MPA Universität Stuttgart

Microstructure, dislocations, defects and cracks in austenitic steels under cycle loading

- Experiments and Simulations -

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Gefördert durch:
Bundesministerium für Wirtschaft und Technologie
aufgrund eines Beschlusses des Deutschen Bundestages

Meeting of the contact persons SP4 JPNM June 03. 2013 Edinburgh

Objective of our project(s)

Possible contribution MPA

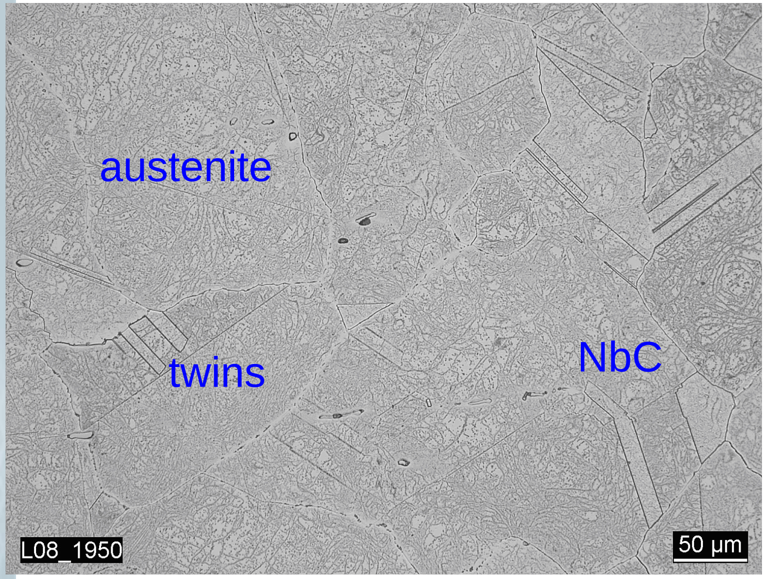
- **Development of defects in austenitic steels under cyclic loading**
- **TEM – investigations of stacking faults in the austenitic matrix prior to nucleation of α‘-martensite (bcc)**
- **EBSD – investigations of local orientation and misorientation caused by phase transformation**
- **EBSD – investigations of phase (austenite and martensite) distribution**
- **Atomistic simulations (MD) of martensite formation incl. dislocations and stacking fault formation**

currently at work:

- **Elastic-anisotropic FE-simulations of deformation and martensitc transformation in the grain-microstructure**
- **Isotropic and anisotropic simulations of martensitic transformation taking into account vol. expansion and change of properties**
- **Initiation of fatigue cracks, plastic zone, phase transformation, lifetime….**

Material, Heat treatment, Microstructure

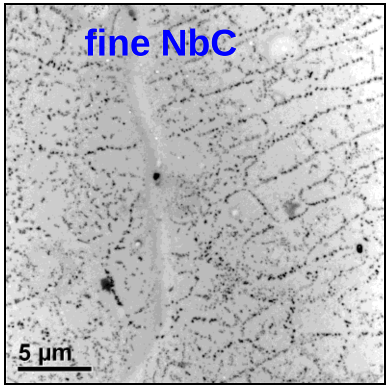
C	Si	Mn	P	S	Cr	Ni	Nb	Ta
0.043	0.410	1.900	0.019	0.002	17.150	10.300	0.660	0.008
balance **Fe** (weight. %)								

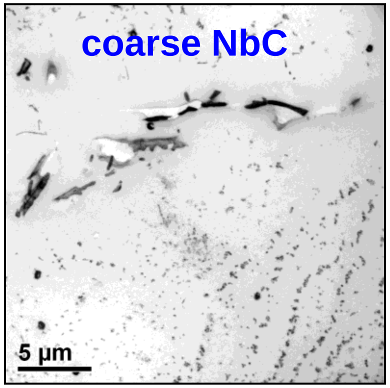


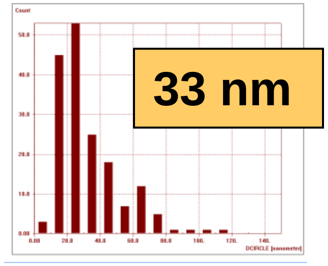
Heat treatment

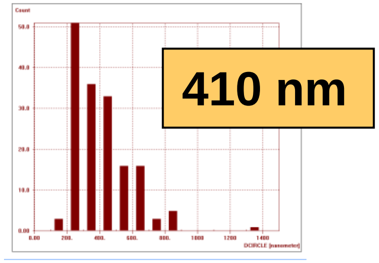
Homogenization: **T=1050°C / 10 min**

Water-quenched to room temperature









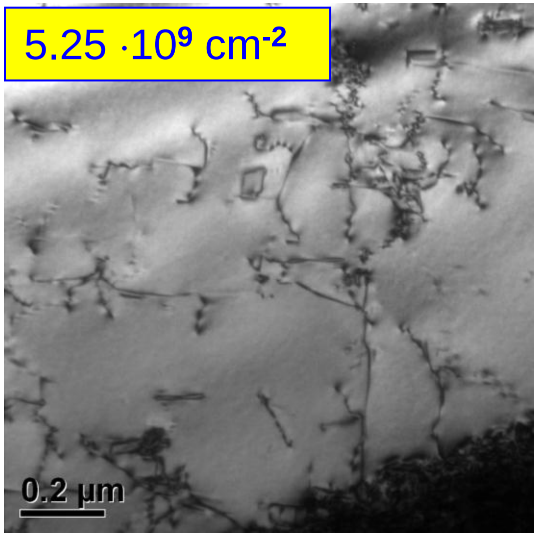
X6CrNiNb18-10

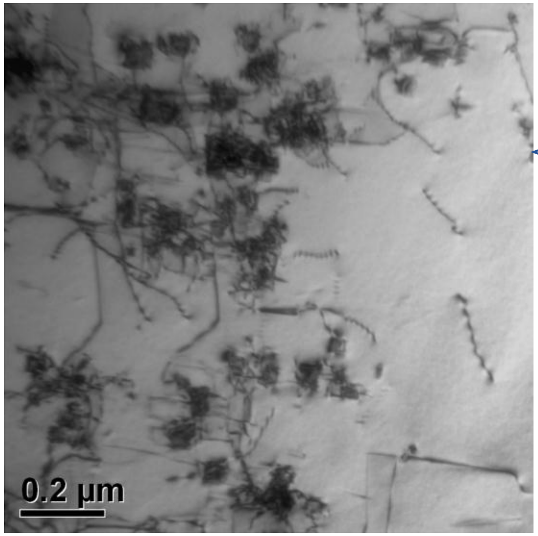
Cr – ↑ corrosion resistance, ferrite stabiliser

Ni – austenite stabiliser

Nb - ↑ corrosion resistance →NbC

Dislocation patterns

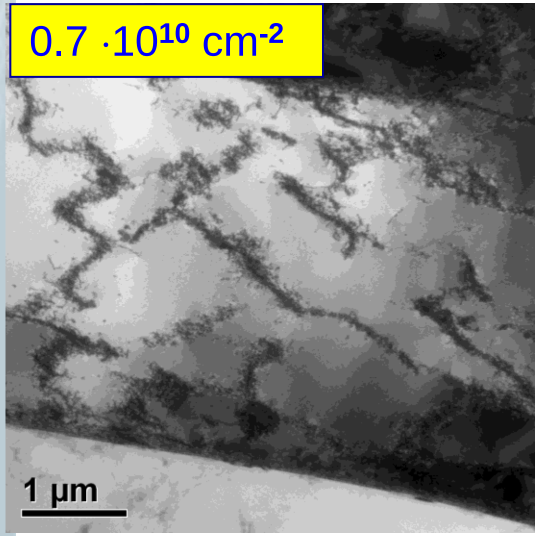




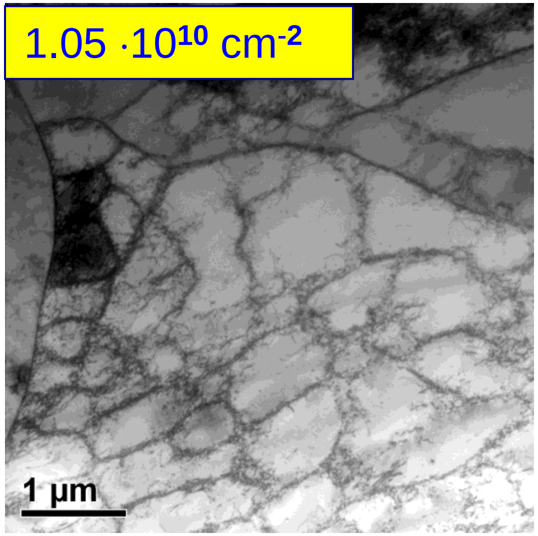
Before mechanical loading

Distribution of NbC has influence on the location of dislocation-rich walls.

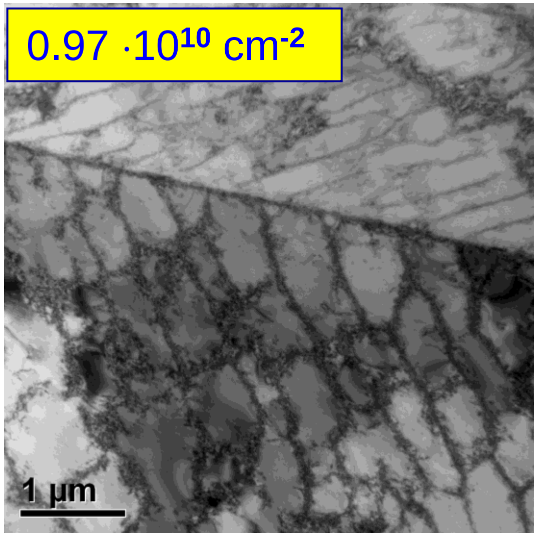
ε_a=0.25%



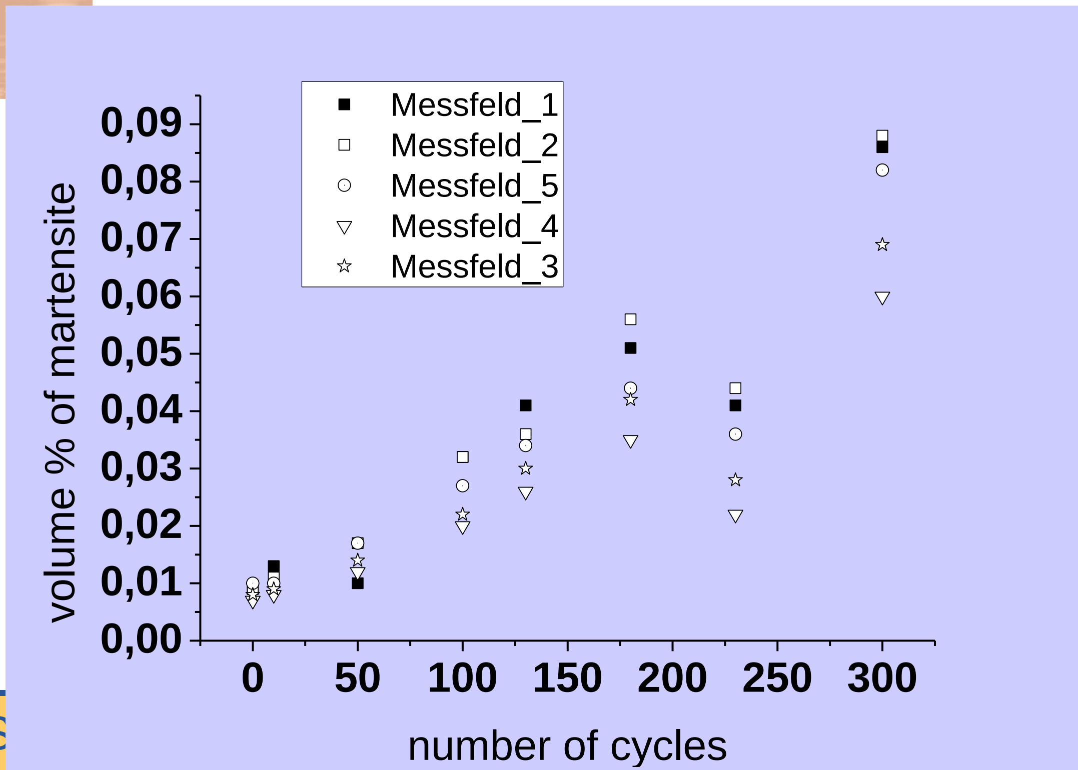
ε_a=0.5%

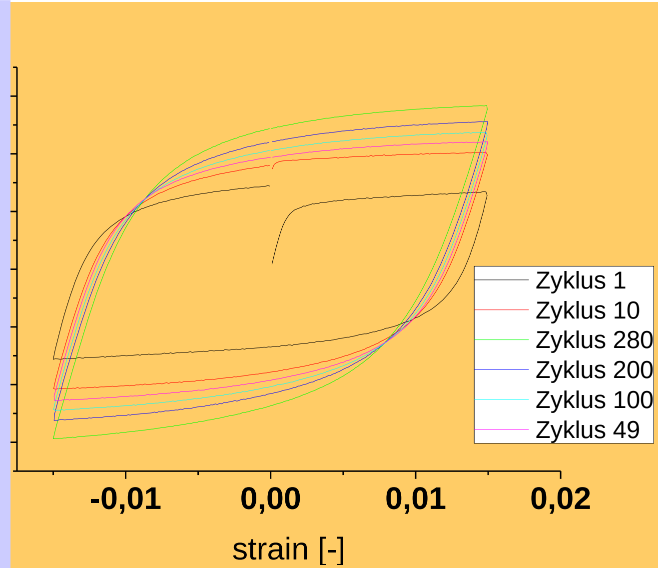


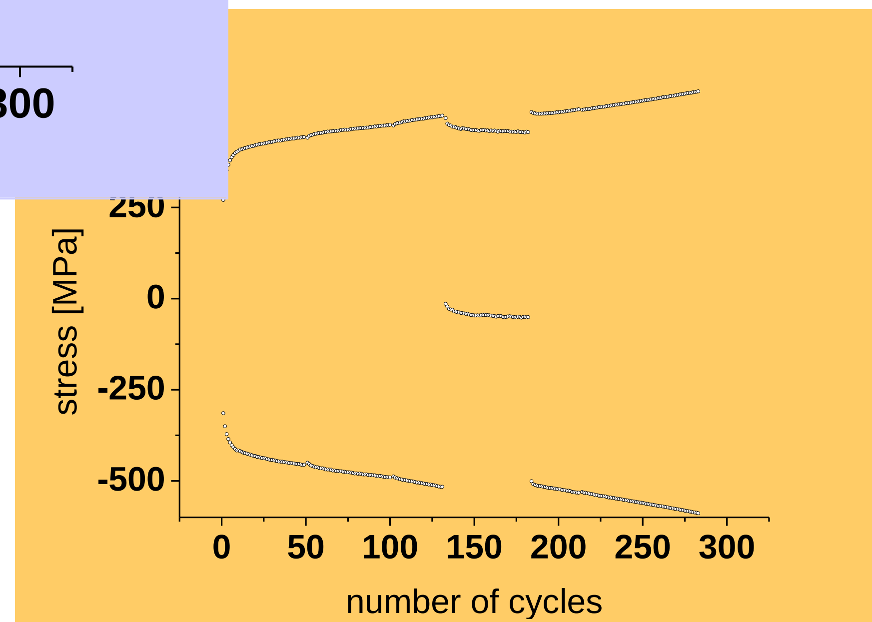
ε_a=1.5%



Combination of LCF and EBSD







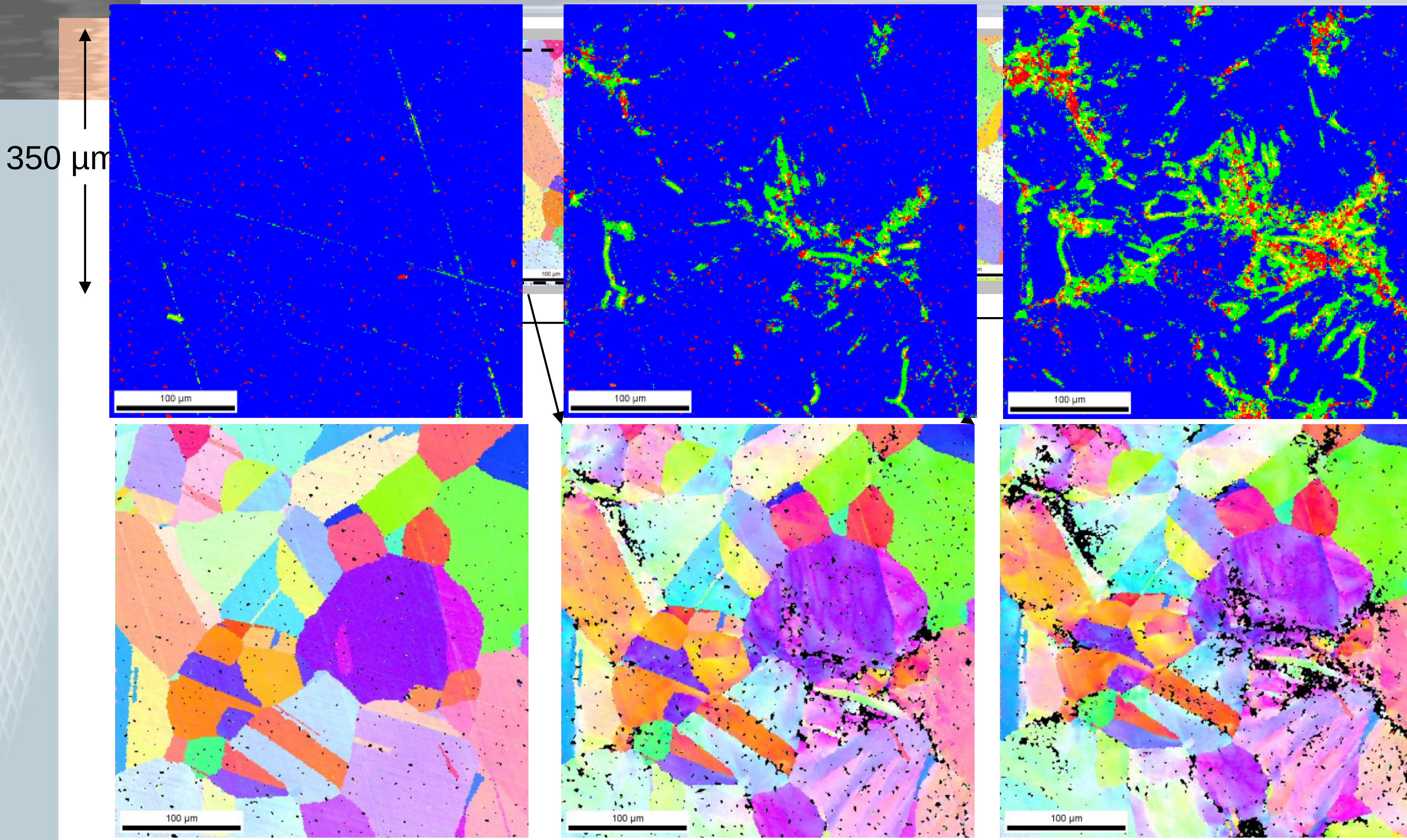
S

amplitude ε=1,5%, R=-1.

Breaks after cycles:

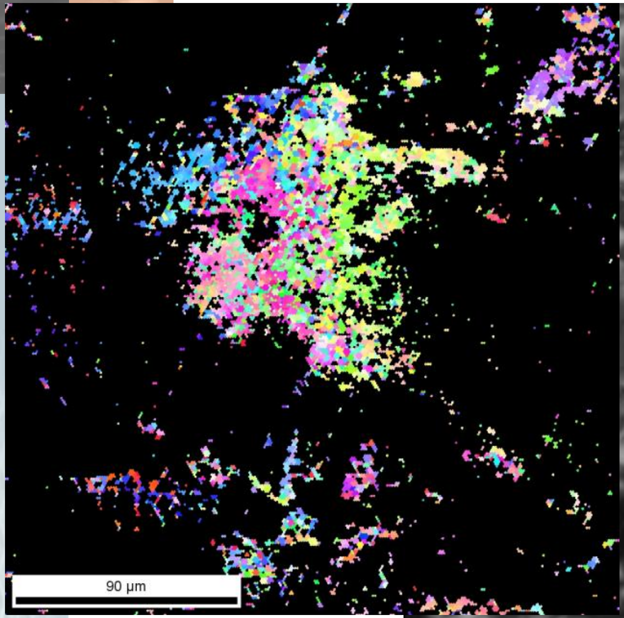
10, 50, 100, 130, 180, 230 and 300.

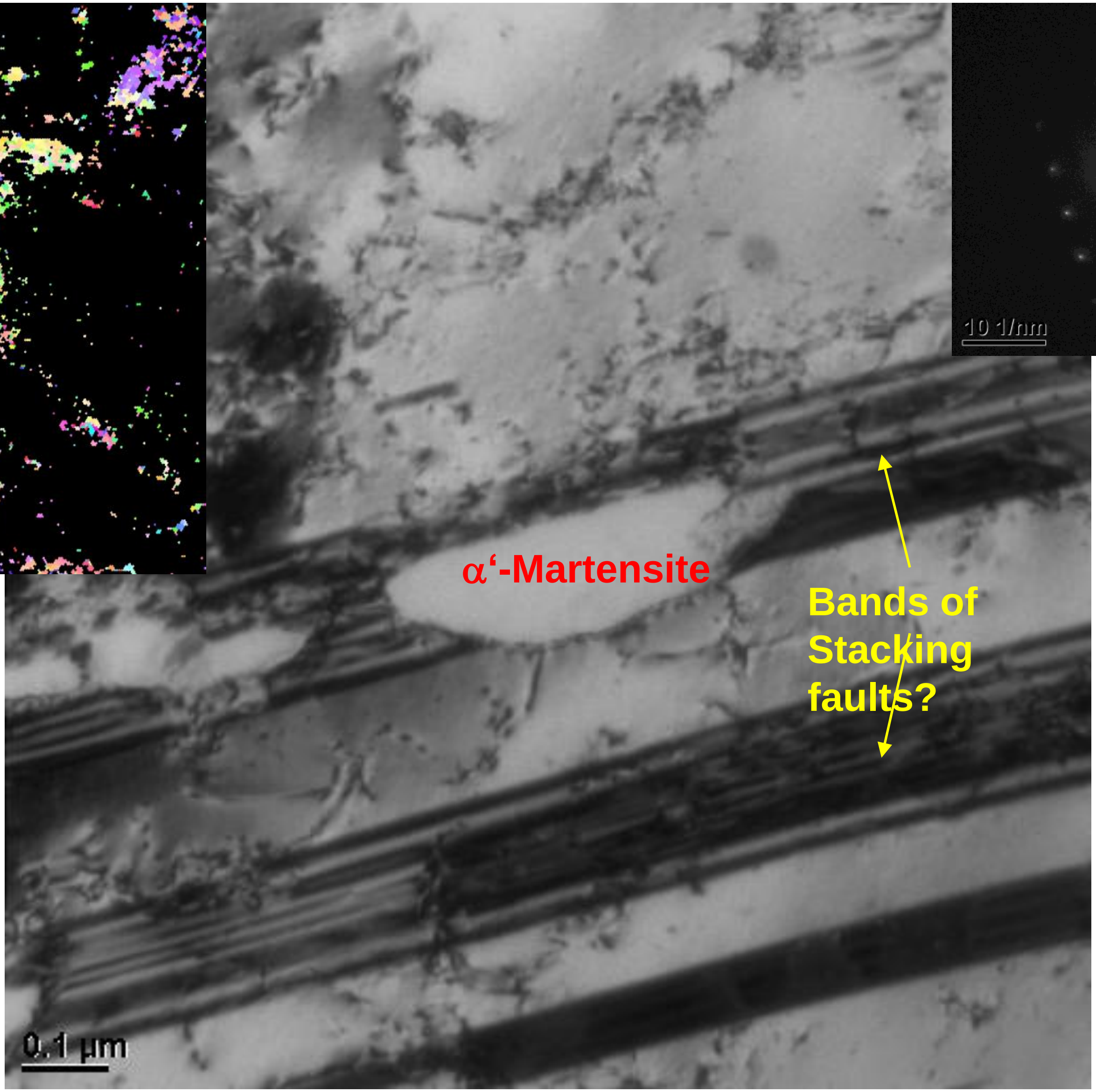
Formation of α'-martensite

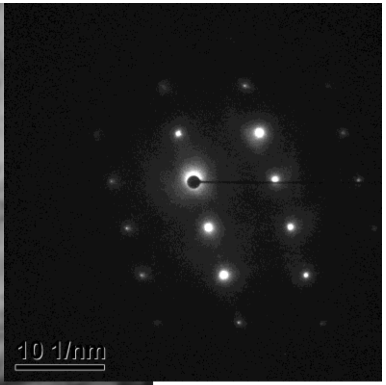


0 cycles (~0%) 180 cycles (~60%) 300 cycles (~100%)

„Nucleation“ of martensite - TEM





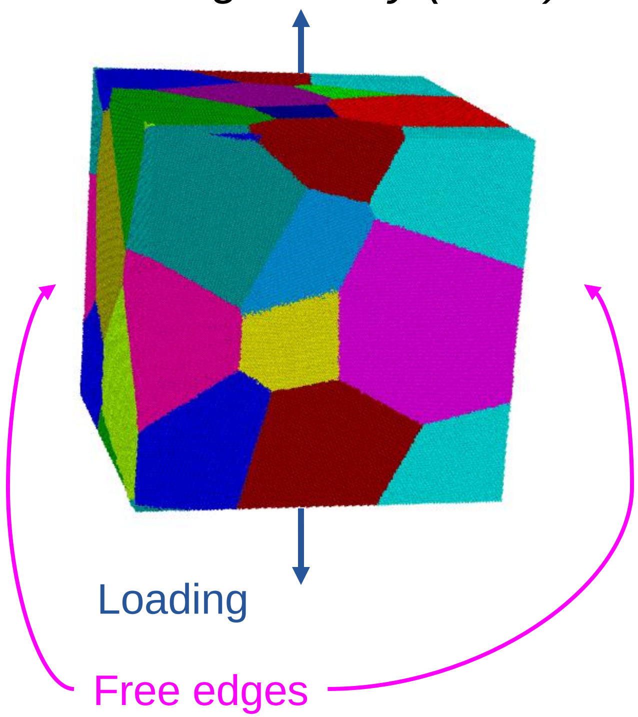


E. Soppa, D. Willer, D. Kuppler, K. Maile: „EBSD- und Praktische Metallographie 5 (2013) 331-345.

Atomistic Simulations

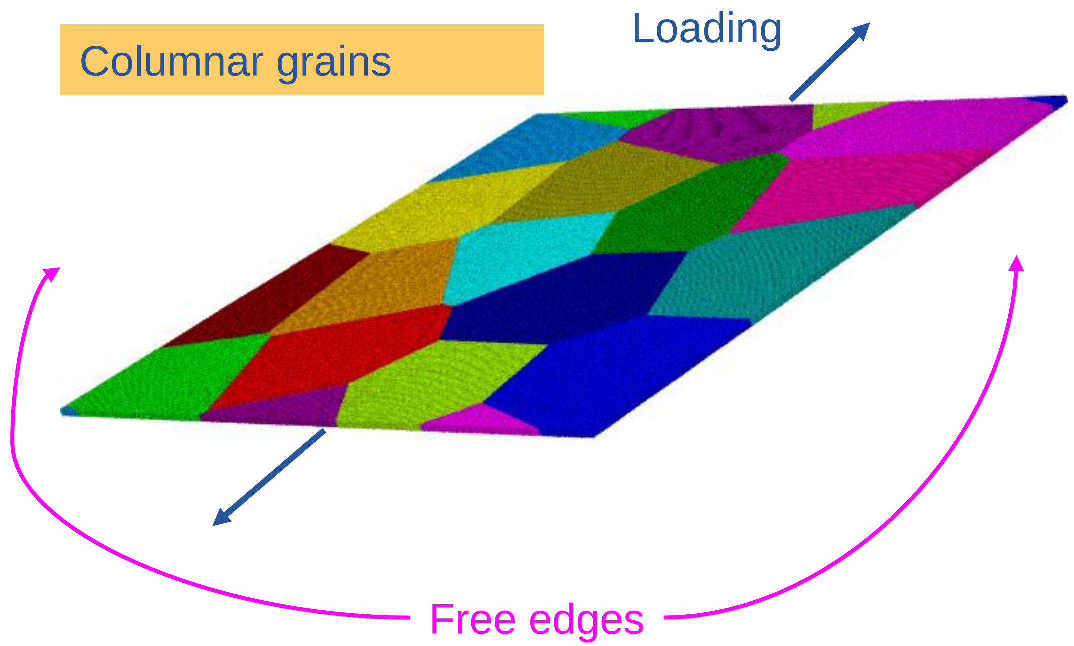
- Classical Molecular Dynamics
- Nanocrystalline models $Fe_{50}Ni_{50}$
- Grains with random orientations
- Periodic boundary conditions in two spatial dimensions

3D-geometry (cube)



Edge length 12,5 nm – 50 nm

Quasi-3D-geometry (plate)



Edge length 50 nm – 250 nm

Atomistic Simulations

Uniform tensile deformation up to 20 %

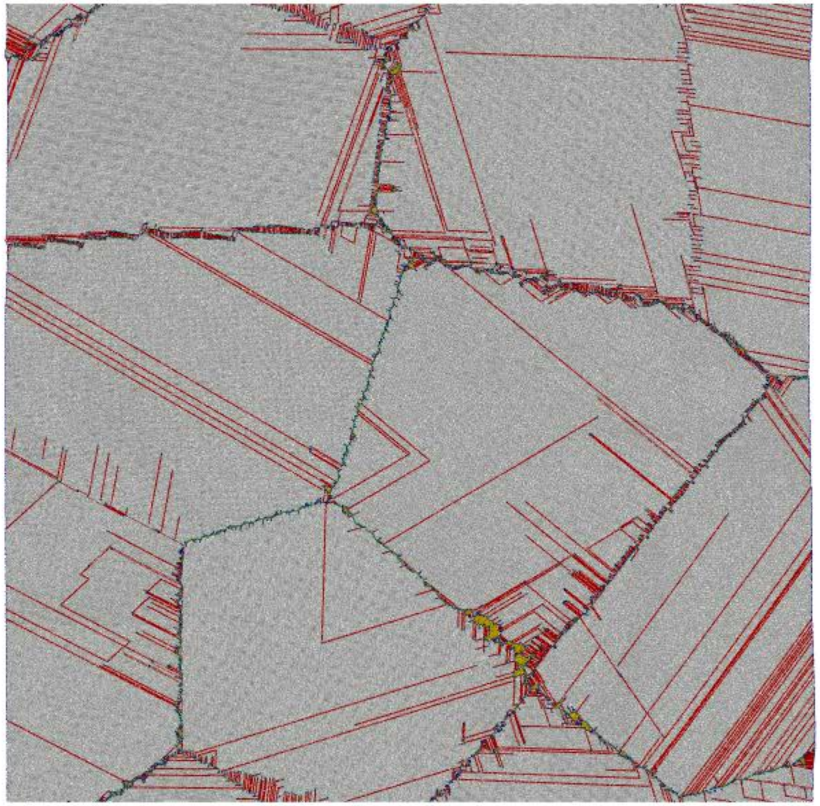
Austenite (kfz)

Martensite (krz)

Stacking fault (hcp)

Defect-atoms

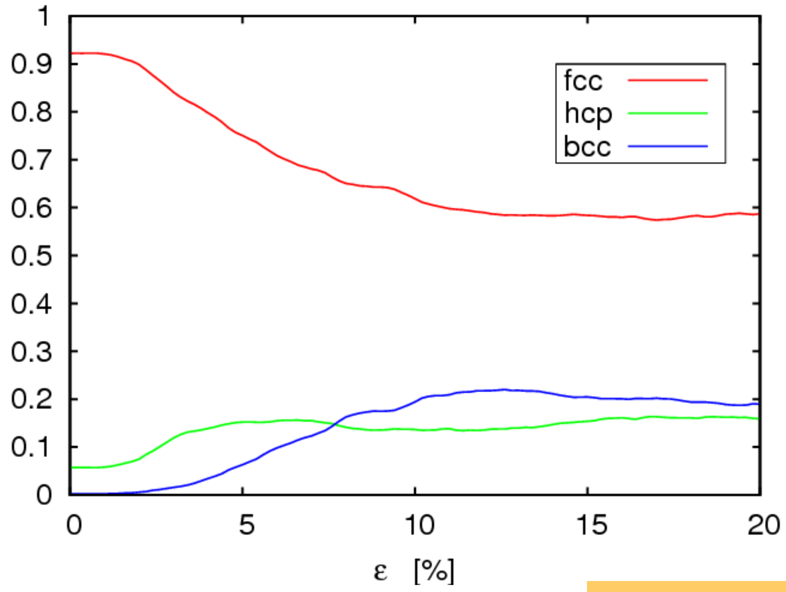
- 250 nm x 250 nm x 2 nm
- 8 grains
- room temperature



Soppa, E.; Kohler, Ch.: Final report, BMWi-Projekt 1501353, Materialprüfungsanstalt Universität Stuttgart, 2011.

Atomistic Simulations

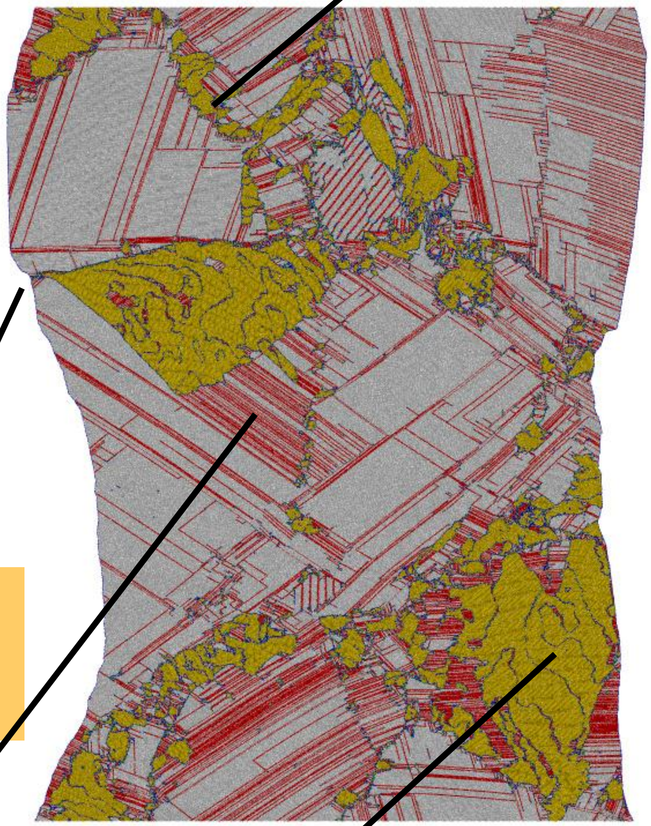
Uniform tensile deformation up to 20 %



Development of crystallinity

Formation of martensite via fcc-hcp-intermediate phase

Martensite formation at grain boundaries



Relief formation at grain boundaries

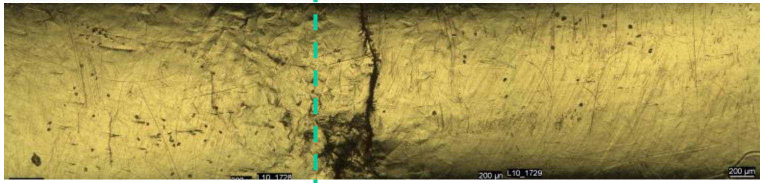
fcc-hcp-phase

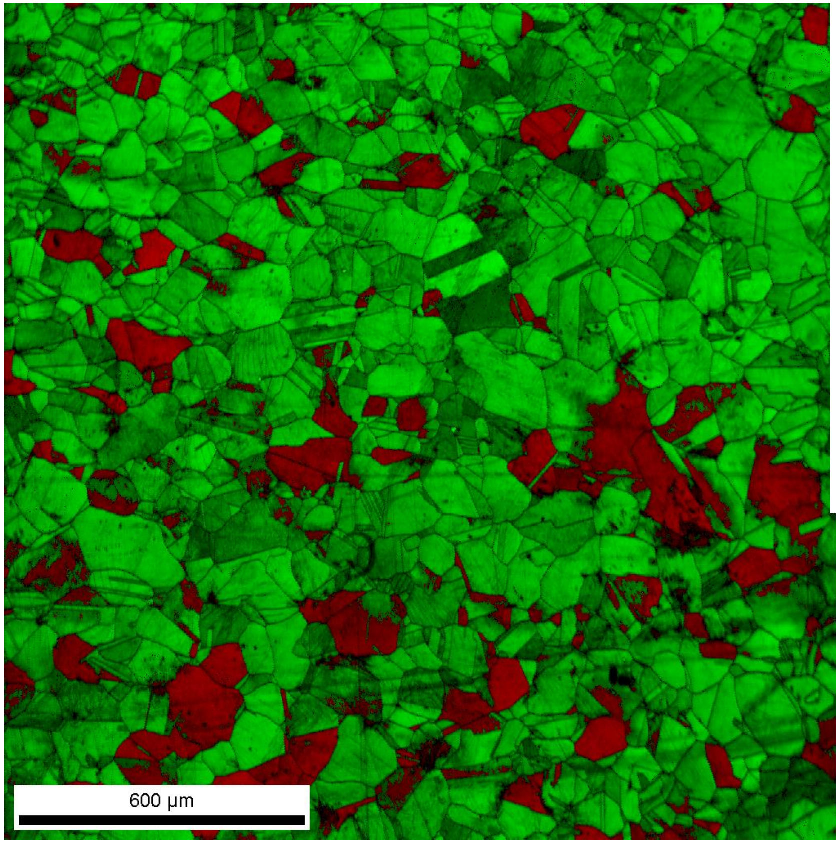
Martensite domains

Two-phase microstructure near the crack

LCF, ε=0.25%, R= -1

cross-section

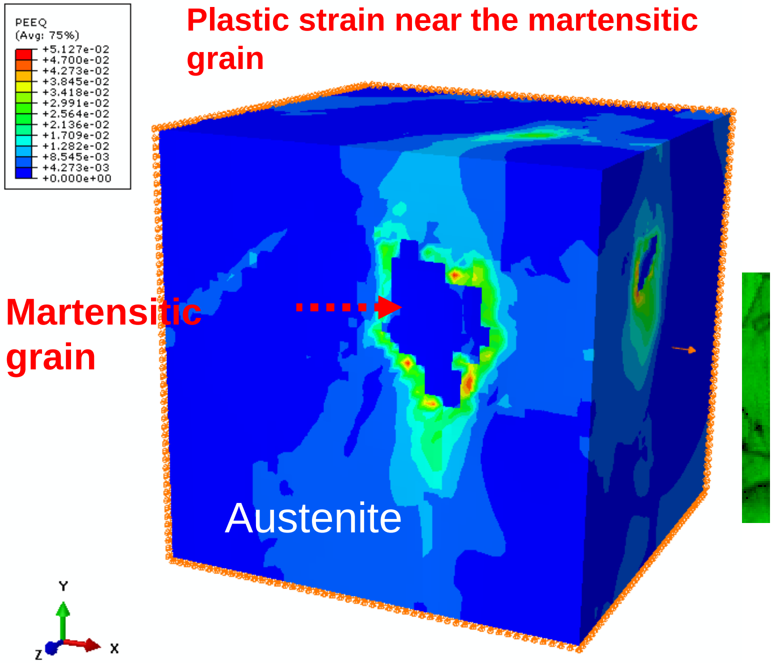


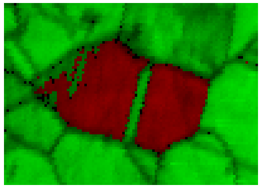


Martensite

Austenite

Plastic strain near the martensitic grain

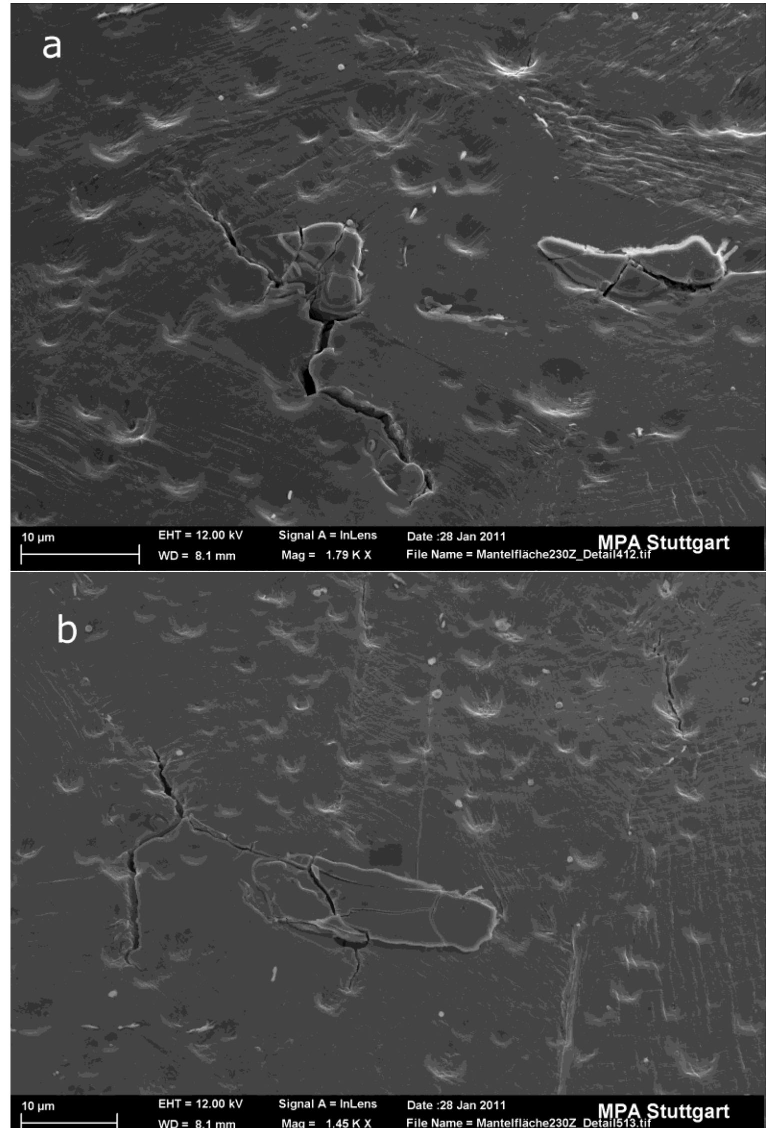




The twin remains austenitic.

Micro cracks at NbC

Crack initiation at broken or debonded NbC



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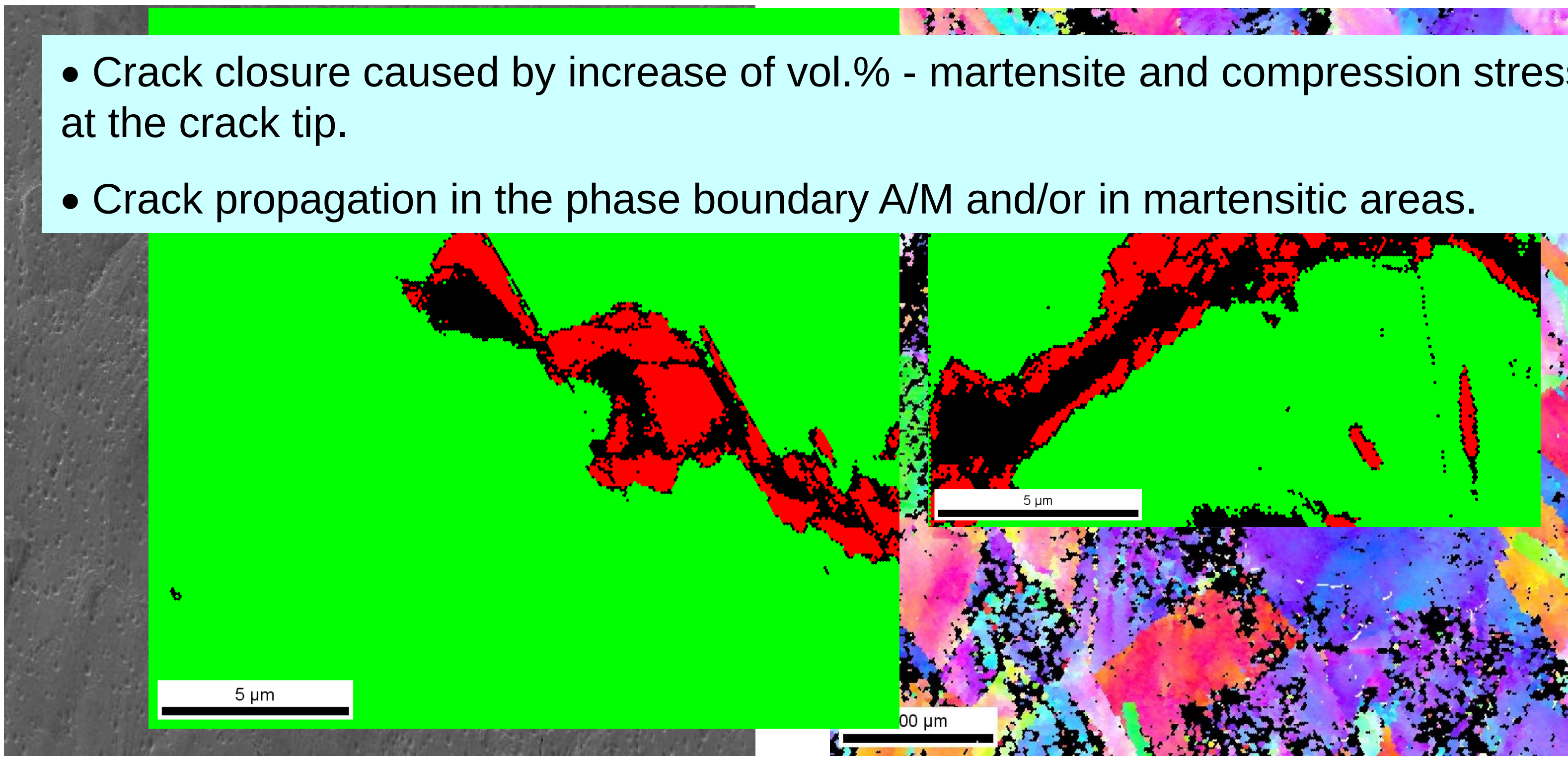
Micro cracks in the phase boundary M/A

Crack formation in the phase boundary between martensite and austenite (former grain or twin boundaries in austenite)

- Crack closure caused by increase of vol.% - martensite and compression stress at the crack tip.
- Crack propagation in the phase boundary A/M and/or in martensitic areas.



Conclusions

- Deformation induced formation of ferromagnetic bcc martensite in fcc austenite under cyclic loading.
- Work hardening due to martensitic transformation depens on the strain amplitude.
- Nucleation of martensite at grain boundaries, defects and free surface.
- Formation of martensite via fcc-hcp intermediate phase.
- Small (~1 µm) martensitic grains.
- Partially back-formation of martensite under compression.
- No extrusions / intrusions were found.
- Fatigue crack initiation at phase boundary martensite / austenite
- …and at broken or debonded NbC.
- Formation of martensite at the crack tip.
- Crack growth in the X6CrNiNb18-10 under cyclic loading at room temperature is mainly controlled by the martensitic phase.

Acknowledgments

This work was performed with support of the **German Federal Ministry of Economics and Technology (BMWi)** which is gratefully acknowledged.

We gratefully thank the **bwGRiD** project for the computational resources.