UNIVERSITY OF CAMBRIDGE

Understanding the Microstructure of High Temperature Processed X80 Steel

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Department of Materials Science and Metallurgy

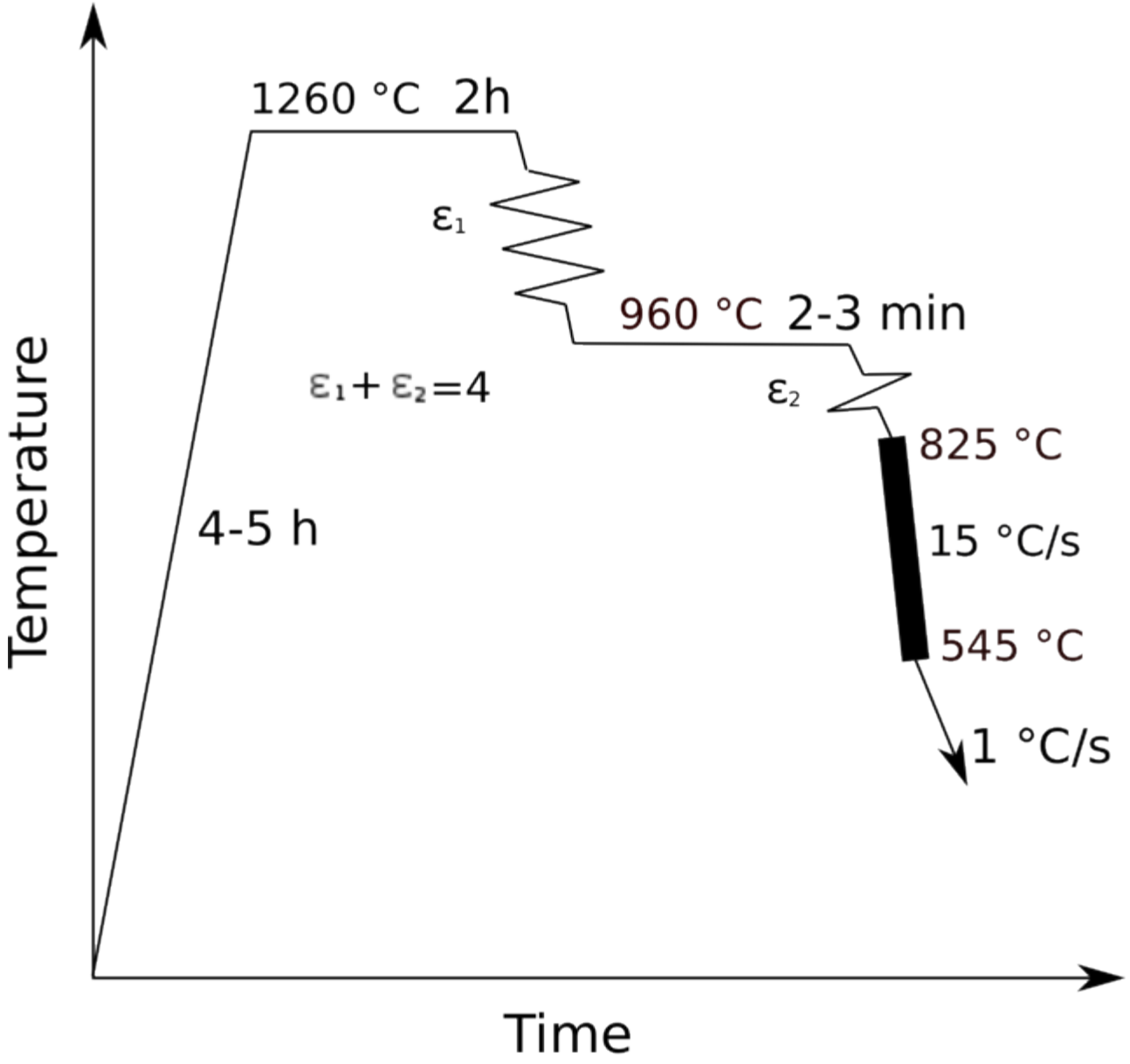
http://www.msm.cam.ac.uk/phase-trans/

Cheyenne plains pipelines

Chemical Composition in wt%

C	Mn	P	S	Si	Cu	Ni	Nb	Al	Cr	Ti	N	Ca
0.05	1.55	0.012	0.002	0.12	0.24	0.13	0.095	0.037	0.23	0.011	0.0033	0.0012

Industrial Processing Route

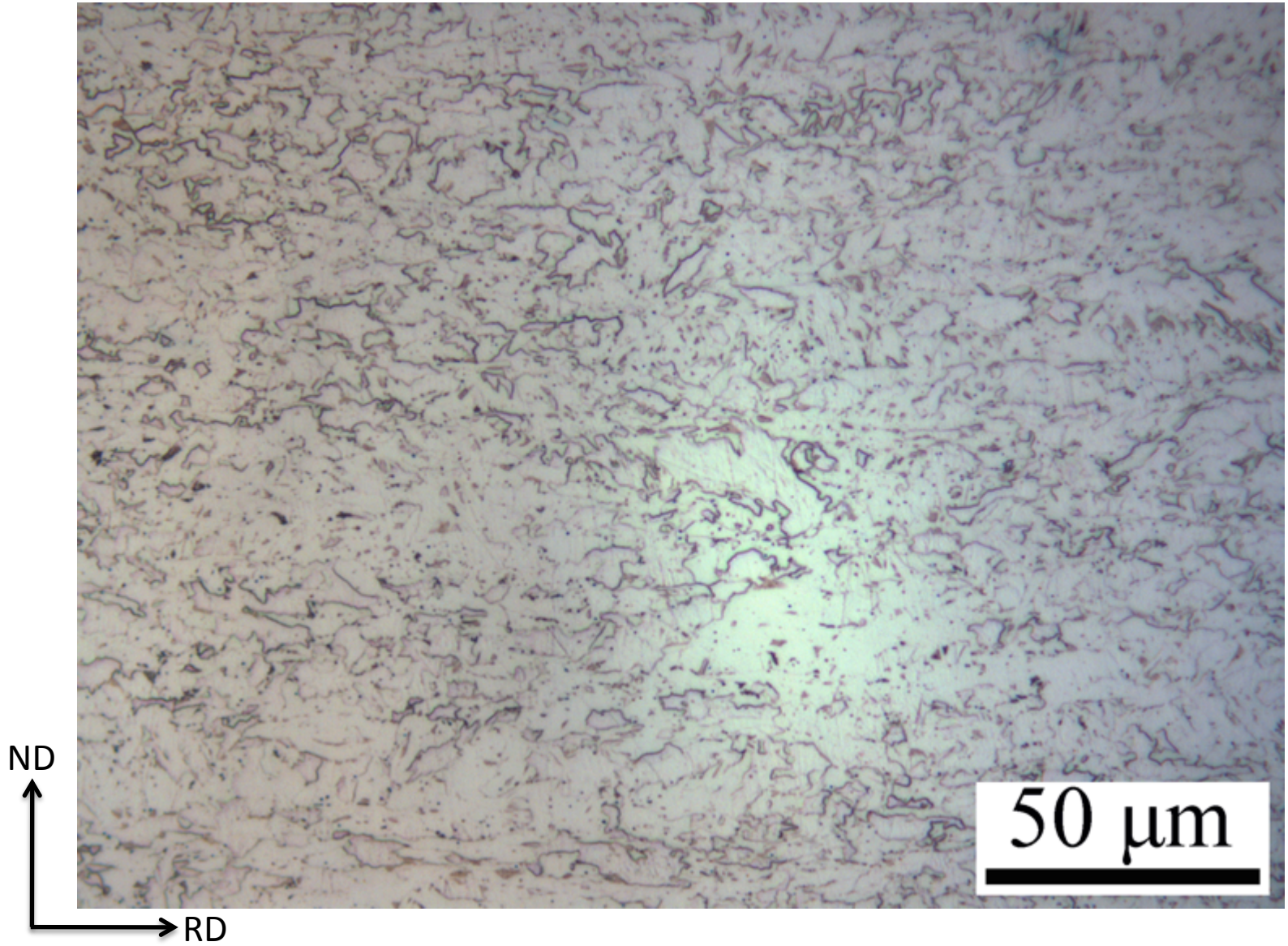


Outline

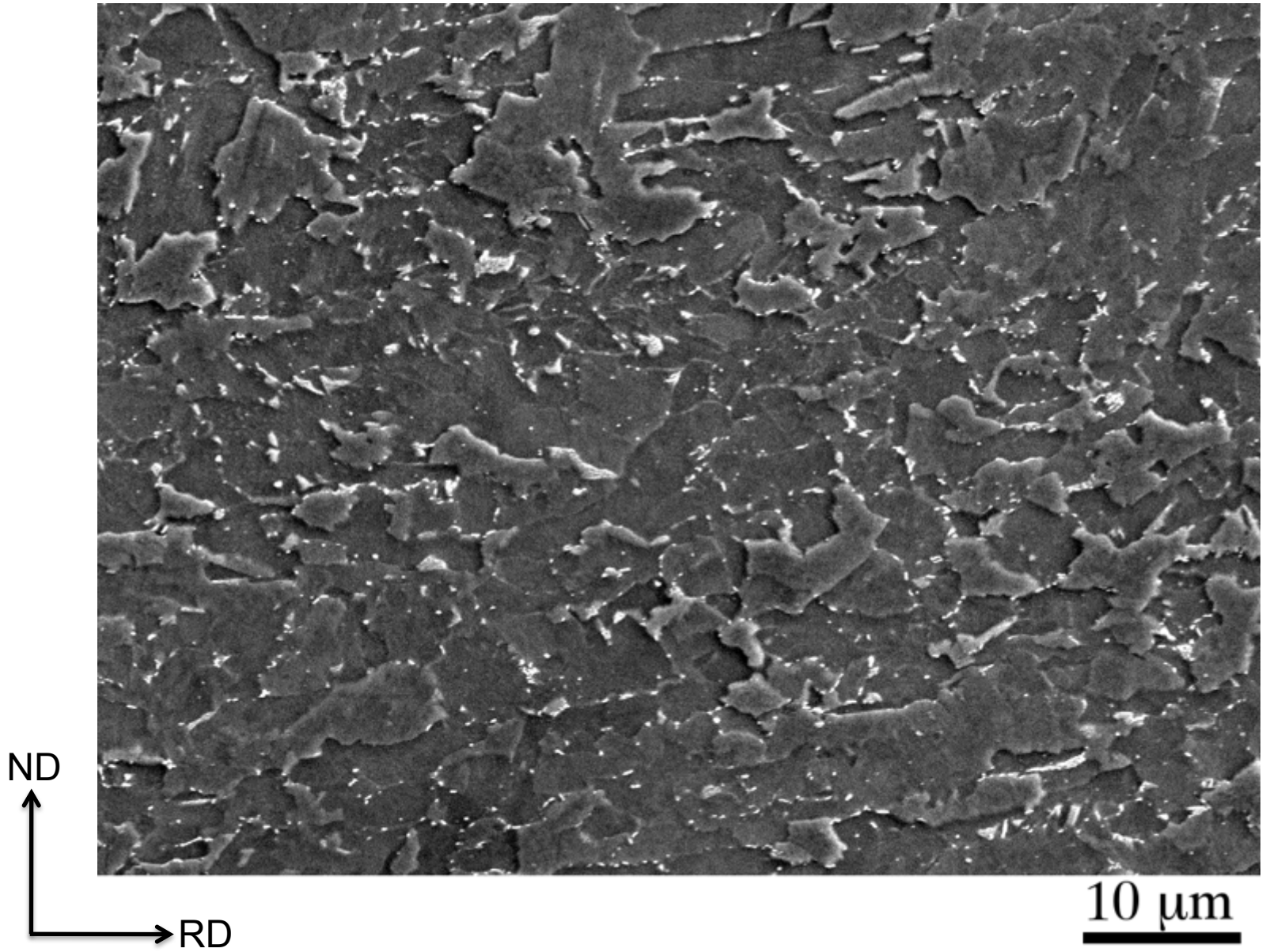
1. Microstructure of the as-received steel
2. Transformation mechanism
3. Effect of niobium on the transformation
4. Weld of the X80 steel

Optical Microscopy:

Irregular shaped ferrite resulted from thermomechanical processing

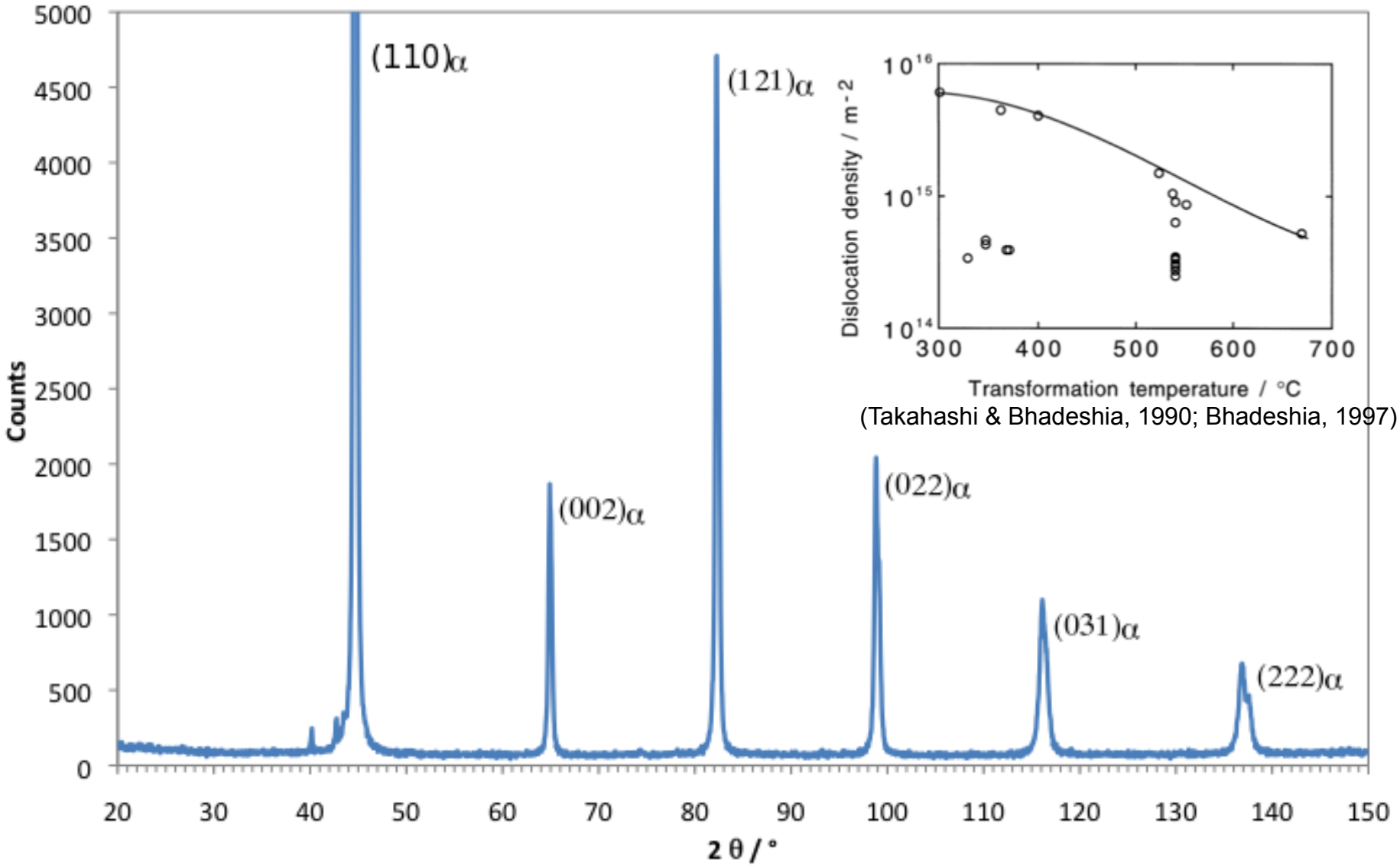


Scanning electron microscopy



Average grain size measured by intercept method: 4±0.2 µm

X-ray diffraction pattern

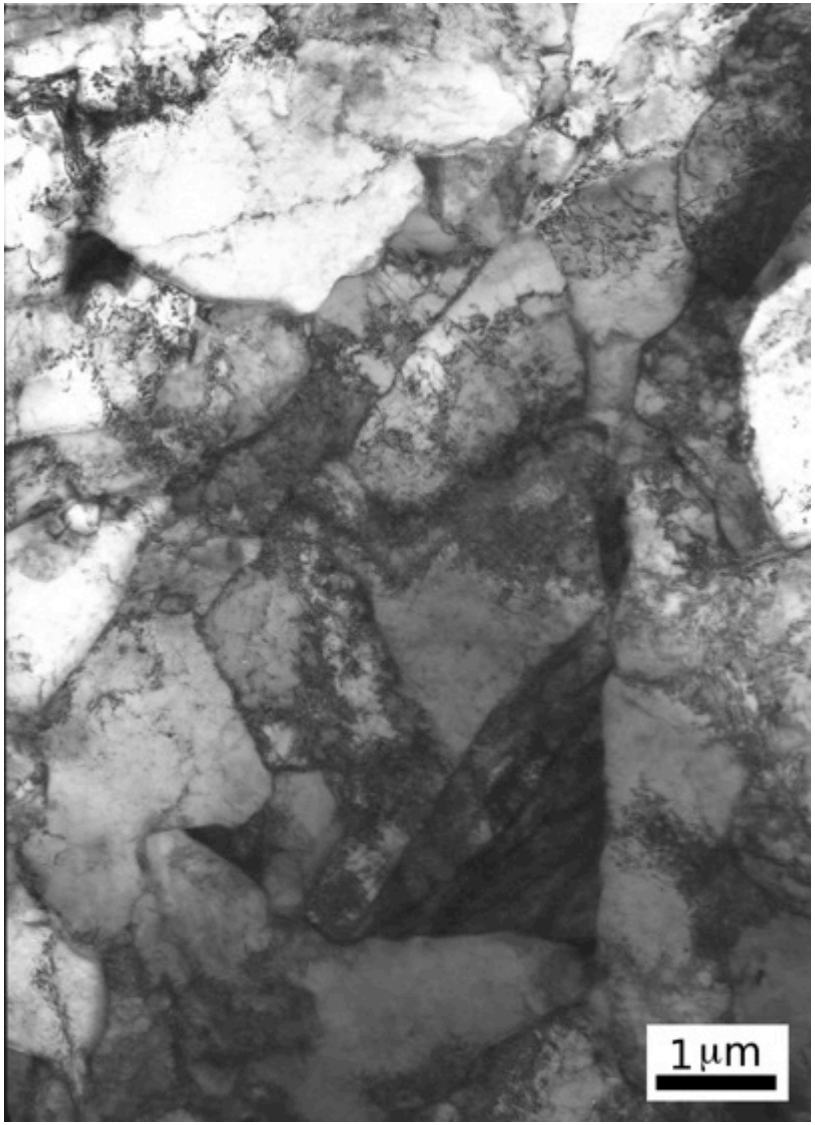


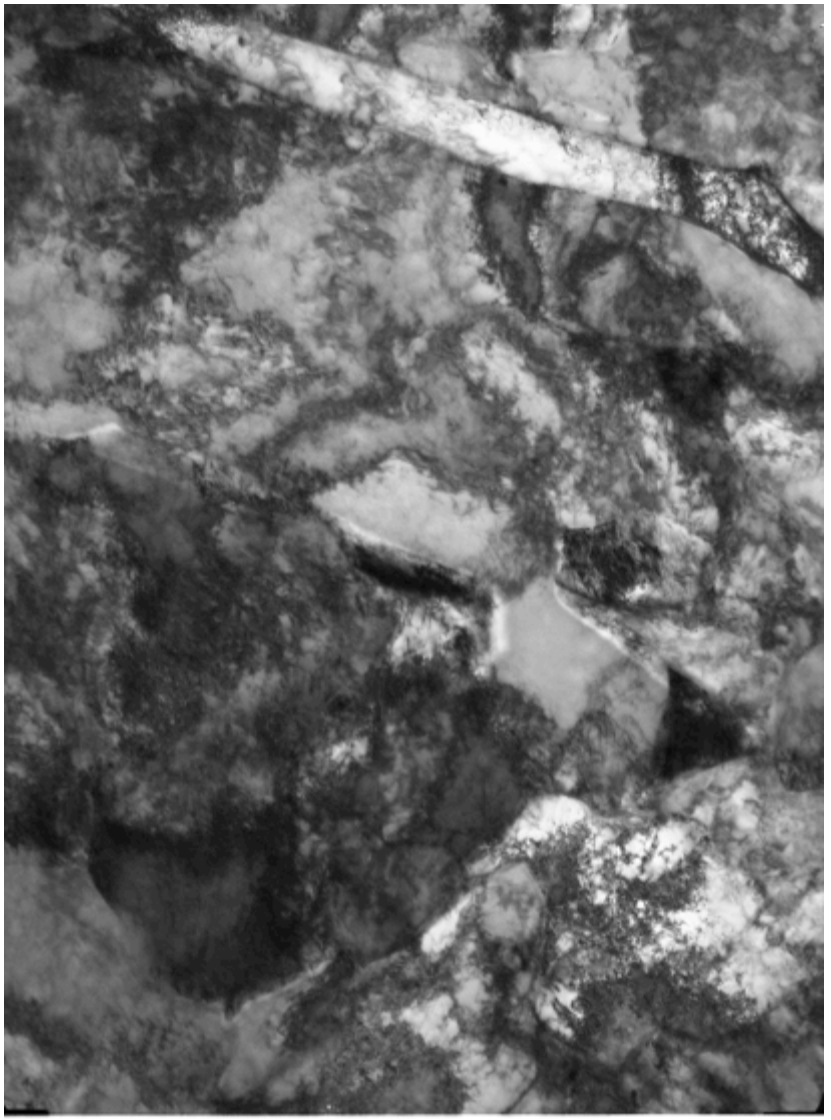
(Takahashi & Bhadeshia, 1990; Bhadeshia, 1997)

Dislocation Density is estimated at $1.4X10^{14}$ m^{-2}

Transmission Electron Microscopy

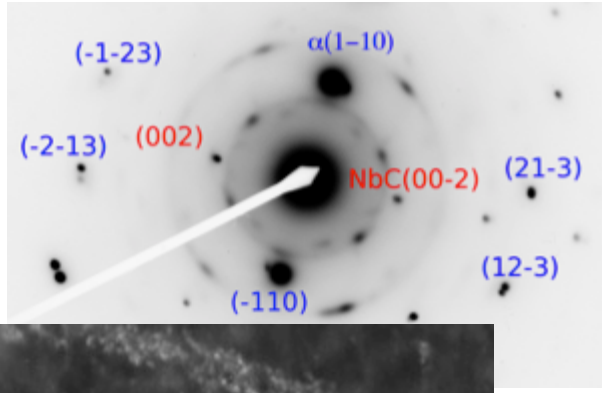
General Grain Structure

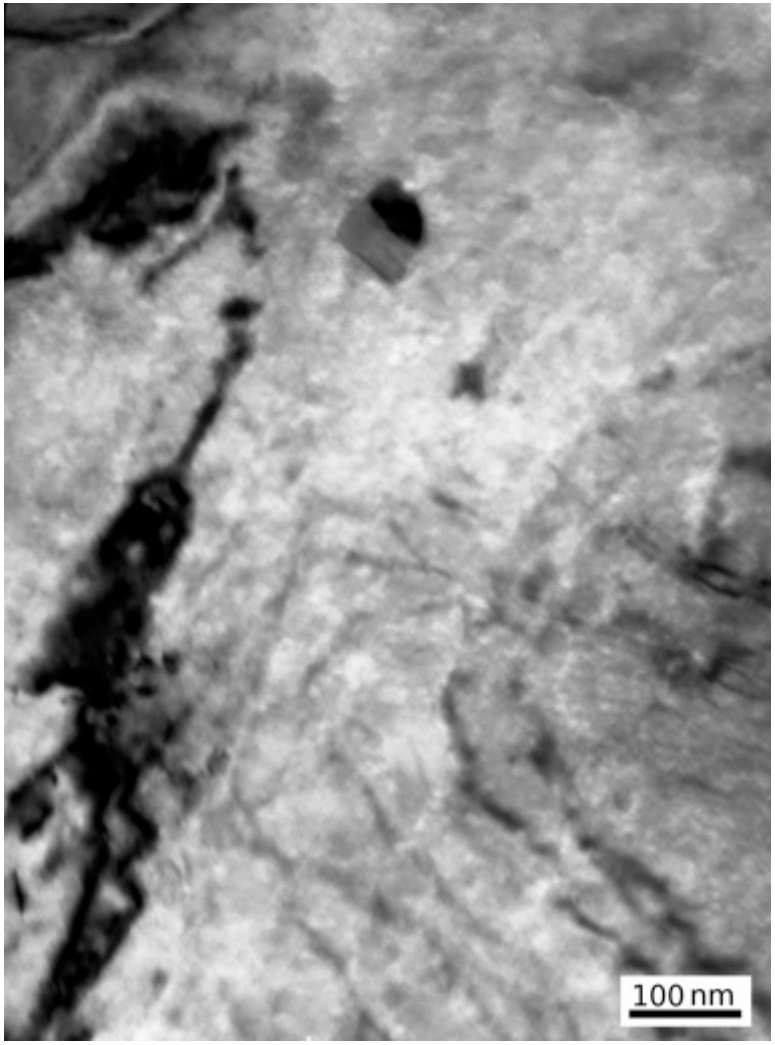


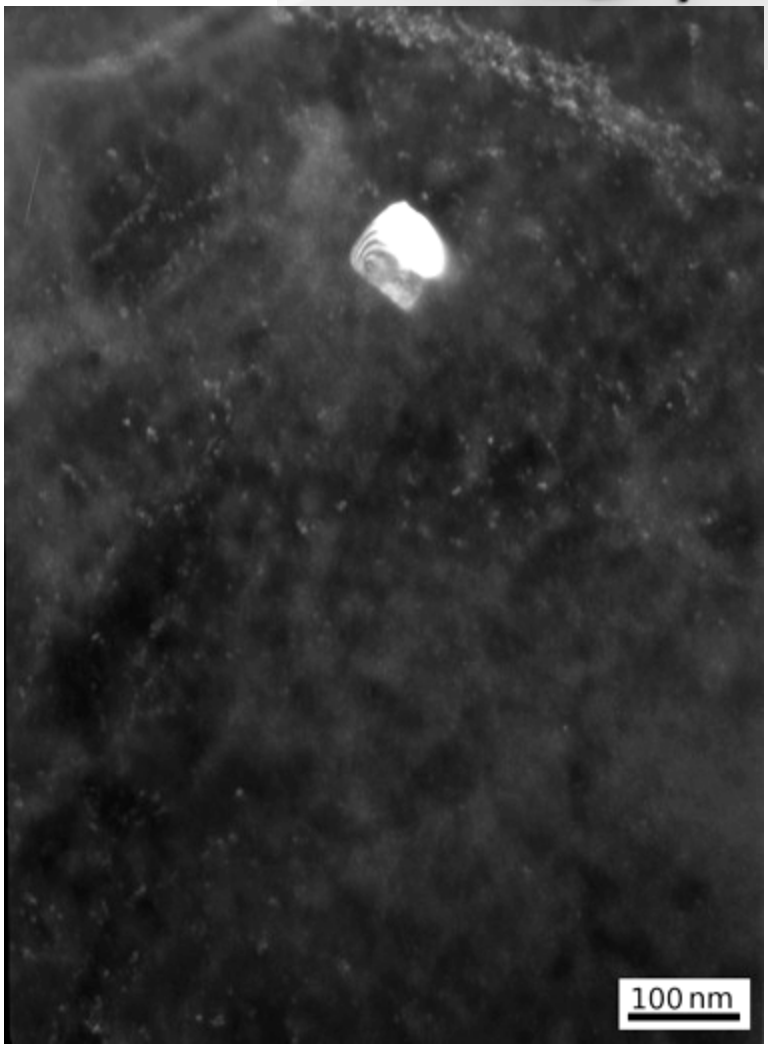


Bimodal size of NbC pecipitates

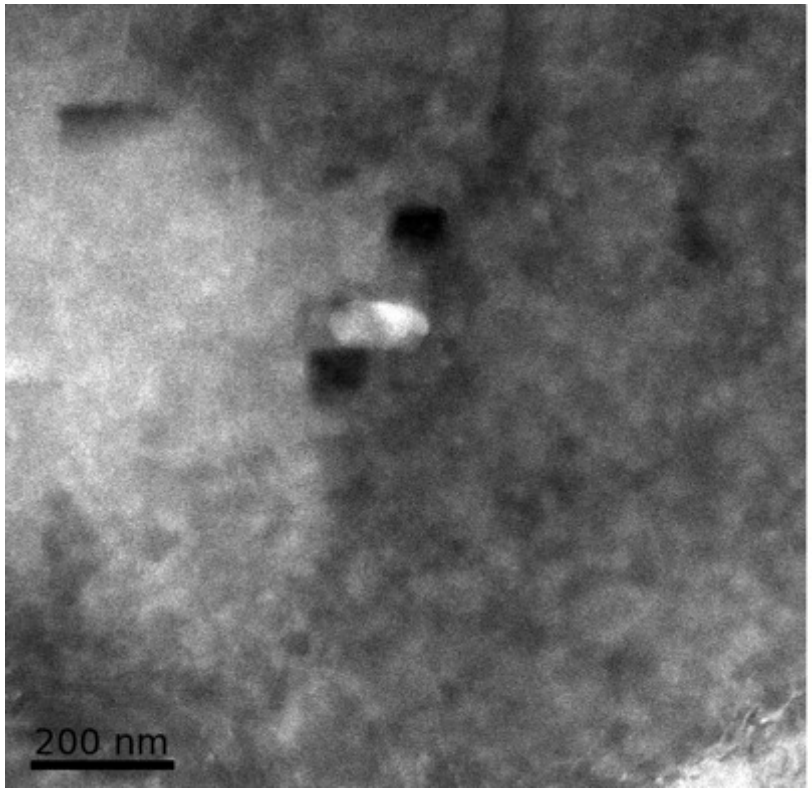
NbC[110]//α[111]
NbC(1-11)//α(0-11)
Small NbC <10 nm

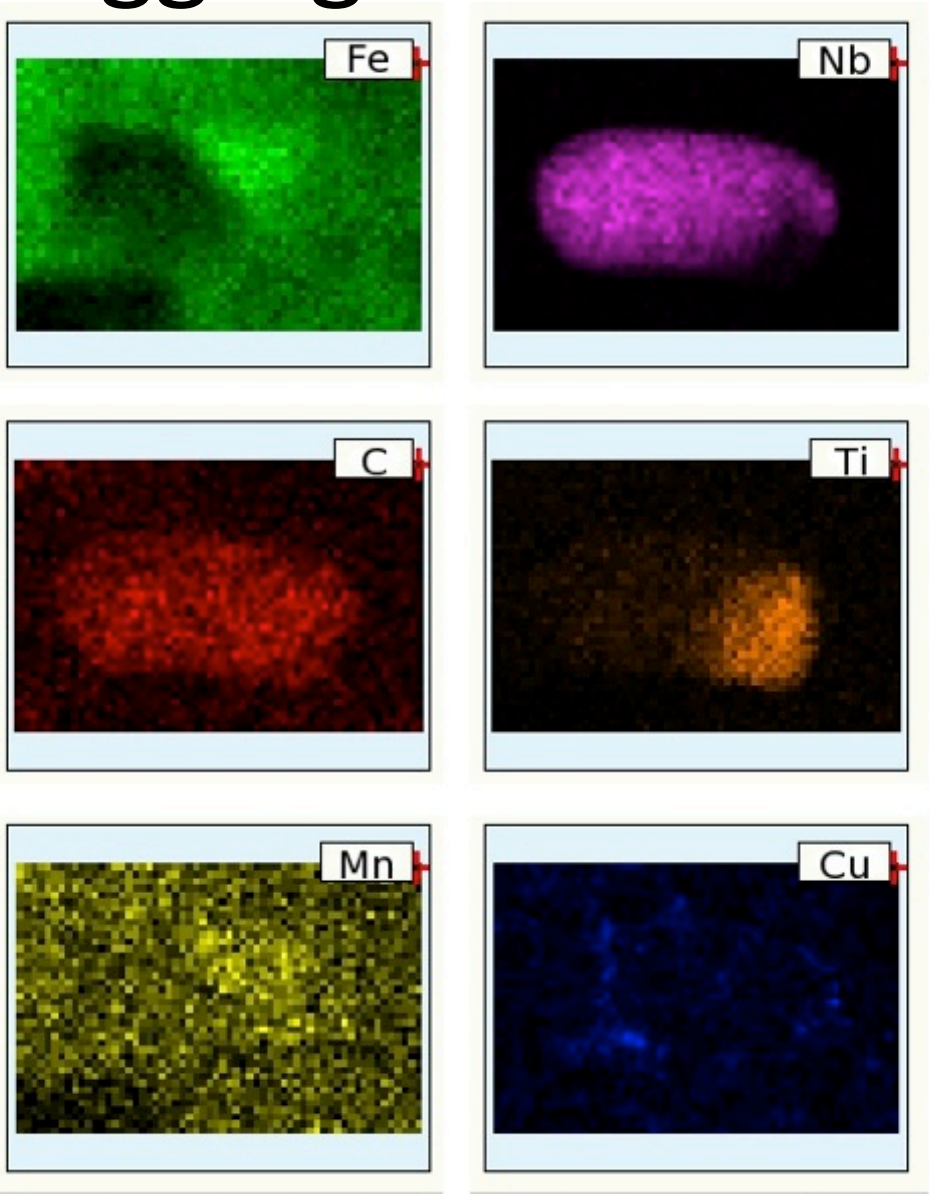






NbC TiCN aggregate



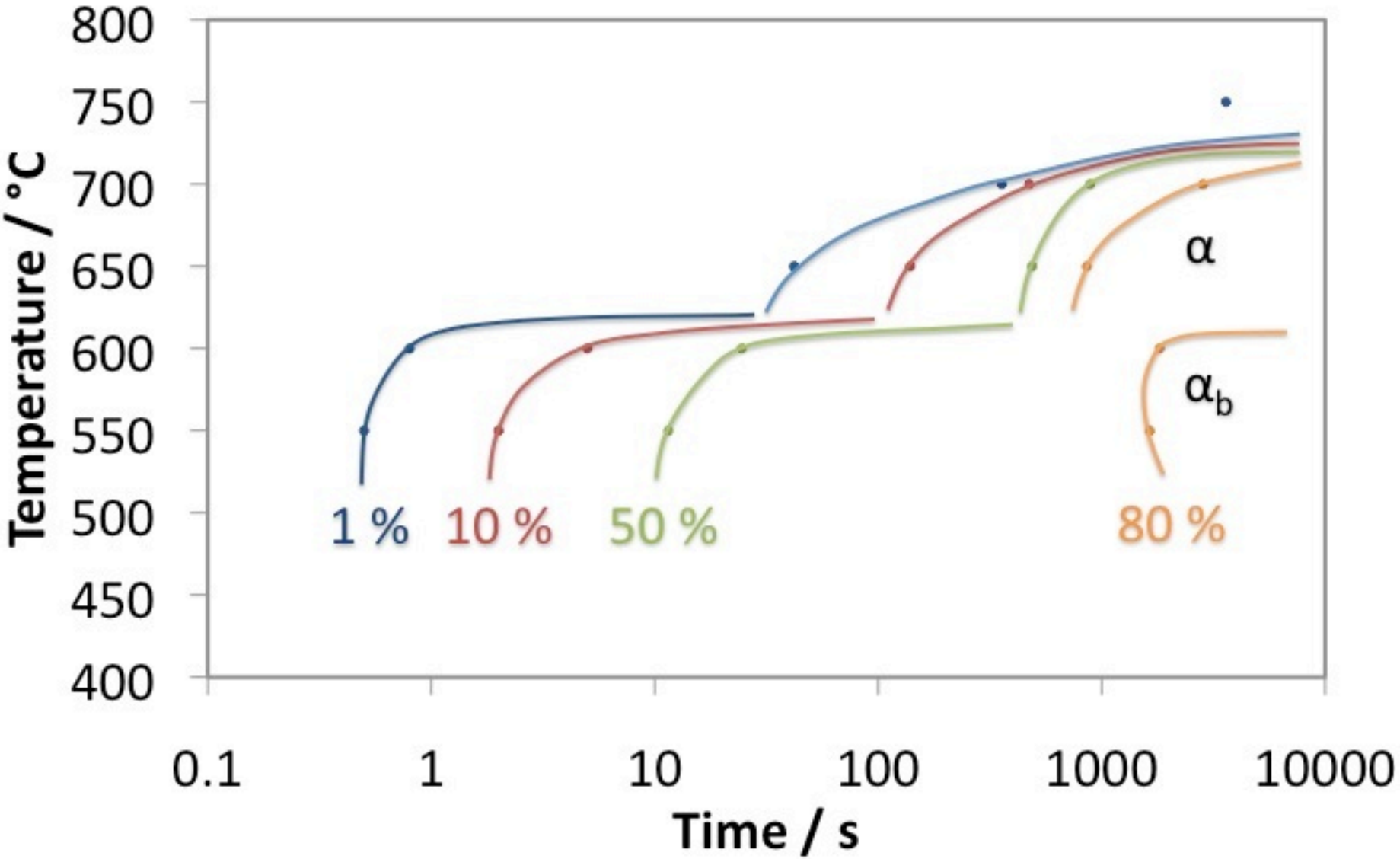


Composition of precipitates proved by EDAX on TEM with ultra-thin window X-ray detector

2. Transformation mechanism of the X80 steel

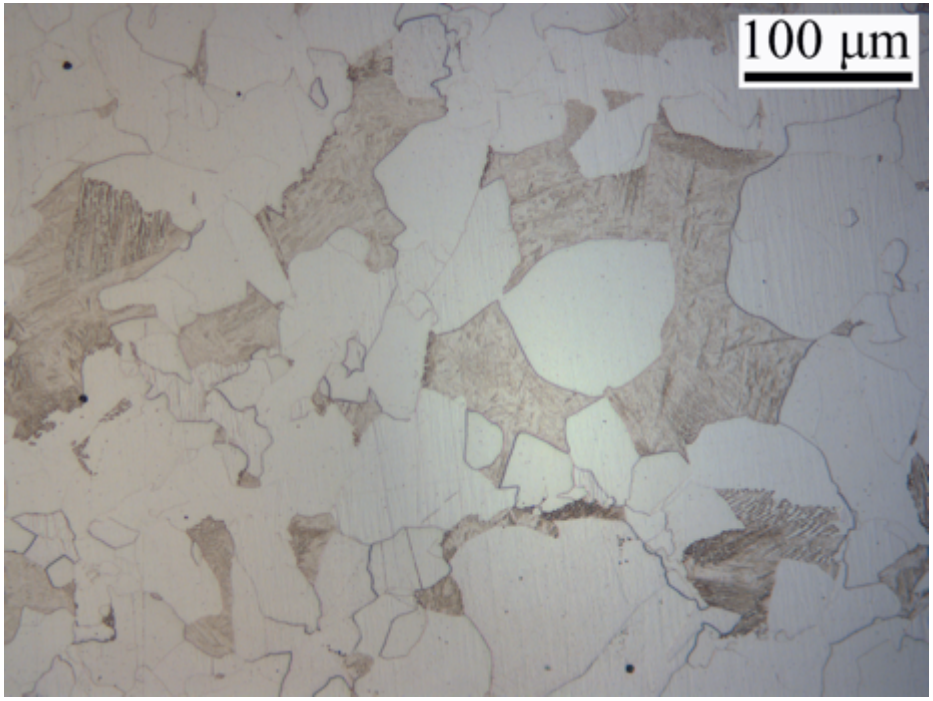
Prepared for submission to peer review journal

Time-Temperature-Transformation Diagram

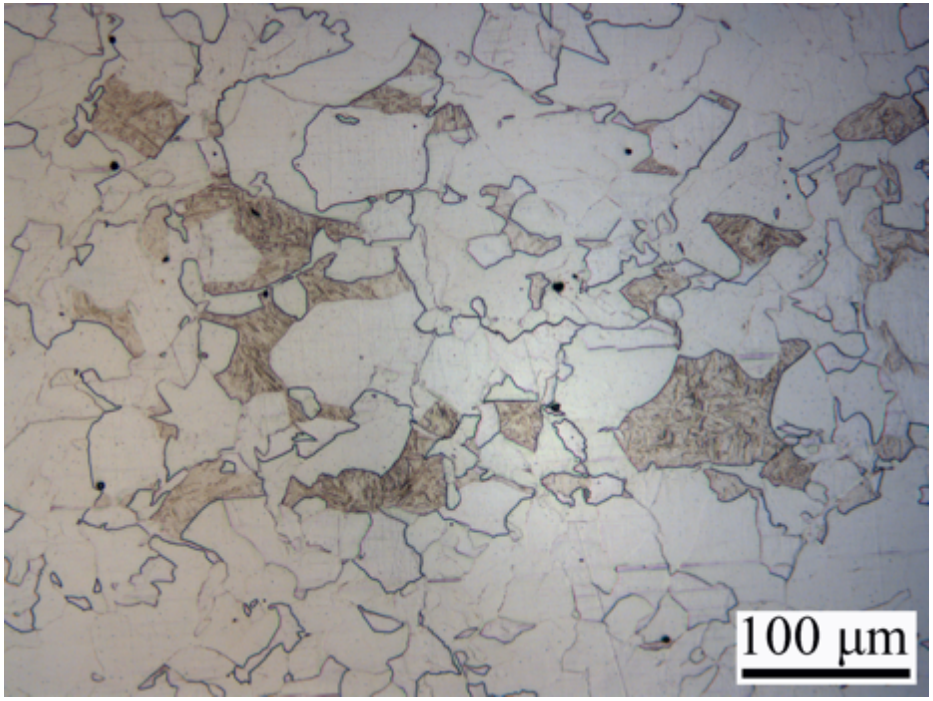


Allotriomorphic ferrite formed during 1 h isothermal holding at these temperatures and remaining austenite transformed to martensite upon cooling

700 °C

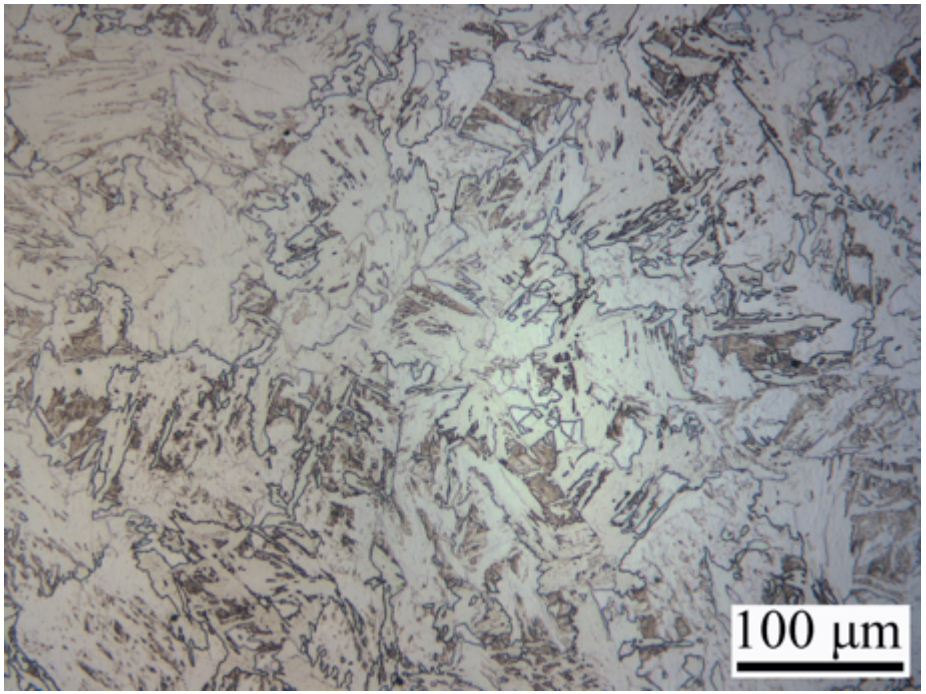


650 °C

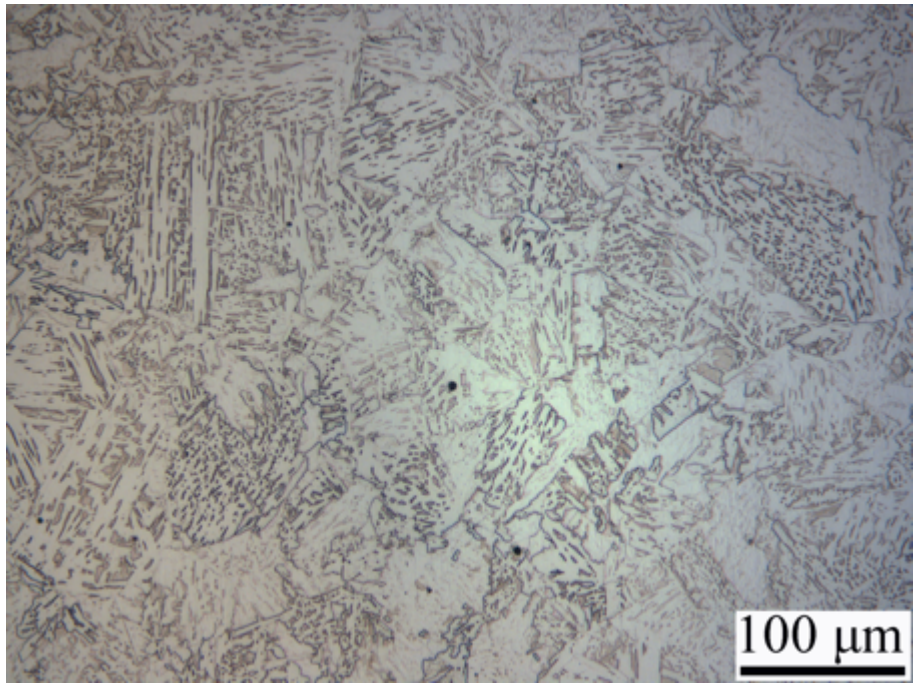


Bainite formed during 1 h isothermal holding at these temperatures:

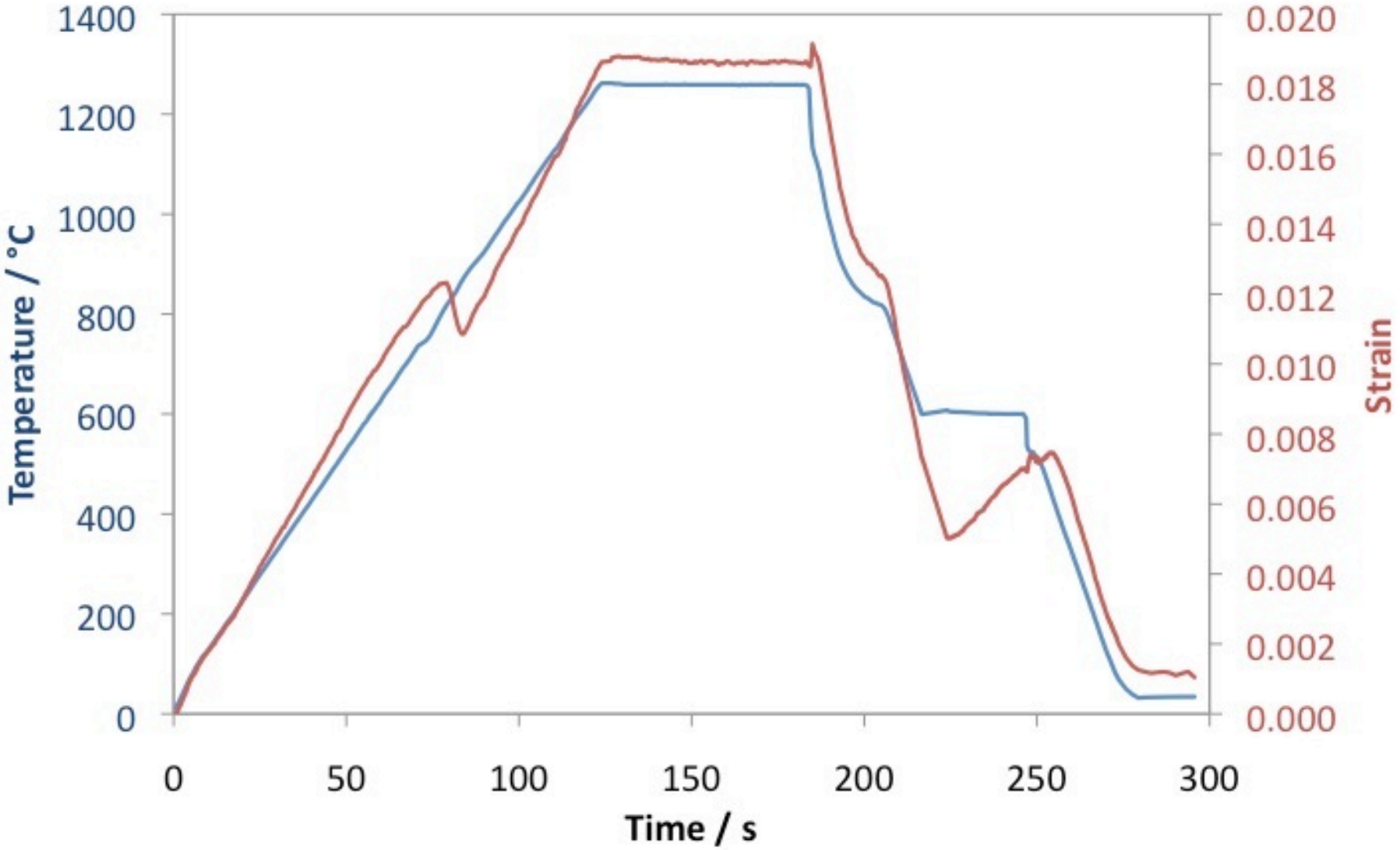
600 °C



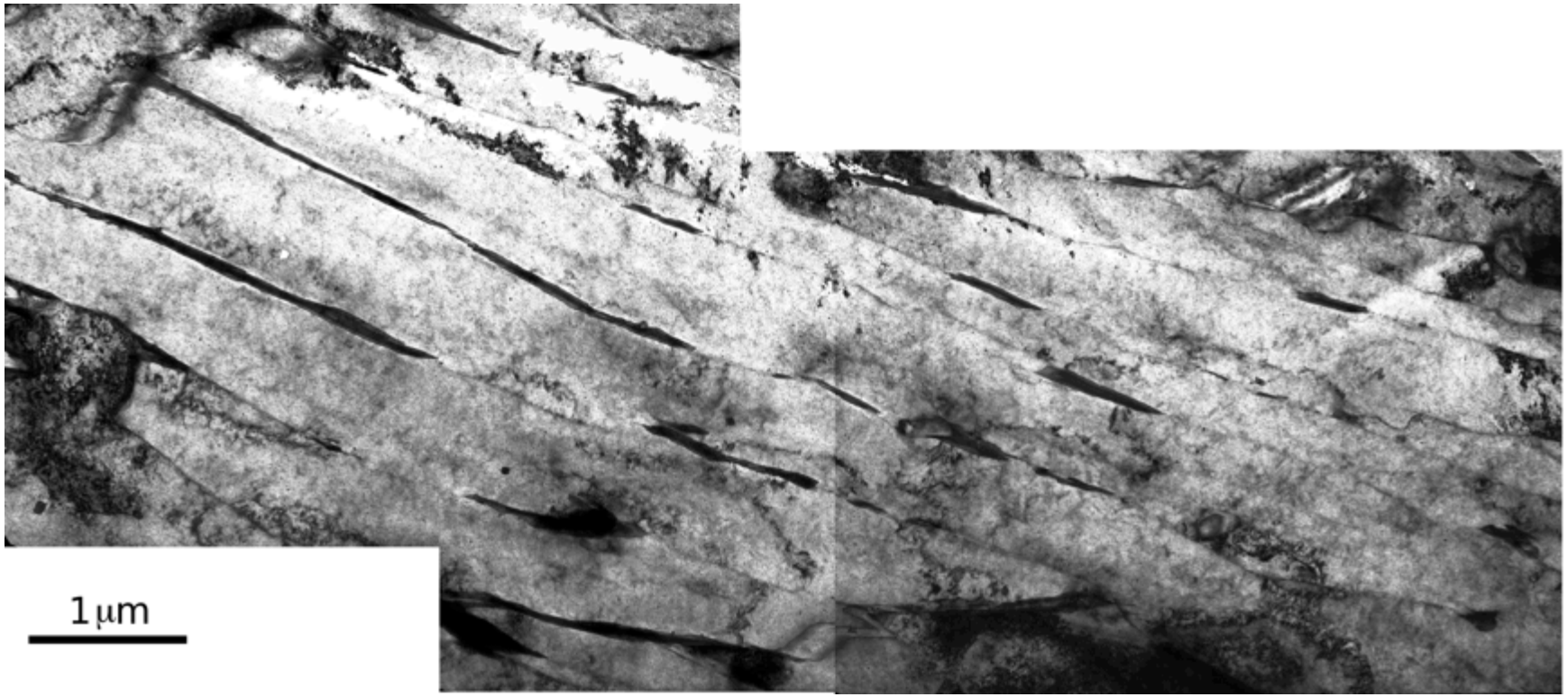
550 °C



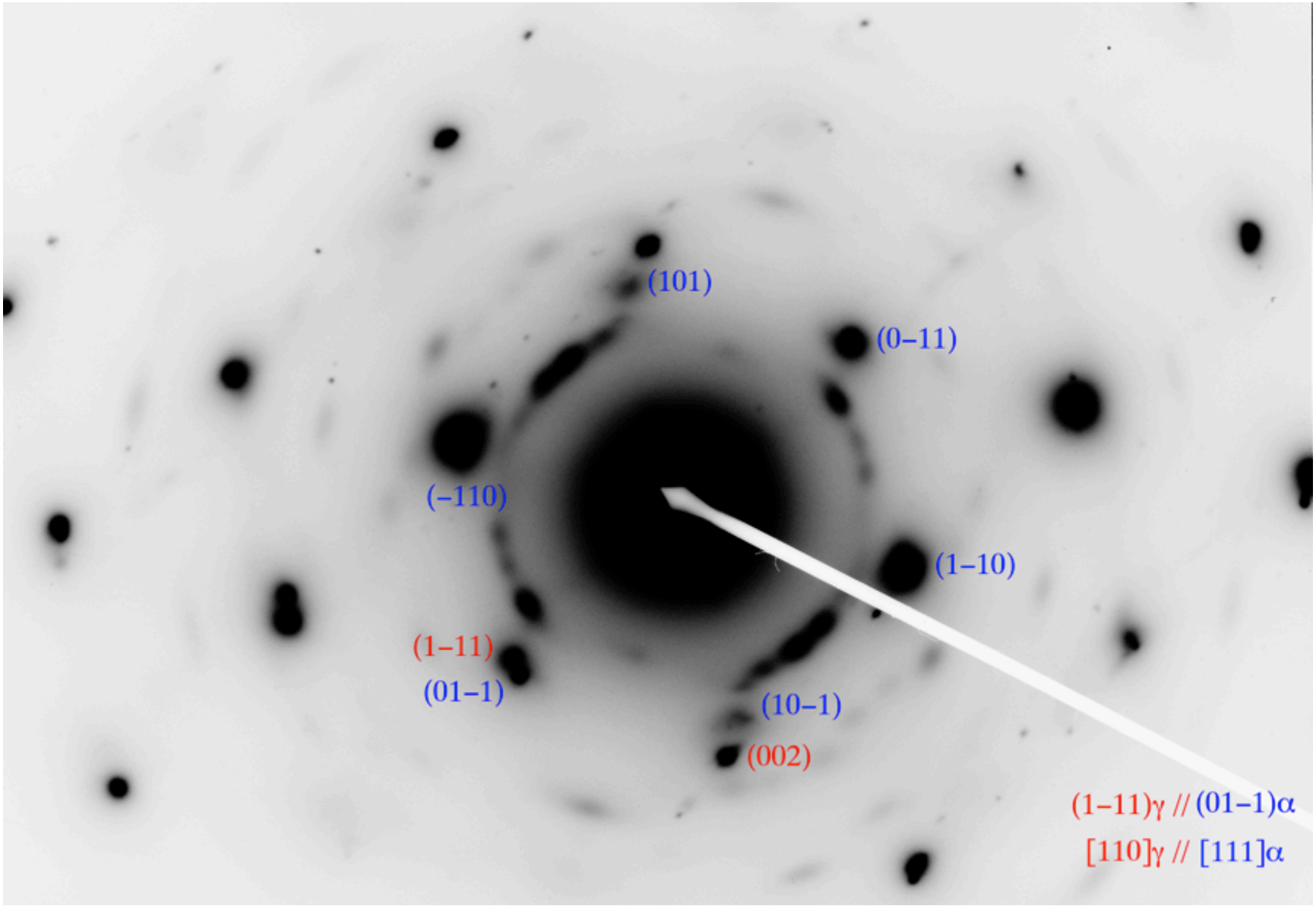
Isothermal transformation at 600 °C for 30 s



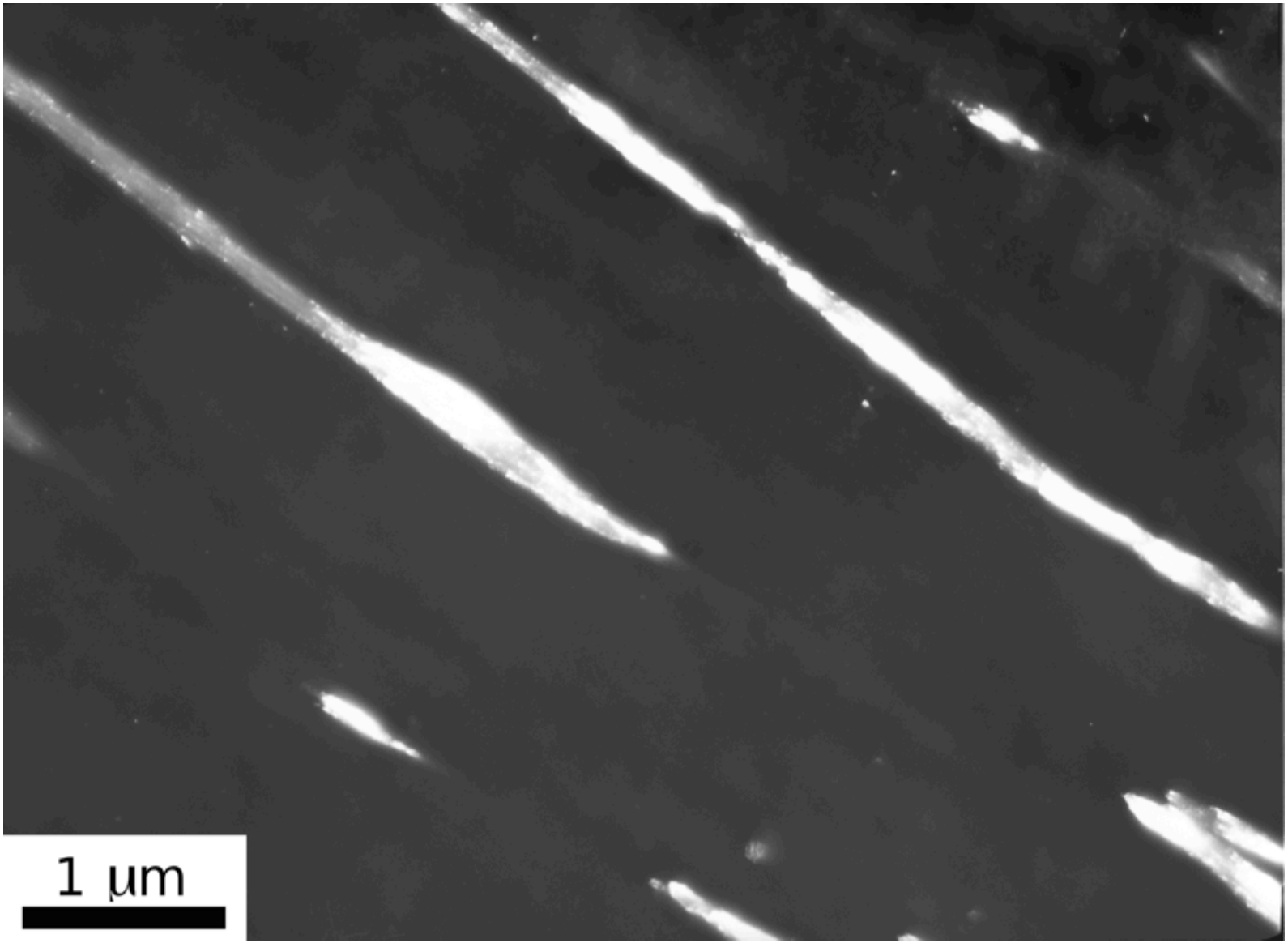
Transmission electron micrograph



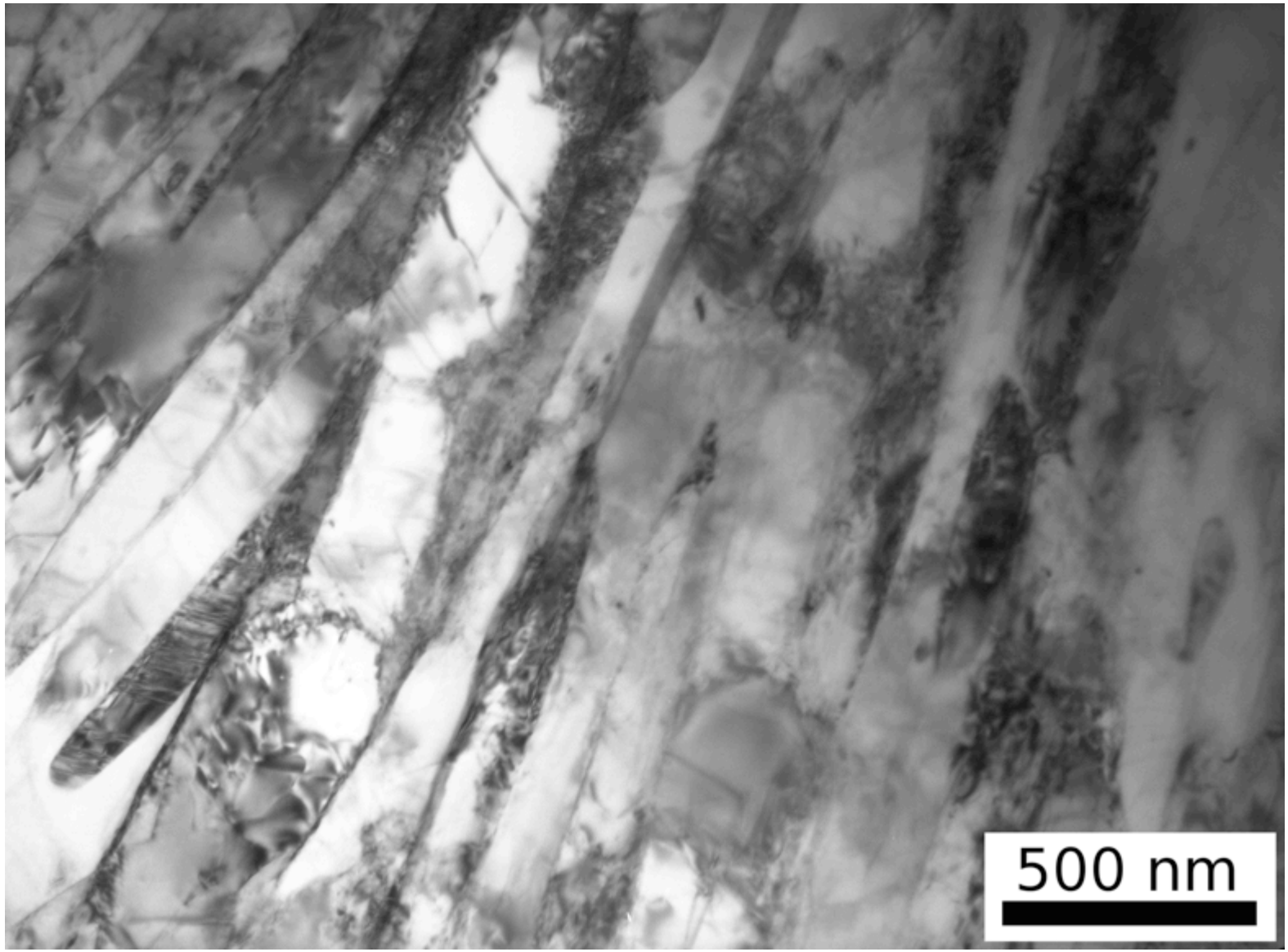
Diffraction Pattern



Dark field image

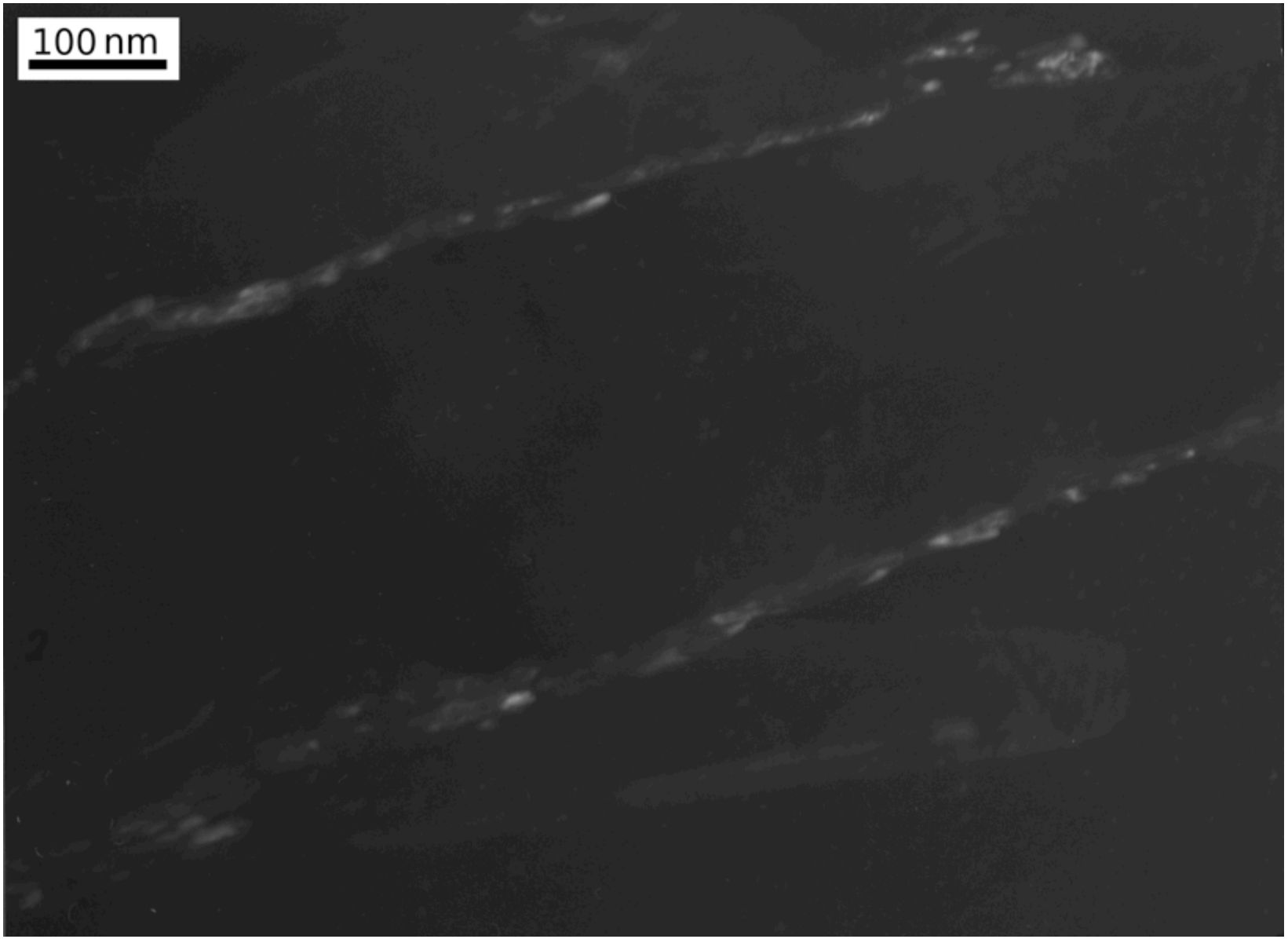


After holding at 600 °C for 1h the bainite plates coalesced

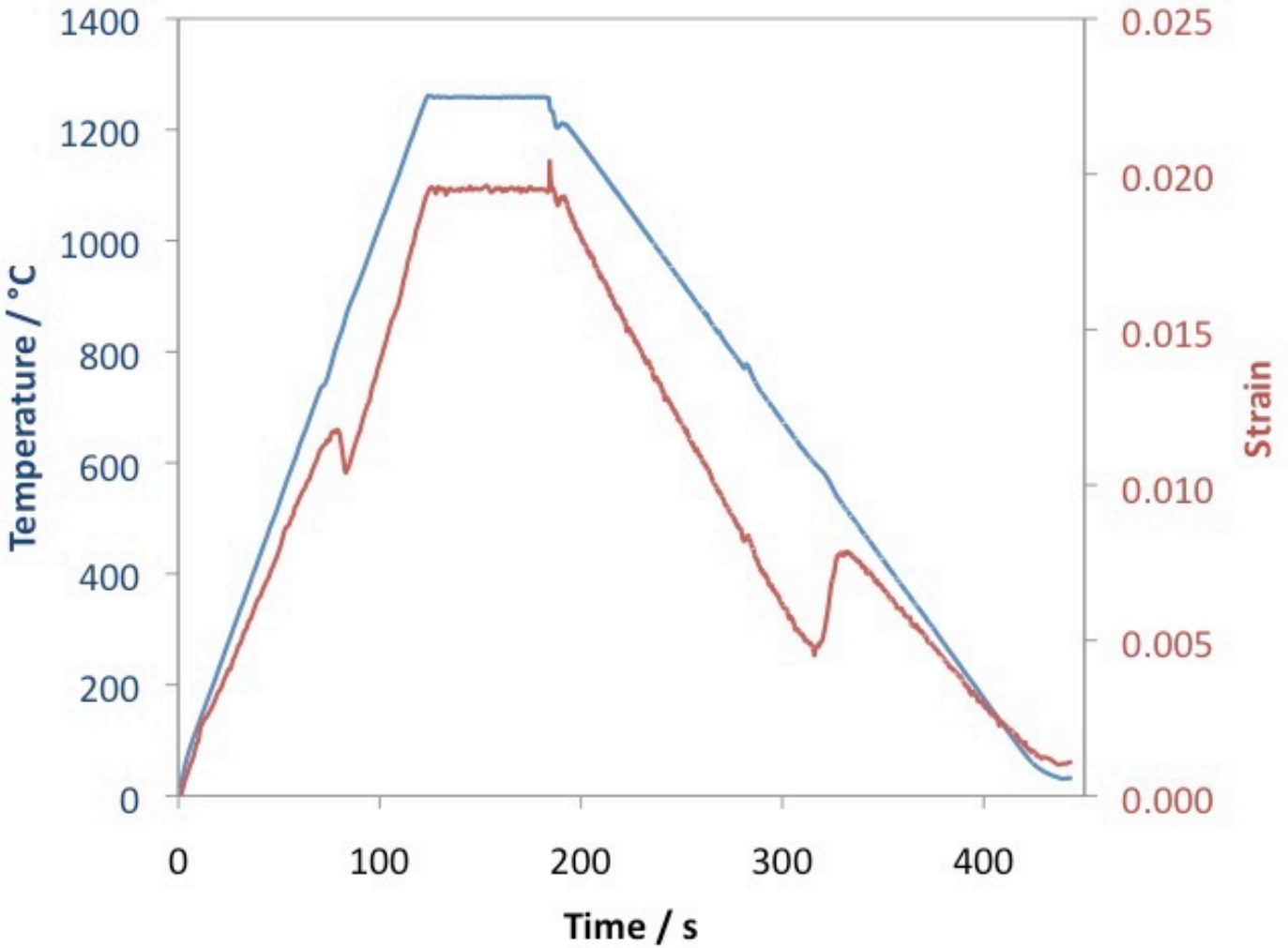


Bright field image of the sample which has been held at 600 °C for 1h

Dark field image shows decomposition of the austeniste

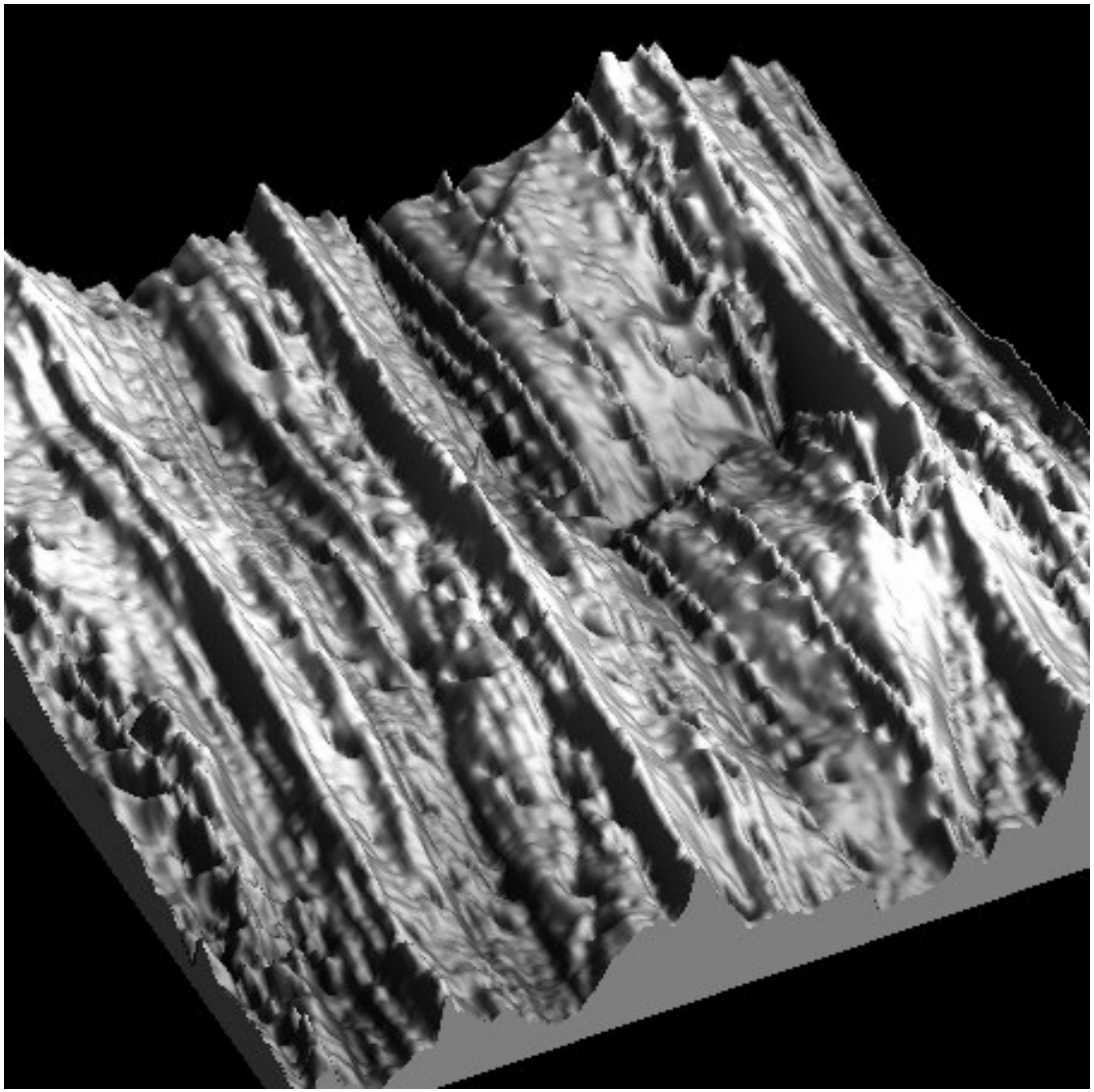


Another sample with a polished surface transformed in vacuum



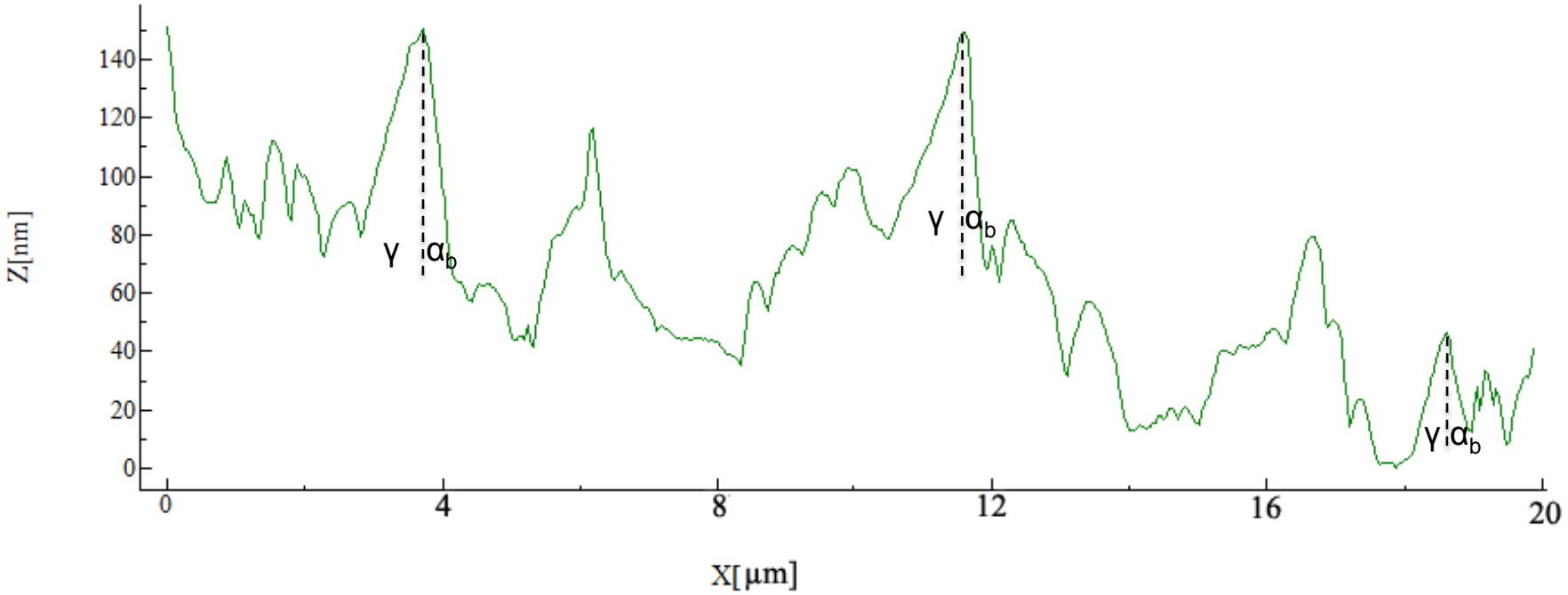
Transformation happened in the bainite region according to dilatometric curve

Surface relief of the bainite plates by atomic force microscopy



20X20 μm surface area, Maximum vertical height: 246 nm

Profile contour



Apparent shear S_A=0.182±0.059

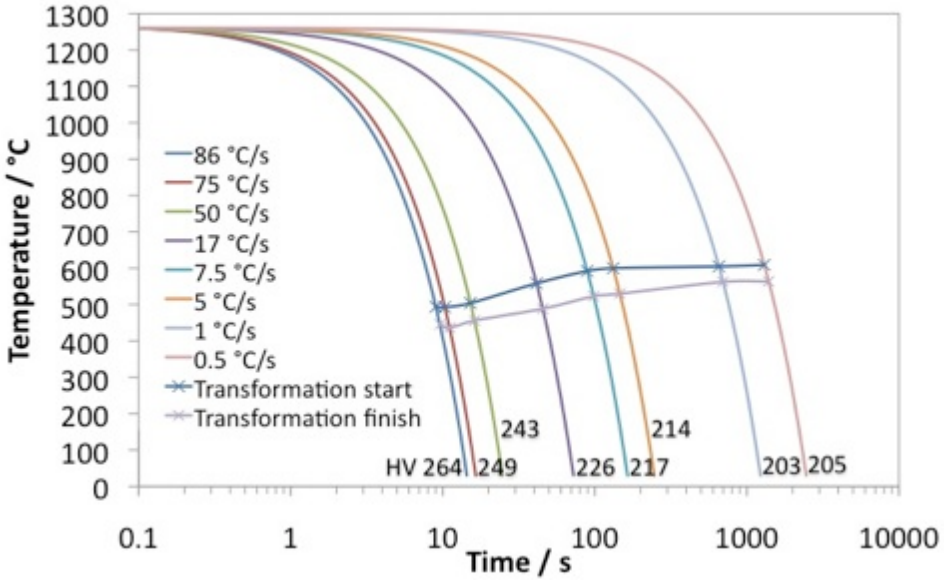
True shear can be considered as the maximum of apparent shear since the plates are inclined to the observed surface

3. Effect of niobium on the transformation

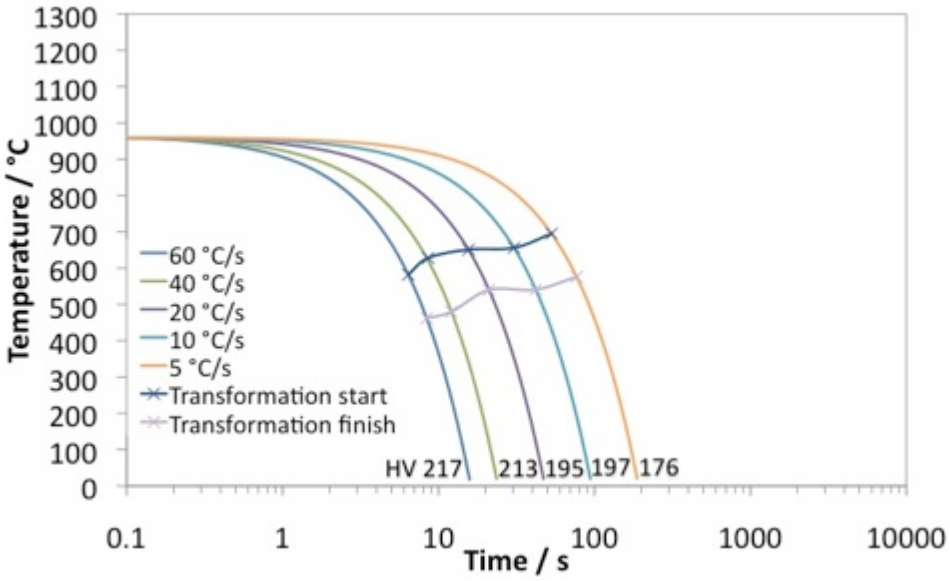
Prepared for submission to peer review journal

Continuous-Cooling-Transformation (CCT) Diagrams

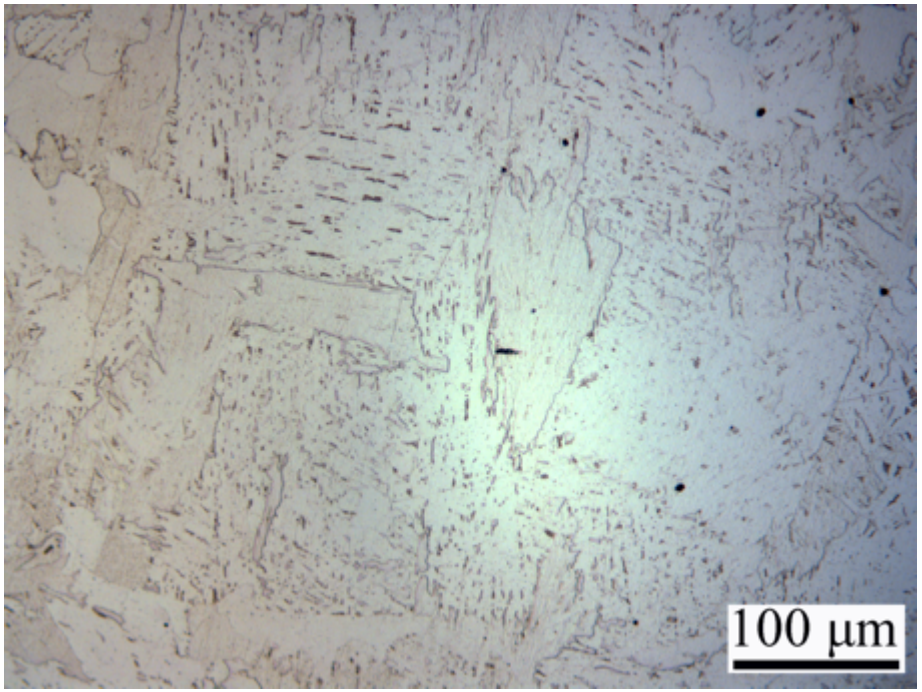
From 1260 °C



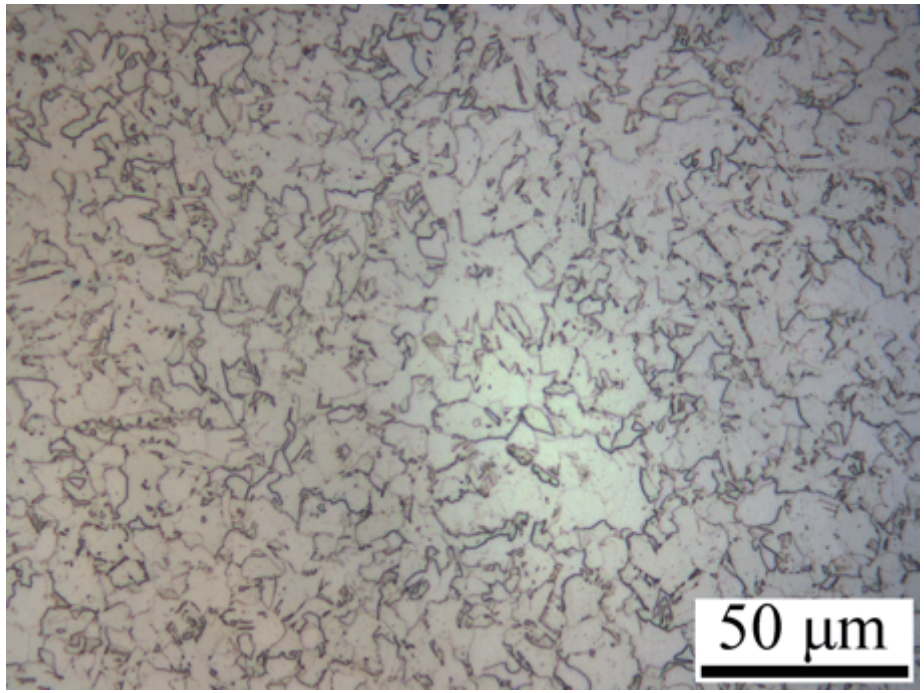
From 960 °C



Bainite formed upon cooling from 1260 °C at 0.5 °Cs^{-1}

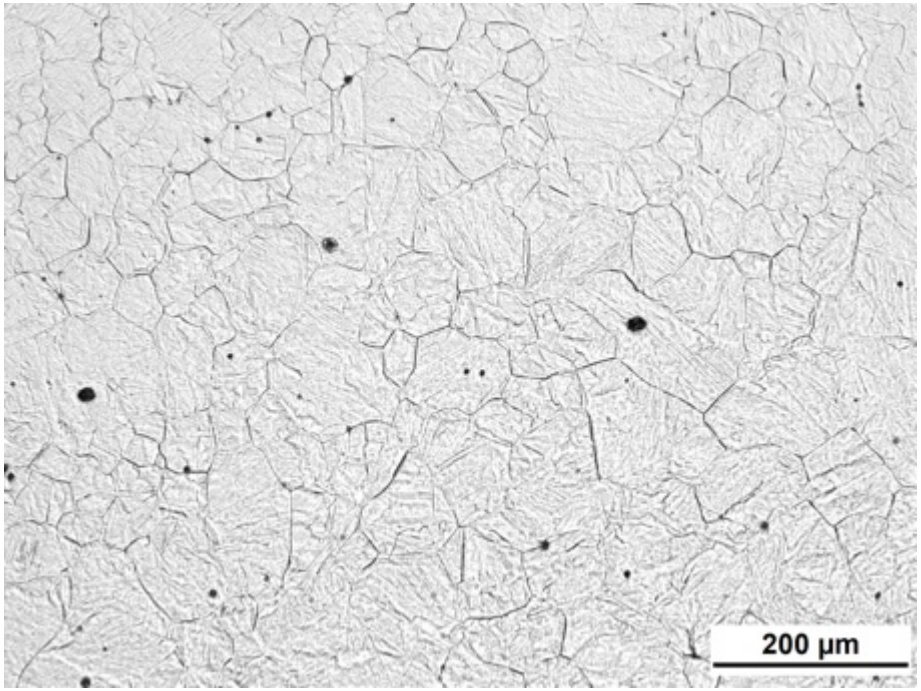


Ferrite formed upon cooling from 960 °C at 20 °Cs^{-1}



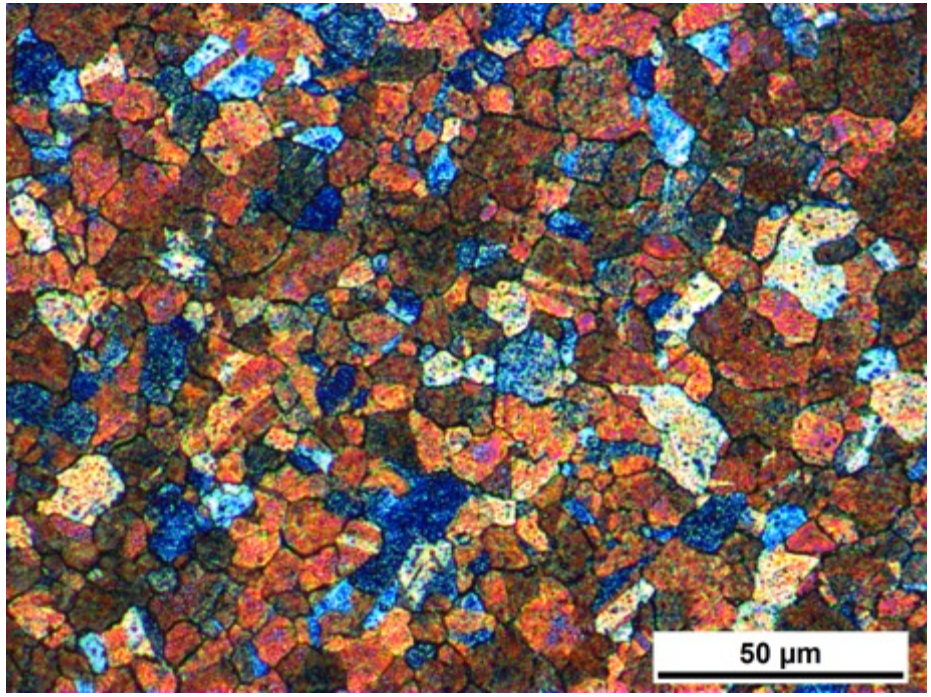
Prior austenite grain size

1260 °C for 1 min



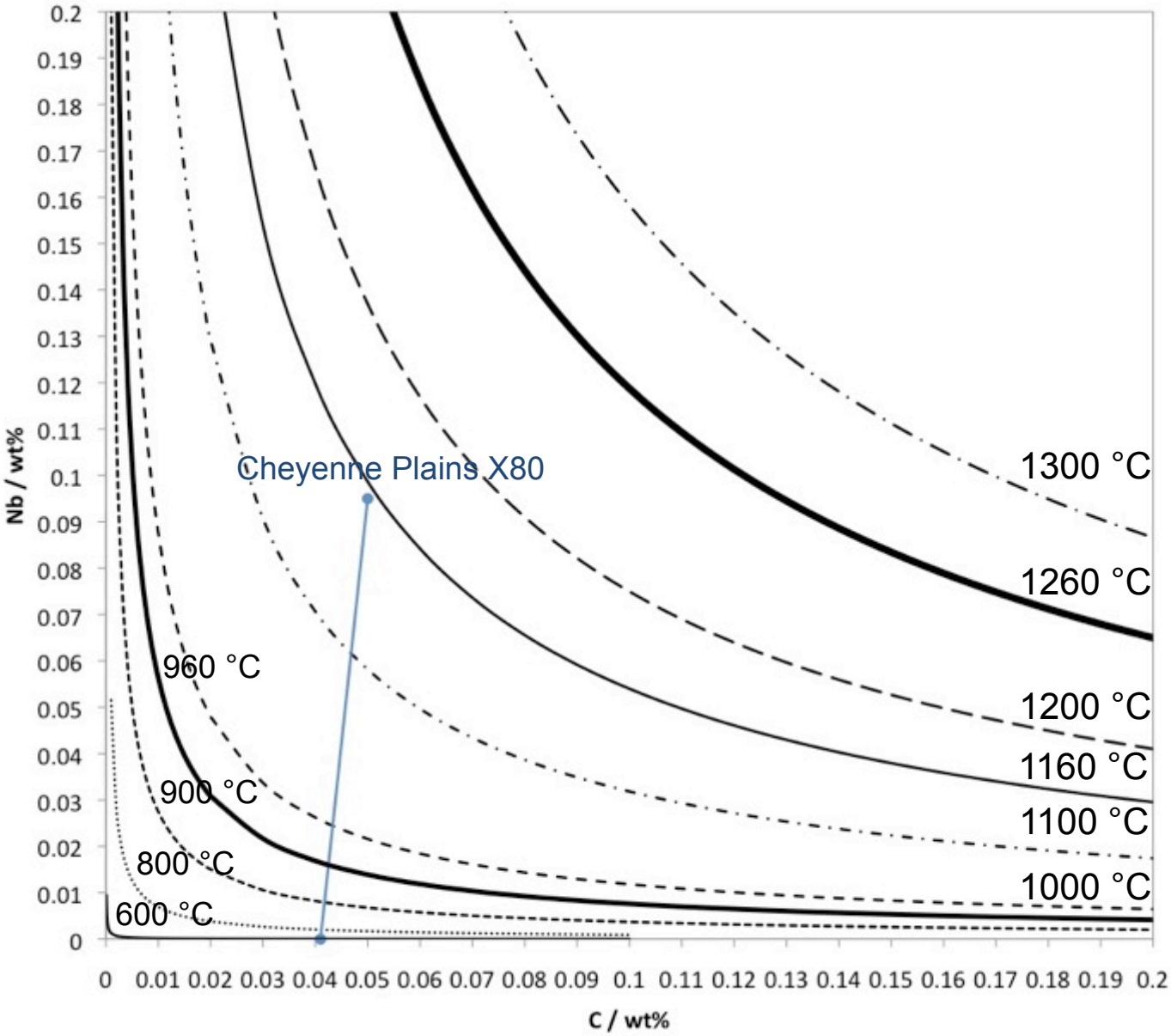
70±6 µm

960 °C for 5 min

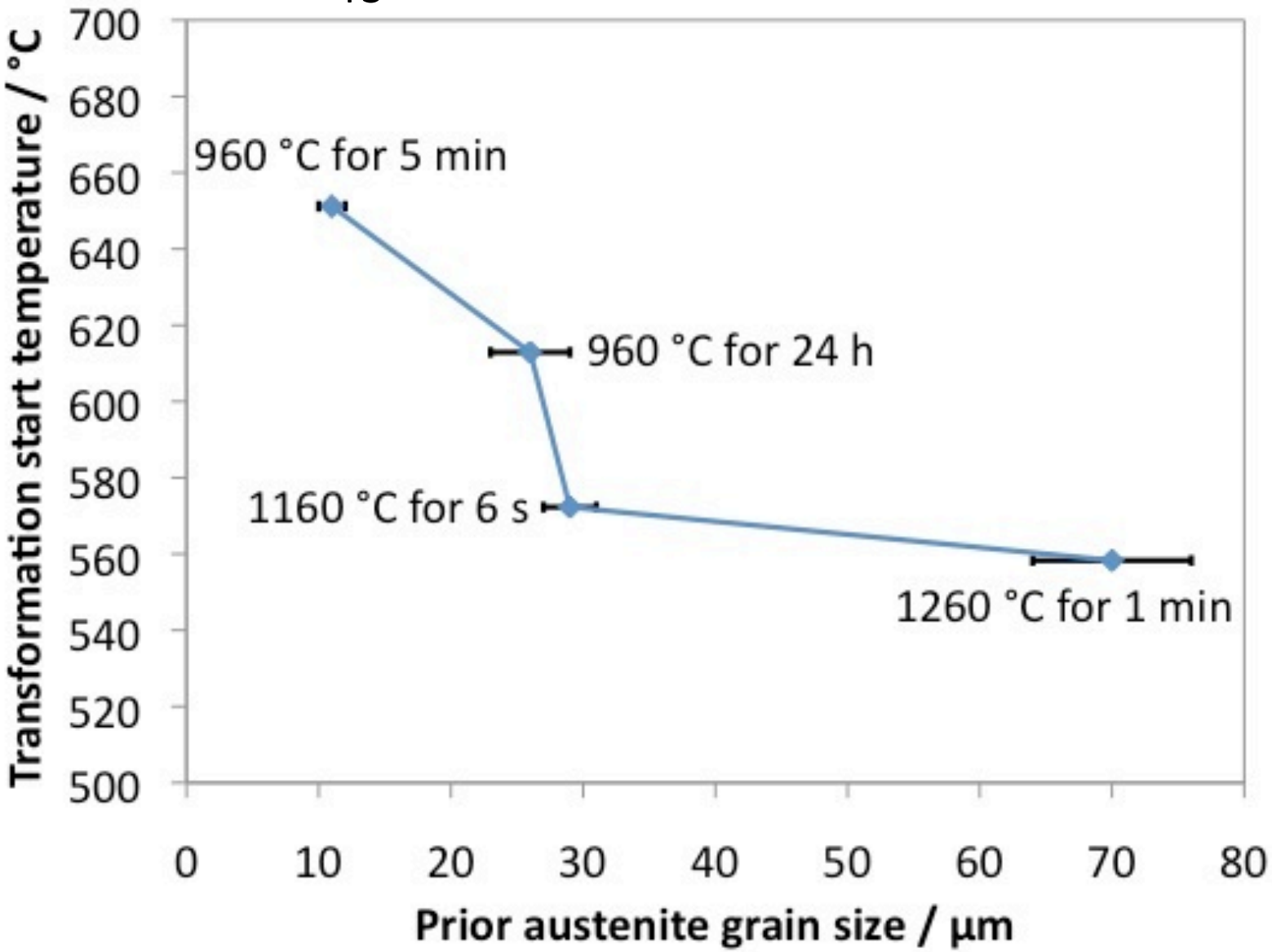


11±1 µm

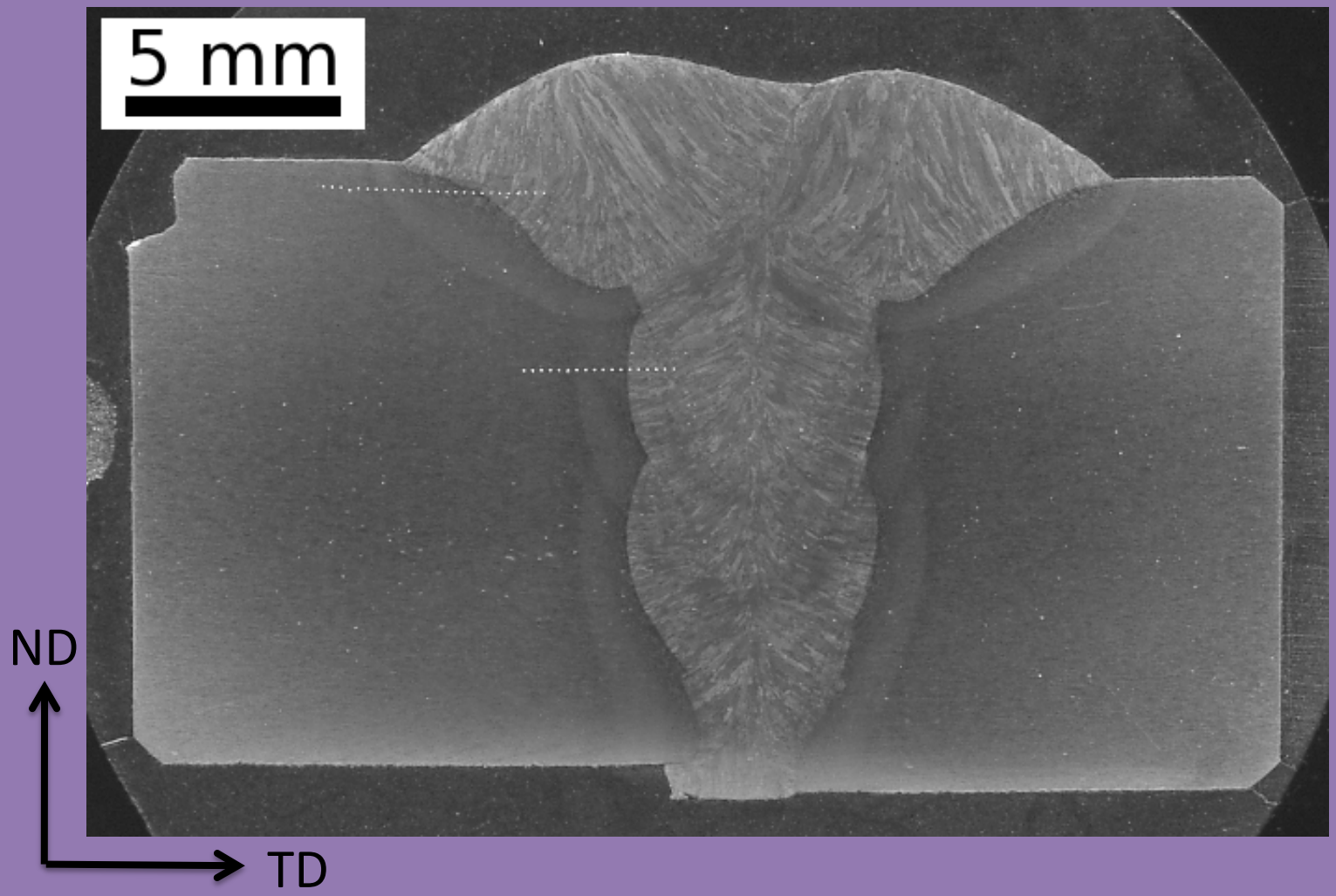
Soluble niobium retards ferrite transformation



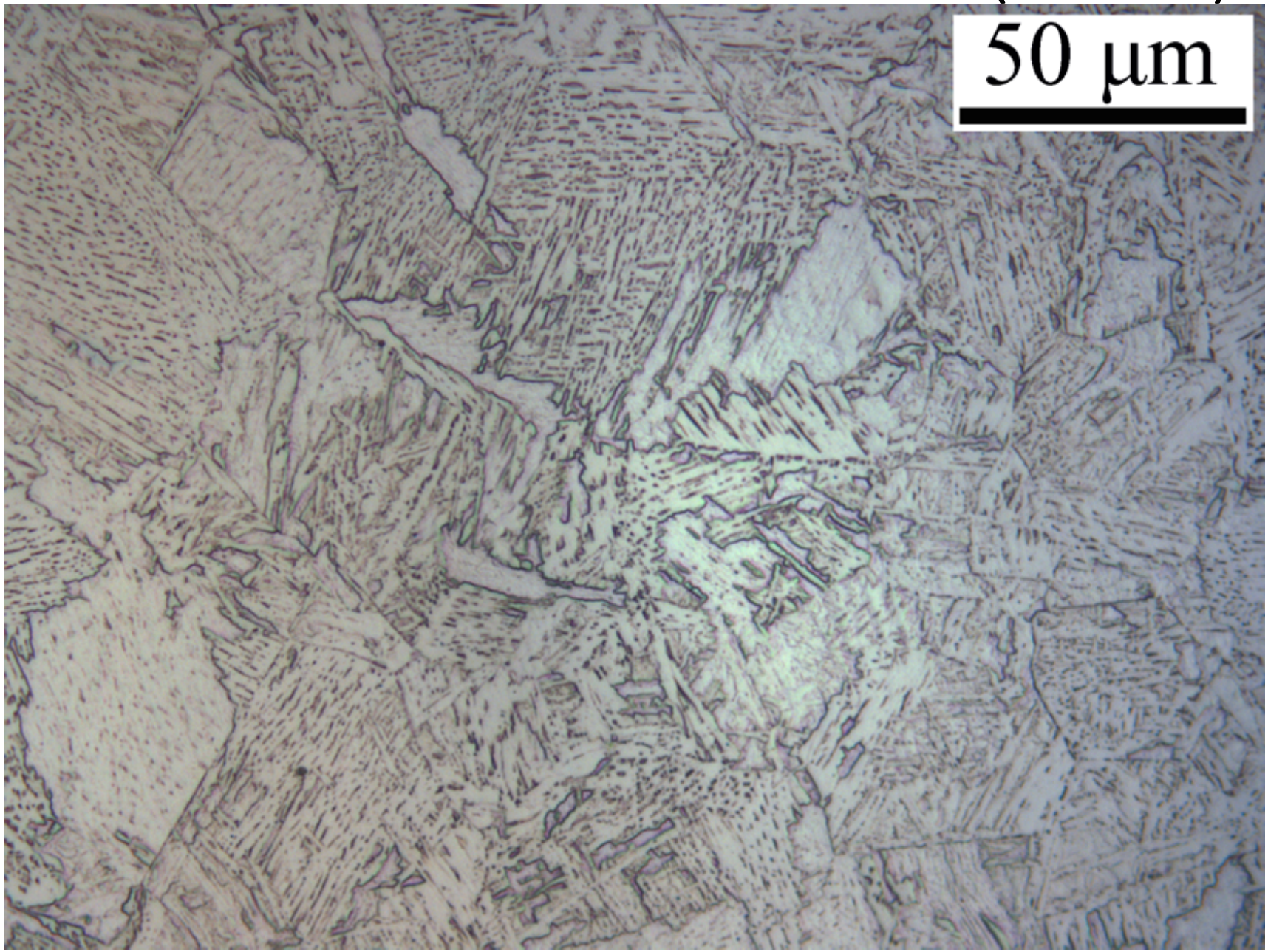
The relation between transformation start temperature (A_{r3}) and the prior austenite grain size



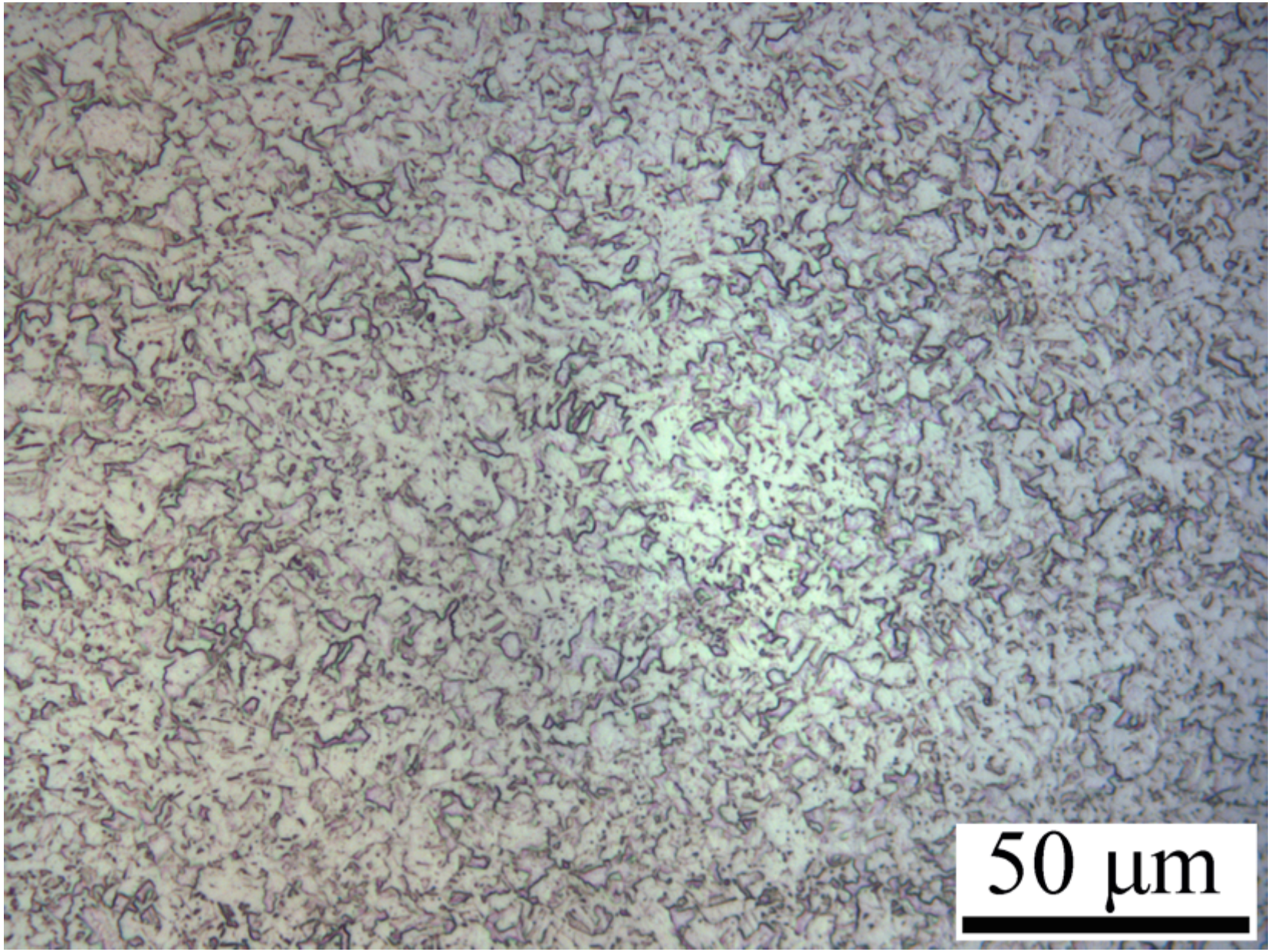
4. Weld on the X80



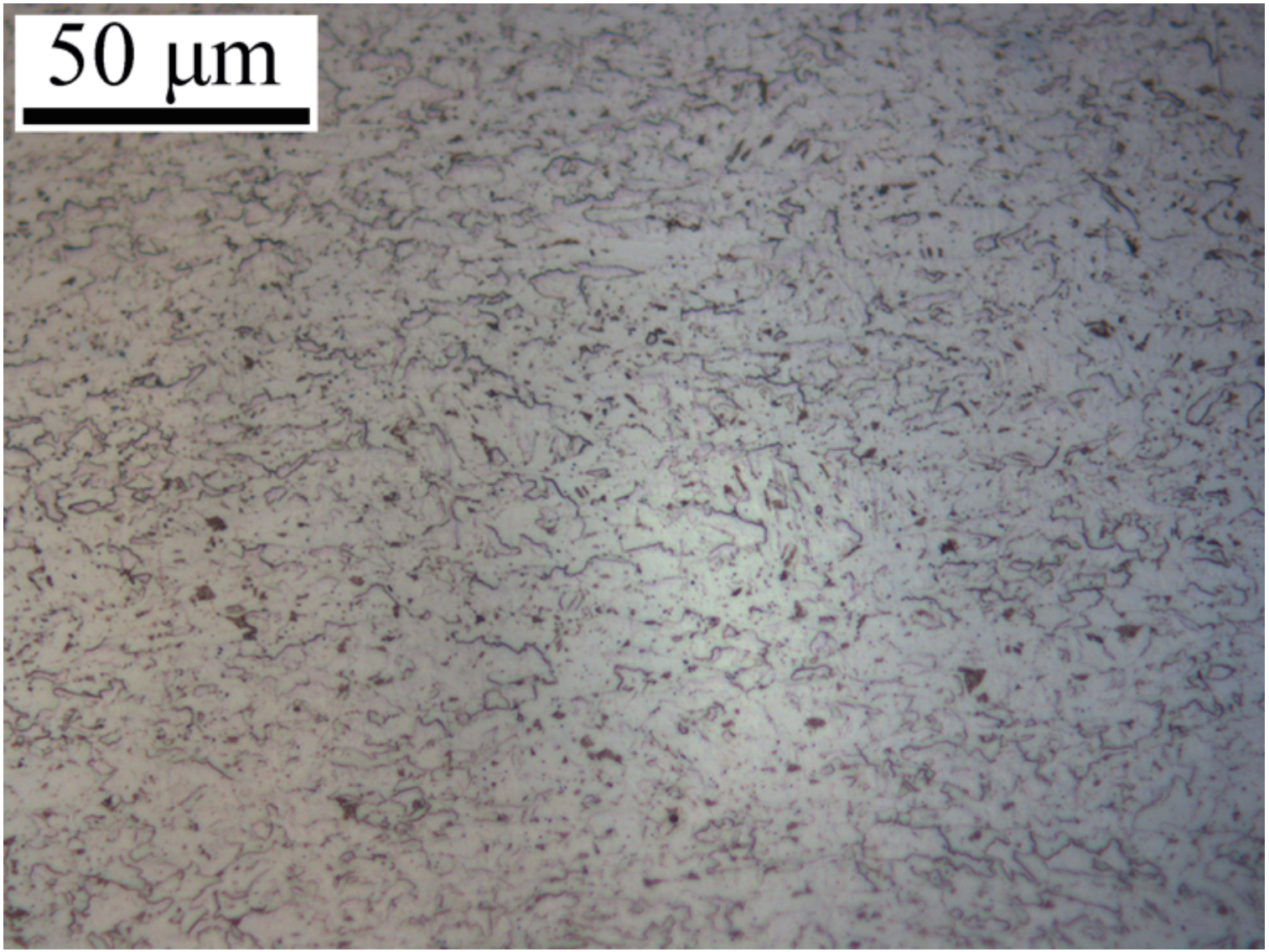
Coarse Grain Heat-affected Zone (CGHAZ)



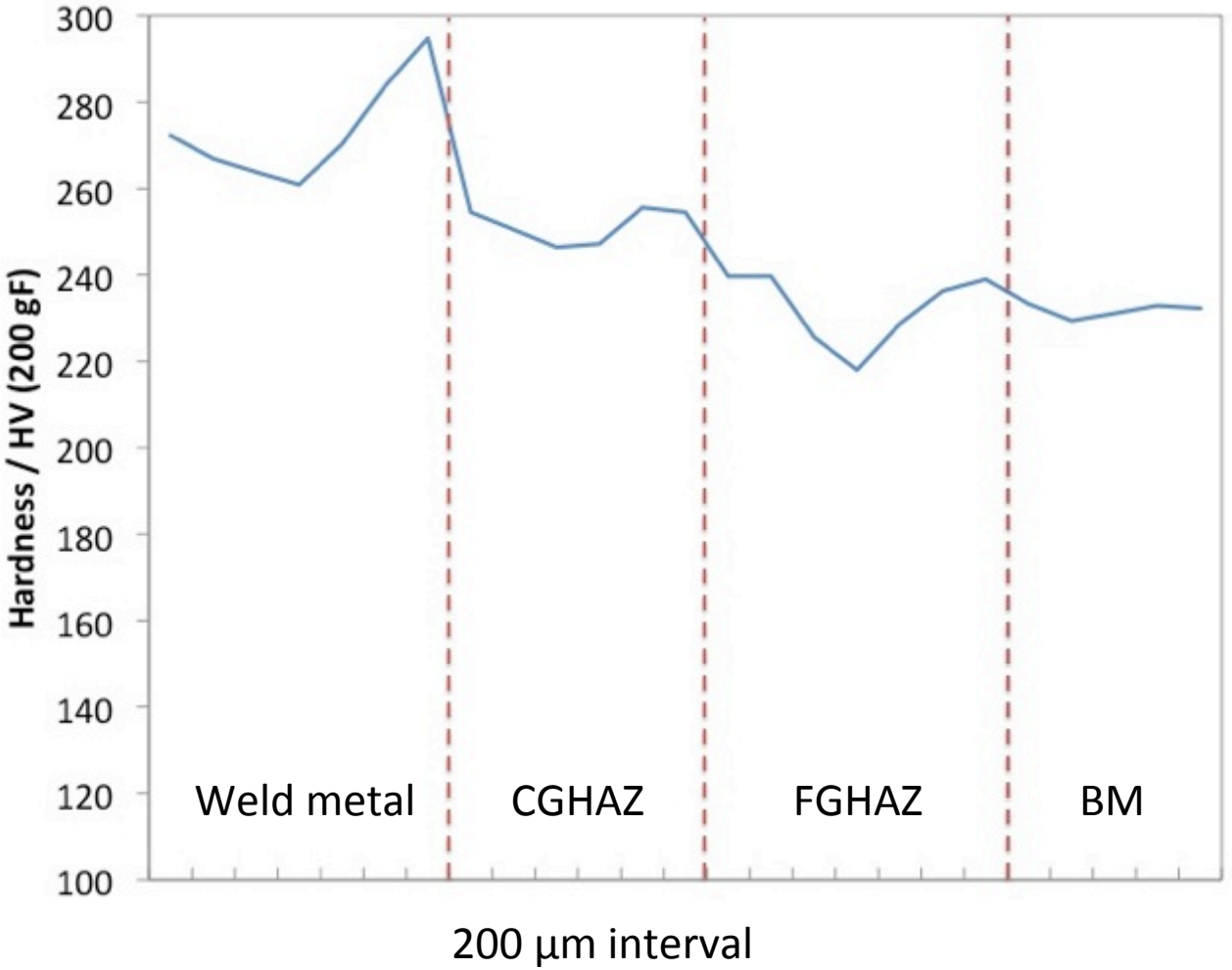
Fine Grain Heat-affected Zone (FGHAZ)



Base Metal



Hardness Profile



Acknowledgement

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- Collaborators:

  Dr Malcolm Gray and Dr Phil Kirkwood