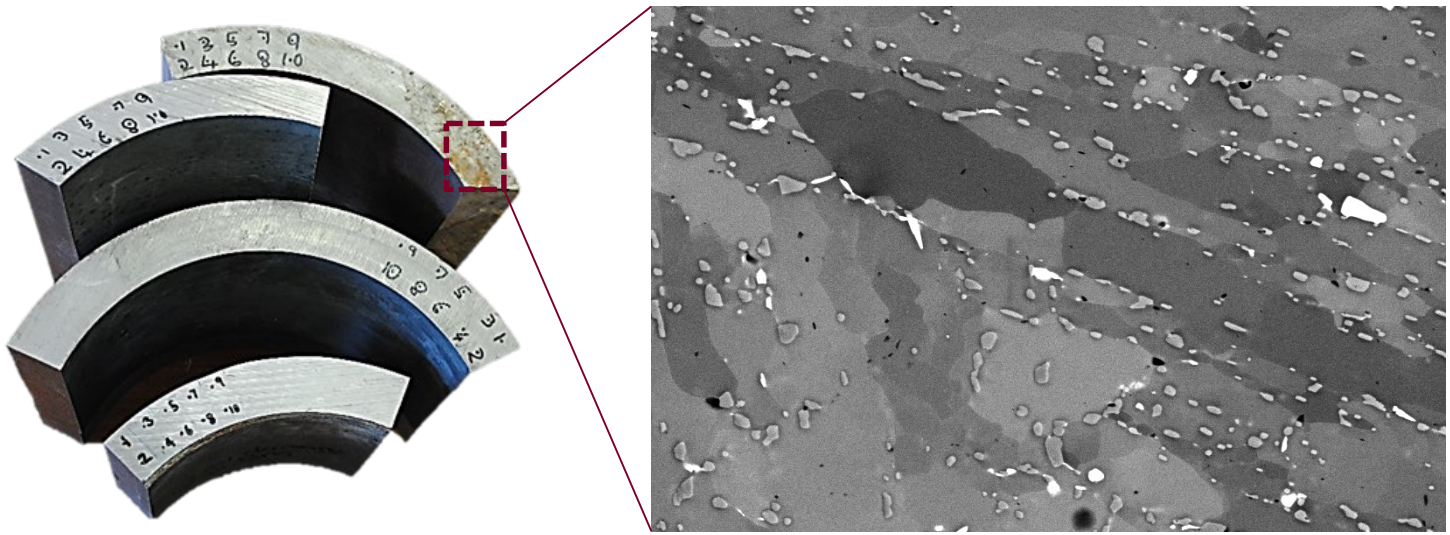
FAKULTEIT INGENIEURSWESE
FACULTY OF ENGINEERING

Microstructural deterioration assessment of ex-service power plant steel using concentric backscatter imaging



Presented By: Melody van Rooyen, **Supervisor**: Prof TH Becker
In collaboration with: CHRTEM, NMU (Dr. J Westraadt and Dr. G Marx)

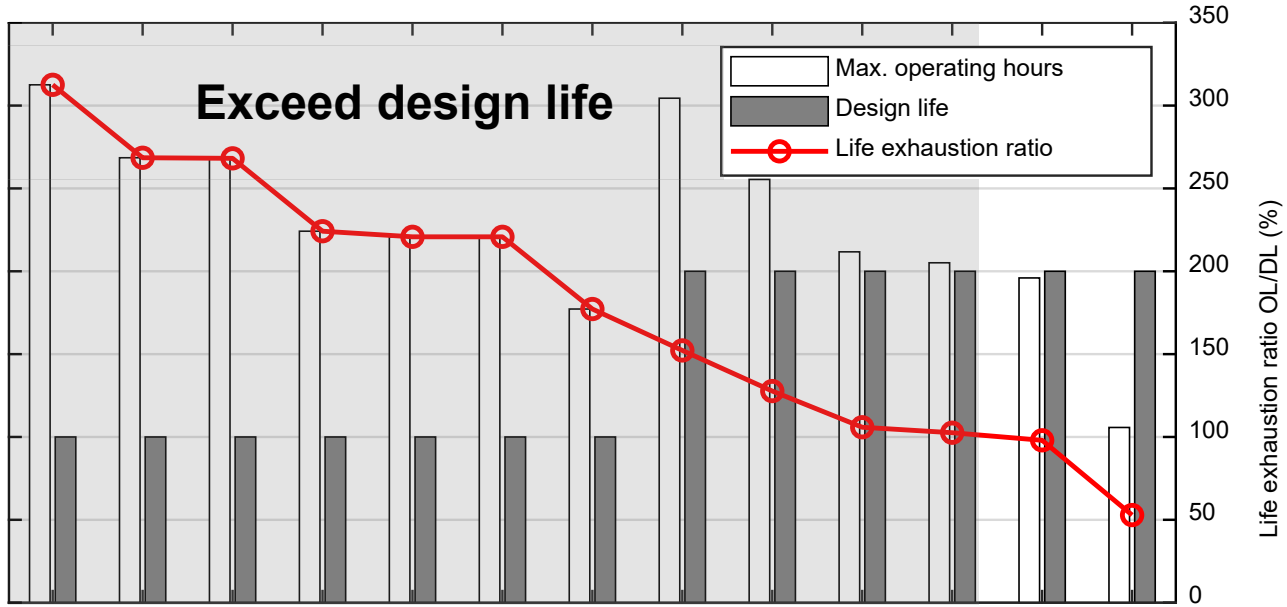
MSSA Conference
1 - 5 December 2019
CLUB MYKONOS • LANGEBAAN • WESTERN CAPE

MATERIALS ENGINEERING

UNIVERSITEIT • STELLENBOSCH • UNIVERSITY

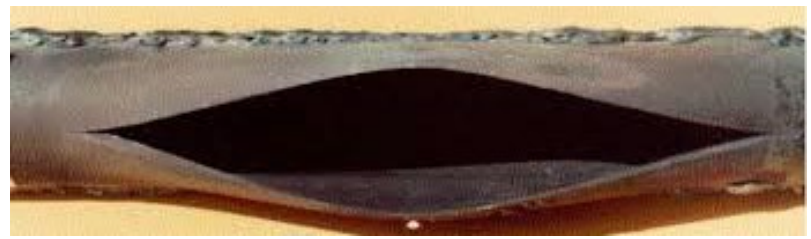
UNIVERSITEIT STELLENBOSCH UNIVERSITY

Background – Power stations and creep



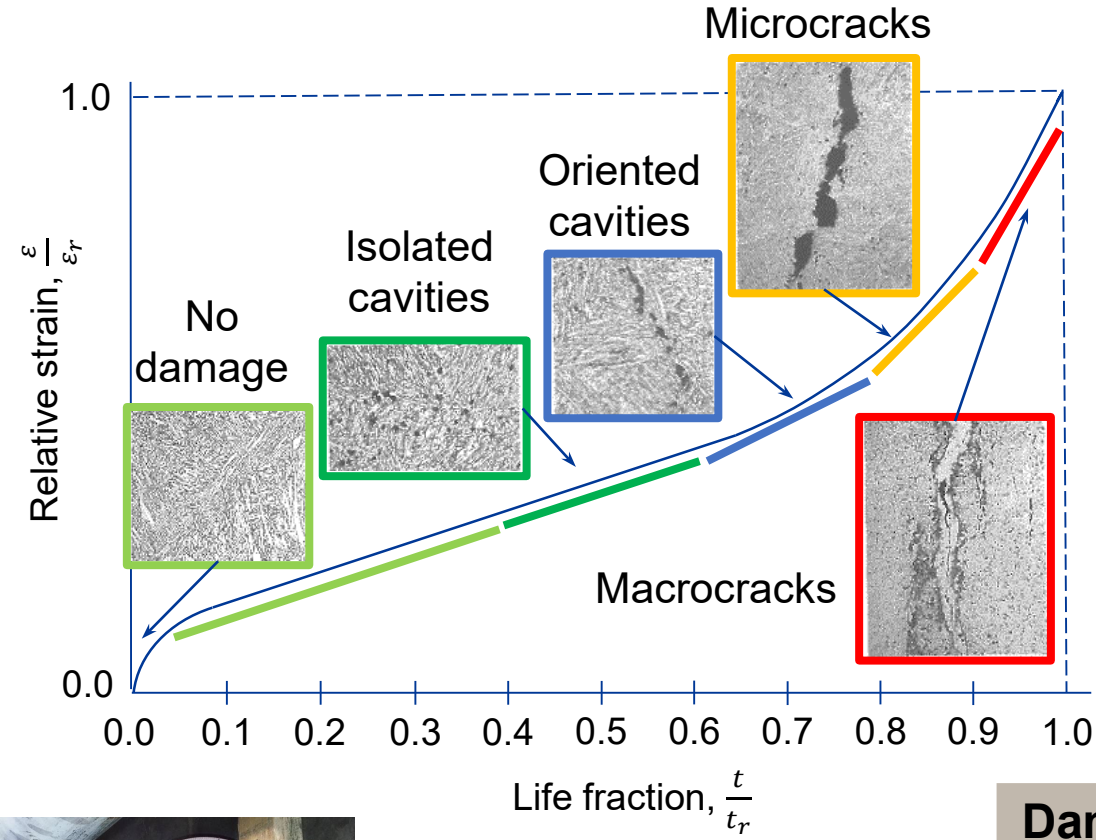
High temperature (> 550 °C), high steam pressures (>15 MPa)

Creep



iosrjournals.org

Background – Material assessment



Class	Action
4	Inspect within 6-9 years
3	Inspect within 3 years
2	Replace within 3 years
1	Replace immediately

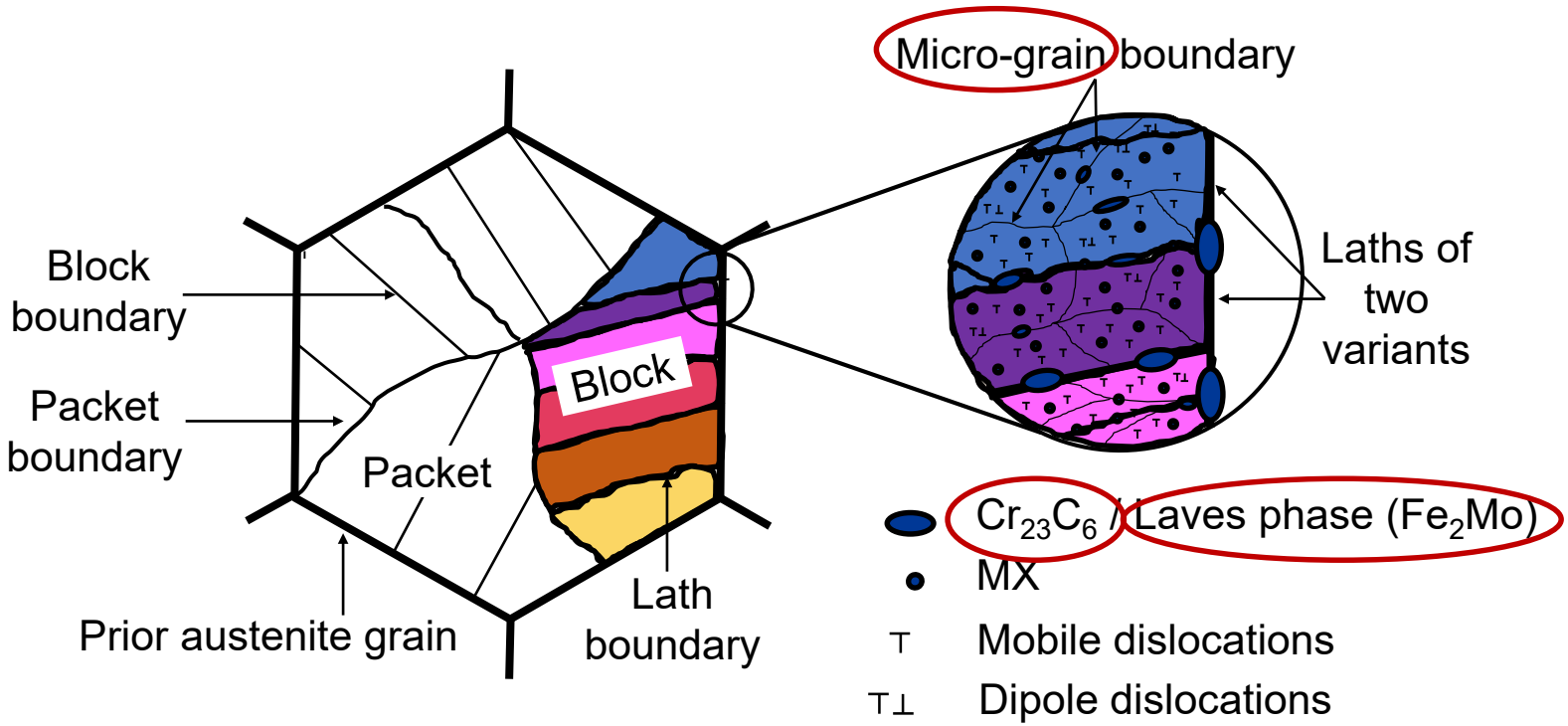
EPPEI

12 % Cr steel:
X20CrMo12-1
(X20 for short)

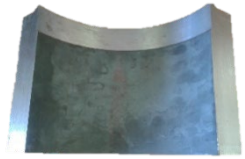
Ex-service X20

Damage state	Cavities/mm²
New	Ideally none
Low	60-90
Medium	≈200
High	>220-690

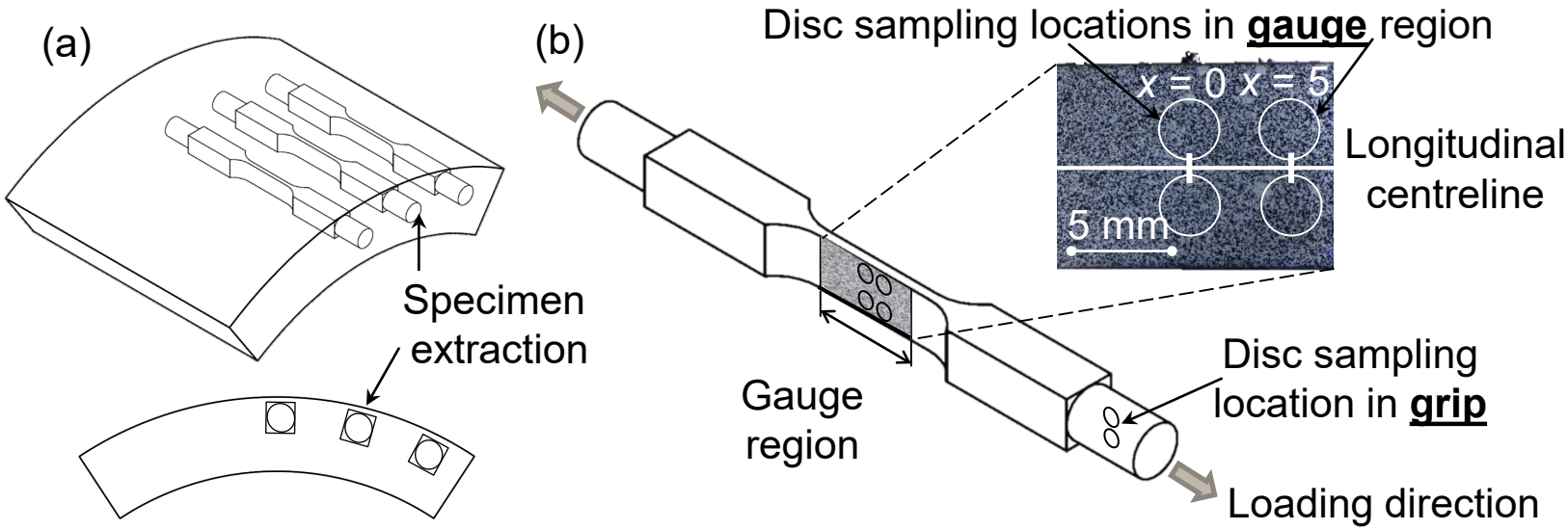
Background – Microstructural analysis



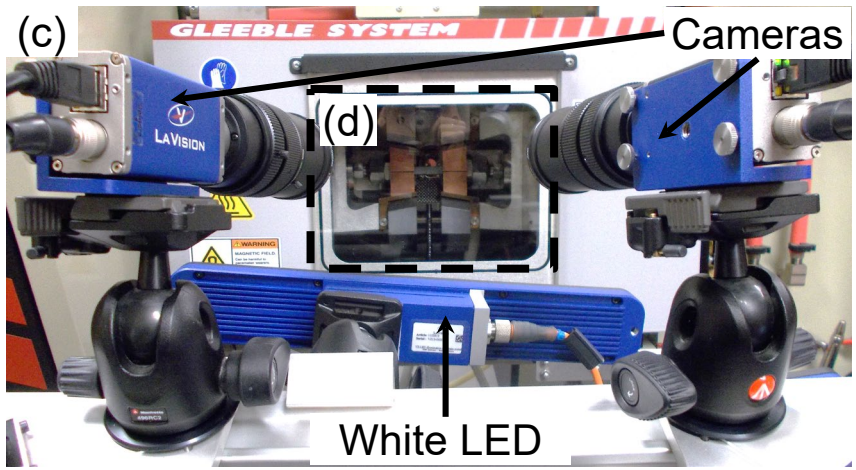
Experimental description - Materials

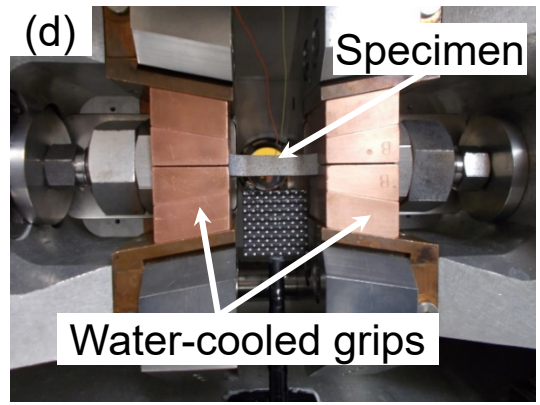
Material Type: X20 CrMoV12-1	Virgin (New)	Low Damage	Medium Damage	High Damage
				
Cavity density measured from BSE-SEM (cavity/mm^2)	<40	70-150	150-250	>250
Operating temperature (°C)	-	545	545	543
Operating steam pressure (MPa)	-	17.0	19.4	18.1
Operating life (hours)	-	130 000	130 000	156 000

Experimental description – Creep testing



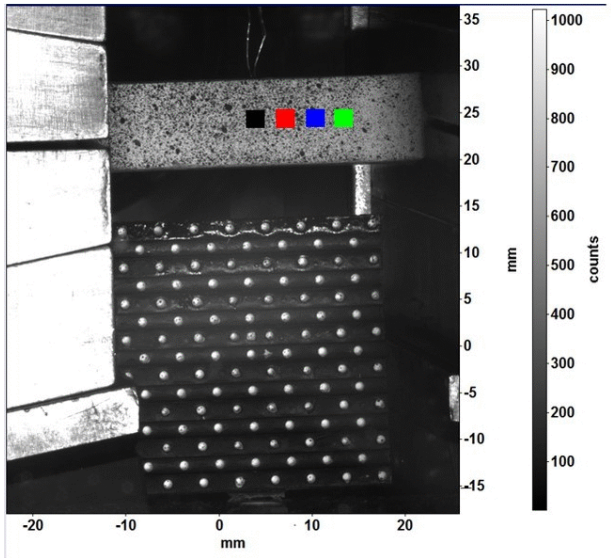
DIC: Digital Image Correlation

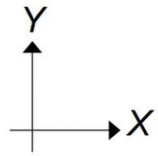


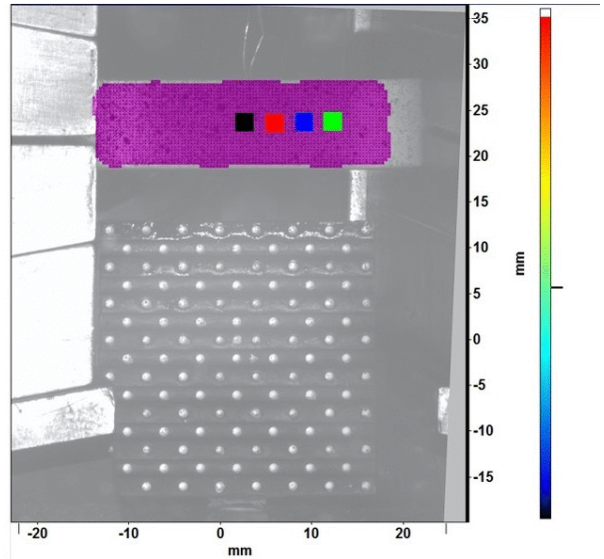


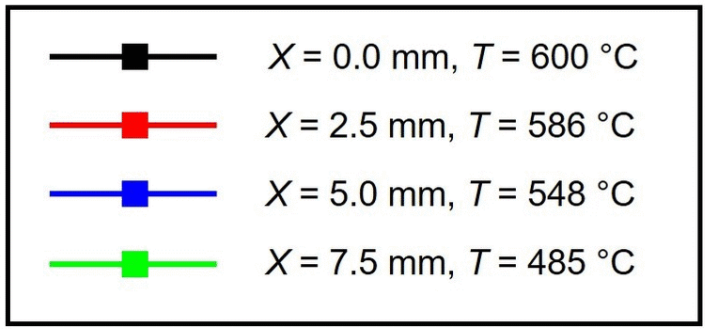
Gleeble vacuum chamber

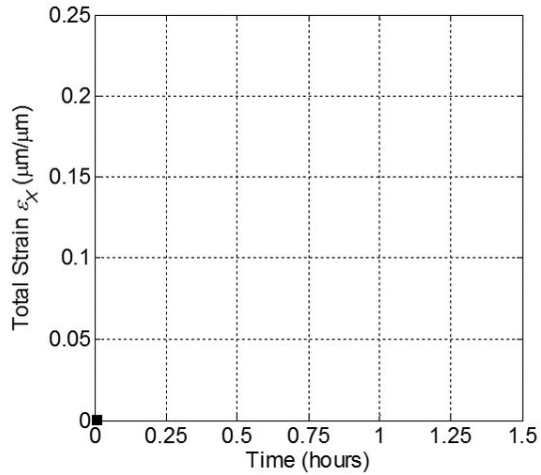
Experimental description – Creep testing (cont.)



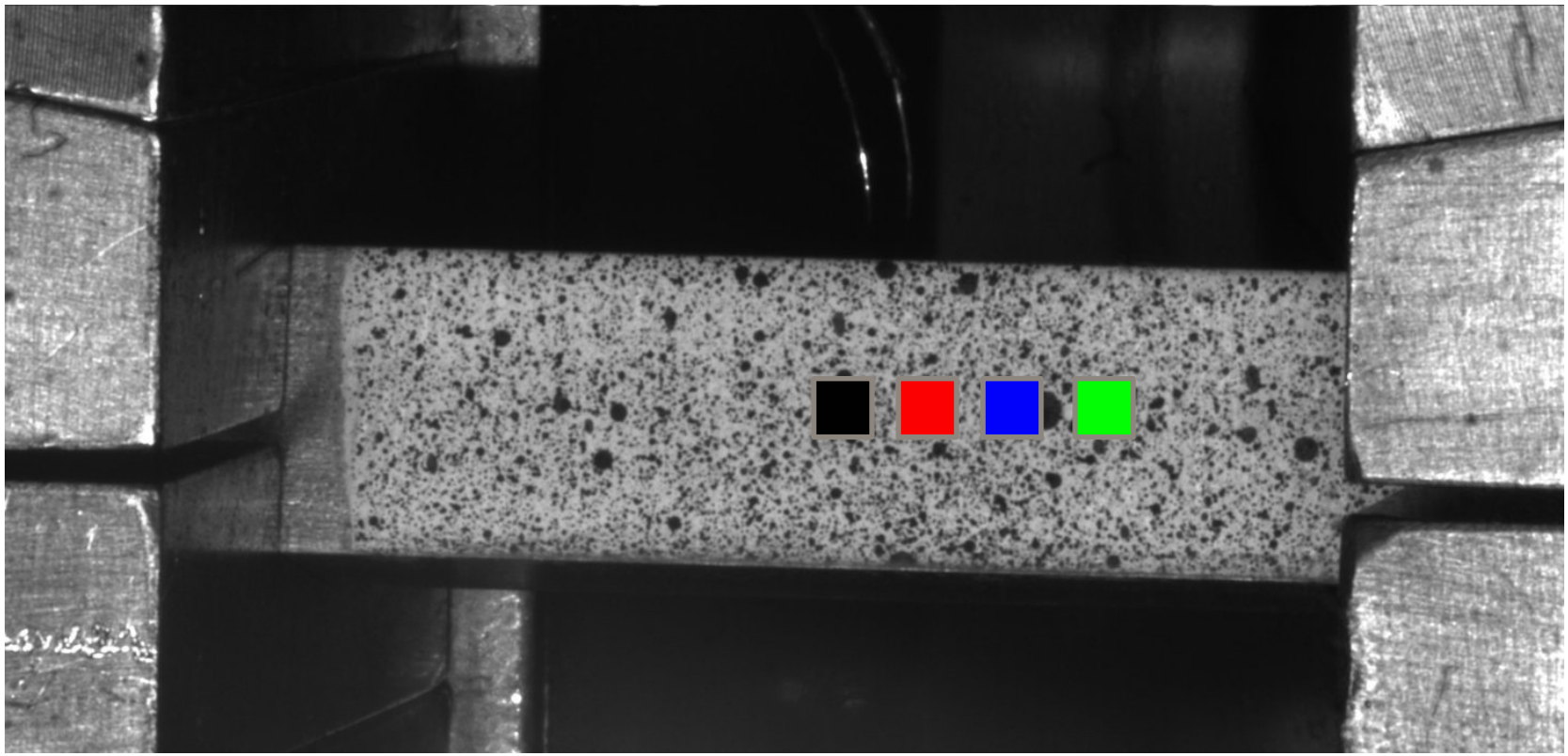


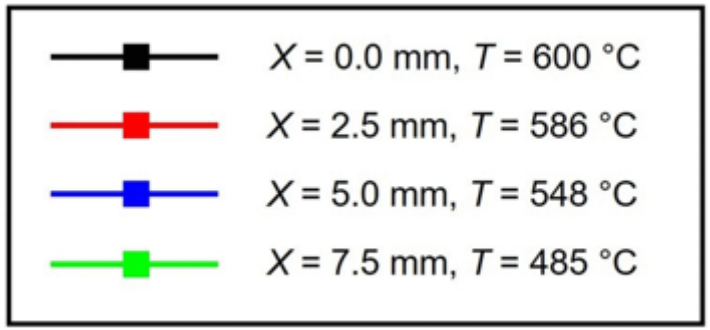






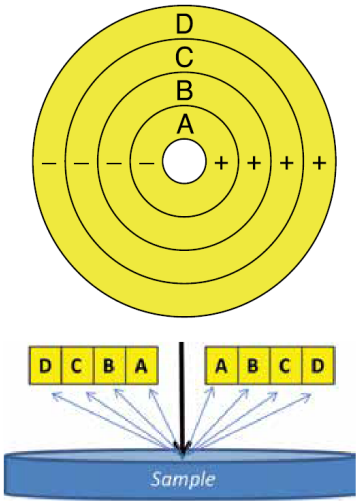
Experimental description – Creep testing (cont.)





Experimental description – Microstructure

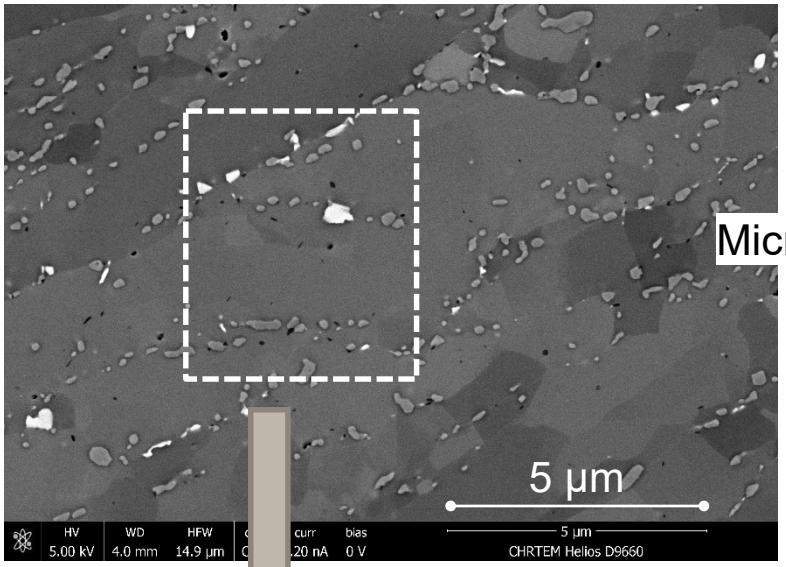
CBS-SEM: Concentric Backscatter-Scanning Electron Microscopy



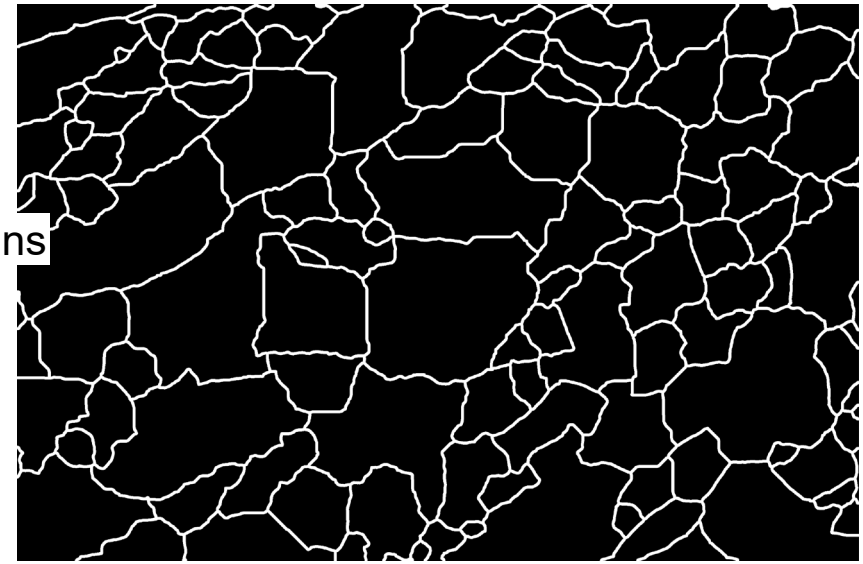
FEI

CBS detector settings	Specimen preparation
• FIB-SEM • 5 kV • 0.20 nA • 4 mm WD • Total of 4 images per site (680 μm^2)	• Twin-jet electropolishing • 5 % $HClO_4$ solution • 21-30 V • -20 °C

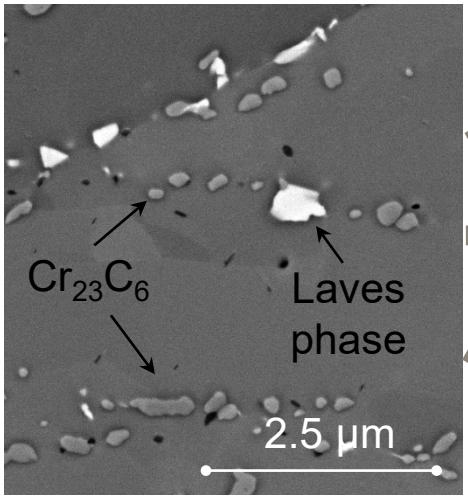
Experimental description – Micro. (cont.)



Micro-grains



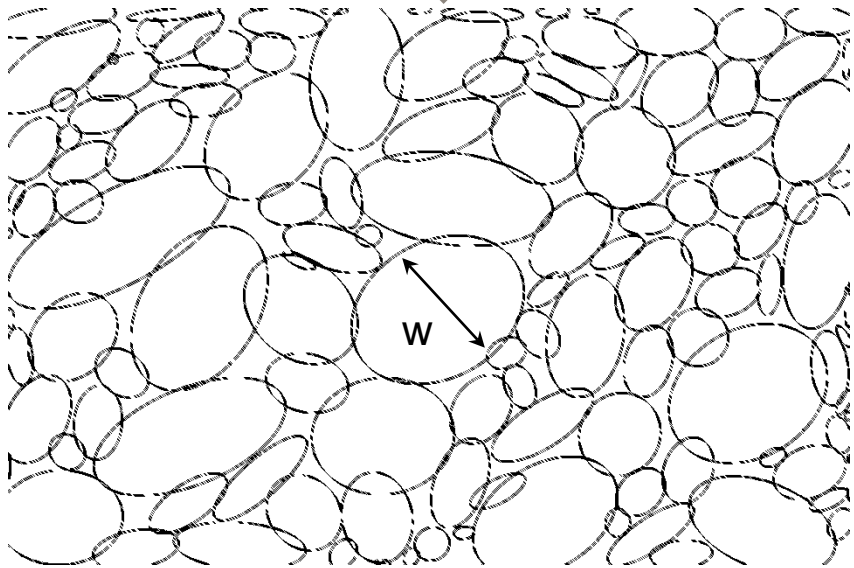
Precipitates



Diameter

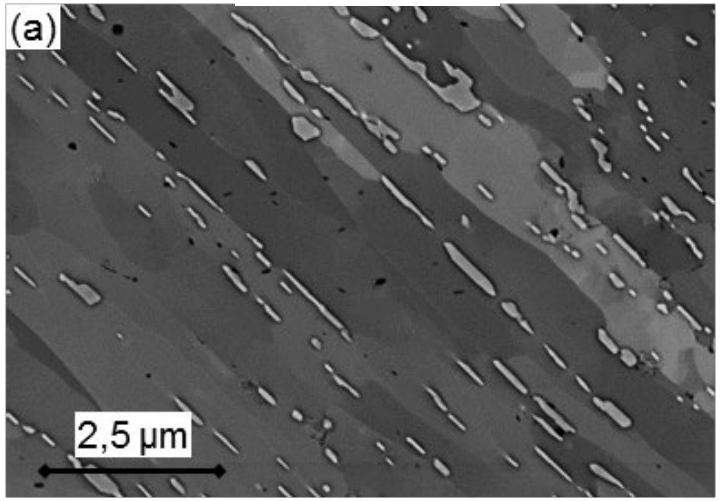
Interparticle spacing

Number density

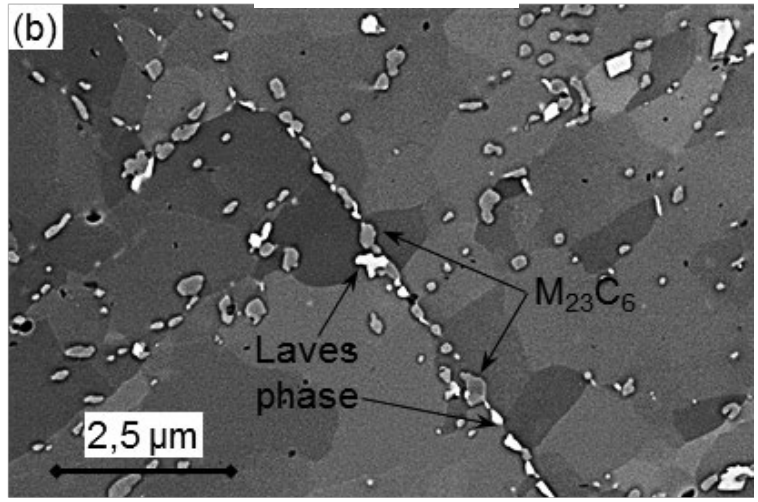


Results - Qualitative

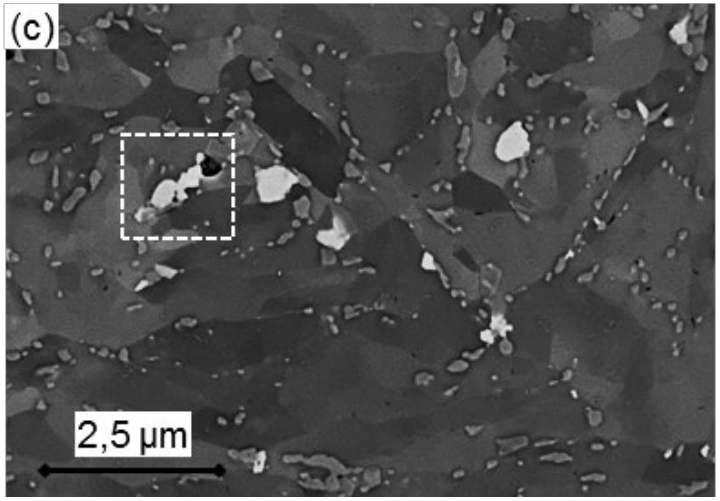
Low - Grip



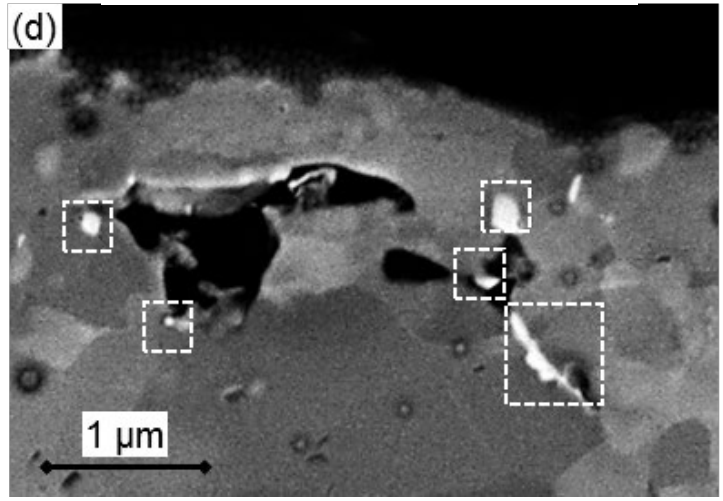
High - Grip



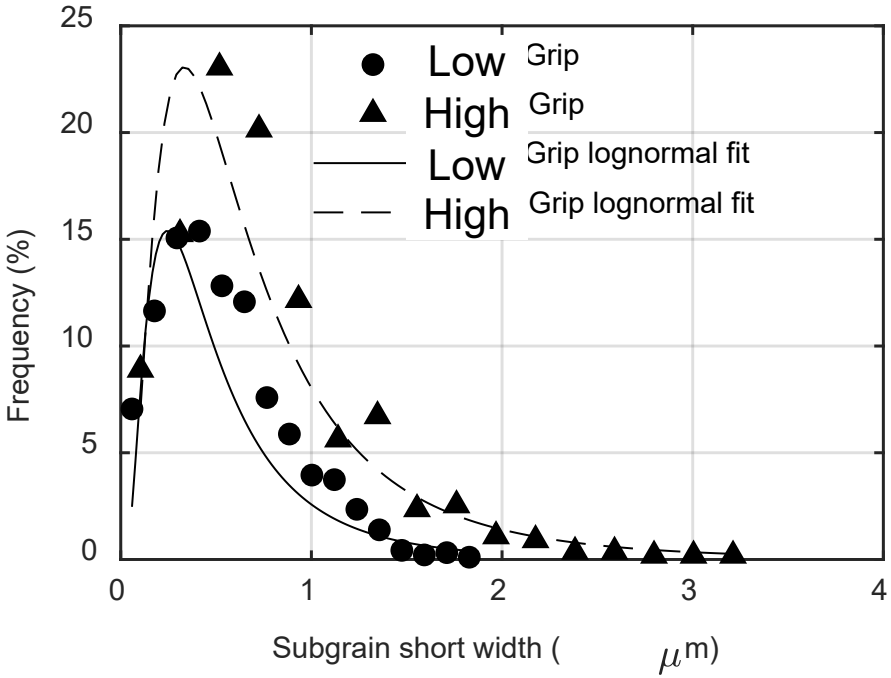
Medium - Grip

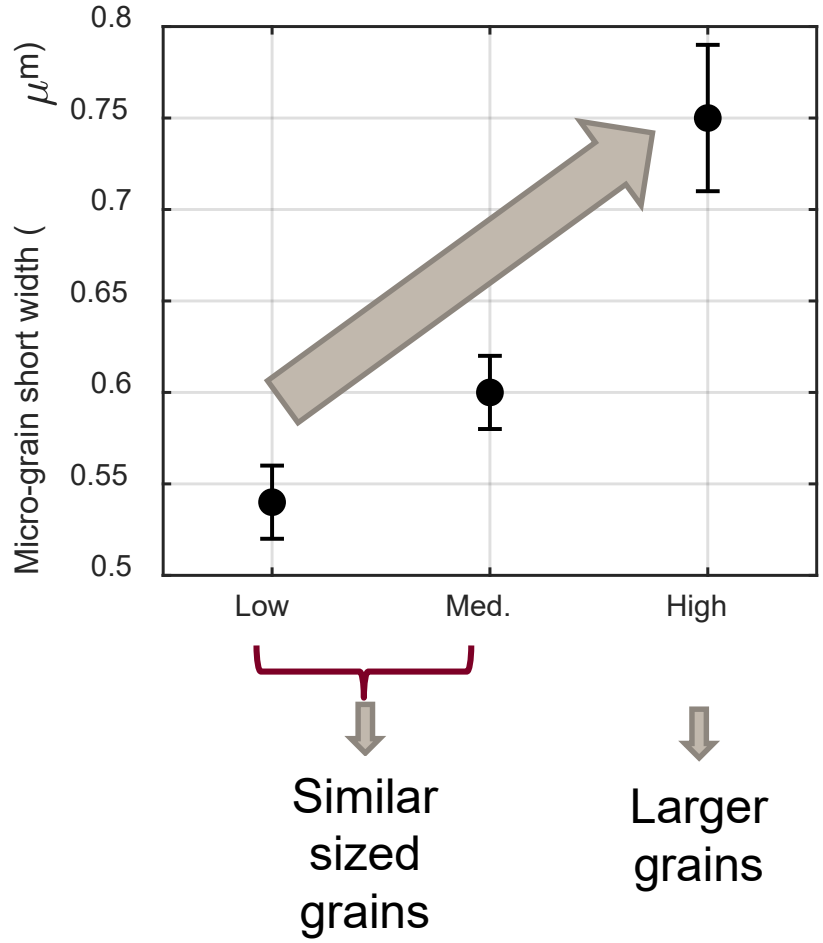


High – Fracture (gauge)

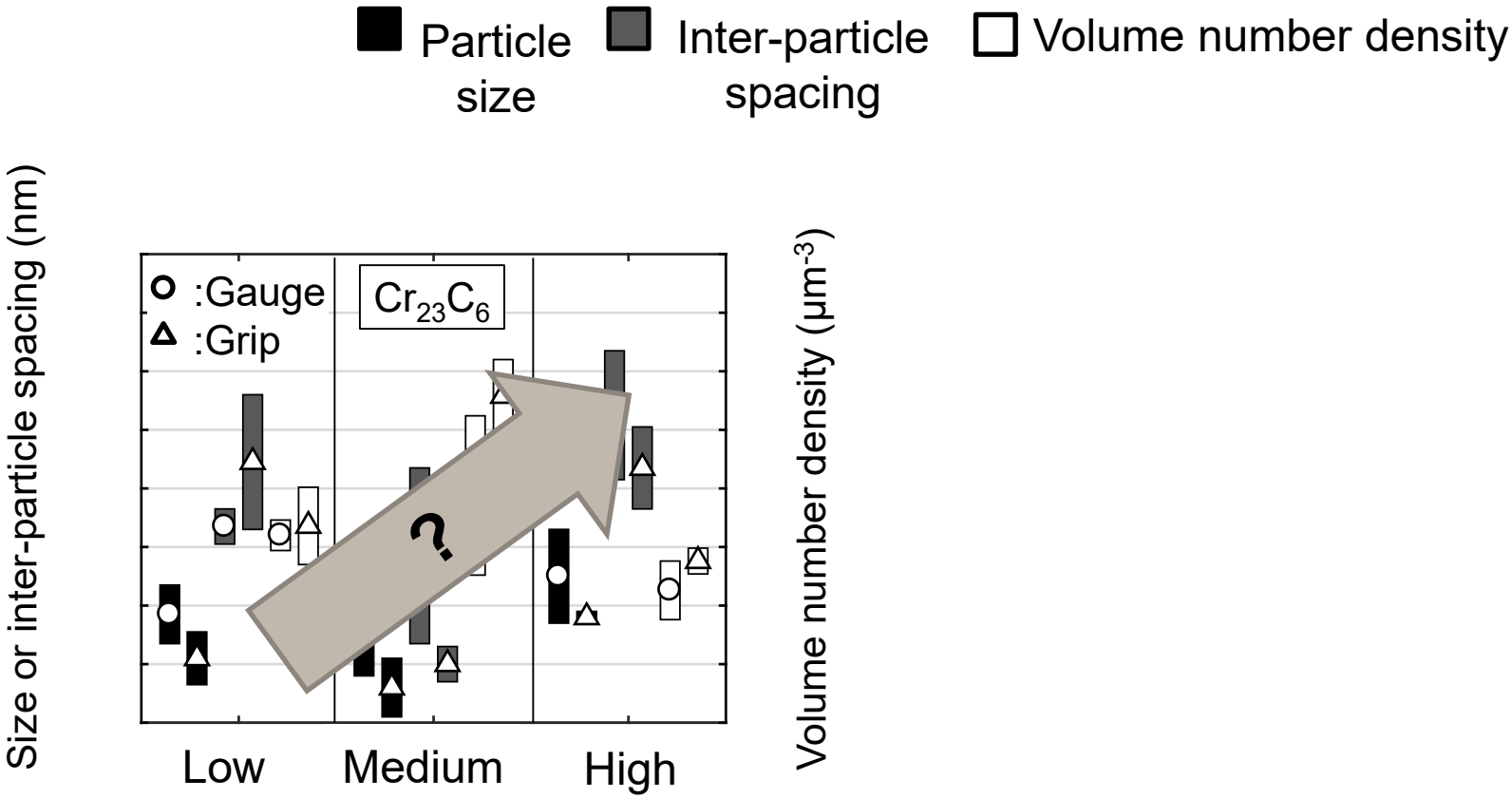


Results – Quantitative (micro-grains)

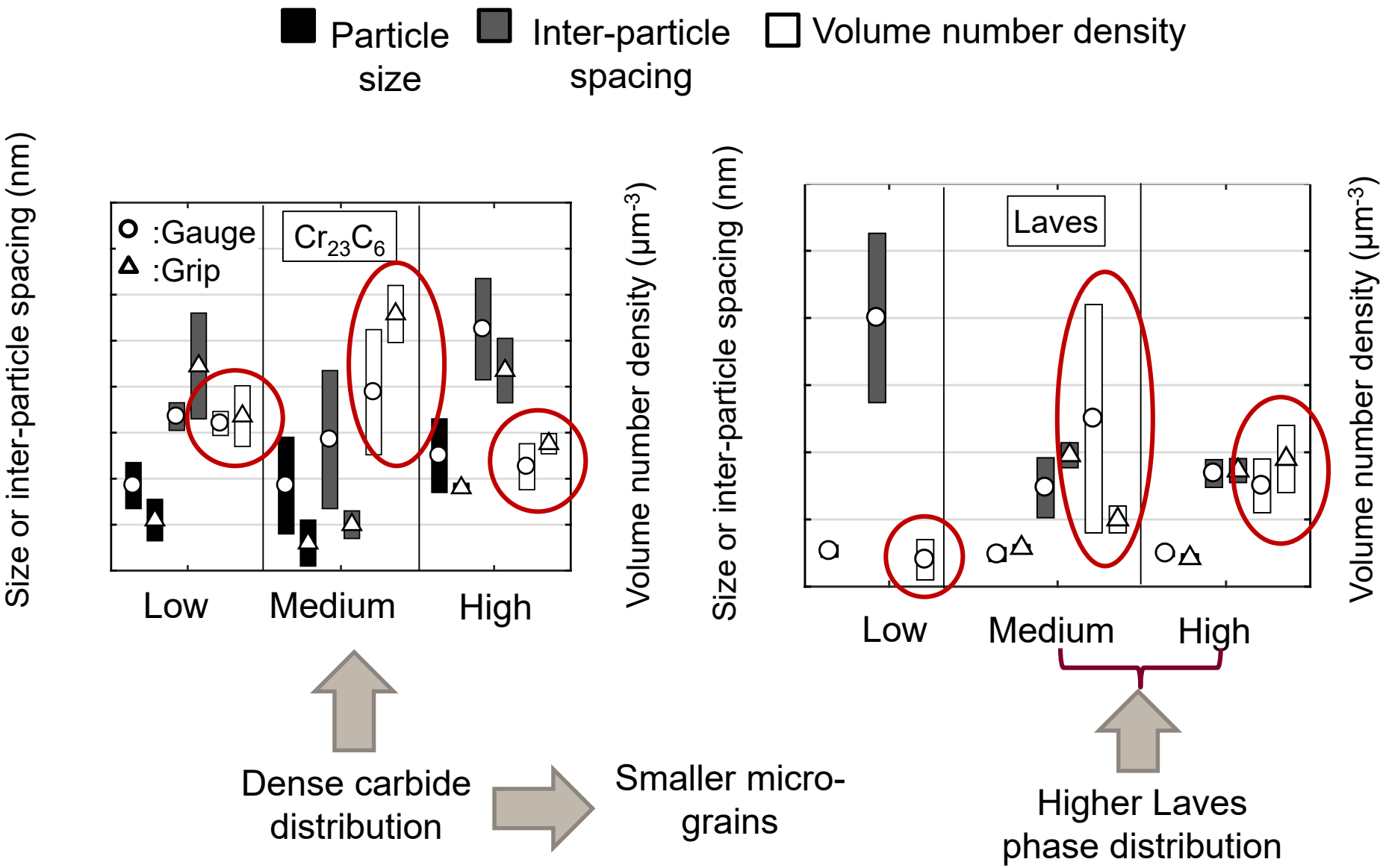




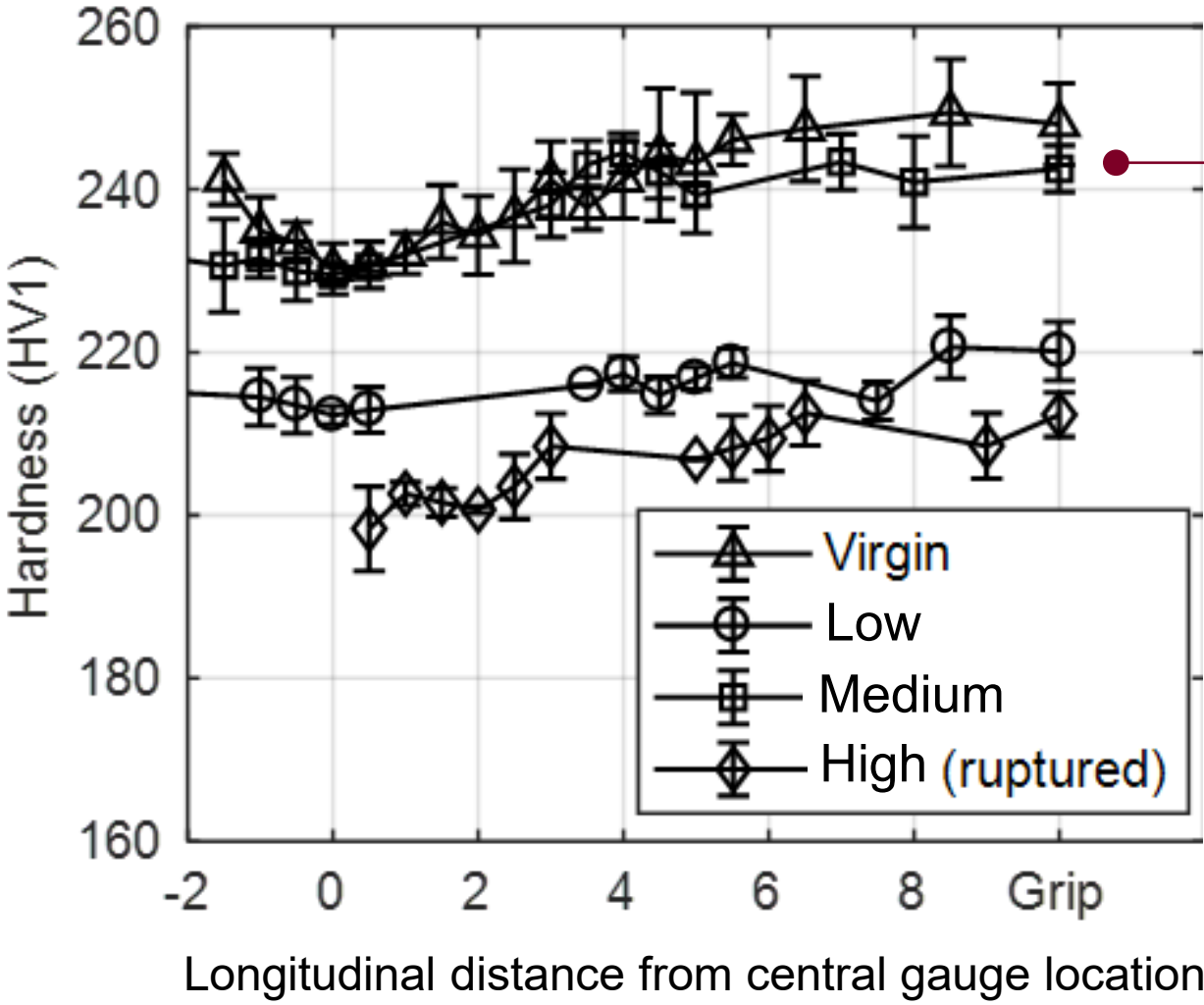
Results – Quantitative (Precipitates)



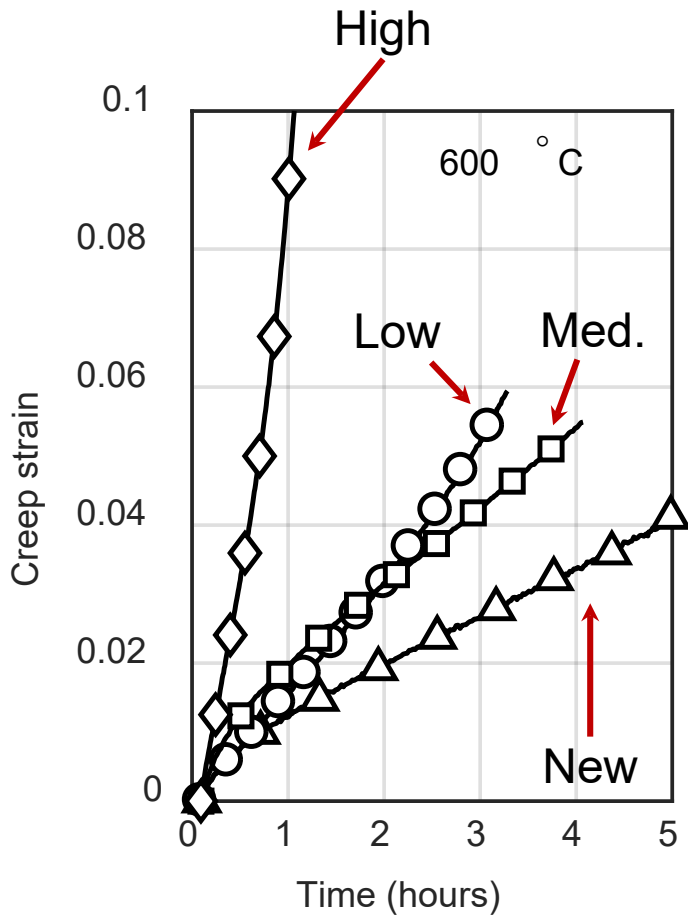
Results – Quantitative (Precipitates)



Results – Hardness

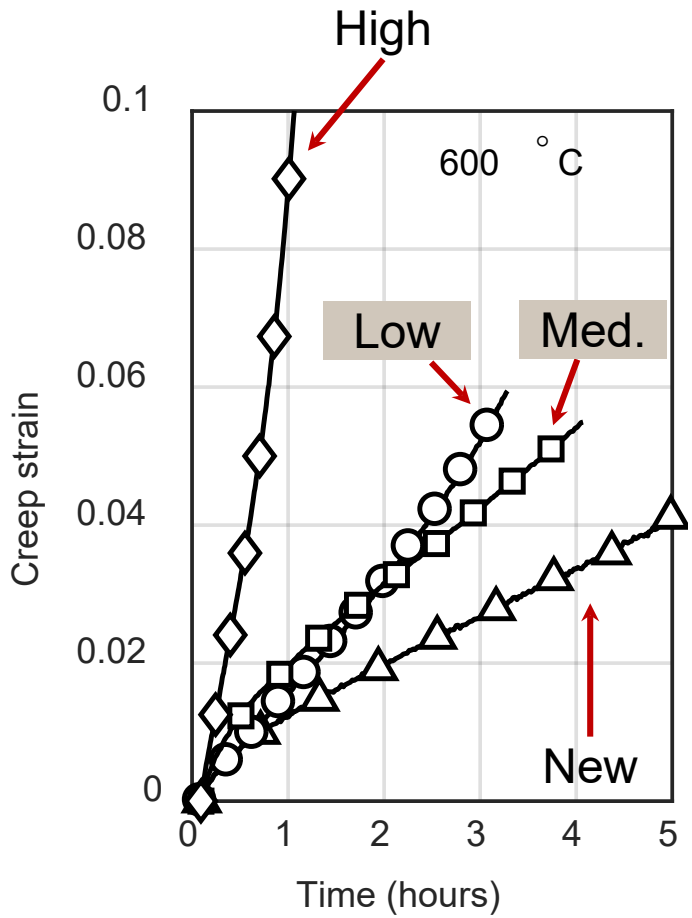


Mechanical response

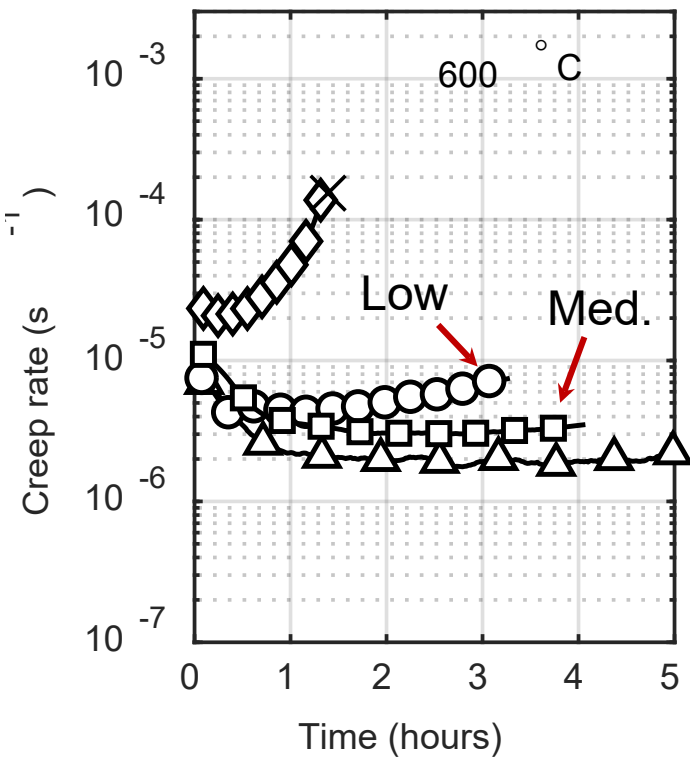


Mechanical response

Confirms CBS results: high $Cr_{23}C_6$ density enhances creep resistance despite cavity density



Faster creep rates for low compared to medium



Conclusion

- CBS is a **convenient microstructural** method for **micro-grain and large particle characterisation** of ex-service material
- **Highly damage** material has **large polygonal micro-grains**, **low density of carbides and high fraction of Laves phase** especially near voids.
- **Low damage** has less Laves phase but had a **lower density of carbides than medium**
- **Medium** displays relatively **smaller grains** due to dense carbide distribution. **Medium and low damage** display **similar creep rates** despite differences in **void distributions**
- **Using CBS allows faster damage assessment through a single microstructural analysis stream – faster maintenance decisions**

Conclusion

"No SINGLE measurement is sufficiently comprehensive to describe the [damage state of] the steel with all requisite completeness"

~ Bhadesia et al. (1998)

Open Access Article

Creep Damage Assessment of Ex-Service 12% Cr Power Plant Steel Using Digital Image Correlation and Quantitative Microstructural Evaluation

by Melody van Rooyen [1,*], Thorsten Becker [1], Johan Westraadt [2] and Genevéve Marx [2]

[1] Department of Mechanical and Mechatronic Engineering, Stellenbosch University, Stellenbosch 7600, South Africa

[2] Centre for High Resolution Transmission Electron Microscopy, Nelson Mandela University, Summerstrand, Port Elizabeth 6001, South Africa

* Author to whom correspondence should be addressed.

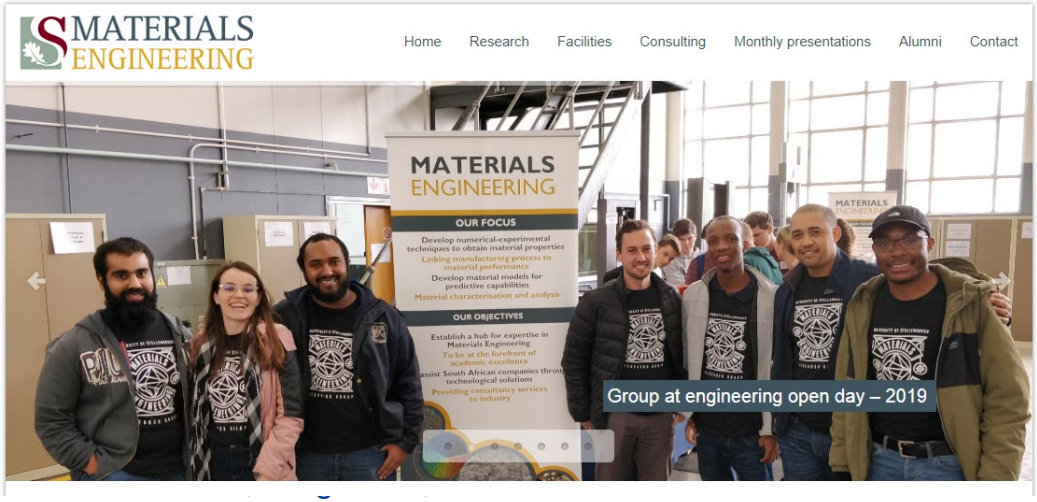
Materials **2019**, *12*(19), 3106; https://doi.org/10.3390/ma12193106

Received: 6 August 2019 / Revised: 28 August 2019 / Accepted: 9 September 2019 / Published: 24 September 2019

Acknowledgements and questions

Thank you to the following:

Supervision:
Prof Thorsten Becker and Materials Engineering Research Group at SU
CBS-SEM imaging:
NMU CHRTEM team, Dr J Westraadt and Dr G Marx
Gleeble testing/specimen preparation facilities:
Prof Rob Knutsen and S. von Willingh at CME
Stakeholder guidance and material provision:
EPPEI staff and fellow students
Funding:
NRF (THRIP) and THUTHUKA, Frank Wilhelm Bursary Fund



MATENG group
www0.sun.ac.za/mateng

ResearchGate

Melody Van Rooyen
5.04 · Master of Engineering · Edit