Multiscale characterisation of S960 AHSS for bendability

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25th February 2020 – 3rd MPI symposium on ferrous metallurgy

Research Rationale

- Drive to improve the performance of UHSS strip steel products aimed at the yellow goods market.
- Cold bending operations form hollow sections from blanks, a limiting factor in the development of the product.
- An understanding of the (micro)structure property relationship is a key to enabling product improvement.

Research Rationale

- Inhomogeneity leads to strain differentials within the microstructure, contributing to poor bending performance.
- A range of factors cause this, some of which are being investigated.

Nanohardness phase mapping of mixed microstructure steels

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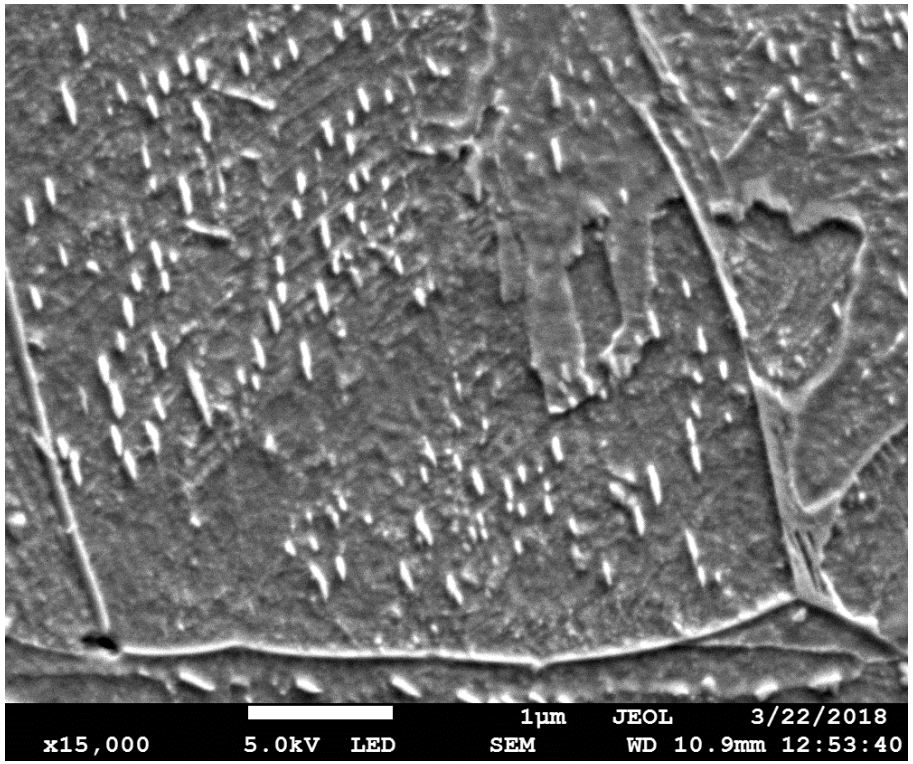
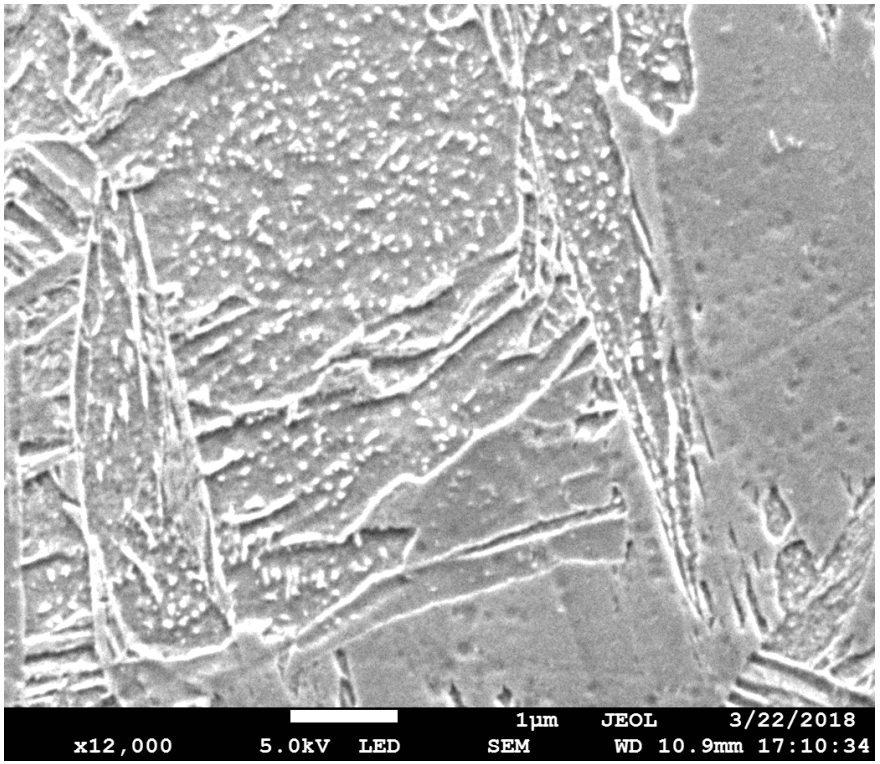
Microstructural Features

Lower bainite



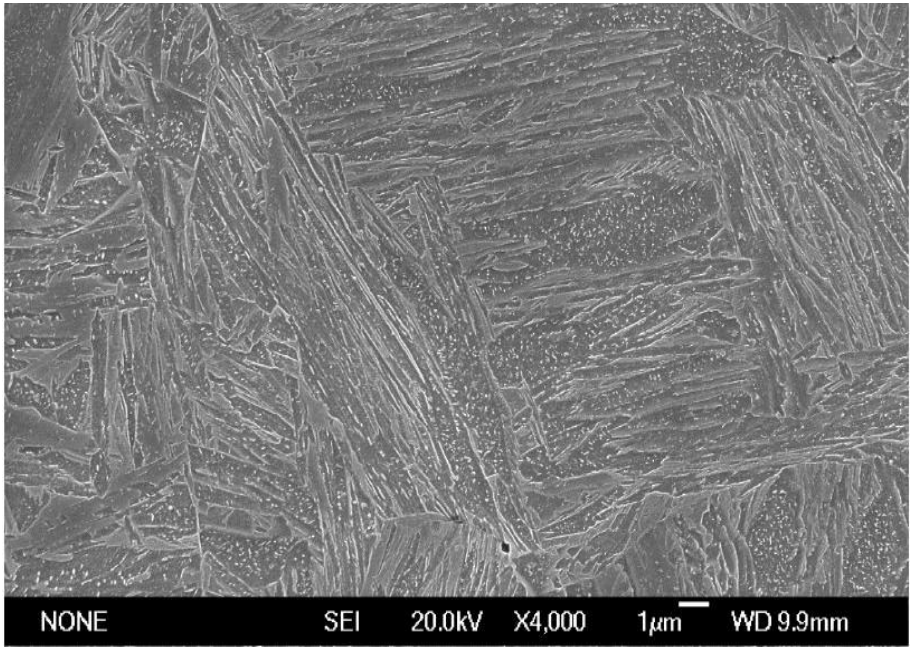
- Carbides along one orientation within lathes

Auto tempered martensite

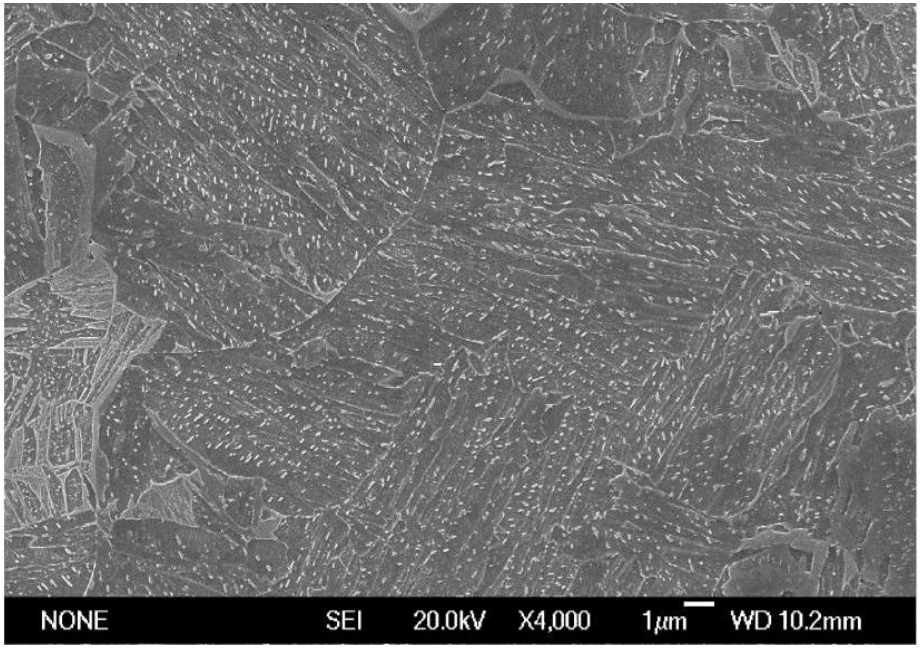


- Carbides along 3 orientations (X,Y,Z)

Martensite/ Bainite Microstructures



25% autotempered martensite,
75% lower bainite



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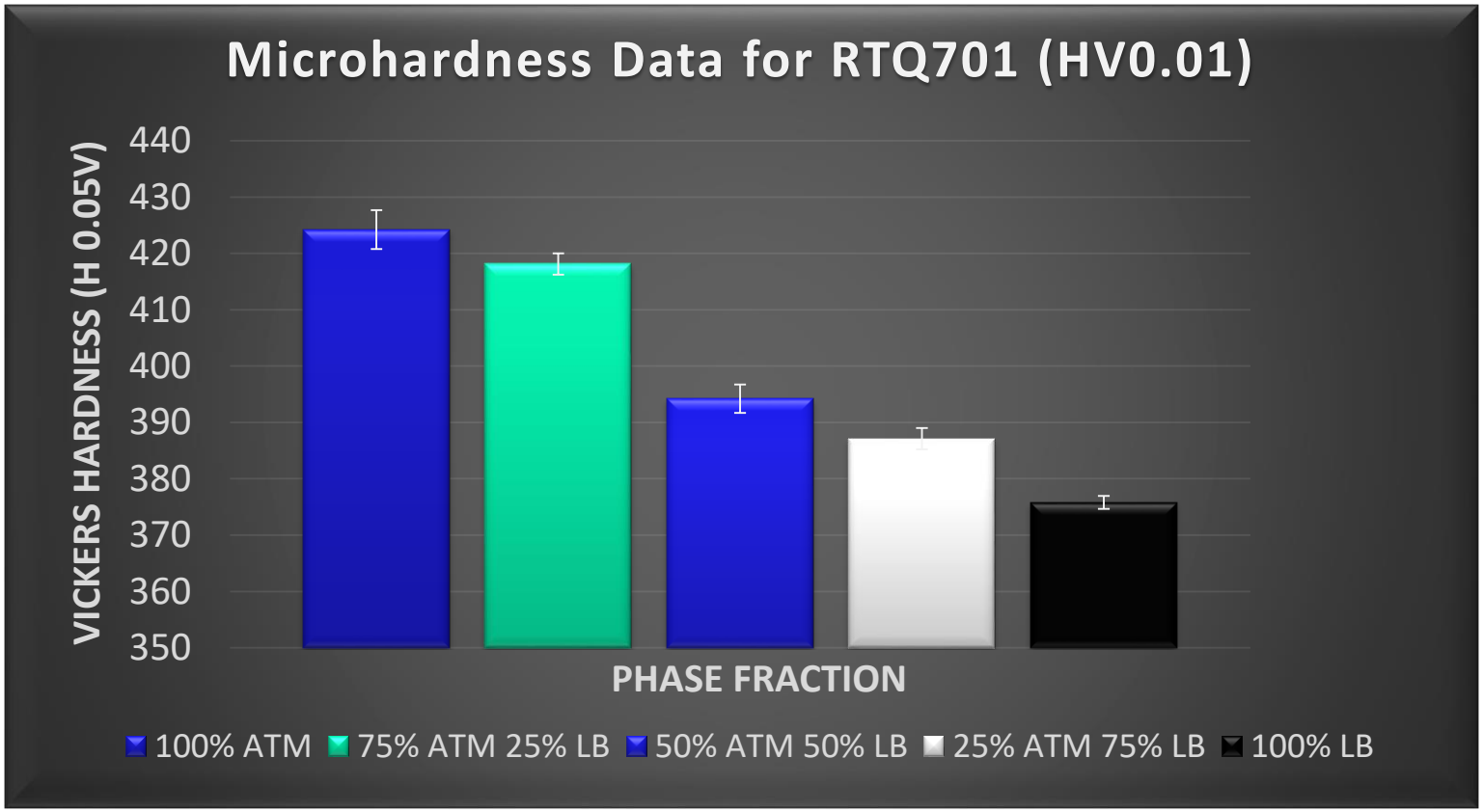
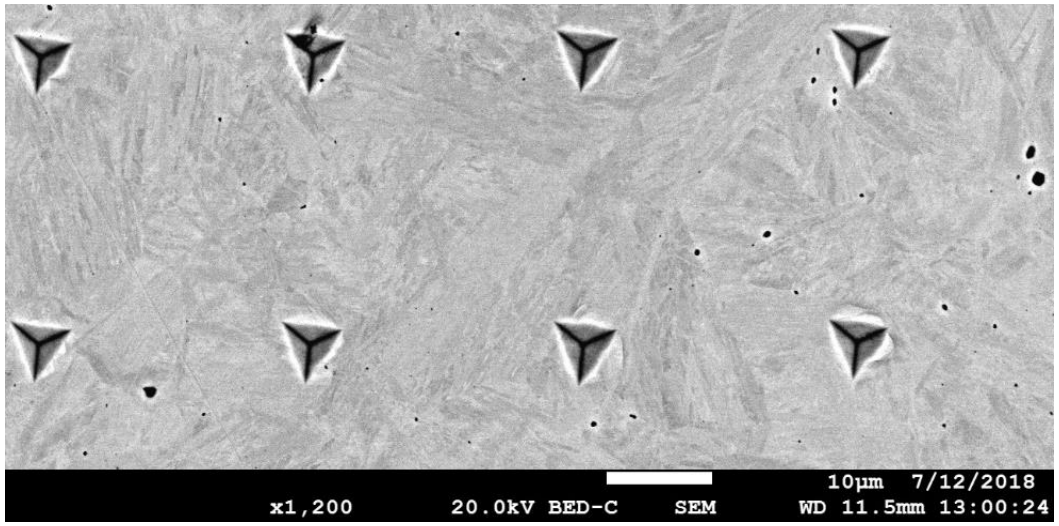


- Mapping arrays created using a range of steels with known phase fractions of lower bainite & autotempered martensite.
- LB microhardness: 378 (HV 0.01), ATM microhardness: 410 (HV 0.01.

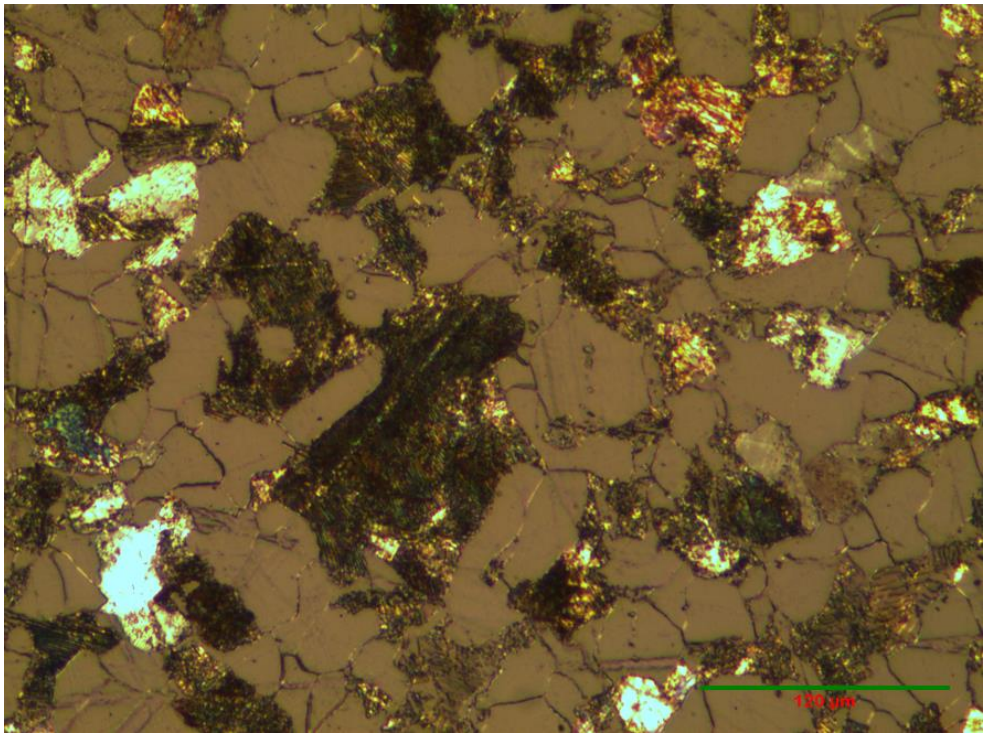
Nanoindentation

- Load capacity from <0.2mN to 500mN with hardness information determined from load/ displacement hysteresis.
- A hardness matrix is used to map changes in the microstructure across a plane section.
- Strong dependence on indent volume of influence/ phase region size.



Hypothesis

- Theoretical indent map overlaid onto etched optical images of a known ferrite/ pearlite mixed microstructure as proof of concept.
- Indent regions identified as ferritic, pearlitic or across a boundary.
- Range of equivalent indent diameters 1μm-6μm (approx. 1mN to 150mN indent load).



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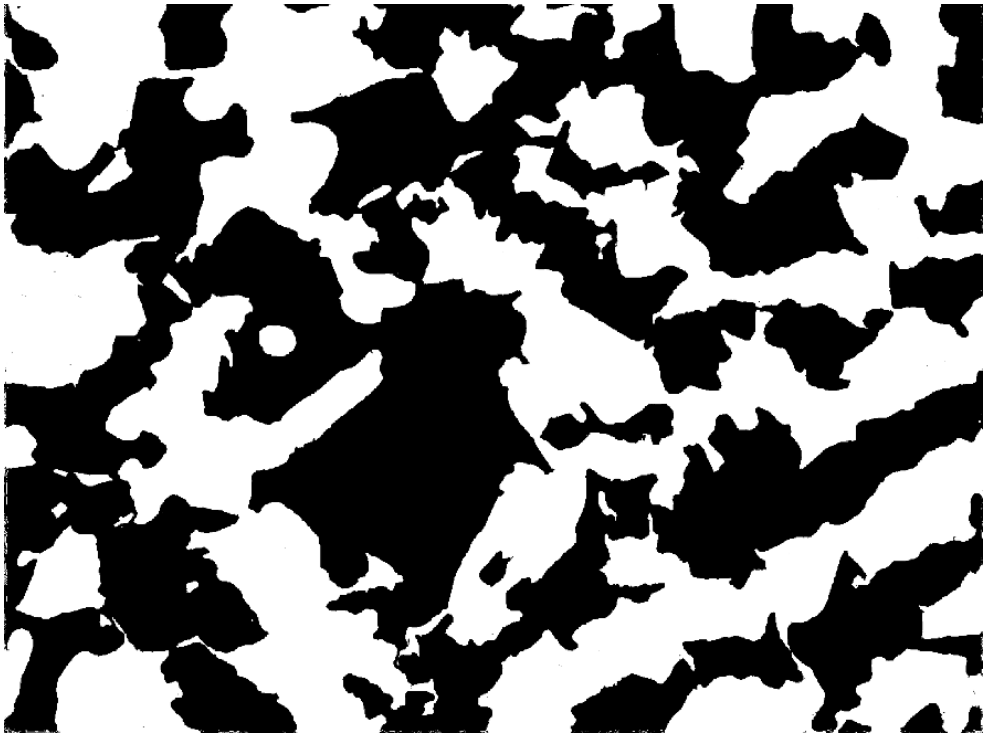

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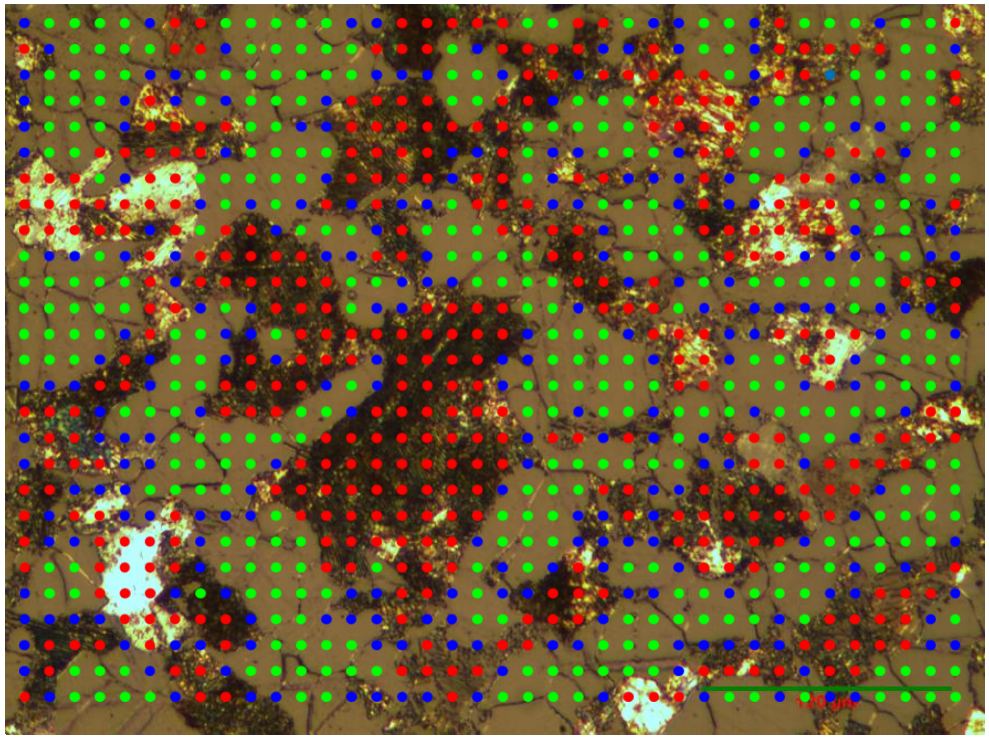

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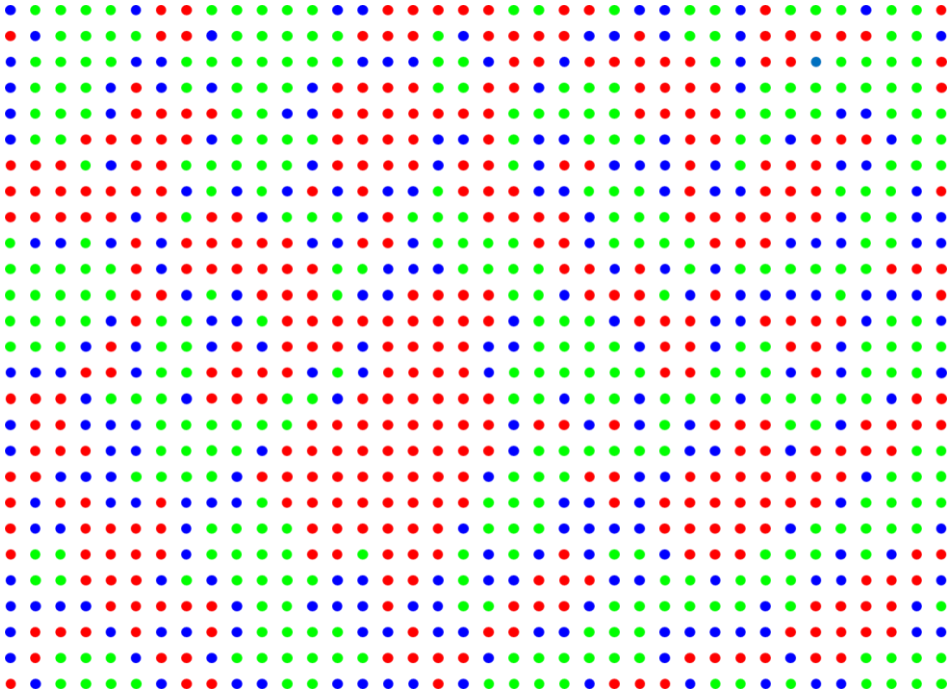

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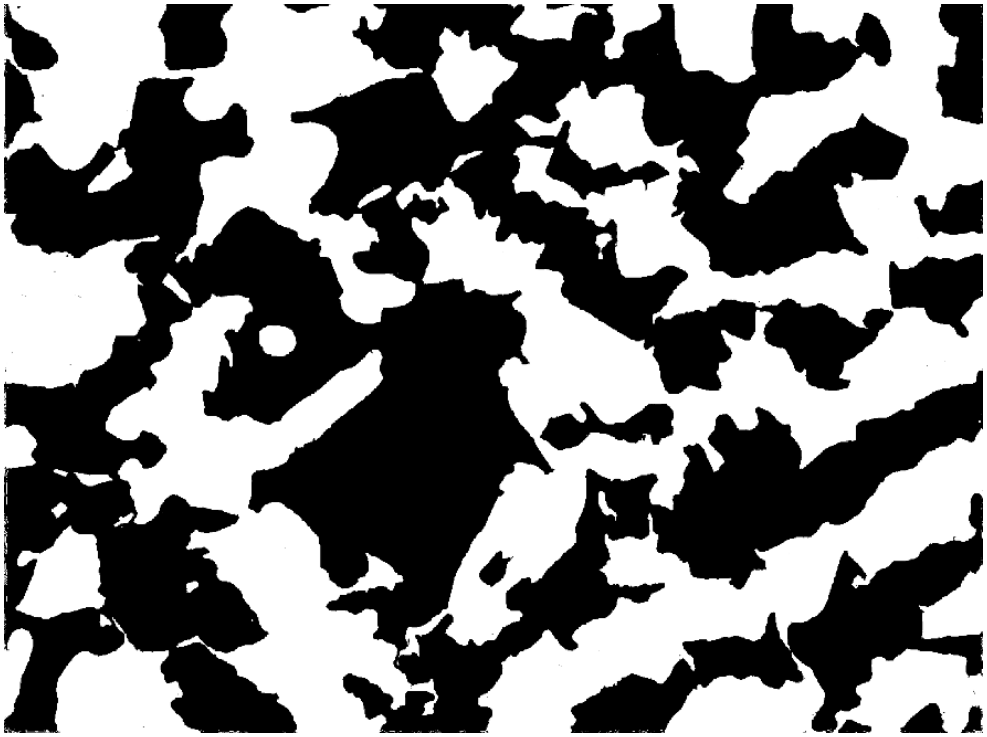
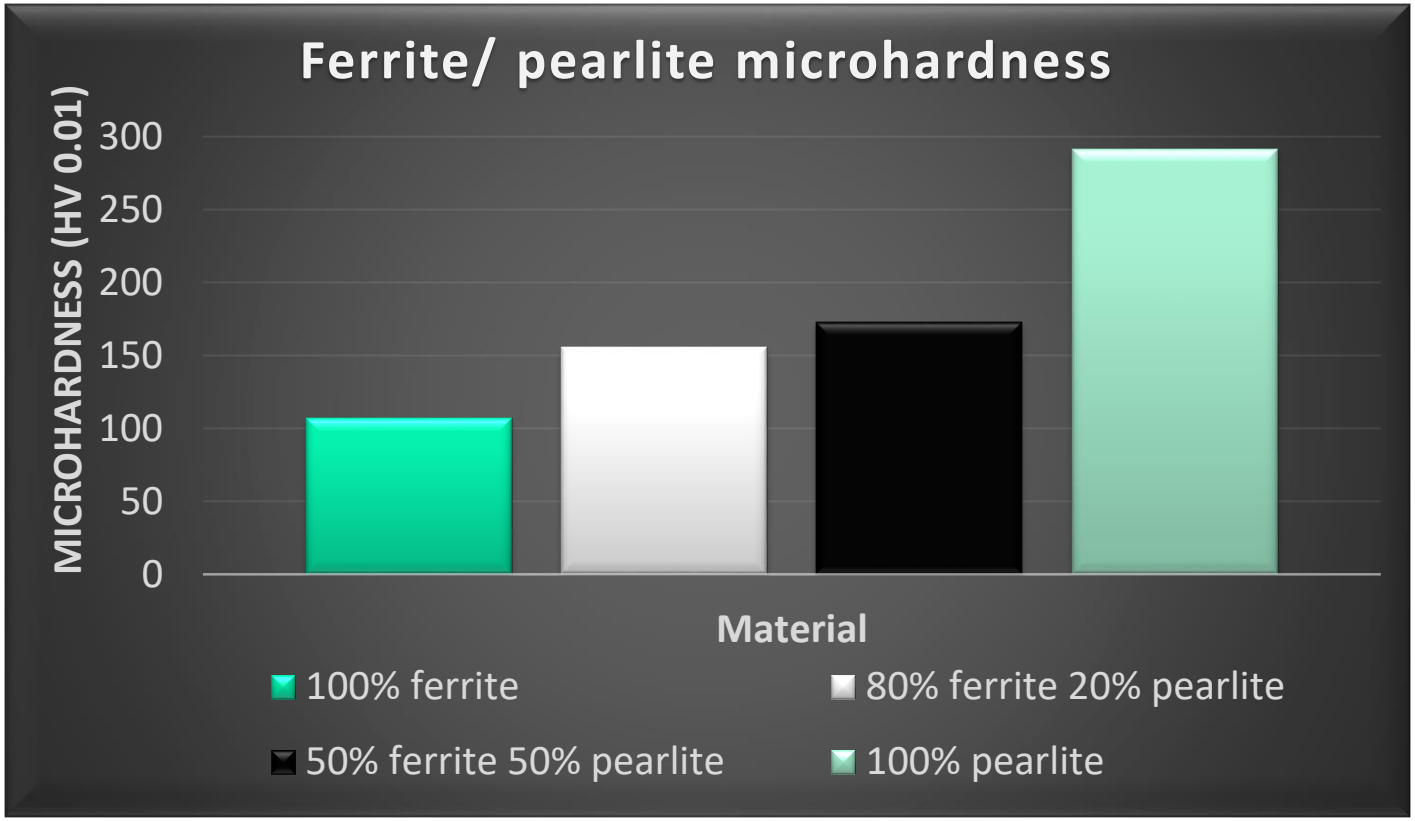


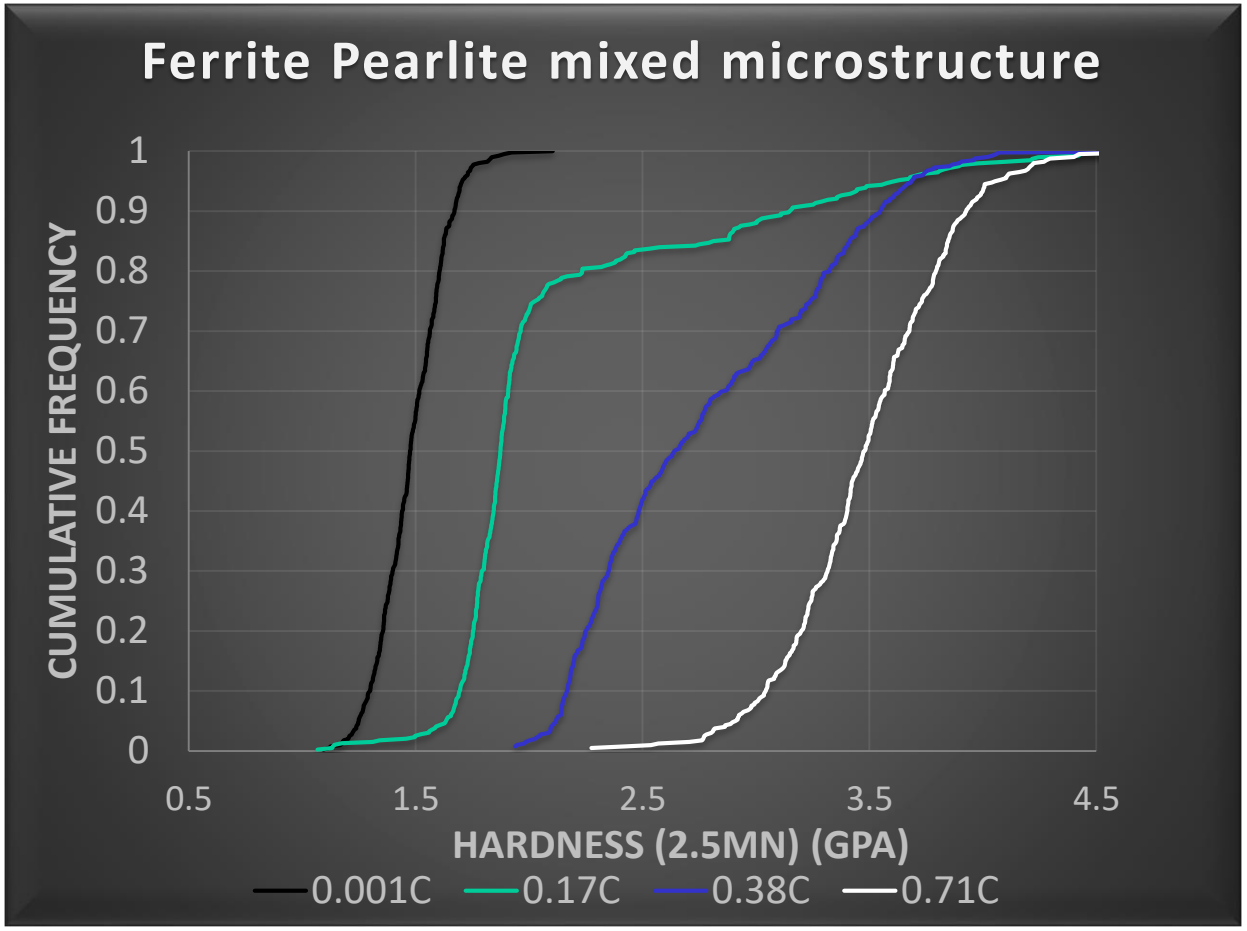
Microhardness profiles



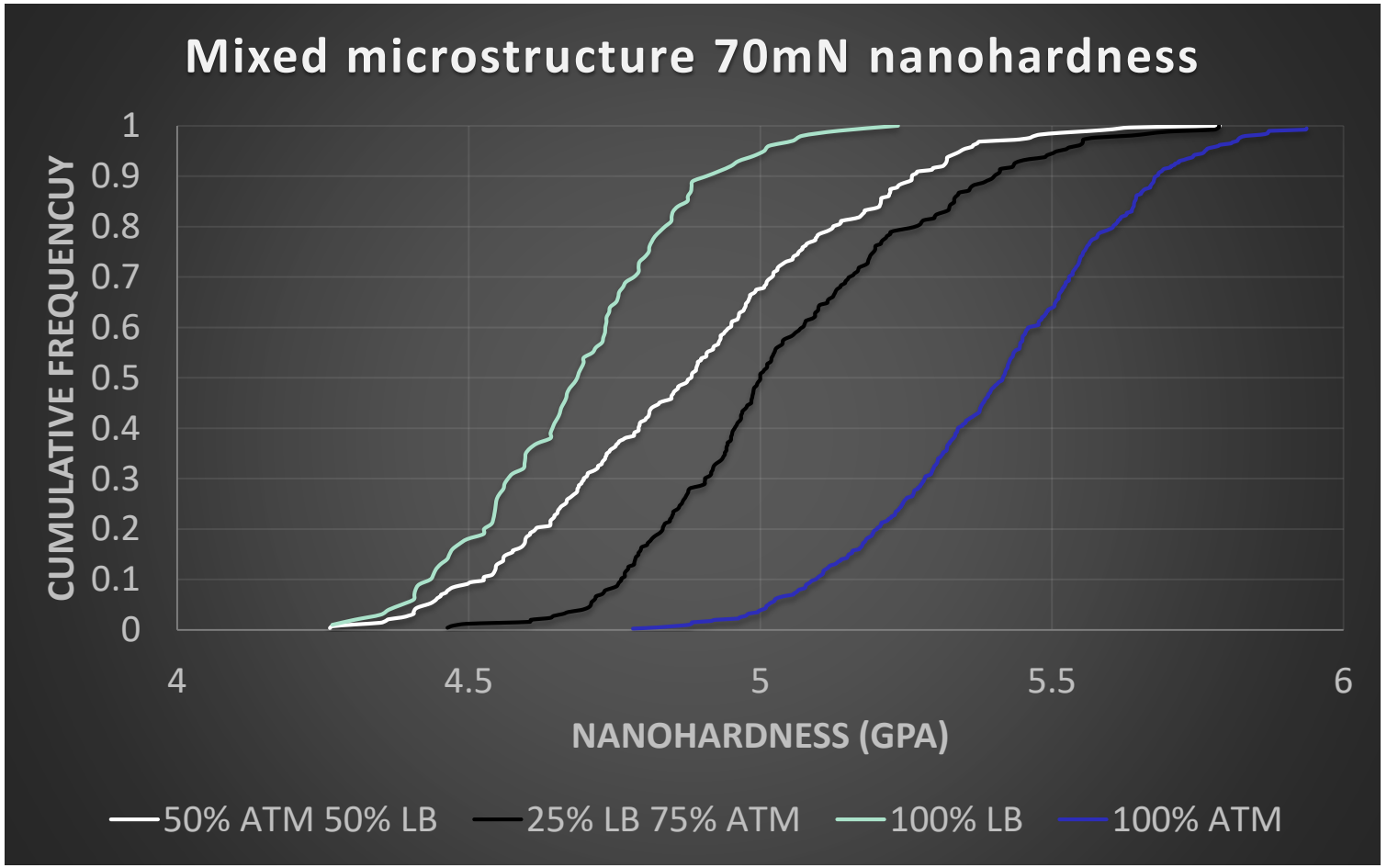
- Vickers HV 0.01 microhardness profiles taken using a Buehler Wilson VH3300 hardness tester.
- Microhardness is representative of the overall hardness of a material.
- Compositionally dependent however – rule of mixtures applies.

Ferrite pearlite phase mapping

- Proof of concept testing undertaken using ferrite/ pearlite mixed microstructure steels.
- Phase fraction compared to quantitative sample data and image analysis of etched sample.
- The “knee point” on the graph can be used to determine a phase fraction.

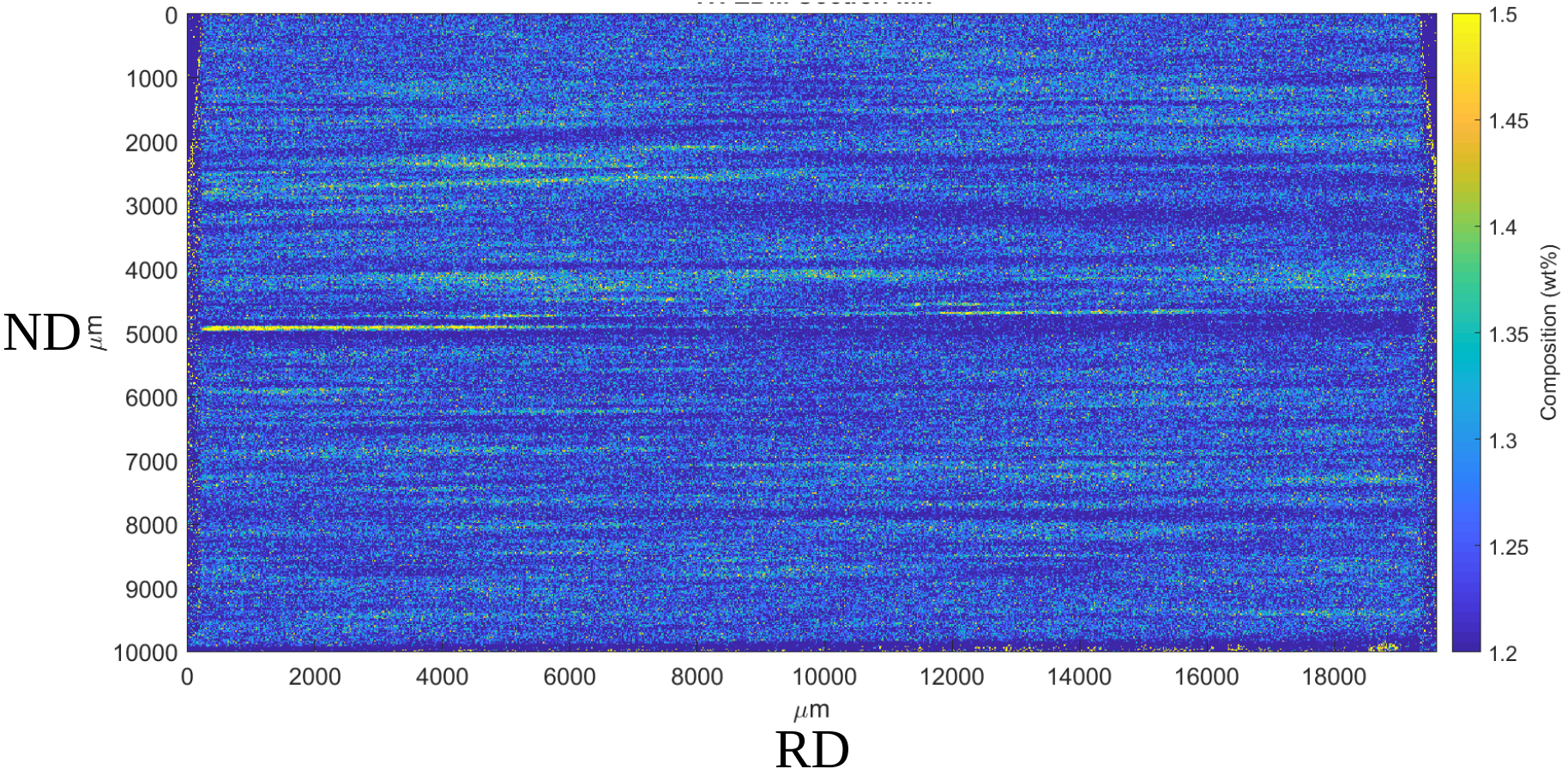


Lower bainite and autotempered martensite hardness arrays

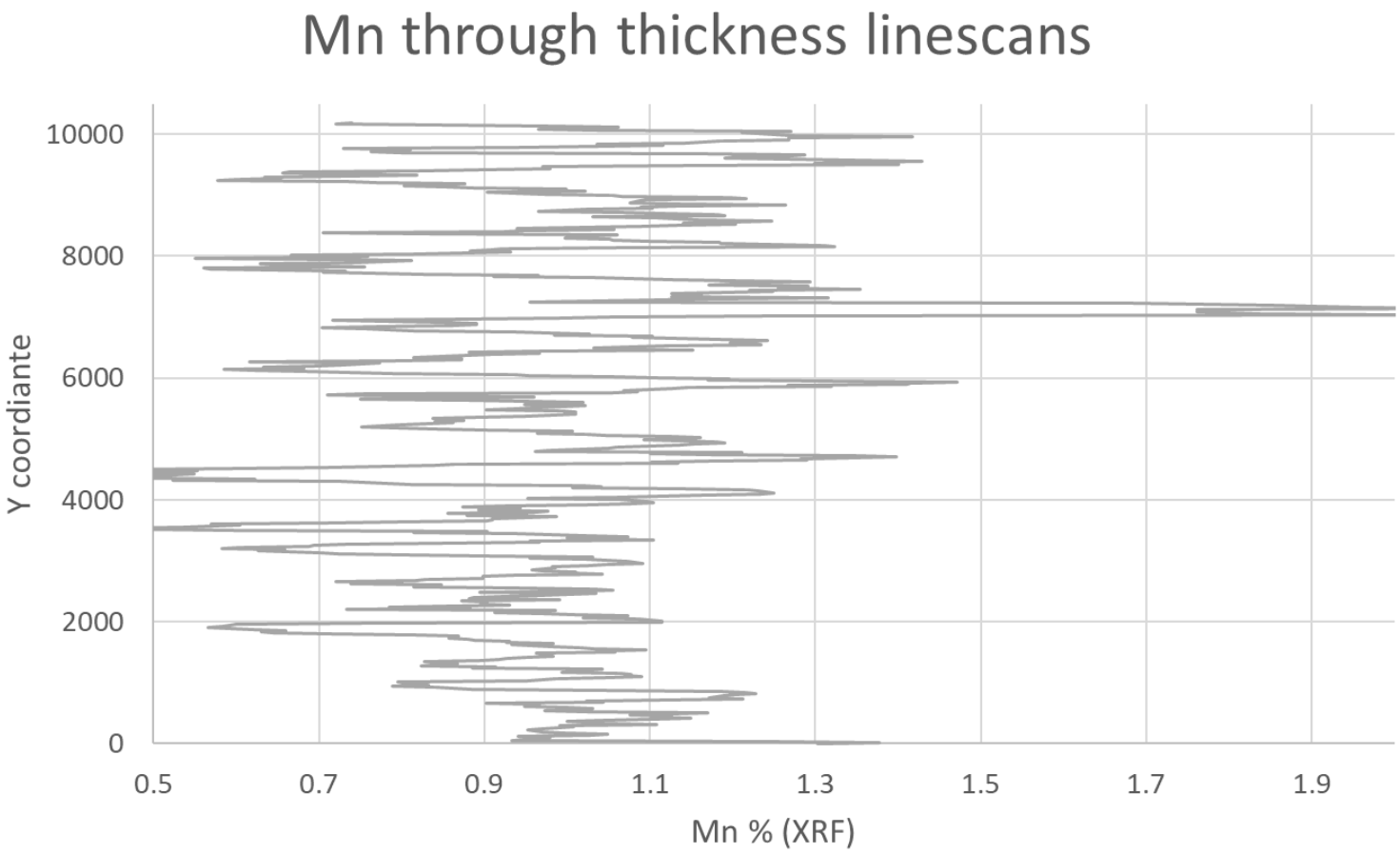


Compositional band mapping

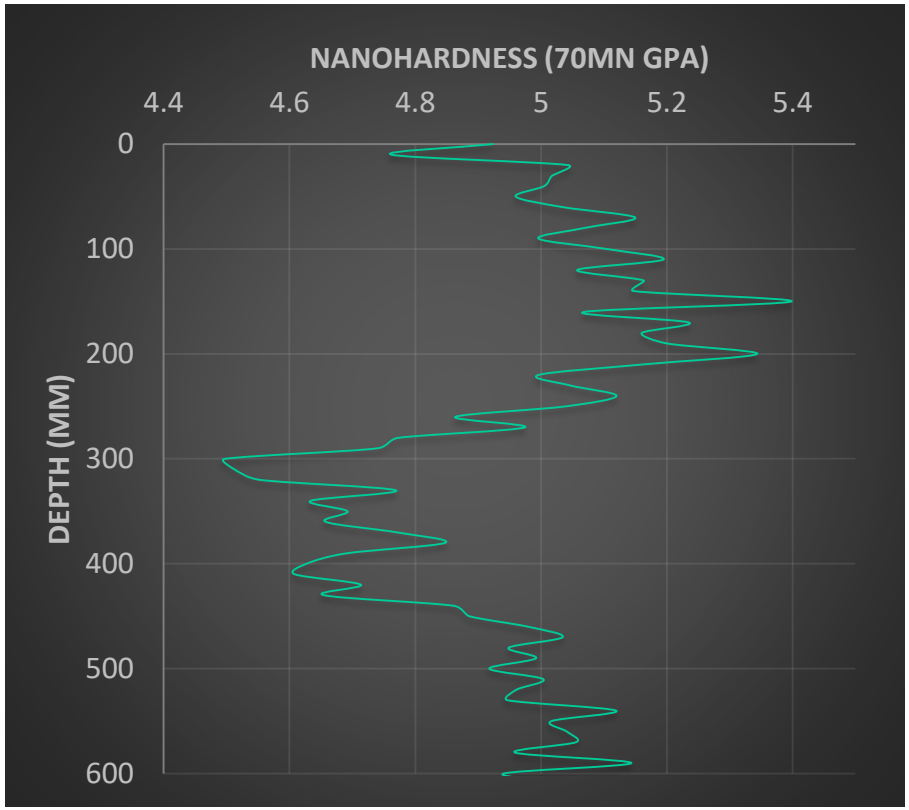
S960 XRF mapping (Mn)

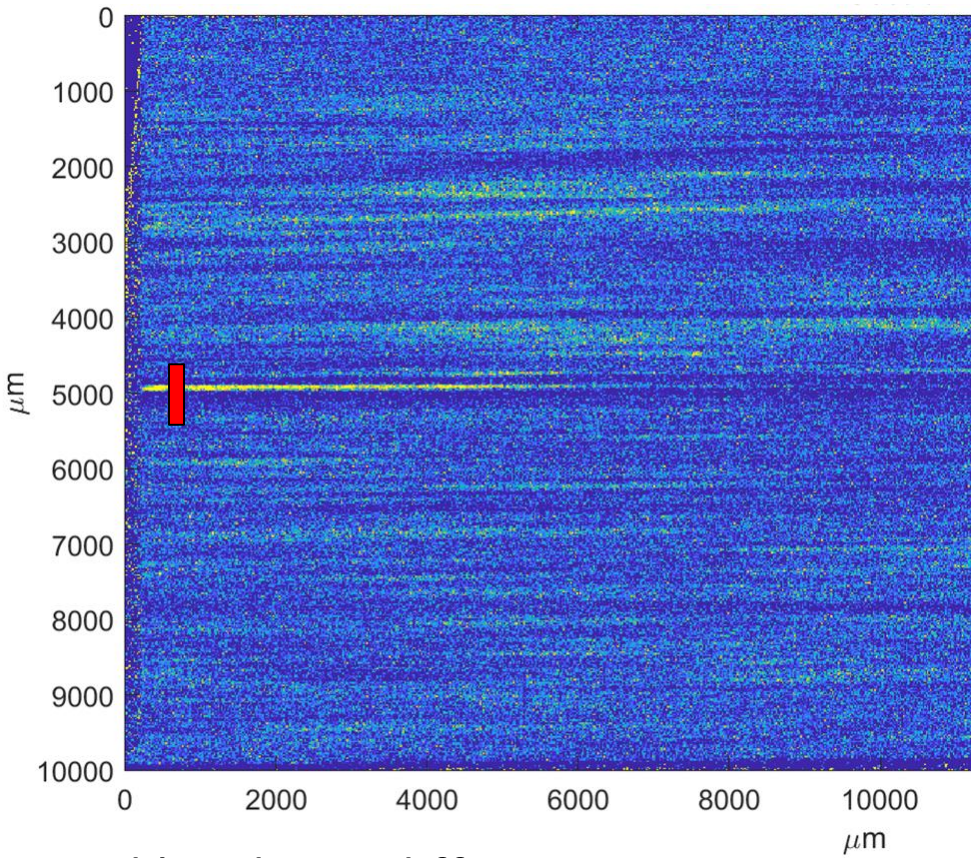


S960 XRF Linescan



S960 centreline nanohardness

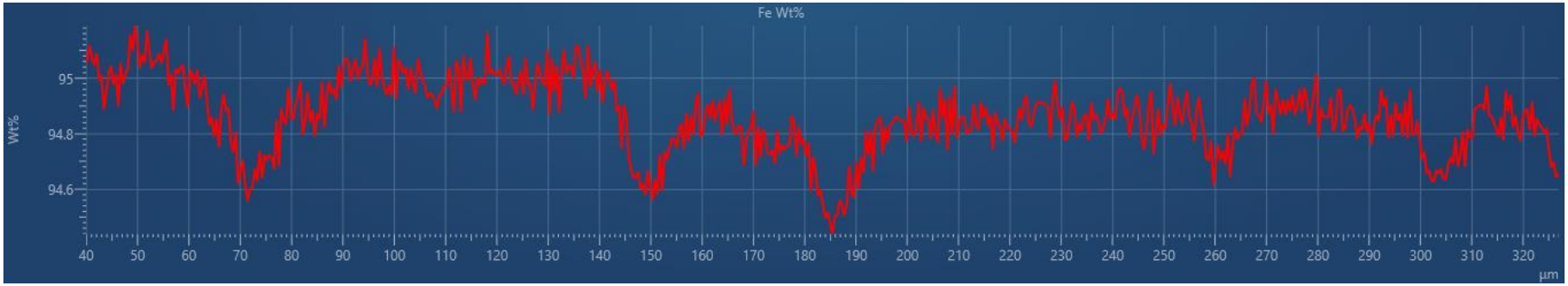




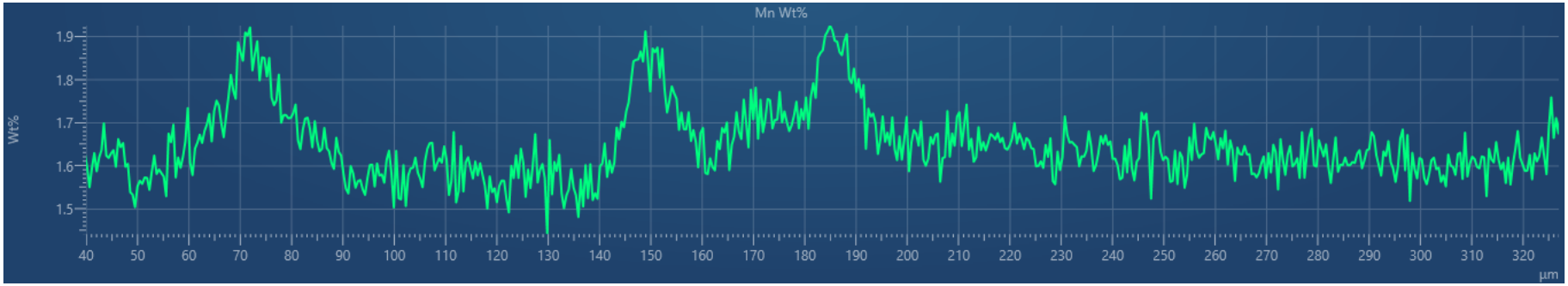
- Approximately a 20% composition and hardness difference between the enriched and depleted reigons measured.

Trial 718 centreline EDS linescans

Fe Wt%



Mn Wt%



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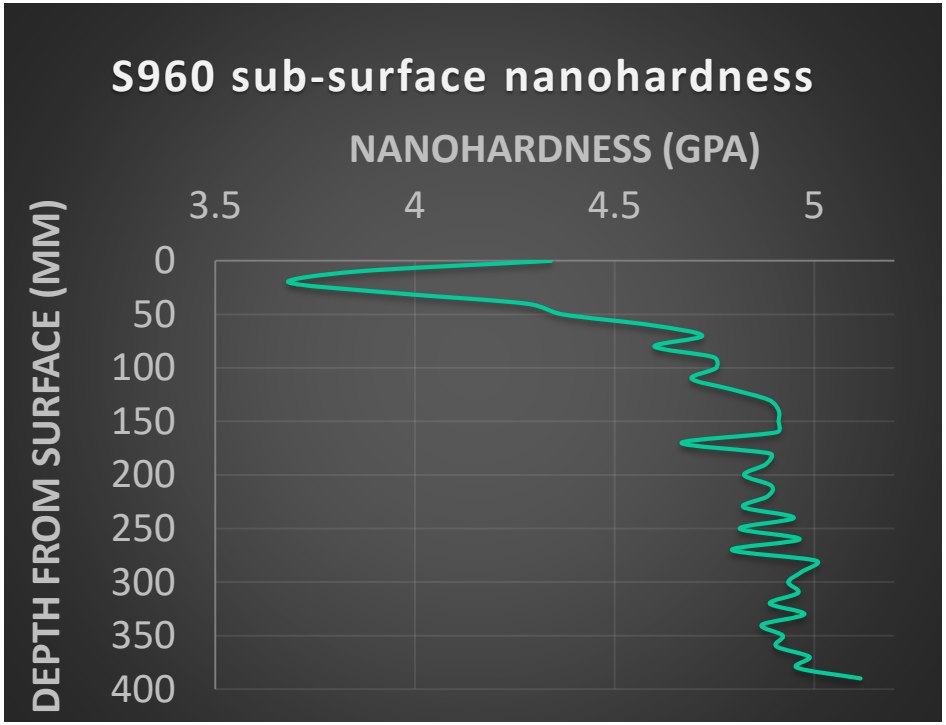
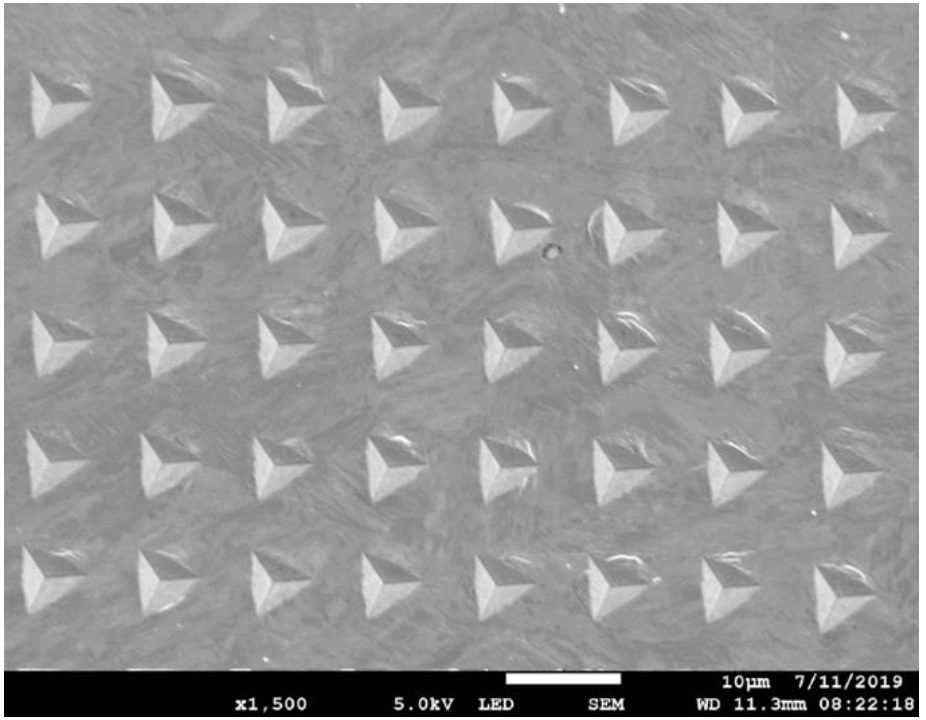


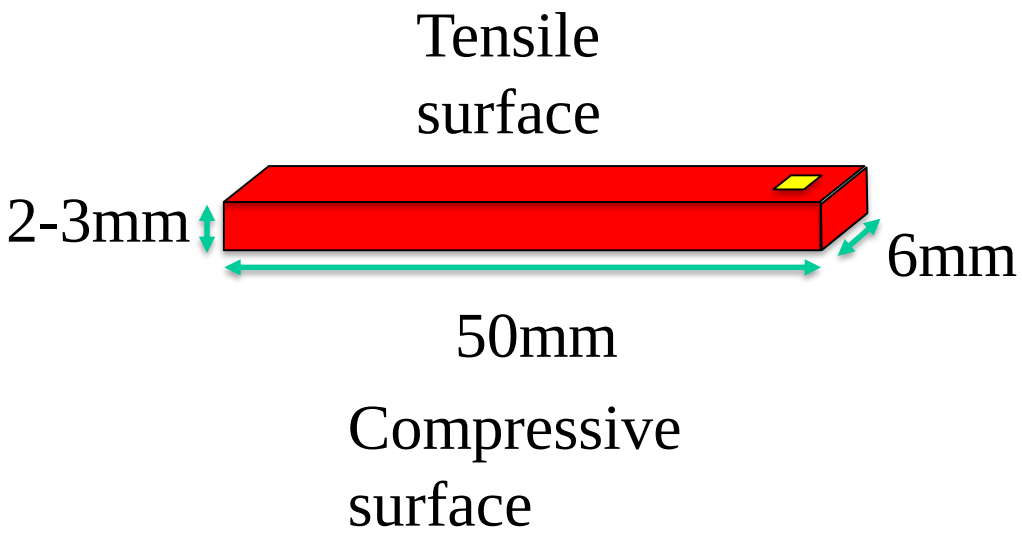


- Average hardness from surface downwards with variance determined and mapped.
- Aim to use comparative tests to relate to strain/ shear band formation.
- Mean max depth: 800nm, Mean indent side length 4.6um.

DIC bend testing/ strain analysis

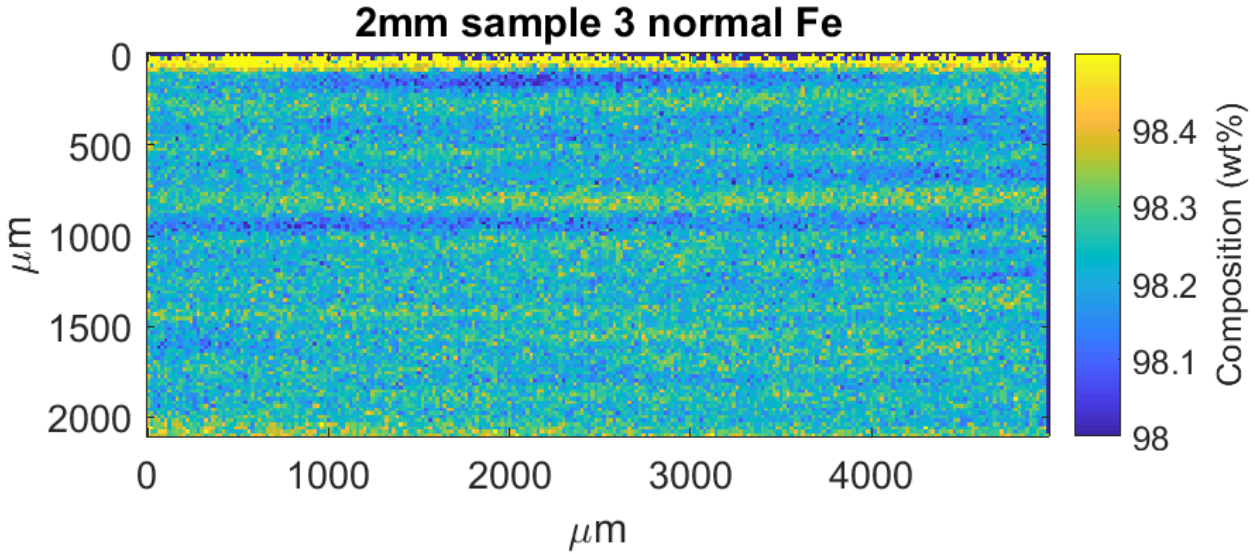
DIC bend testing

- Insitu SEM bend testing following sample characterisation.
- Post test DIC strain analysis.
- Test to ASTM standards to minimise shear.



Bend test XRF

- XRF through thickness of primary bend region.
- Potential for localised EDS in DIC area.
- Identification of compositional band density and magnitude.



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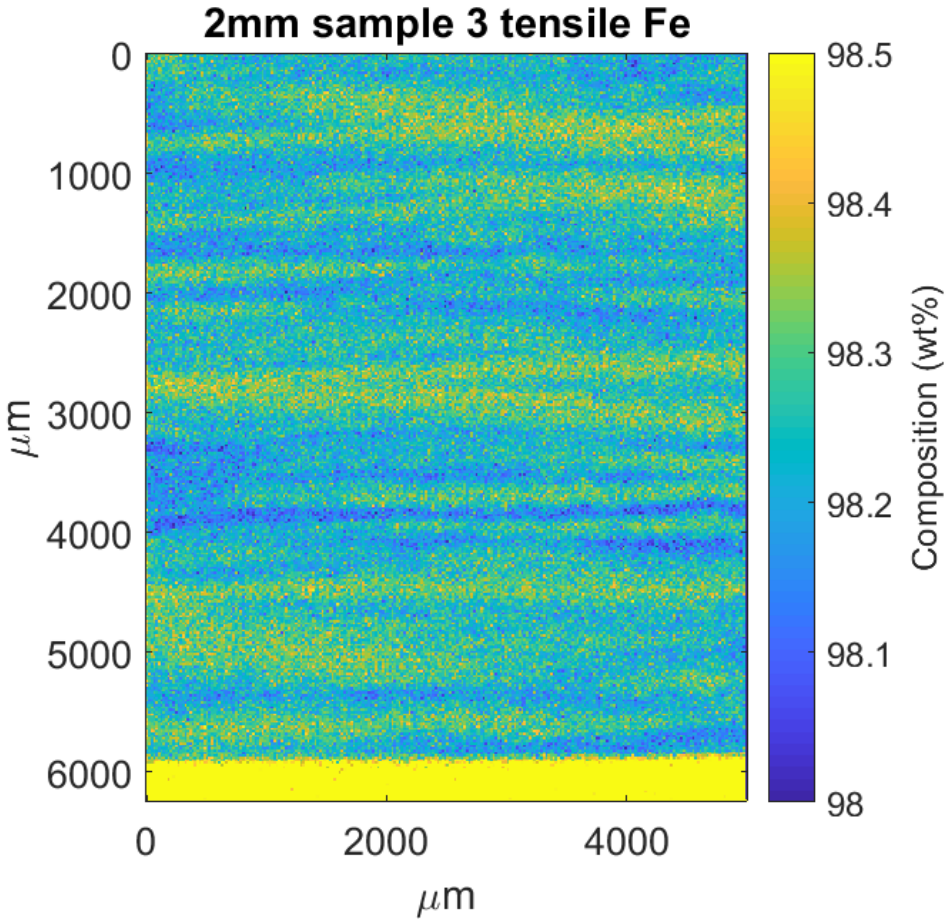
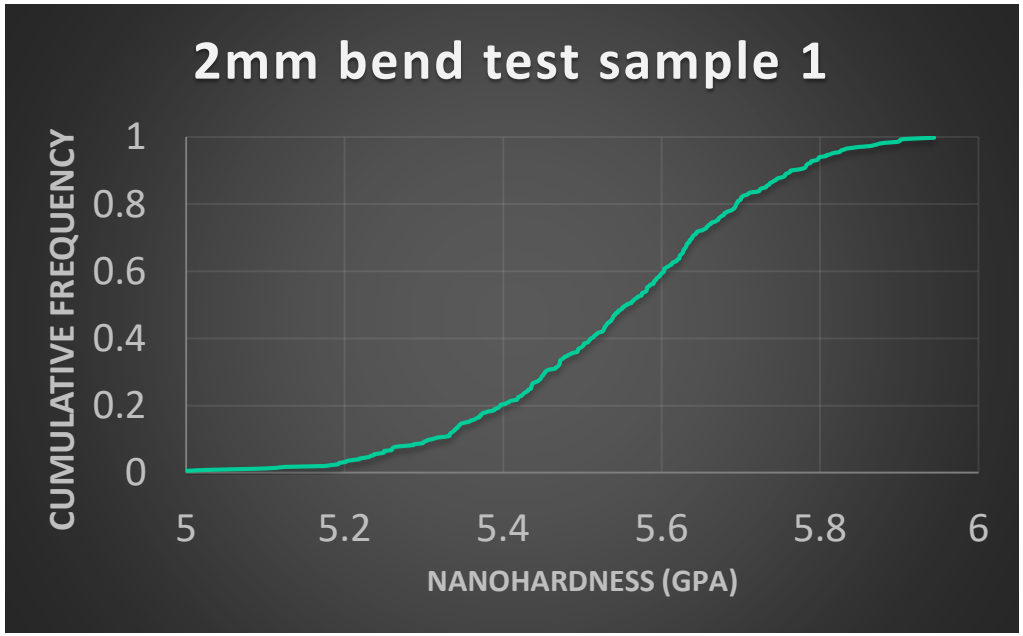


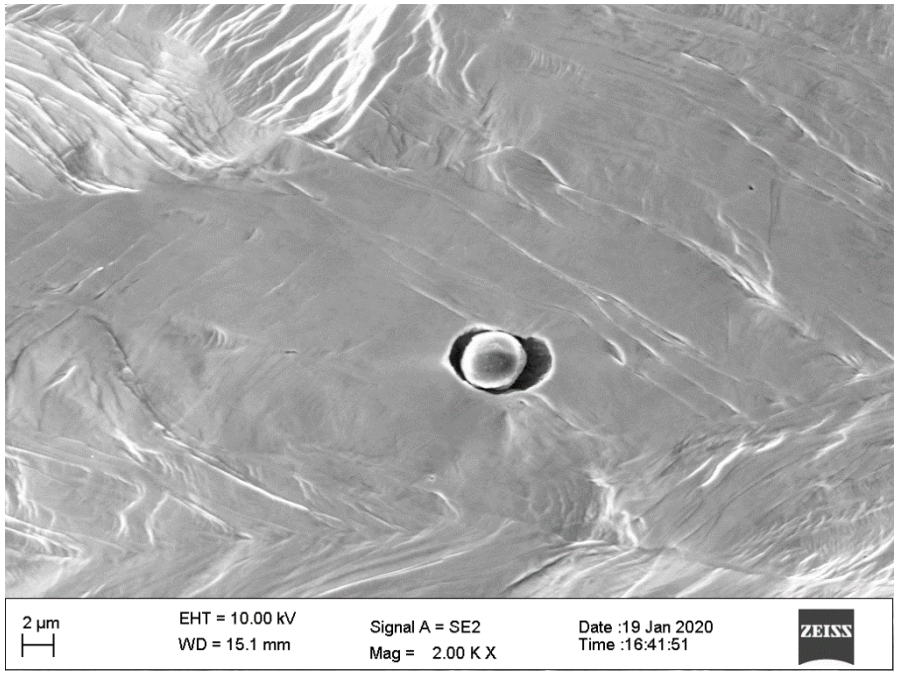
2mm Sample 1 (initial test) – nHV

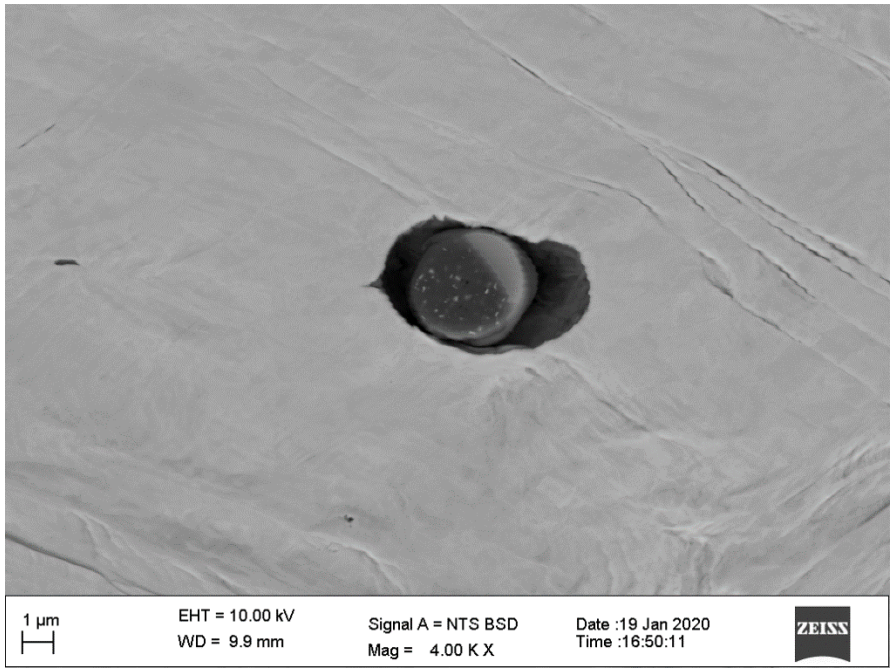
- Cumulative frequency plot for 20x20 nanohardness array at 70mN.
- Array taken away from bend test location so as not to induce surface defects/ surface work hardening.
- Maps/ plots can be compared.



Inclusions

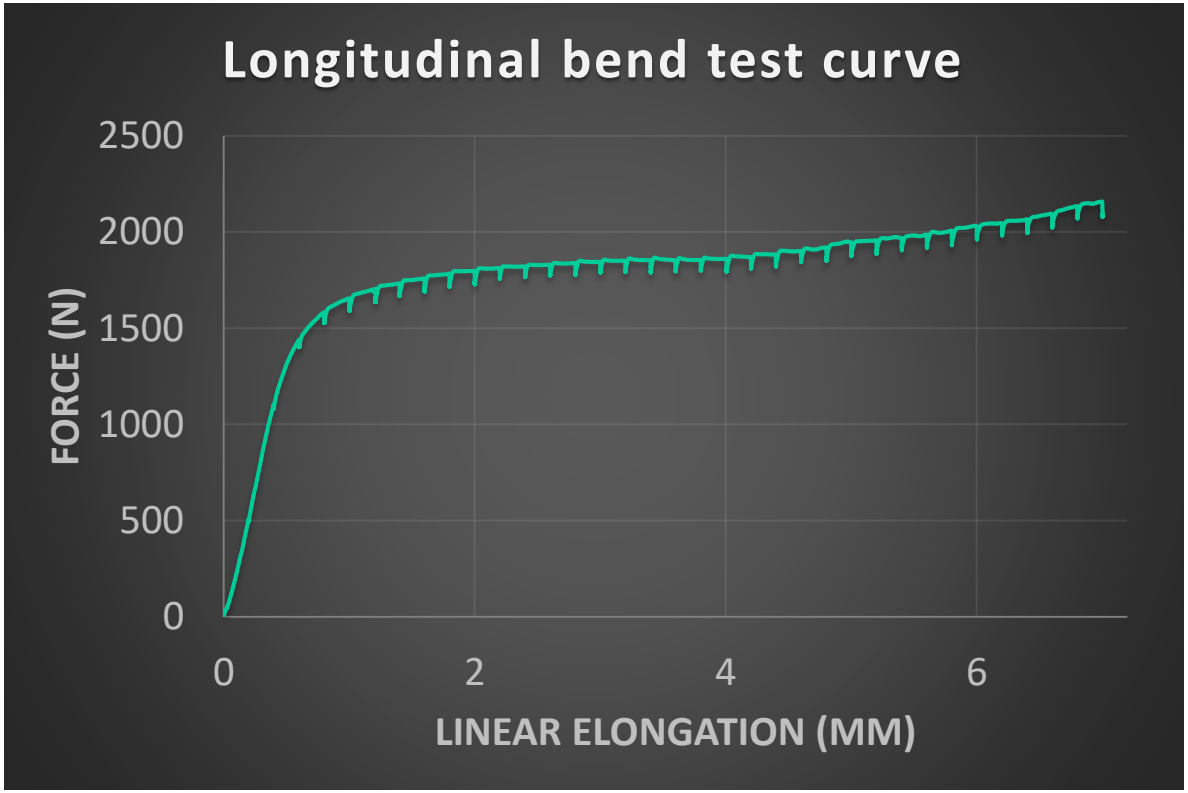
- Variety of inclusions have been found in the sample including CaS, MnS and Alumnia based compounds.



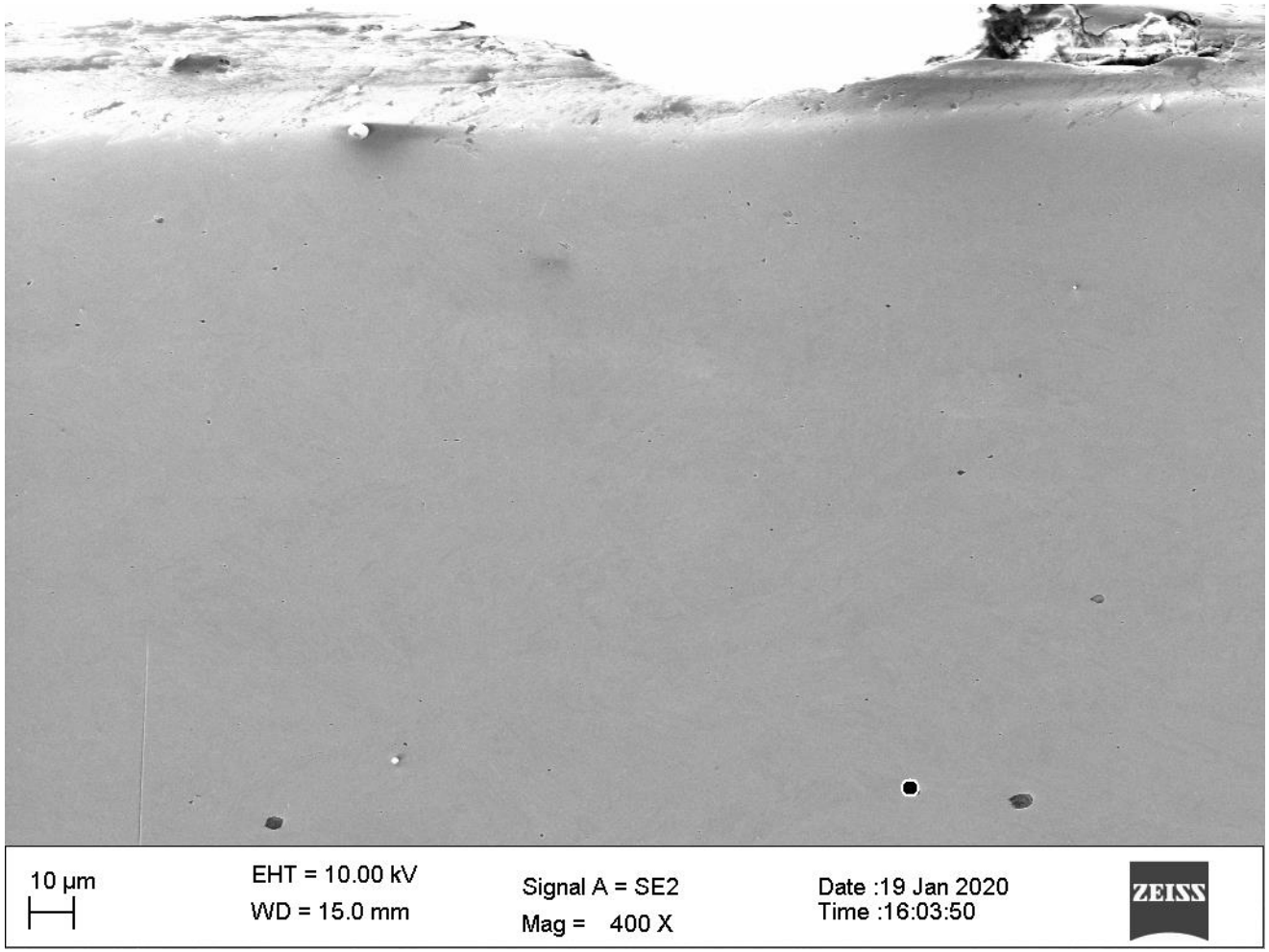


Longitudinal bend test data

- Force/ extension curve for bed test.
- Test objective for identification of strain features rather than mechanical testing, but graph included for reference.



DIC strain analysis



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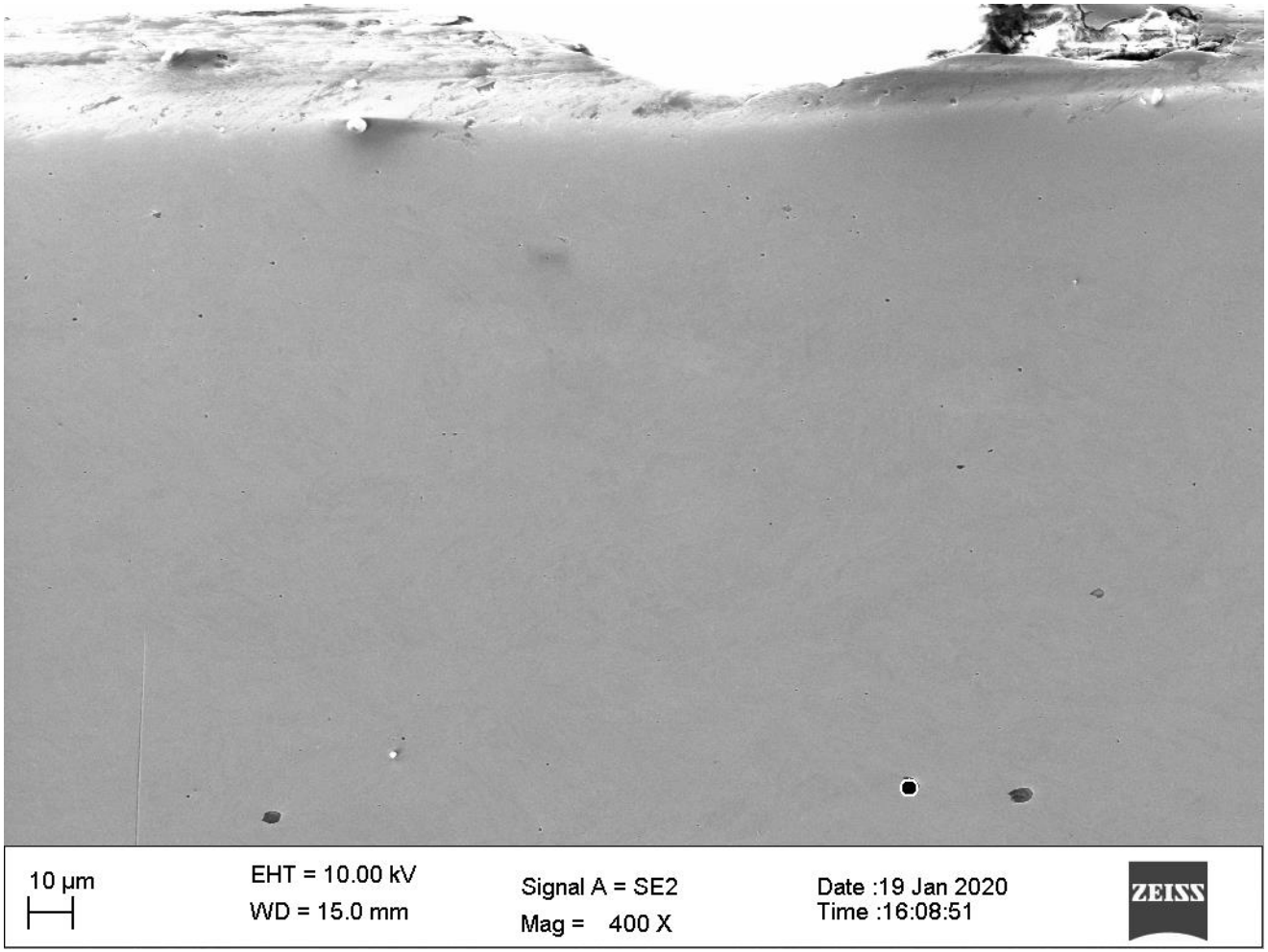

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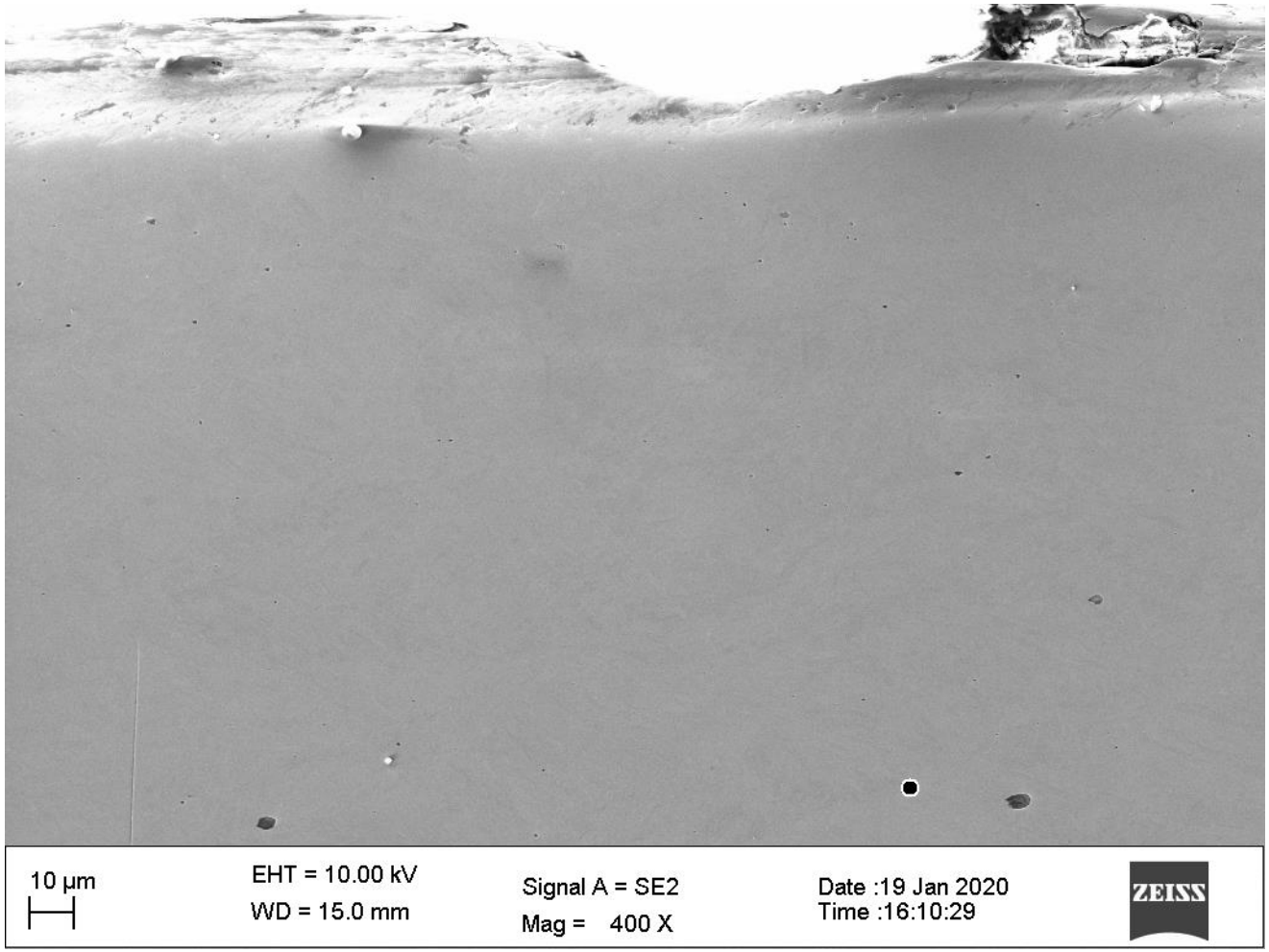

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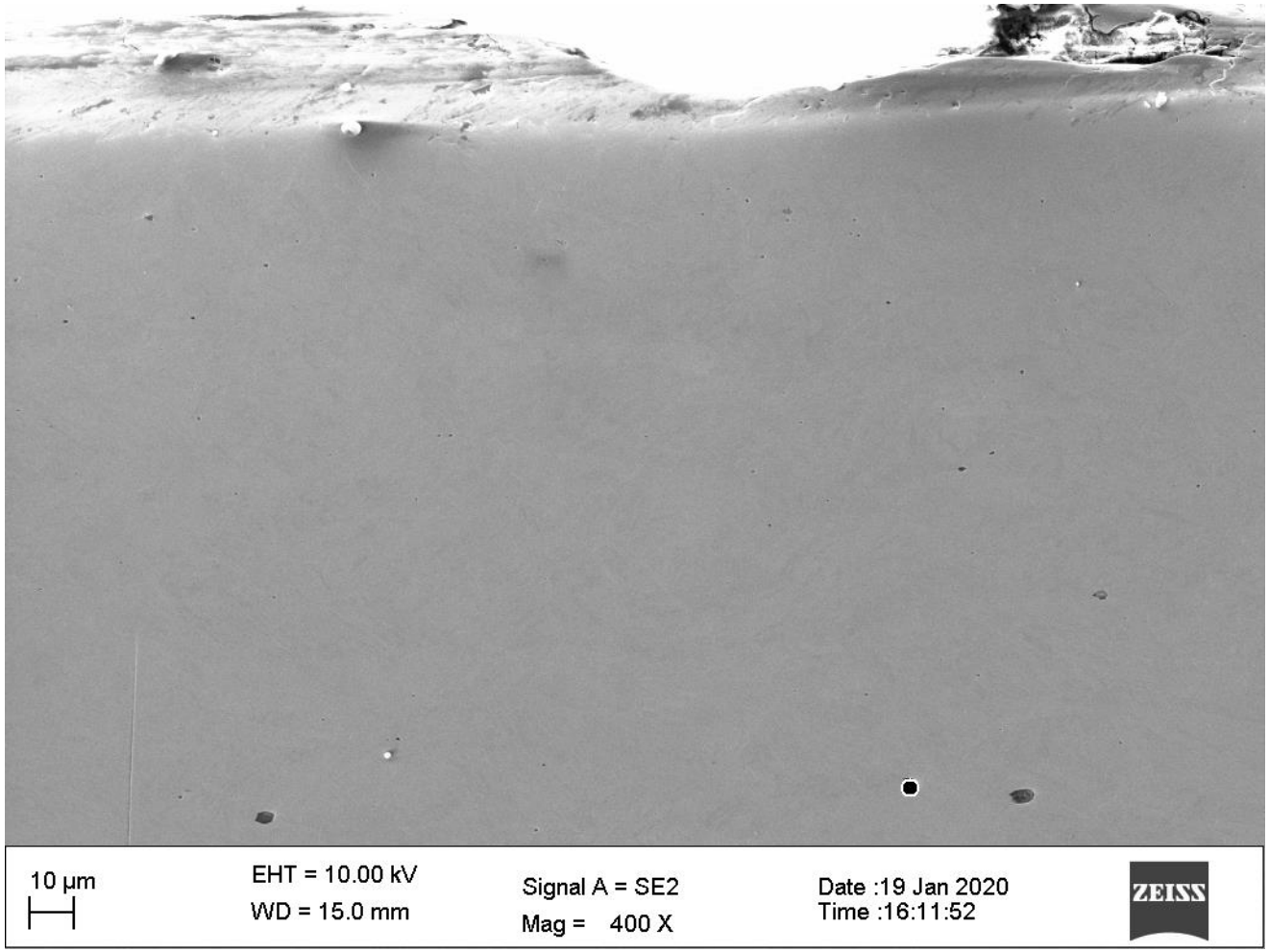

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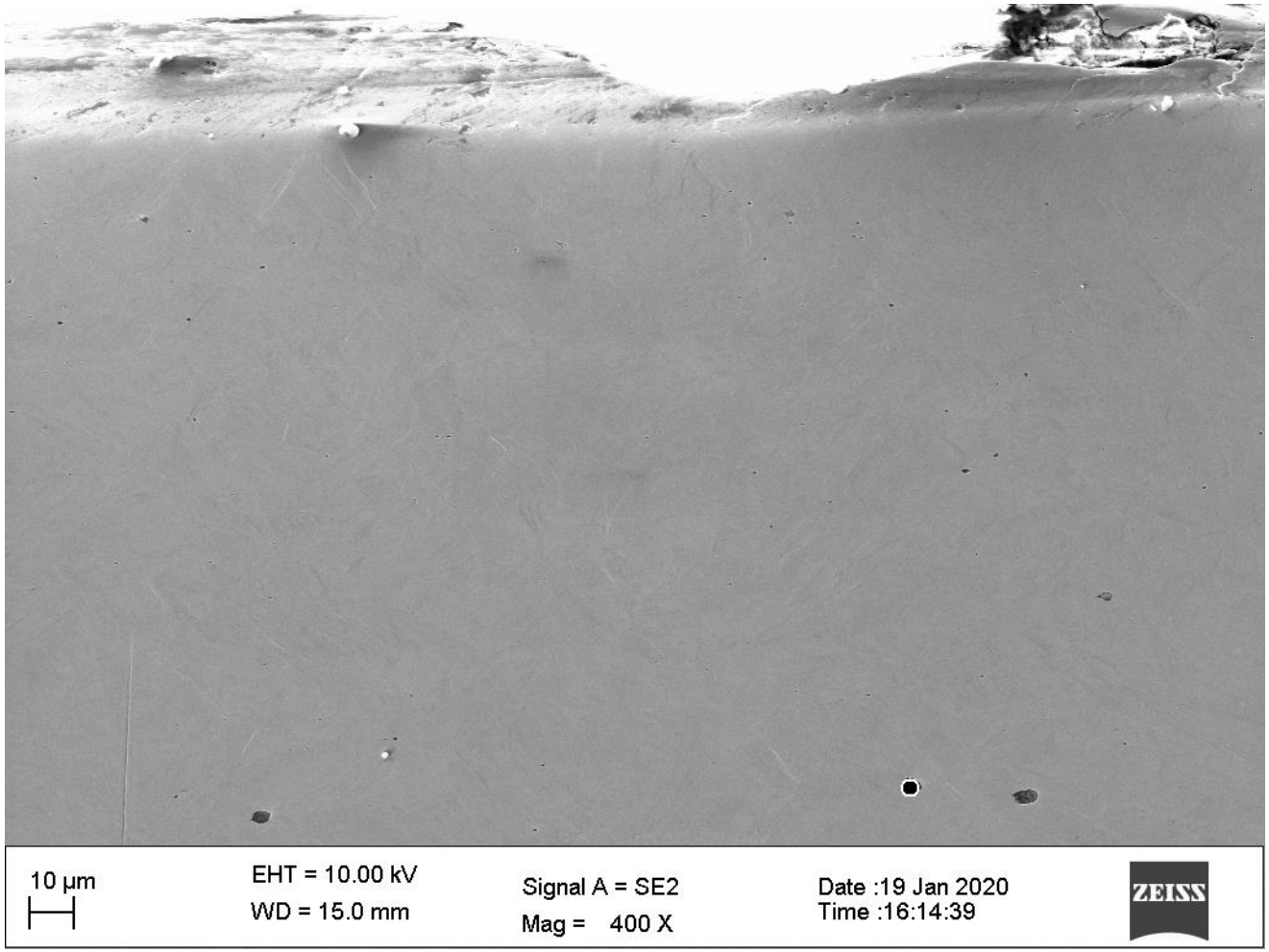

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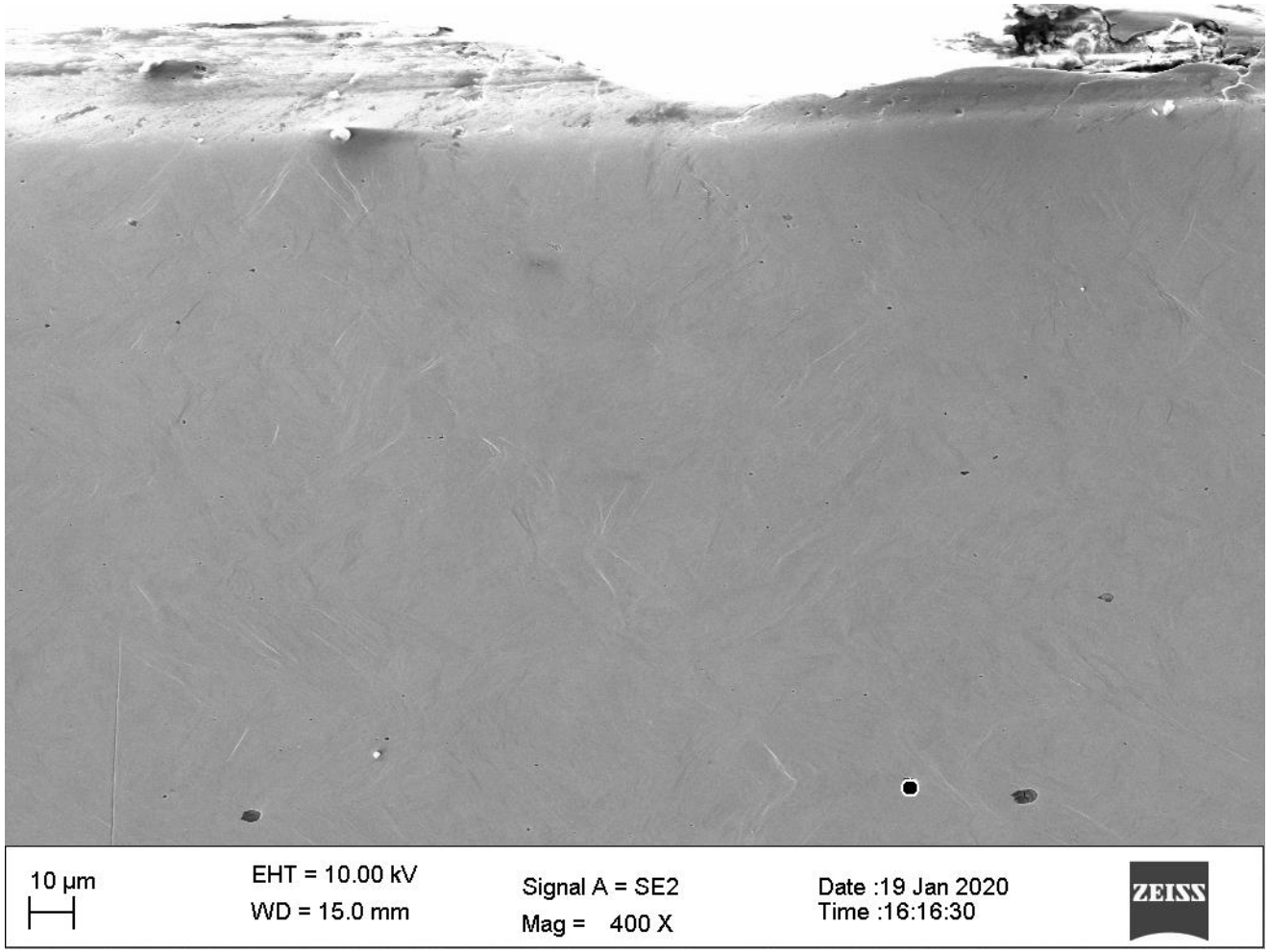

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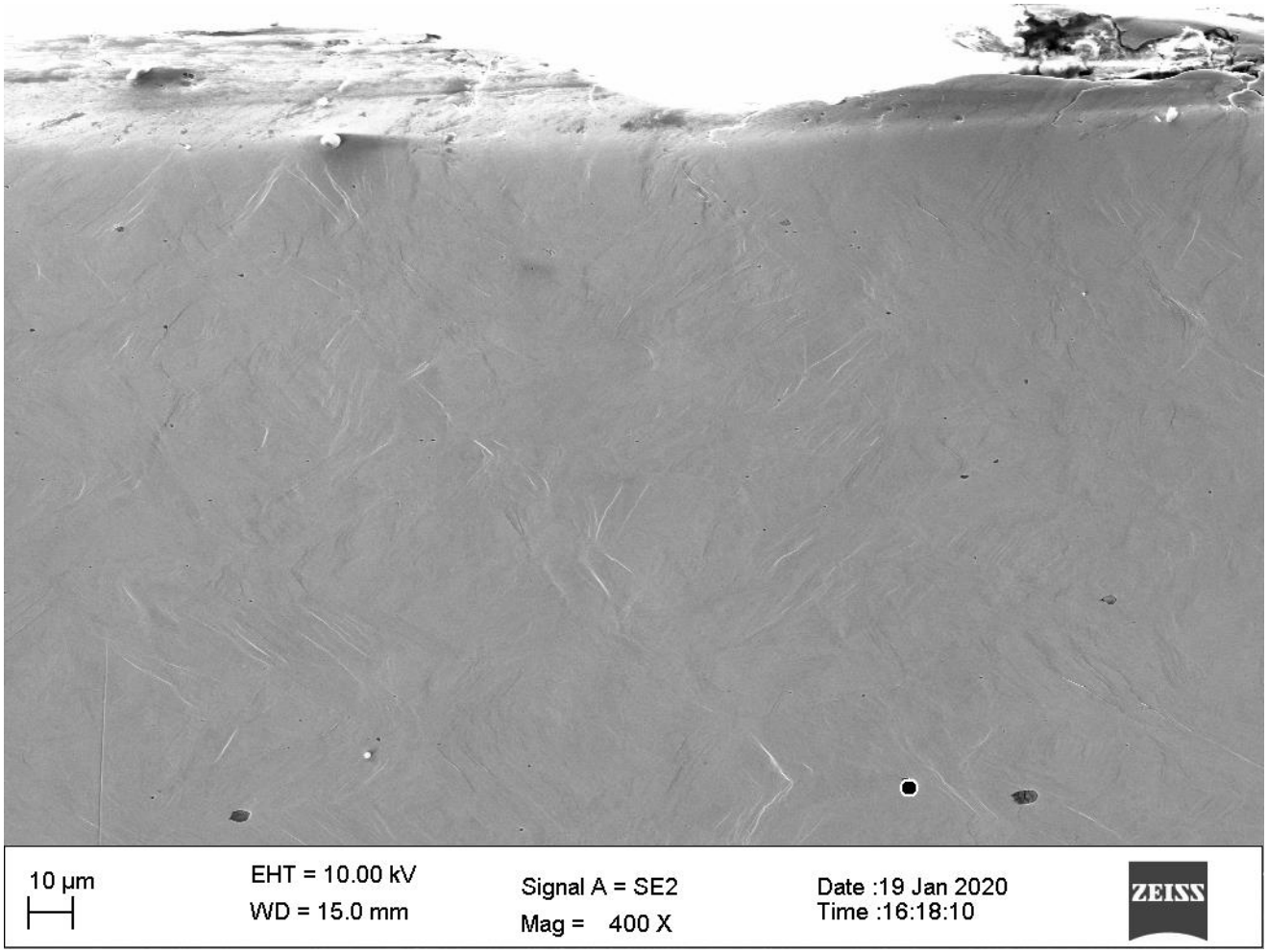

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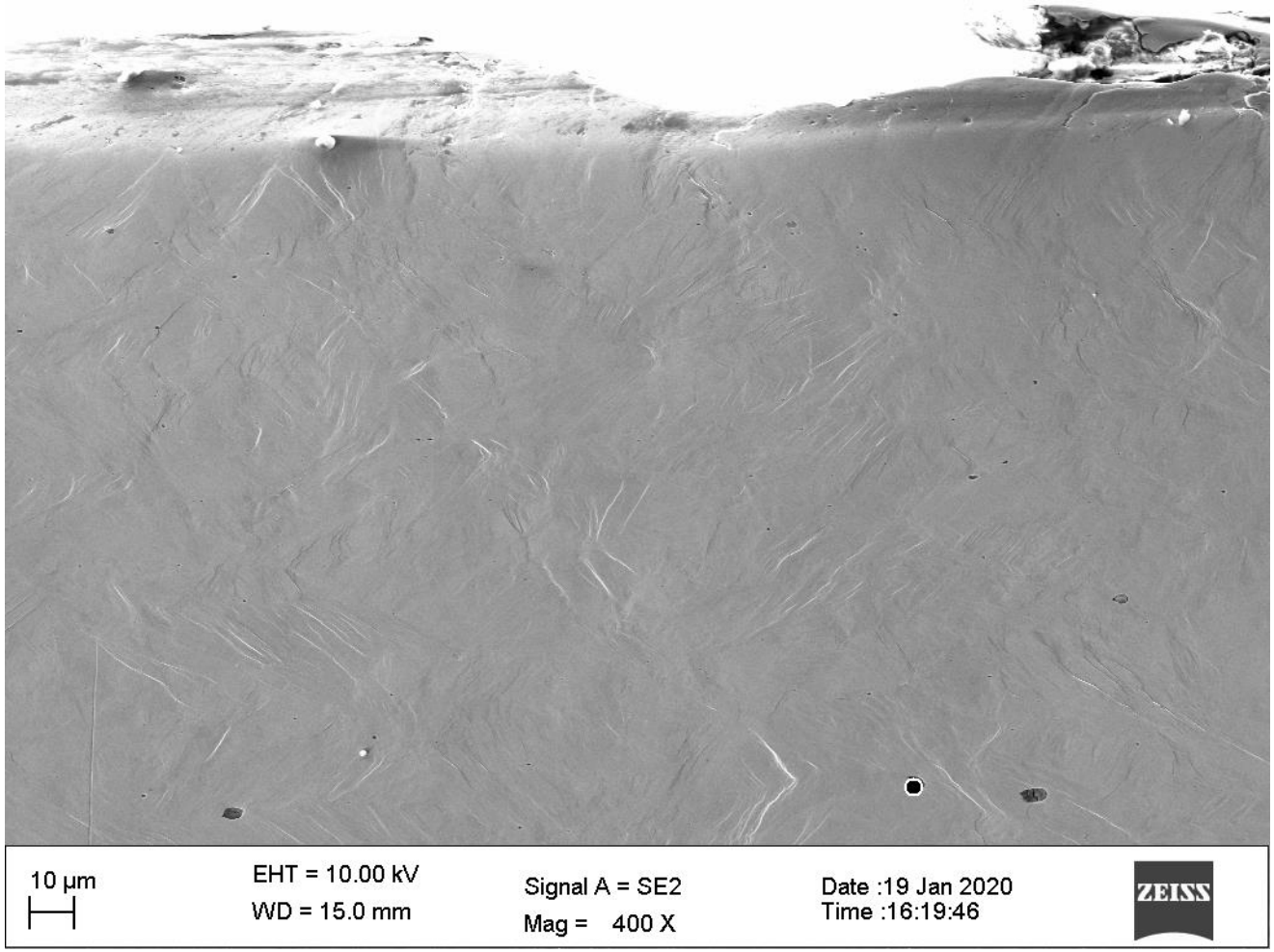

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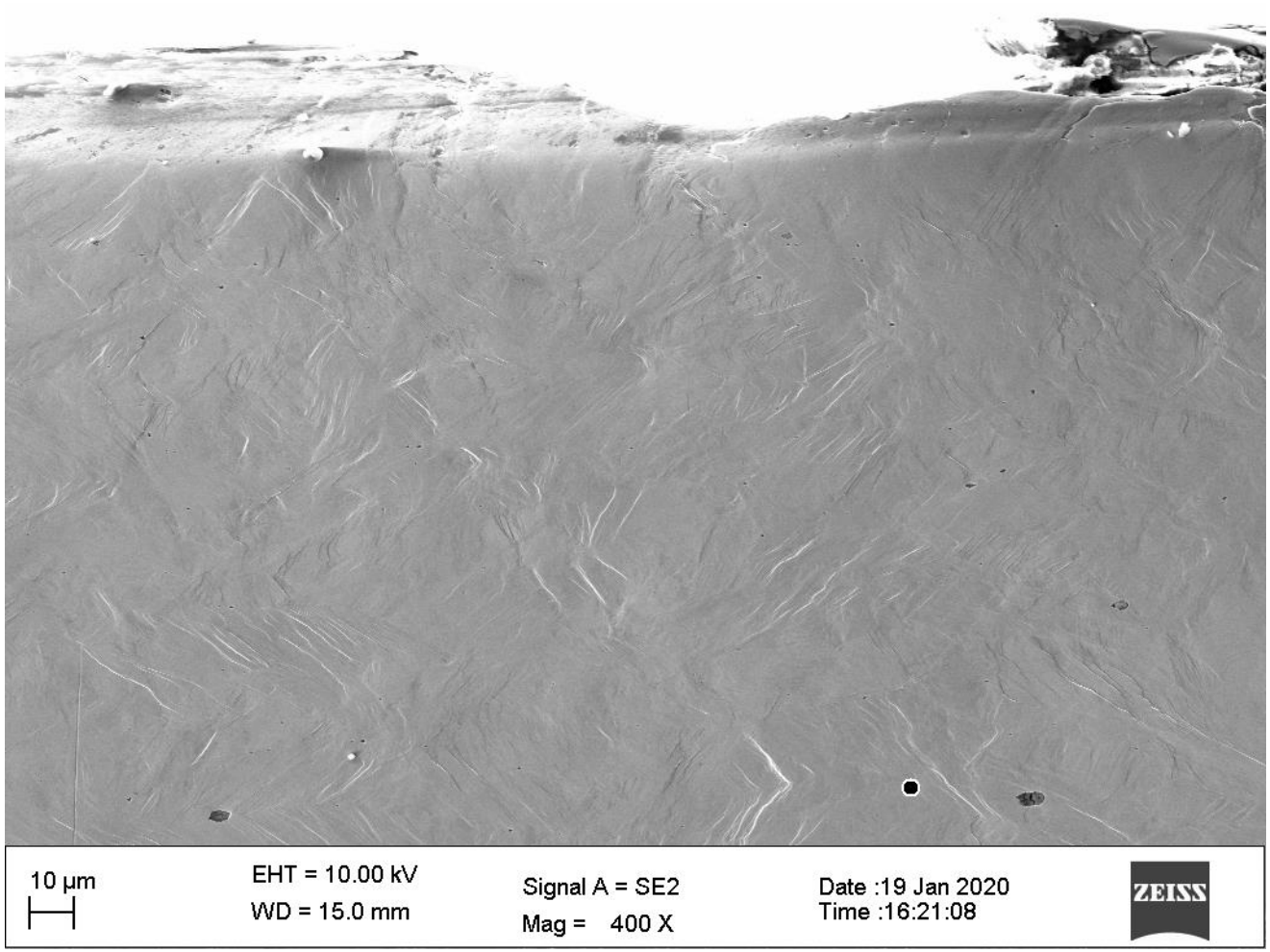

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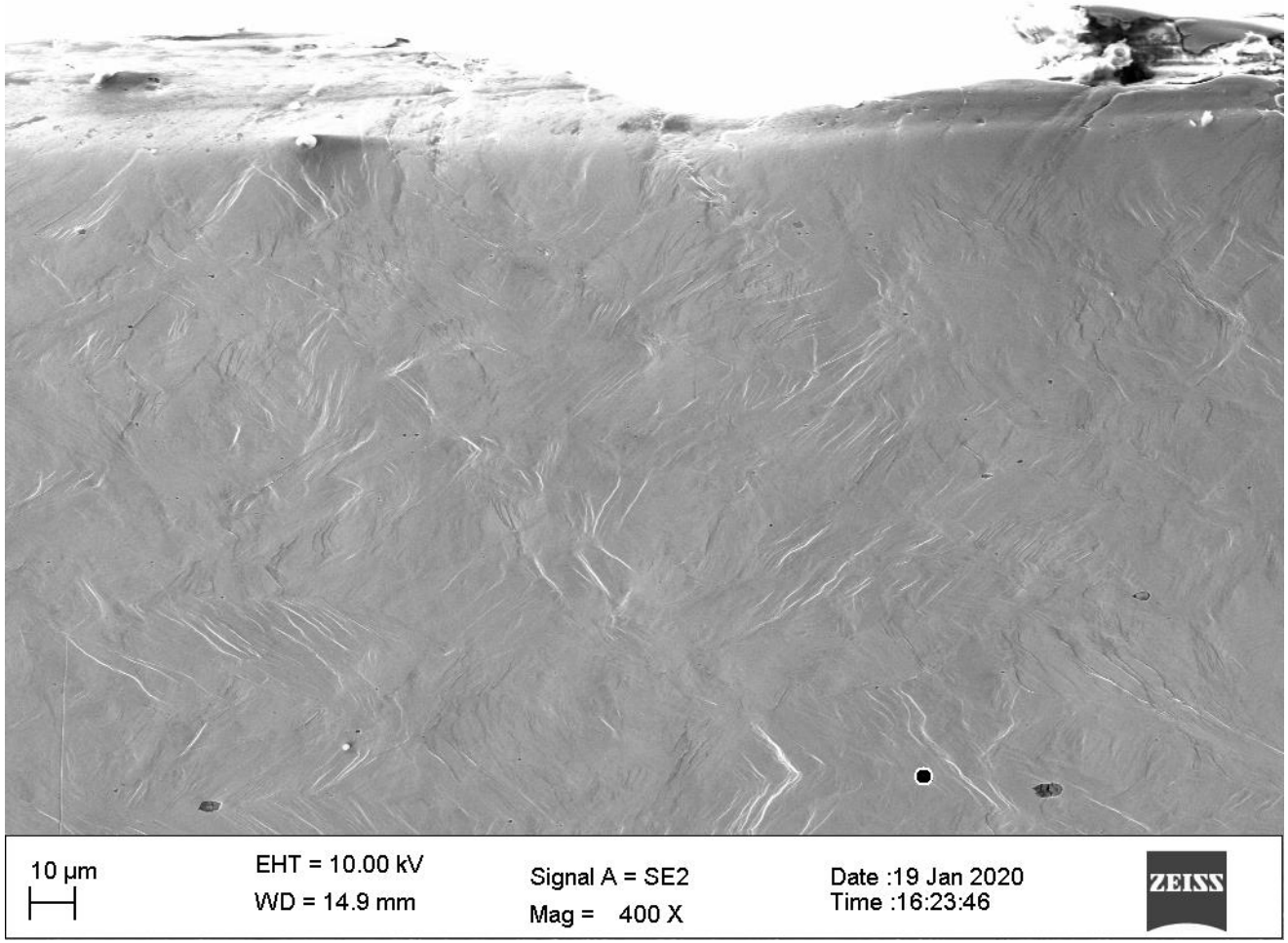

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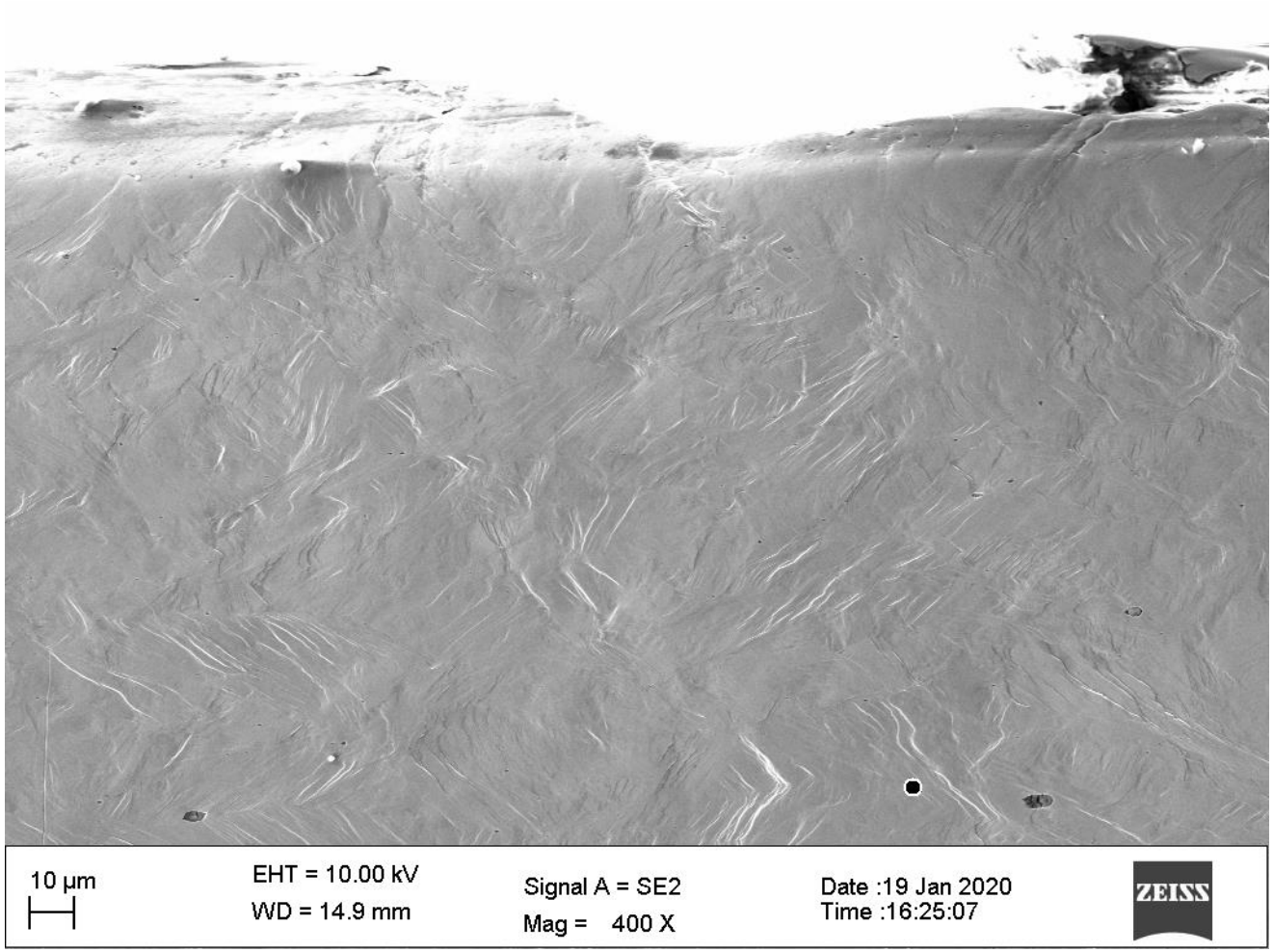

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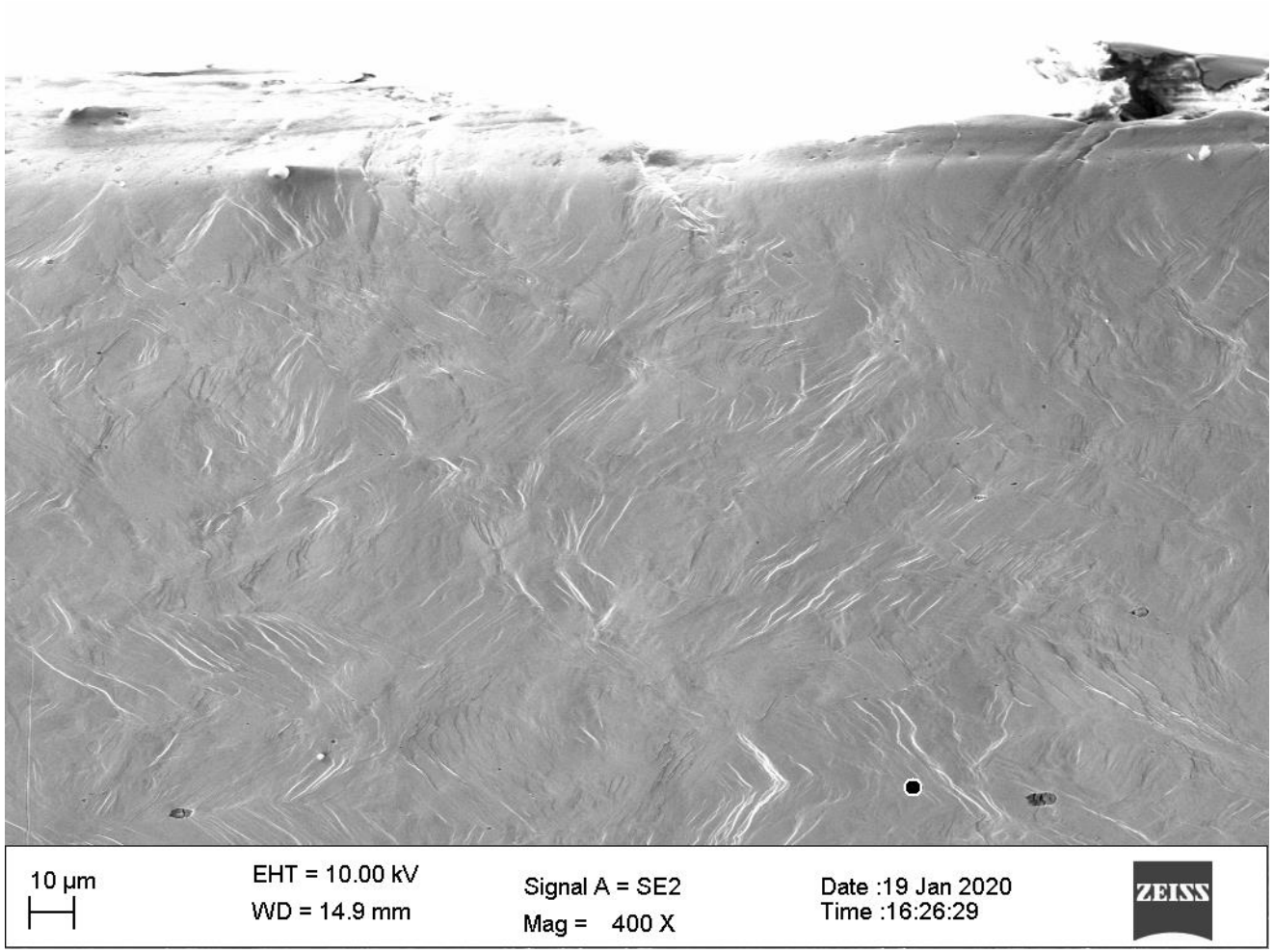

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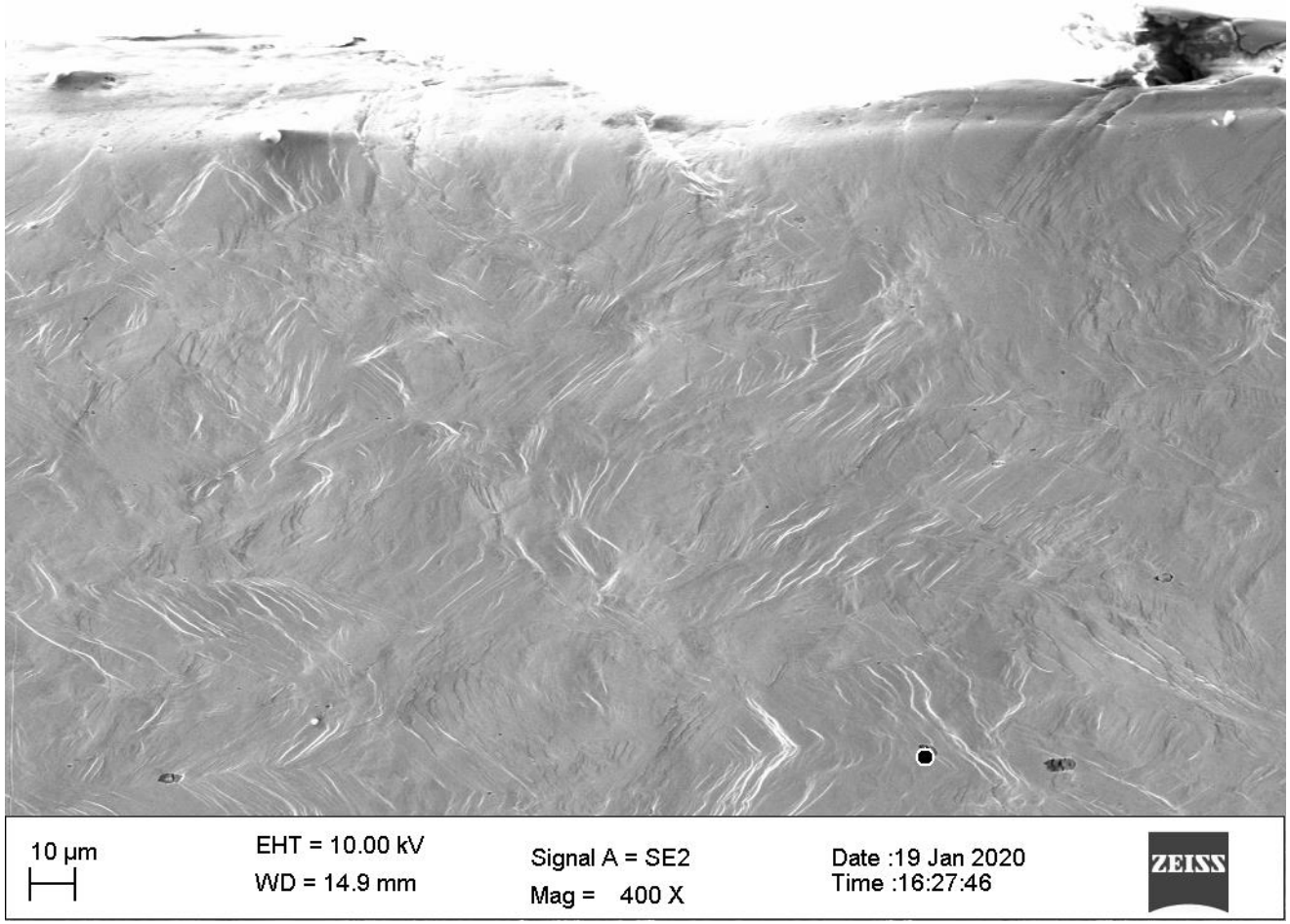

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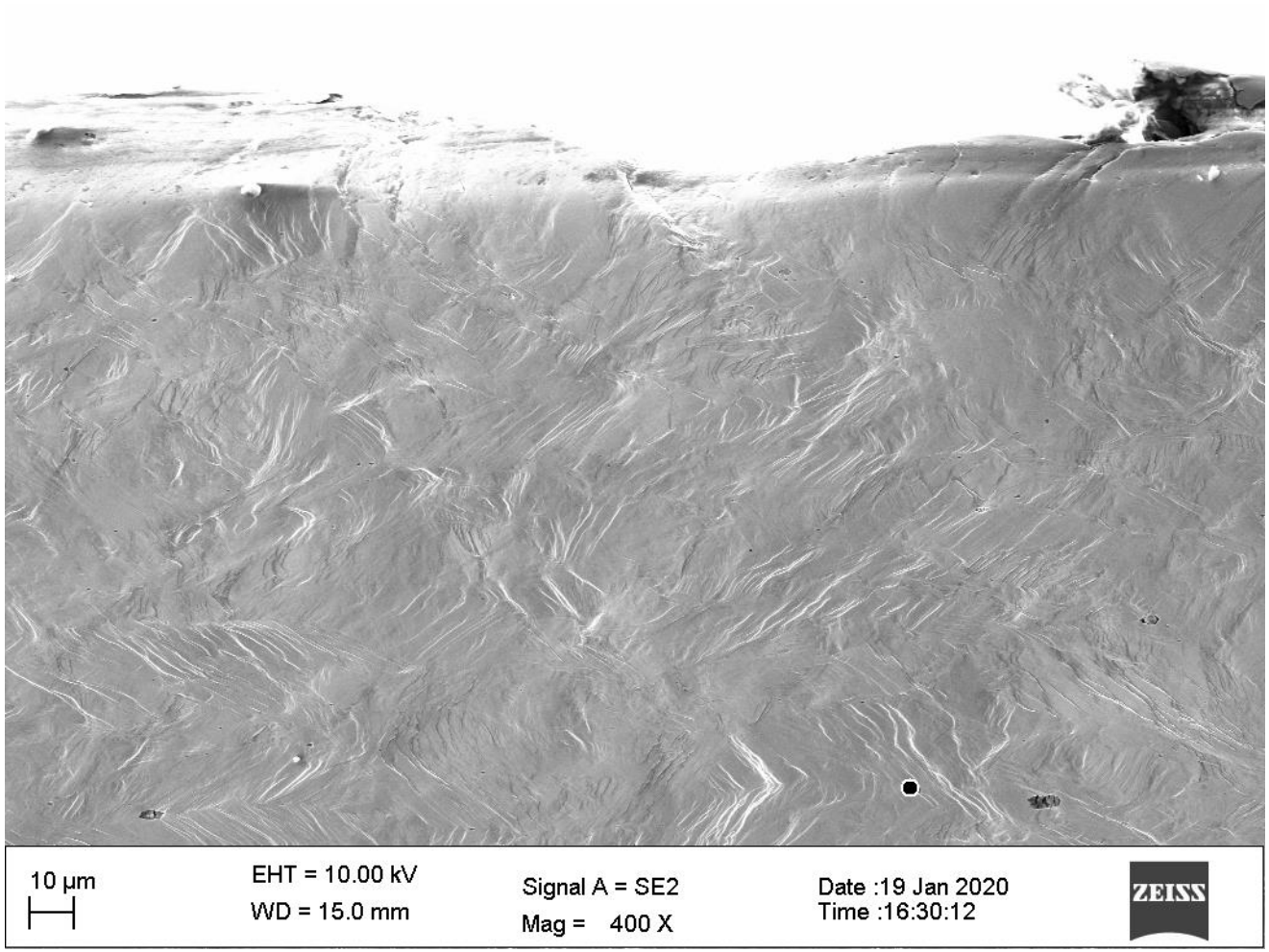

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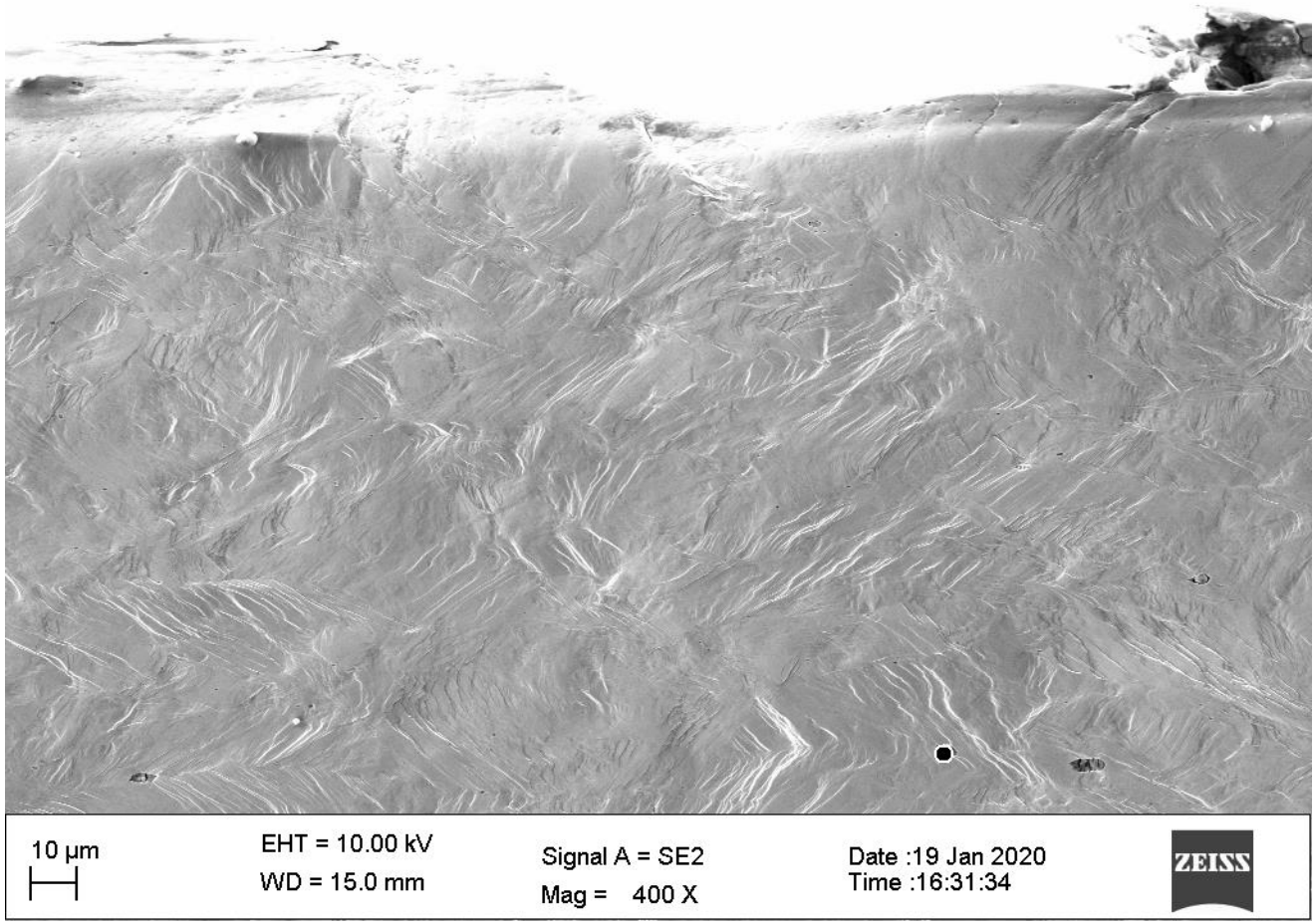

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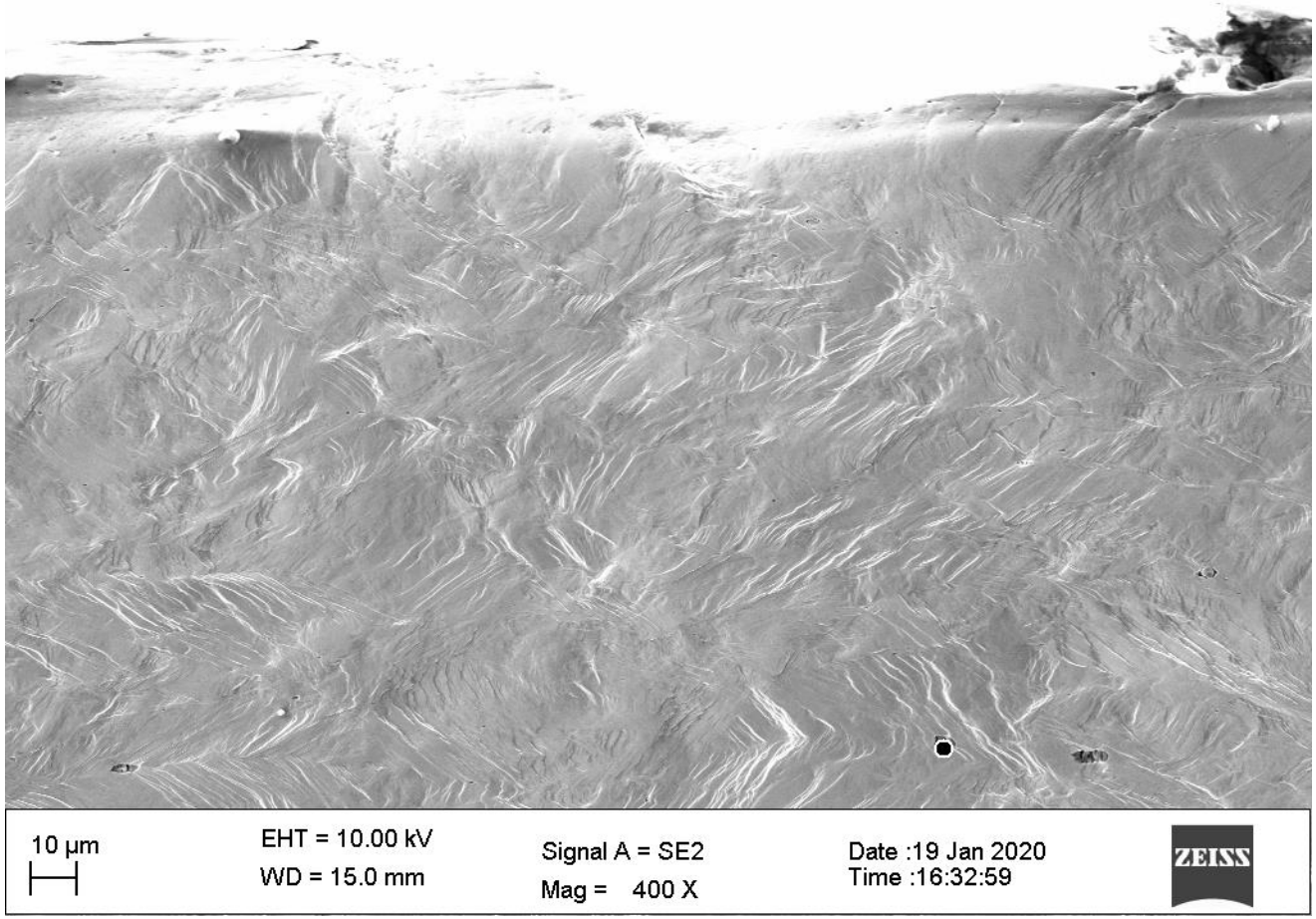

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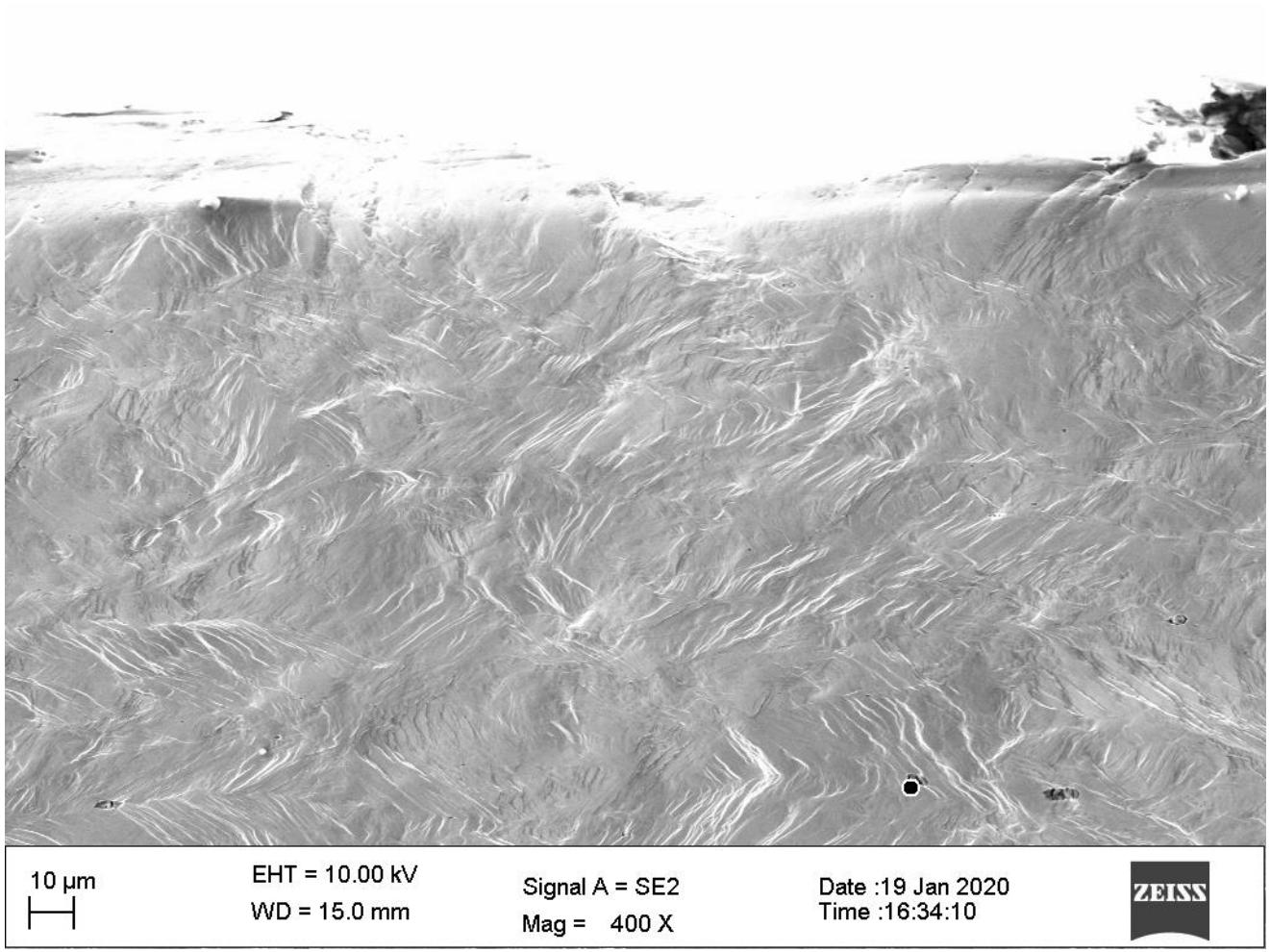

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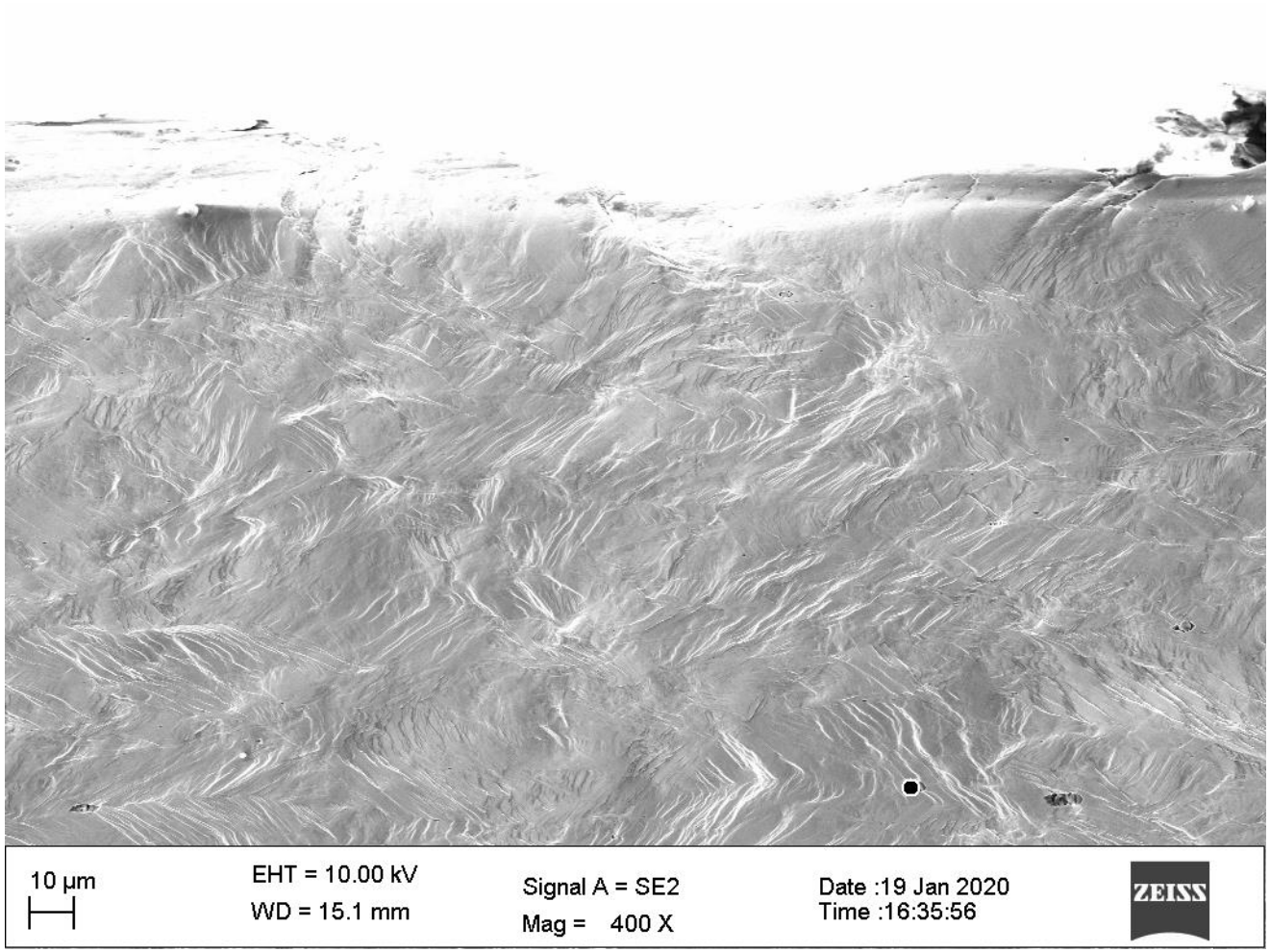
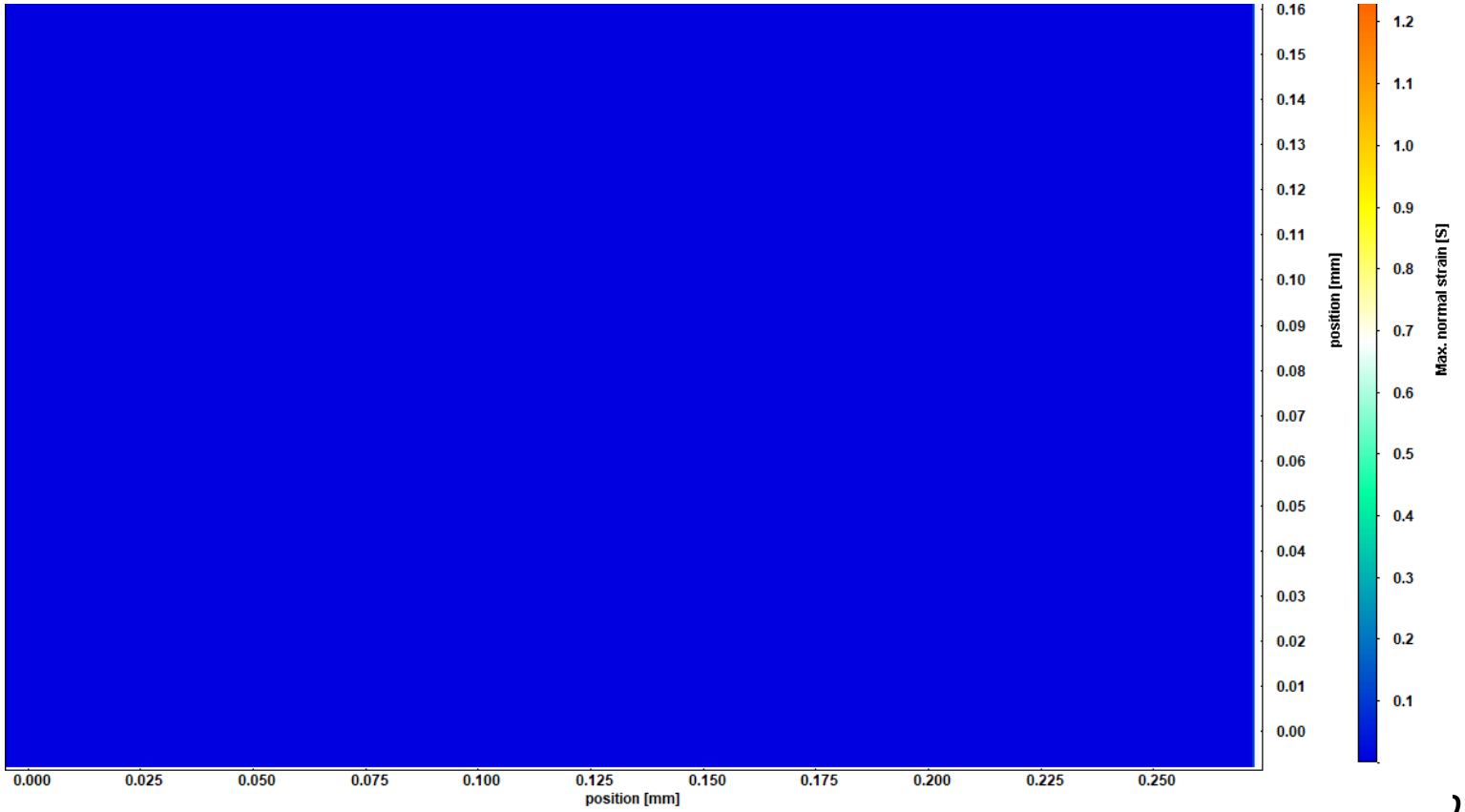


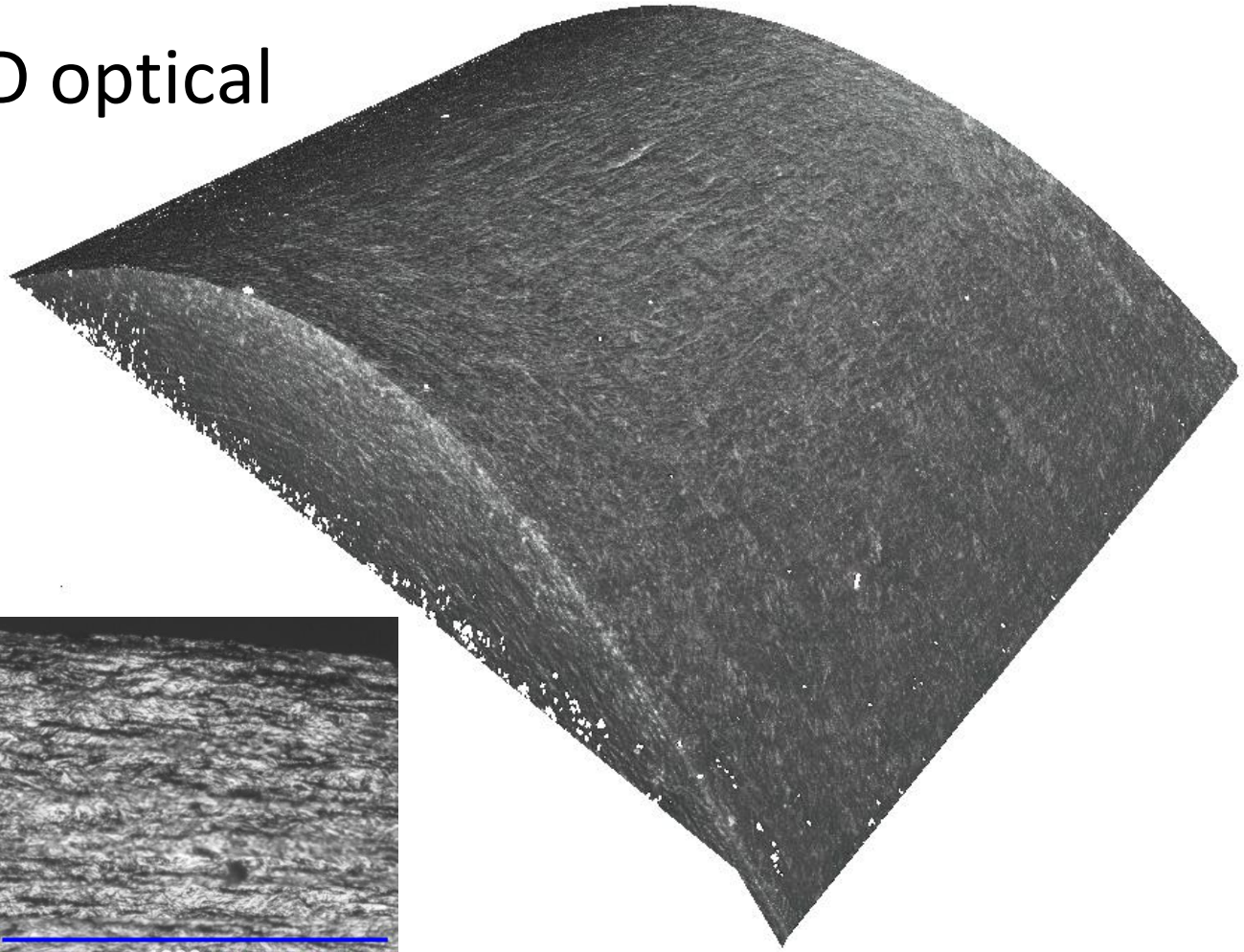
2mm sample 1 – DIC strain analysis

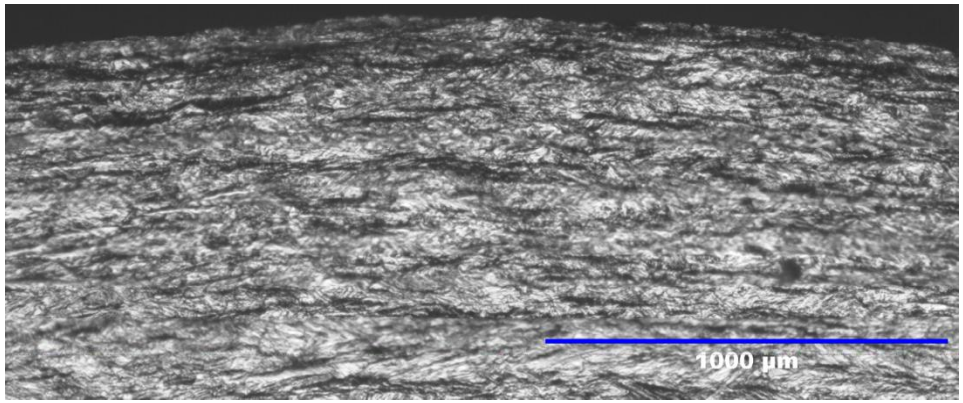
- Strain localisation shown using DAVIS 8 DIC analysis software.



Strain Analysis

- Post test 3D optical images.





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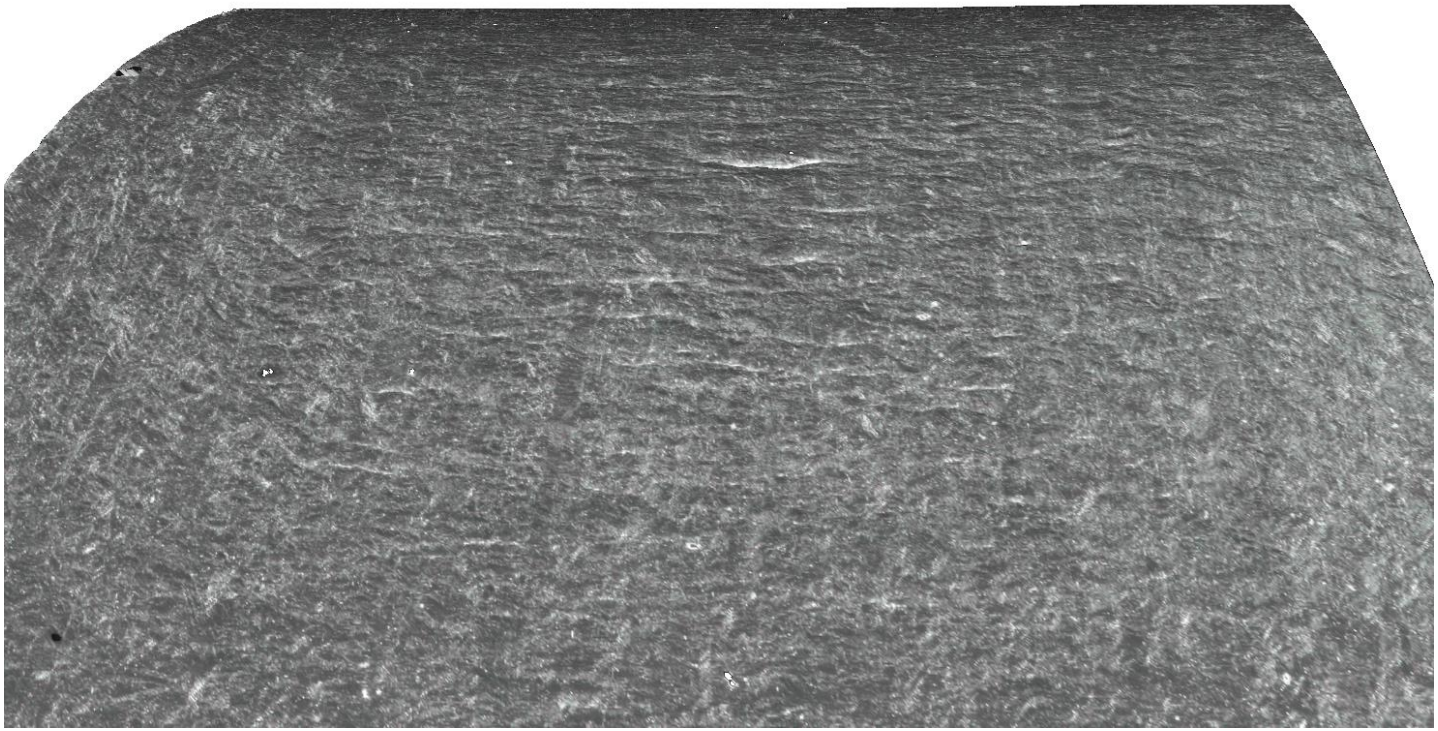

Summary

- Improved bending performance is a development area for S960 AHSS strip.
- Characterisation methods are being used to improve understanding of the structure-property-relationship.
- Compositional inhomogeneity has been identified and is being tested using DIC SEM bend testing.

Questions?