

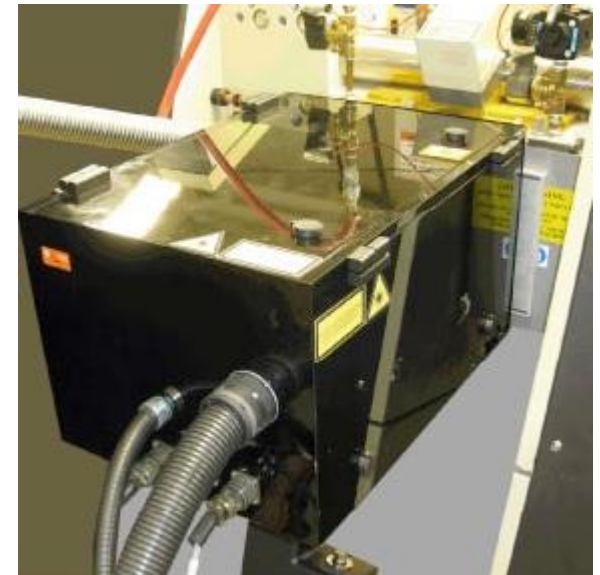
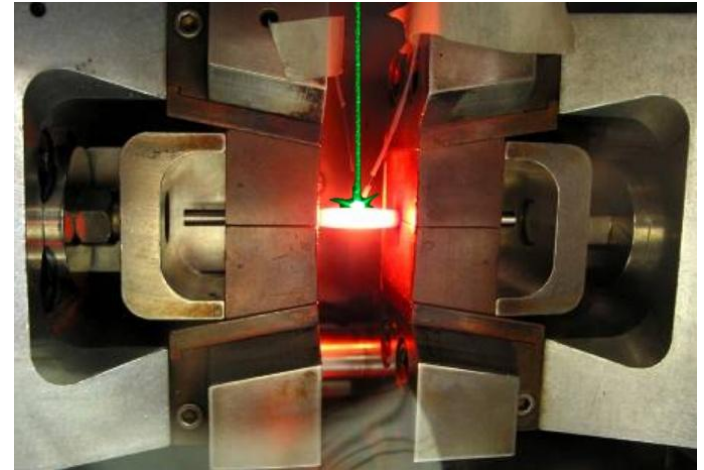
Laser ultrasonics for in-situ monitoring of microstructure evolution in steels

Application to welding simulation

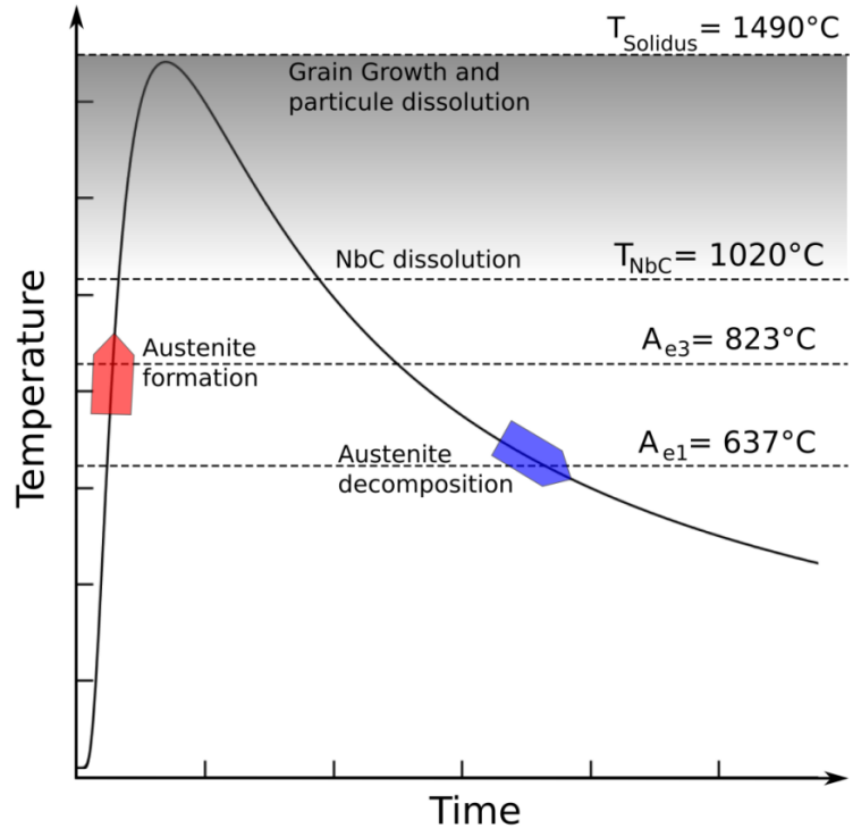
The Centre for Metallurgical Process Engineering

The University of British Columbia

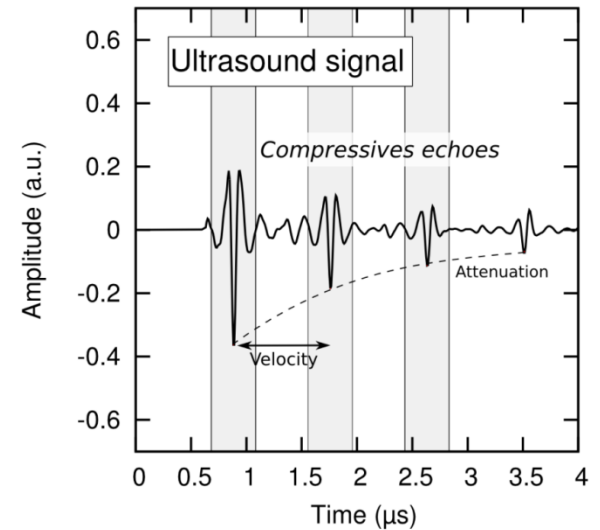
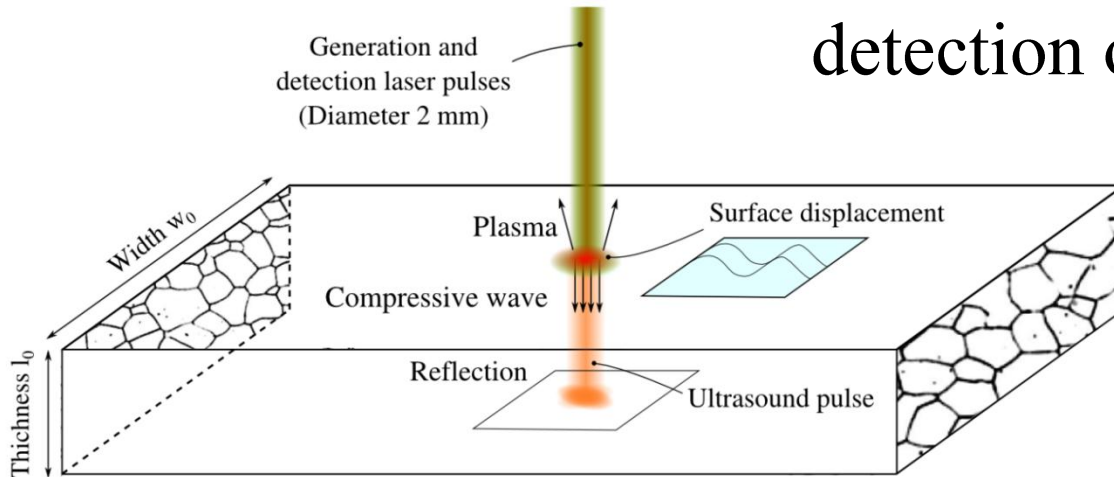
- Properties of ultrasonic waves depend on microstructure characteristics
- Laser ultrasonics measurement during thermo-mechanical simulation



- 1) Austenite grain size measurement
- 2) Austenite grain growth and Nb precipitate interaction
- 3) Ferrite / austenite transformations



Method : Laser generation and detection of ultrasounds

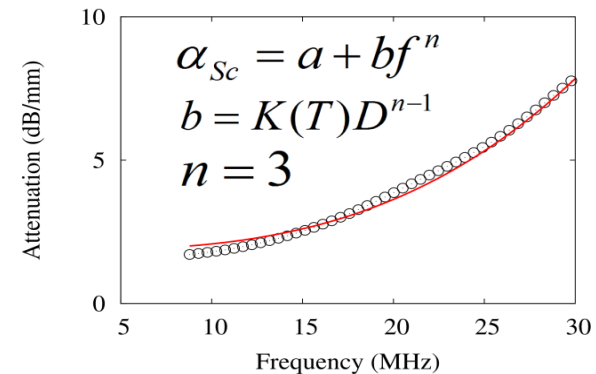


Parameters :

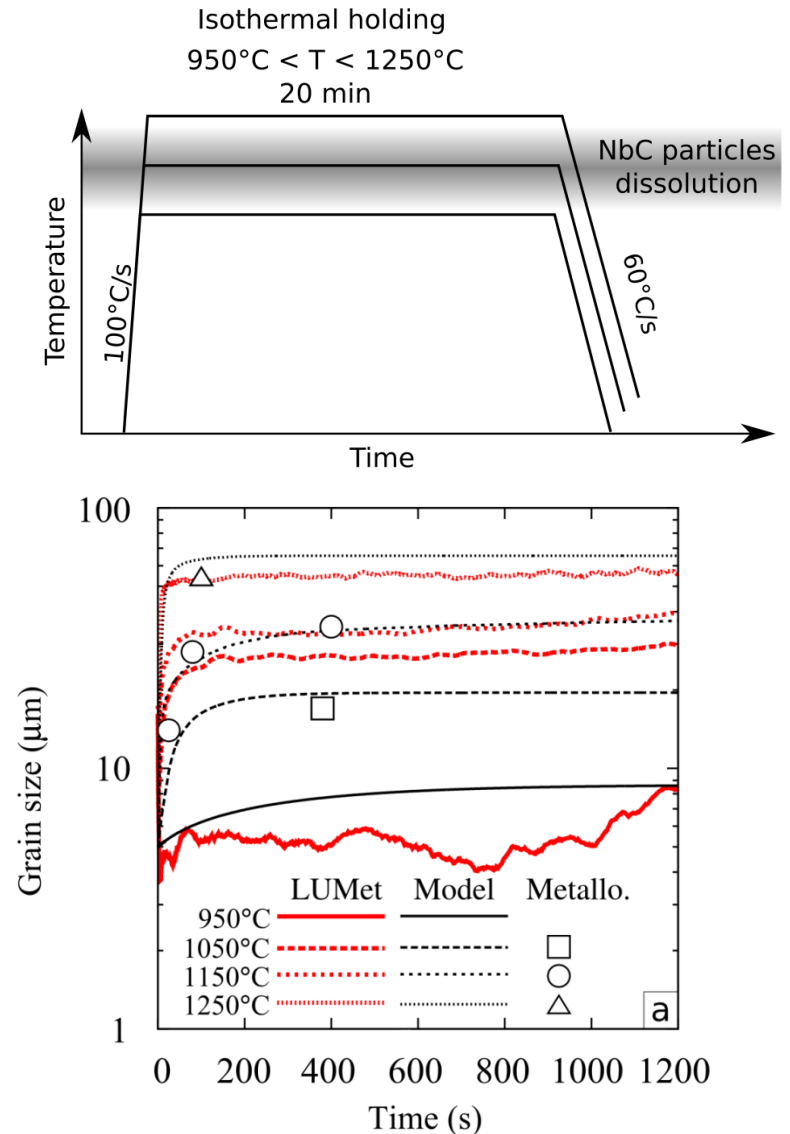
1- Velocity = Elasticity, density

$$v_L = \frac{2(e + \varepsilon)}{\text{delay}} = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

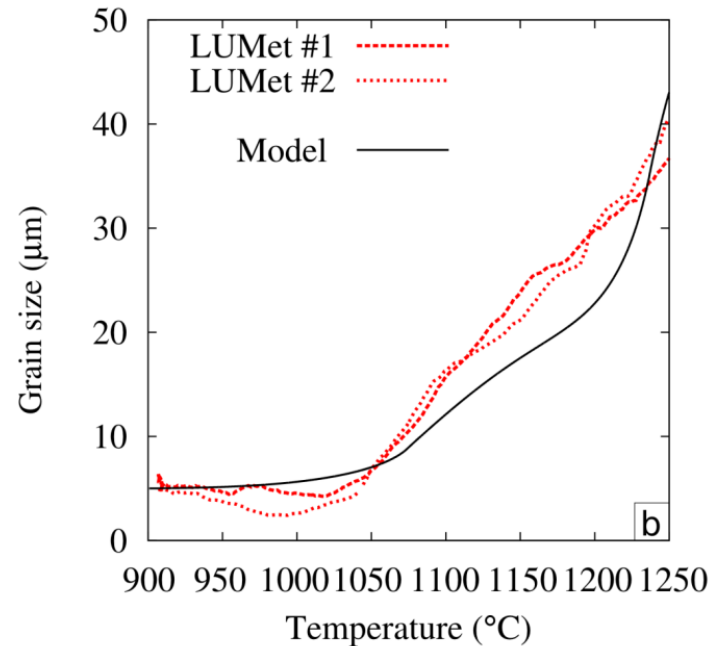
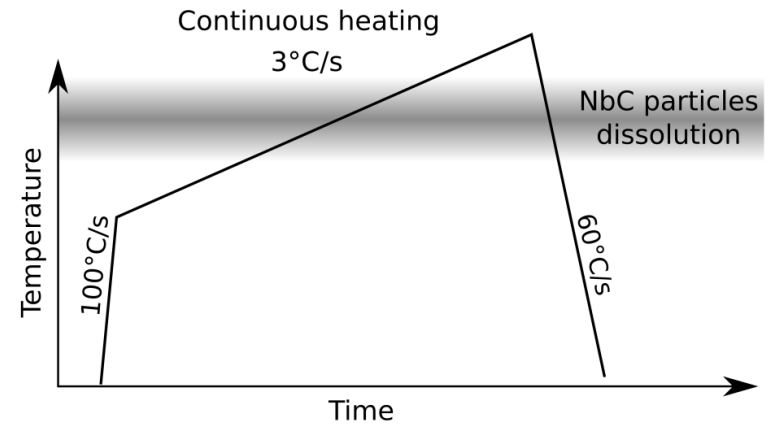
2- Attenuation = Grain size, ...



- 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.



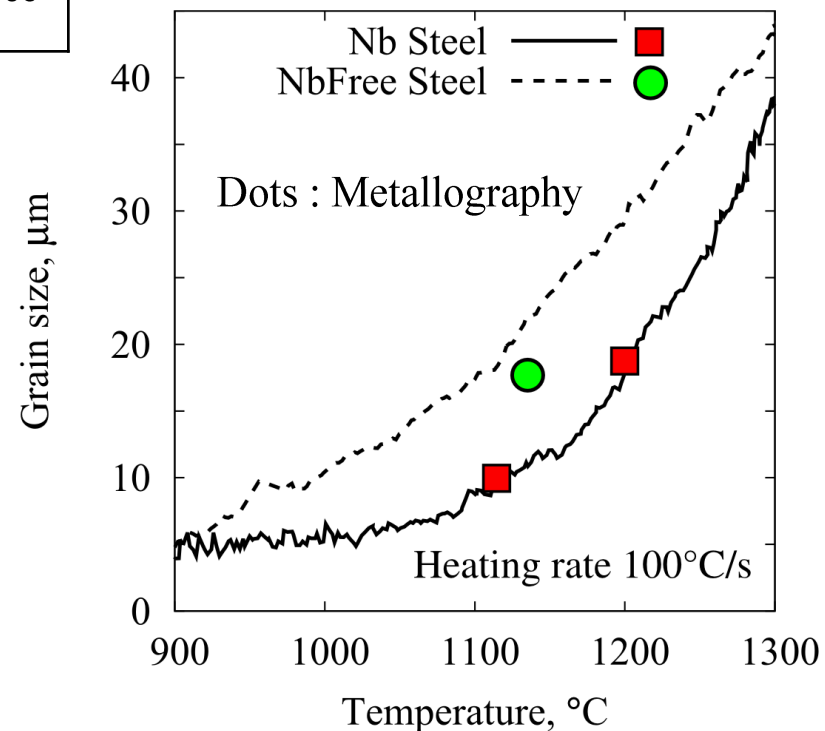
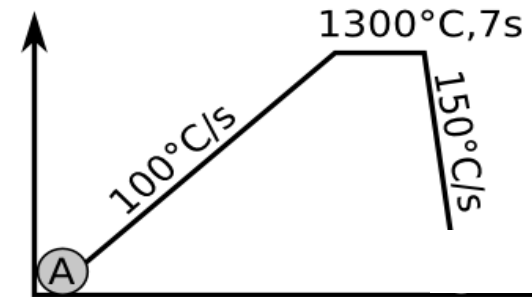
- Continuous heating grain growth tests in X80 steel
- Below 1050 C, grain size stays relatively small due to the strong grain boundary pinning associated with the presence of NbC precipitates.
- Above this temperature, NbC precipitates dissolve: increase of the grain growth



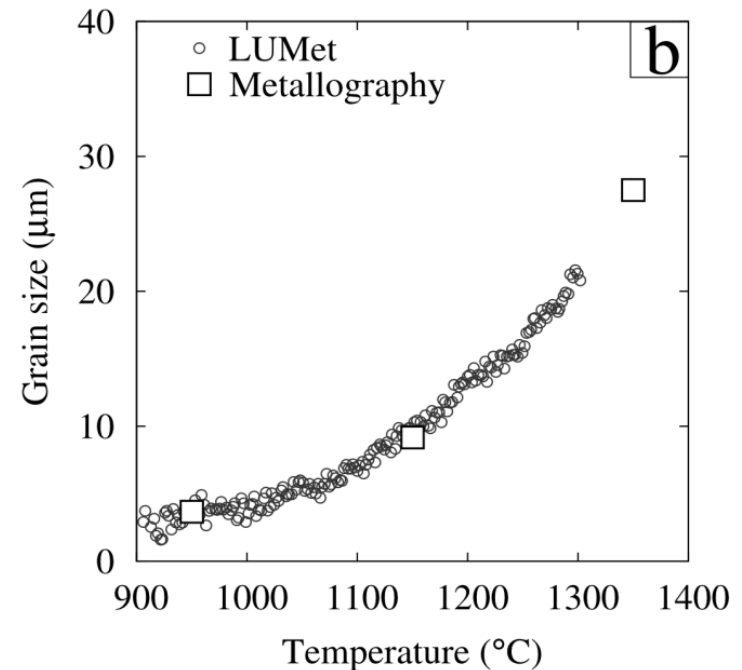
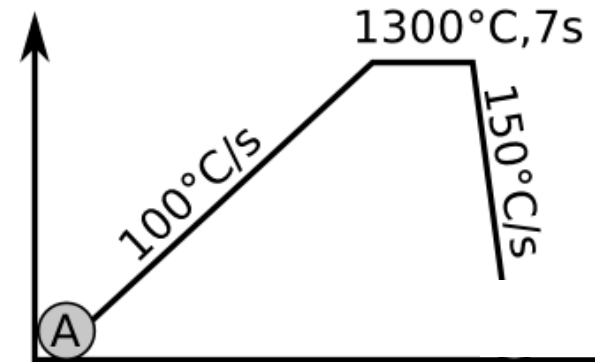
- Continuous heating in two model alloys

	C	Si	Mn	Mo	Nb	Ti
Nb free Steel	0.057	0.085	1.8	-	-	0.006
Nb Steel	0.058	0.086	1.84	1.45	0.045	0.006

- Measurement possible at high heating rate
- Discrimination between grain growth mode (precipitate pinning/solute drag)

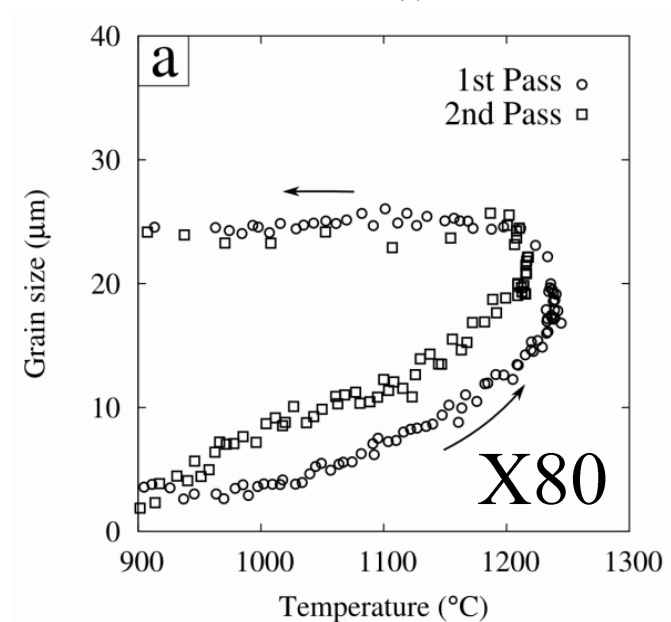
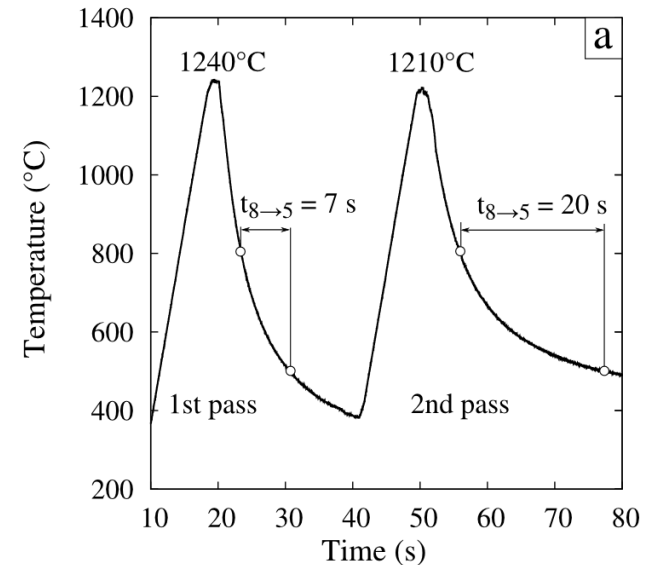


- Simplified heat treatments conditions that typically occur in the HAZ of girth welds
- Austenite grain size increases from 5 μm at 950 $^{\circ}\text{C}$ to 28 μm at 1350 $^{\circ}\text{C}$.
- Limitation: Laser ultrasonic measurements only up to 1300 $^{\circ}\text{C}$ because the signal to noise ratio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

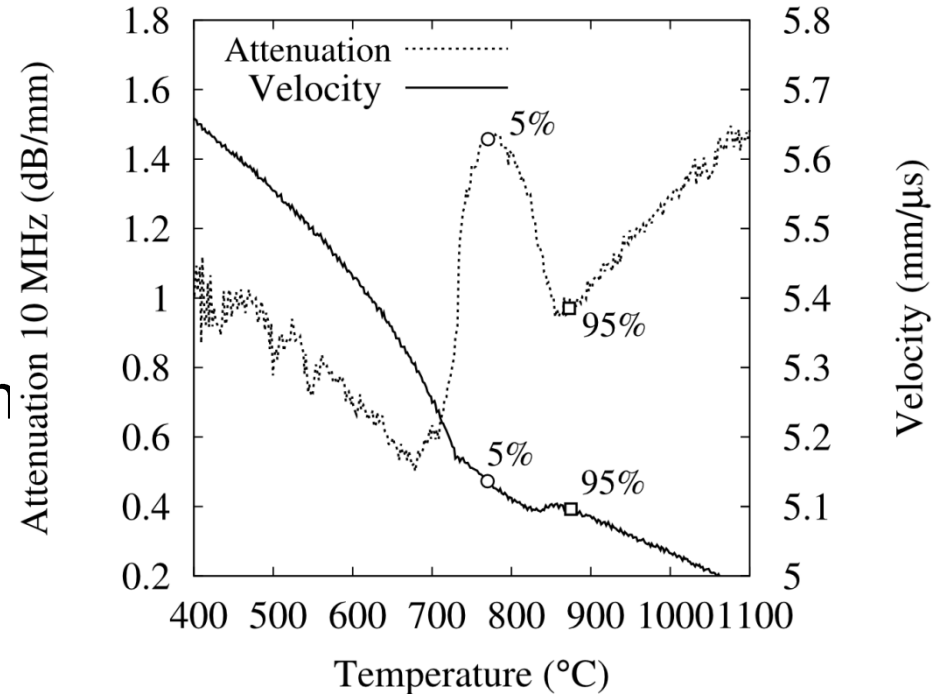


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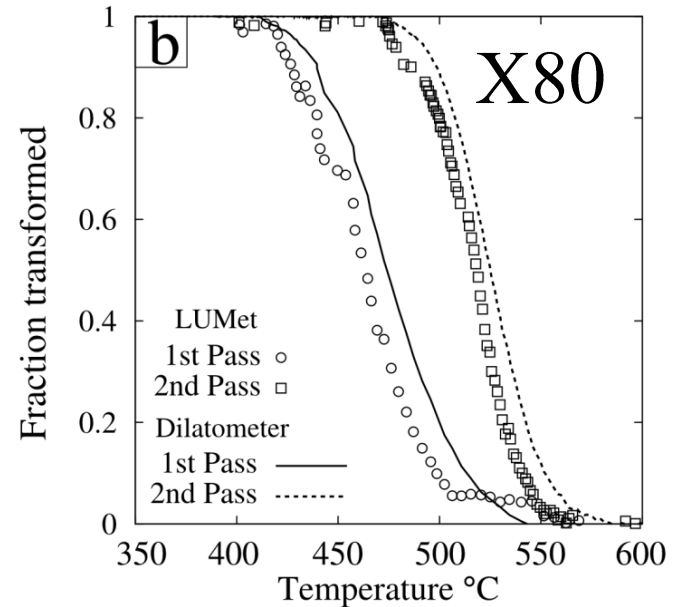
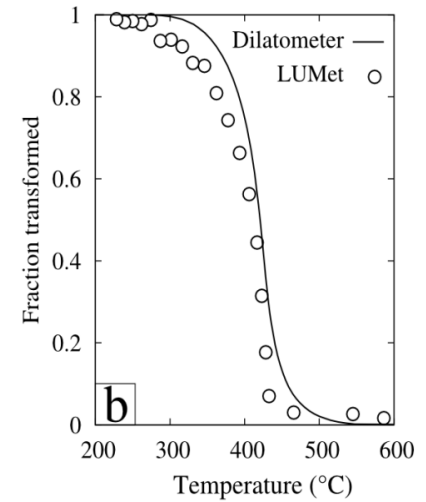
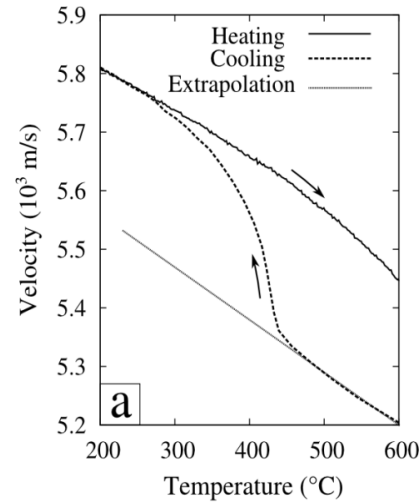
- Real time-temperature path (Rapid heating steps at a rate of 100 °C/s)
- During the first pass, the austenite grain growth rate gradually increases upon reaching the peak temperature.
- The measured growth rate is constant during the second pass.



- 5 and 95 % of transformation are determined by dilatometry
- The decrease in attenuation correlates well with the austenite formation temperature range
- No specific variation of the velocity is measured in the beginning of the austenite formation



- In the ferromagnetic domain of ferrite, ultrasound velocities in ferrite and austenite are significantly different
- Lever rule is employed between the velocity of ferrite measured upon heating and the linear extrapolation of the temperature dependence of the velocity in austenite



- LUMet is an attractive tool complementing more traditional methods, i.e. metallography and dilatometry
- Able to monitor austenite grain growth in the HAZ thermal cycles (Indirect information about state of precipitates)
- Austenite-ferrite transformations accurately measured if transformation temperatures are below the 750 ° C
- Potential use of attenuation to record the austenite-ferrite transformations above the Curie temperature.