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Characterisation of Thermally Aged Stainless Steels for Power Generation Applications

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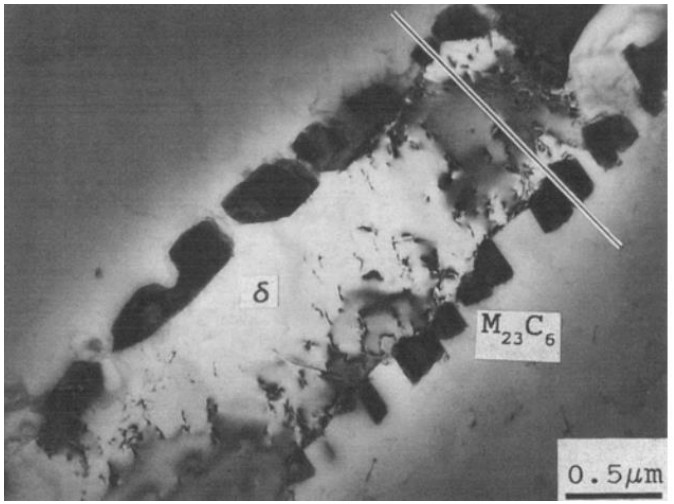
- Conclusion

Background

- Austenitic stainless steels can be subjected to high temperatures for extended periods of time in service. This can cause the formation of secondary phases.
- Sigma Phase and $M_{23}C_6$ can degrade the mechanical properties and corrosion resistance of the material.
- Regions of ferrite transform fastest.
- Previous work has relied heavily on TEM investigations to detect and characterise these phases.
- Work is needed to understand how the microstructure of these metals develop during time in service.



Tseng, C. C. Shen, Y et al, "Fracture and the formation of sigma phase, $M_{23}C_6$, and austenite from delta-ferrite in an AISI 304L stainless steel" *Metallurgical and Materials Transactions A, Vol 25, 1994*

Experimental Method

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- Material: Cast 304L Stainless Steel:

Fe	Cr	Ni	C
70.0%	18.7%	8.86%	0.0136%

- Thermal aging of stainless steel components at 750^{o}C and 650^{o}C up to 10,000Hrs.

- Characterisation of the microstructure:
  - Optical Microscopy
  - Scanning Electron Microscopy - Electron Backscatter Diffraction (EBSD)
  - Transmission Electron Microscopy - Samples prepared using Focus Ion Beam (FIB)

Initial Condition Of Material

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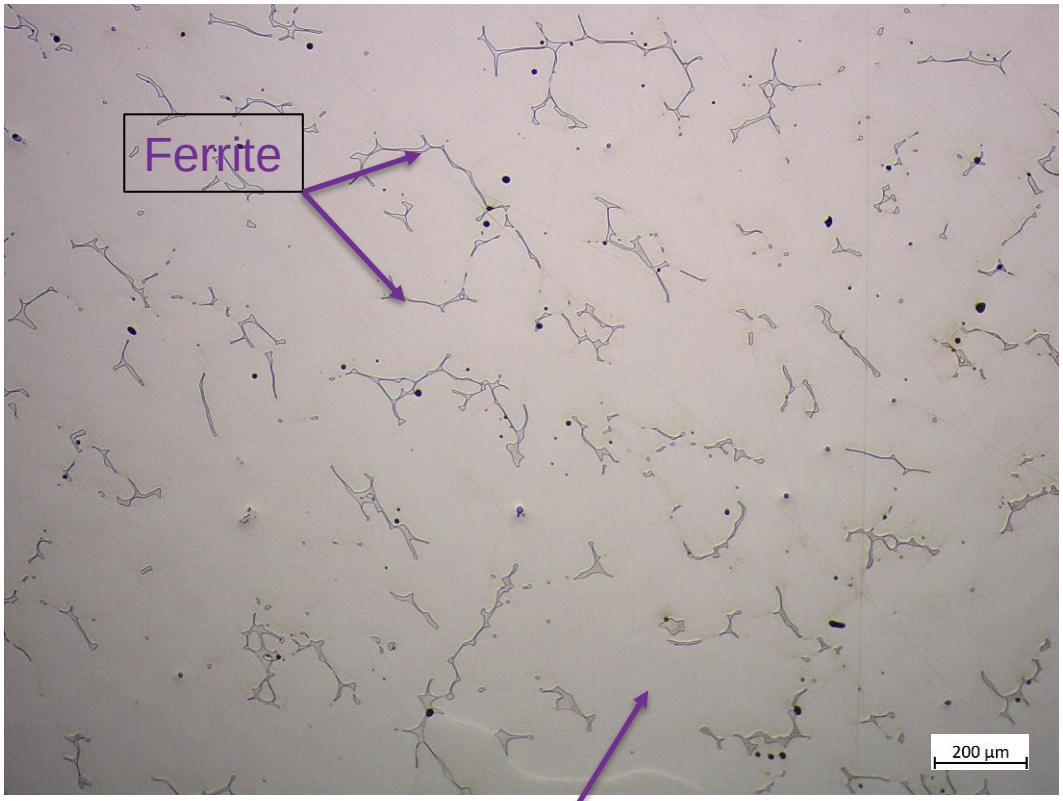
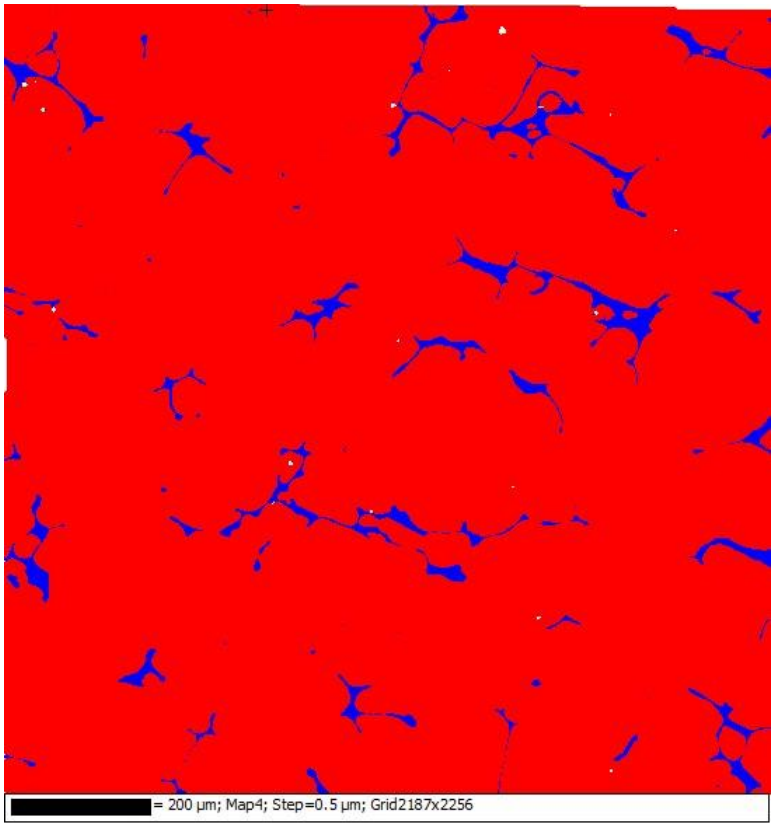
Optical Image



EBSD Phase Map



Ferrite Austenite

Ferrite	Austenite	Zero Solutions
2.03%	97.55%	0.42%

Initial Condition of Material

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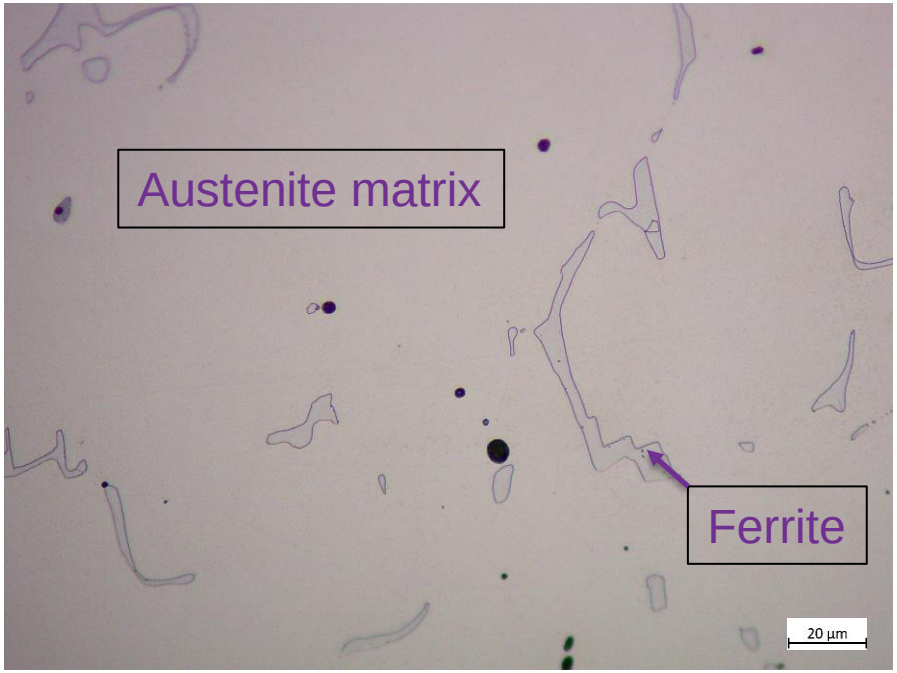
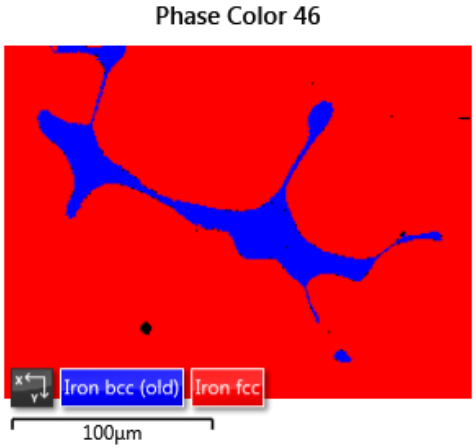
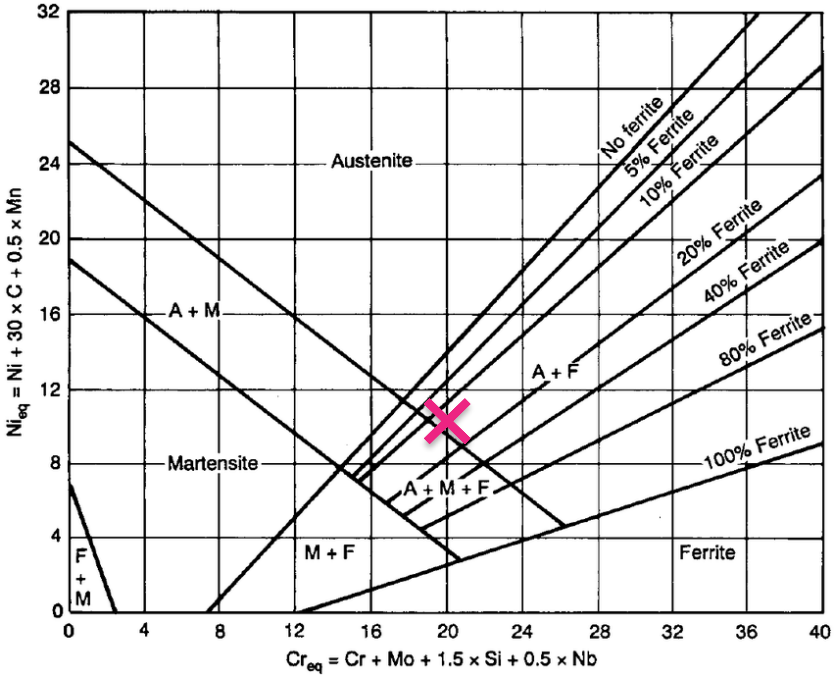
Optical Image



Equivalent:
Cr 20.23%
Ni 9.67%





Thermocalc

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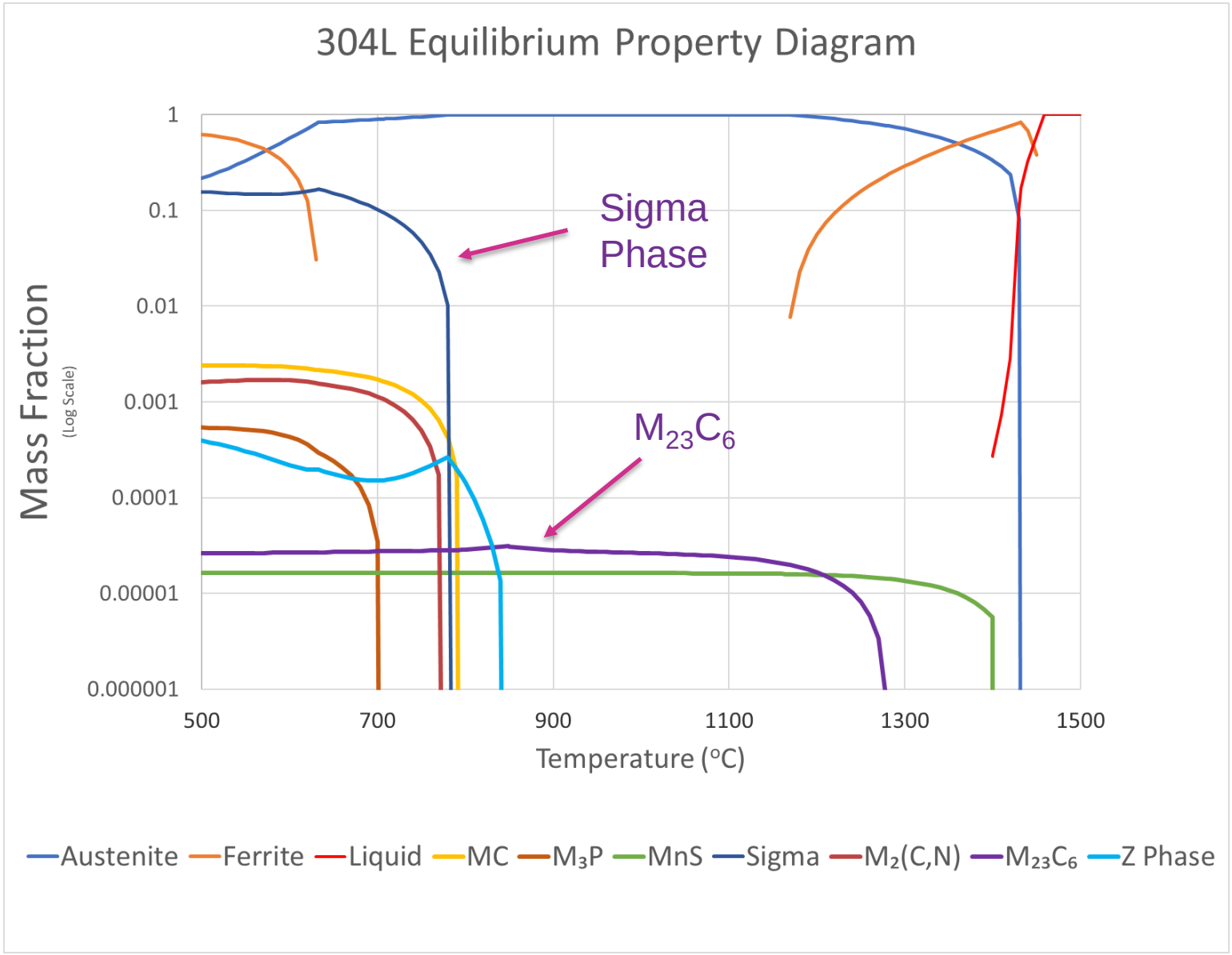

Investigation of Aged Material

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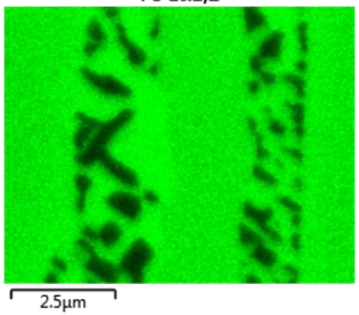
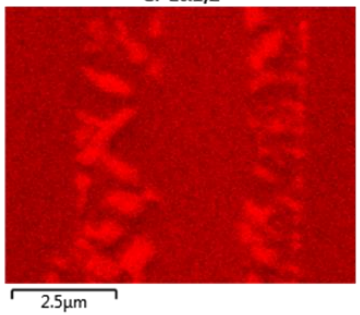
750°C 200Hrs

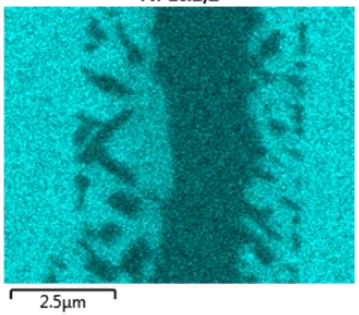
Fe Lα1,2



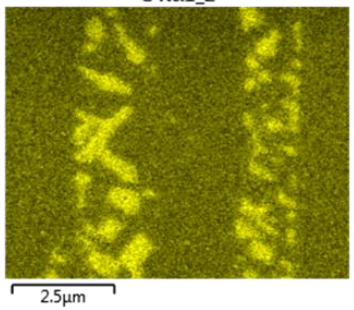
Cr Lα1,2



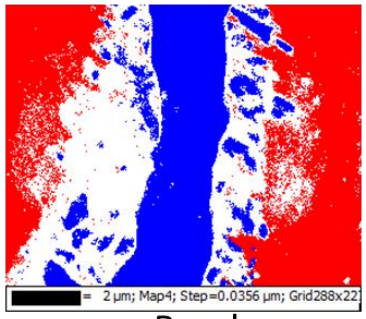
Ni Lα1,2



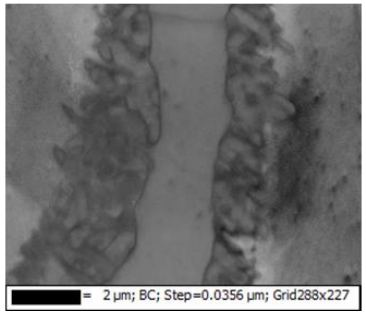
C Kα1_2

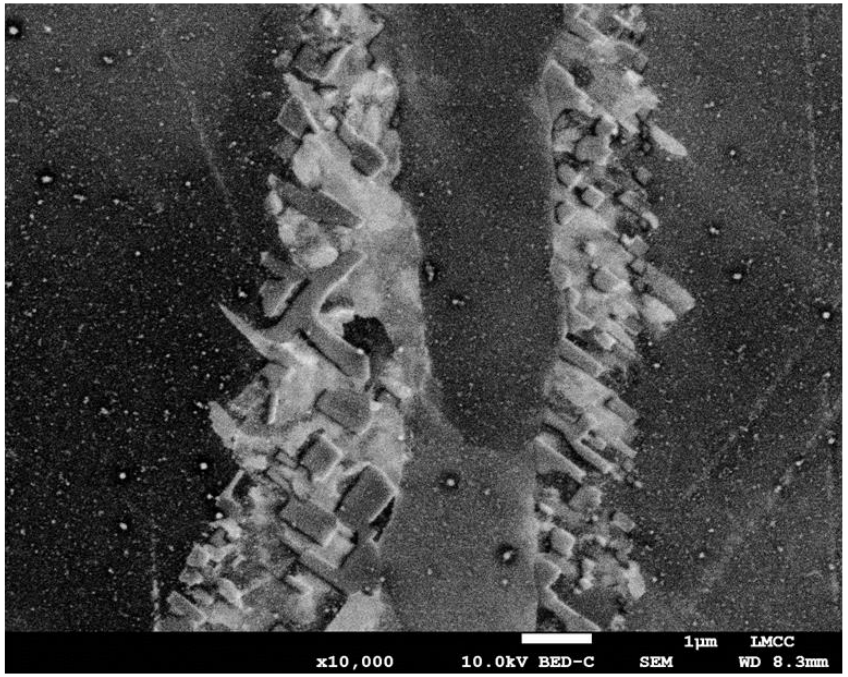


Phase Map



Band Contrast





Sample prep for TEM using FIB

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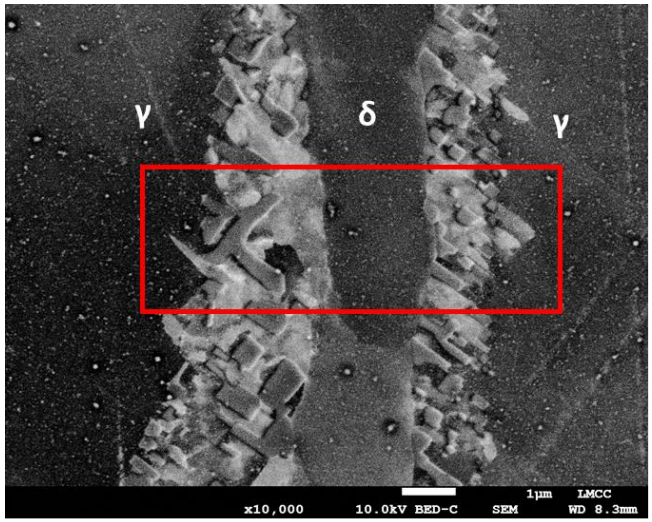

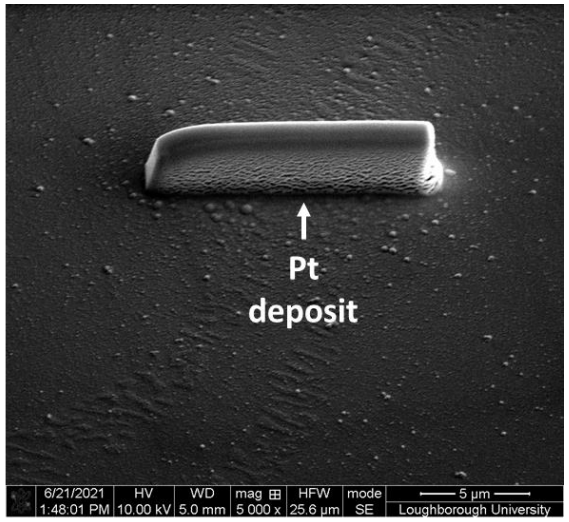

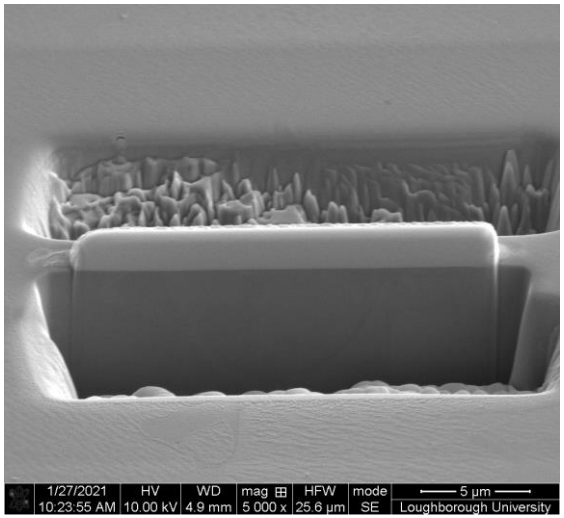

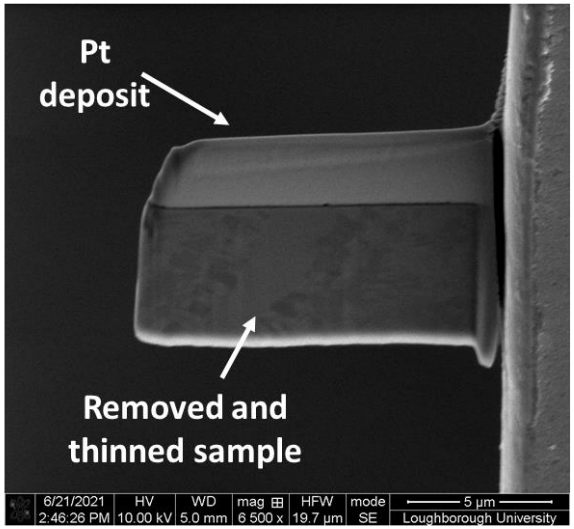

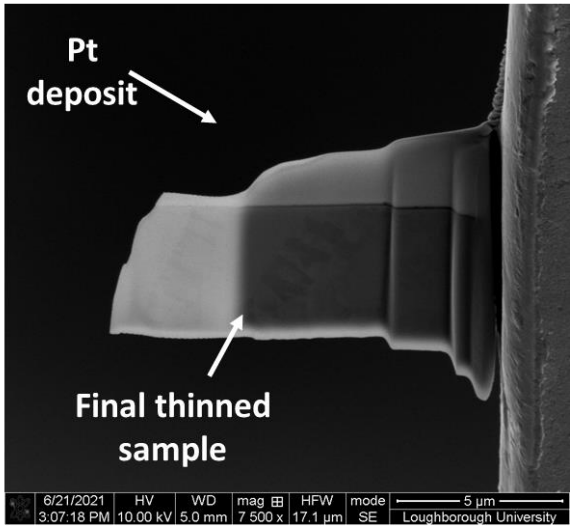

TEM Results

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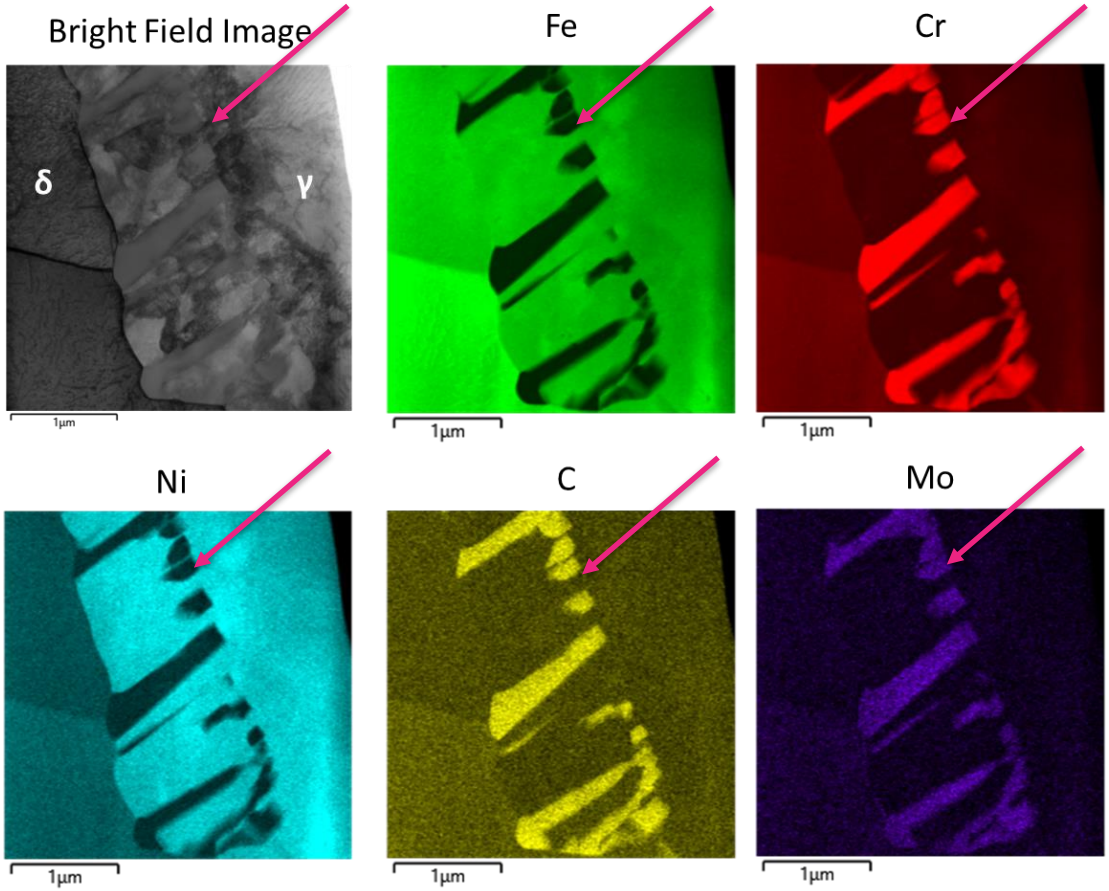

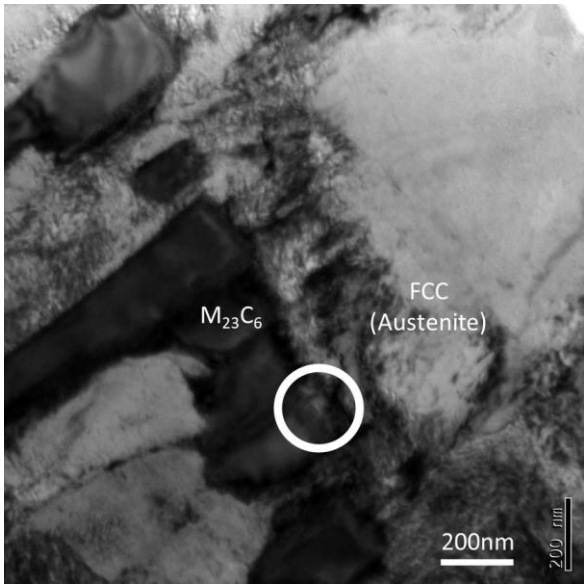

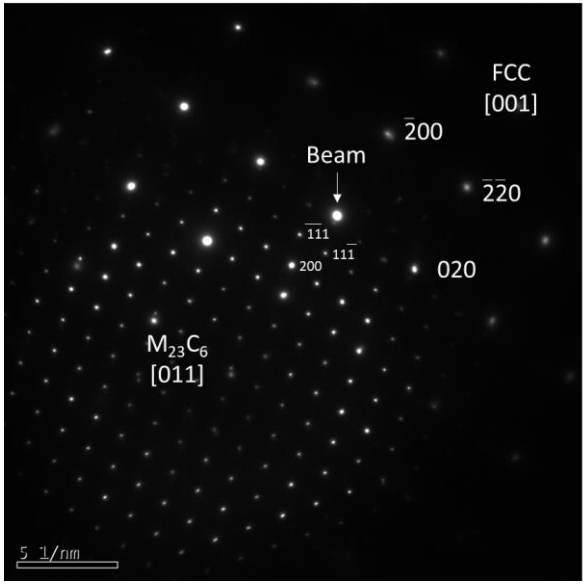

Updated EBSD CCD Detector (Close couple device)

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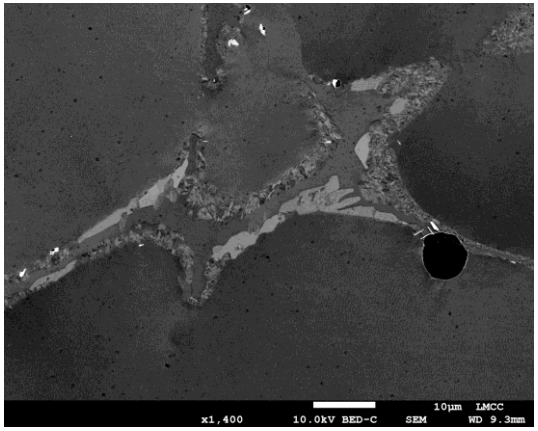
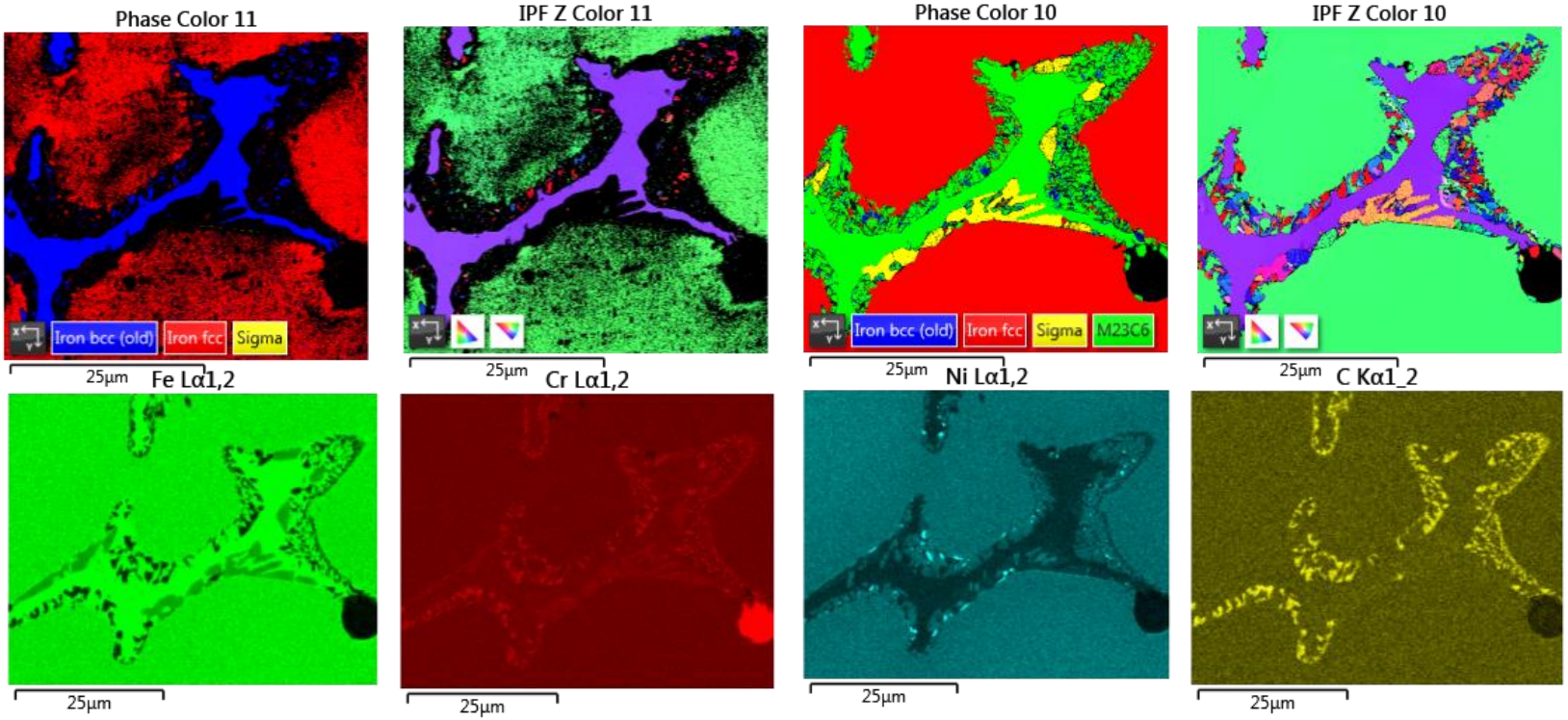
650ºC 500Hrs





EBSD Data from “Symmetry” Detector Microscope

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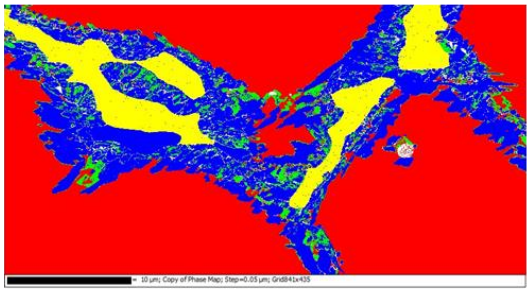
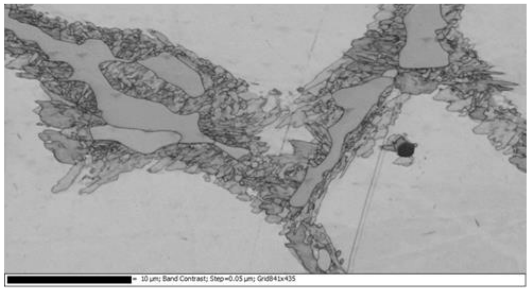
750°C 5000Hrs

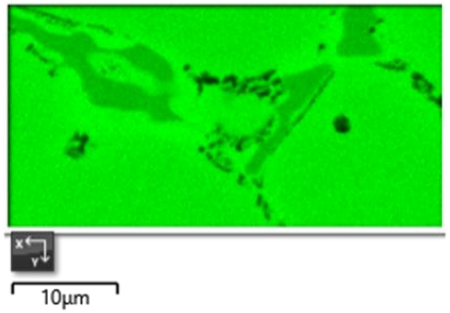
Phase Map



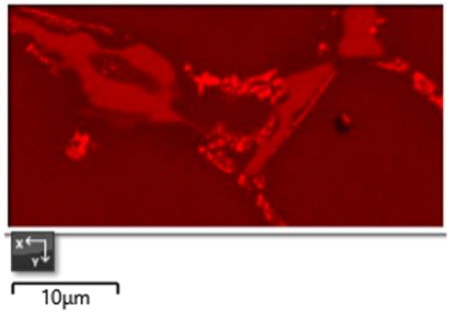
Band Contrast



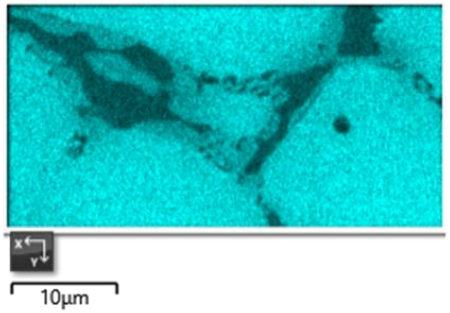
Fe



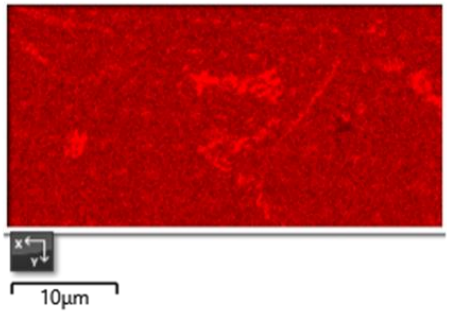
Cr



Ni



C



Results Achieved Using:

- Sensitivity Binning Mode
- Refined Accuracy Indexing Mode
- Centre Band Detection Mode

EDS for 750ºC 5000Hrs Sample

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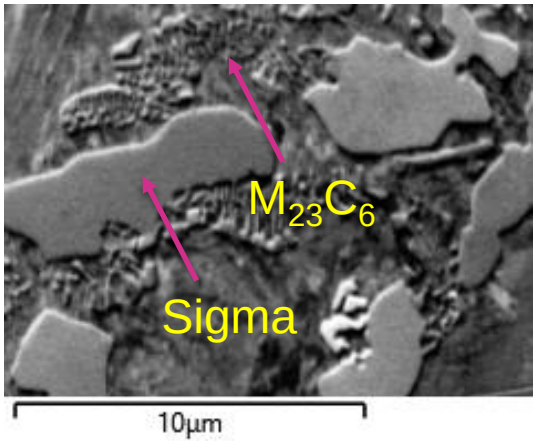
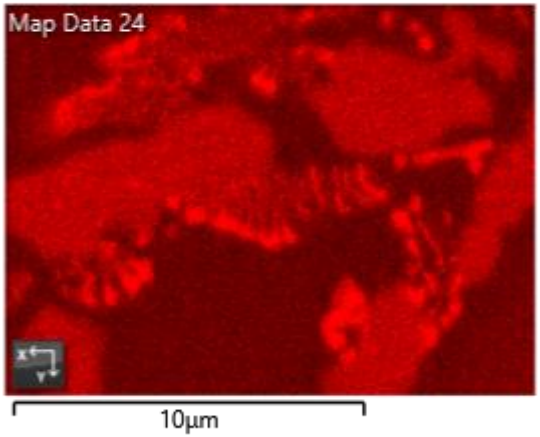
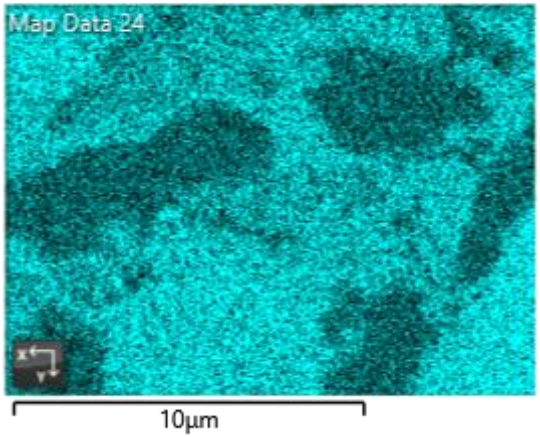
Forward Scatter Diffraction



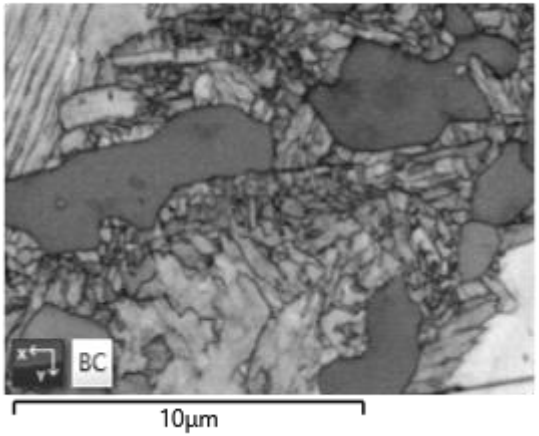
Cr Kα1



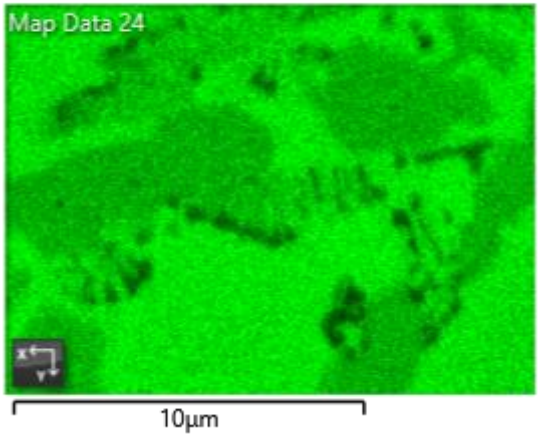
Ni Kα1



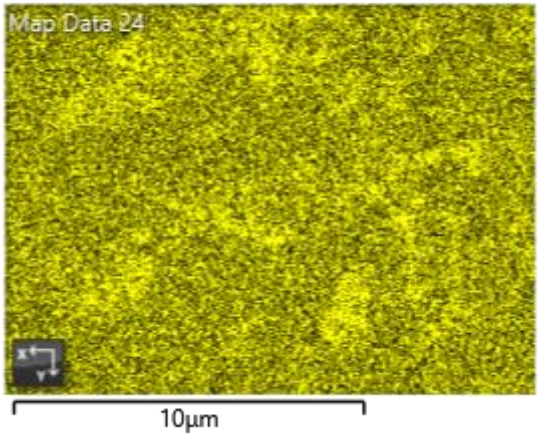
Band Contrast 21



Fe Kα1



C Kα1_2



Processed Data Using Aztec Crystal

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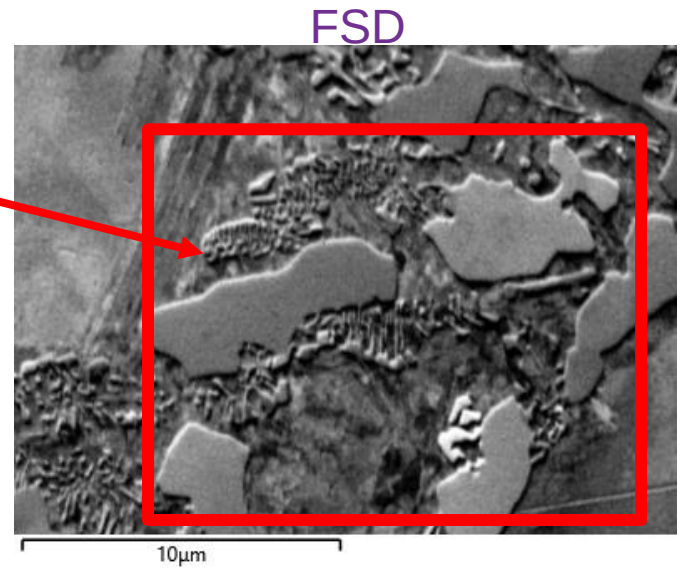
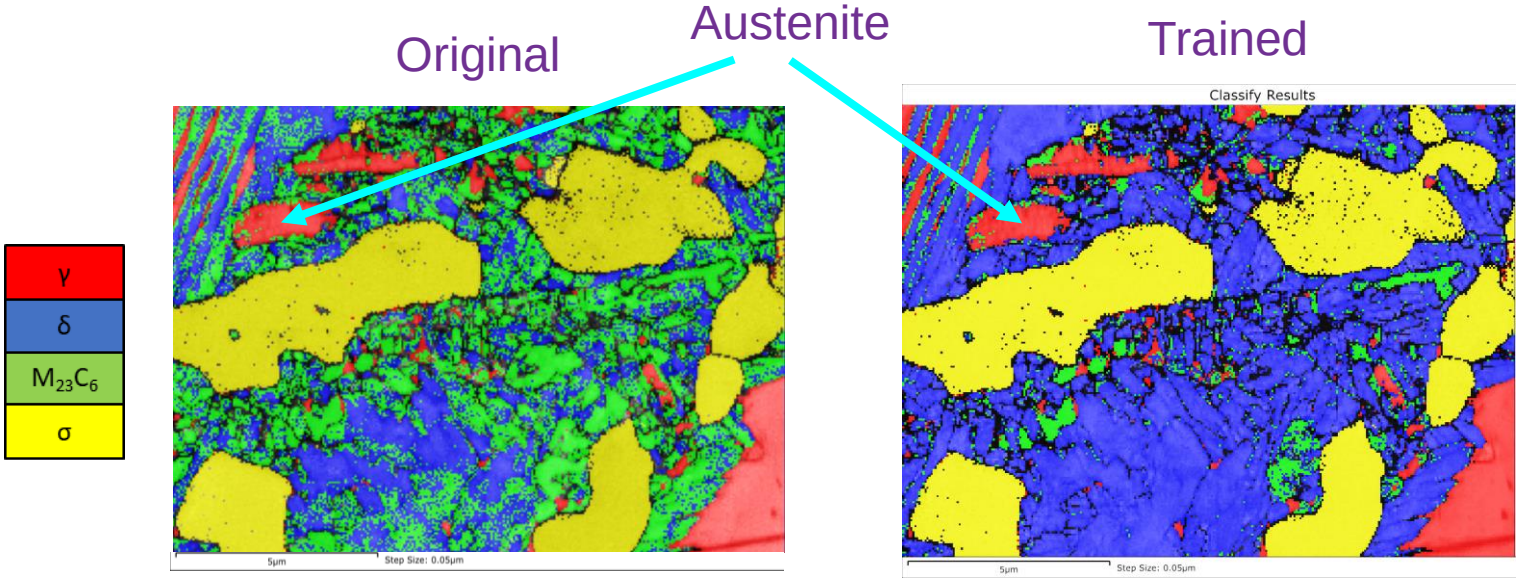
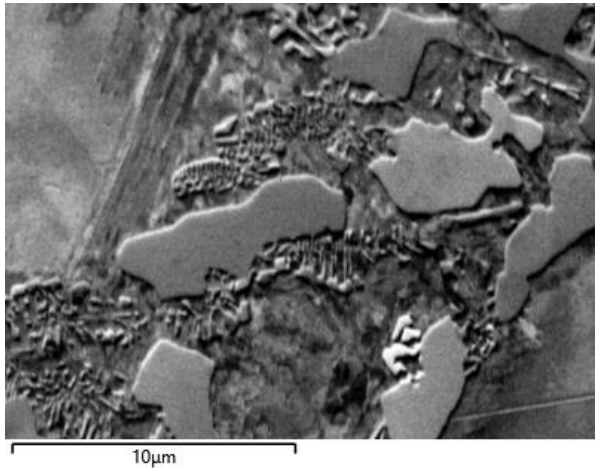
- AZtecCrystal “Classify” tool
- Plotted maps showing the band slope, and the KAM value (using a 7x7 array), and then trained the system to separate the carbides and ferrite.
- Protected the sigma phase, zero solutions and the austenite.

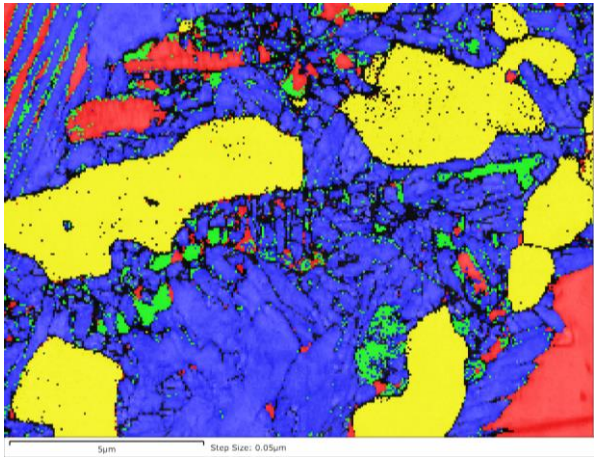




Conclusions

- Long term thermal aging has created more complex transformations than previously observed.





- Carbides were observed to form within the delta ferrite and not just at the interface.
- New grains of ferrite have also formed within the original delta ferrite.

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Any Questions?