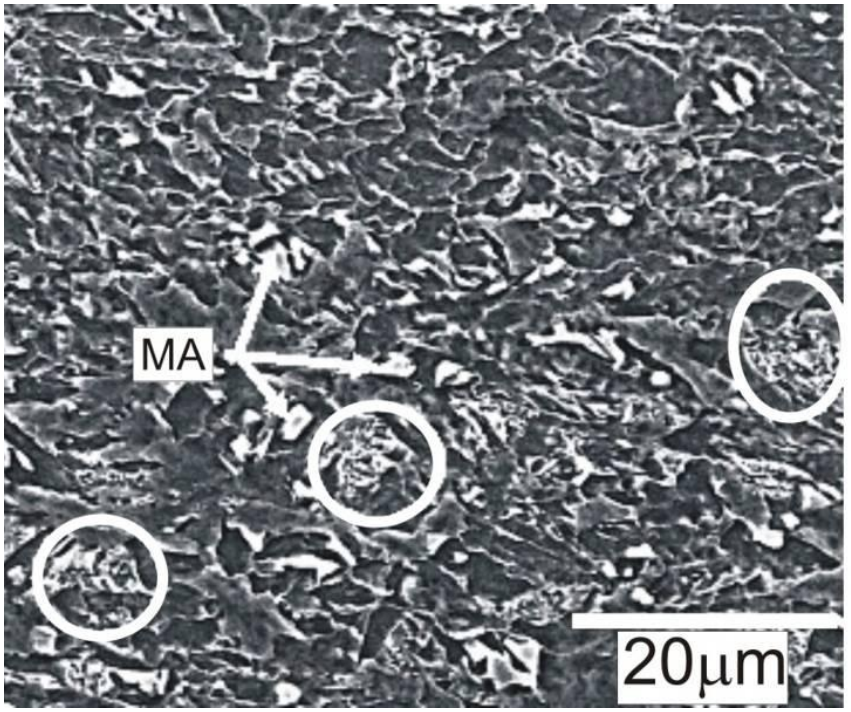
Alaska Pipeline Project
http://www.thealaskapipelineproject.com



X-80 Linepipe Steel (as received)

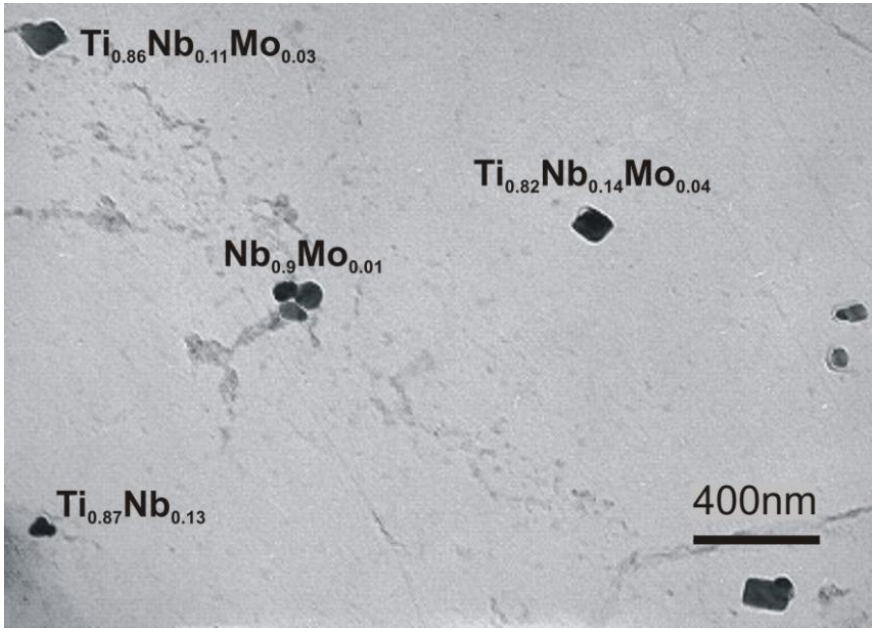
	C	Mn	Nb	Ti	Mo	N
(wt pct)	0.06	1.65	0.034	0.012	0.24	0.005

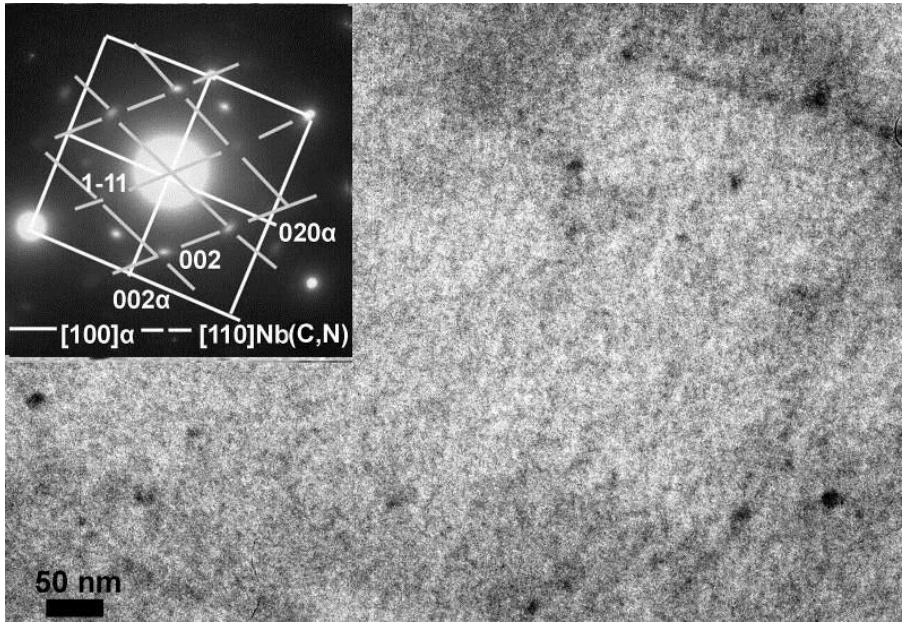




Fine ferrite with martensite and austenite (MA) constituents

Precipitates in as received X-80 Steel





Ti, Nb and Mo containing precipitates

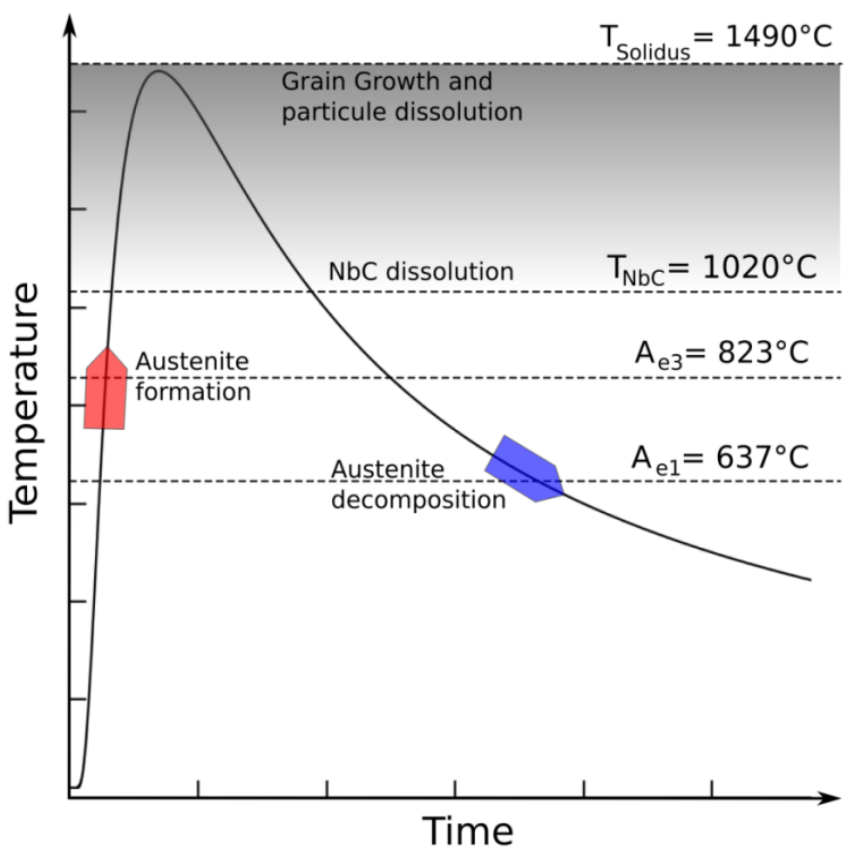
Small and coarse NbCN

Application of LUMet to X80 linepipe steel

Monitoring of the microstructure evolution during rapid thermal cycle

1) Austenite grain growth and Nb precipitates interaction

2) Austenite decomposition

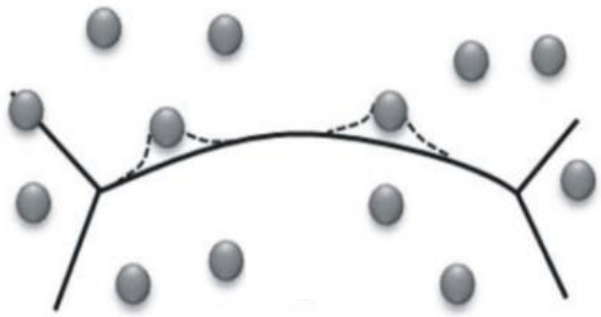


Austenite Grain Growth

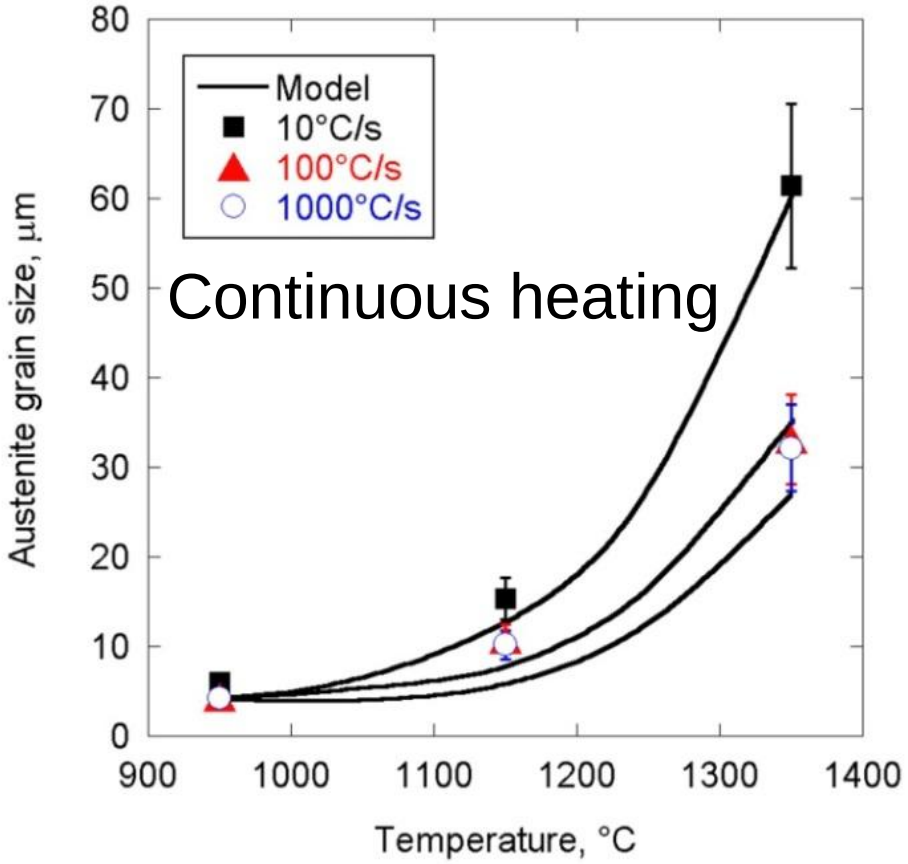
1) **Grain growth** affected by the presence of precipitates

$$\frac{dD}{dt} = M\left(\frac{\alpha\gamma}{D} - P_z\right)$$

2) **Pinning force** due to precipitates
3) **Dissolution** of precipitates

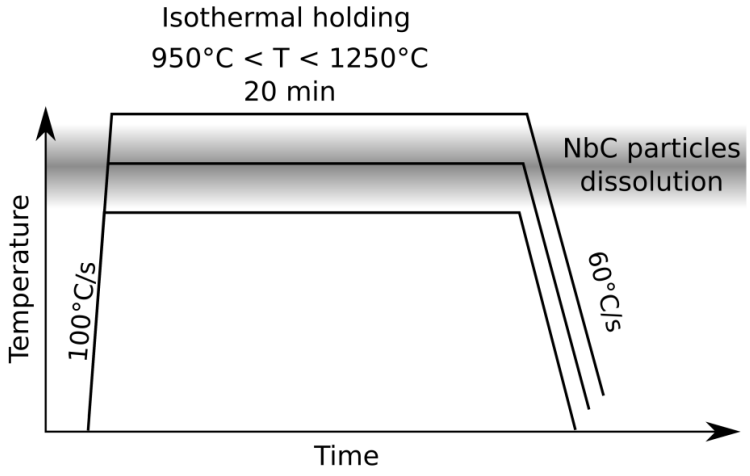


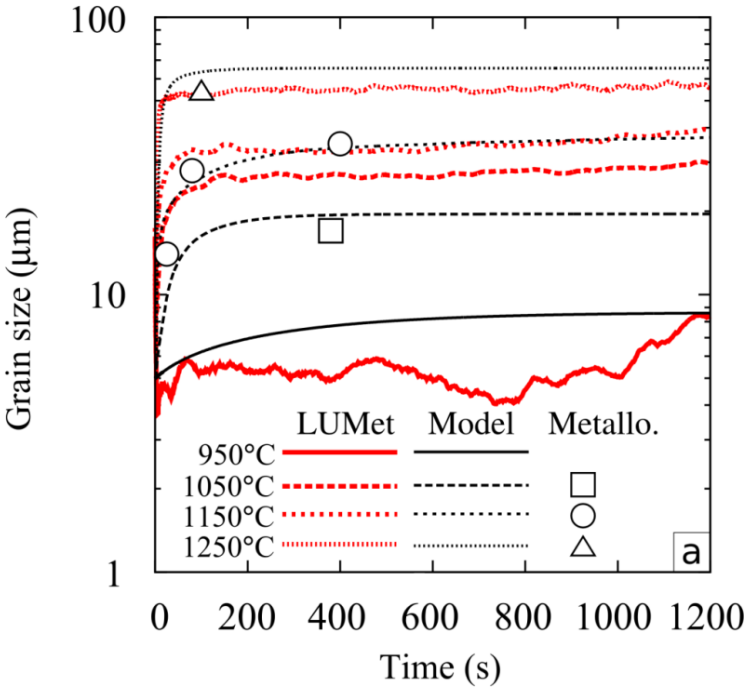
Conventional metallography



Austenite grain size measurement

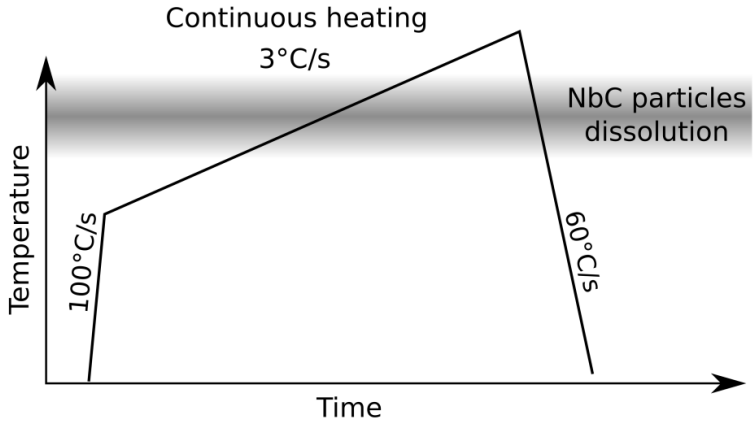
- Isothermal holding between 950 and 1250°C in X80 steel
- At 1050°C, the LUMet grain size is larger than the comparison data
- Grain coarsening temperature associated with the beginning of the dissolution of NbC precipitates.

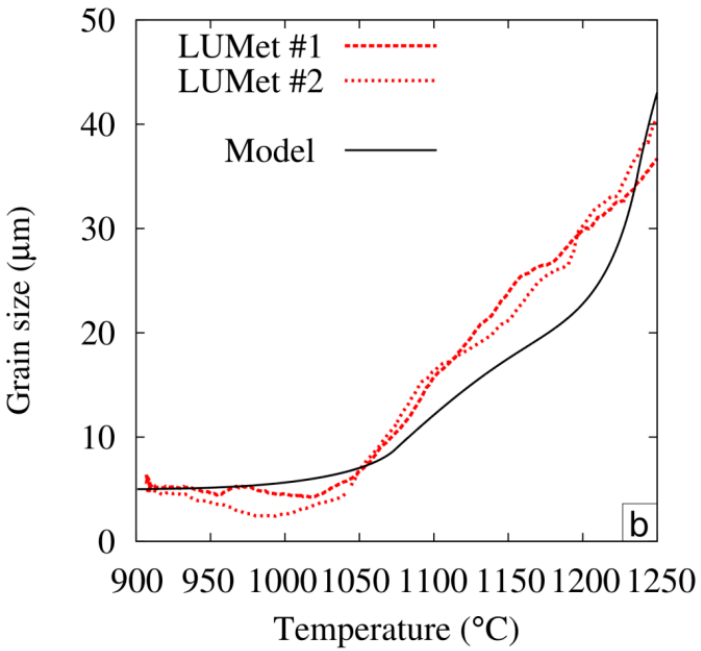




Grain growth and precipitates interaction

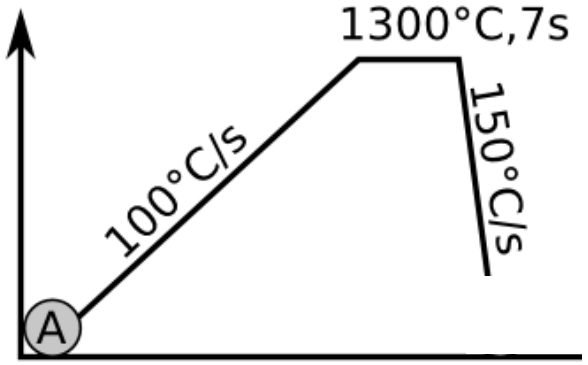
- Continuous heating grain growth tests in X80 steel
- Below 1050°C, grain size stays relatively small due to the strong grain boundary pinning associated with the presence of NbC precipitates.
- Above this temperature, NbC precipitates dissolve: increase of the grain growth

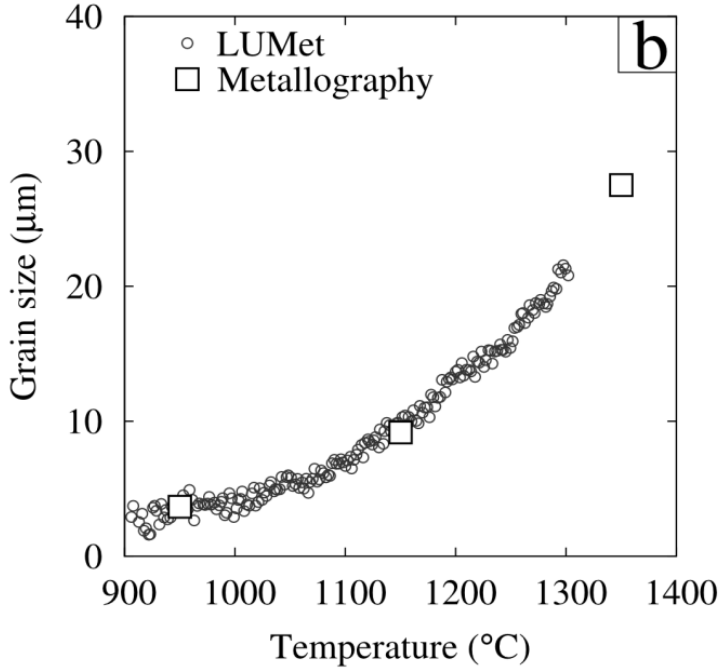




Application to X80 during rapid heating

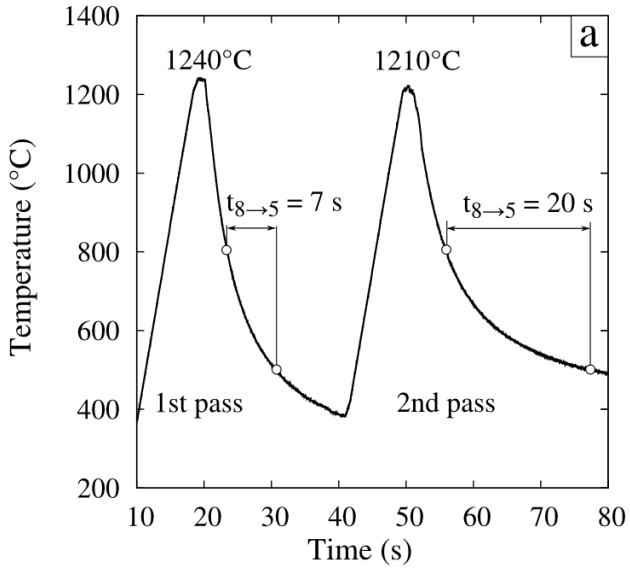
- Simplified heat treatments conditions that typically occur in the HAZ of girth welds
- Austenite grain size increases from 5 µm at 950 °C to 28 µm at 1350 °C.
- Limitation: Laser ultrasonic measurements only up to 1300 °C because the signal to noise ratio becomes too large

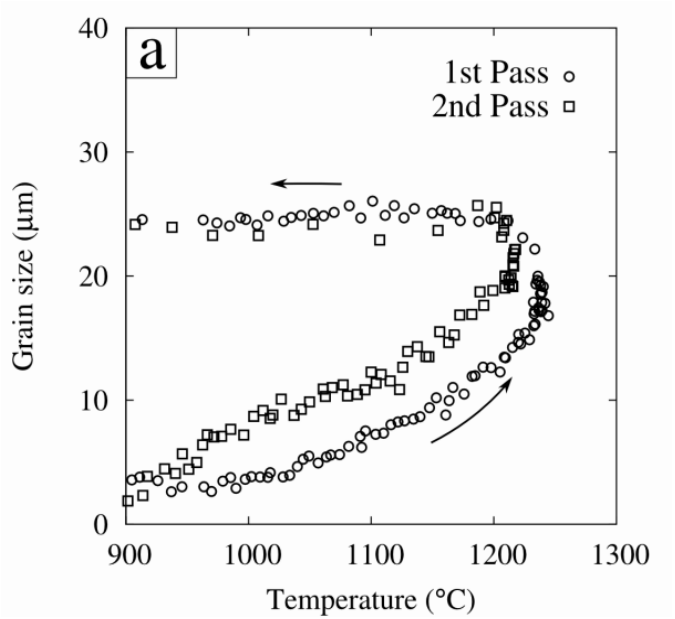




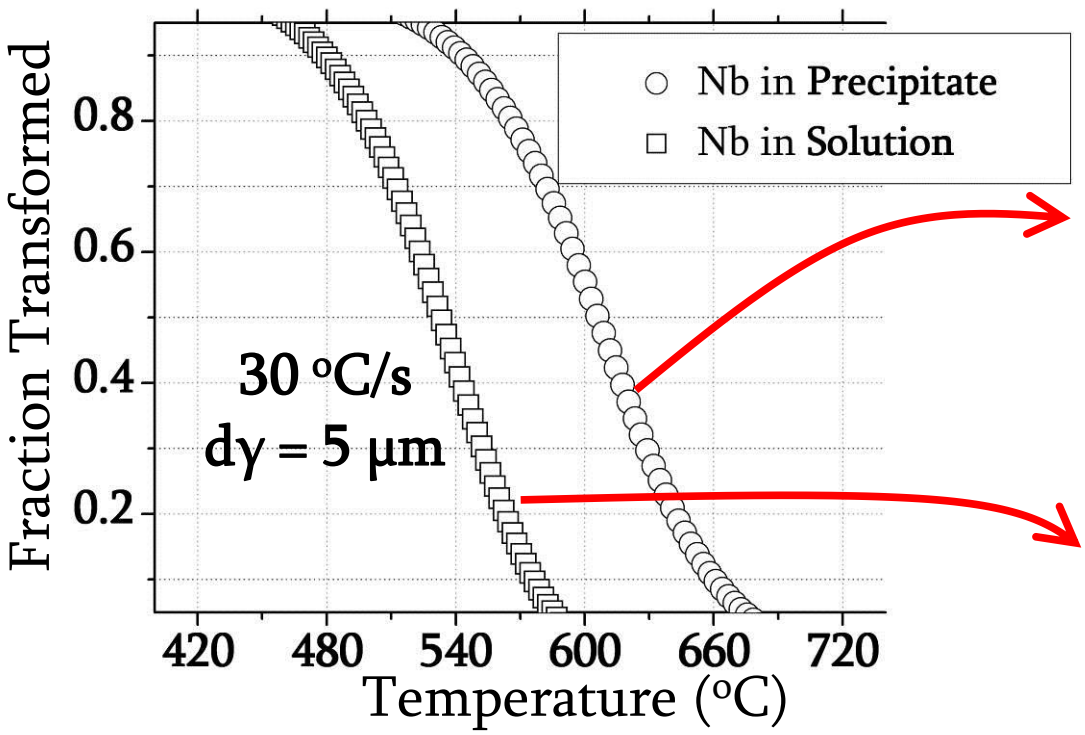
Two pass simulation in Gleeble

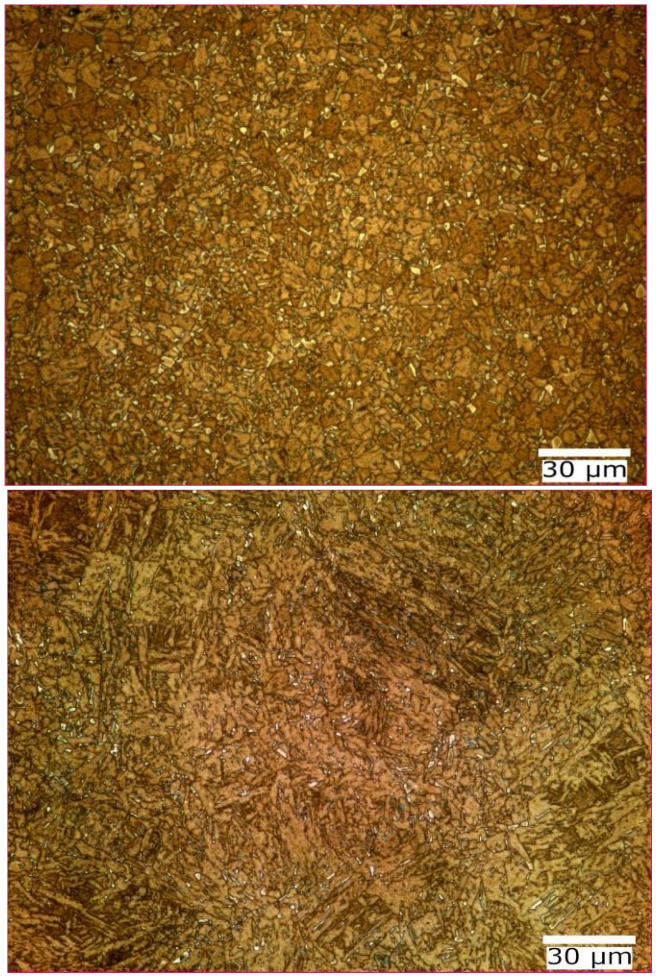
- Real time-temperature path (Rapid heating steps at a rate of 100 ºC/s)
- During the first pass, the austenite grain growth rate gradually increases upon reaching the peak temperature.
- The measured growth rate is constant during the second pass.





Effect of Nb on Austenite decomposition

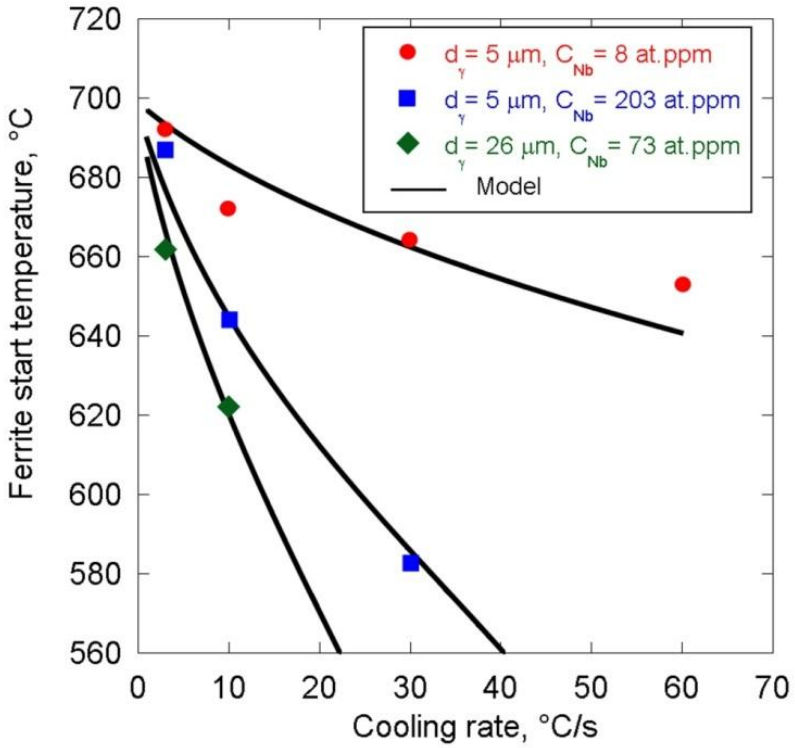




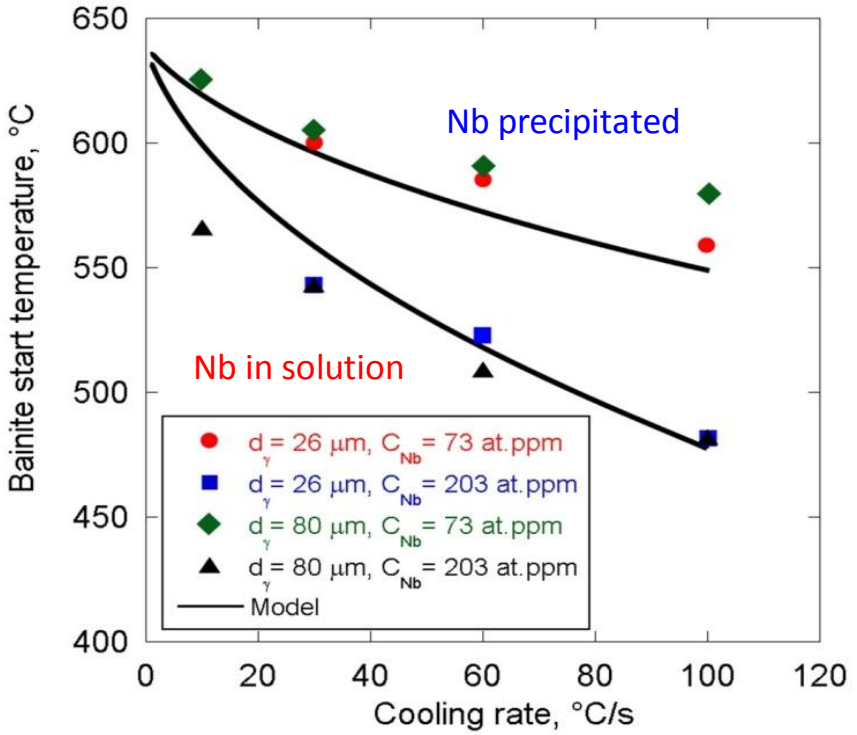
Up to 100 °C difference in transformation temperatures

Transformation Start Model

Ferrite start Model



Bainite start Model



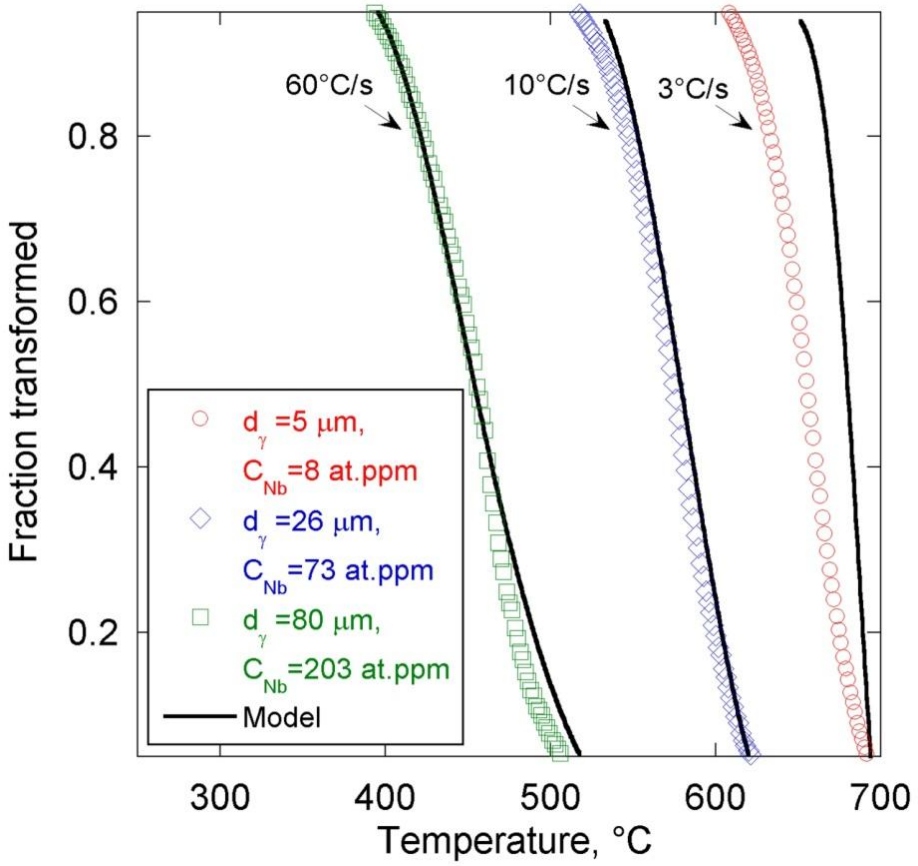
Ferrite and Bainite growth model

- Evaluation of a normalized fraction transformed X

$$X = 1 - \exp\left(- \frac{1}{d_{\gamma}^{m}} \int_{T}^{T_S} \frac{\beta\left(T, c_{Nb}\right)}{\psi\left(T\right)} dT \right)^{n}$$

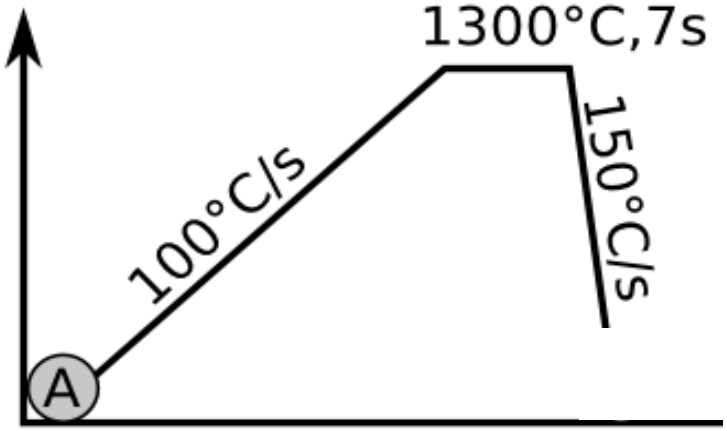
- Ferrite fraction: $F=XF_{eq}$
- Bainite fraction: $B=X(1-F$ M/A)

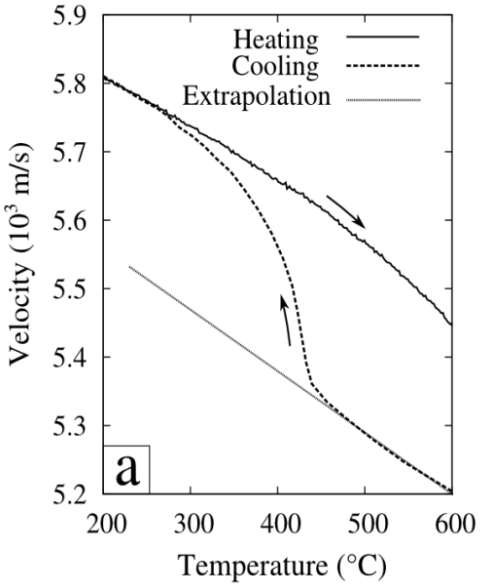
Continuous cooling transformation

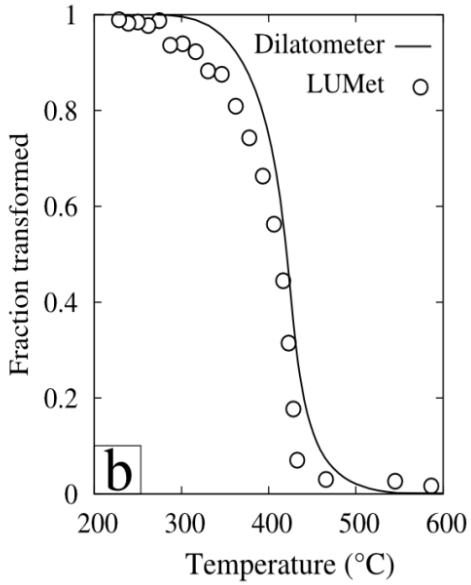


Austenite decomposition

- Laser ultrasound measurements during rapid cooling
- In the ferromagnetic domain of ferrite, ultrasound velocities in ferrite and austenite are significantly different
- Application of lever rule

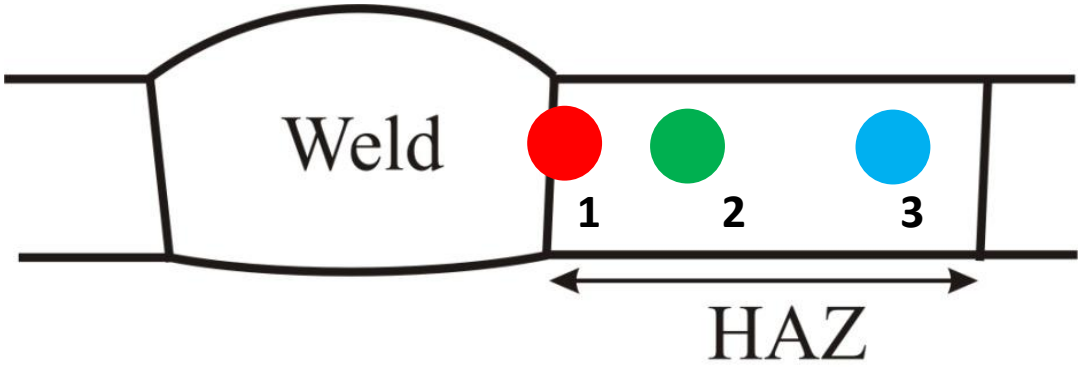


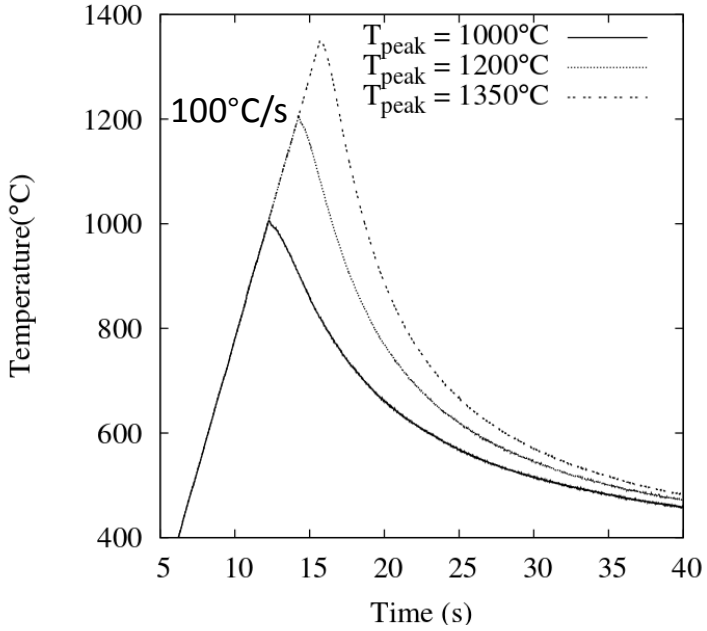


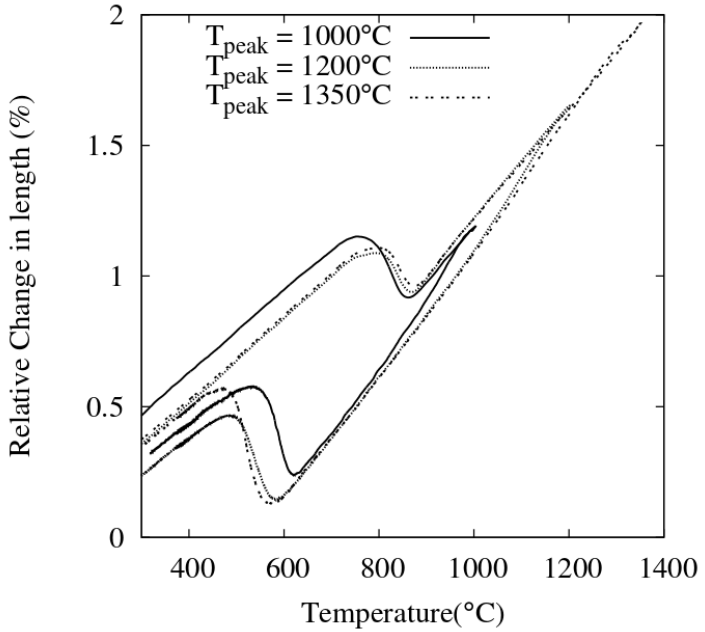


Single pass simulation

- 3 welding simultations in Gleeble
- Three different peak temperatures
- t_{8-5}= 20 s (15°C/s)



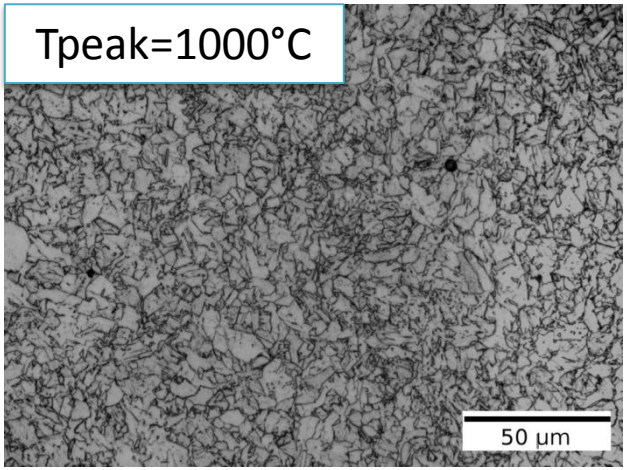




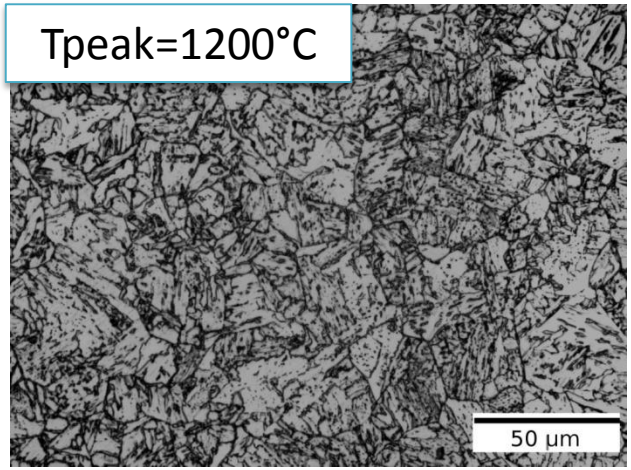
Prediction of transformation products

Experimental observations – Gleeble tests with different Tpeak

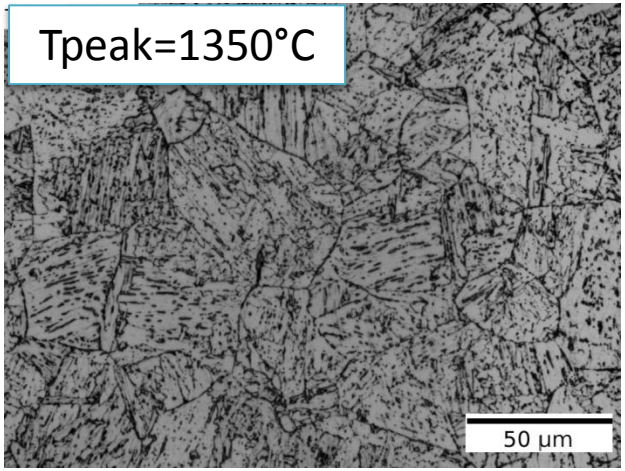
F=90%, B=0%, M/A=10%



F=0%, B=92%, M/A=8%



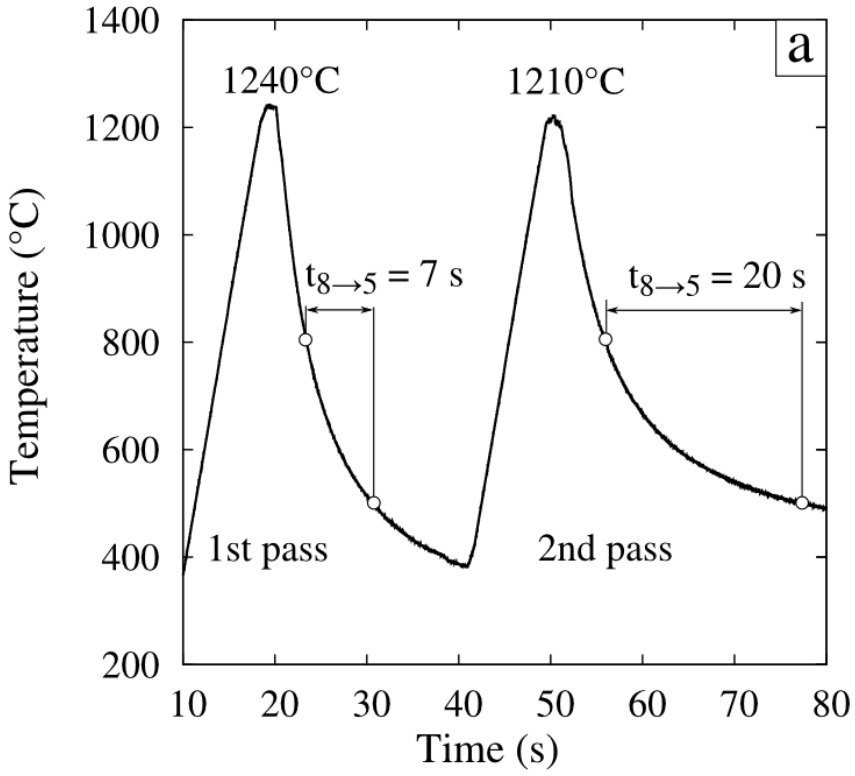
F=0% B=95%, M/A=5%

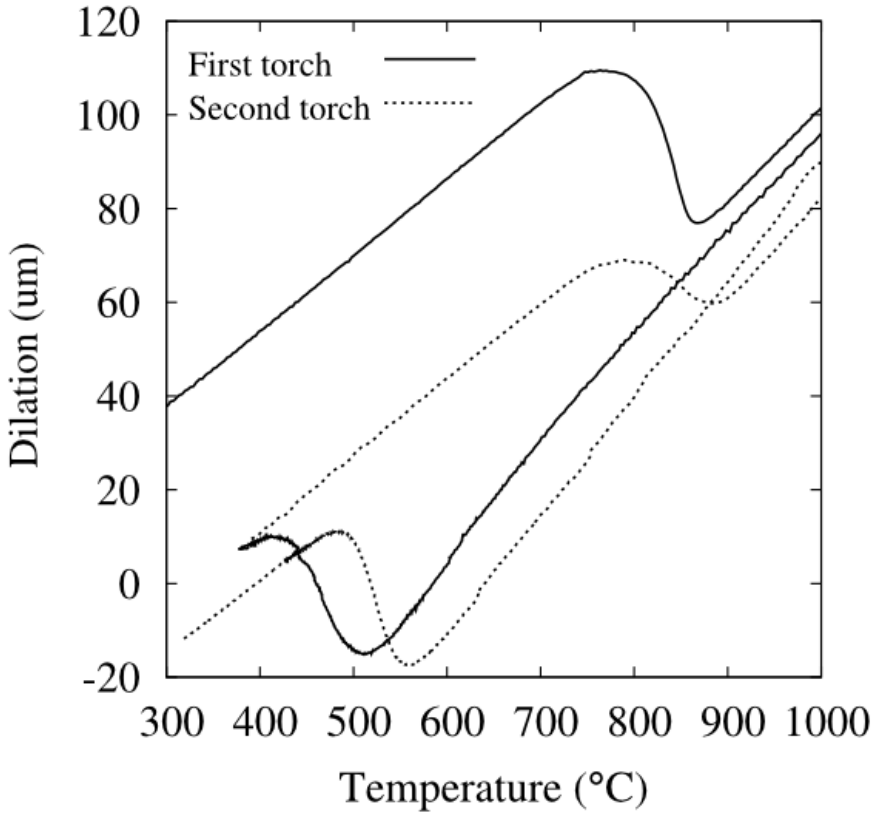


T_{peak} (°C)	Ferrite Fraction (%)	bainite Fraction (%)	M/A Fraction (%)
1000	95	0	5
1200	0	88	12
1350	0	89	11

Dual pass simulation

- Measure of dilation and Laser Ultrasonics during the two passes.

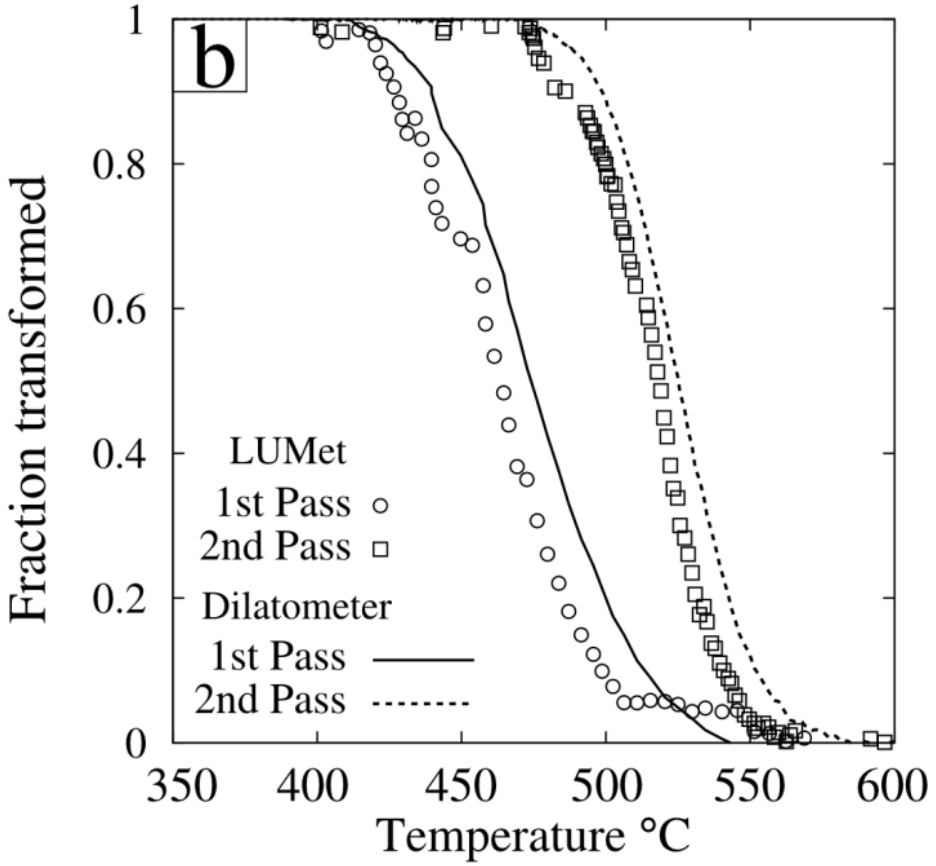




Austenite decomposition during two pass simulation

- Application of the lever rule method on the velocity measurements.
- Excellent correlation with dilatometer measurement
- Good method as long as the transformation occurs below 750°C

LUMet & Dilatometry



Conclusions and Future work

- LUMet is an attractive tool complementing more traditional methods, i.e. metallography and dilatometry
- Able to monitor austenite grain growth and austenite decomposition kinetics during real HAZ thermal cycles
- Many other applications for LUMet