Laser ultrasonic measurements of microstructure evolution in steels

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Acknowledgement

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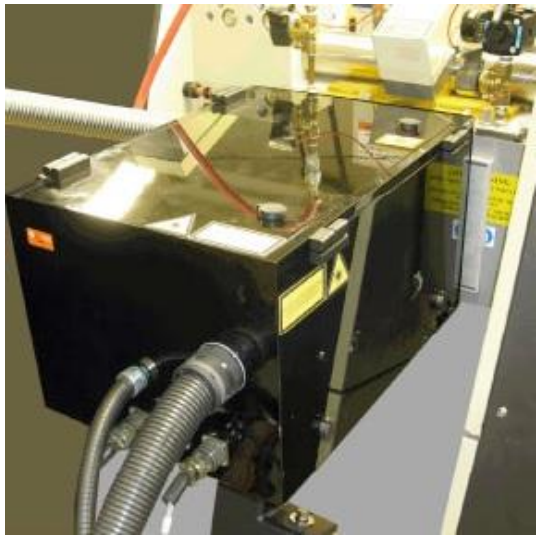
Evraz Inc. NA

A commercial sensor for metallurgist

- ✓ Laser Ultrasonics for Metallurgy (LUMet)
- ✓ Attachment to a Gleeble thermo-mechanical simulator
- ✓ Dedicated sensor for measurements during processing of metals



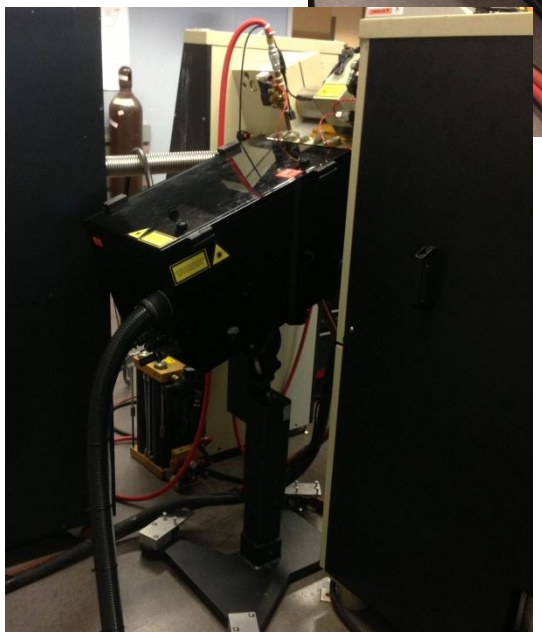
NRC·CNRC
Industrial Materials Institute

TECNAR

DSI®
Dynamic Systems Inc.

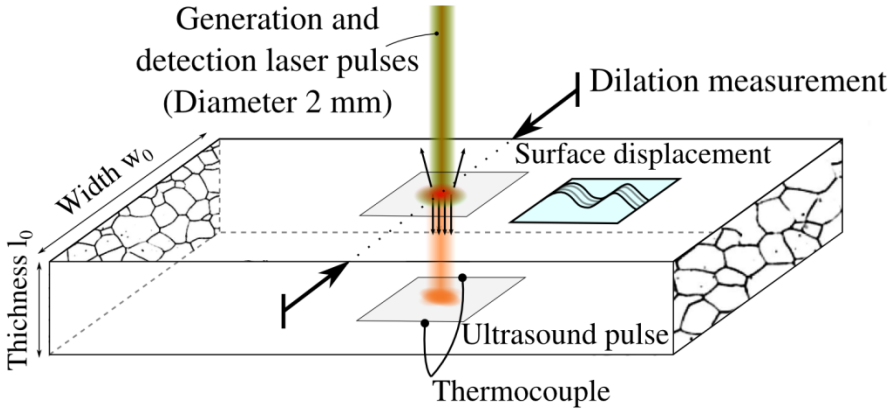
LUMet : Technical specifications

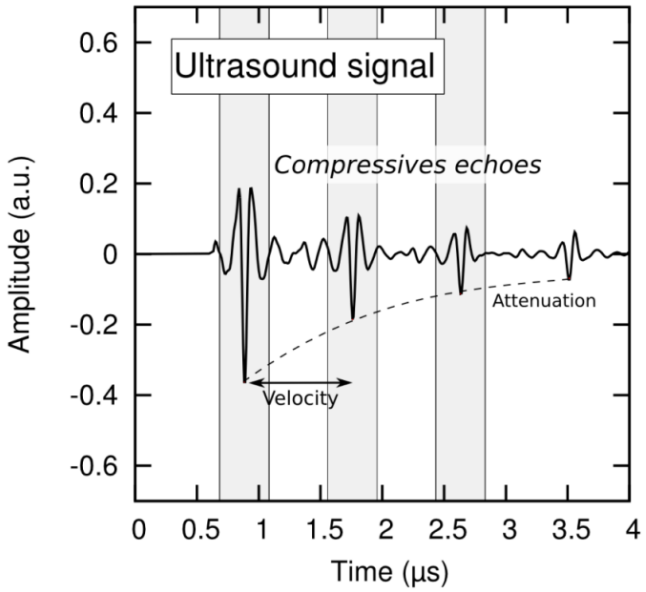
- ✓ Generation pulse laser: Frequency double Q-switch Nd:YAG (532nm, 72mJ, 9 ns)
- ✓ Detection pulse laser: Frequency stabilized Nd:YAG (1064nm, 90 µs)
- ✓ Photorefractive interferometer
- ✓ Bandwidth: 4 to 20 MHz
- ✓ Up to 50 pulses per second



LUMet : Methodology & applications

- ✓ Generation and detection of ultrasonic wave by lasers
- ✓ Velocity is related to elasticity → Texture
- ✓ Attenuation mainly due to grains scattering → Grain size
- ✓ Recrystallization, phase transformation, grain growth





Time Delay and ultrasonic velocity

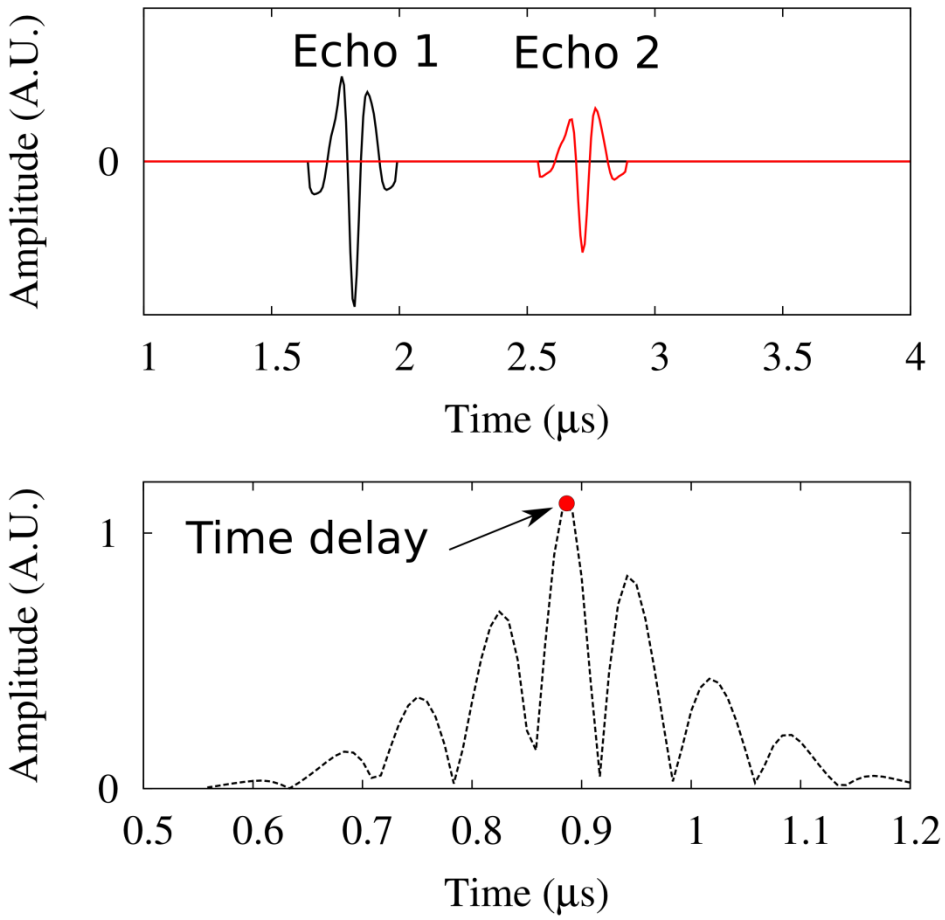
$$v_L = \frac{2(e+\varepsilon)}{delay}$$

Propagation distance :

Thickness + Thermal expansion

Time delay :

Phase shift between two successive echoes by cross-correlation method

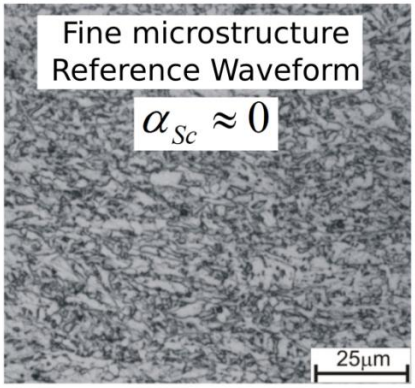


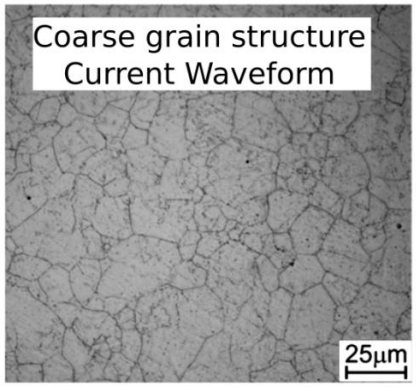
Austenite grain size measurement

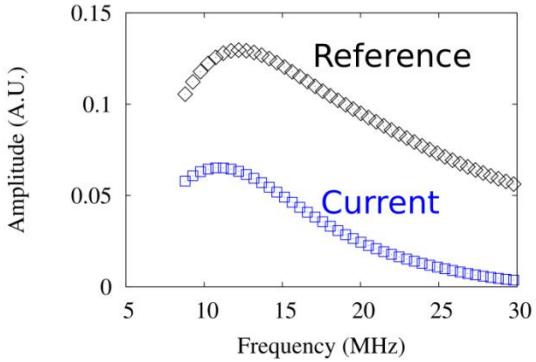
- ✓ Attenuation spectrum from single echo technique

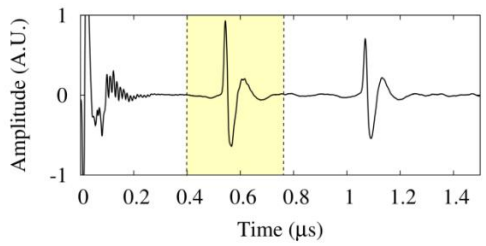
$$\alpha = \alpha_D + \alpha_{Sc}$$

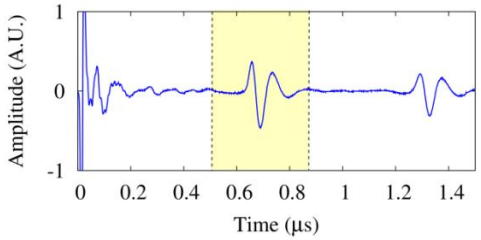
$$\alpha_{Sc} = \frac{20}{2e}\log\left(\frac{A_{Current}}{A_{Reference}}\right)$$

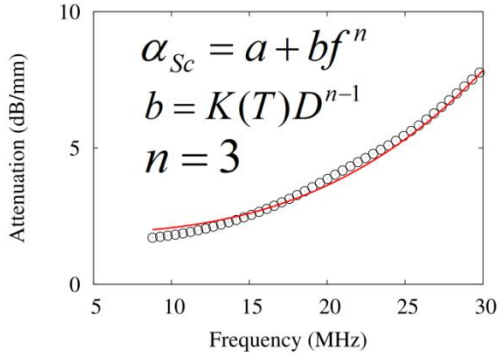








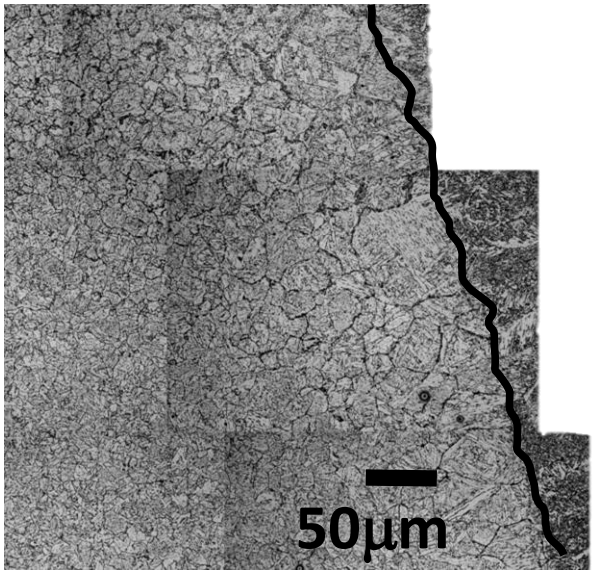


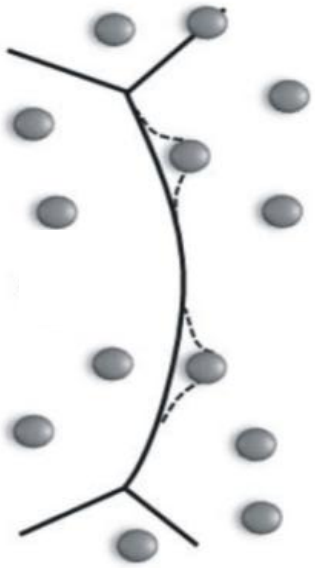


- ✓ Calibration available for austenite in low alloy steel : S.E. Kruger et al., Iron Steel Technol, (2005), 2(10),25

Welding of linepipe steel

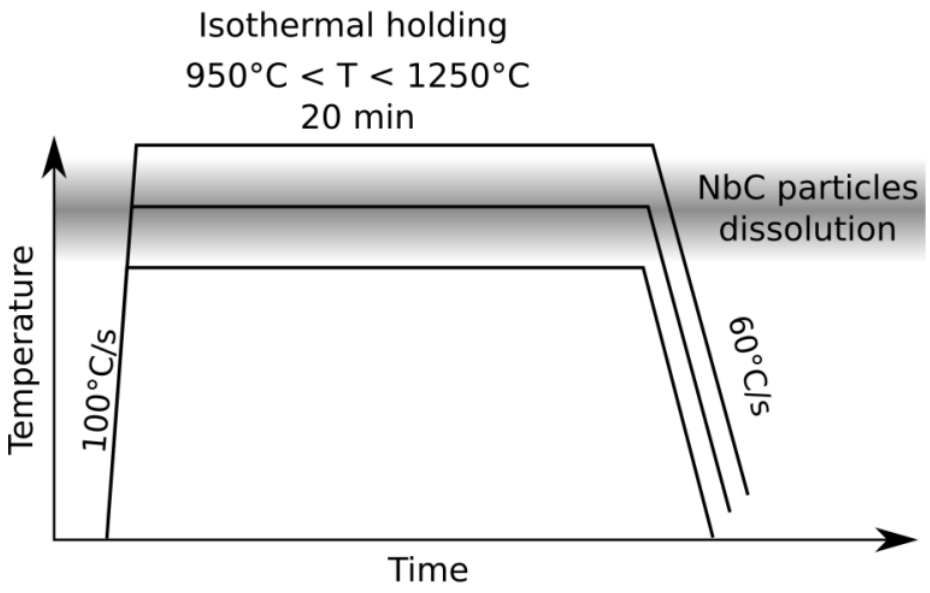
- ✓ Austenite grain size: critical parameter affecting the final microstructure
- ✓ Grain growth influence by presence of precipitate
- ✓ This parameter is difficult to measure by ex-situ technique

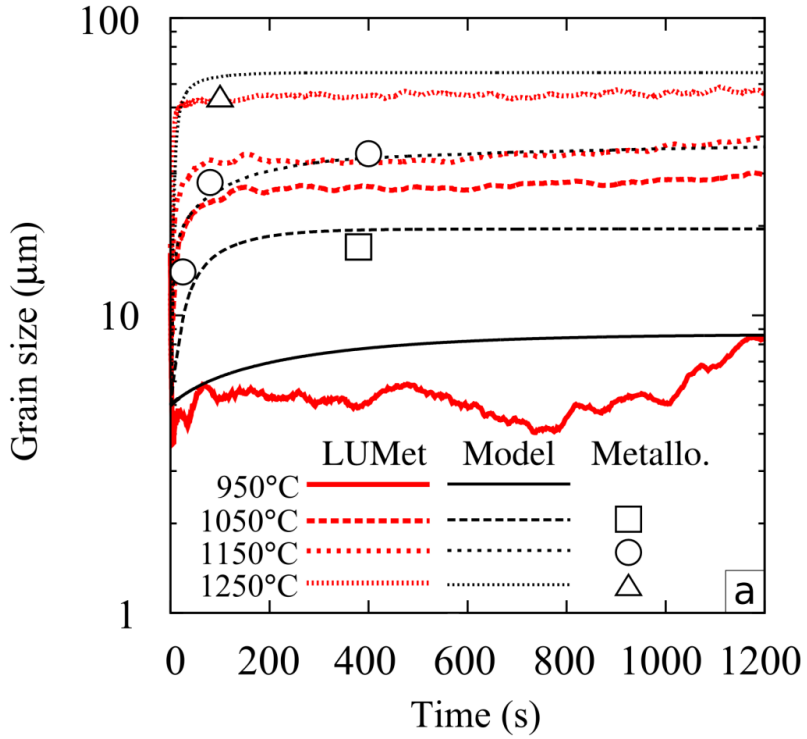




Austenite grain size measurement

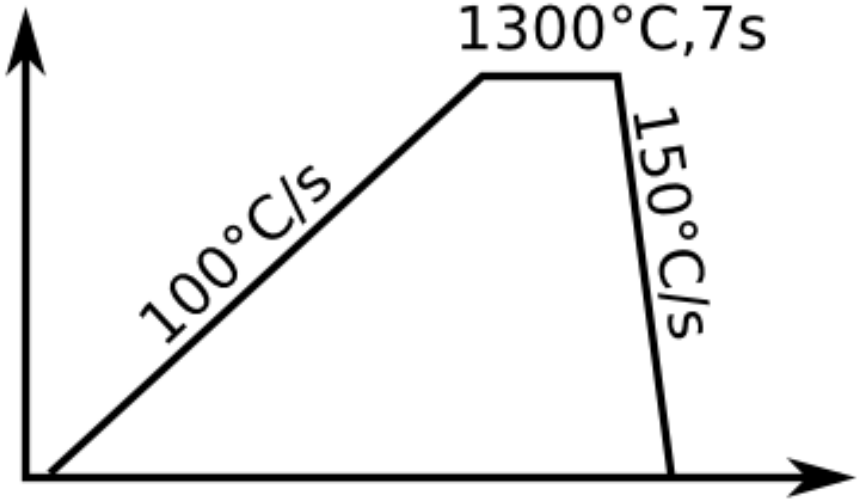
- ✓ X80 linepipe steel : 0.06C, 1.65Mn, 0.24Mo, 0.034Nb, 0.012Ti, 0.005N (wt%)

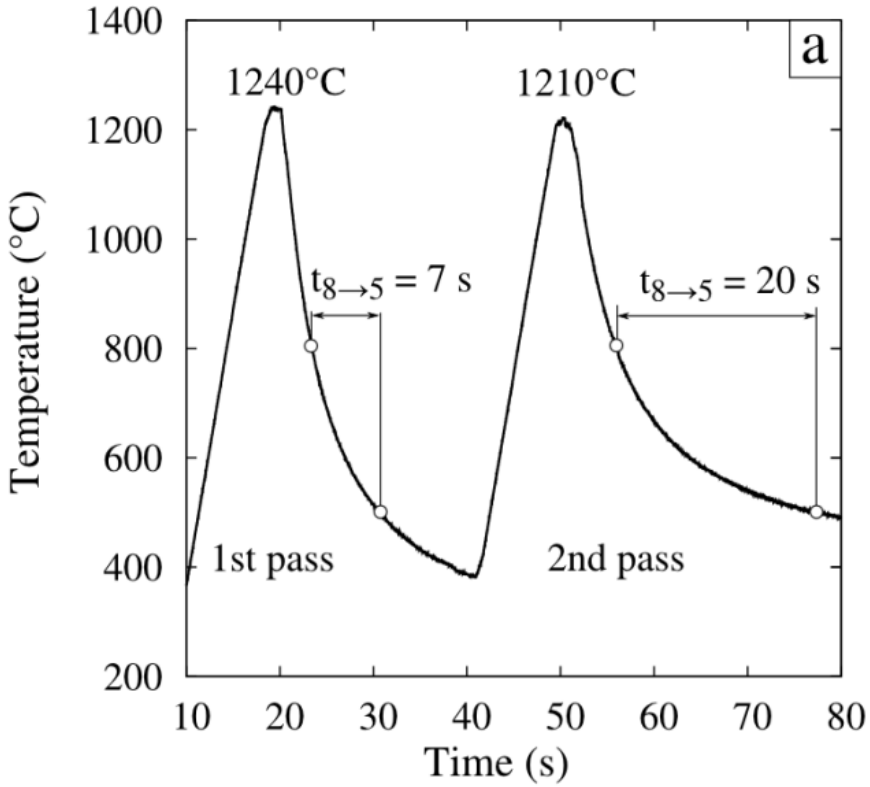




Austenite grain size in the HAZ

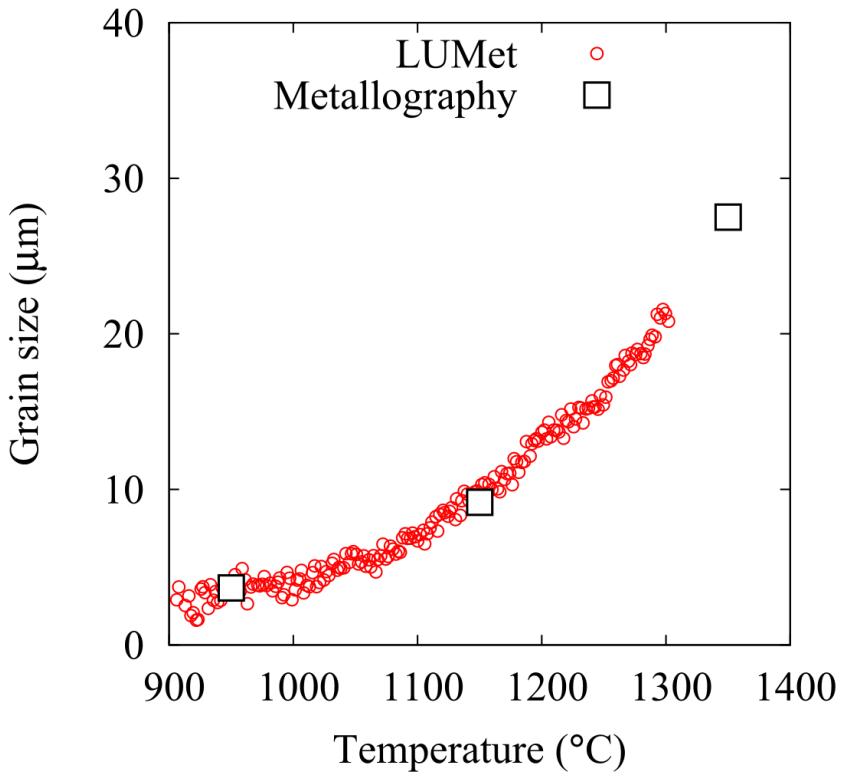
- ✓ Continuous heating at high heating rate
- ✓ Two pass scenario (Dual torch welding)

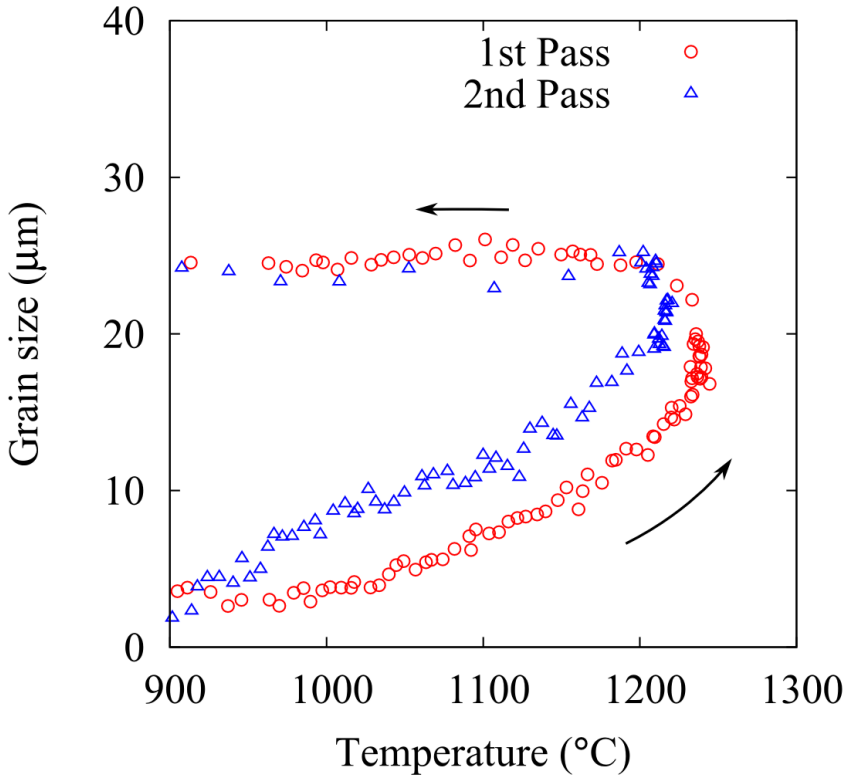




Results on grain size measurements

- ✓ Grain coarsening temperature associated with the beginning of the dissolution of NbC precipitates





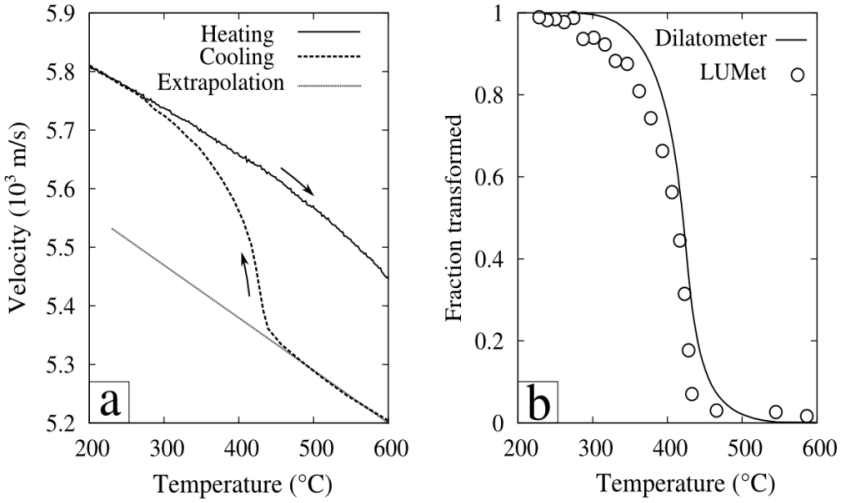
Austenite decomposition

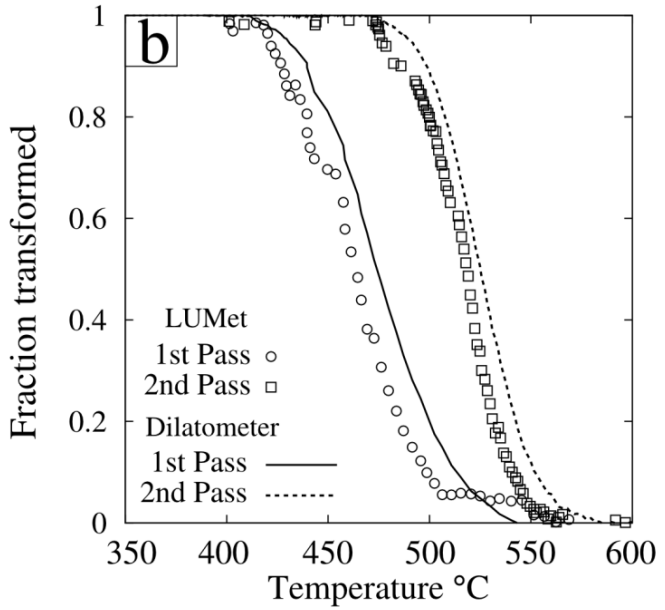
- Velocity difference between ferrite and austenite

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

- Application of the lever-rule method on ultrasonic velocity

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





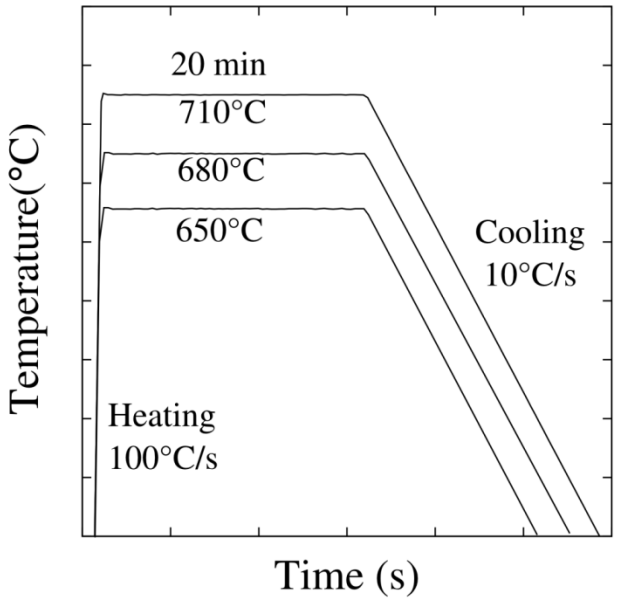
Ferrite recrystallization in DP Steel

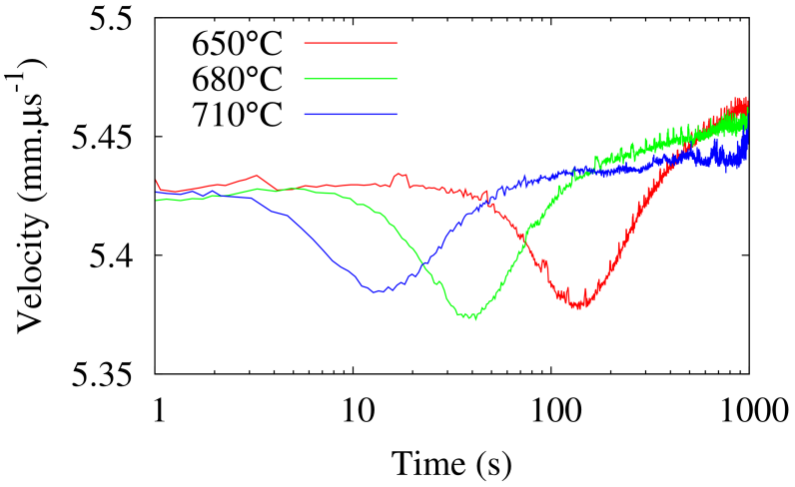
- ✓ Dual Phase Steel 55% Cold Rolled

Key element (wt%)

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

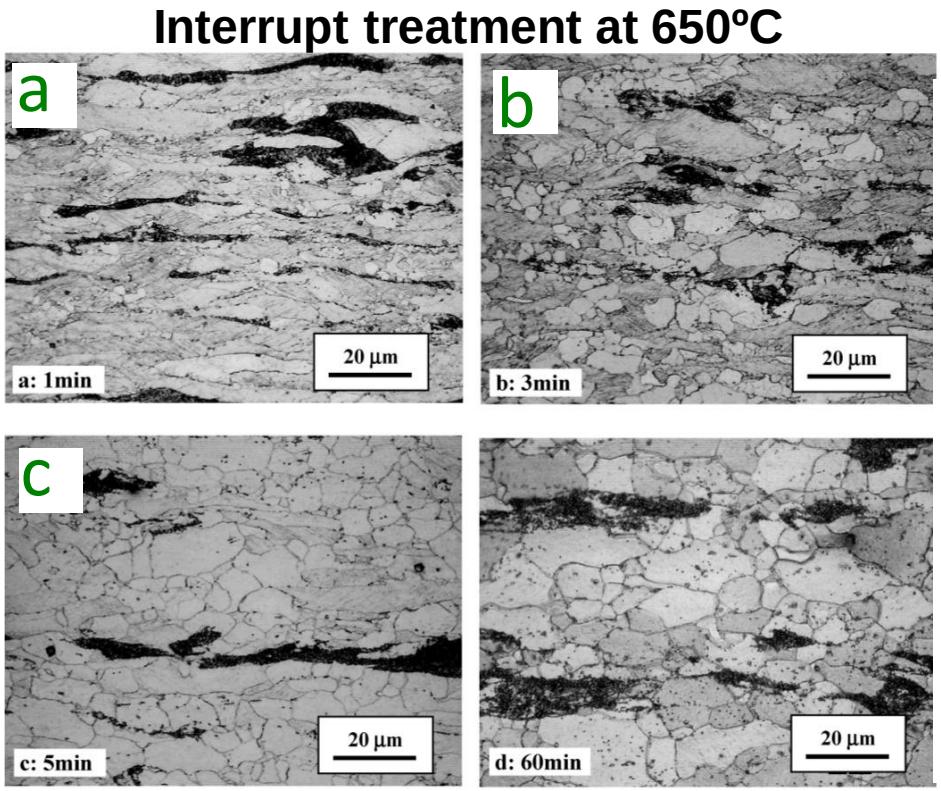
- ✓ Ultrasonic velocity measurements in Normal Direction during isothermal annealing

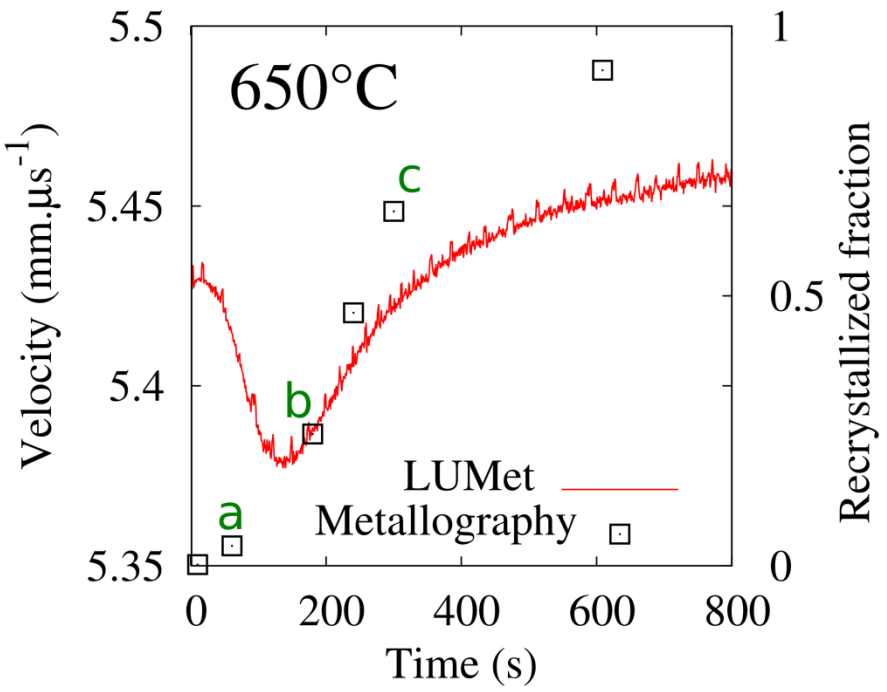




Velocity vs Hardness measurements

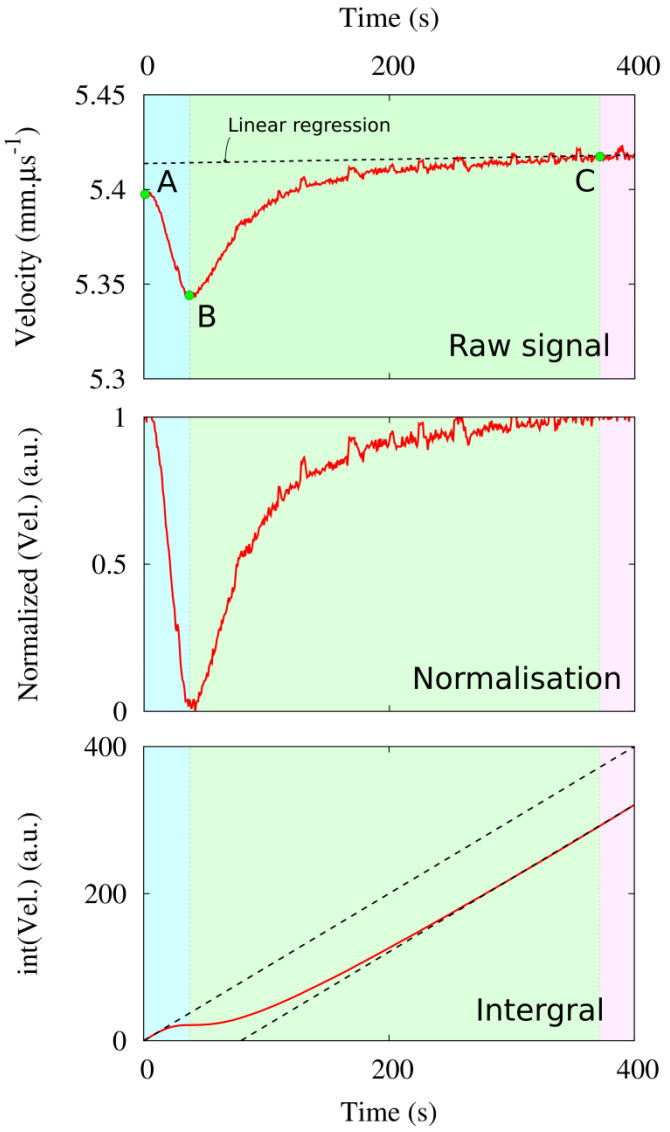
- ✓ Minimum velocity at 25% of recrystallization



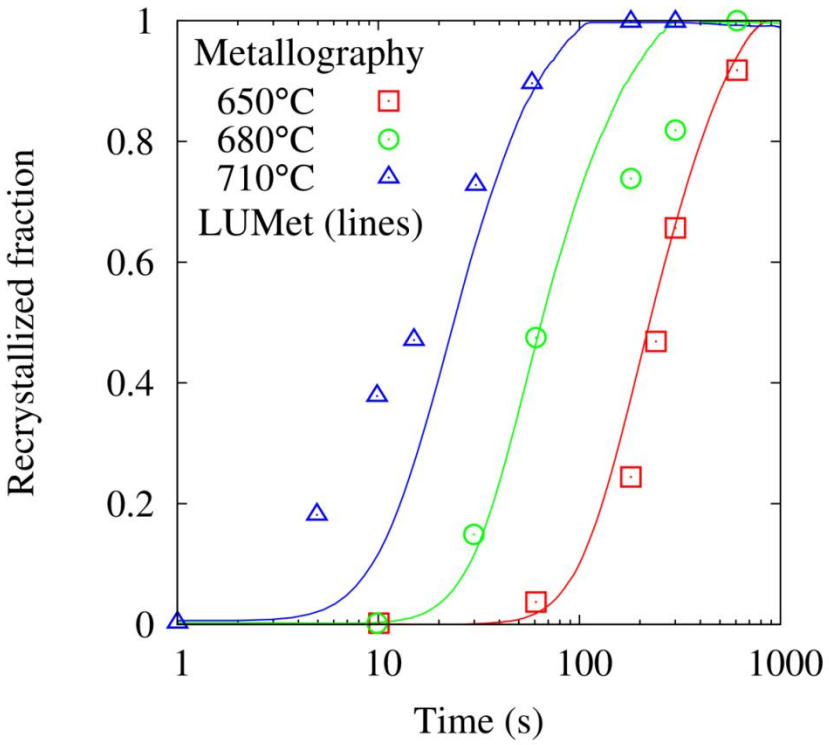


Huang J, Poole W J, Militzer M, Metall. Mater Trans.(2004) 35A, pp3363

Modified lever rule method

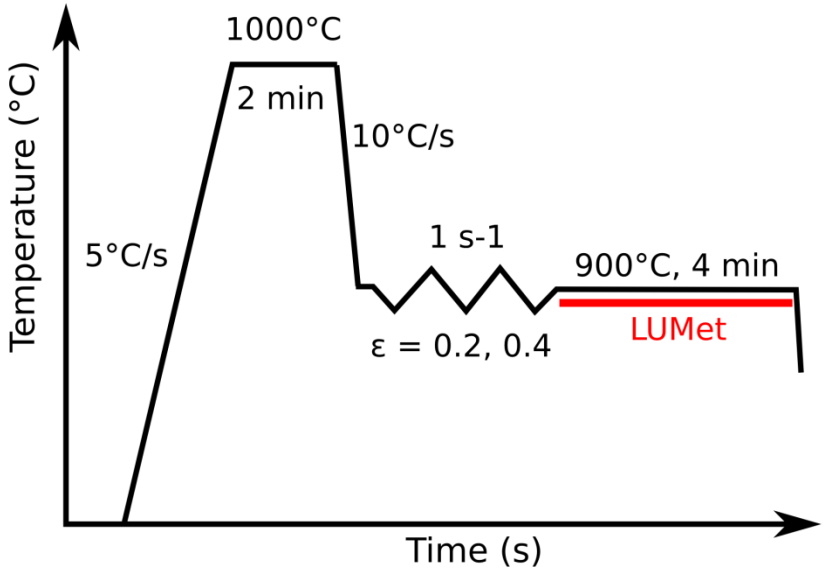


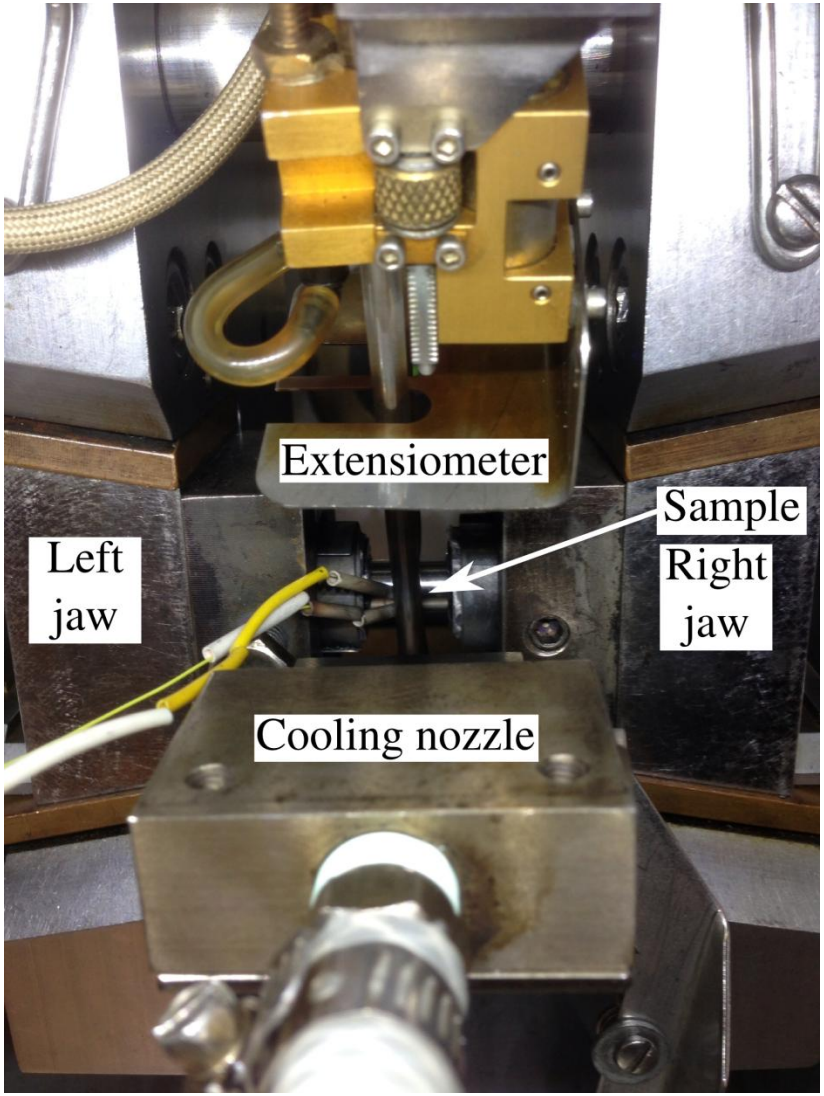
- ✓ Evolution of the recrystallized fraction validated with metallographic observations



Static recrystallization in austenite

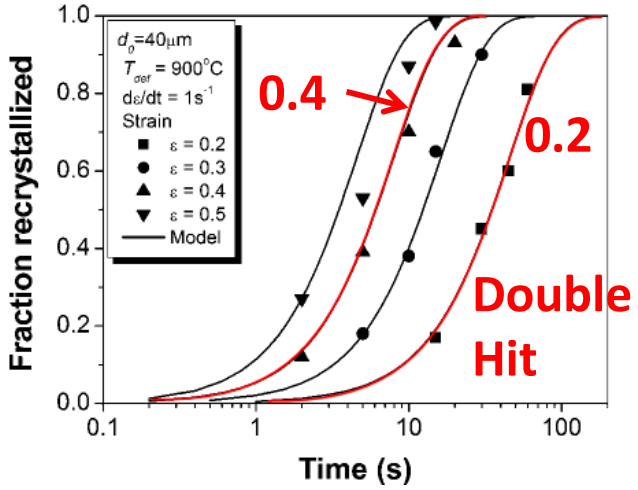
- ✓ TRIP steel: 0.19C, 1.5Mn, 1.6Si, 0.2Mo (wt%)
- ✓ Grain size measurement after hot-deformation
- ✓ Strain = 0.2 and 0.4

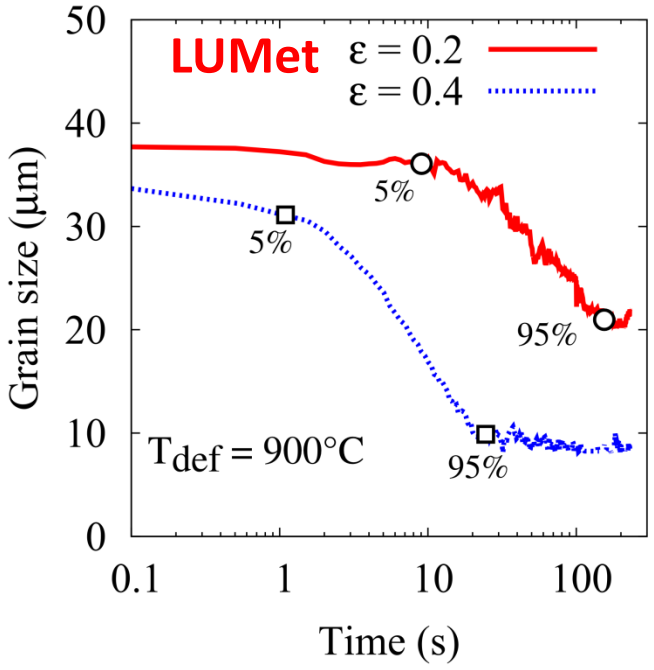




Austenite grain size evolution

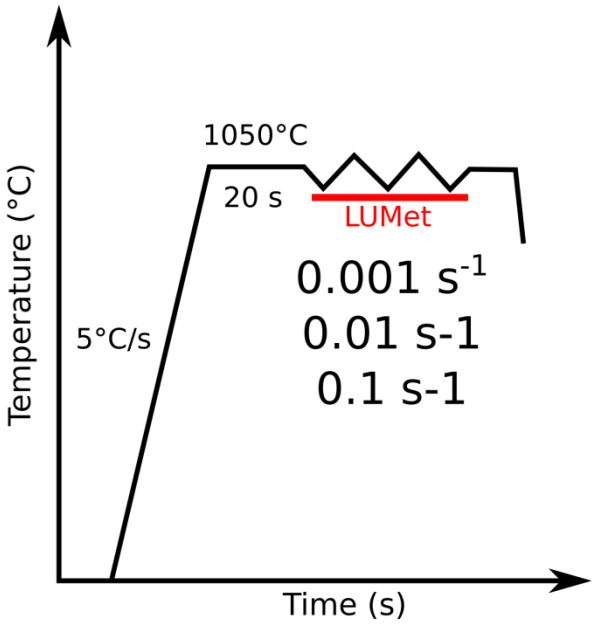
- ✓ Initial austenite grain size prior to deformation: 40 µm (*Liu.D et al. Met. Mater. Trans 38A, 2007, pp 897*)
- ✓ Recrystallization kinetics measured from interrupt compression test (double hit tests).
- ✓ Larger grain refinement at higher deformation strain

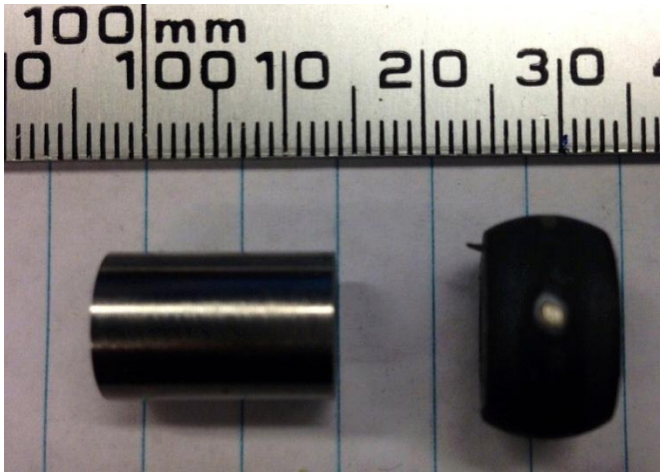


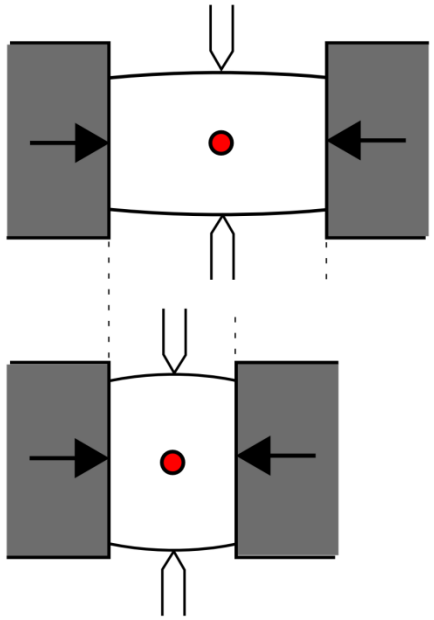


Hot-compression experiment

- ✓ TRIP steel: 0.19C, 1.5Mn, 1.6Si, 0.2Mo (wt%)
- ✓ Attenuation measurement during hot-compressions
- ✓ 3 strain rates, 3 deformation temperatures
- ✓ Laser position follows the center of the specimen

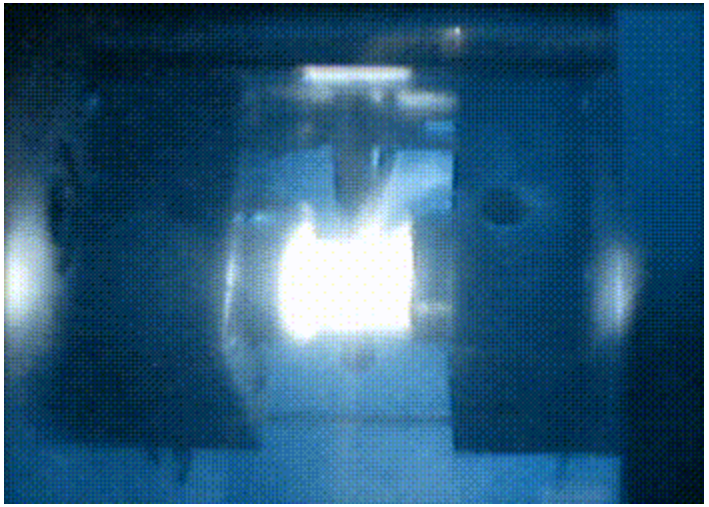


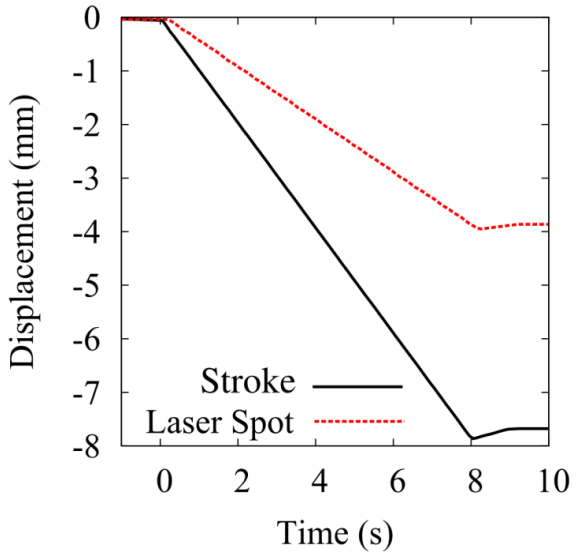




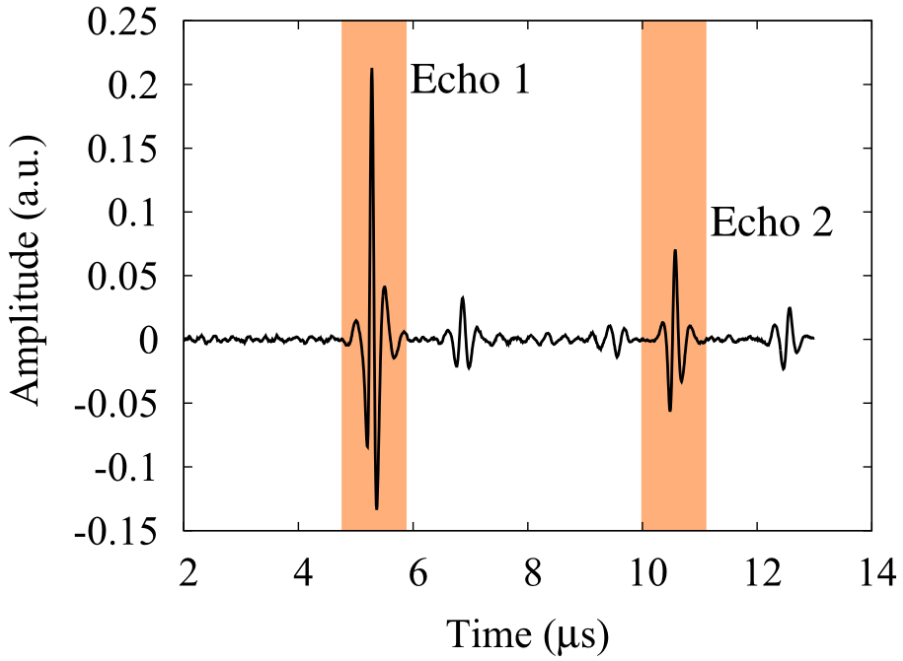
Analysis methodology

Video of in-situ LUMet inspection



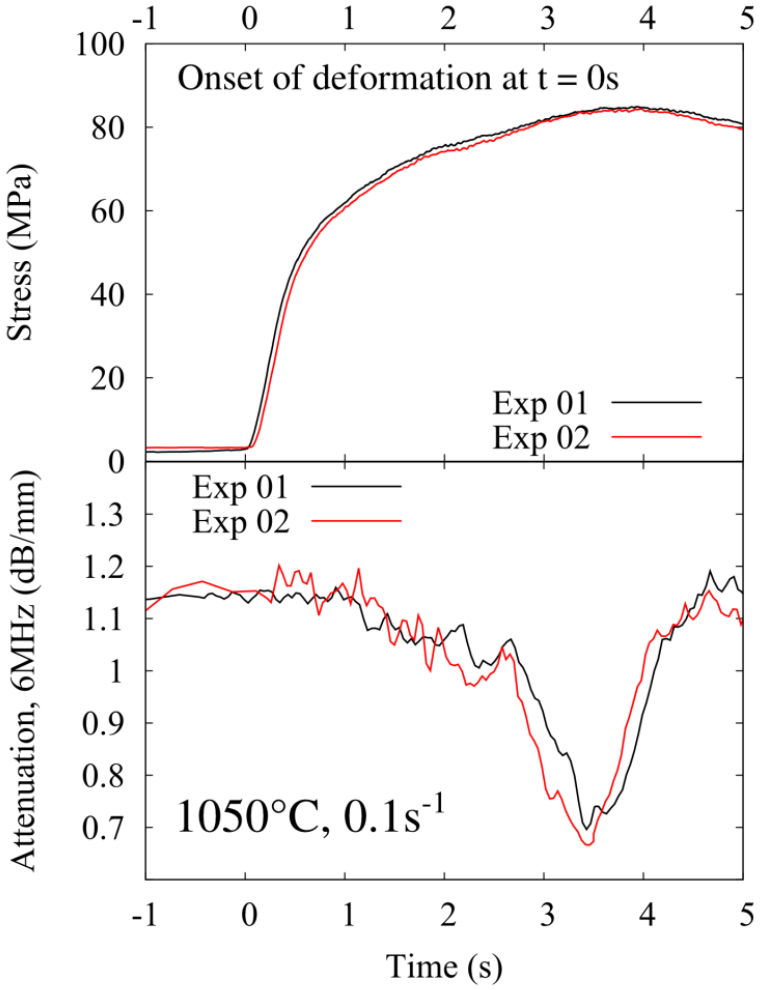


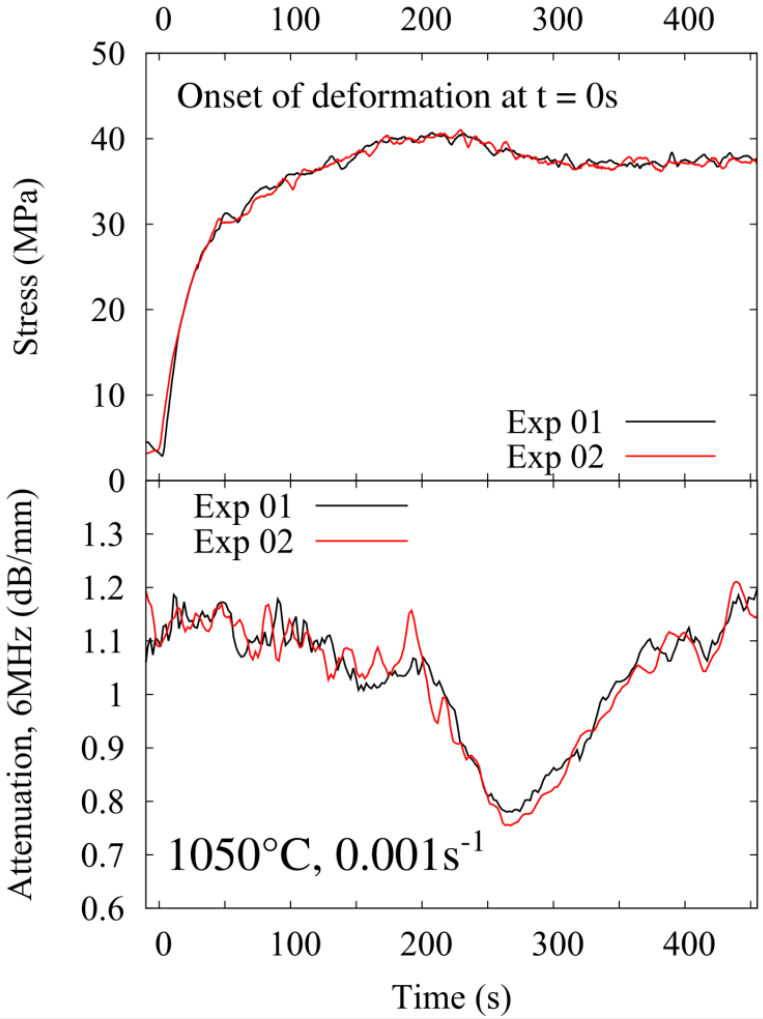
- ✓ Attenuation calculated by the ratio of amplitude spectrum of first and second echoes
- ✓ Variation of attenuation at 6MHz as a function of time



Attenuation change during deformation

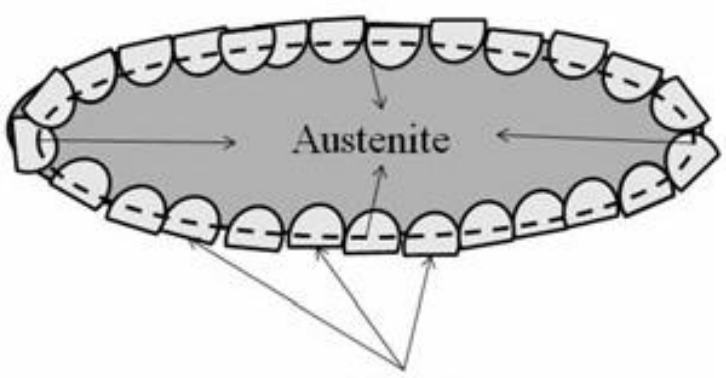
- ✓ Measurements are reproduced to test repeatability



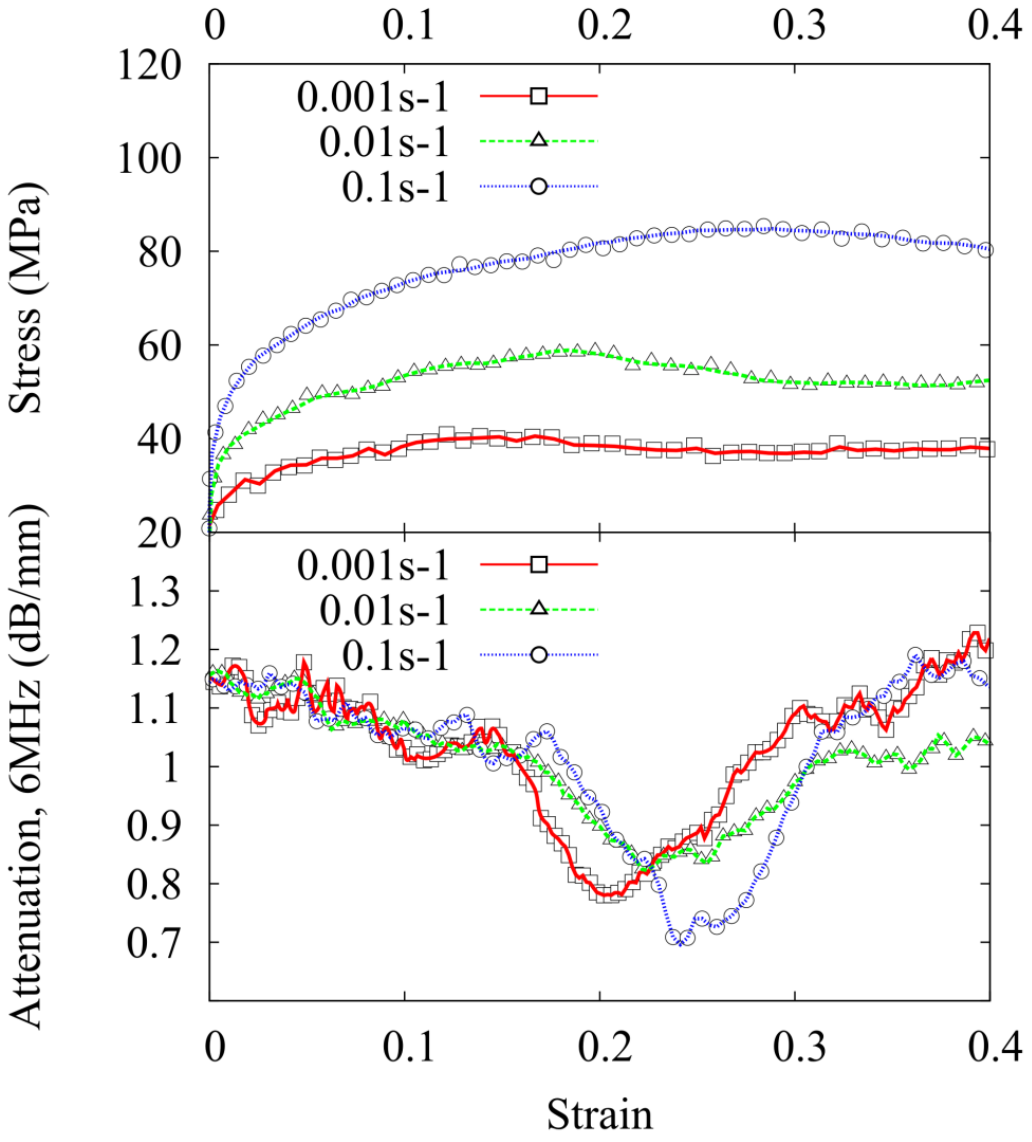


Effect of strain rate

- ✓ Higher strain rate delays the onset of dynamic recrystallization.

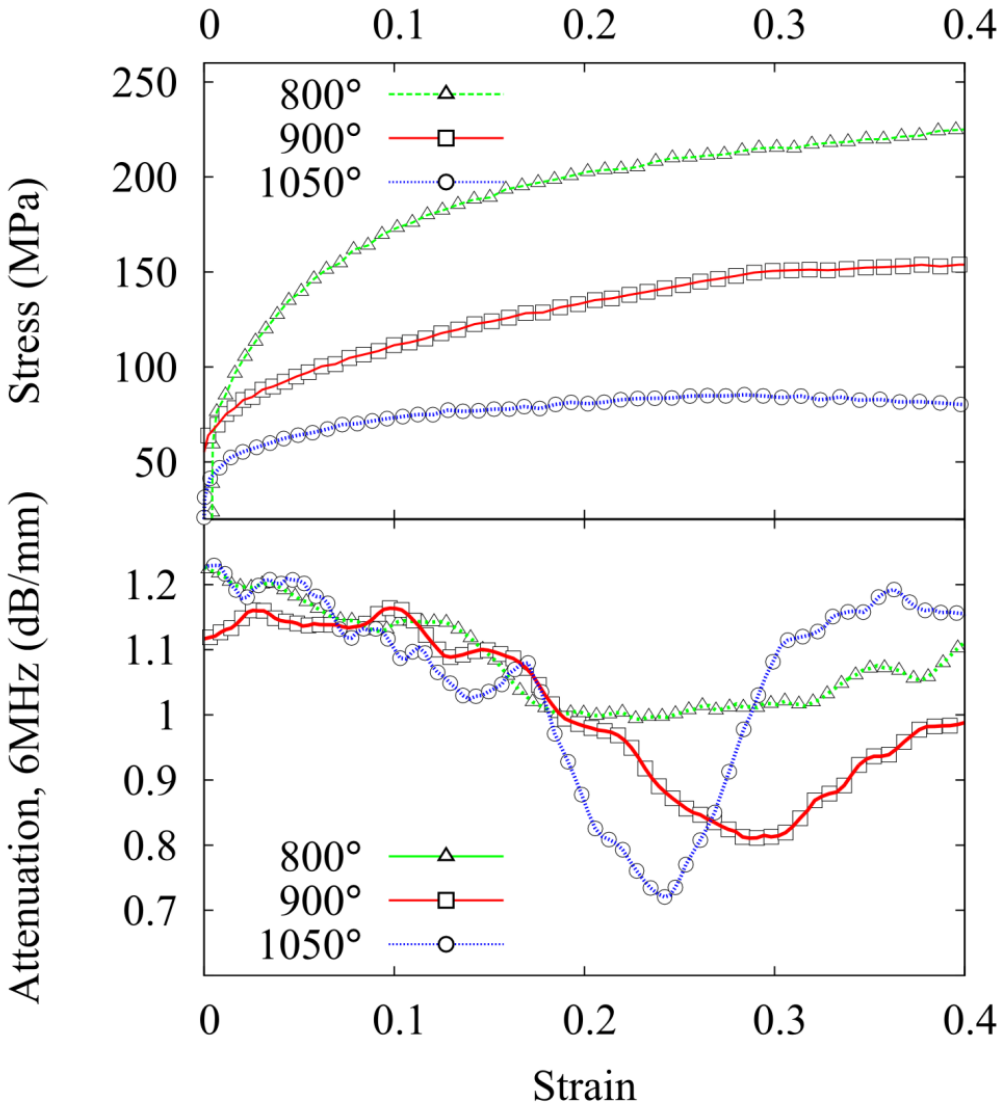


Effective grain size



Effect of deformation temperature

- ✓ Smaller deformation temperature delays the onset of dynamic recrystallization
- ✓ No sign of recrystallization at 800°C on the stress strain curve
- ✓ No marked drop in attenuation observed at this deformation temperature.



Conclusions & Outlook

- ✓ **LUMet – disruptive sensor technique for Research and Development, process modelling and process control: Innovative microstructure design for better steels**
- ✓ **First time monitoring of dynamic recrystallization in austenite**