Hochfeste Stähle mit verbesserter Duktilität – Potentiale für den Leichtbau

High-strength steels with improved ductility - potentials for lightweight engineering

F. Roters, C. Tasan, D. Yan, M. Diehl, P. Shanthraj. I. Gutierrez-Urrutia, H. Springer,
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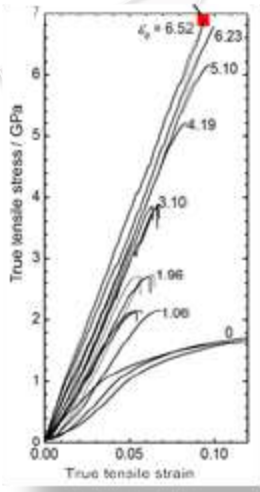
Why steel ?

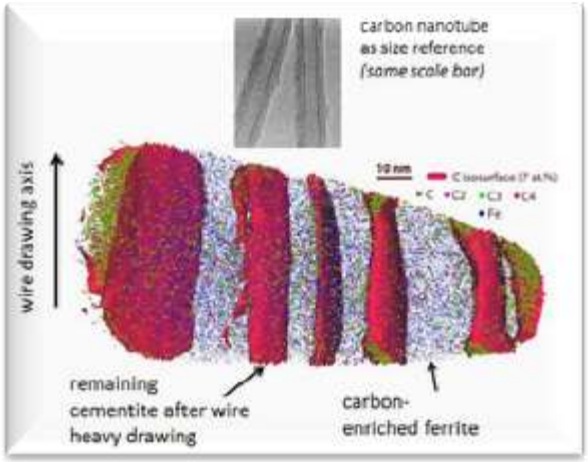
0.3 ton / (person year) x 10^{10} persons
= 3 x 10^{9} tons / year in 2050

inexpensive

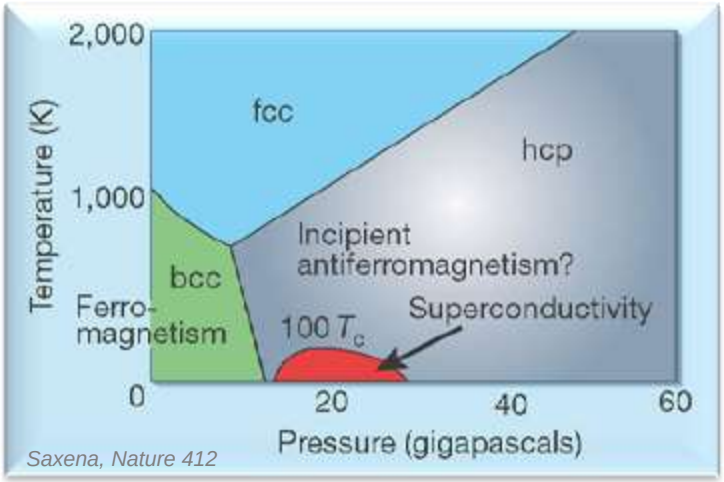
strong & ductile



nanostructured



phase transformations



Saxena, Nature 412

Overview: intrinsically nanostructured steels

Dual Phase steels:

Microstructure optimization and damage initiation

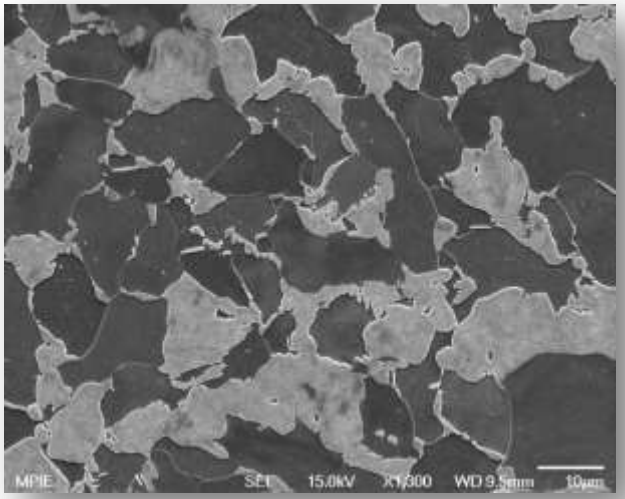
Density-reduced steels:

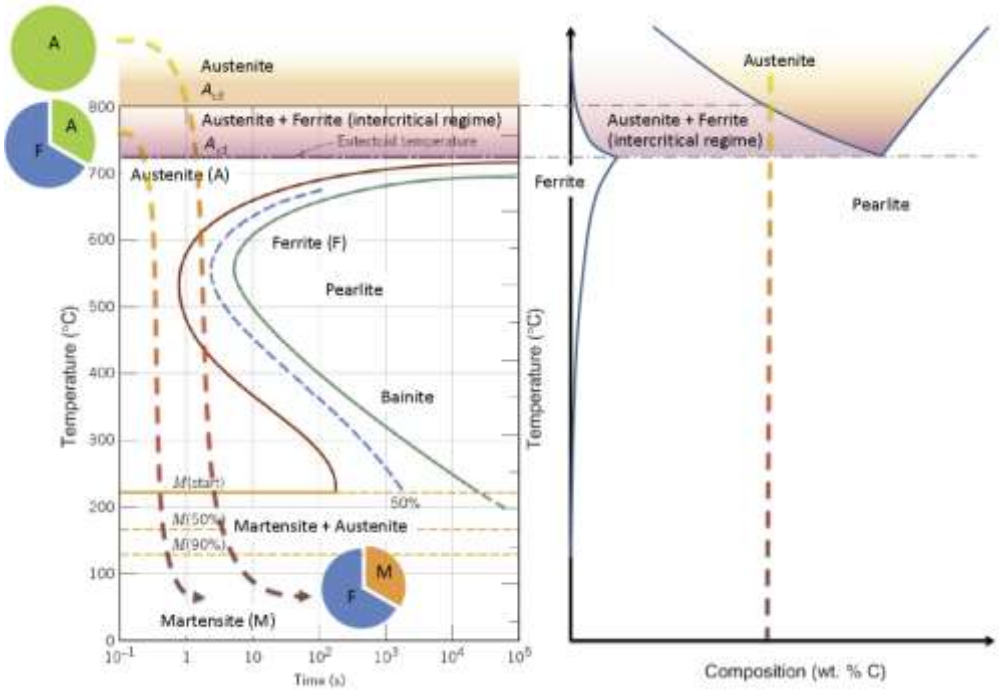
Strain hardening and rapid alloy prototyping

Introduction - DP steels

High strength
High ductility
Good formability

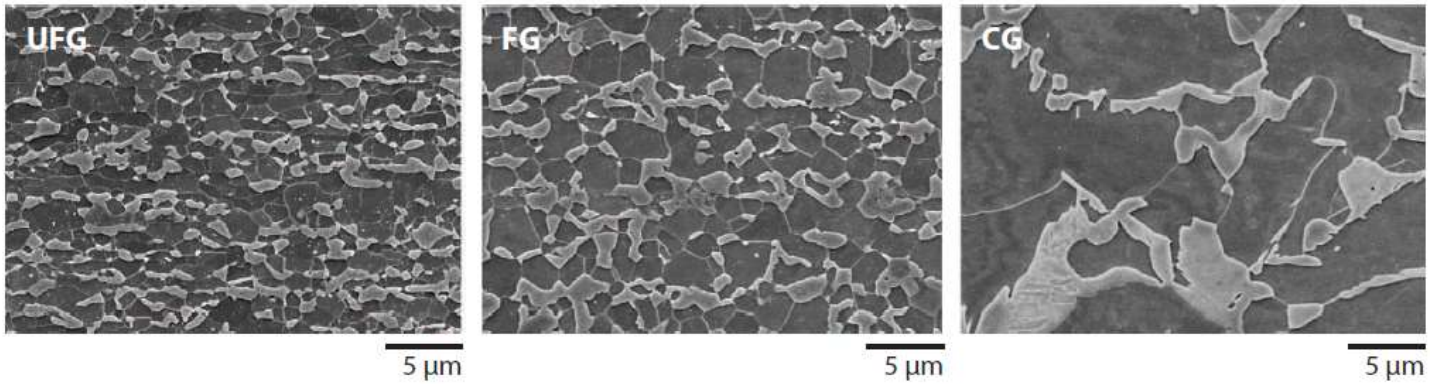
Increase in strength (e.g. by increasing martensite fraction) results in deteriorated ductility

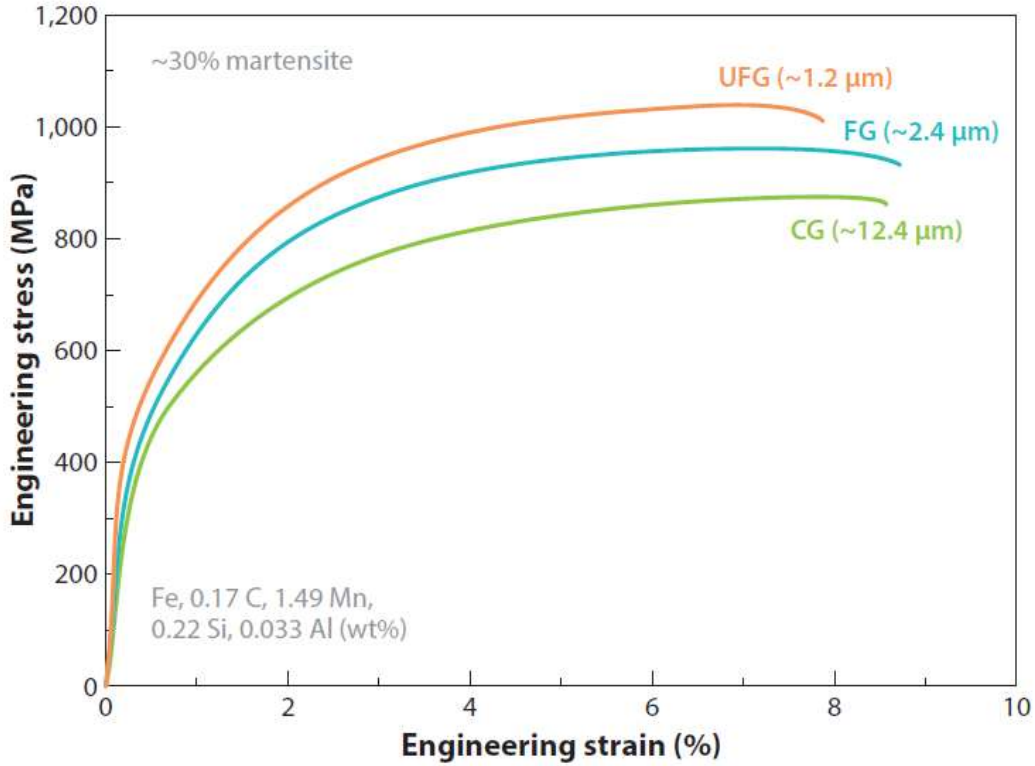




Calcagnotto et al. Acta Mater 2011; vol 59: 658.

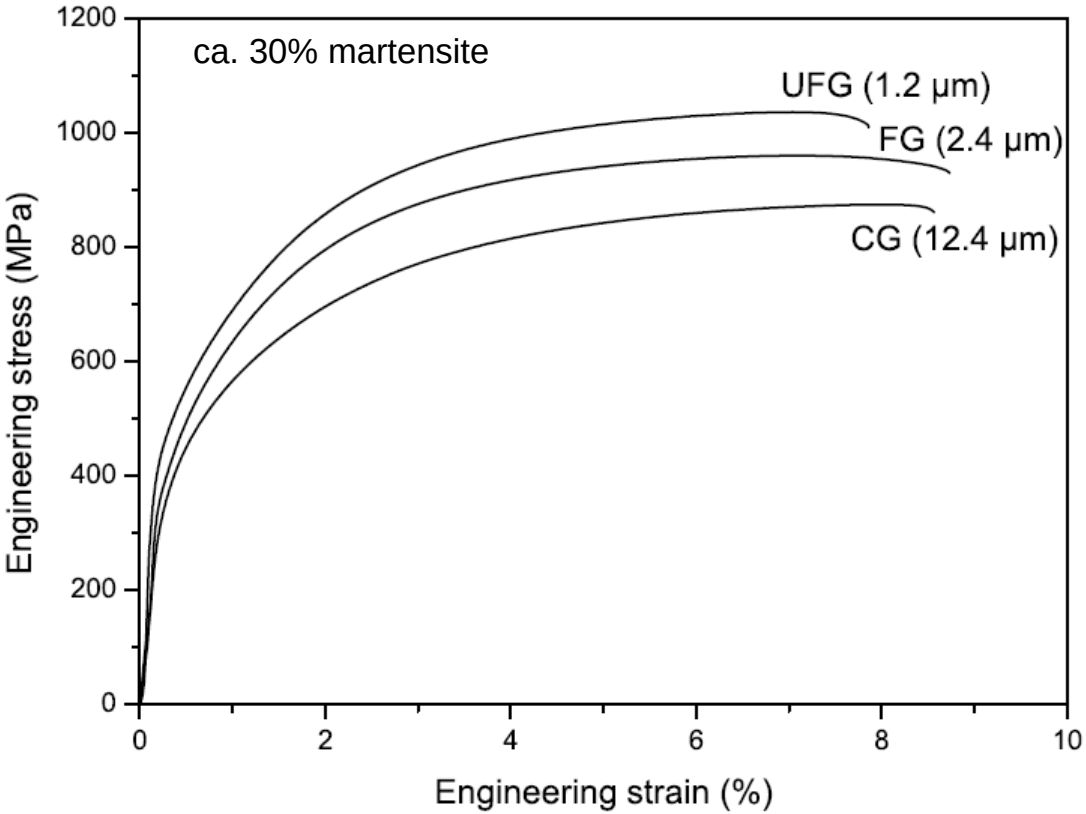
Introduction – Mechanical properties

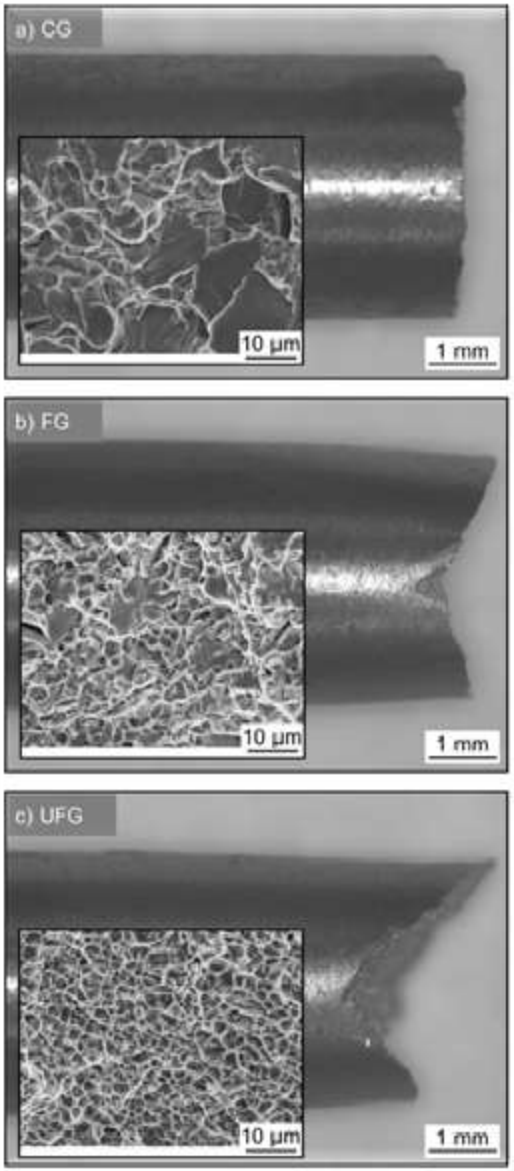




Calcagnotto et al. Mater. Sc. Engin. A 527 (2010) 2738

Introduction – Mechanical properties





Comp (wt.%): Fe 0.17 C 1.49 Mn 0.22 Si 0.033 Al

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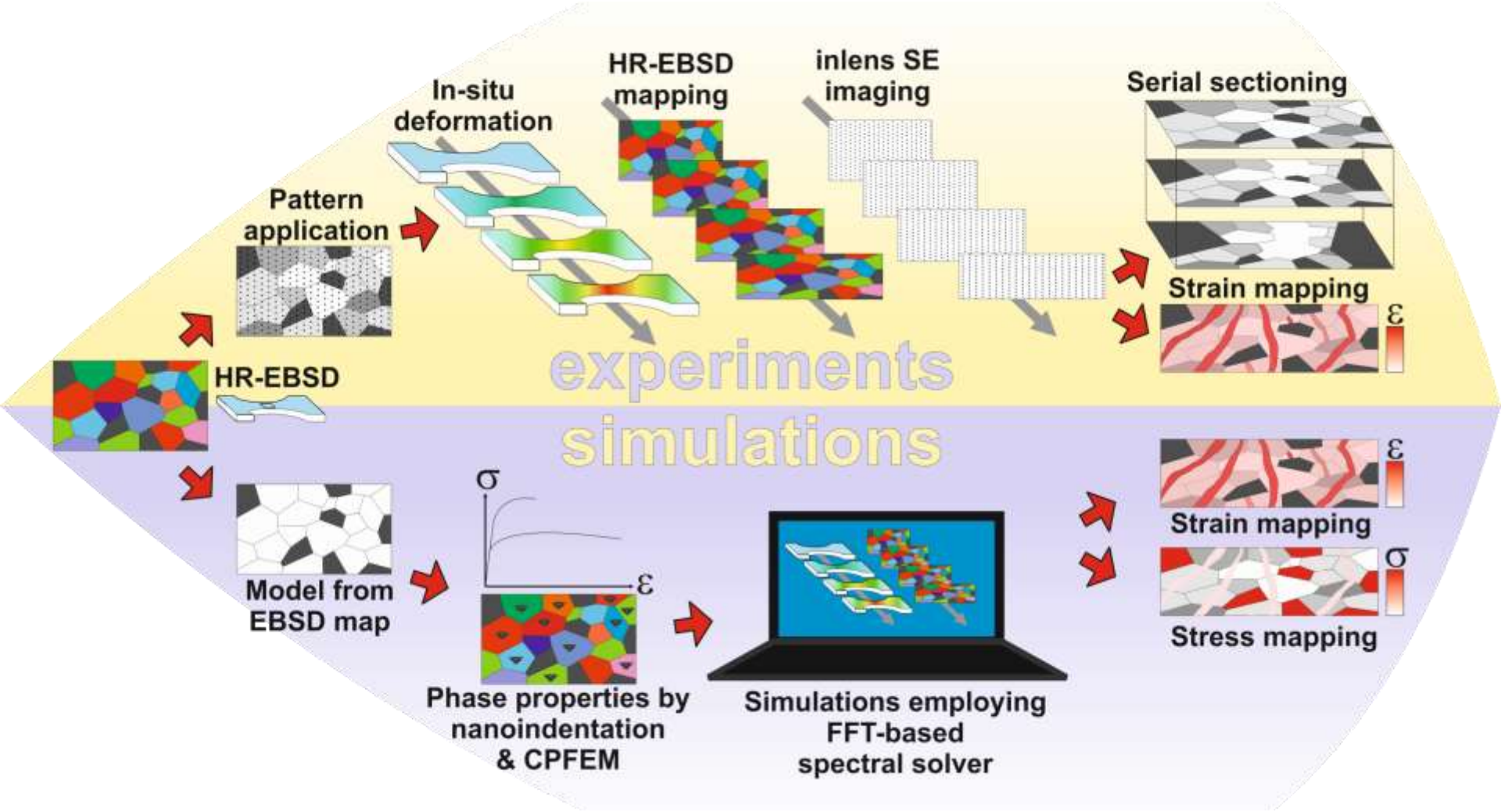
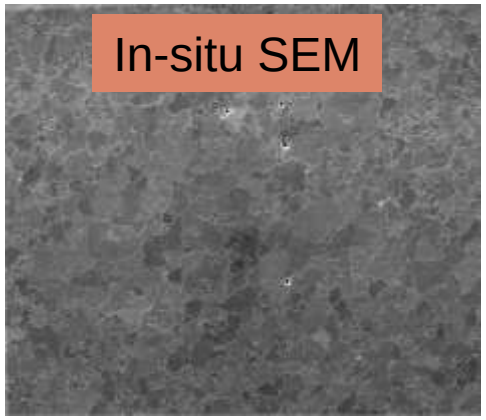
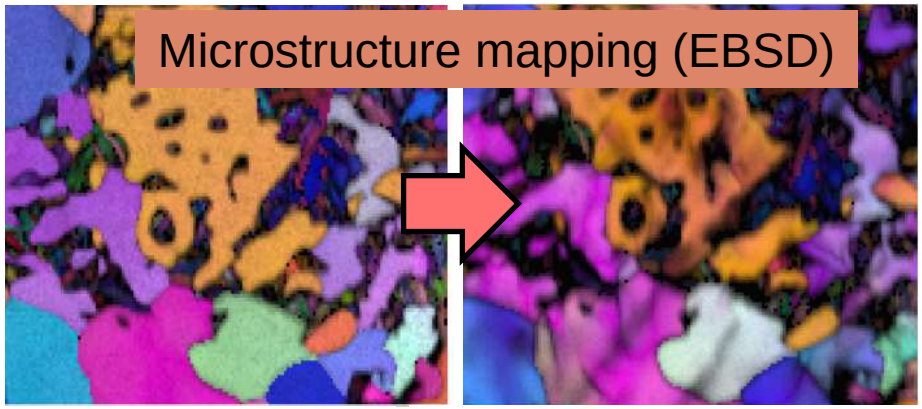
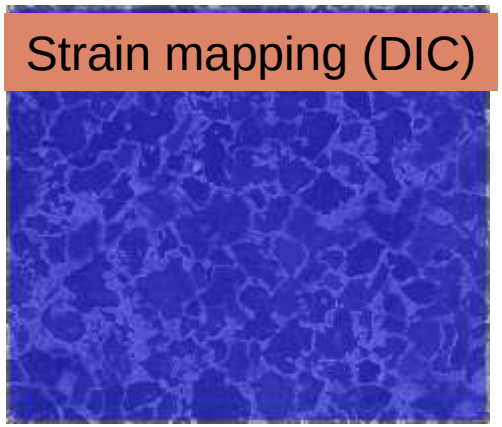
Methodology – Example of DP Steel

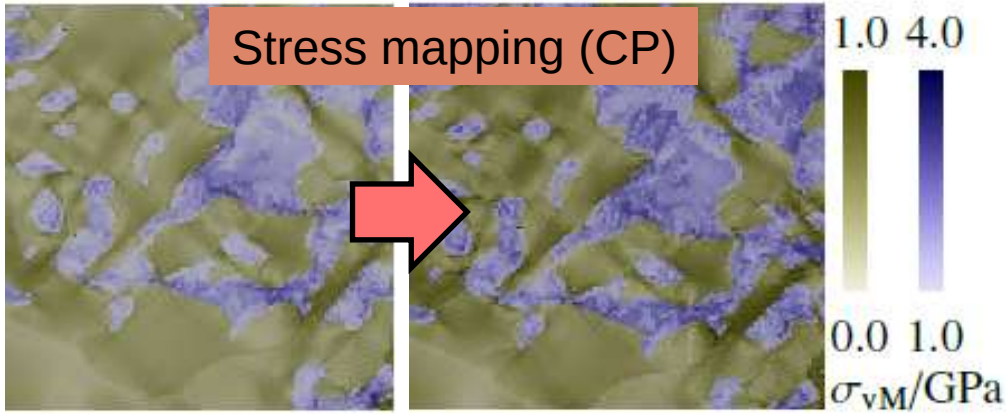


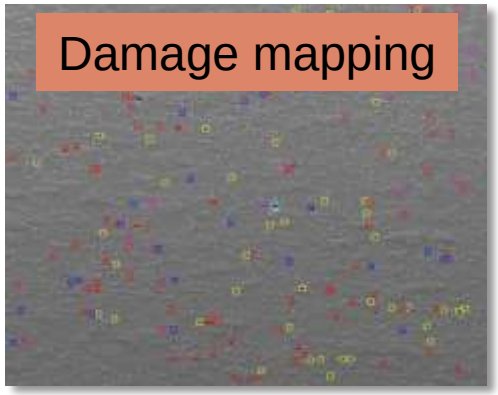
Methodology (ii) - Overview

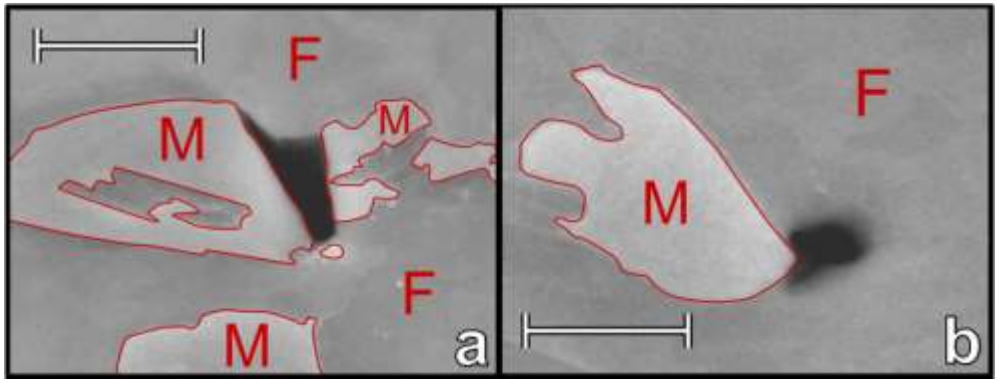






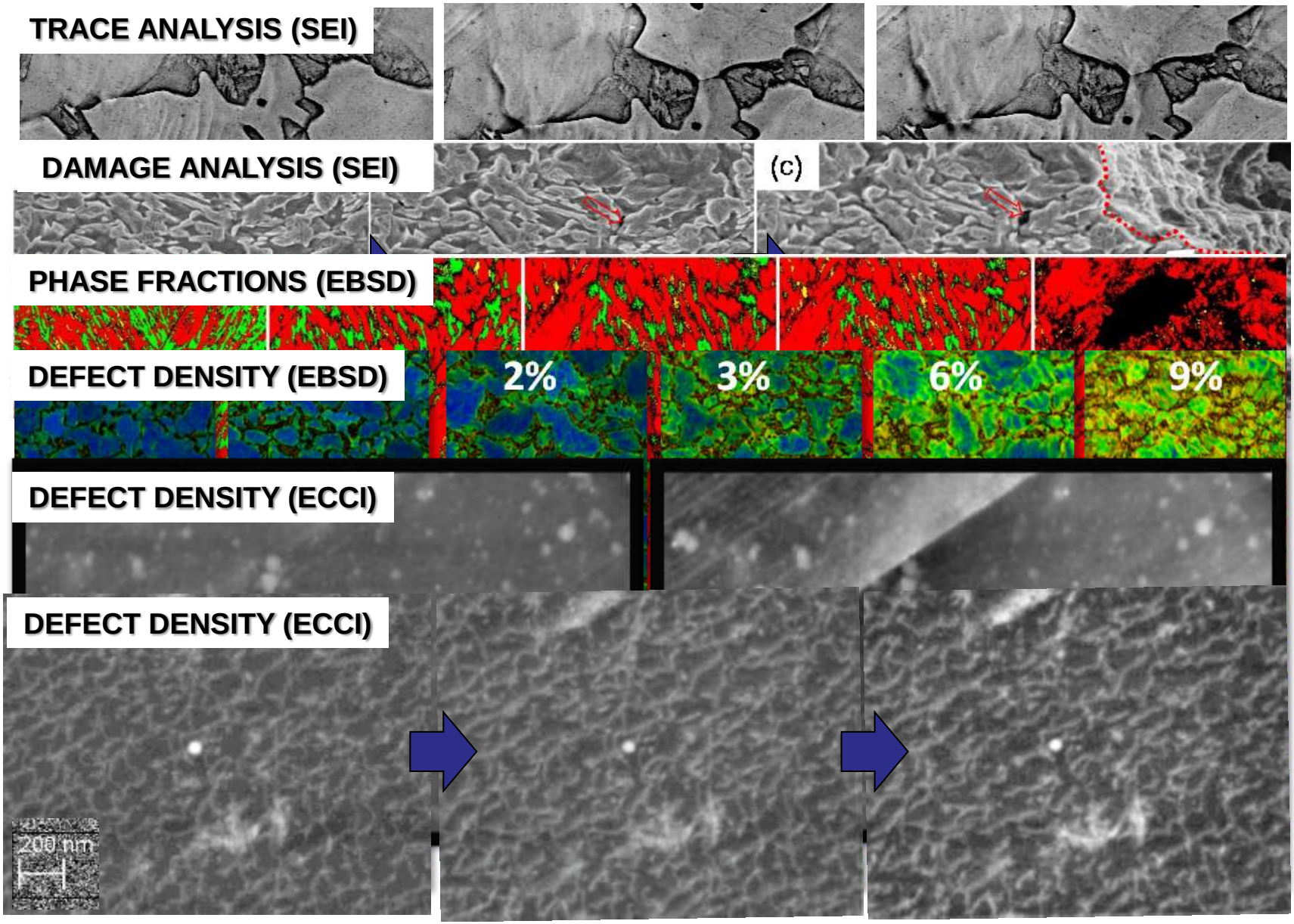






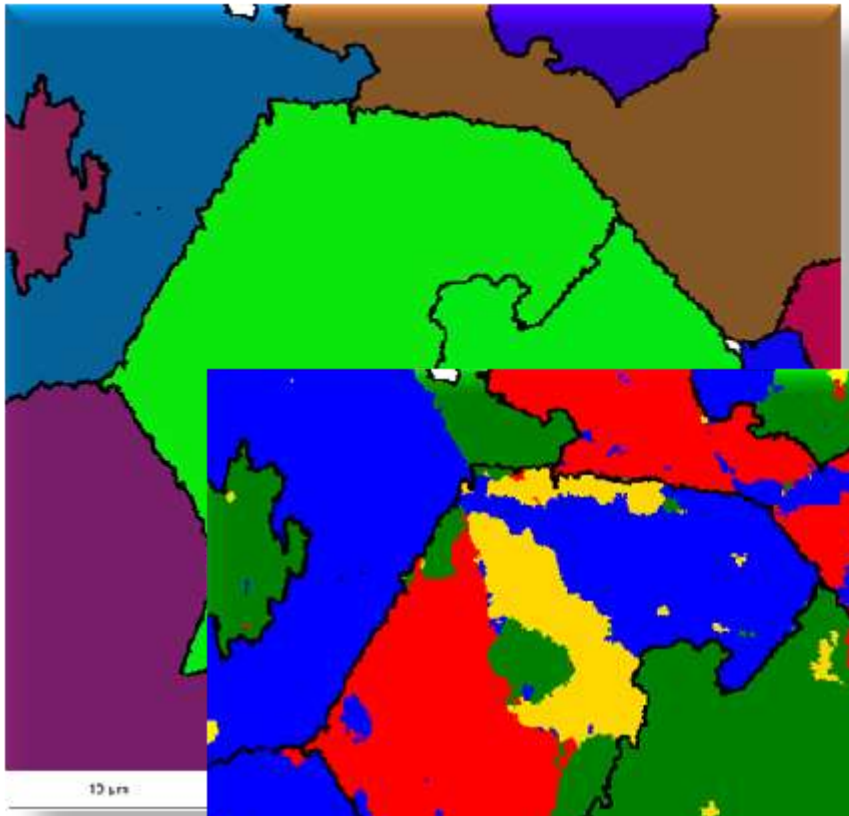
[Tasan et al., 2010]

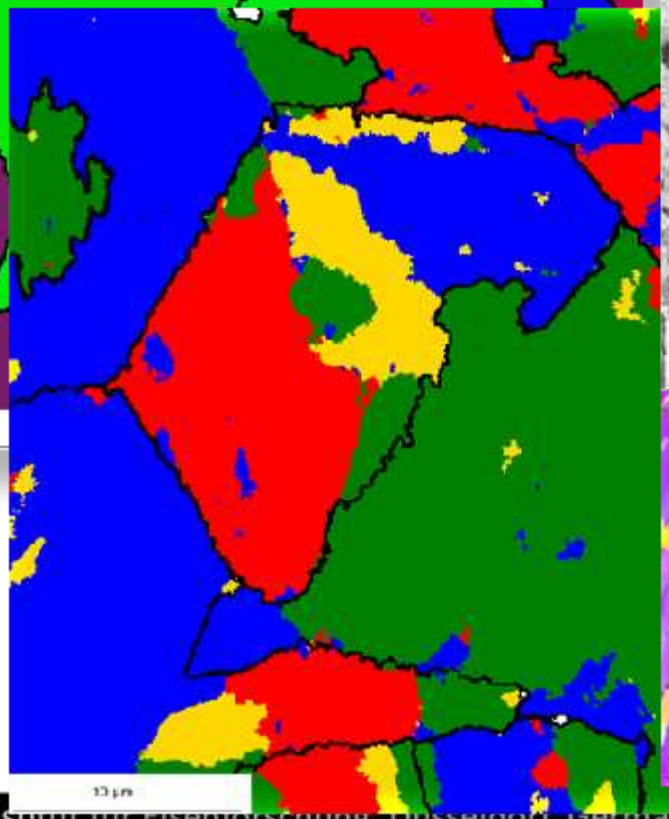
Microstructure: Mesoscopic imaging: SEM – Imaging modes

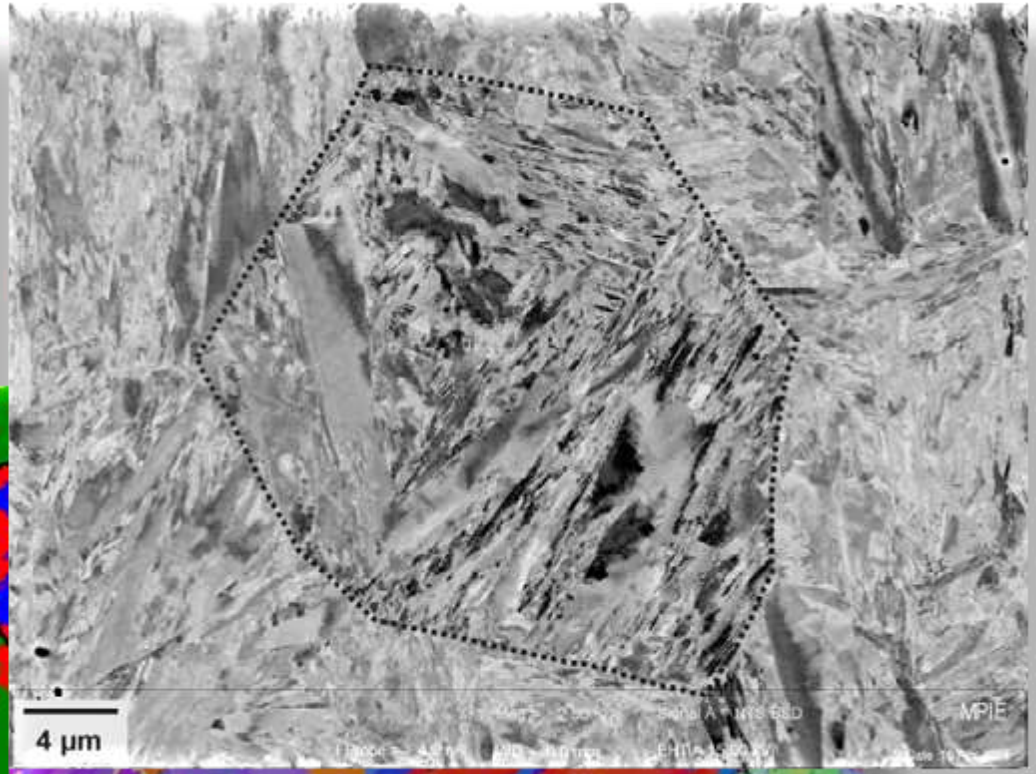


Martensite: Hierarchical microstructure analysis

Morsdorf, L., Tasan, C.C., Ponge, D., Raabe, D., 3D structural and atomic-scale analysis of lath martensite: Effect of the transformation sequence, (2015) Acta Materialia, 95, pp. 366-377.







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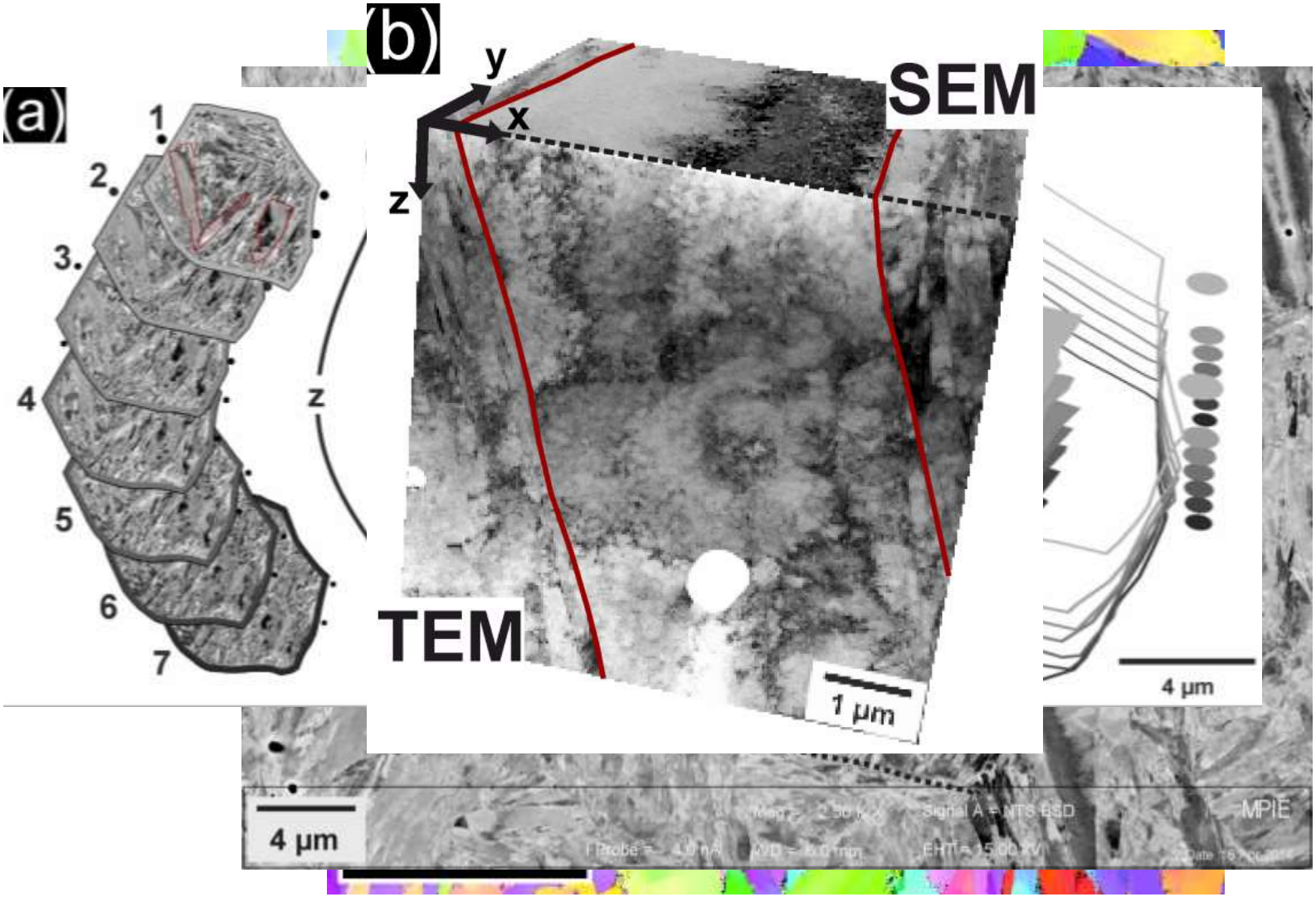

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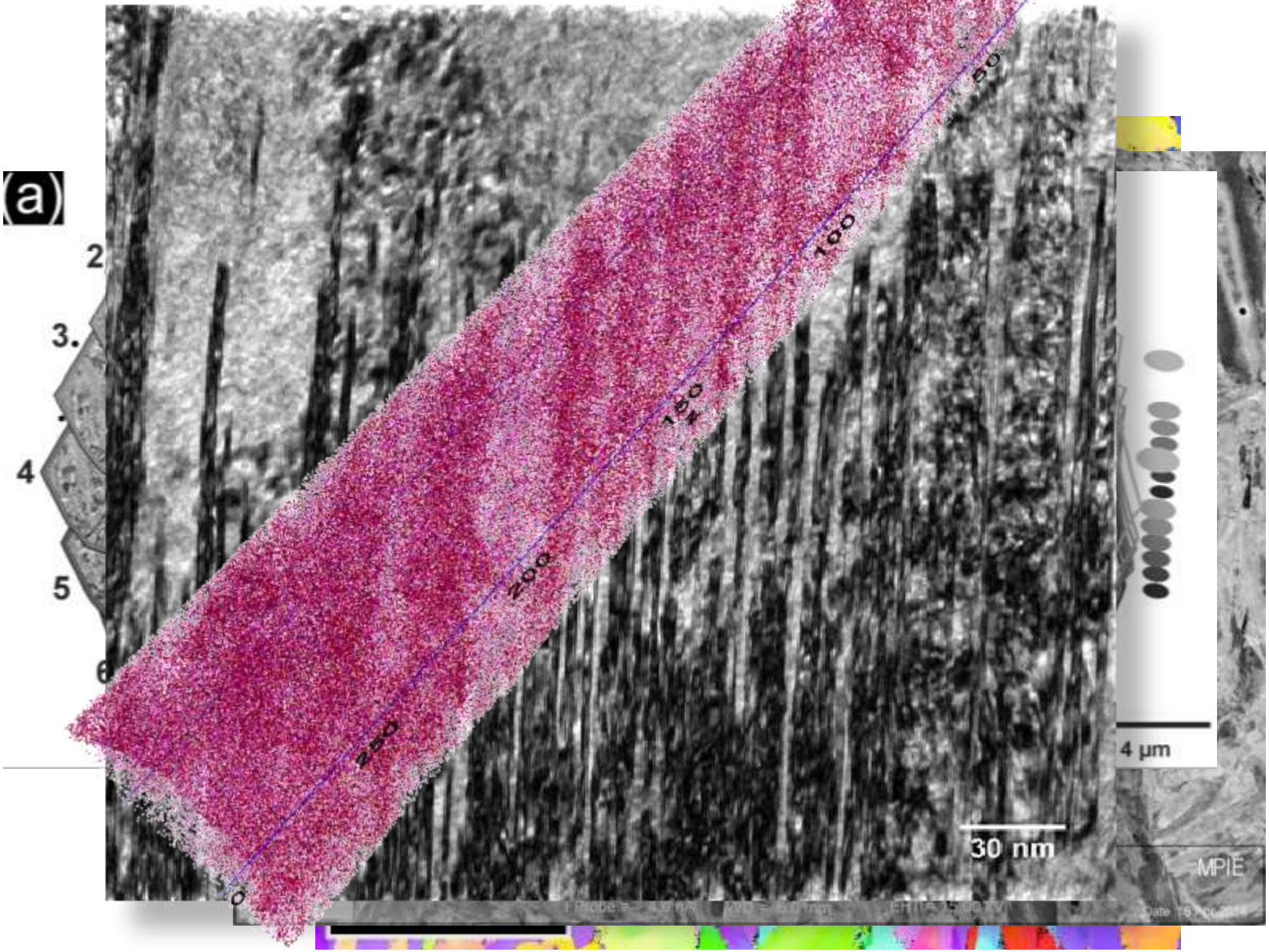
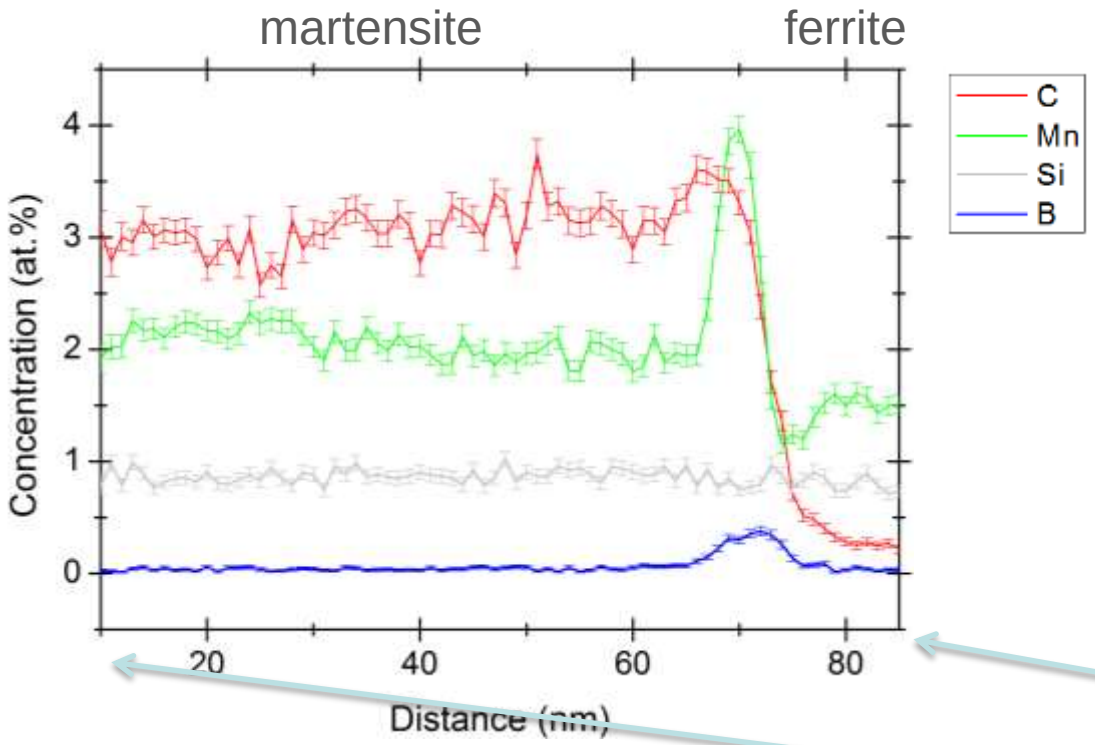
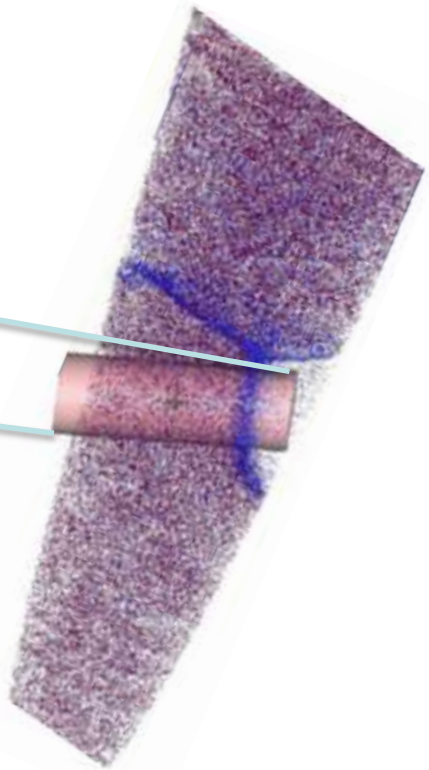


Transition zone between martensite and ferrite at atomic scale



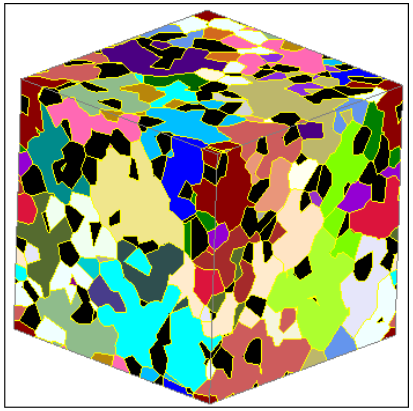


Multi Level Voronoi + Fourier Spectral Solver

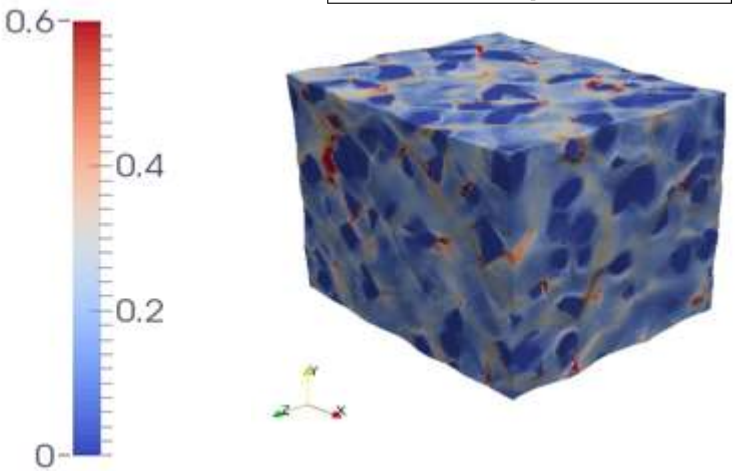
Tasan, C.C., Hoefnagels, J.P.M., Diehl, M., Yan, D., Roters, F., Raabe, D. Strain localization and damage in dual phase steels investigated by coupled in-situ deformation experiments and crystal plasticity simulations (2014) International Journal of Plasticity, 63, pp. 198-210.

Crystal plasticity simulation of Dual Phase, 23% uni-axial deformation

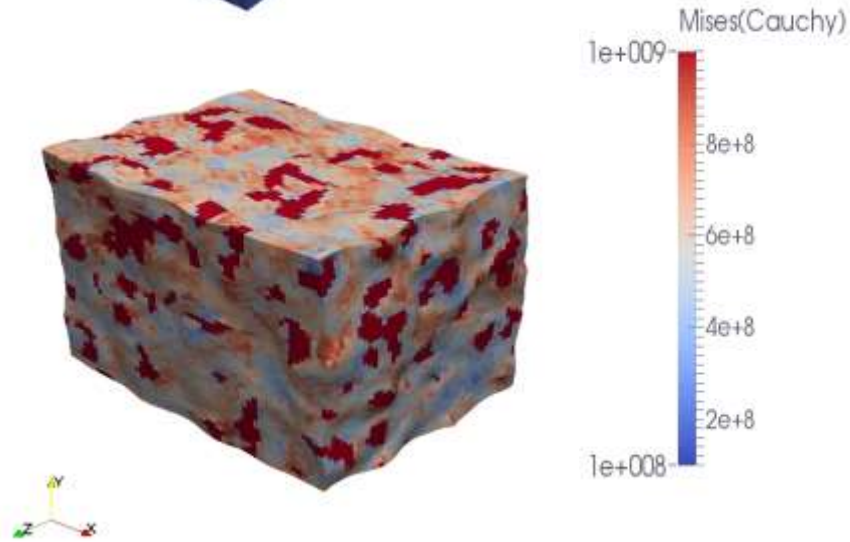
microstructure input



Fourier grid



Strain distribution



Stress distribution

Details: simulation results

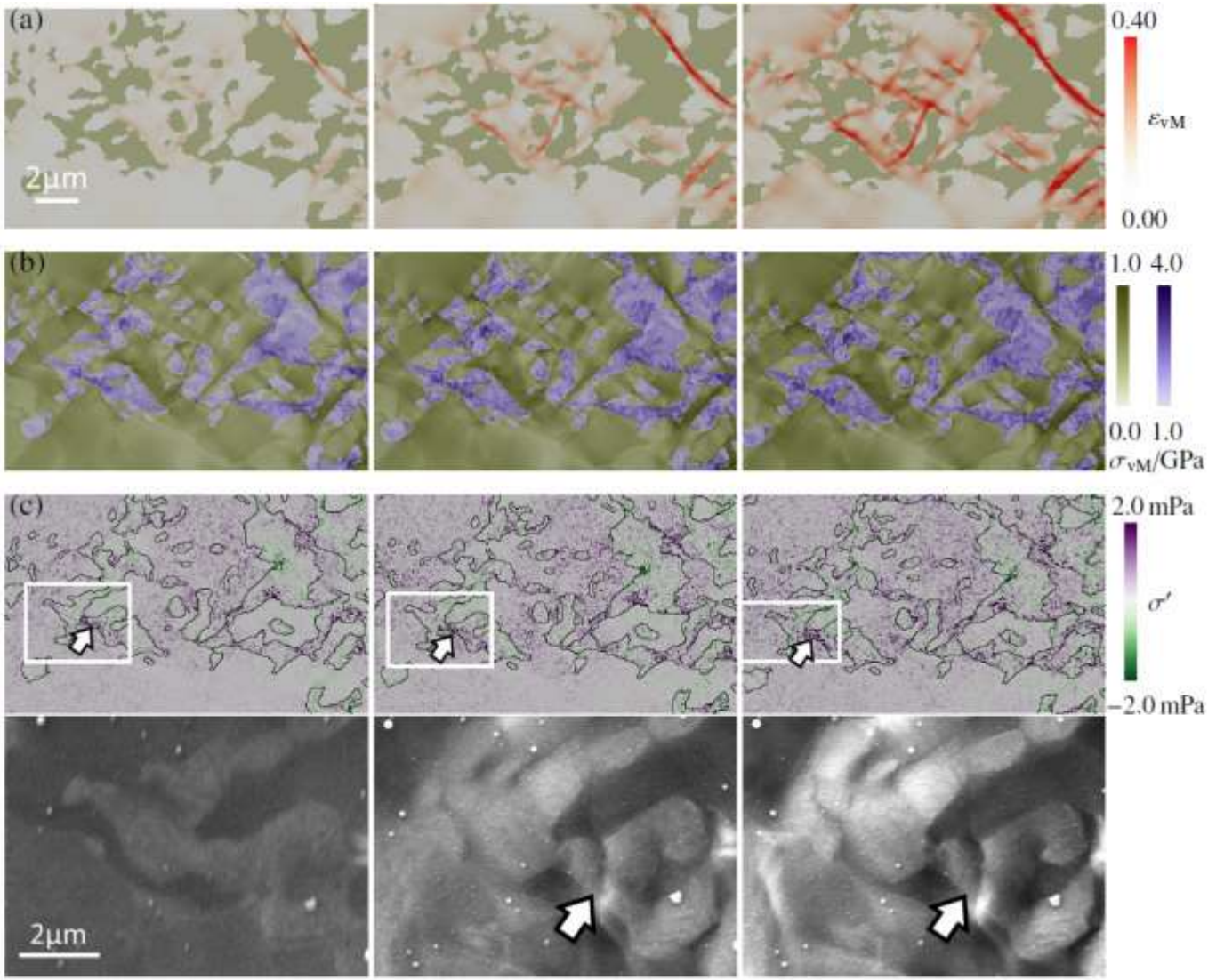
Tasan, C.C., Hoefnagels, J.P.M., Diehl, M., Yan, D., Roters, F., Raabe, D. Strain localization and damage in dual phase steels investigated by coupled in-situ deformation experiments and crystal plasticity simulations (2014) International Journal of Plasticity, 63, pp. 198-210.

Strain (sim.)

Stress (sim.)

Tensile (sim.)

Microstructure (exp.)

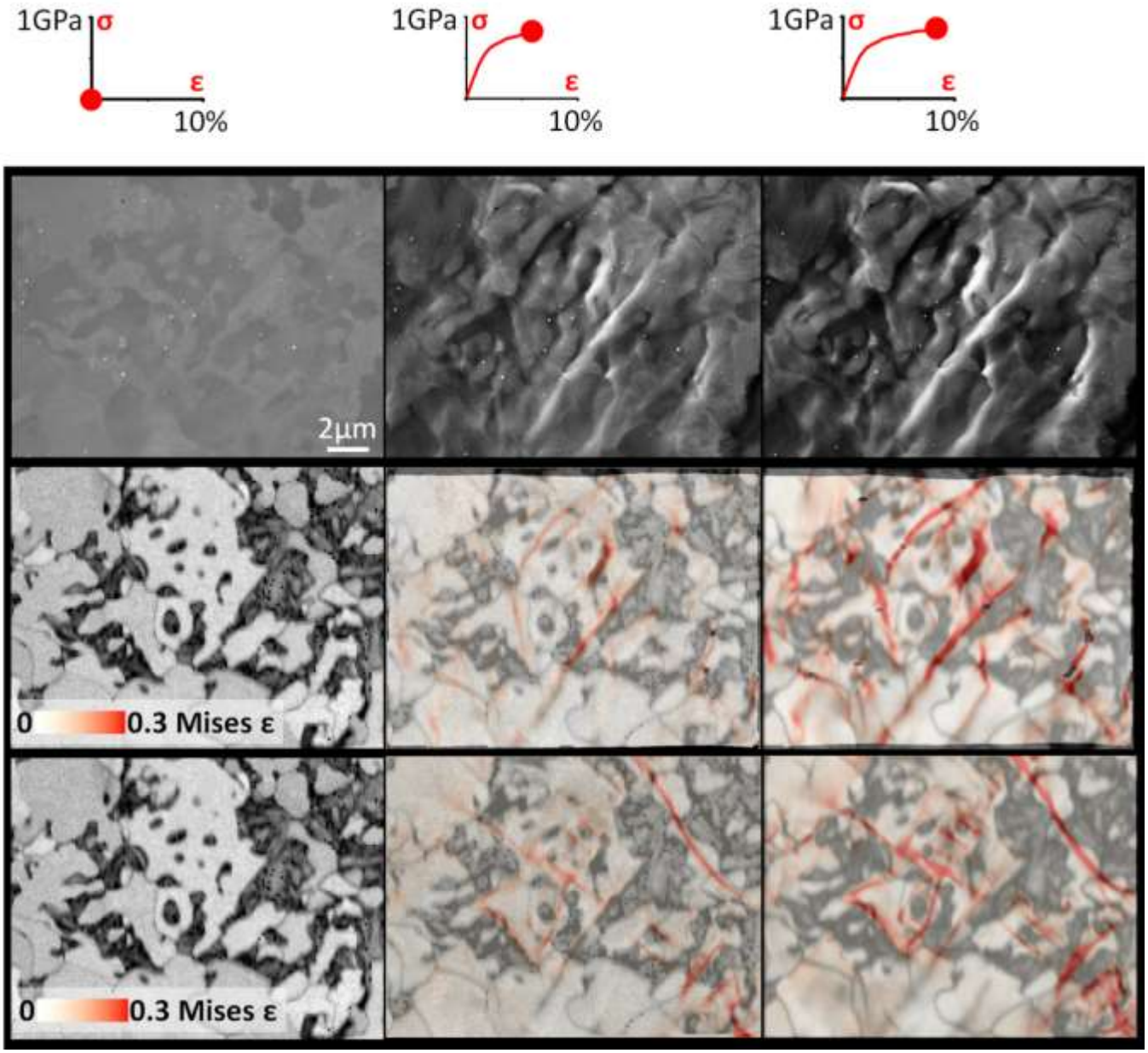


Experimental results vs simulation results

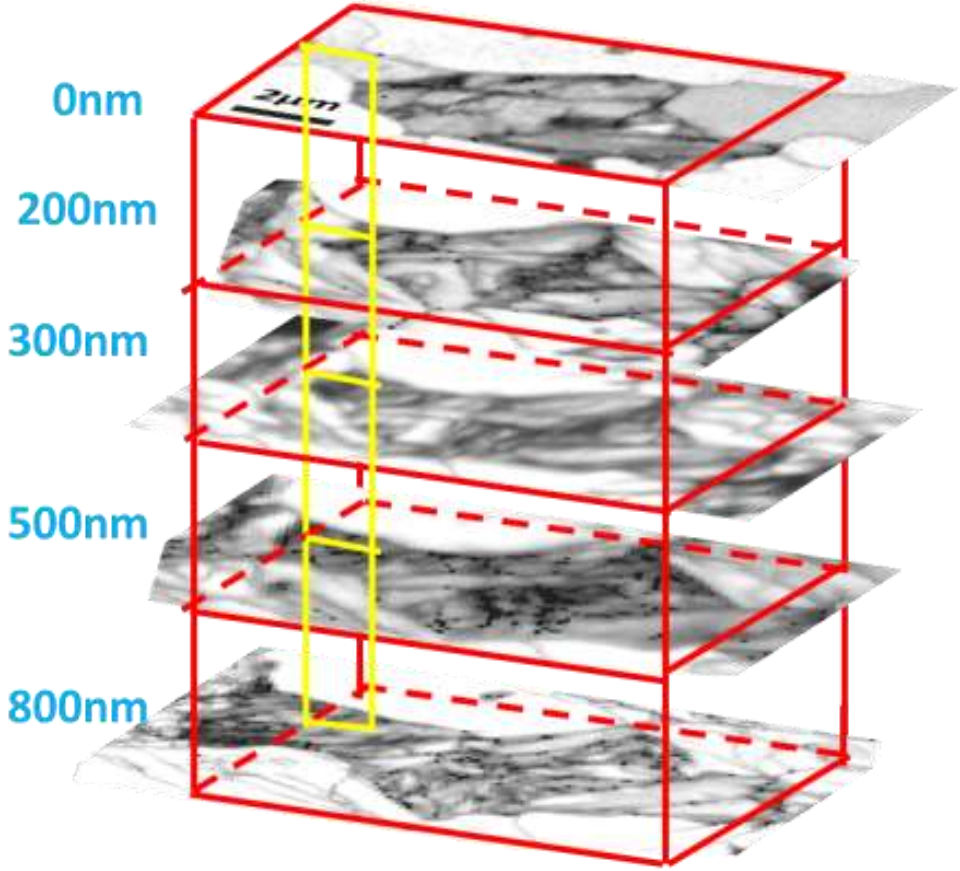
SE→

IQ+ DIC strain→

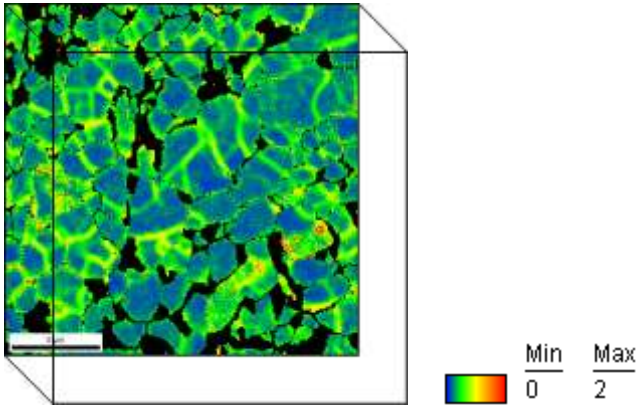
IQ + CP strain→



Surface effects: serial sectioning to check surface effects (sim)



Kernel Average Misorientation (martensite highlighted in black)



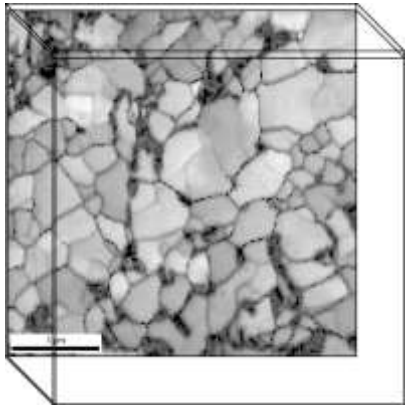
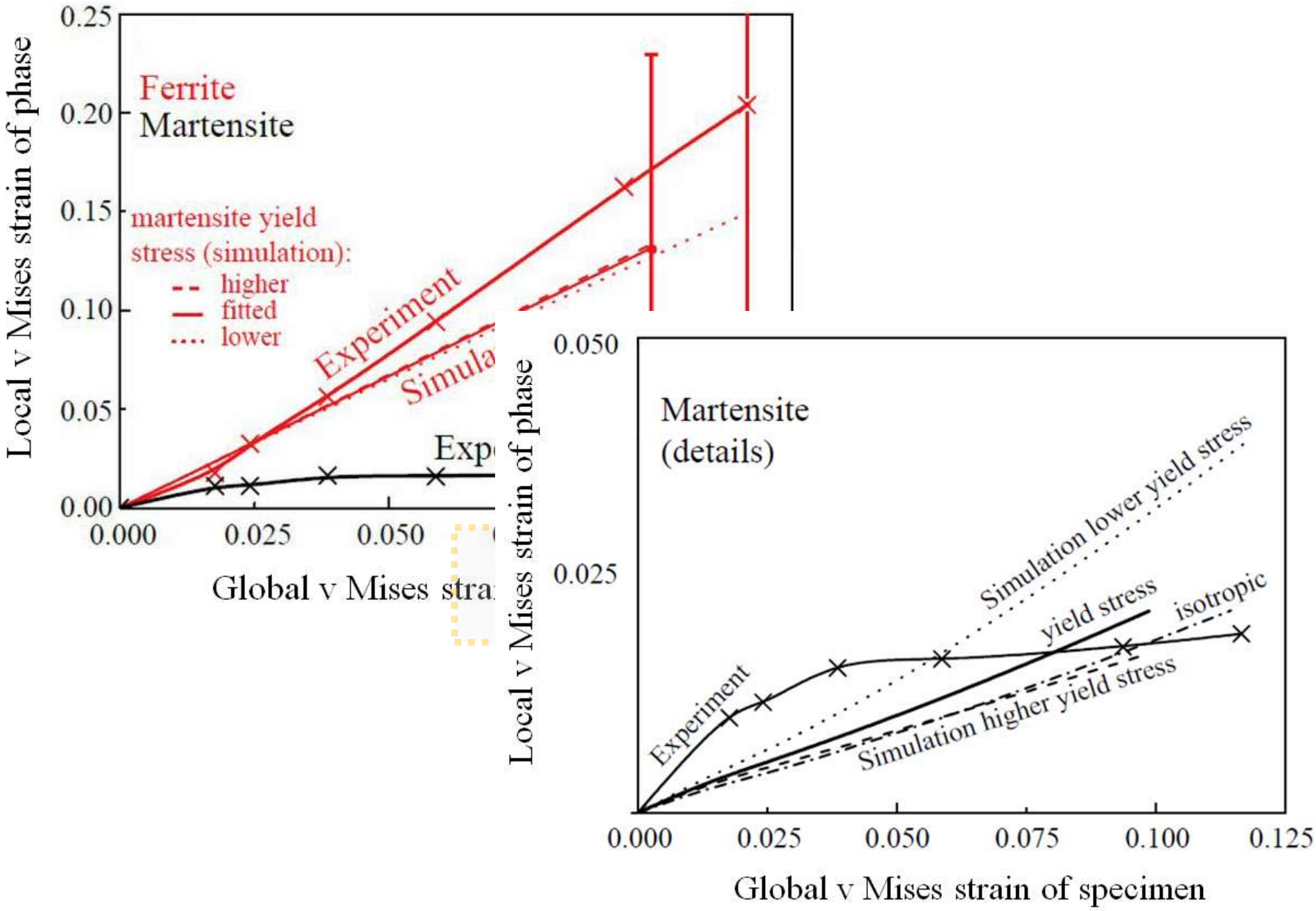


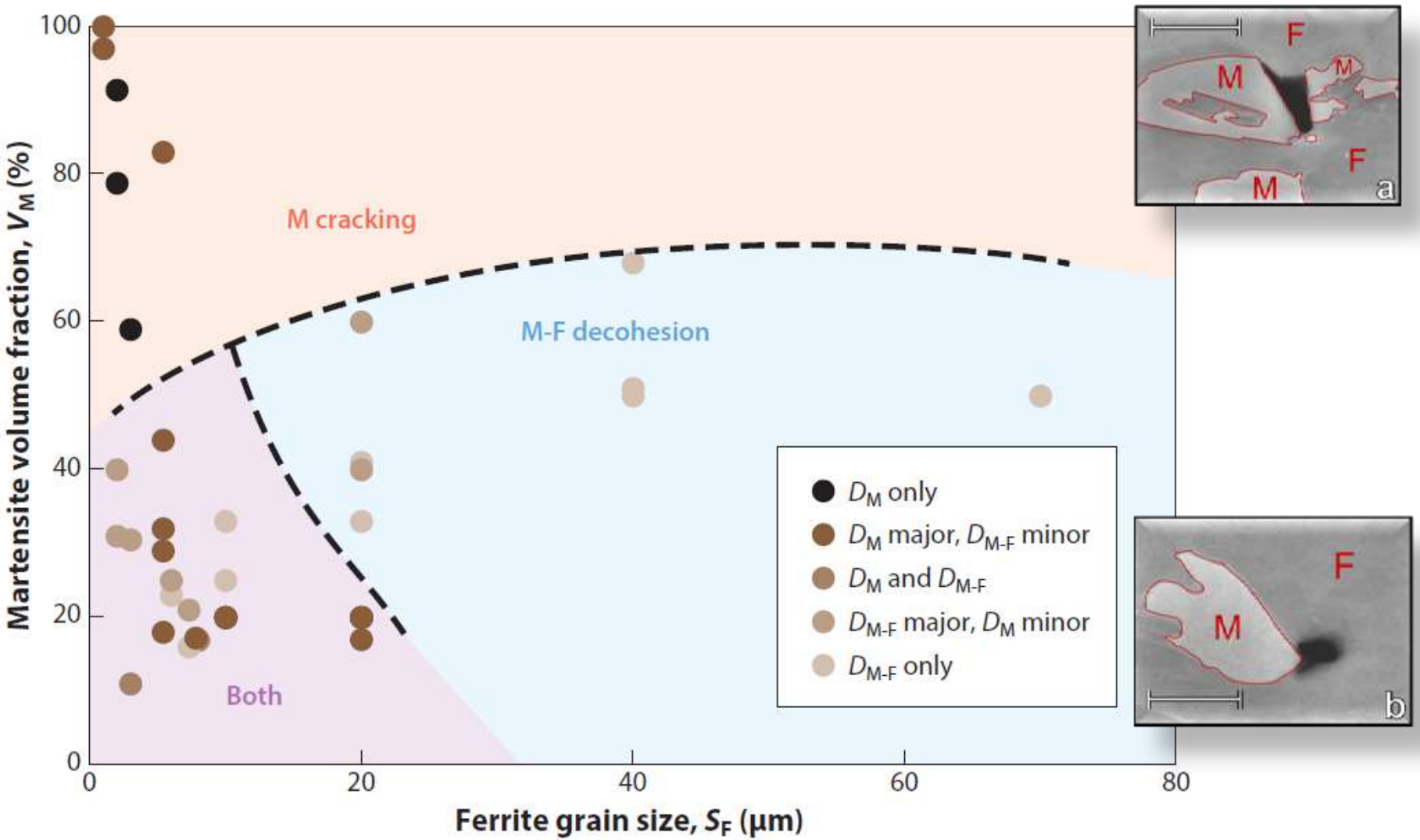
Image Quality

Calcagnotto et al. Mater. Sc. Engin. A 527 (2010) 2738

Experimental results vs simulation results : partitioning



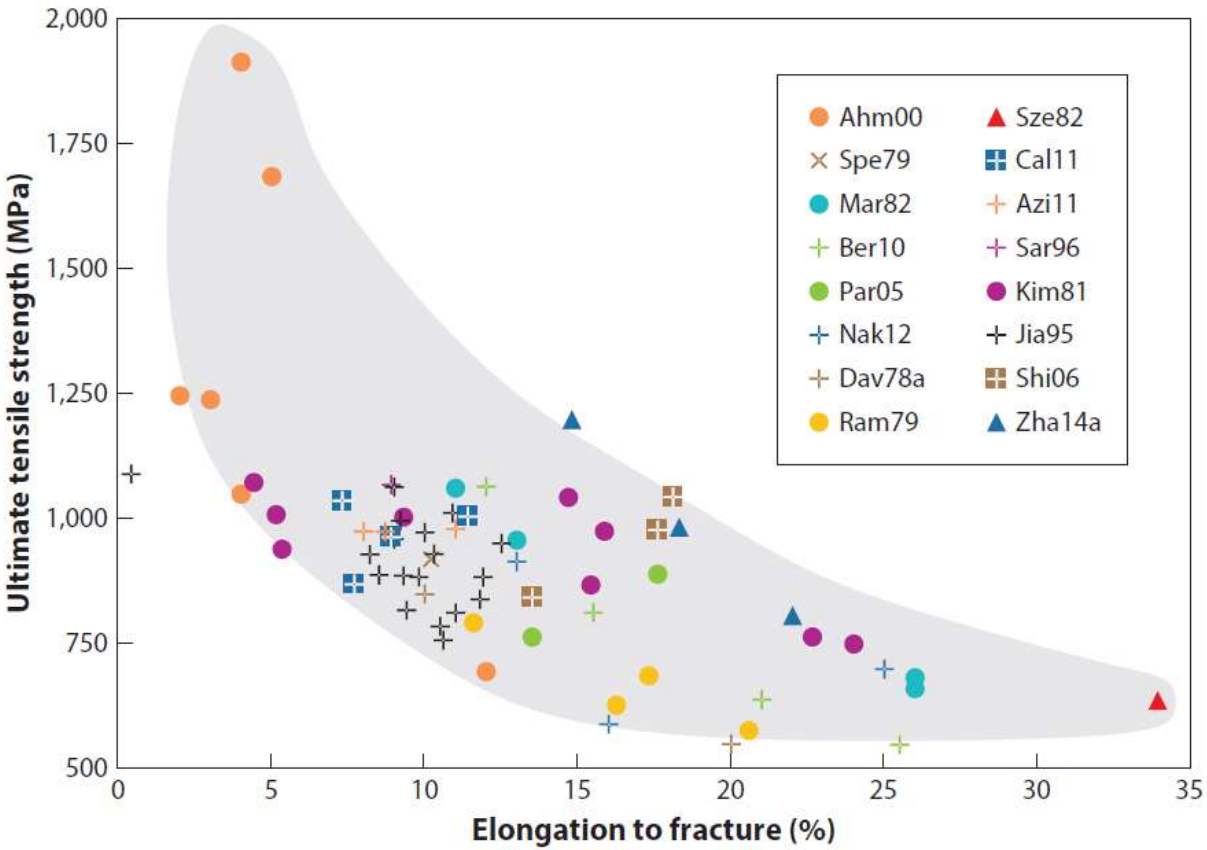
Defect characteristics, trends, dual phase steels



Damage mechanism analysis as function of ferrite grain size and martensite volume fraction

*D*M: martensite cracking *D*M−F: martensite-ferrite decohesion F: ferrite; M: martensite

Mechanical properties, trends, dual phase steels



CM: martensite carbon content
SM+F: martensite and ferrite grain size
SM: martensite grain size
VM: martensite volume fraction

Overview: intrinsically nanostructured bulk high Mn steels

Dual Phase steels:

Microstructure optimization and damage initiation

Density-reduced steels:

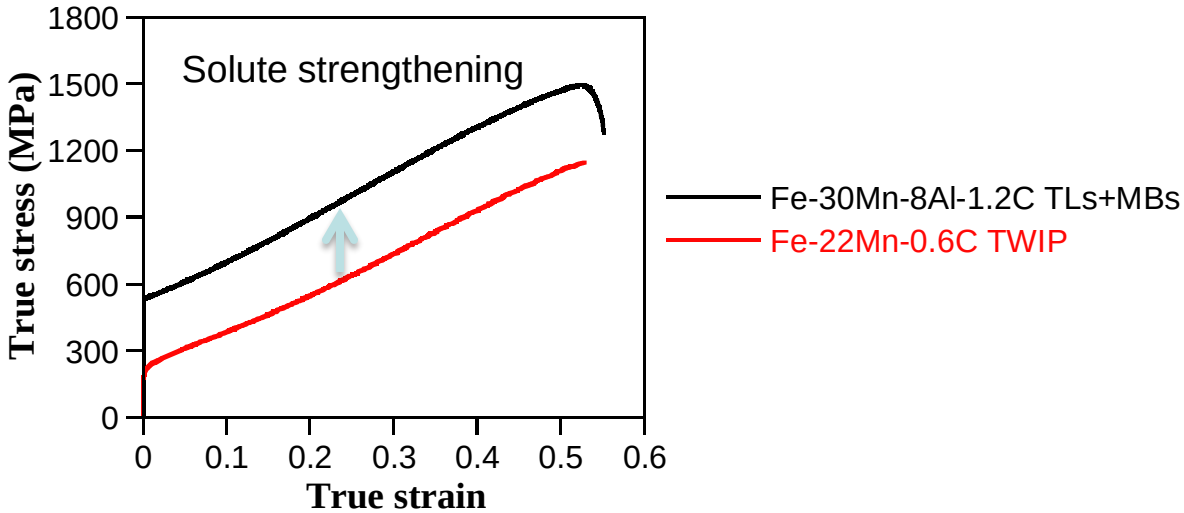
Strain hardening and rapid alloy prototyping

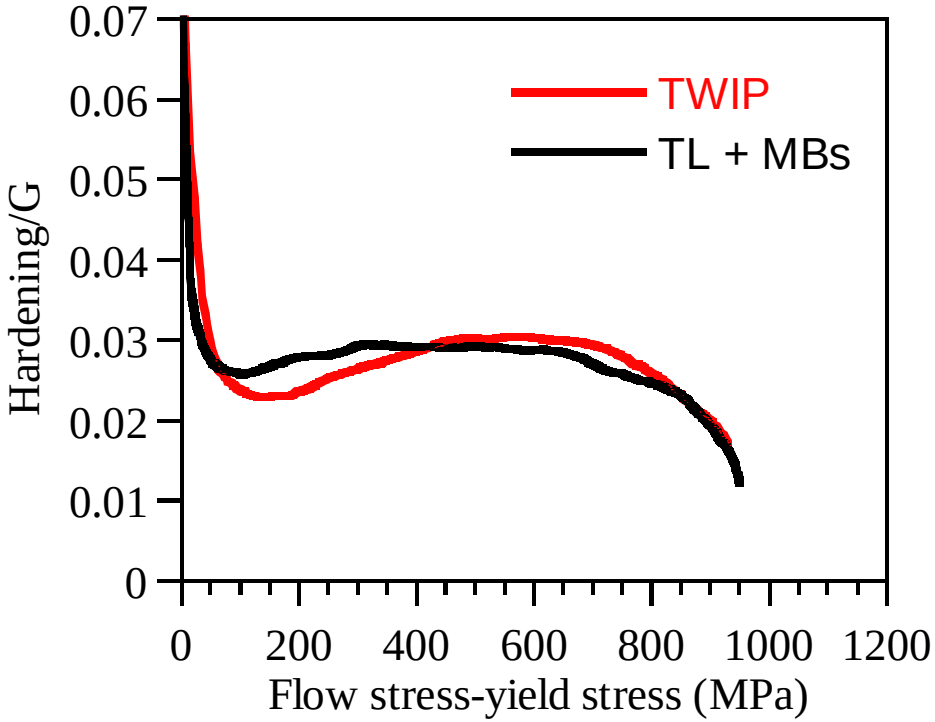
Weight reduced steels: Fe-Mn-Al-C

Austenitic steels with up to 18% reduced mass density

Fe-Mn-Al-C system

Fe-Mn-Al-C: massive solid solution, strain hardening



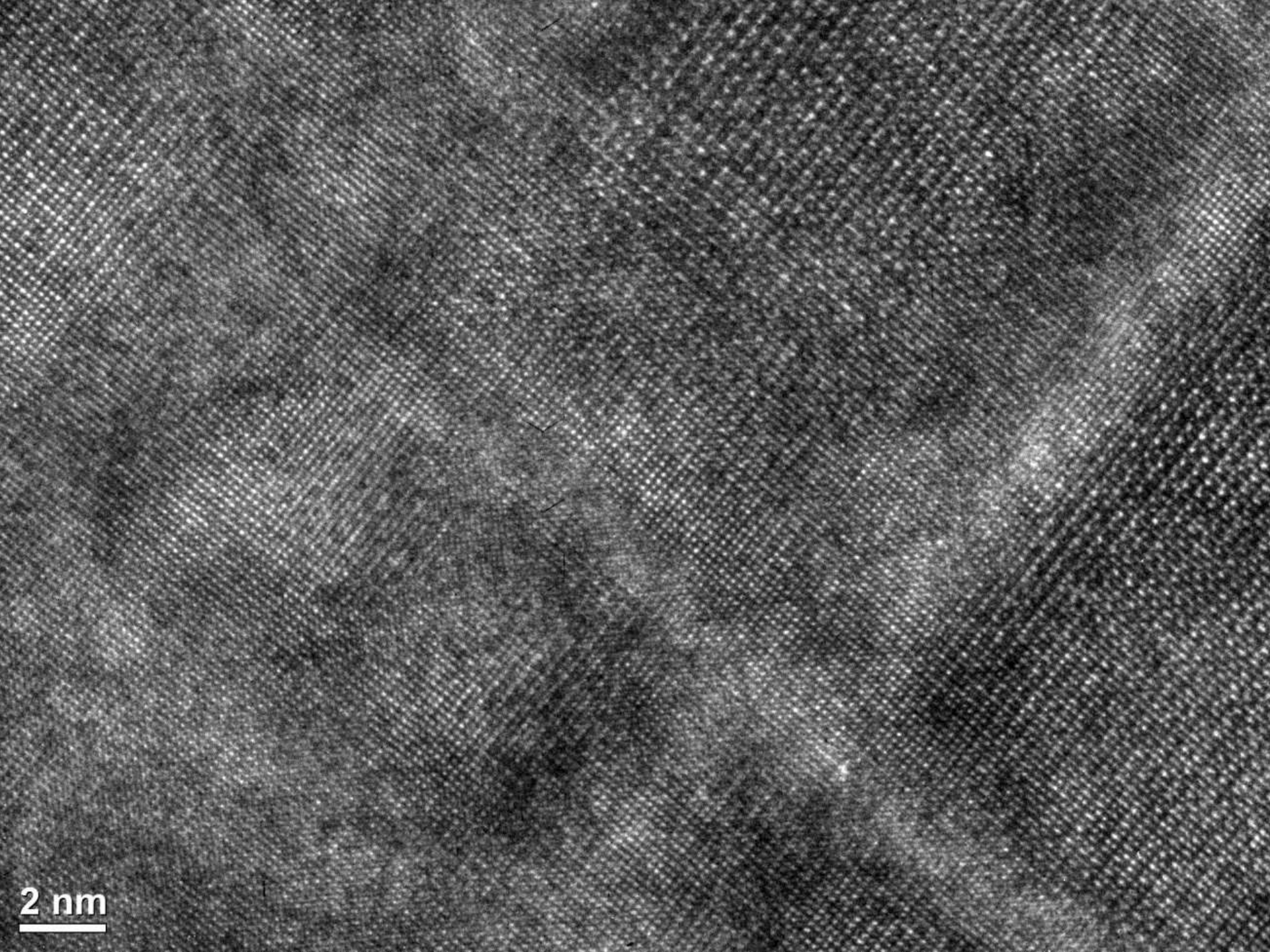


TLs: Taylor lattices
MBs: Microbands

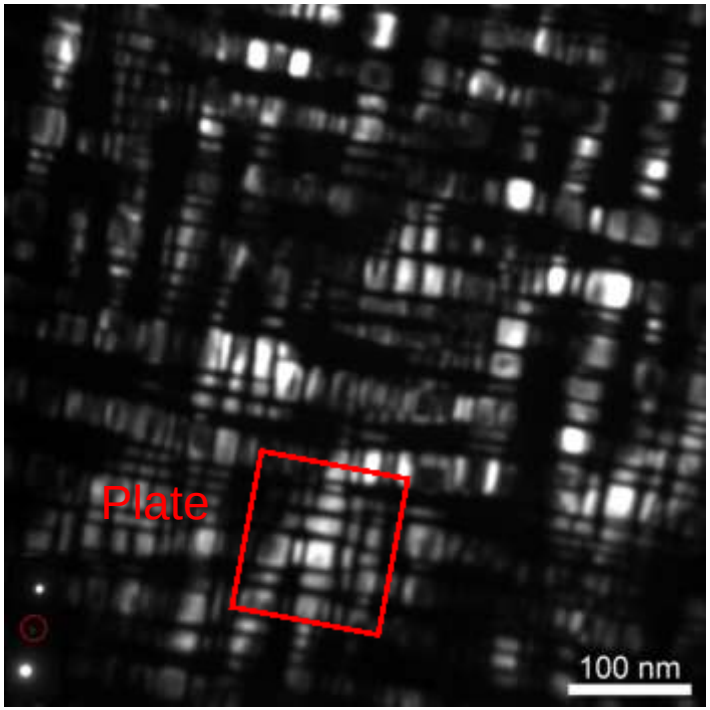
Similar strain hardening behavior!

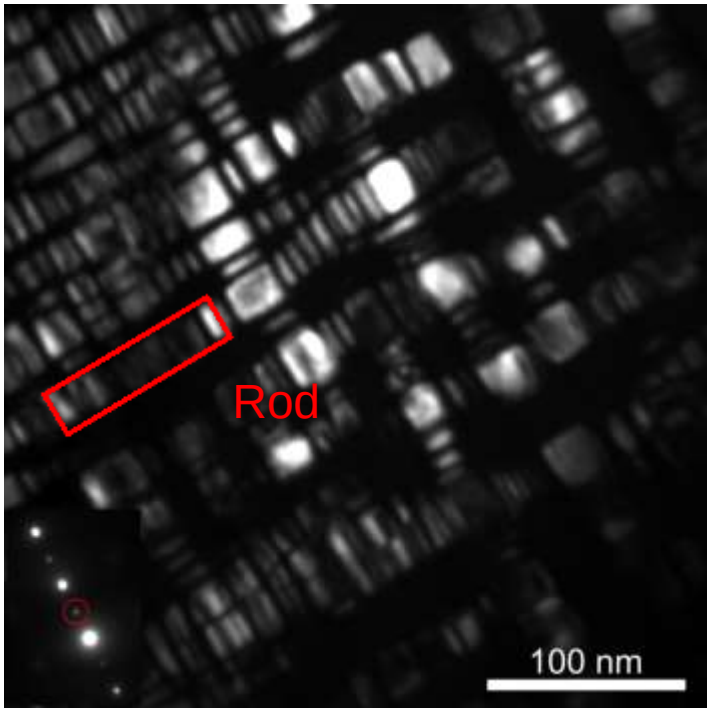
Mechanical twins required?

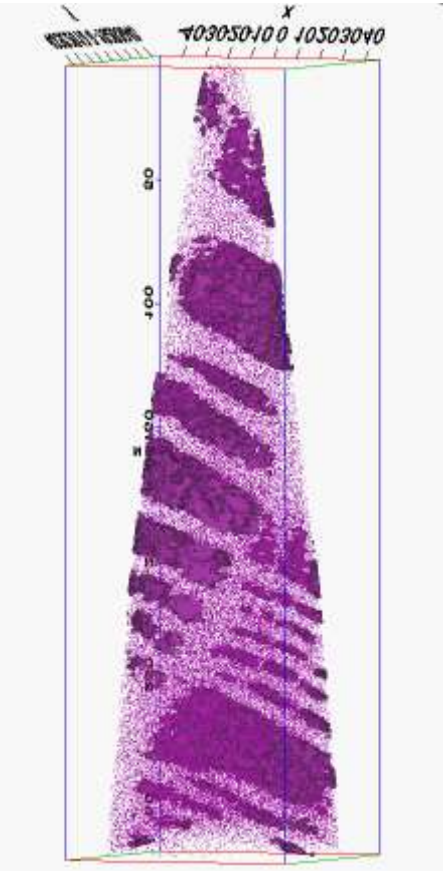
Work in progress & Springer Acta Materialia, v. 60, p. 4950


2 nm

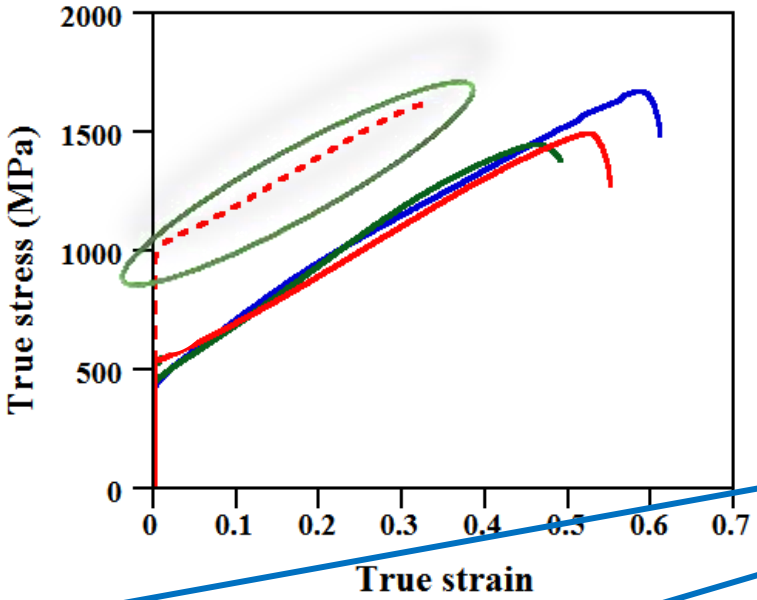
TEM image of sample 24h/600°C: carbide morphology



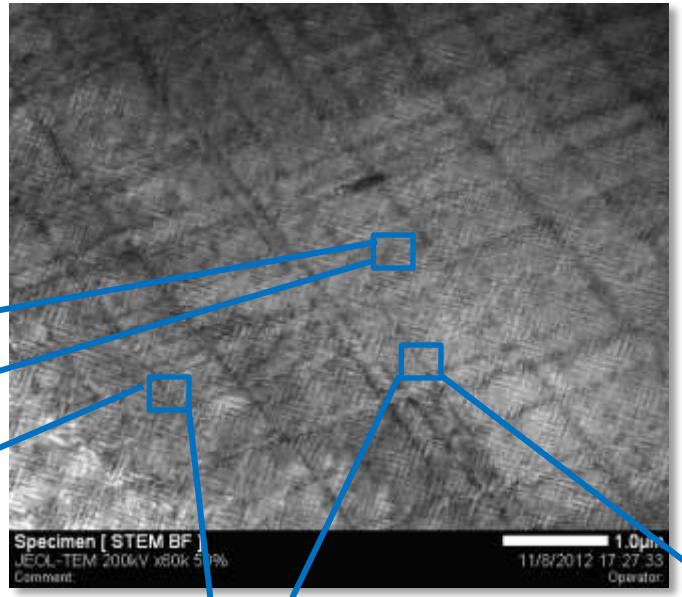


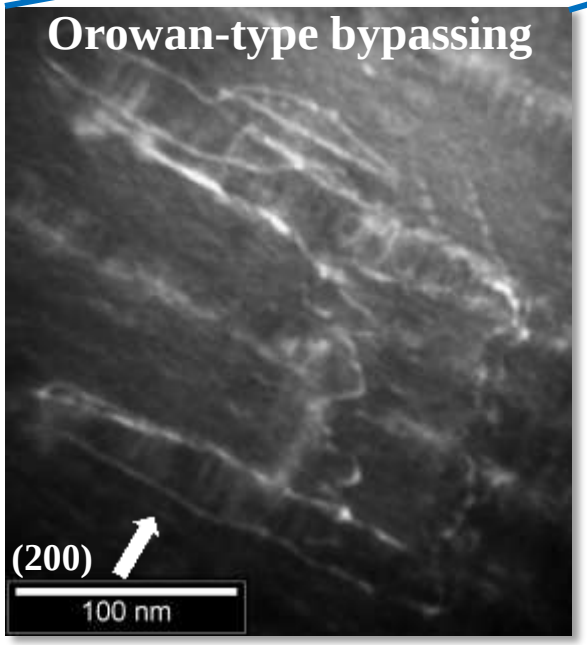


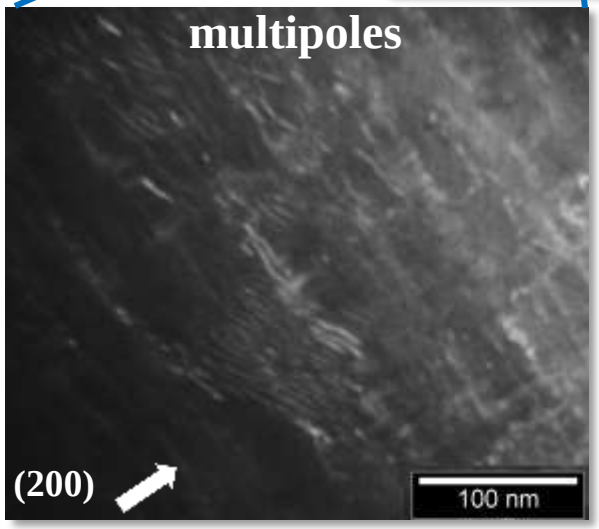
Deformation mechanisms of density-reduced steels

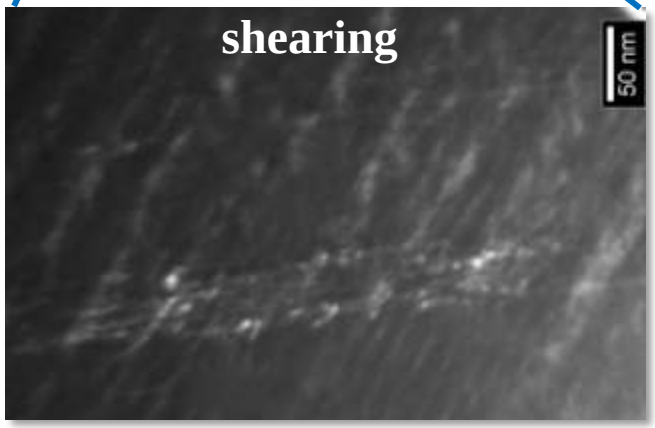


Homogeneous distribution of κ carbides (24 h/600°C)

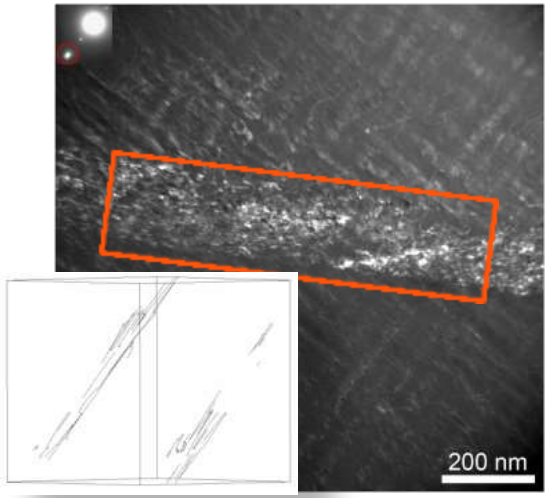


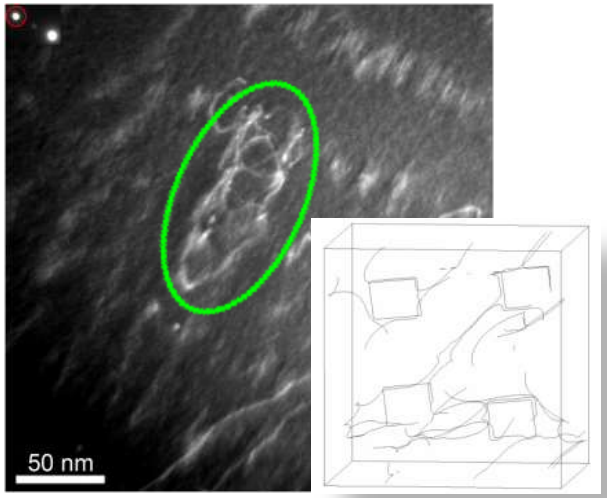


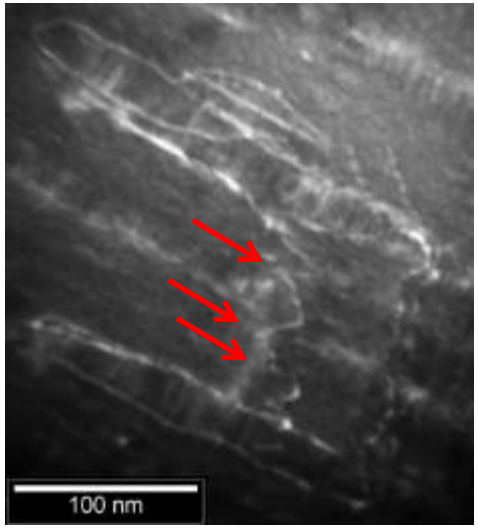


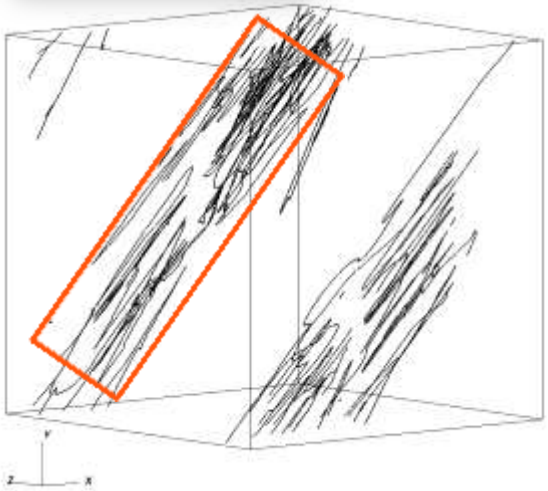


Analyzing microstructure features using DDD

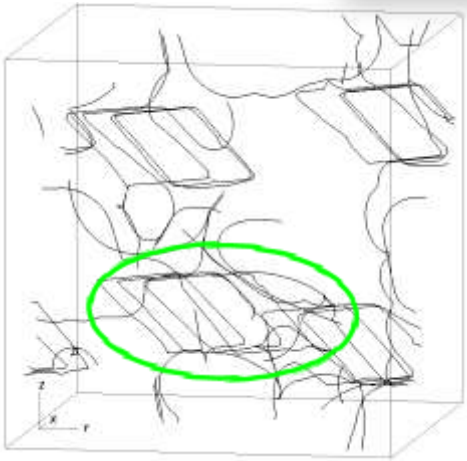




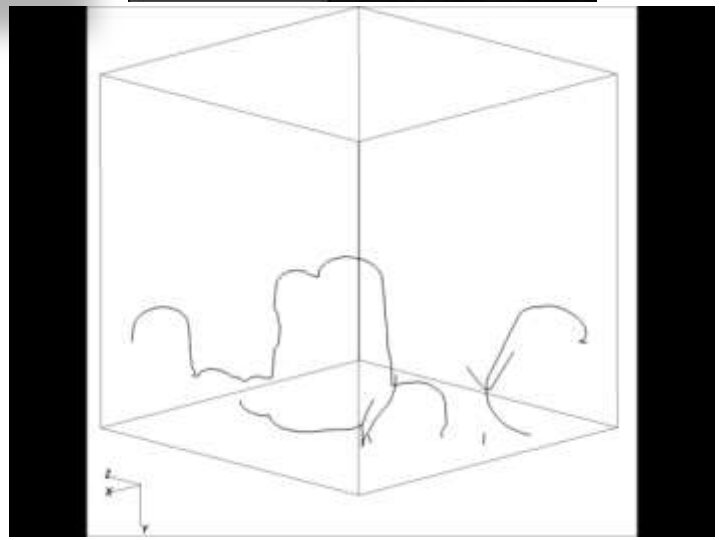




Formation of slip bands from individual dislocation sources

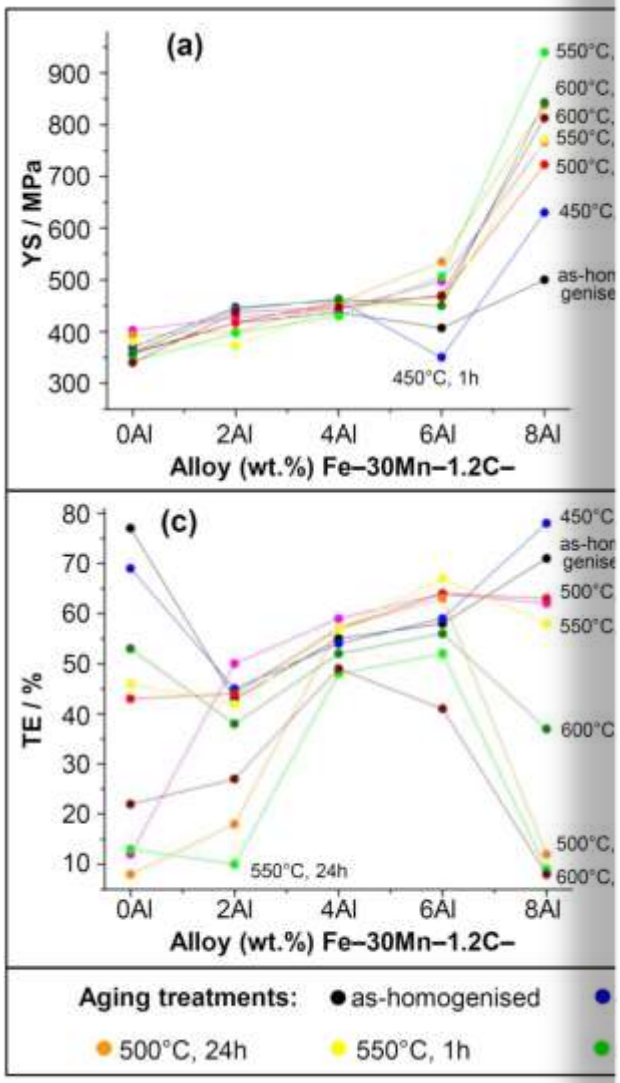


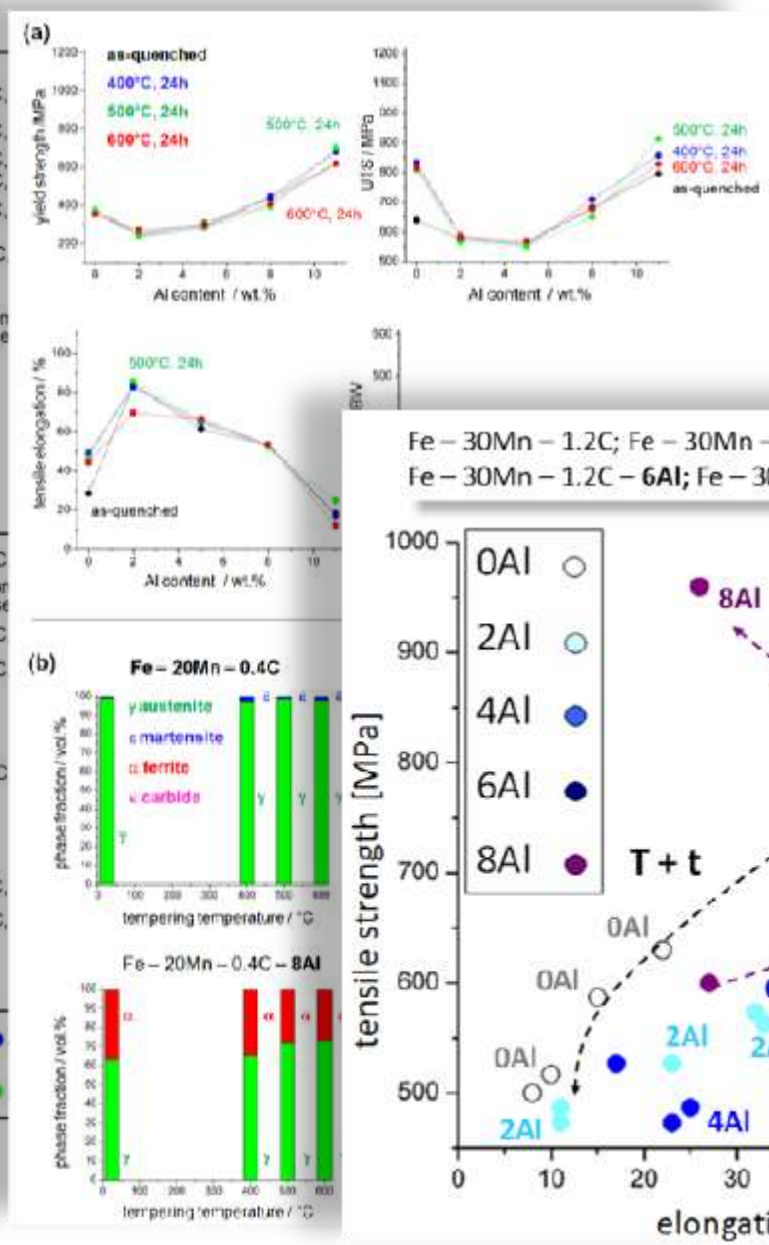
Dislocation wrapping around κ-carbides

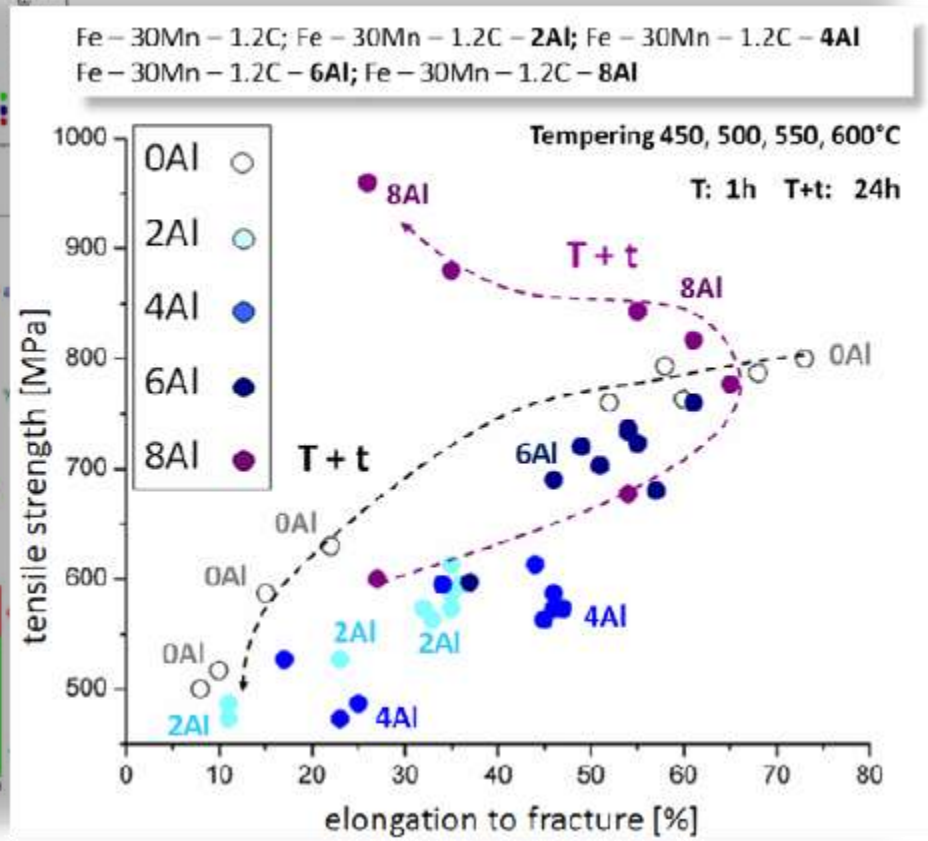


Dislocation pinning due to cross-slip into different conjugate glide plane

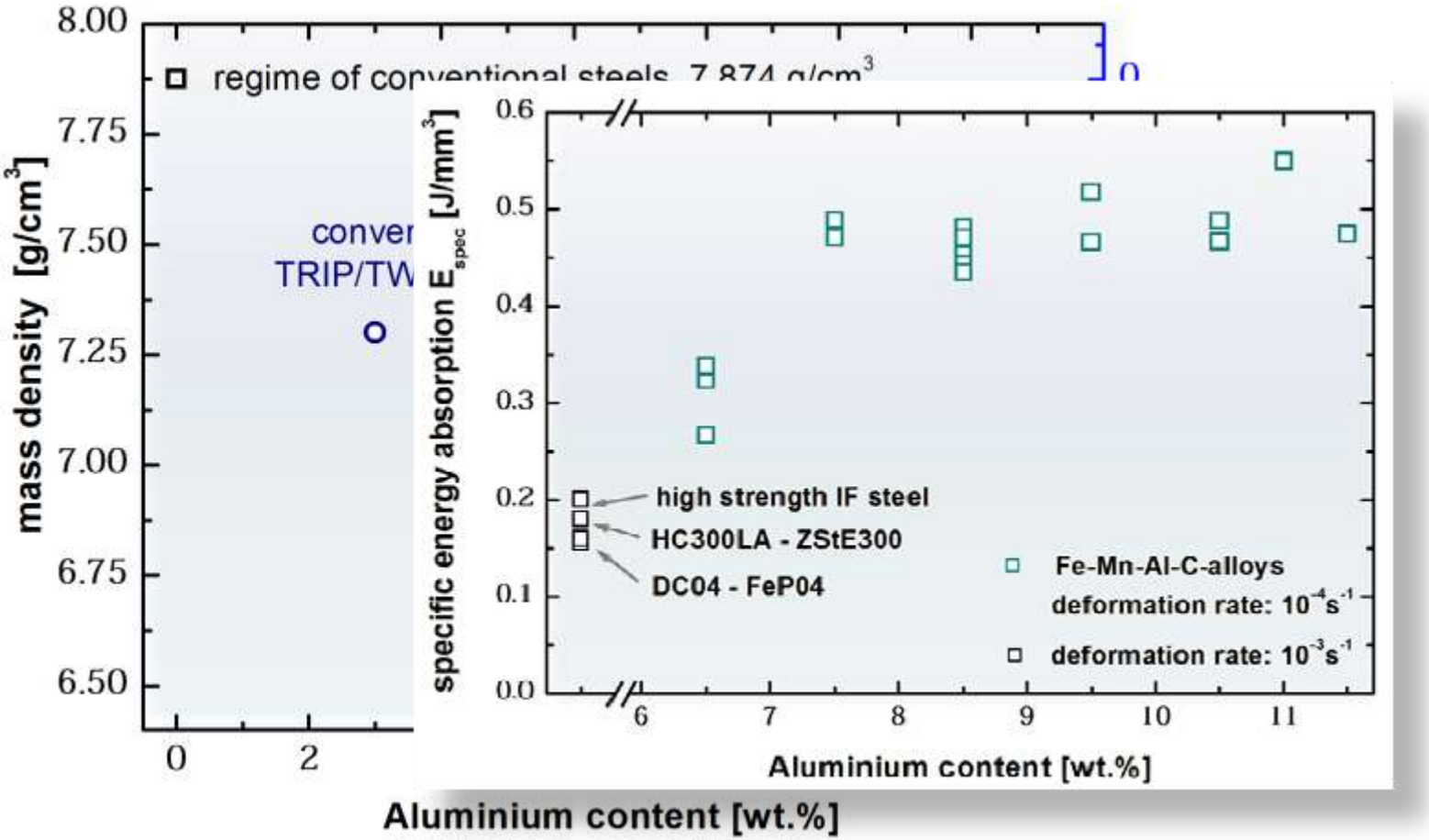
Fe-Mn-Al-C: RAP – bulk combinatorial design: steel plant in a box







Weight reduced steels: Fe-Mn-Al-C



Density reduction in Fe-Mn-Al-C TWIP steels as a function of Al content.

Conclusions

Dual Phase steels:

Local ICME damage analysis; reduce ferrite grain size; tune martensite strength; avoid narrow ferrite bridges; avoid hydrostatic tensile components; avoid large martensite clusters; avoid percolative structures and banding

Density-reduced steels:

Combined weight reduction and high crash resistance; metallurgical combinatorics enables rapid alloy propotyping