In-Situ Grain Size Measurement During Dynamic Recrystallization And Hot Rolling Simulations By Laser Ultrasonics/GLUS®


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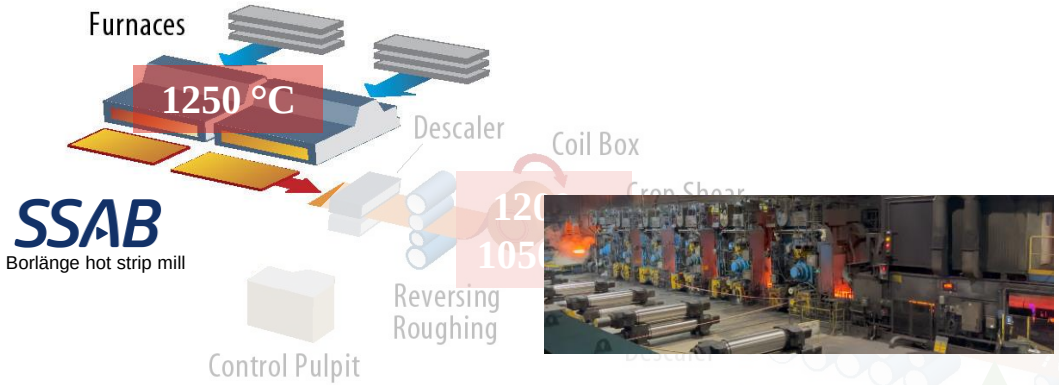
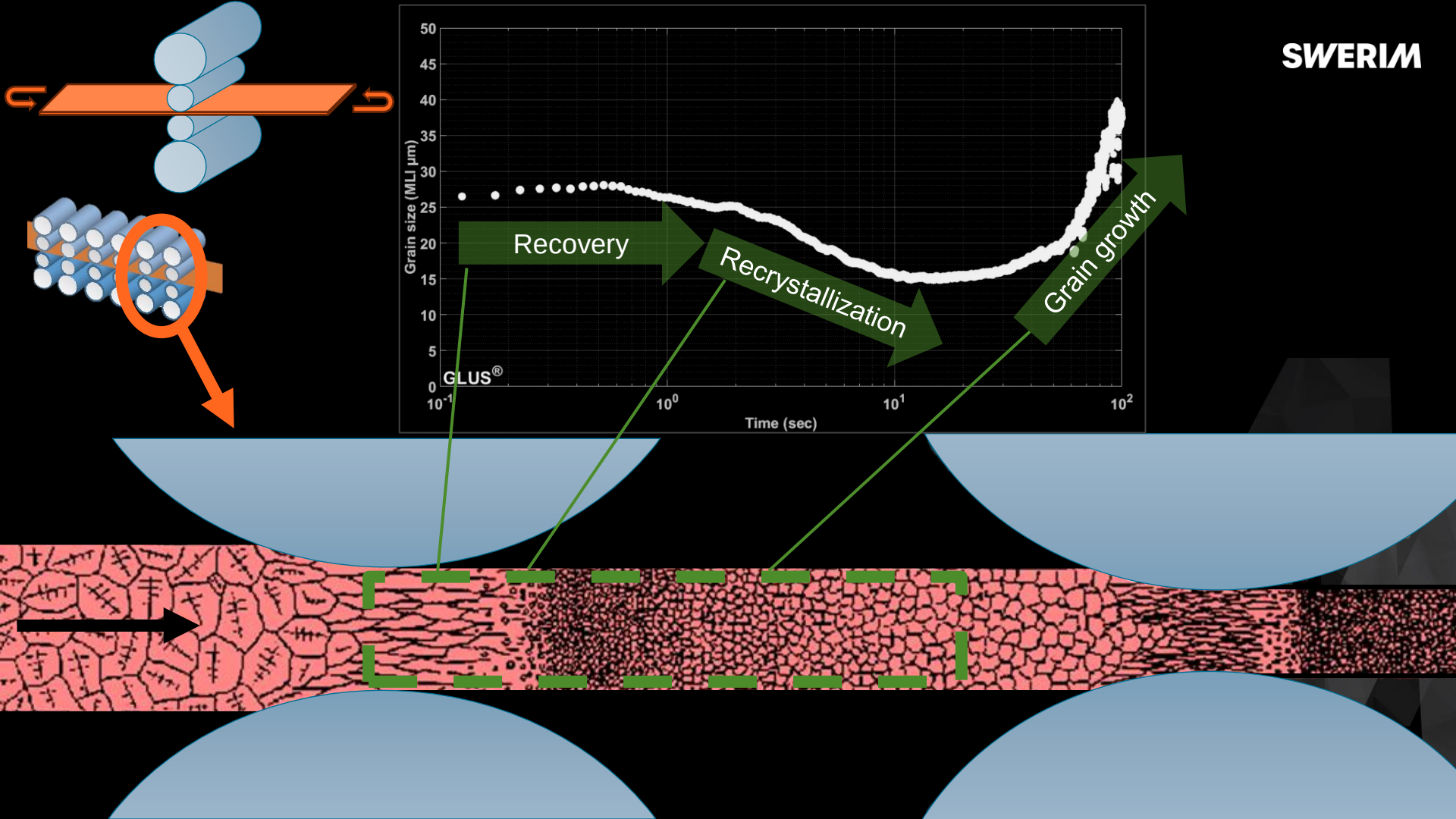
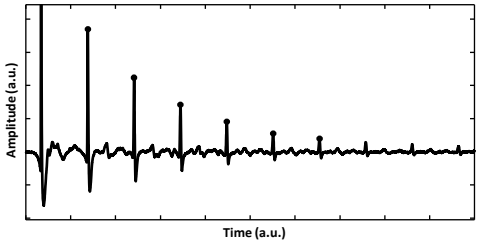
Introduction

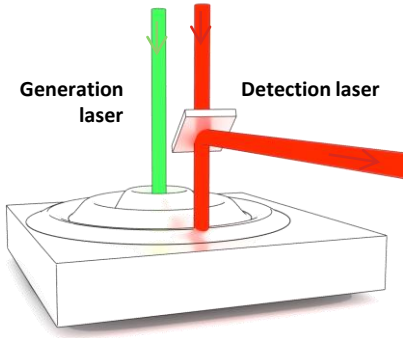



SWERIM
Grain size (MLI µm)
50
45
40
35
30
25
20
15
10
5
0
GLUS®
10^{-1}
10^{0}
10^{1}
10^{2}
Time (sec)
Recovery
Recrystallization
Grain growth

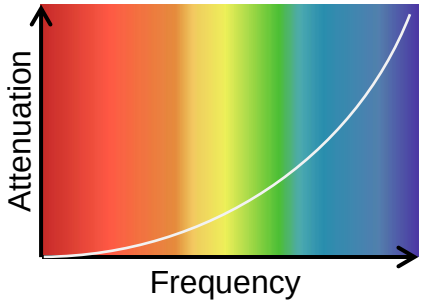
The principle of grain size measurement with GLUS

Measure the ultrasound

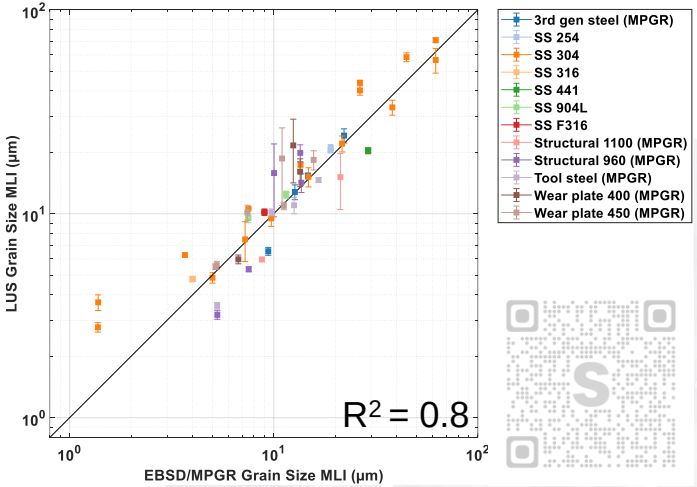




Calculate the attenuation



Calculate the grain size



GLUS® with hot deformation

- 6-hit GLUS trials
- Single hit with dynamic recrystallization

Gleeble and LUS trials
Multi-hit trials

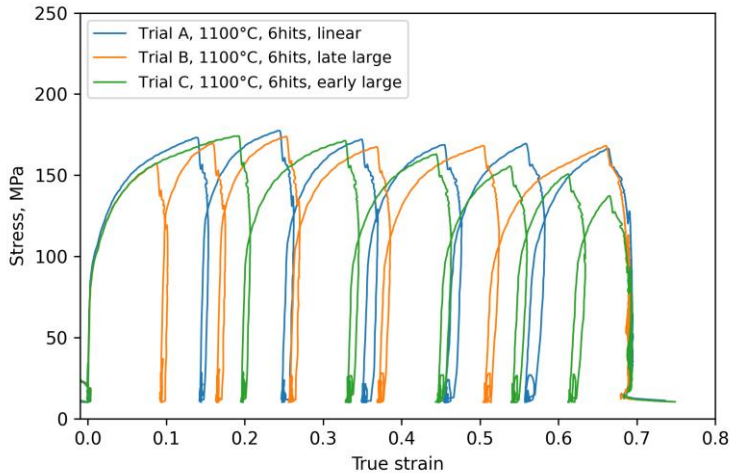
- 316L austenitic stainless steel
- Multi-hit trials at **1100ºC**
- Deformation rate **5 s^{-1}**
- Interpass time **10 s**
- Reduction in each hit are shown below

Trial \ Hit no	1	2	3	4	5	6
A	0.10	0.10	0.10	0.10	0.10	0.10
B	0.05	0.07	0.09	0.11	0.13	0.15
C	0.15	0.13	0.11	0.09	0.07	0.05

Gleeble data
Multi-hit trials

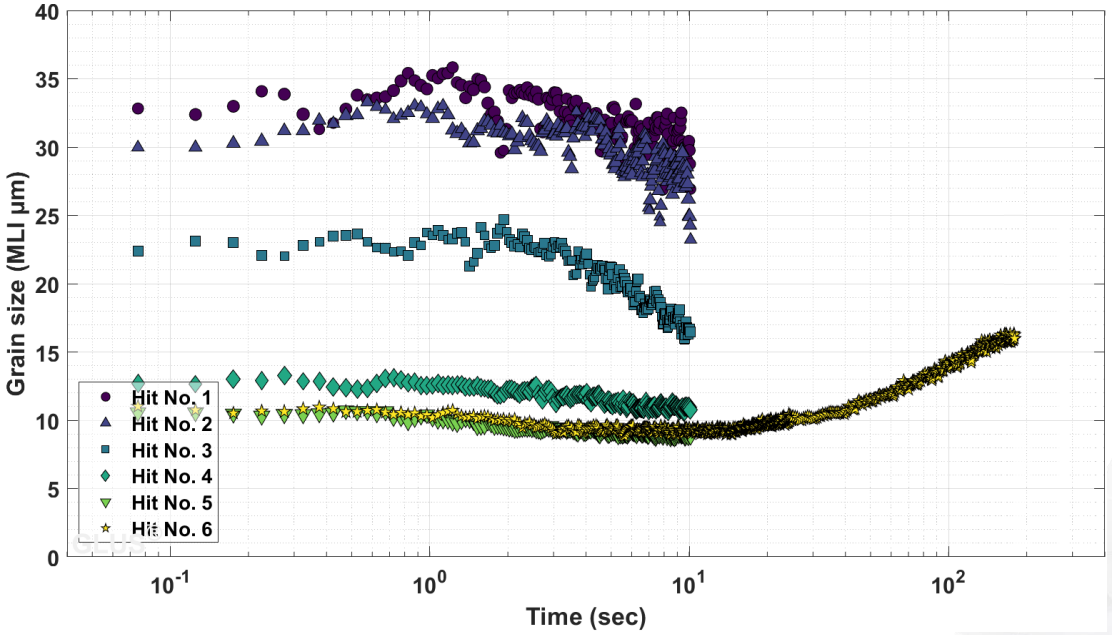
- Flow-stress curves for each hit.
- Stress relaxation is quick at 1100 ºC, and material has low yielding point at following hit
- Similar total reduction, but different approaches to reach this with same temperature, deformation rate and interpass time.

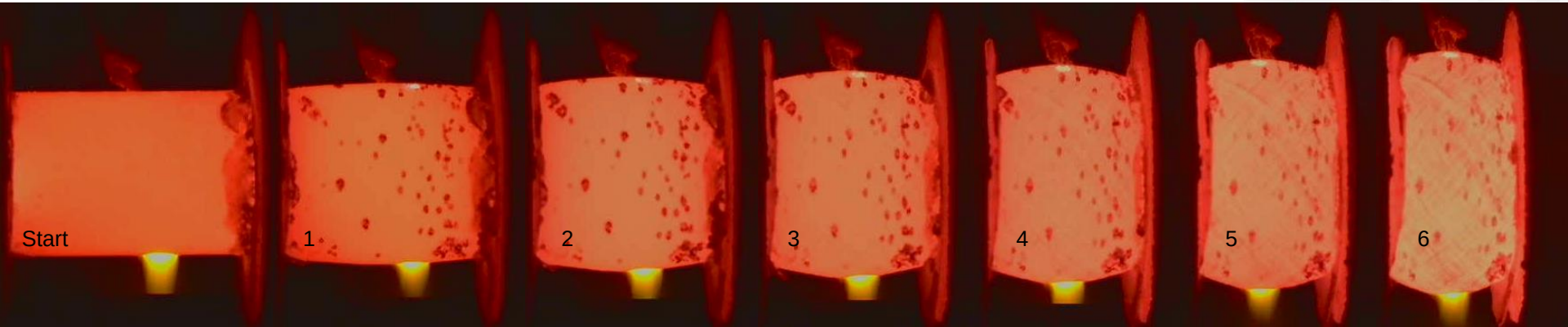
Trial \ Hit no	1	2	3	4	5	6
A	0.10	0.10	0.10	0.10	0.10	0.10
B	0.05	0.07	0.09	0.11	0.13	0.15
C	0.15	0.13	0.11	0.09	0.07	0.05



GLUS Data Multi-hit trials

The grain size as function of time following the 6 hits

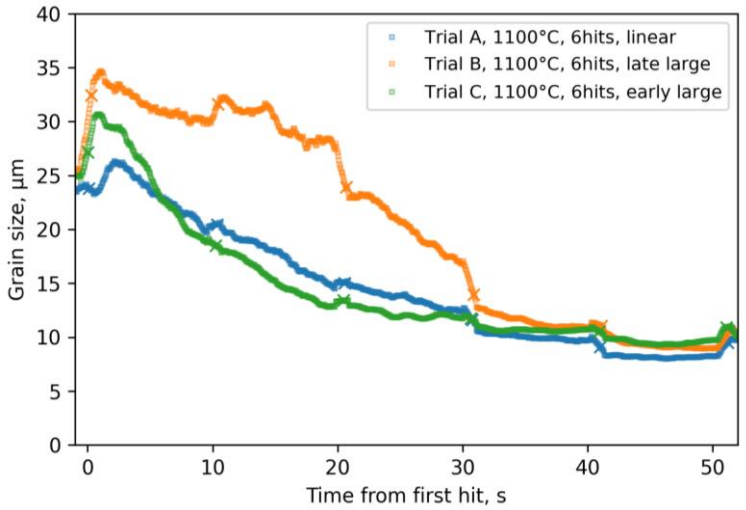




LUS data
Multi-hit trials

- Grain refinement occurs by recrystallisation, driven by the size of the deformations.
- Grain size refines slower/faster for Trial B/Trial B with initially lower/larger reductions.
- All materials approaches similar final grain size, related to similar total reduction.

Trial \ Hit no	1	2	3	4	5	6
A	0.10	0.10	0.10	0.10	0.10	0.10
B	0.05	0.07	0.09	0.11	0.13	0.15
C	0.15	0.13	0.11	0.09	0.07	0.05



x indicates position of peak stress in every hit

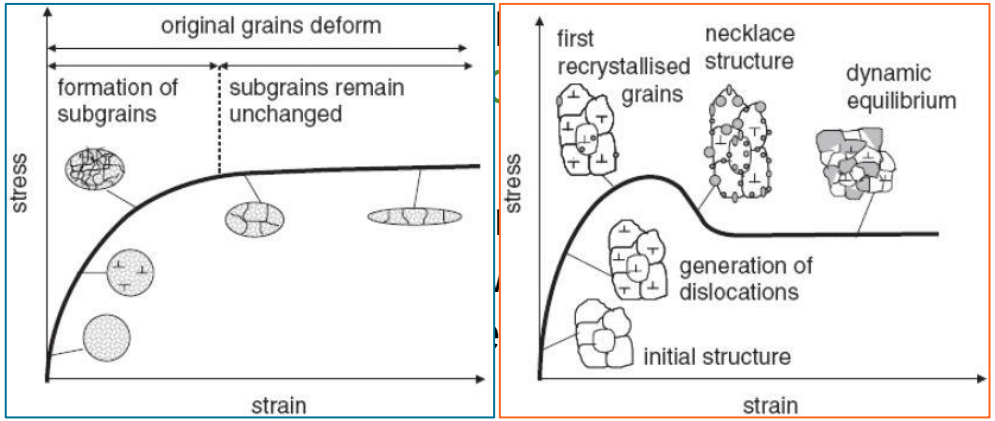
Gleeble and LUS trials
Dynamic recrystallisation

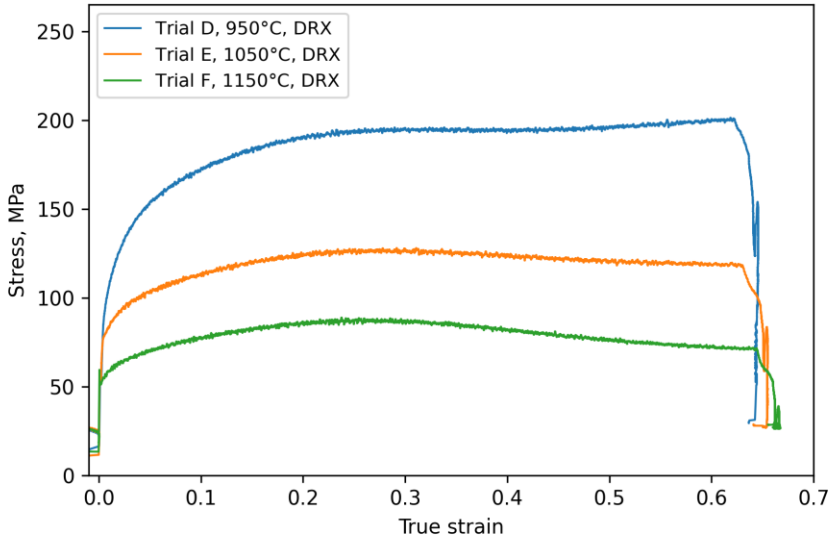
- 316L austenitic stainless steel
- Single-hit trials at three temperatures 950, 1050, 1150 ºC
- Deformation rate **0.05 s^{-1}**
- Total reduction **0.6** (true strain)

Trial	Temperature
D	950 ºC
E	1050 ºC
F	1150 ºC

Gleeble data
Dynamic recrystallisation

- Dynamic recrystallisation is often seen at high temperature testing and slower deformation rates.



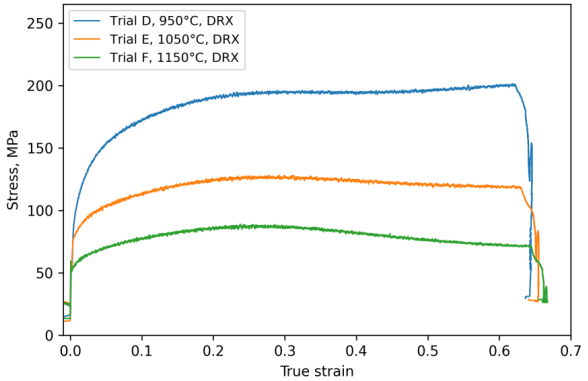


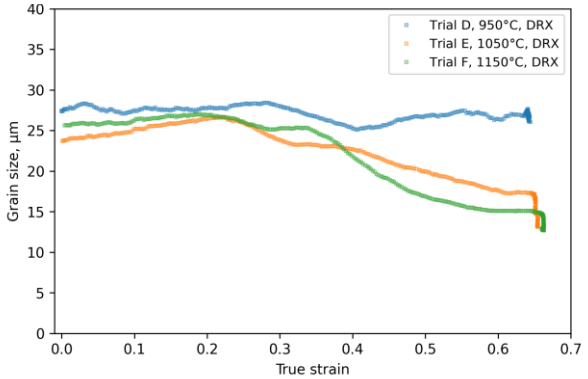
[1] Q. Guo-Zheng, “Characterization for Dynamic Recrystallization Kinetics Based on Stress-Strain Curves,” in *Recent Developments in the Study of Recrystallization*, IntechOpen, 2013. doi: 10.5772/54285. Available: https://www.intechopen.com/chapters/41650. [Accessed: May 21, 2024]

LUS data
Dynamic recrystallisation

- LUS confirms dynamic recrystallisation for 1050 and 1150 ºC, but grain size remains stable for 950 ºC.

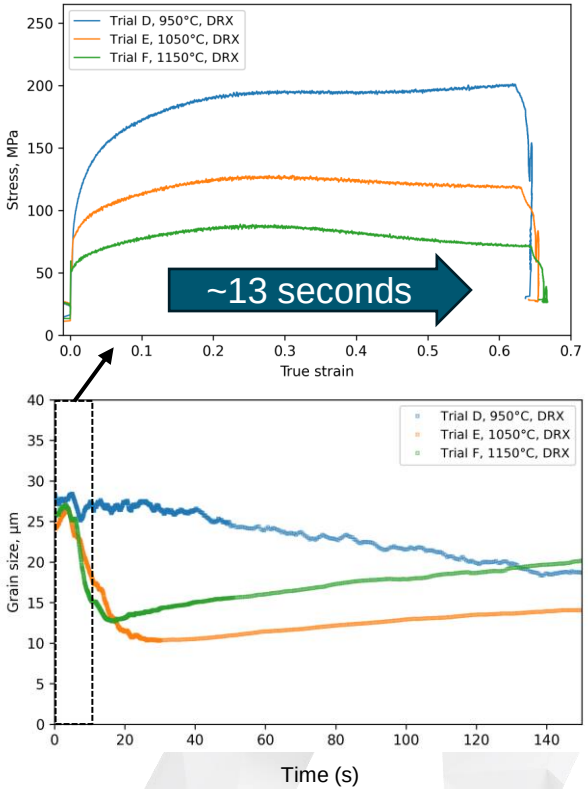
- Grain size during hit in agreement with stress-strain curve, according to classic theory of dynamic recrystallisation.





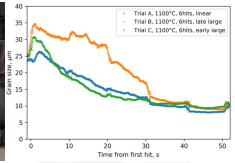
LUS data
Dynamic recrystallisation + after deformation

- For testing at lower temperature 950 °C, recrystallisation continues after final hit.
- To some extent, this is also seen for 1050 and 1150 °C, but recrystallisation is finished after about 30 and 20 seconds.
- Later part is grain growth (coarsening)

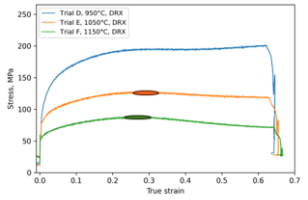


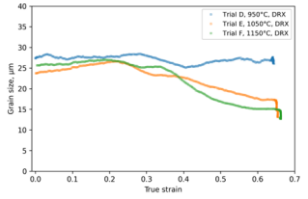
Summary

- GLUS methods offer unique possibility to study grain refinement in-situ while simulating industrial production processes like rolling or forging.



- With in-situ measurements feedback is available during whole trial, and not only after quench, if using traditional methods to study recrystallisation.





- This is useful to optimize metal working strategies to reach desired grain refinement.

More LUS/GLUS®/LUS-online info:

https://www.swerim.se/en/services/material-analysis-process-monitoring/laser-ultrasonics-lus/glusr-gleeble-lus

https://www.swerim.se/en/services/material-analysis-process-monitoring/laser-ultrasonics-lus

http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-300906 (Recorded presentation)

http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-259955