Impact fatigue in several low alloy steel grades used in railway switches

Strain partitioning and damage in carbide free bainitic steels using µ DIC.

SYM INTELLISWITCH, Copenhagen, Denmark (29-08-2017)

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Sustainable switches and crossings (Problem & objective)

Loading conditions

1. High dynamic loading due to Irregularity/Gap.
2. Sliding and Impact occurs during transition of wheel.
3. Irregular wear, accumulated plastic deformation, Cracking, Head checks, Squats and partial brittle fracture.

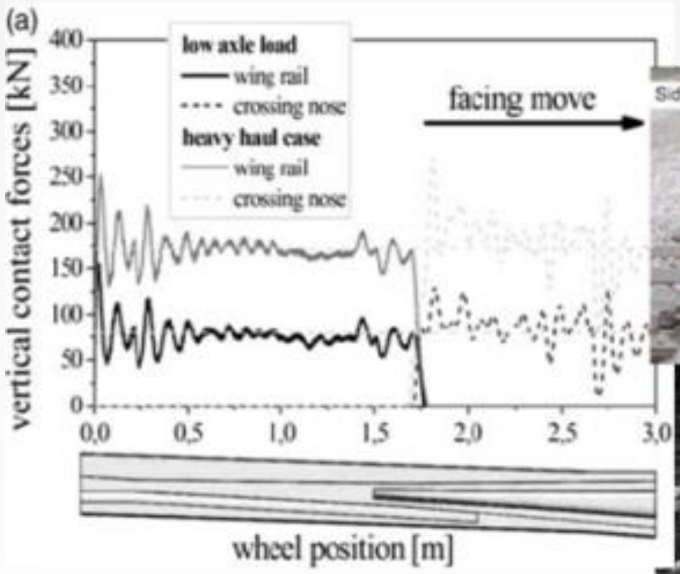
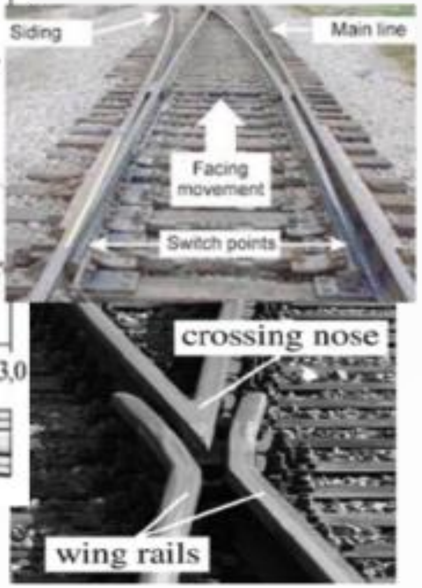


Fig: Martin et al. showed high contact forces at crossing nose using MBS.



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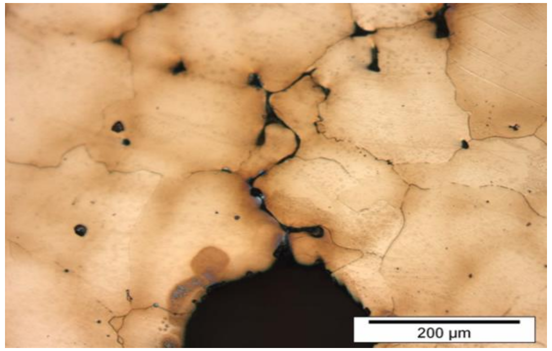
NS network

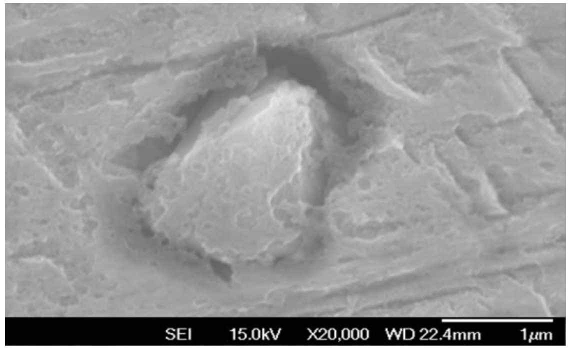
- 7500 switches and crossings .
- 100 urgent replacement and 400 urgent maintenance per year .
- Study of damage in different steel grades ranging from conventional to AHSS in correlation with their microstructure from macro to atomic scales.
- Design material/steel for future rail infrastructure.

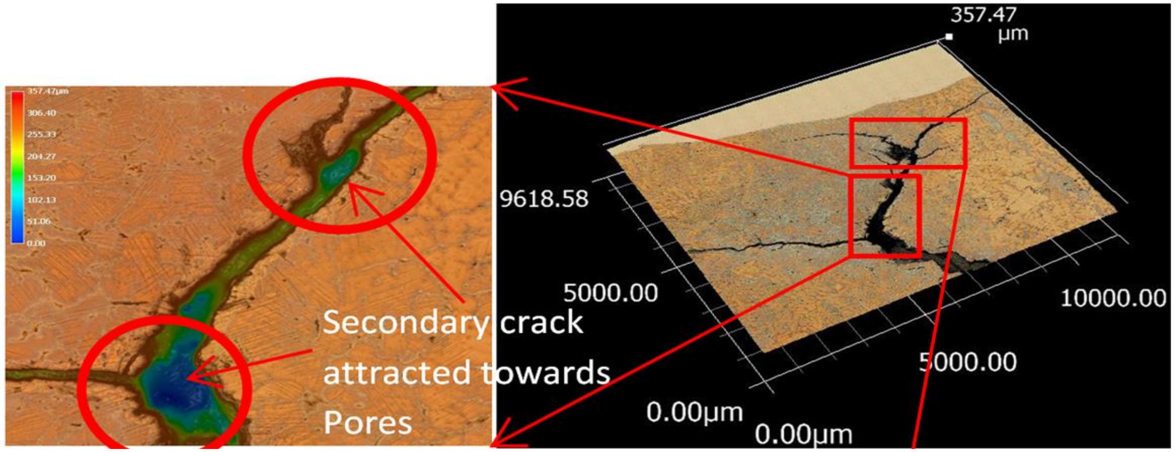
Cast Headfield Steels-

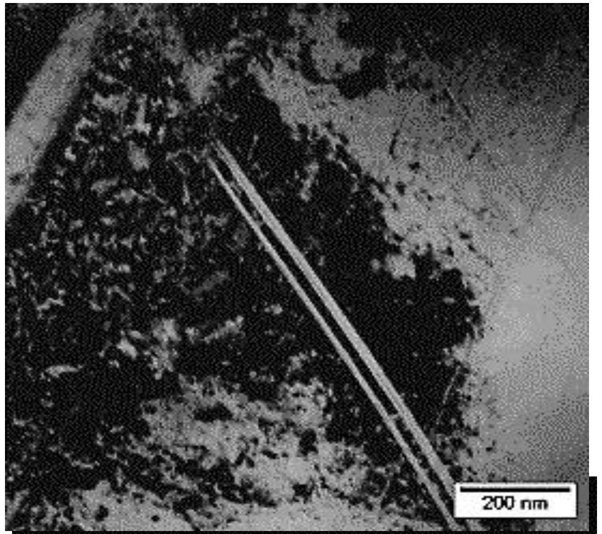
Casting defects like porosity and inclusions as a cause of failure.

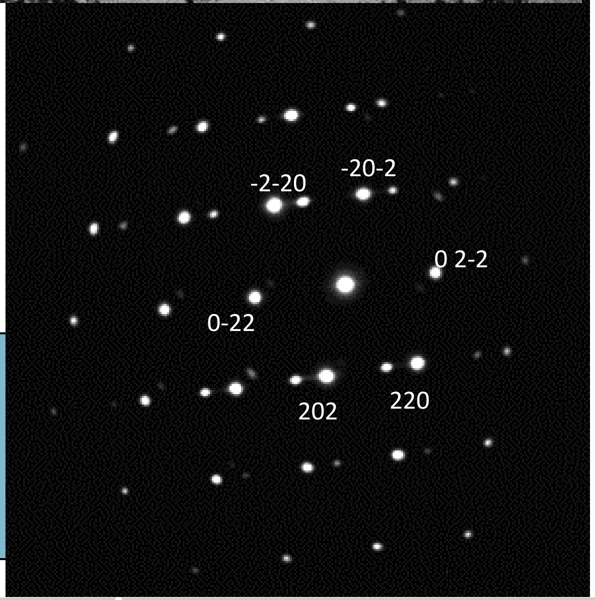
Study of failure in relation with deformation twinning.





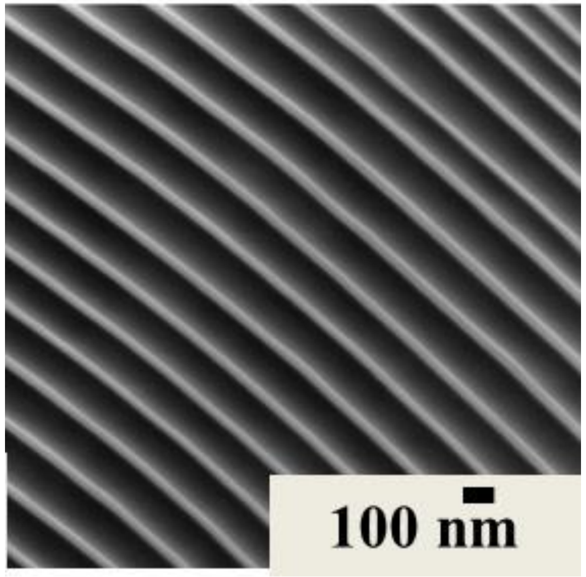


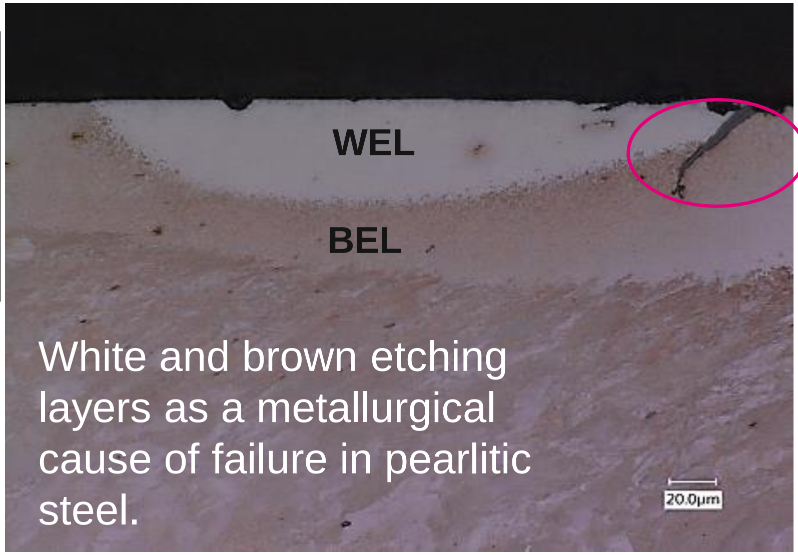




Nano twinning with a spacing ranging from 5 – 10 nm formed close to the crossing surface. Crack growth is restricted when it propagates perpendicular to twin orientation whereas assisted when it grows along the twins. Cracks are being attracted towards the pores/casting defects.

Heat treated pearlitic steels- contains fine carbide laths leading to carbide dissolution forming WEL. To understand it's formation and failure mechanism will provide the strong understanding for proper material design for crossing application.





White and brown etching layers as a metallurgical cause of failure in pearlitic steel.

Micromechanical testing of WEL

Carbide dissolution showed using TEM image and carbon map in atom probe tomography.

Deformed cementite close to rail surface/under the White etching layers

Strain incompatibility between α and θ causes dislocation nucleation from α/θ interface

Dislocation accumulated at α/θ interface with ferrite in chanelling condition

Restriction to dislocation motion by α/θ interface causes the deformation, fragmentation and shear bending in cementite laths.

Defect assisted short range thermal diffusion of carbon lead to carbon from cementite to ferrite causing the dissolution of cementite under the combined effect of plastic deformation and temperature rise.

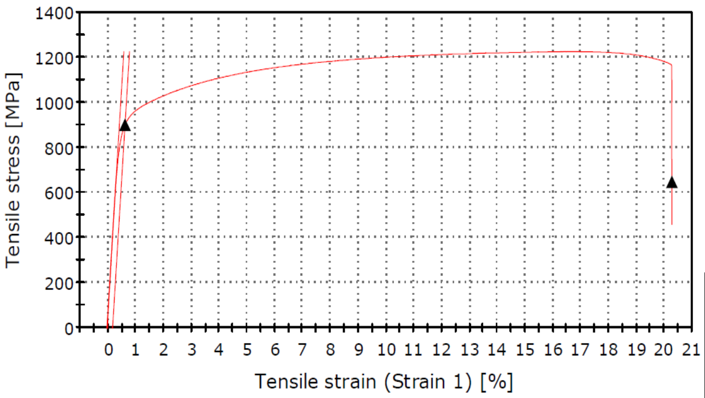
Carbide free bainitic steels B 360 (Basic characterisation)

Absence of detrimental carbides improves fatigue life.

High resistance to crack initiation due to complex bainitic microstructure

Low wear resistance than conventional steels removes RCF layer in switches.

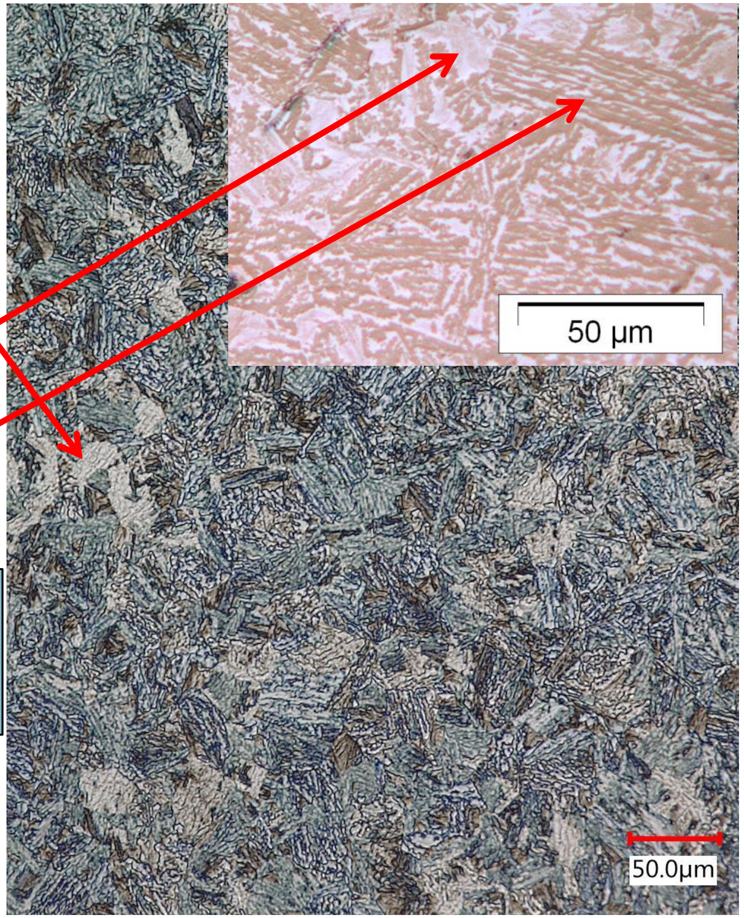
Resistant to RCF defects leads to reduced maintenance.

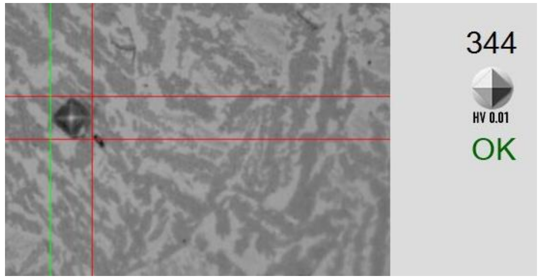


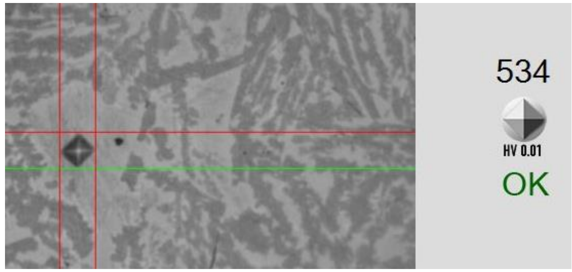
Martensite/RA

Bainite (Bainitic ferrite +thin film retained austenite)

Avg. Hardness White and grey zones- 540 & 350 HV0.01

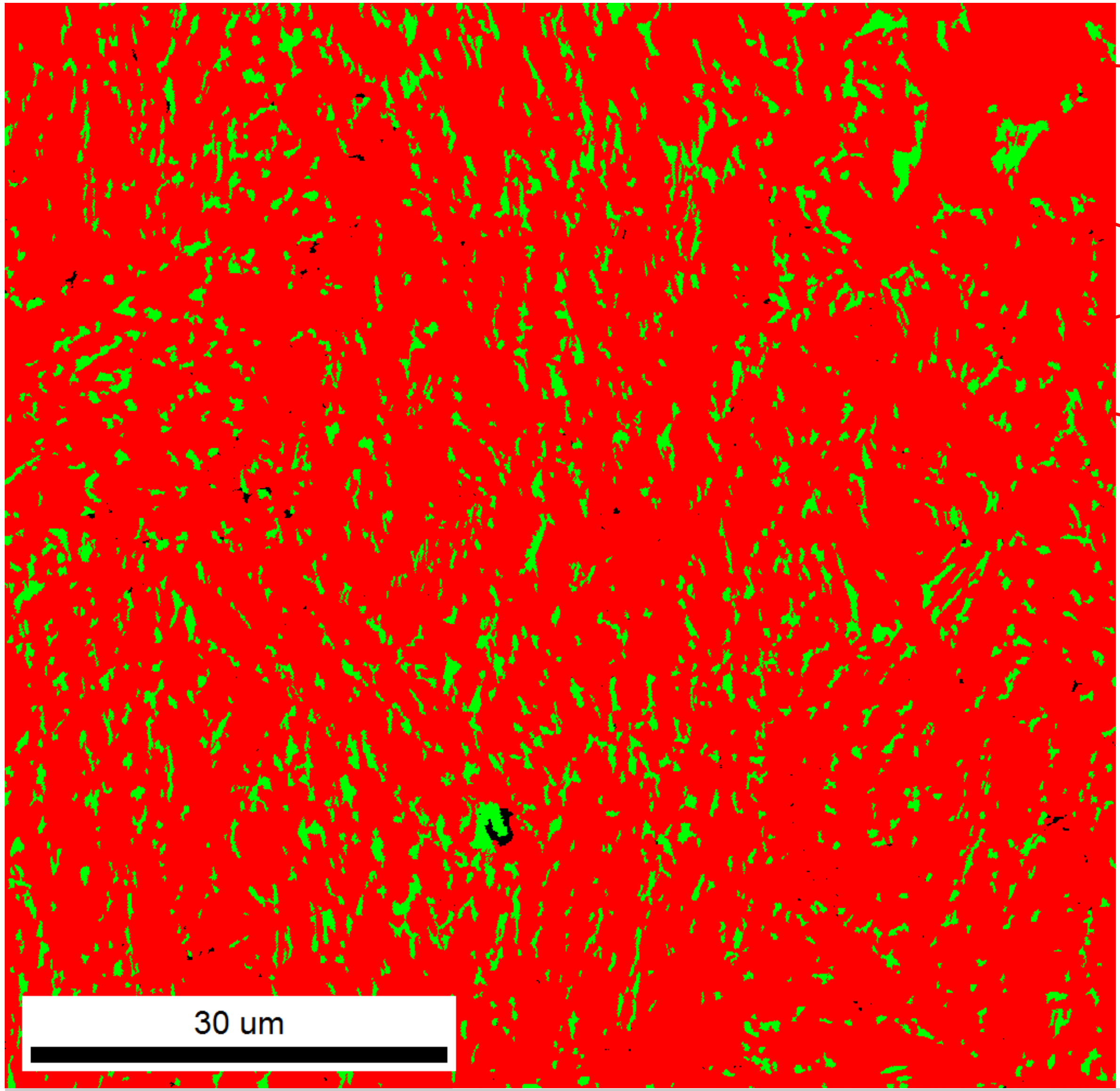






Heat Treatment- Rails are formed by 6 pass hot rolling and further heated in furnace at 800 ºC for 2 hours and then cooled down in air.

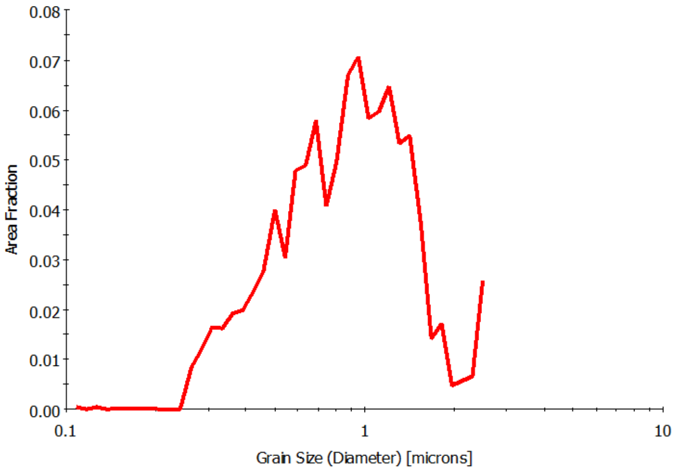
Characterisation using EBSD-



High image quality Bainite (Bainitic ferrite+ Thin film retained austenite)

Intermediate image quality retained austenite)

Low image quality Martensite (distorted BCC)



RD

TD

(Highlighted Points)/(Total Number of Points) = 0.000
(Highlighted Points)/(Number of Good Points) = 0.000
(Highlighted Points)/(Number of Partition Points) = 0.000

Gray Scale Map Type:<none>

Color Coded Map Type: Image Quality

	Min	Max	Total Fraction	Partition Fraction
(blue)	347.882	980	0.274	0.274

Boundaries: <none>

RD

TD

(Highlighted Points)/(Total Number of Points) = 0.000
(Highlighted Points)/(Number of Good Points) = 0.000
(Highlighted Points)/(Number of Partition Points) = 0.000

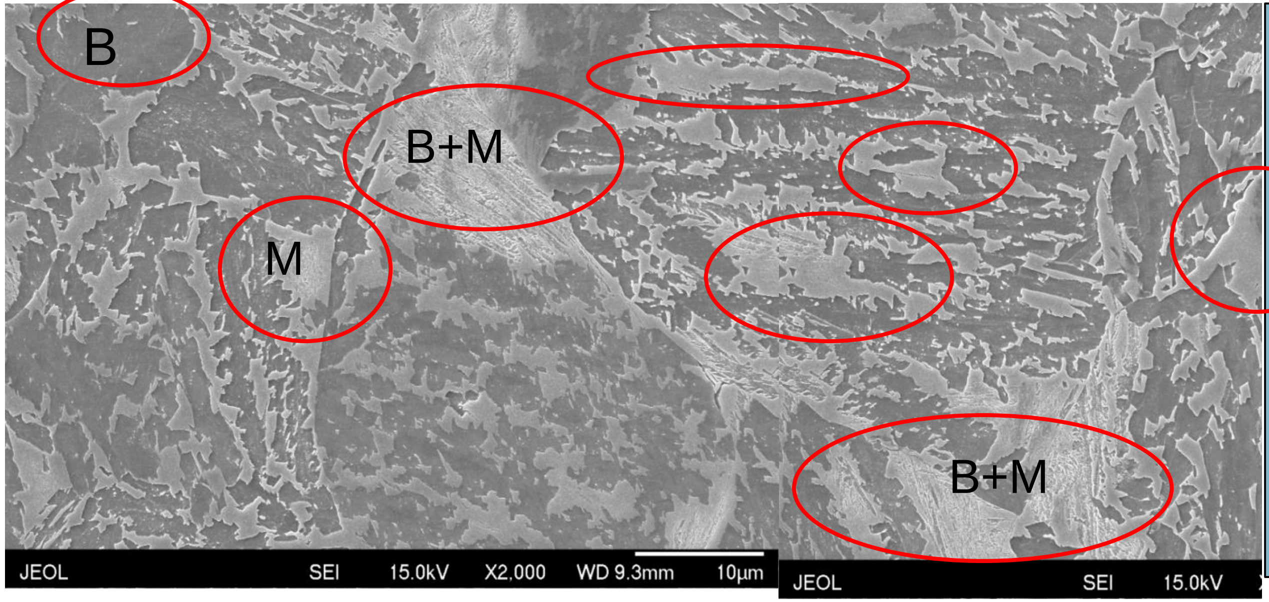
Gray Scale Map Type:<none>

Color Coded Map Type: Phase

	Phase	Total Fraction	Partition Fraction
(red)	Iron - Alpha	0.905	0.906
(green)	Iron - Gamma	0.094	0.094

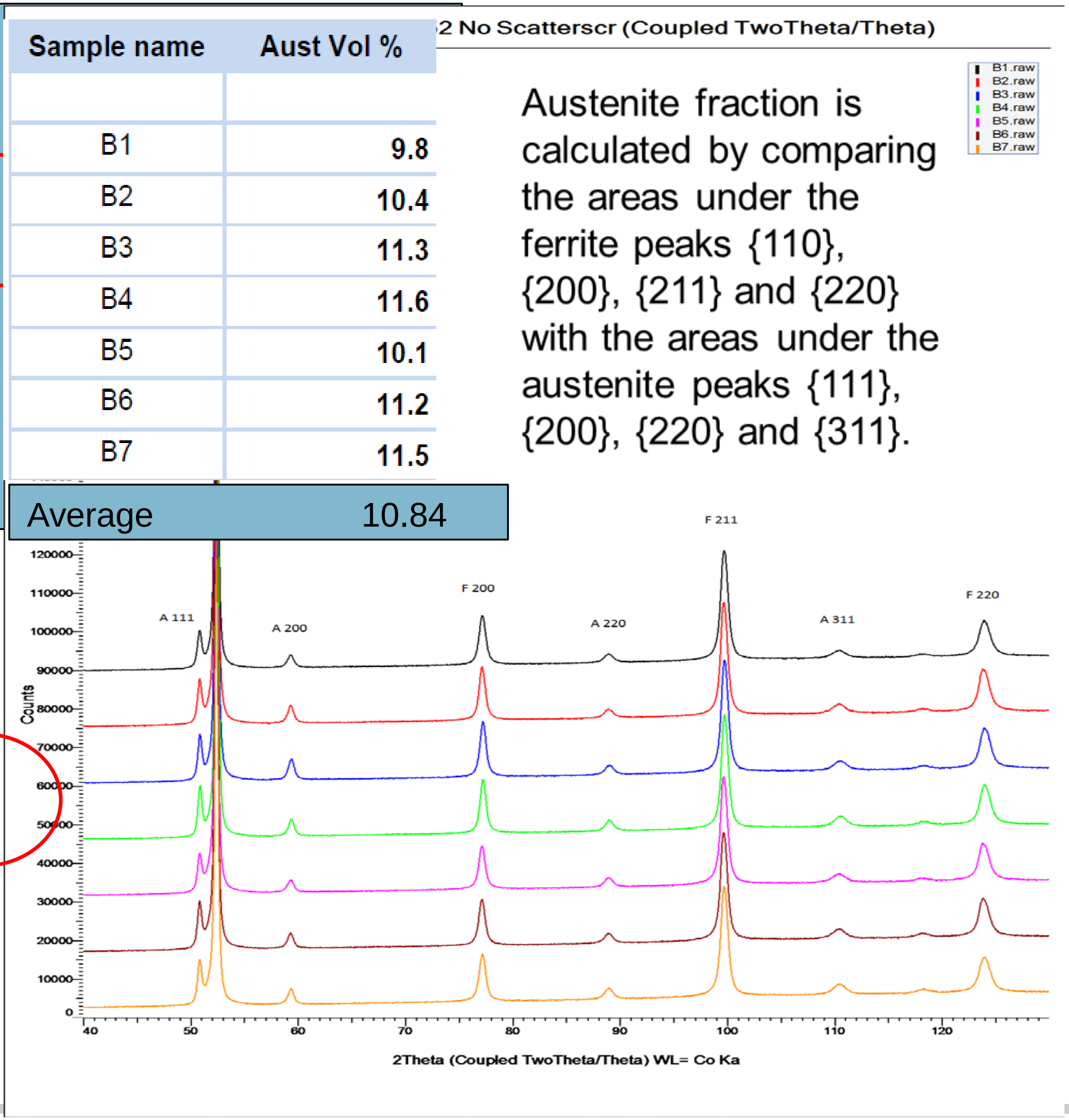
Boundaries: <none>

Comparison with SEM Micrographs and XRD measurements



Sample name	Aust Vol %
B1	9.8
B2	10.4
B3	11.3
B4	11.6
B5	10.1
B6	11.2
B7	11.5
Average	10.84

Austenite fraction is calculated by comparing the areas under the ferrite peaks {110}, {200}, {211} and {220} with the areas under the austenite peaks {111}, {200}, {220} and {311}.



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In-Situ tensile testing in scanning electron microscope
Strain partitioning in low carbon CFBS using micro-DIC (digital image correlation)

DIC requires registering and correlation of random patterns to calculate displacement fields and from these corresponding strain maps.
Mechanical response and damage initiation/propagation in multi-phase complex steels is strongly governed by microscopic strain and stress partitioning among the microstructural constituents.
Conventional DIC is not capable of understanding these phenomena at sub- micron scale due to limited resolution.
µ-DIC in SEM uses amorphous silica nanoparticles monolayer deposited by modified drop casting methodology for pattern making.

Imaging conditions- In lens detector, HT=1.5kv, 30um aperture & low current, (3mm or 6mm WD)

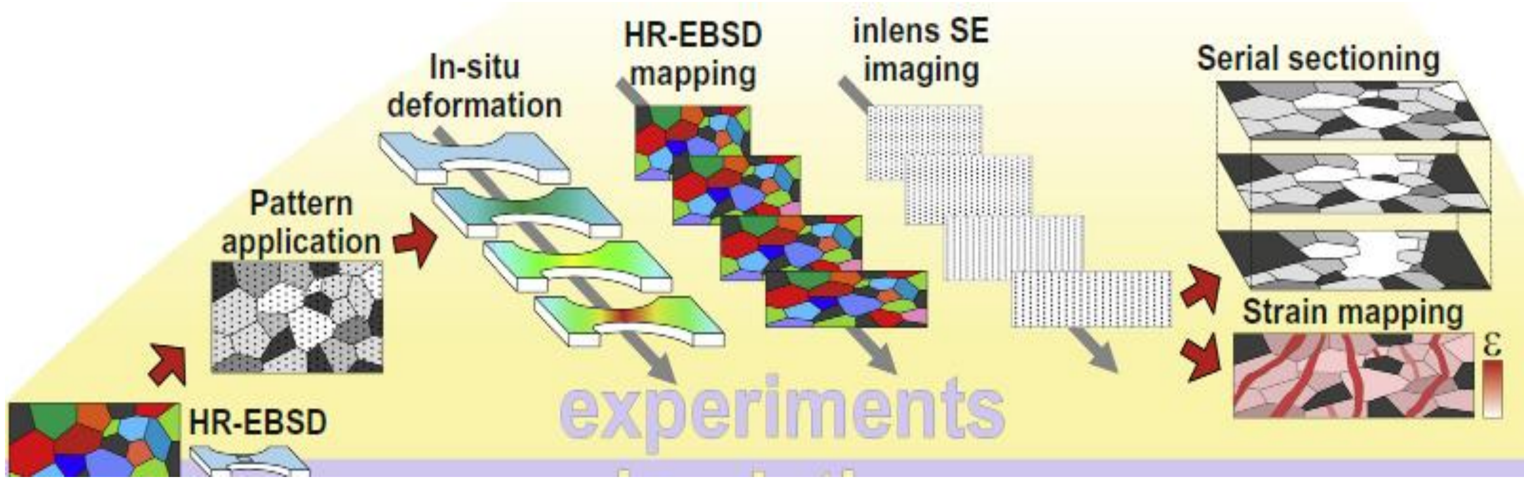
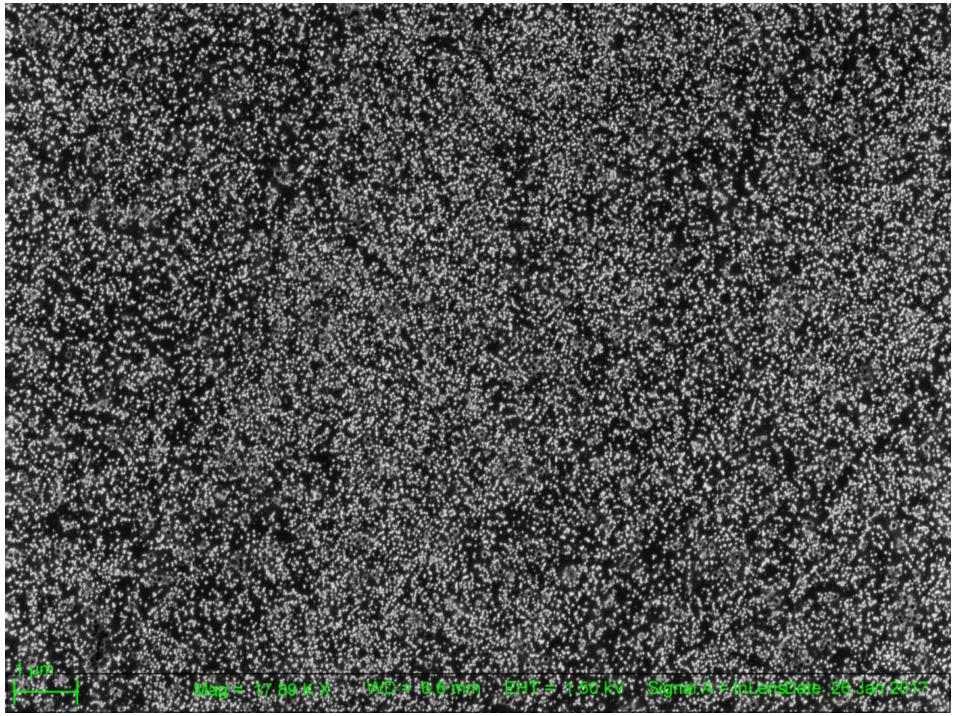
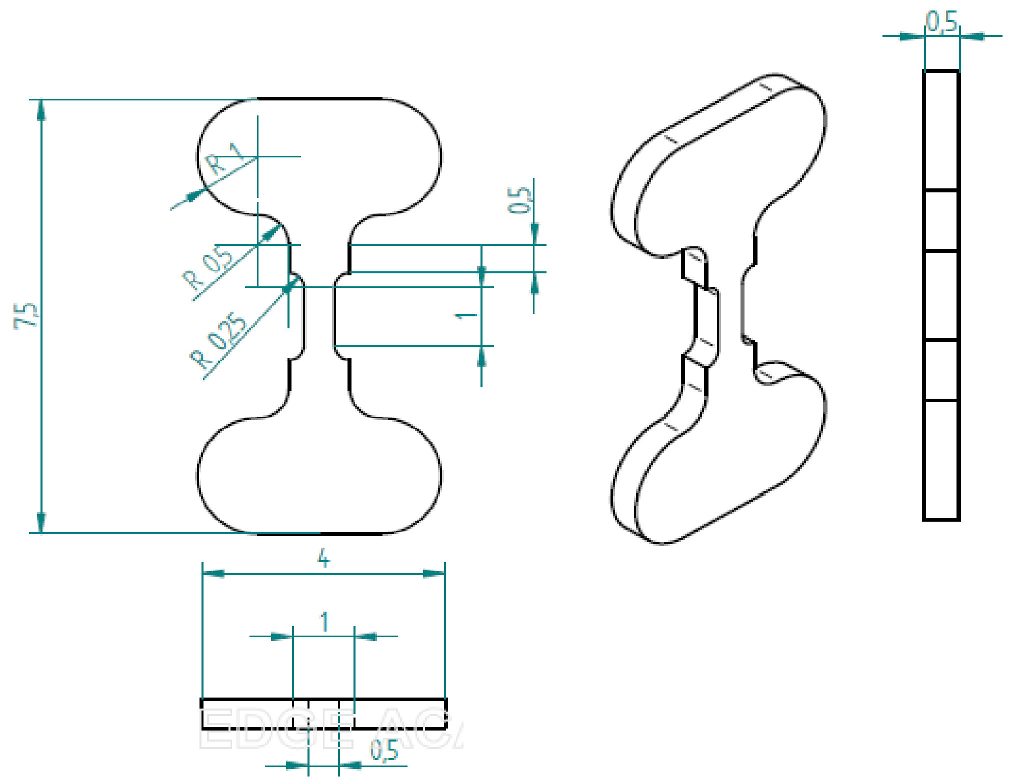
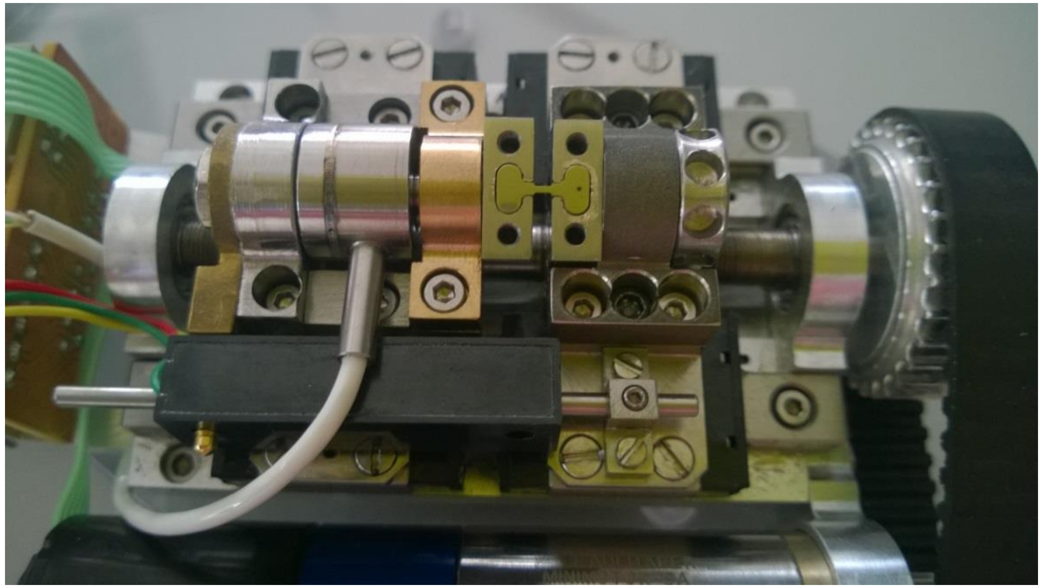


Figure: Image showing Set up for micro DIC Ref. (Tasan, Diehl et al. 2014)



Sample geometry and experimental setup





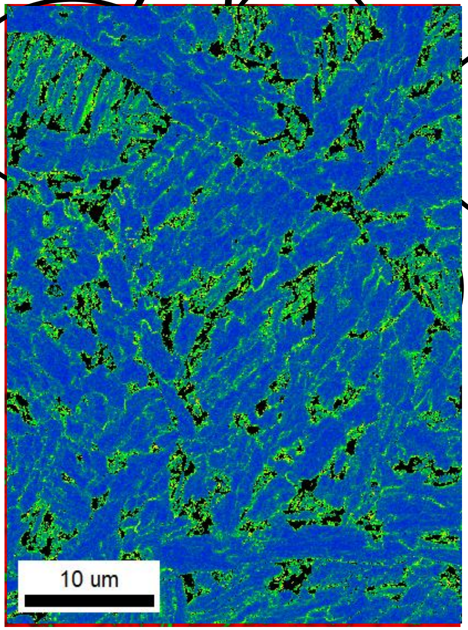
1. Samples are first prepared to colloidal silica (OPS) finish to capture the EBSD image.
2. EBSD area is marked by FIB milling.
3. Pattern making using OPS silica nanoparticles.
4. Specimens are deformed step wise at 3 μm/s constant cross head speed corresponding to an initial strain rate of 6 x 10^{-4} /s.

Micro-DIC test results-

Martensitic islands with low image quality

EBSD Phase map- Red ferrite and green austenite

High strain concentration in ferrite between martensitic islands



Global strain: 0 %

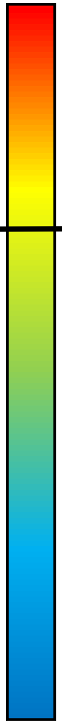
	Min	Max	Total Fraction	Partition Fraction
	0	5	0.610	1.000

2.7%

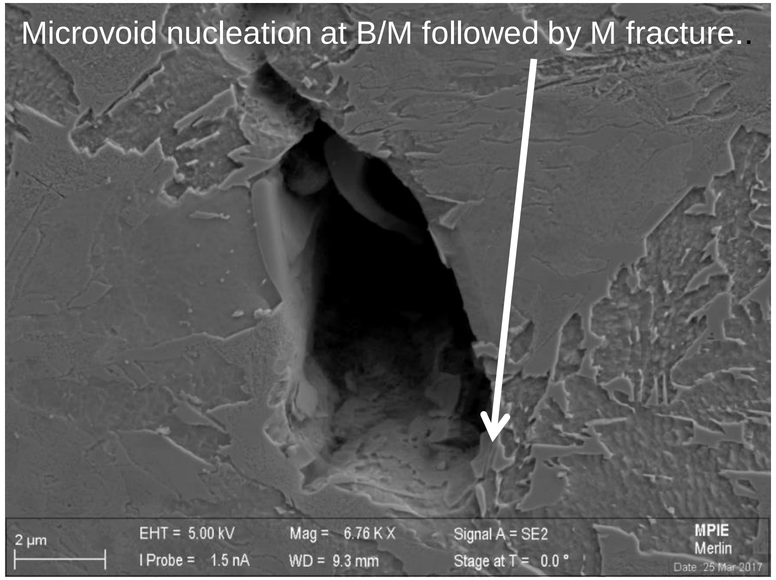
4.7%

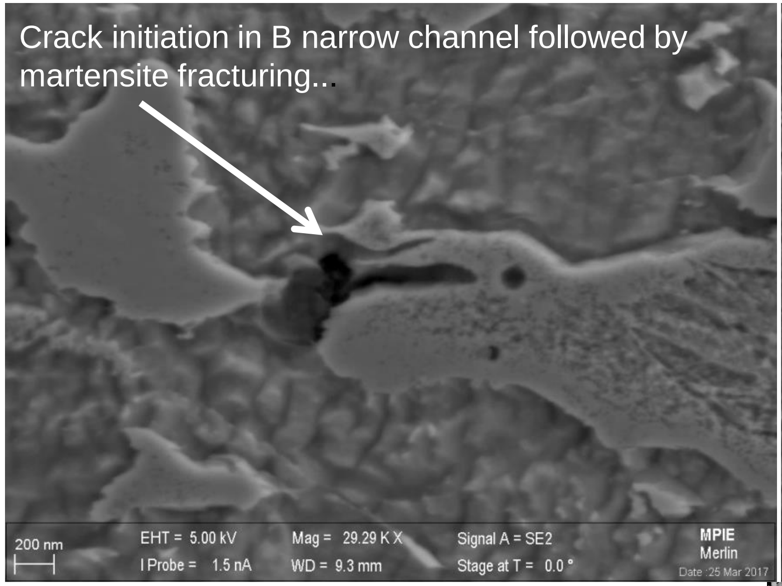
9%

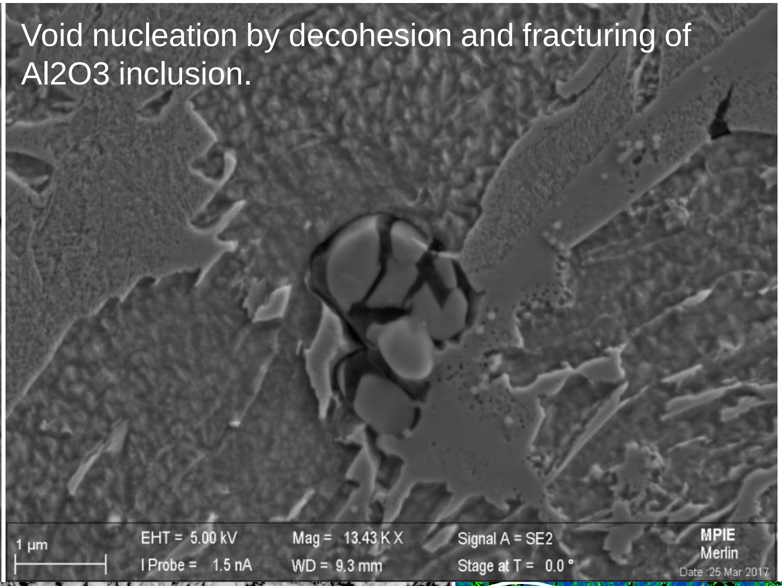
Crack

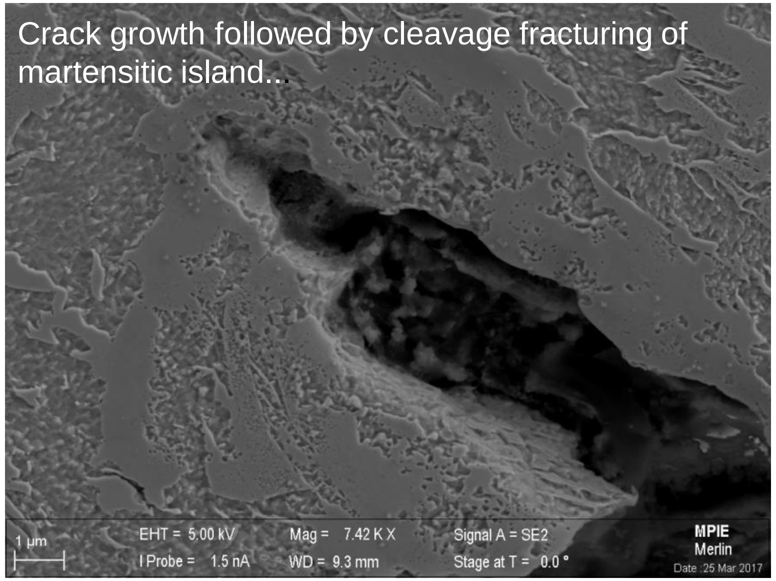


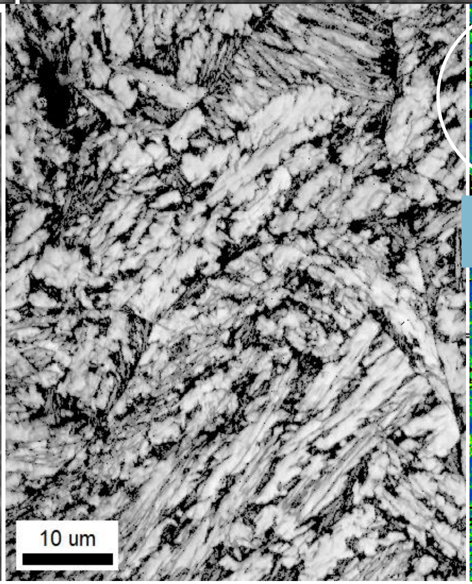
Investigation after testing -

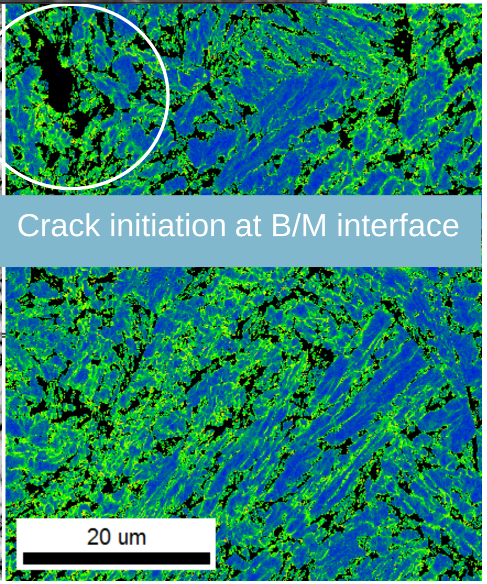












Min	Max	Total Fraction	Partition Fraction
0	5	0.610	1.000

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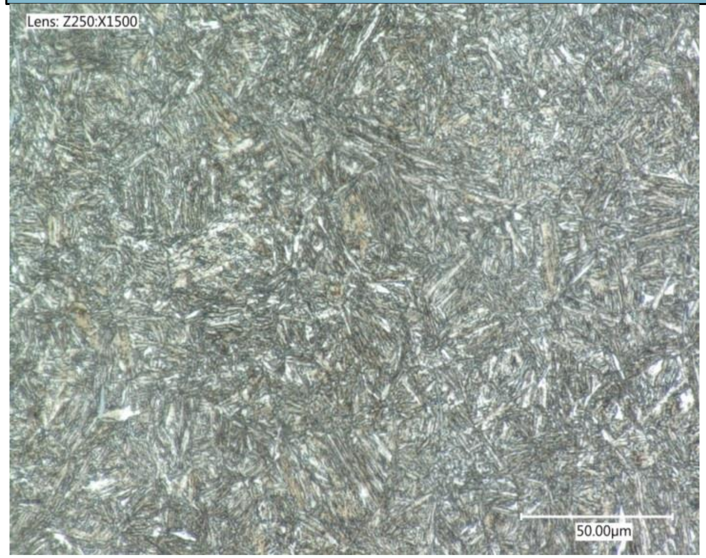
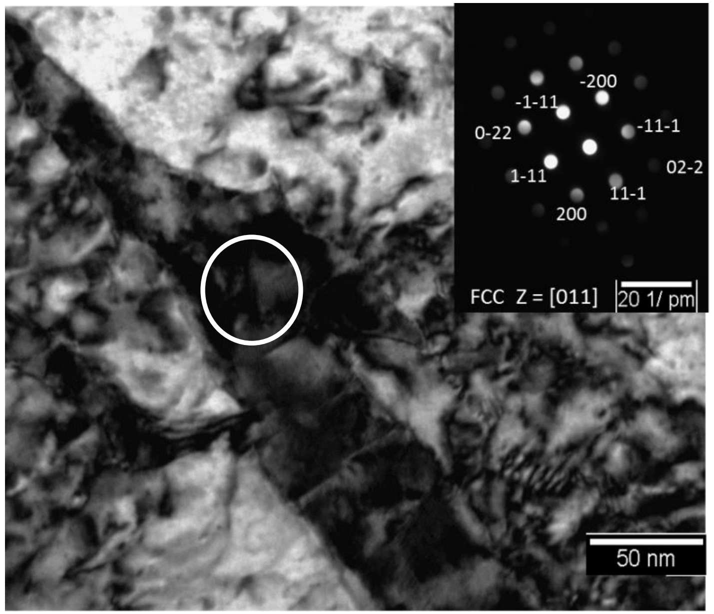
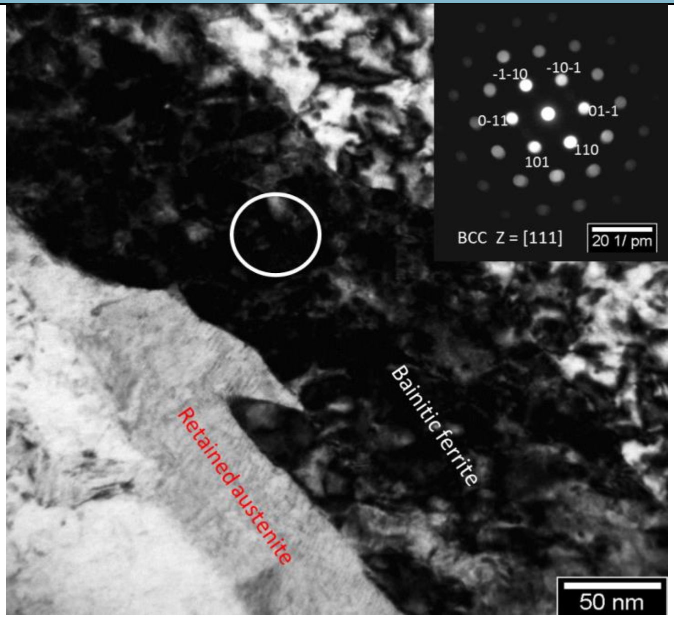
Microstructural development for better impact fatigue life



Bainite with no martensite present .

Extremely fine bainitic microstructure at low isothermal transformation





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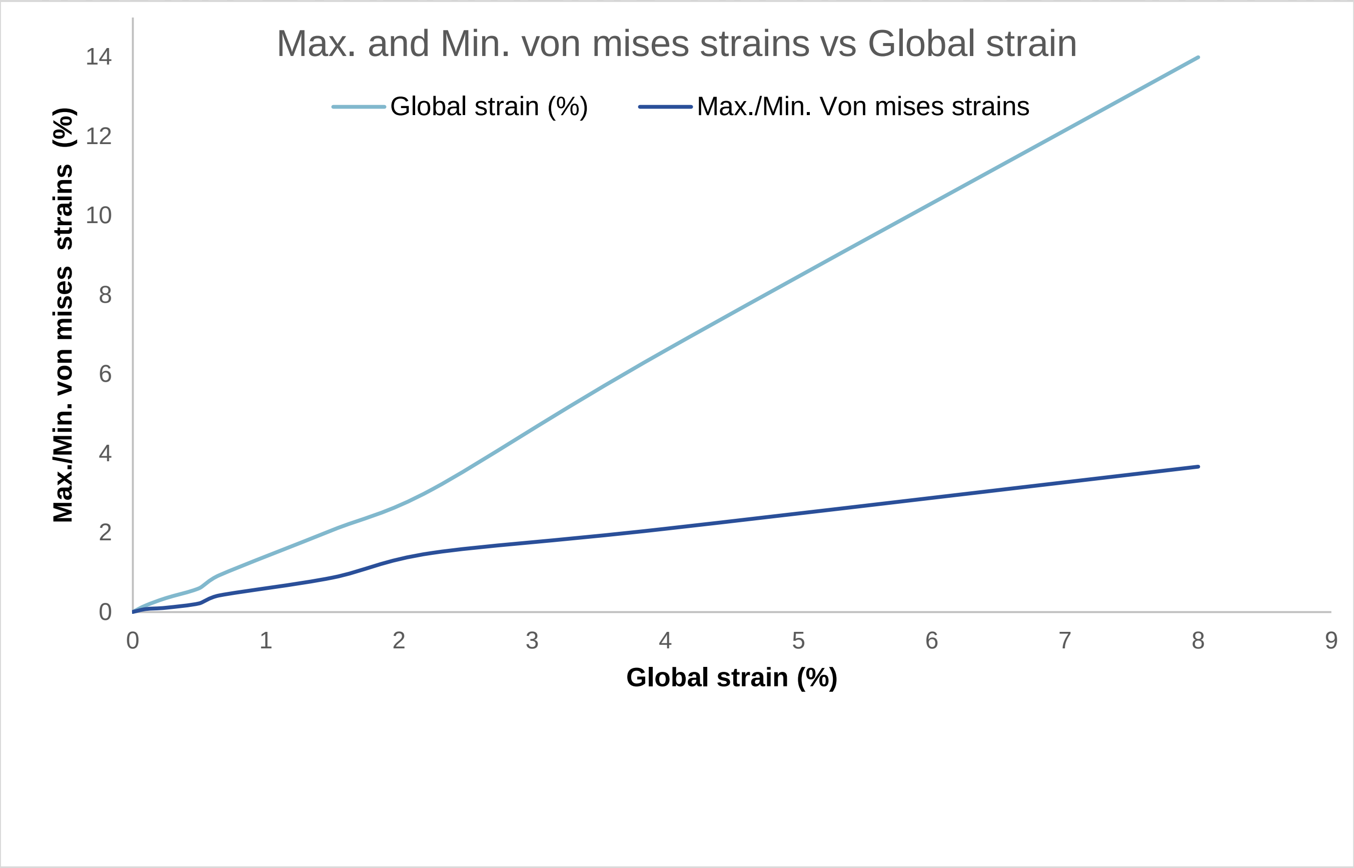
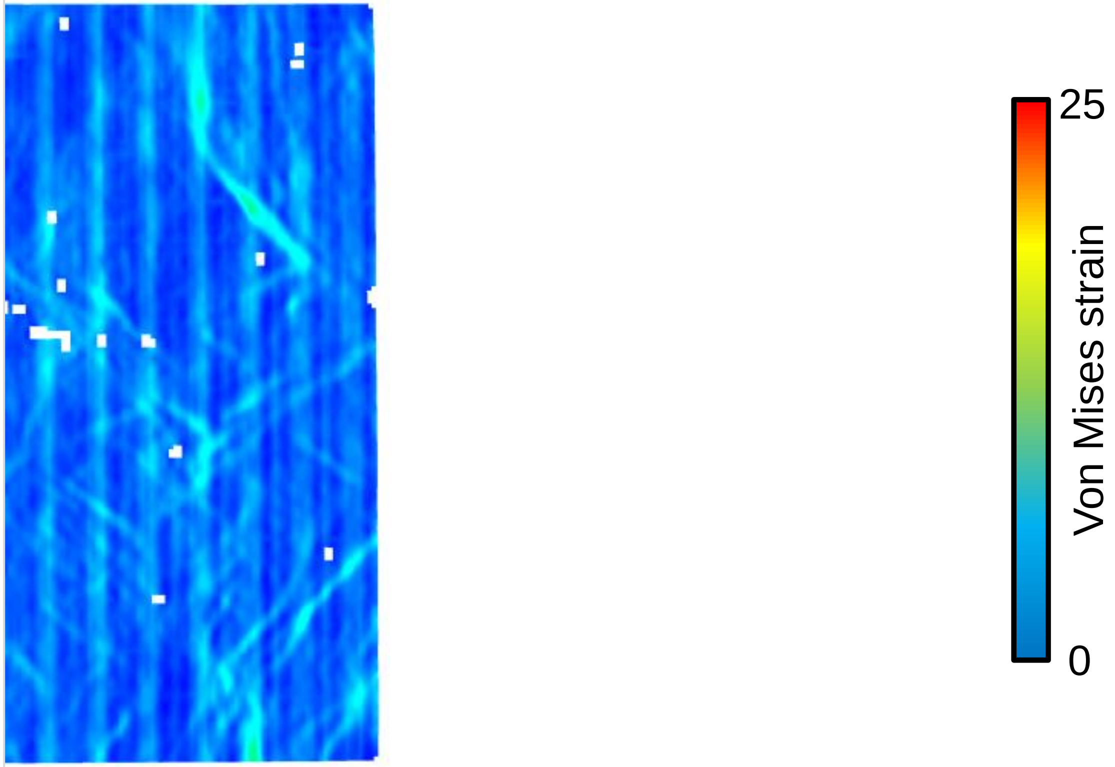
Micro-hardness Comparison

1= B360,
2= CrB,
3= B1400 P

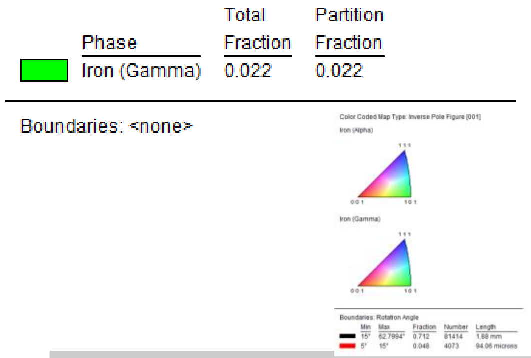
Development of new carbide free bainitic steels with extremly fine retained austenite with excellent mechanical properties shown in TEM images and atom probe tomography.

In-situ experiments on heat treated R360





2% 4 % 8 %



- Tensile axis is horizontal direction.
- Thin film retained austenite cannot be indexed in the EBSD because of limit of spatial resolution.
- No severe strain partitioning observed after the heat treatment than in as received condition.
- Maximum Von-mises strain observed in the bainitic laths oriented at 45 deg to the tensile axis.

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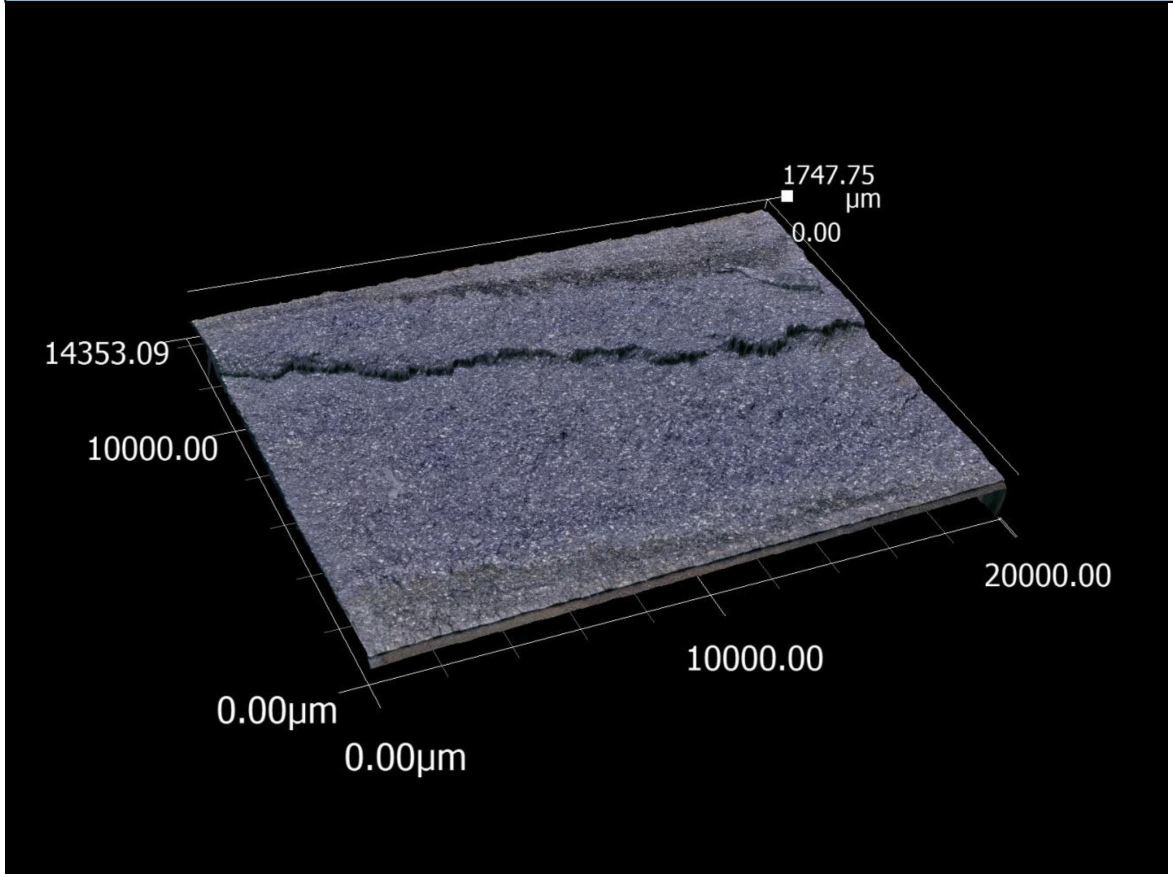
Impact fatigue performance of complex bainitic microstructures (Dr. Michael Steenbergen, CITG, TU Delft)



Brittle crack propagation and unstable crack growth under impact fatigue in continuously cooled CFBS due to presence of brittle martensite. (16450 impact cycles)

Conclusions

- During continues cooling, bainitic transformation is not complete in CFBS and the most of the retained austenite converts into martensite. Thus it contains complex microstructure with combination of bainite, austenite and martensite.
- EBSD qualitative image quality criteria is a promising way for distinguishing bainite and martensite.
- Micro DIC in combination with EBSD, XRD, give a complete understanding of strain partitioning and damage mechanism among the microstructural constituents in complex multiphase microstructure.
- Plastic deformation is predominantly localised inside the bainitic ferrite specially in narrow channels extended between martensitic islands.
- Austenite takes maximum strain up to 2% global strain and start transforming to martensite (strain induced martensitic transformation) which is confirmed by XRD measurements.
- Thin film austenite is even stable after final fracture of the specimen confirmed by EBSD measurements.

Conclusions contd.

- Almost no strain is being taken by the martensitic islands.
- Damage initiates primarily in F specially in narrow channels extended between martensitic islands, M/F interfaces and de-cohesion at brittle inclusions etc.
- Crack growth is followed by M/F interfaces or cleavage fracturing of the martensitic islands.
- Damage studies in relation with microstructure gives strong understanding for better microstructural design.
- New heat treatment designed to get better mechanical properties and avoid detrimental phases or weak links from the microstructure (No martensite and less blocky retained austenite).
- Heat treated B360 shows stable fatigue crack growth than brittle like crack propagation.

Thank you

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