Laser ultrasonics examination of dynamic recrystallization in Mo-TRIP steel

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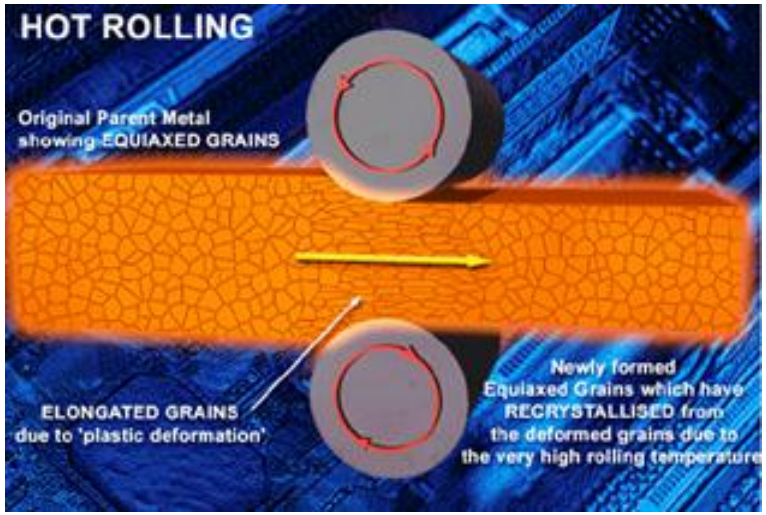
Motivation

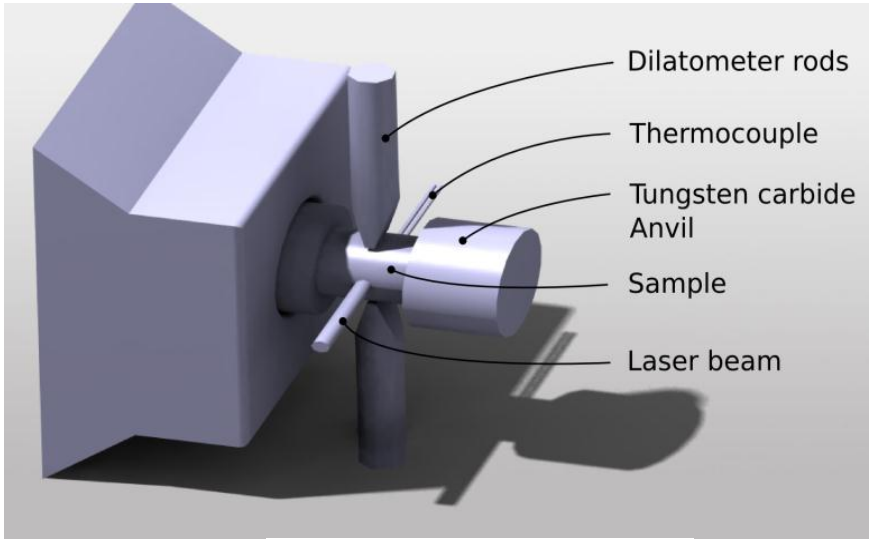
- ✓ Monitoring in-situ the microstructure evolution in steel after and during hot-deformation
- ✓ Work-hardening, recovery, recrystallization
- ✓ Static or dynamic processes
- ✓ Challenging processes to characterise in austenite with existing techniques
- ✓ What type of information can LUMet provide ?

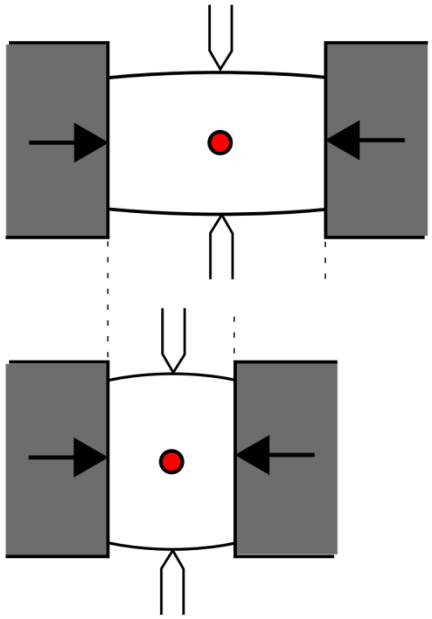


Caption:
Charles Sturt University, Sydney, Australia, Material Engineering

Material and setup

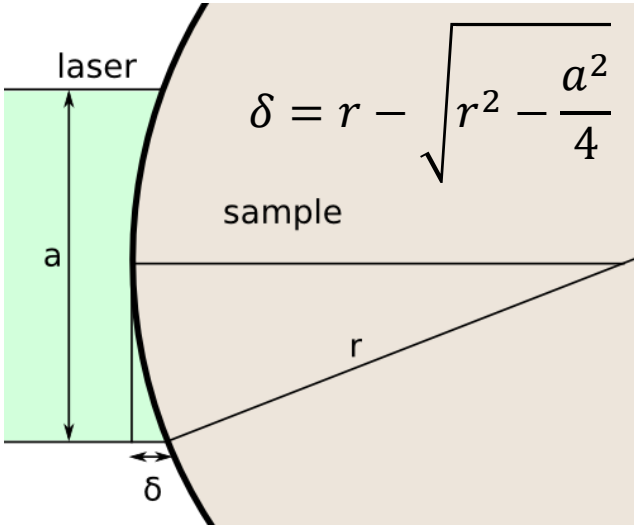
- ✓ Mo-TRIP, forged bar
- ✓ Composition (wt %) C0.19, Mn1.5, Si1.6,Mo0.2
- ✓ Cylindrical sample 10*15
- ✓ Uniaxial compression tests
- ✓ Translating laser table to follow the center of the sample





Measurement on cylinder

- ✓ Pulse echo configuration
- ✓ Small beam spot size
  Generation: radiation pattern similar as for plate
  Detection: Negligible phase shift
- ✓ F_c = 6 MHz
  Wavelength = 1000 µm
  Beam spot size 1.5 mm
  Phase shift = 18 µm



Fresnel parameter

$S = \lambda z / a^2$

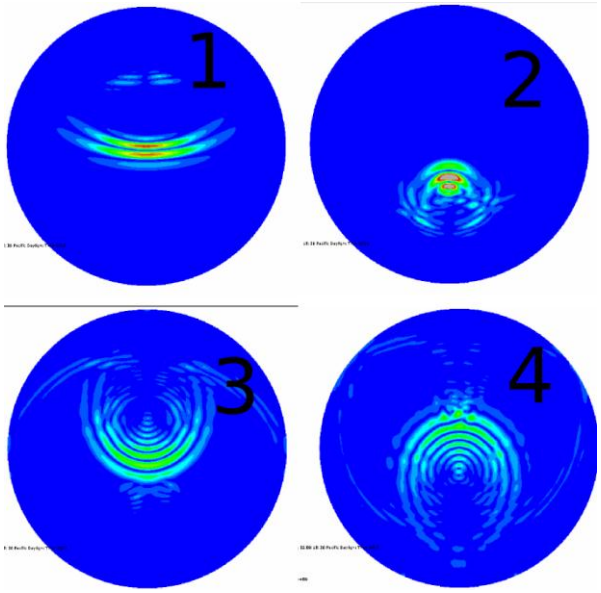
First echo S = 9

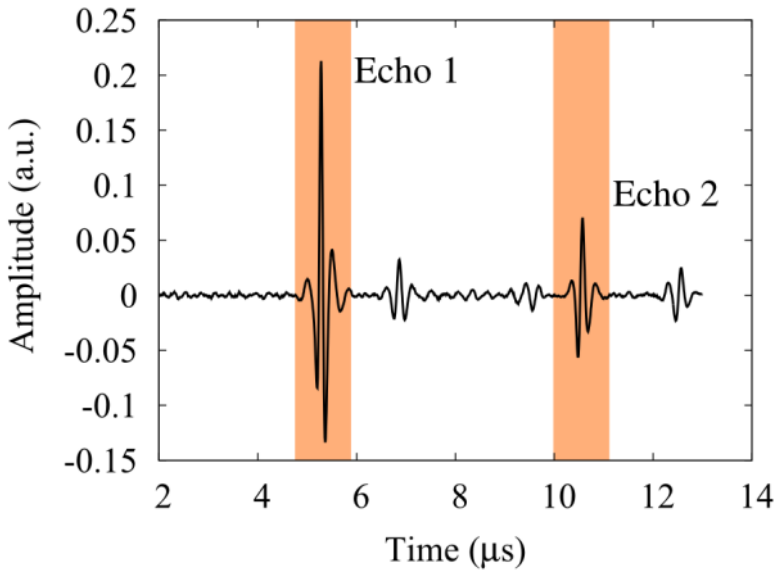
Second echo S = 18

Far Field Region

Complex waveform

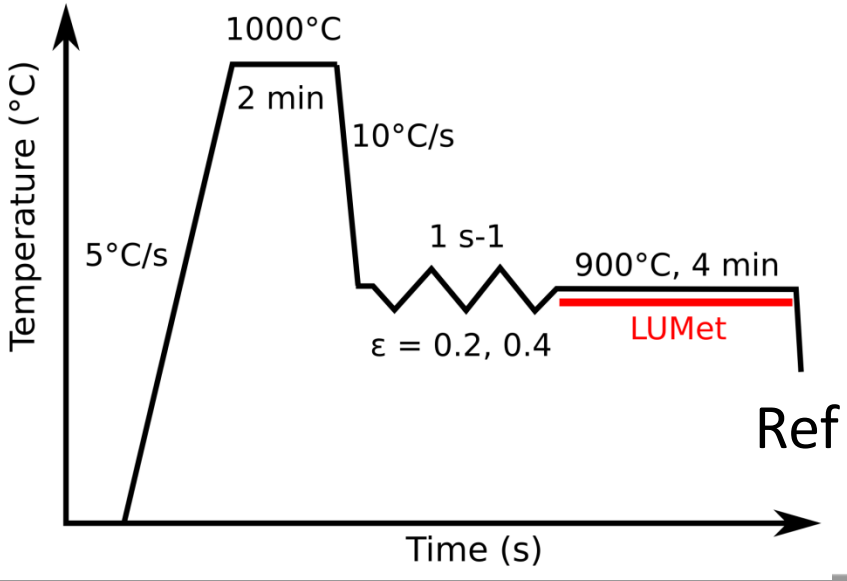
- ✓ Multiple acoustic waves are being generated and start to propagate in various directions
- ✓ High intensity pressure pulse travels across the diameter
- ✓ Surface wave of lower amplitude propagates around the circumference
- ✓ Lower amplitude pressure waves reflect and mode-convert into shear waves

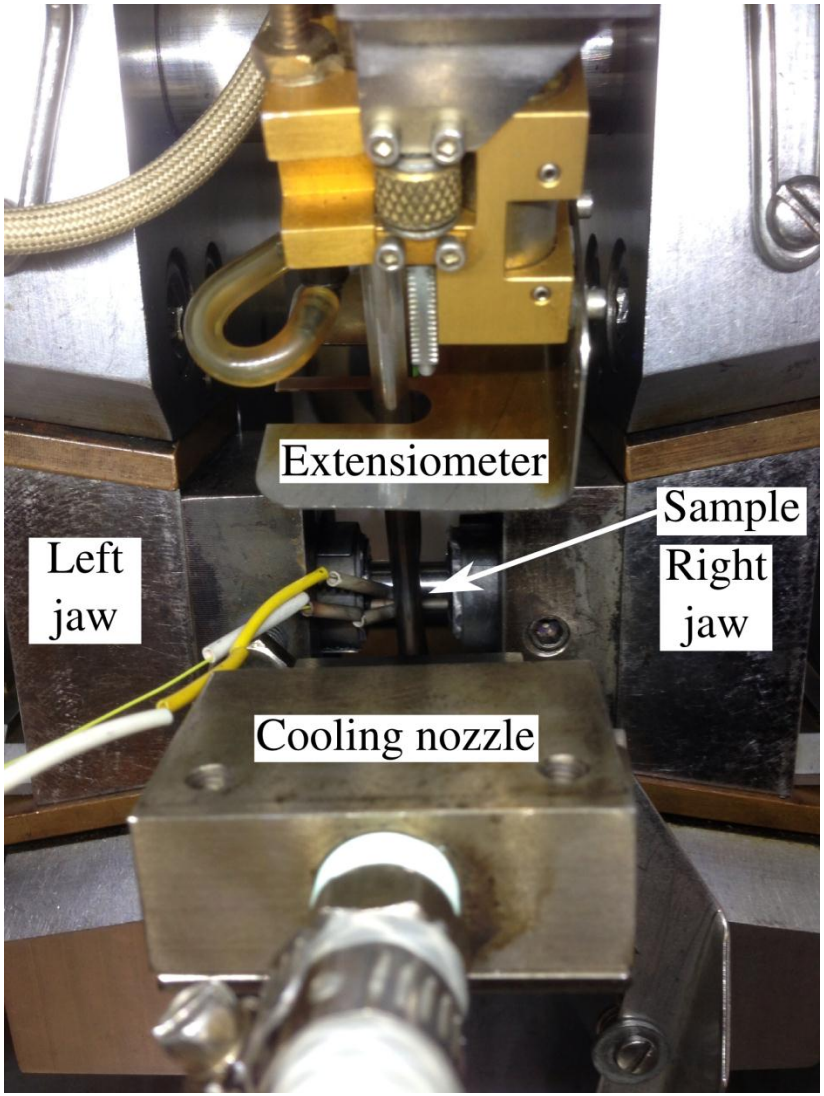




Static recrystallization in austenite

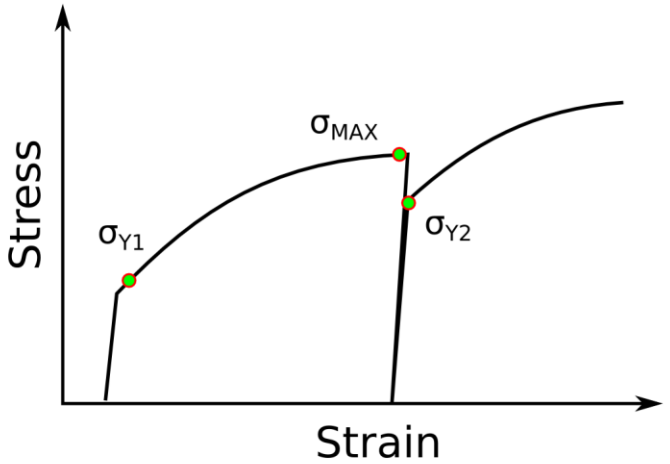
- ✓ Grain size measurement after hot-deformation
- ✓ Strain = 0.2 and 0.4
- ✓ Single echo technique + Available austenite calibration



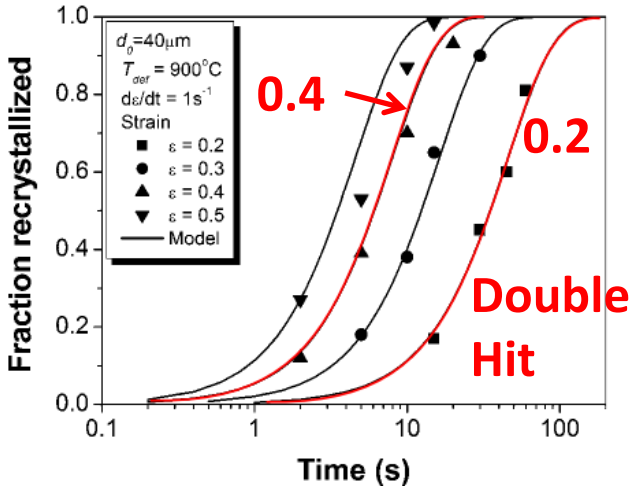


Recrystallization kinetics

- ✓ 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).

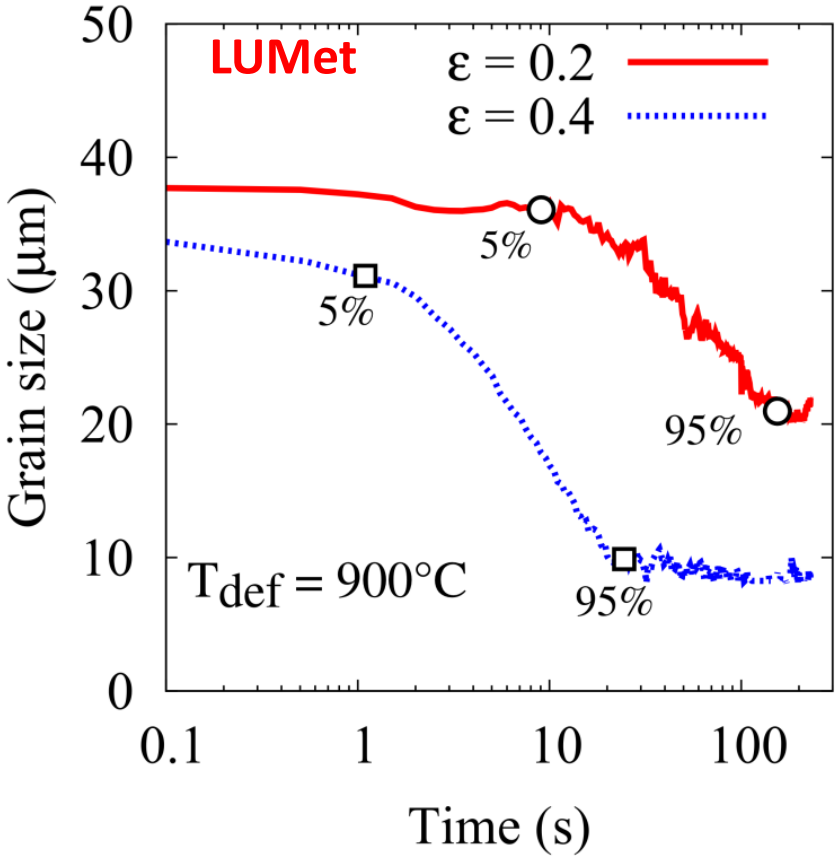


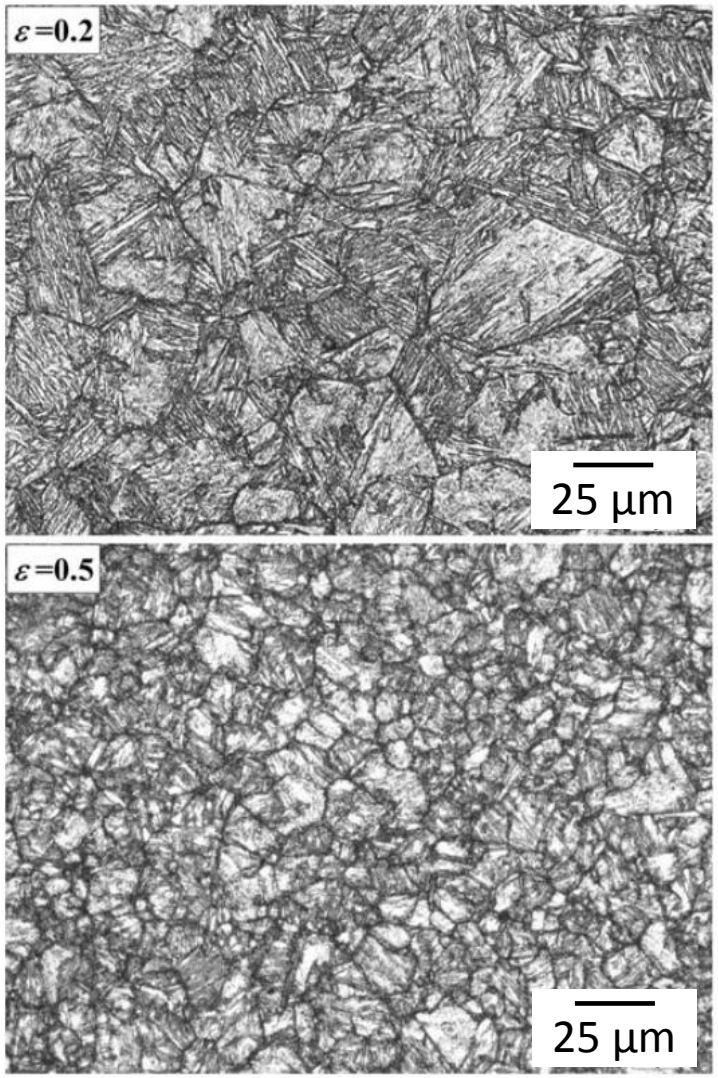
$$F_s = \frac{\sigma_{max} - \sigma_{Y2}}{\sigma_{max} - \sigma_{Y1}}$$



Austenite grain size evolution

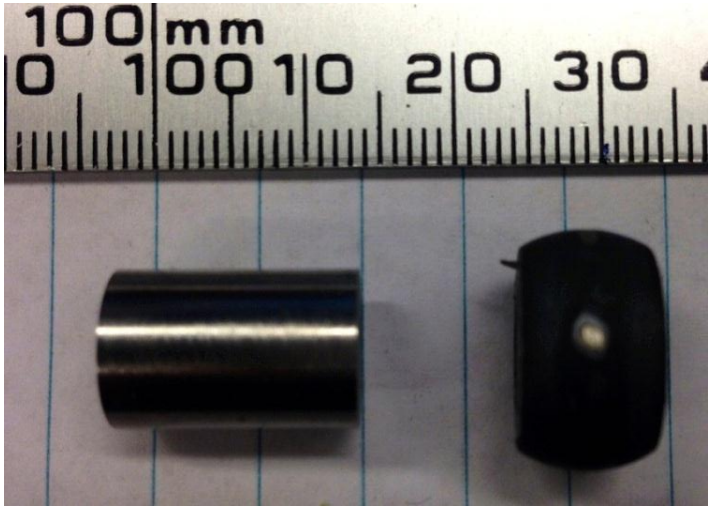
- ✓ Larger grain refinement at higher deformation strain

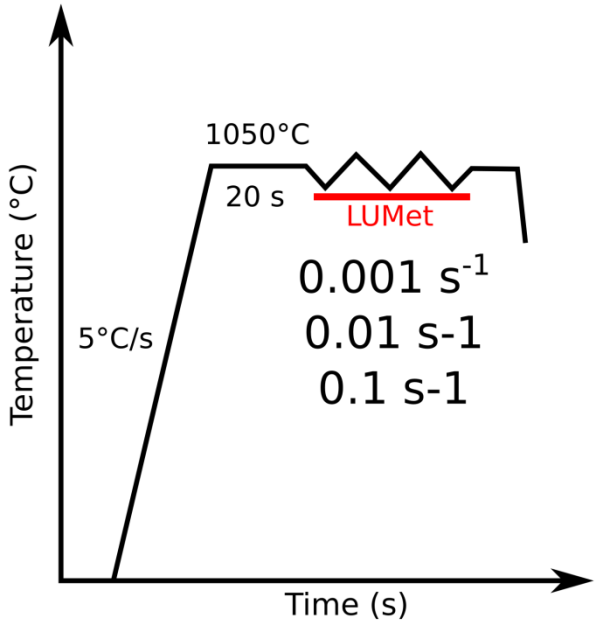


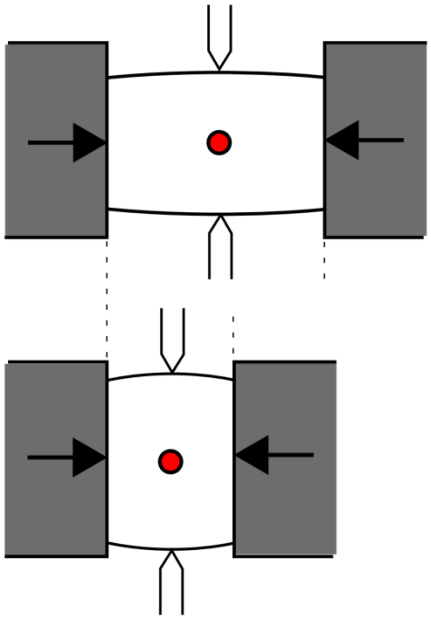


Hot-compression experiment

- ✓ Attenuation measurement during hot-compressions
- ✓ 3 strain rates



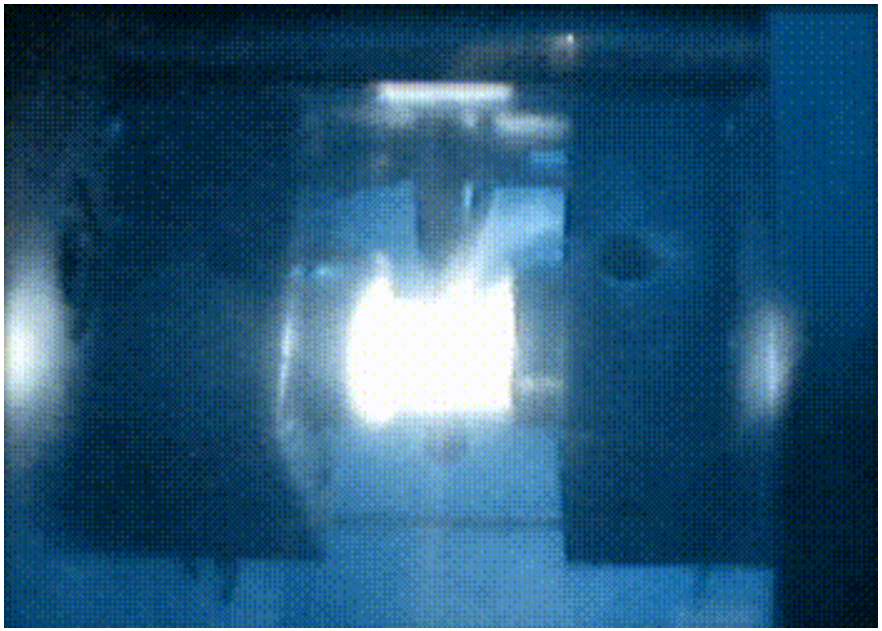


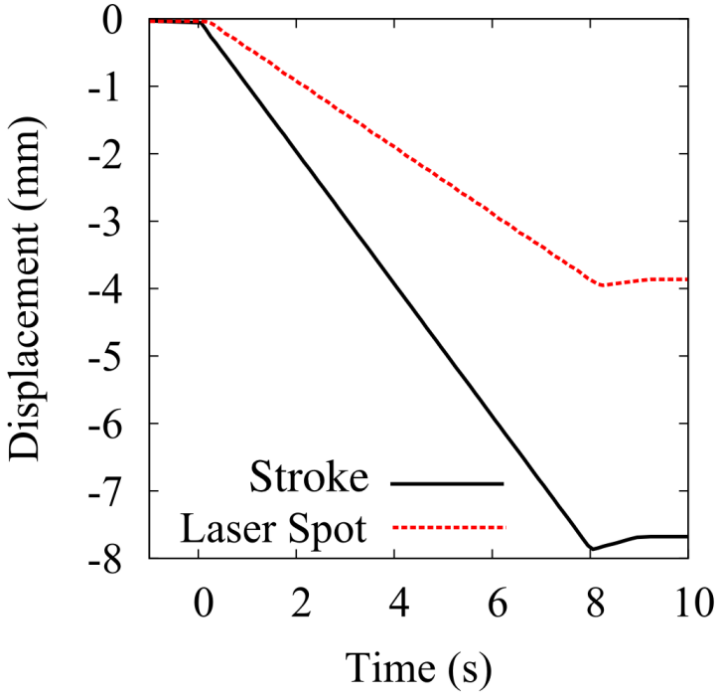


In-situ monitoring during deformation

- ✓ Successfully follow the center of the sample up to a rate of 1mm/s^{-1}

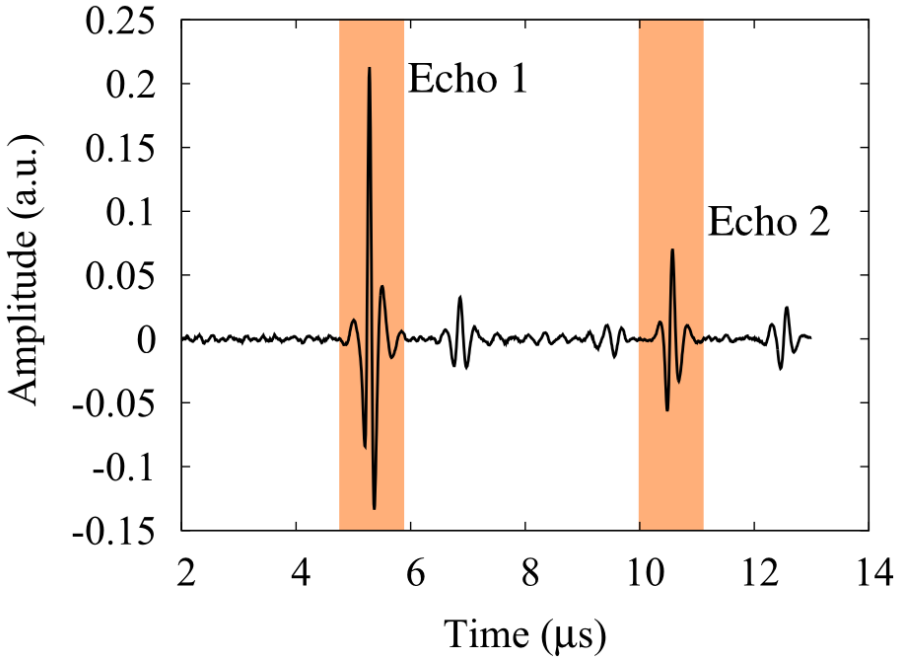
Video of in-situ LUMet inspection





Analysis methodology

- ✓ Sample is continuously changing in shape
- ✓ No reference microstructure can be obtained
- ✓ Attenuation calculated by the ratio of amplitude spectrum of first and second echoes
- ✓ Variation of attenuation at a single frequency

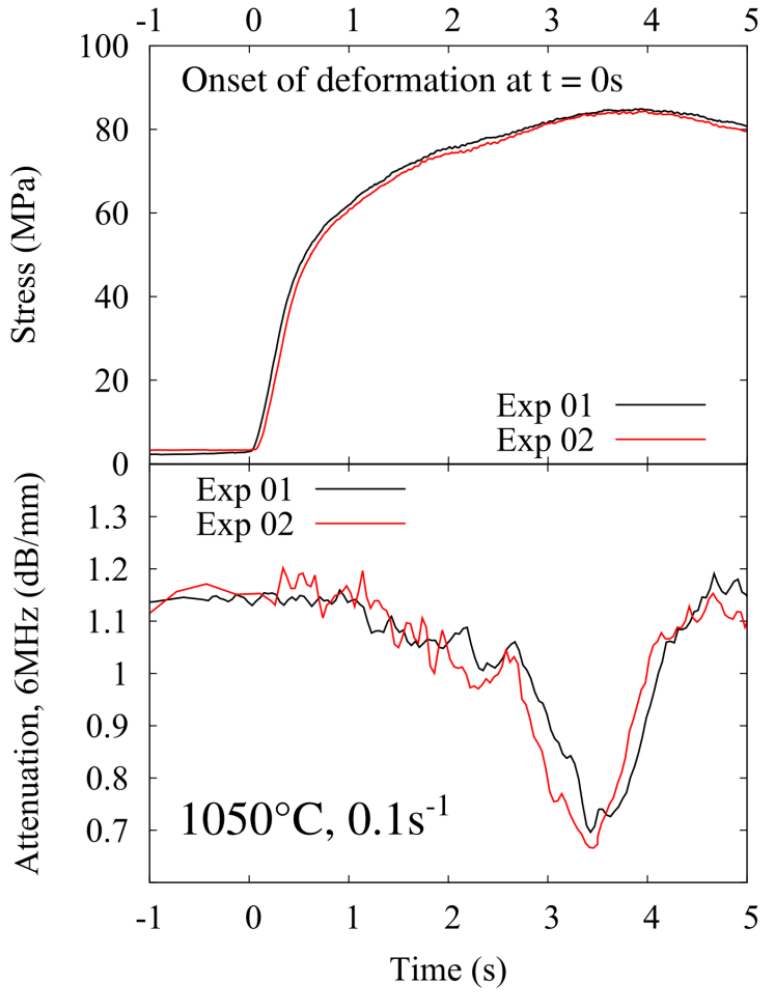


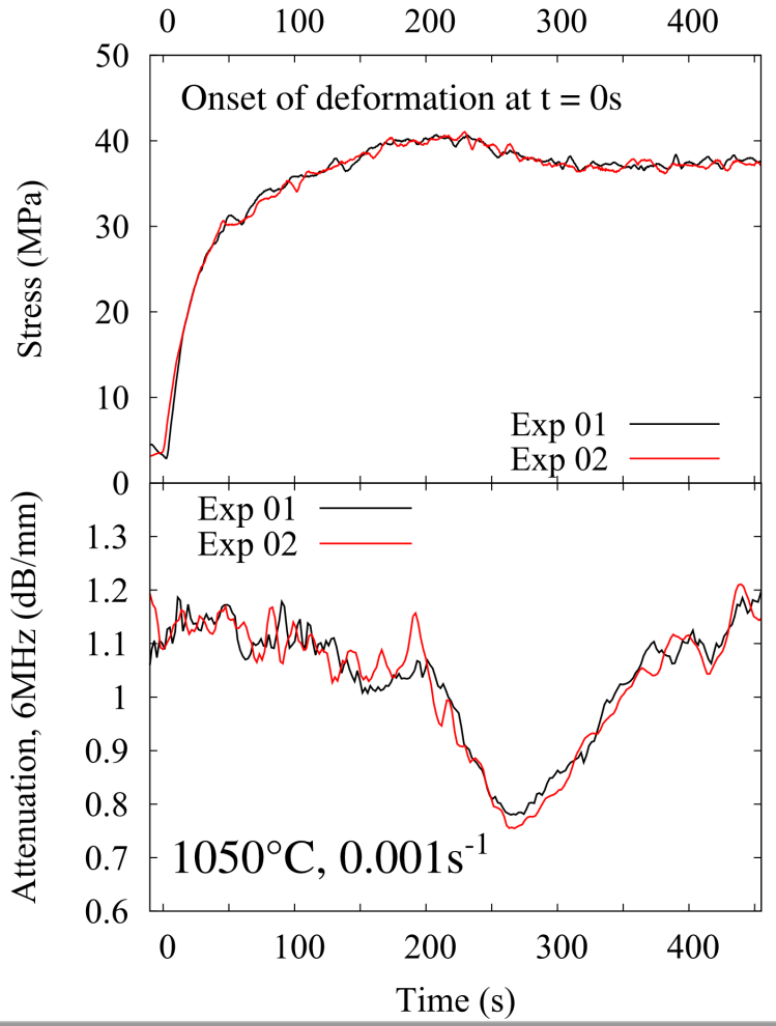
$$\alpha(f) = -\frac{20}{2D(1+\varepsilon)} log10\left(\frac{1}{g}\frac{A_2(f)}{A_1(f)}\right)$$

$$v = \frac{2(D+\xi)}{\tau}$$

Attenuation change during deformation

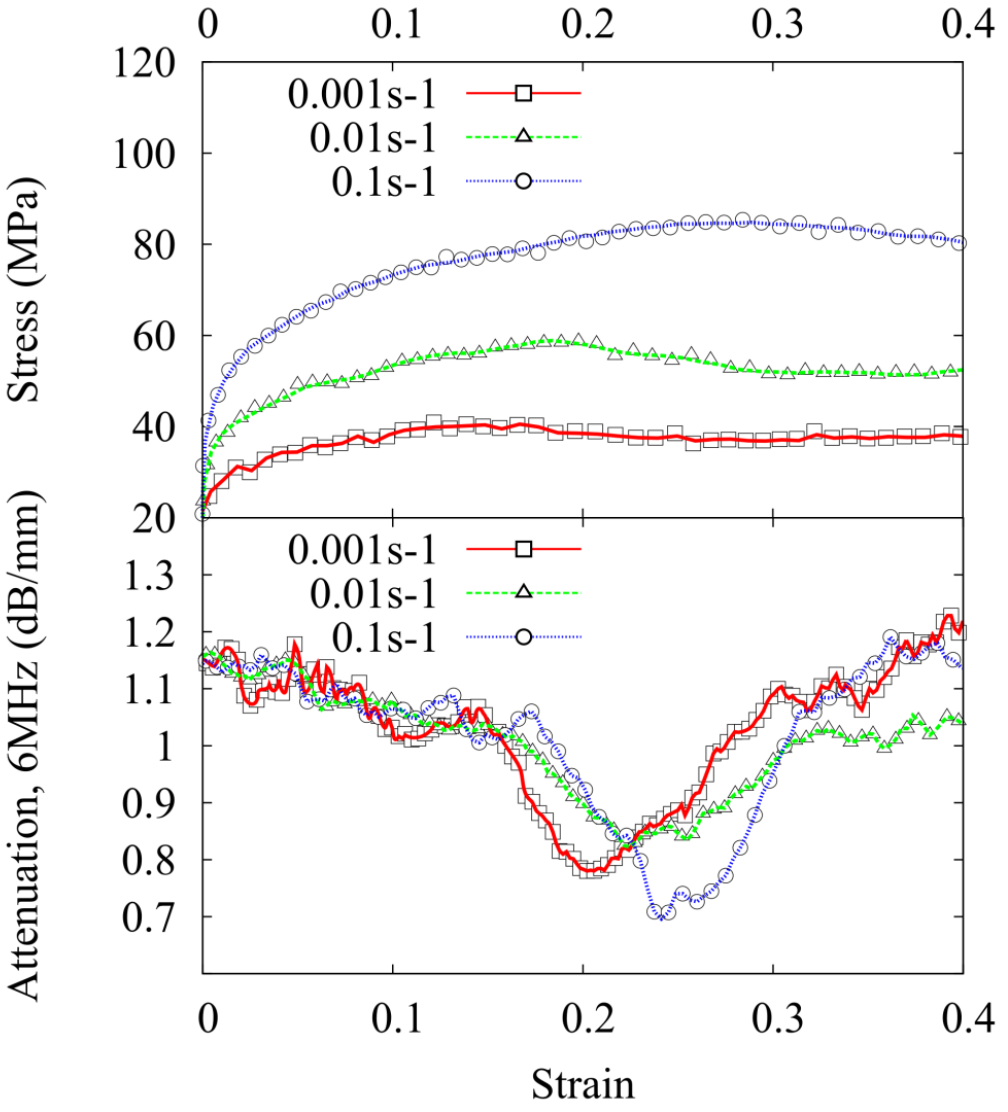
- ✓ Measurements are reproduced to test repeatability





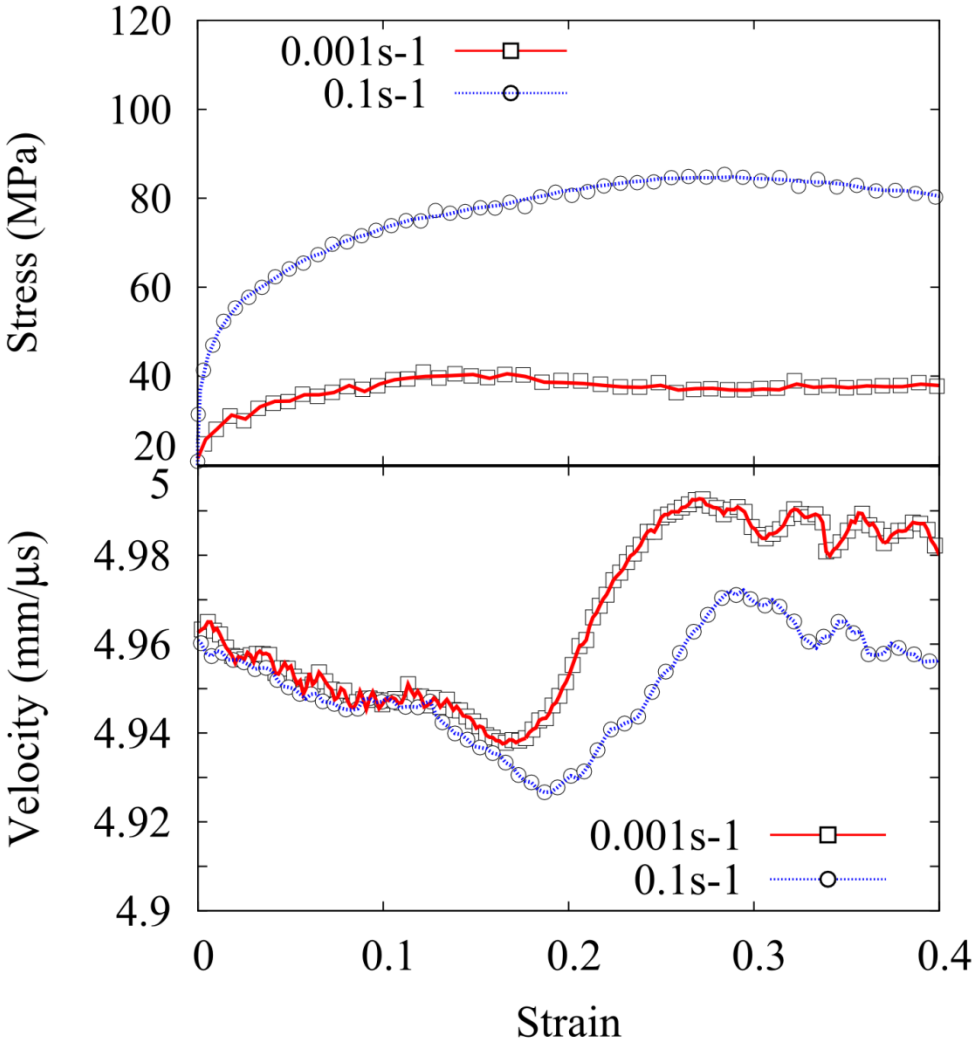
Effect of strain rate on attenuation

- ✓ Higher strain rate delays the onset of dynamic recrystallization.
- ✓ 1/ Attenuation decreases at a constant rate
  2/ later, marked decrease
  3/ increases again at decreasing rate
- ✓ Minimum of attenuation is shifted toward higher strain



Effect of strain rate on velocity

- ✓ When recrystallization occurs, this should be associated to a change in the bulk texture in austenite
- ✓ Several stages are evidenced on the velocity curve during the deformation
- ✓ Transition depends on strain rate



Discussion and future work

- ✓ Single peak in the flow stress curves
- ✓ Indication of dynamic recrystallization
- ✓ Systematic variation of ultrasound parameter
- ✓ Ex-situ metallography for validation
- ✓ Measurement on transmission ?