Characterising reheated microstructures of microalloyed multipass C-Mn steel welds

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Sponsored by Framatome

Funded by the EPSRC and Framatome

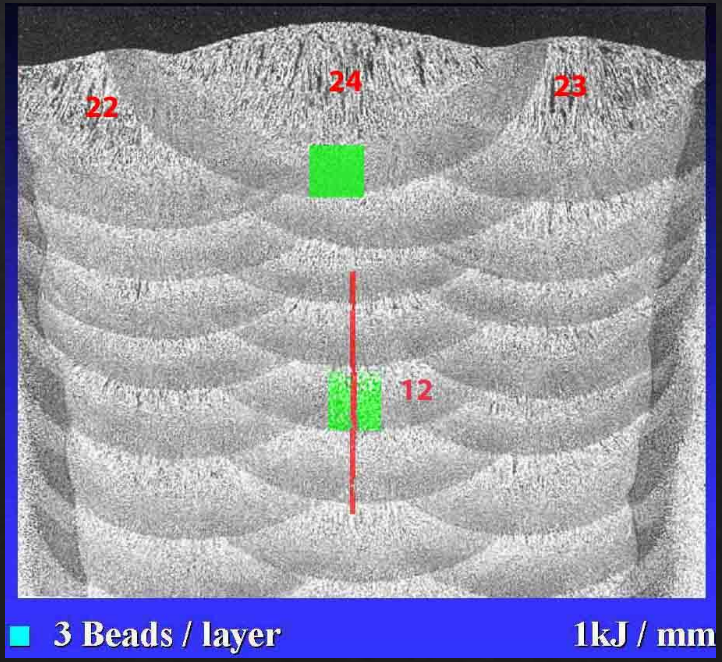
Contents

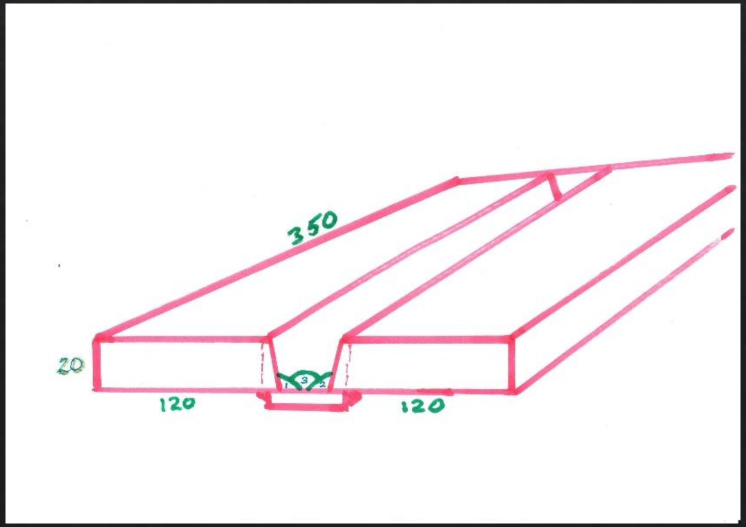
Introduction

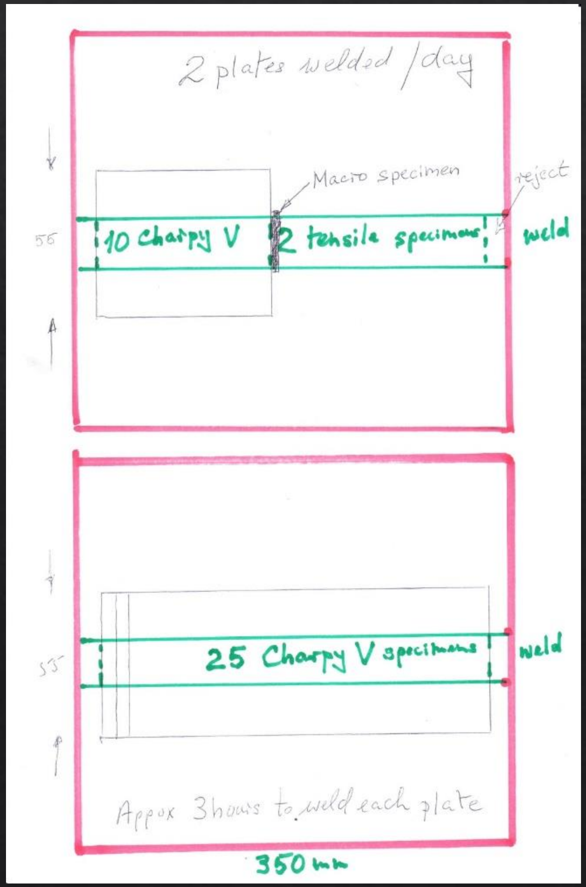
- Last pass microstructures containing acicular ferrite are re-austenitised in multipass welds
- Relationship between weld chemistry and microstructures in re-heated weld beads is not thoroughly understood
- Samples and data from Glyn Evans have served as a foundation for further study
- Evans and co-workers systematically investigated the effects of 16 different chemical elements on microstructures and mechanical properties in multipass welds

Experimental work of G. M. Evans *et al.*

- Manual metal arc (MMA) welds
- 1 kJ/mm heat input
- Most samples are in as-welded condition
- Goal was to create a reproduceable thermal history in every weld
- Microstructure analysed only at top bead



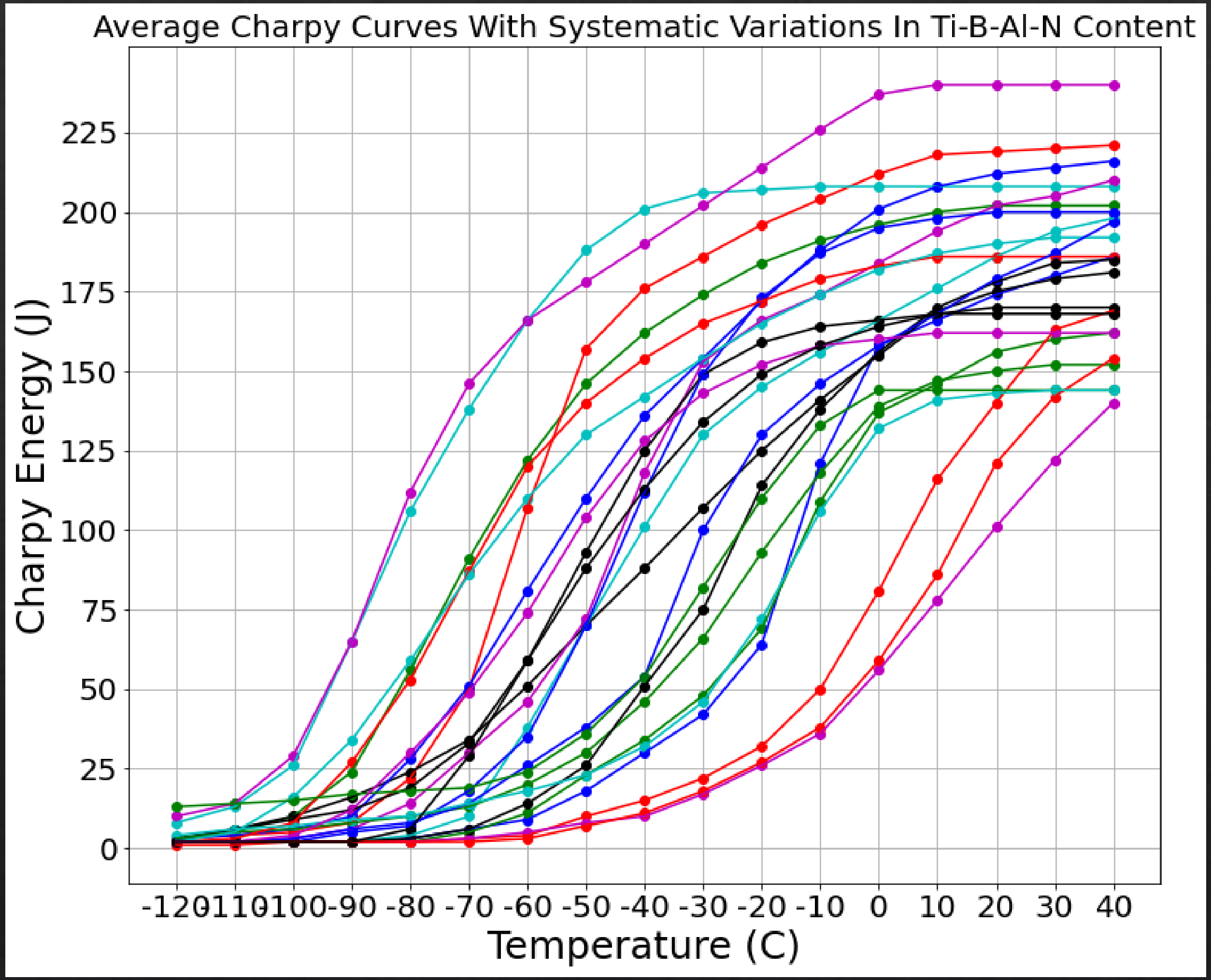




Courtesy of G.M.Evans

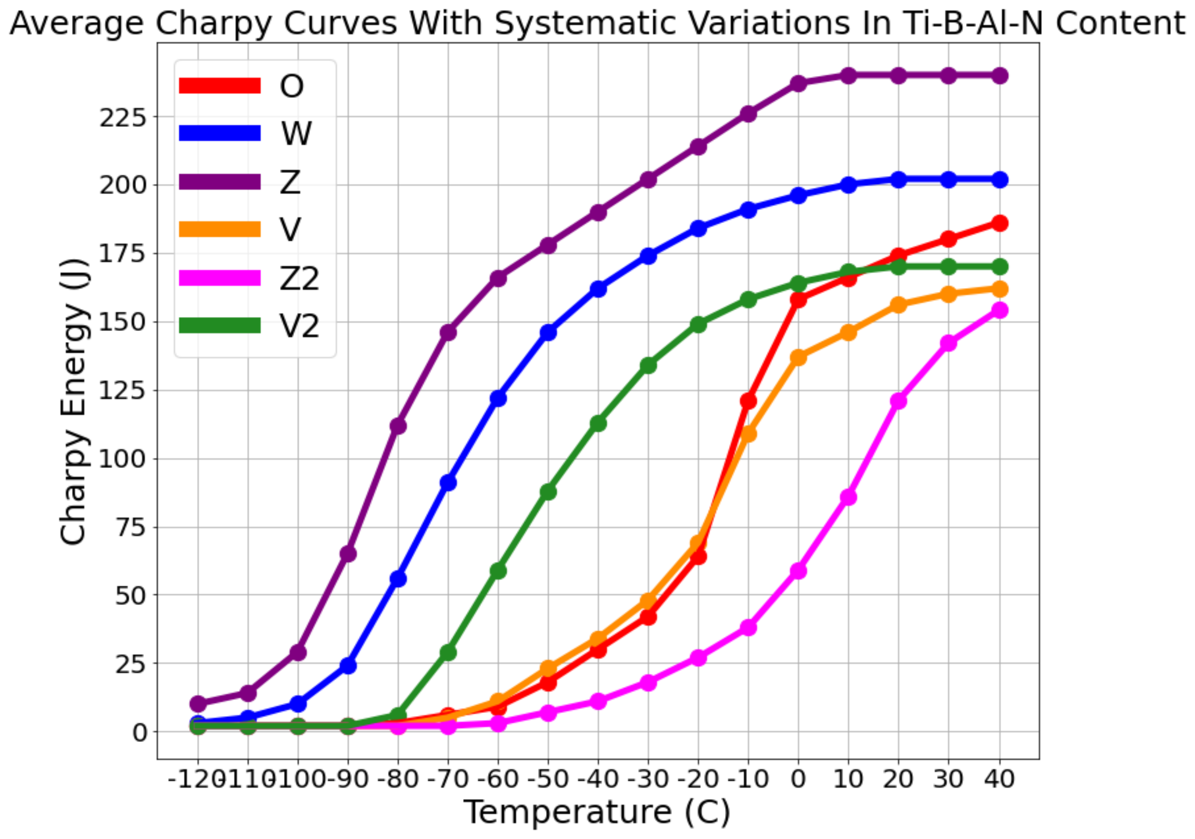
Motivation

- The effect of microalloying additions can be very significant even at ppm levels
- Plot to the right shows transition curves for 24 welds all having compositions suitable for nuclear pipe joints, but with different values for Ti-B-Al-N. Pipe joint welds could have any one of these Charpy curves!
- We need to know the effect chemical composition has on microstructure
- 6 samples with different compositions are shown in this presentation



Microstructural variations with composition

- Control sample: O
- Commercial electrode sample: W
- Samples with systematic compositional variations: Z, V, Z2, V2
- Additions of Ti, Al **or** N change Charpy curves in a clear way
- Additions of Al **and** N change Charpy curves in a less clear way
- Microstructural analysis necessary to study the problem in detail



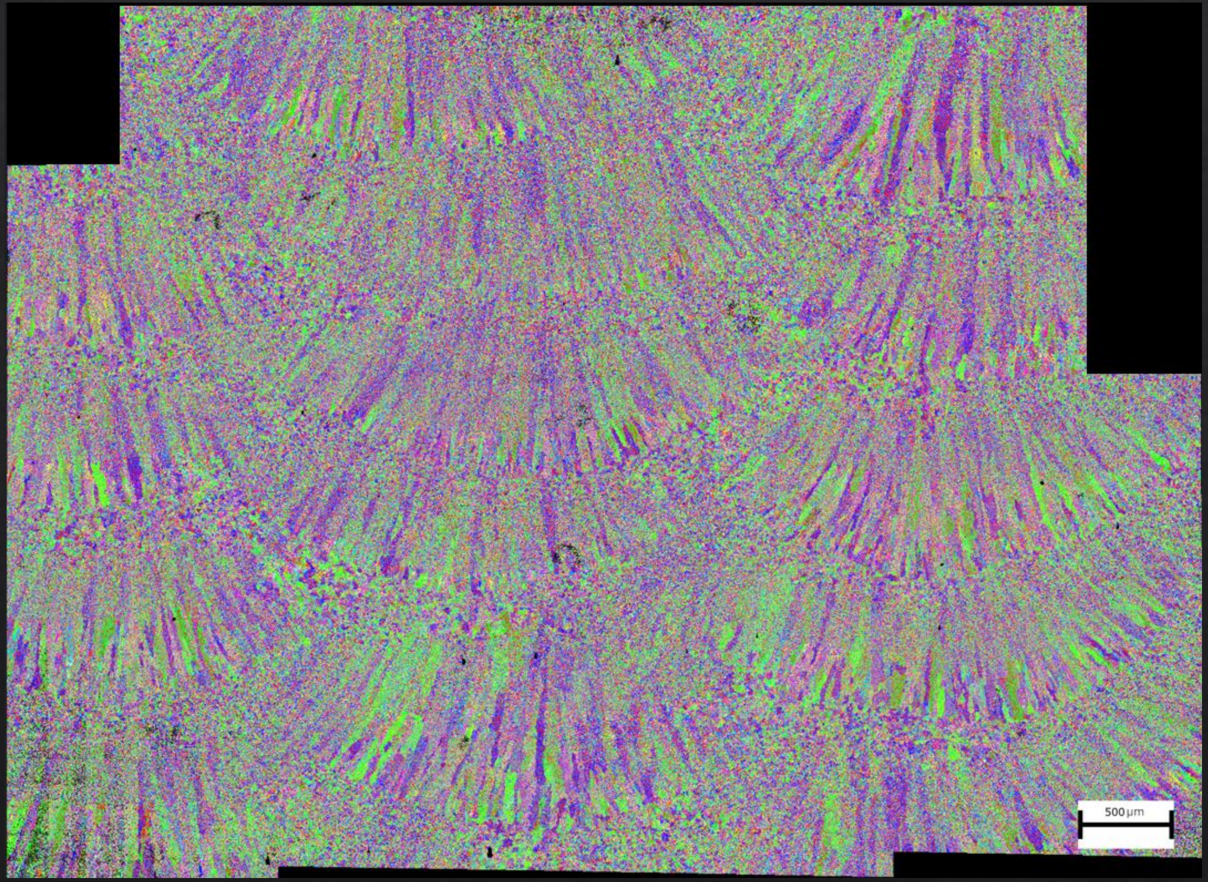
Macro specimen	C wt. %	Mn wt. %	Si wt. %	S wt. %	P wt. %	**Ti ppm**	**B ppm**	**Al ppm**	**N ppm**	O ppm	Cr wt. %	Ni wt. %	Mo wt. %	V ppm	Cu wt. %	Nb ppm
O	0.074	1.40	0.25	0.008	0.007	**1**	**1**	**6**	**79**	475	0.03	0.03	0.01	5	0.03	5
W	0.077	1.46	0.27	0.008	0.007	**28**	**3**	**5**	**81**	459	0.03	0.03	0.01	5	0.03	5
Z	0.072	1.56	0.49	0.007	0.010	**420**	**48**	**160**	**67**	438	0.03	0.03	0.01	5	0.03	5
V	0.078	1.44	0.60	0.006	0.007	**540**	**56**	**580**	**41**	440	0.03	0.03	0.01	5	0.03	5
Z2	0.068	1.45	0.50	0.006	0.011	**470**	**45**	**180**	**230**	440	0.03	0.03	0.01	5	0.03	5
V2	0.069	1.42	0.60	0.006	0.012	**430**	**35**	**560**	**235**	470	0.03	0.03	0.01	5	0.03	5

Current work

- Microstructural characterization using optical and EBSD mapping
  - Mapping microstructural variations in weld metal to determine microstructural sources of Charpy energy variation across different compositions
- Study of variations in local chemistry as a function of thermal cycling
  - NanoSIMS maps of N and B to determine how the distribution of N and B changes in the weld metal as a function of thermal cycling and how that might affect Charpy energy values

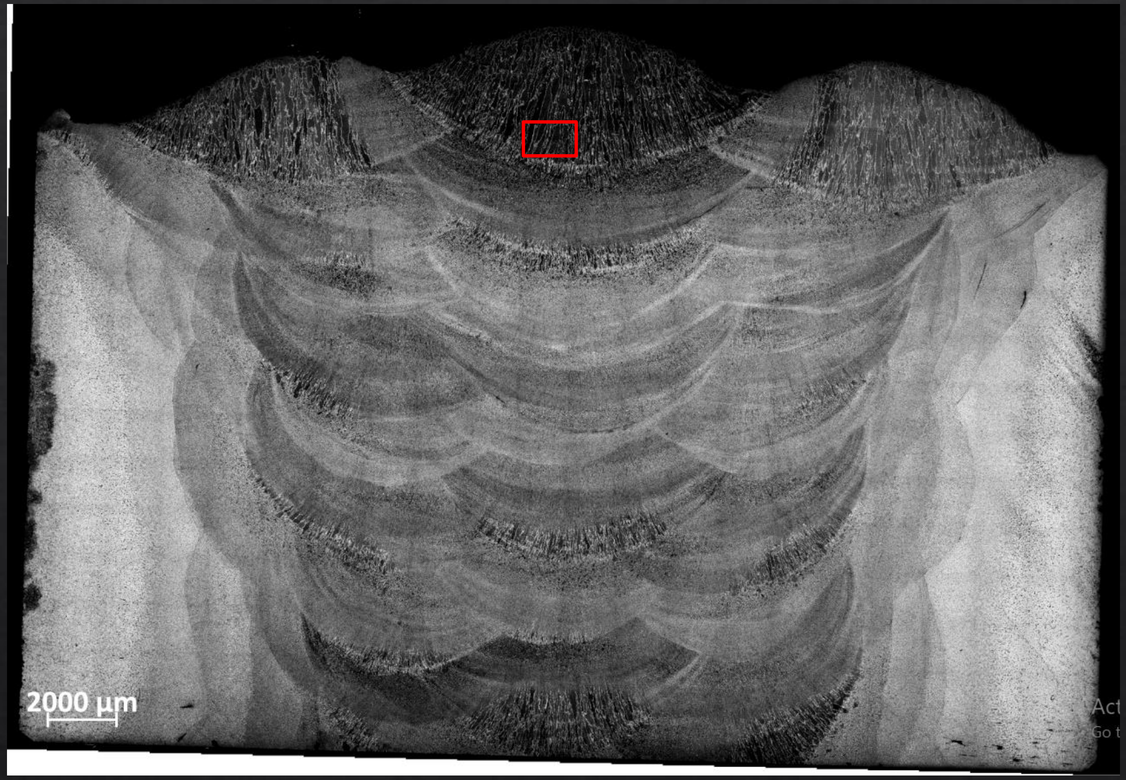
Characterization – EBSD vs. Optical

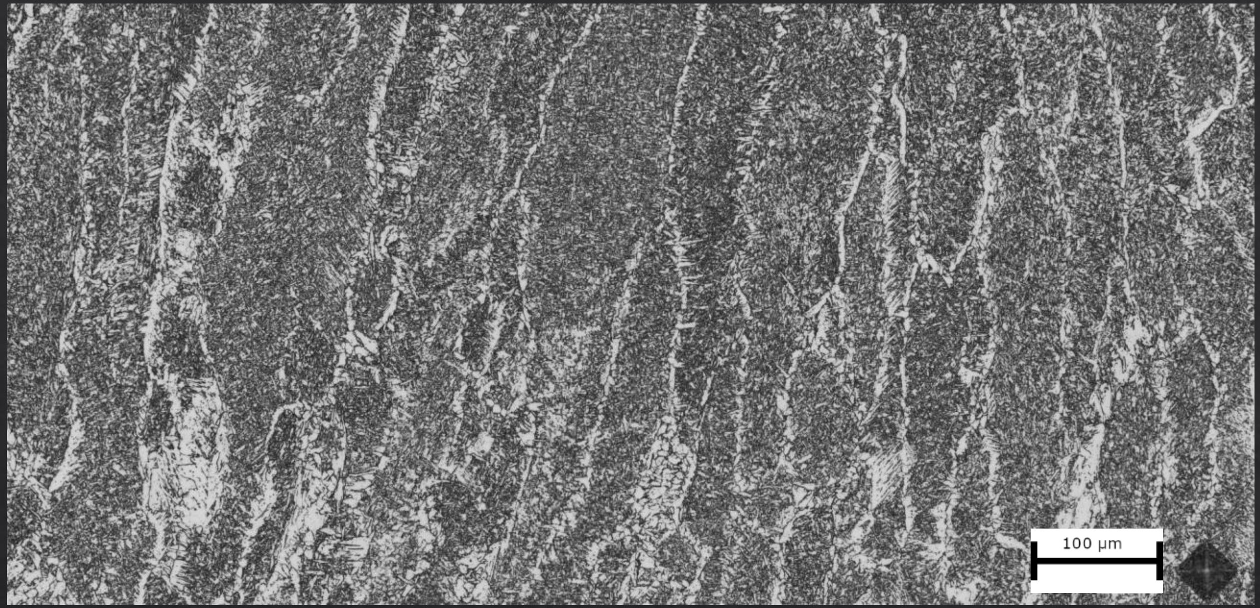
- Evidence of the columnar grain structure being retained across thermal cycles
- Microstructure looks fully recrystallized under optical imaging, but EBSD shows otherwise

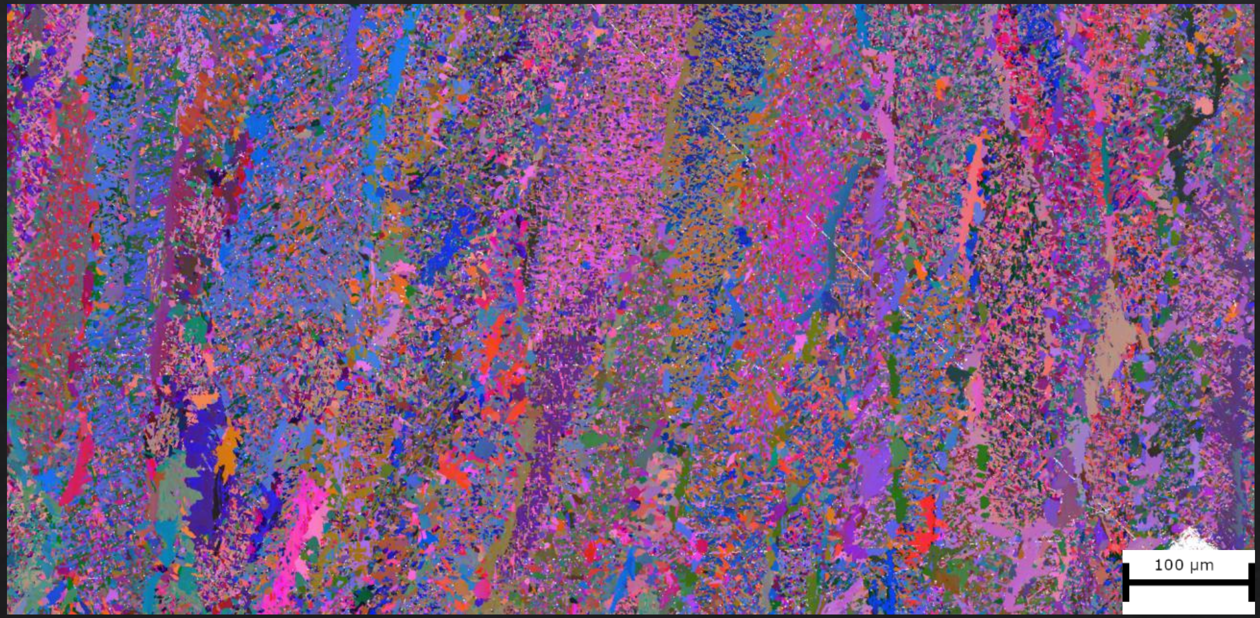


Characterization – Optical vs. EBSD

Last pass columnar zone

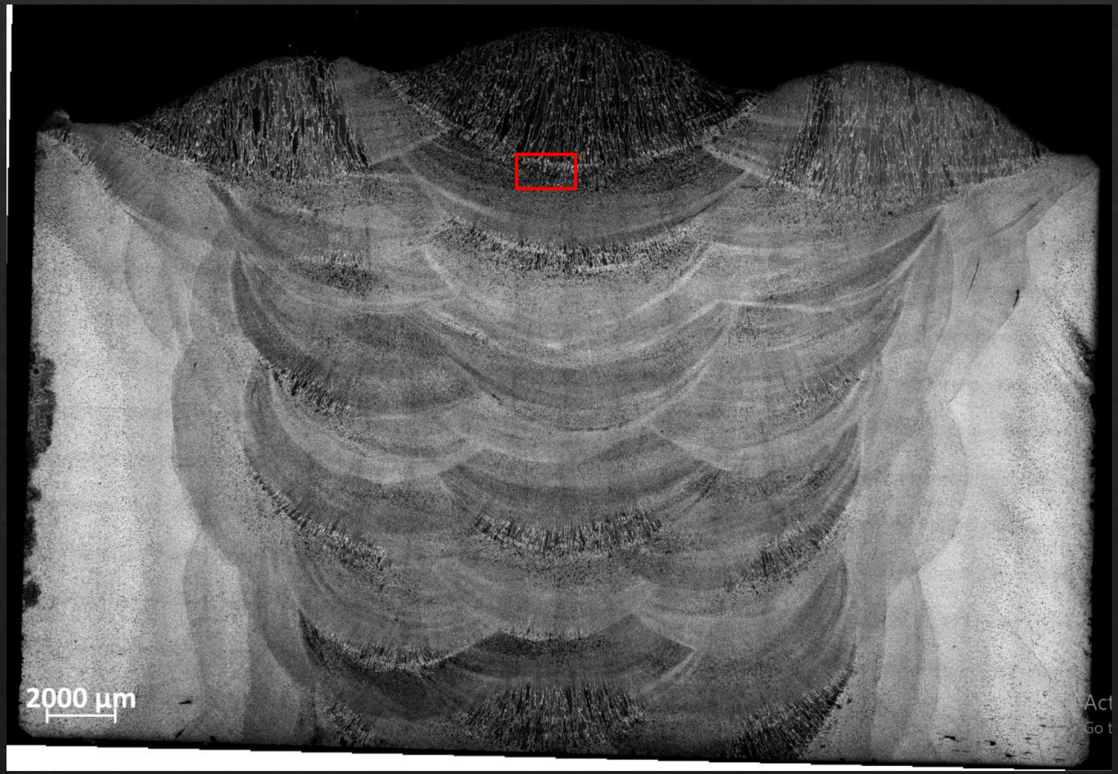


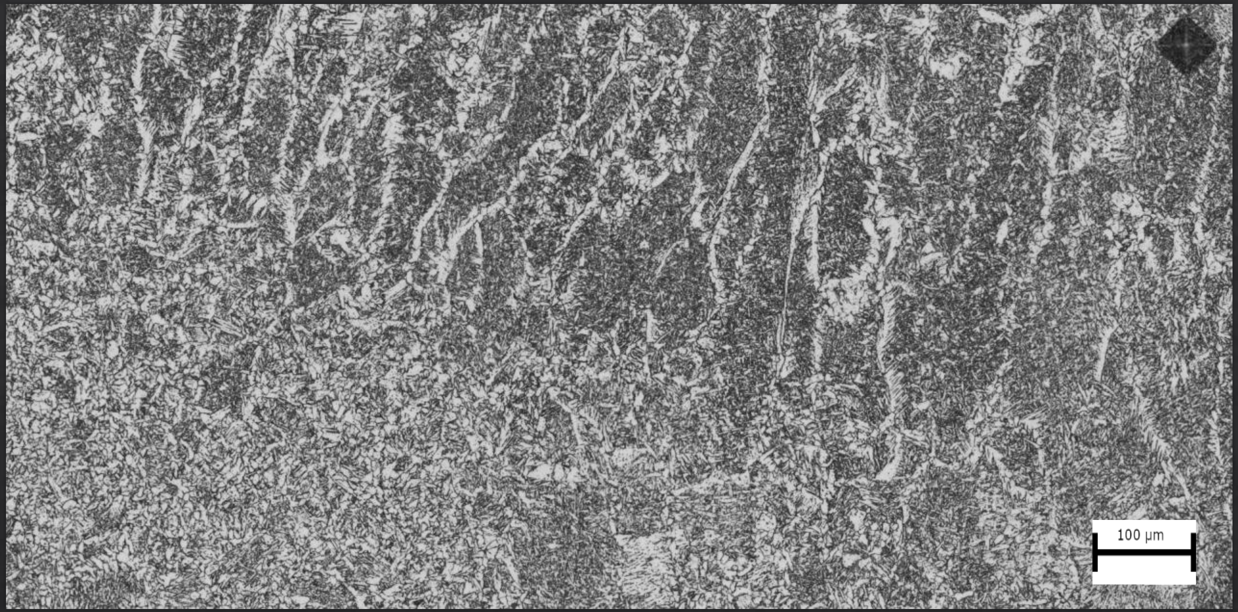


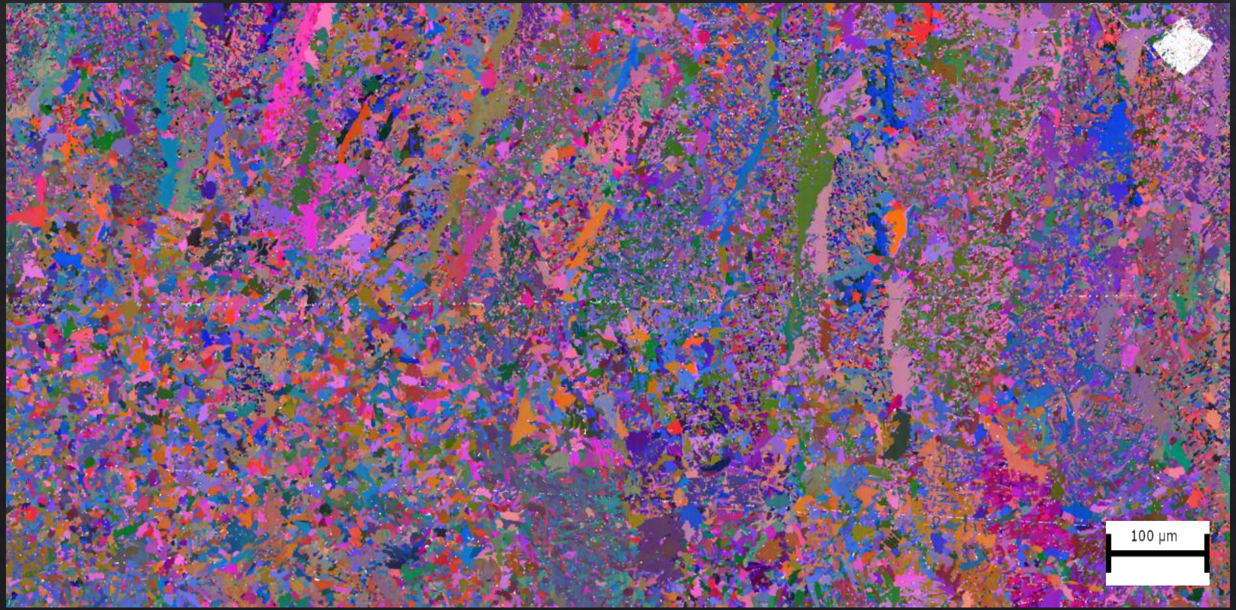


Characterization – Optical vs. EBSD

Last pass fusion zone

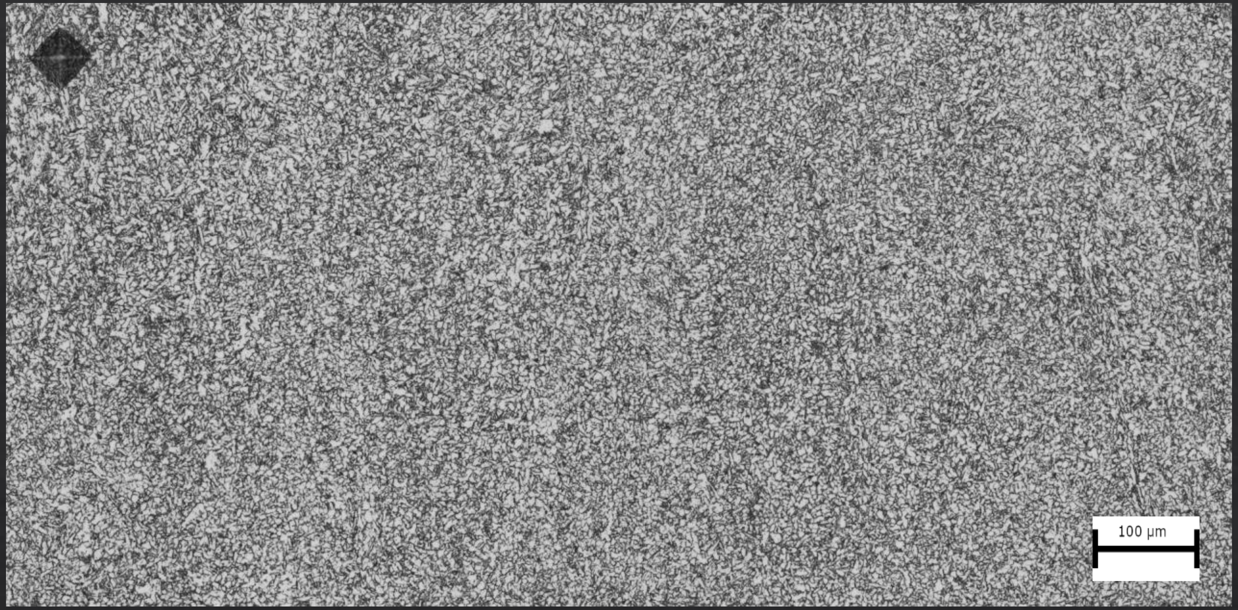


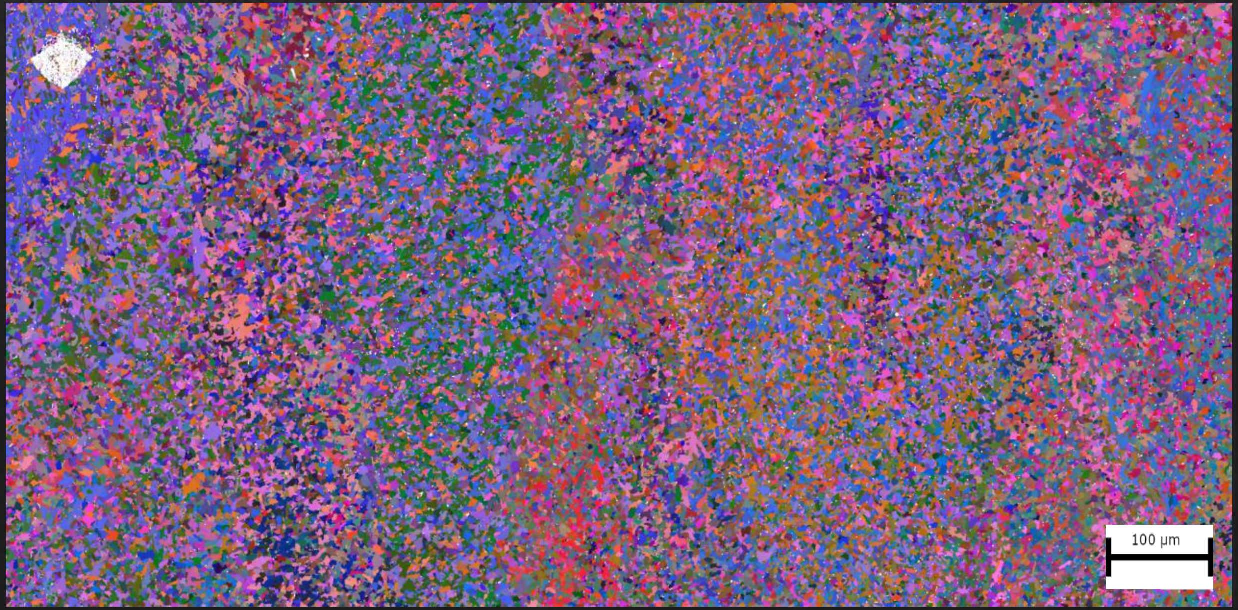




Characterization – Optical vs. EBSD

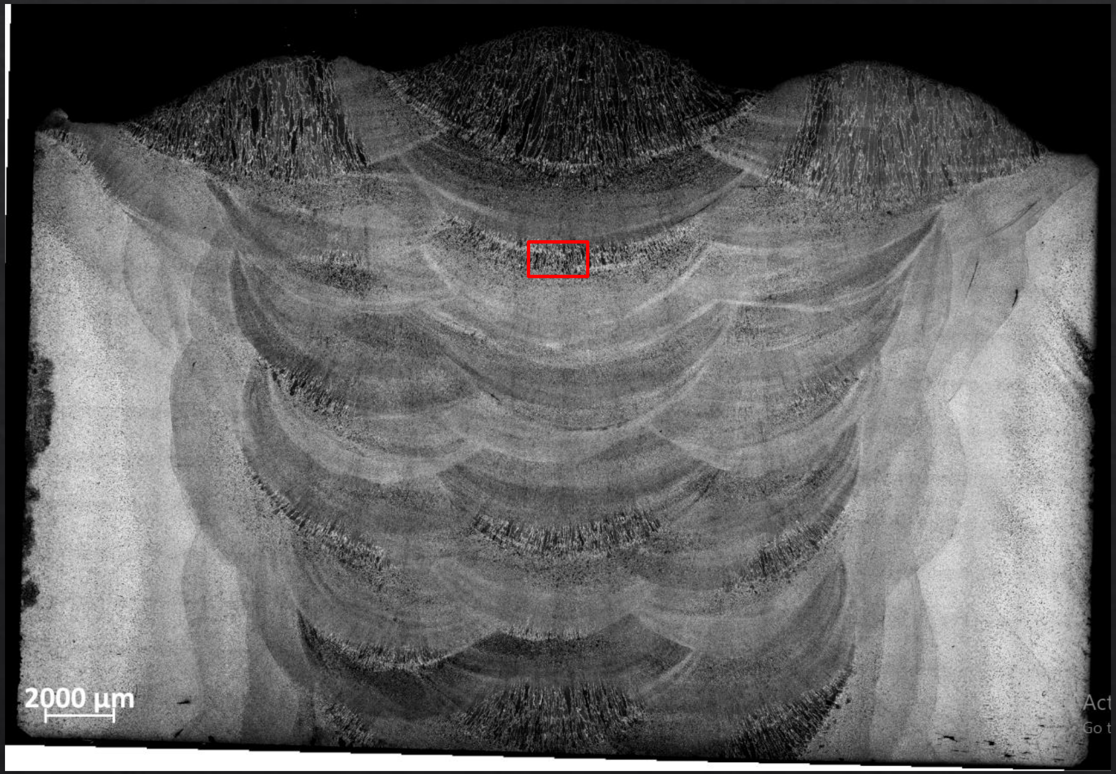
Fine-grained heat affected zone (FGHAZ)

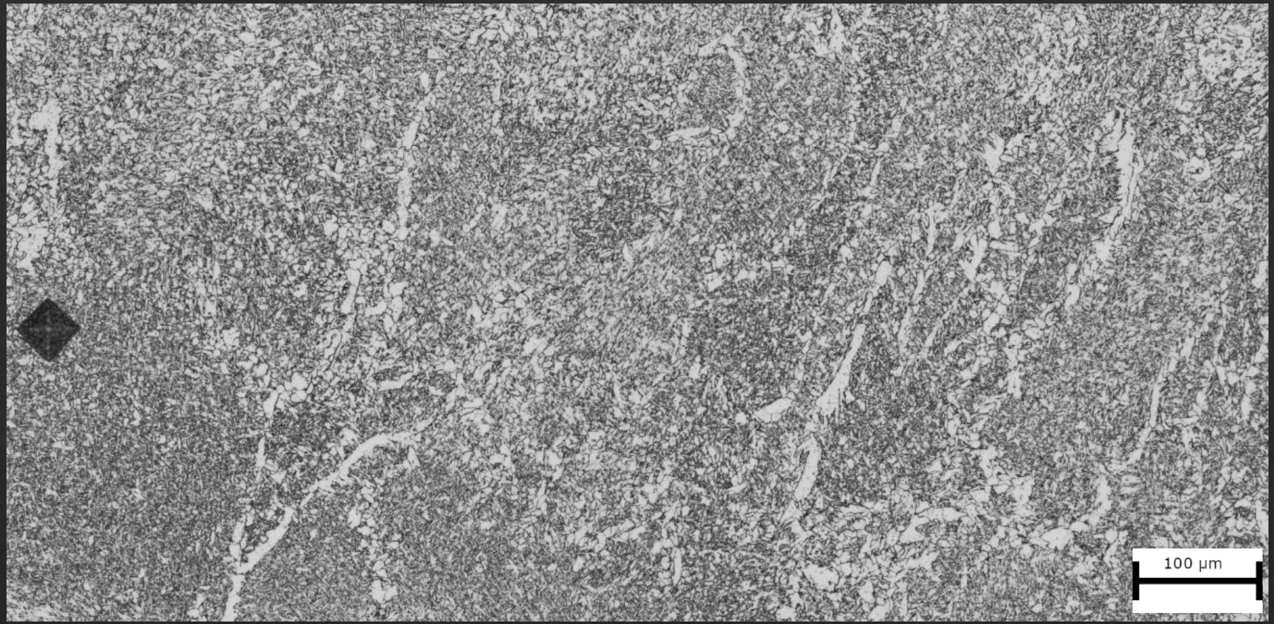


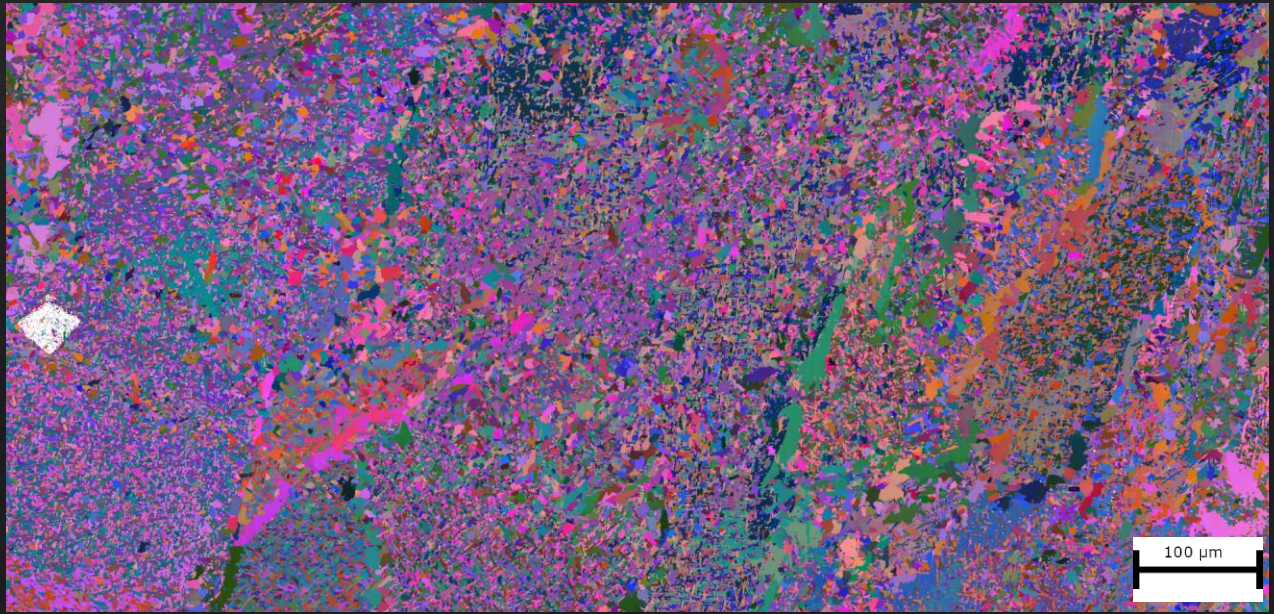


Characterization – Optical vs. EBSD

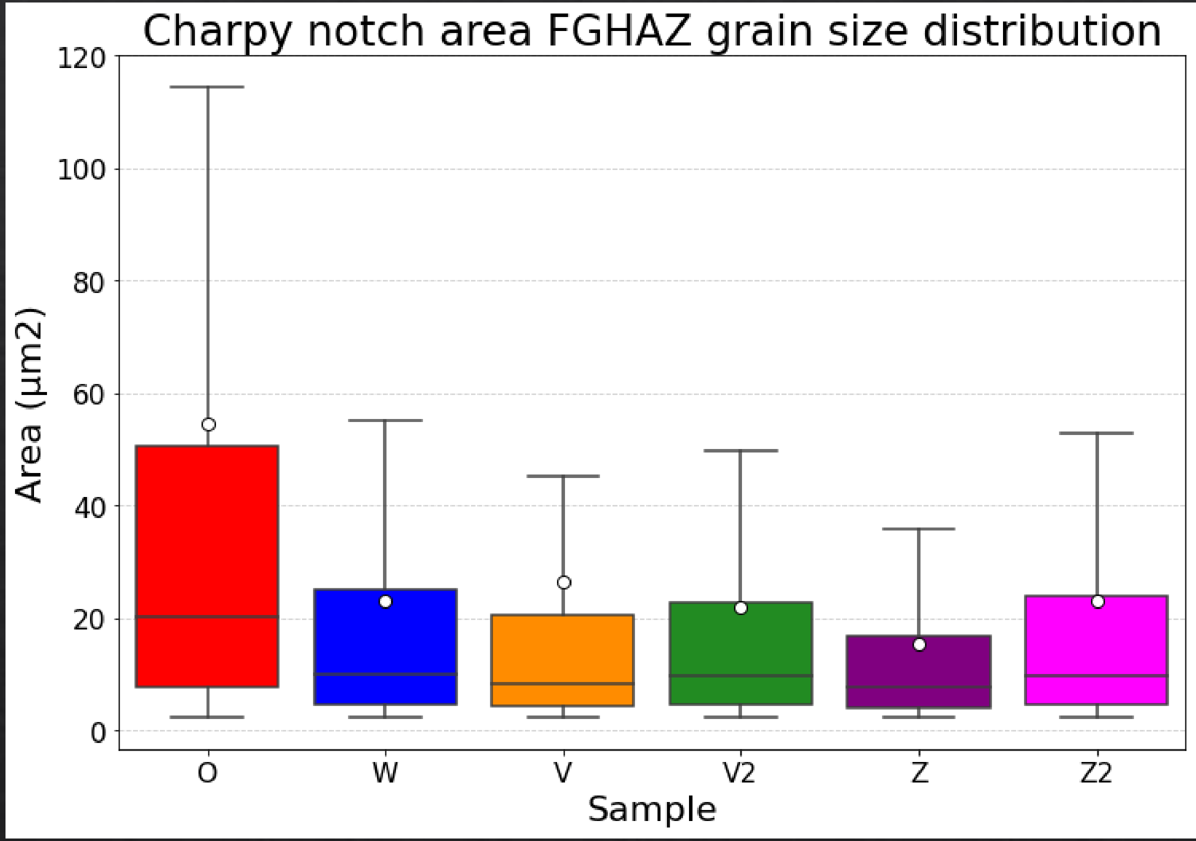
Coarse-grained heat affected zone (CGHAZ)

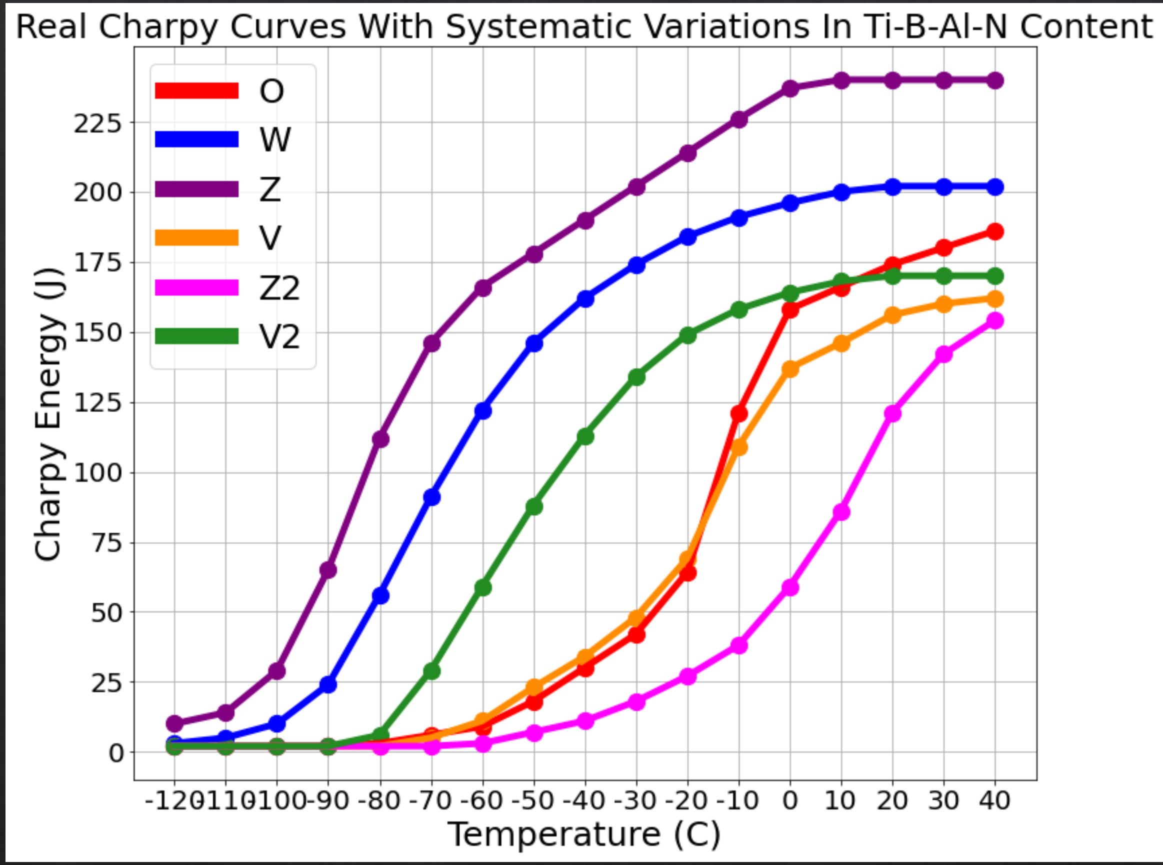






Microstructural variations with composition





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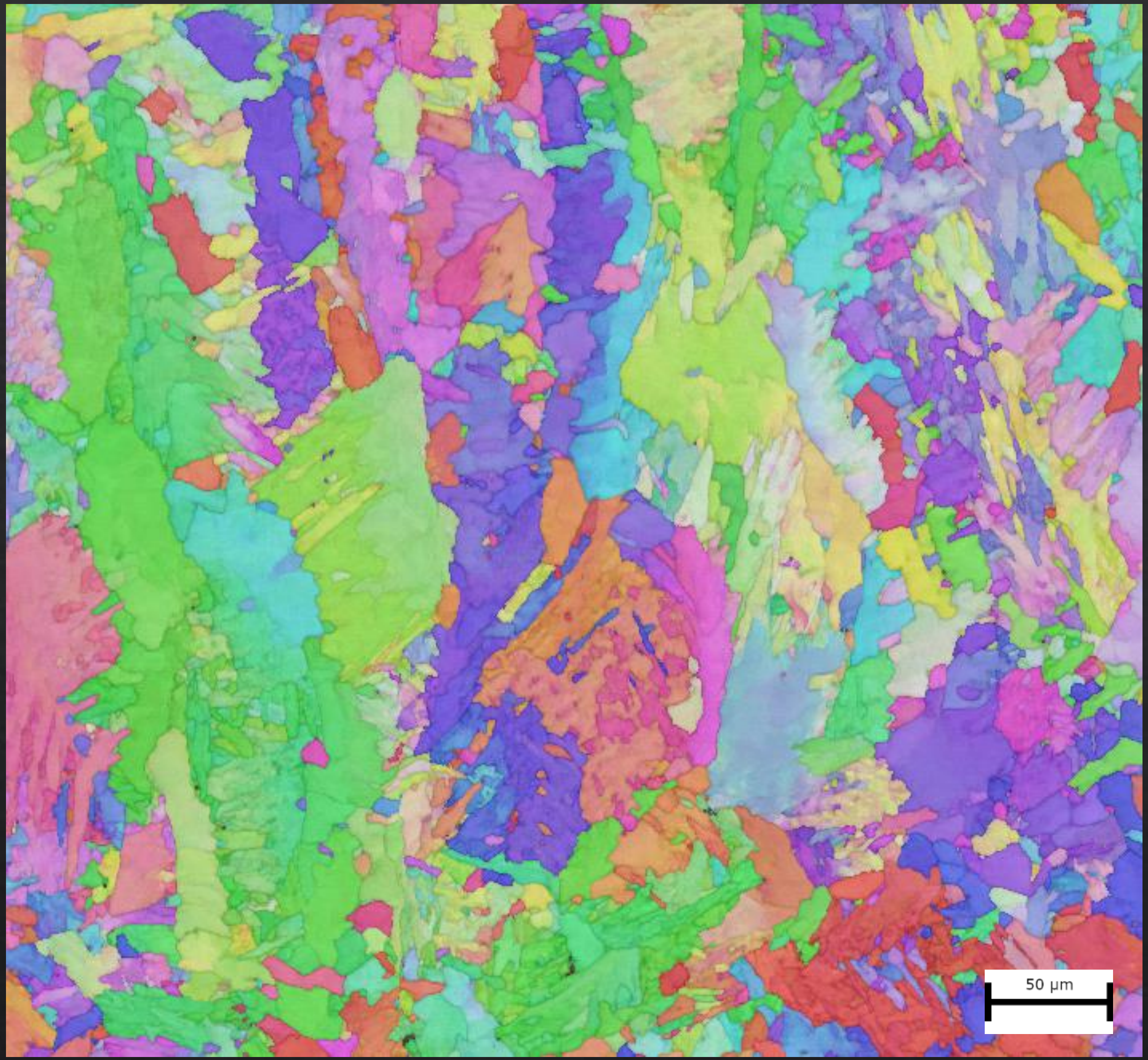
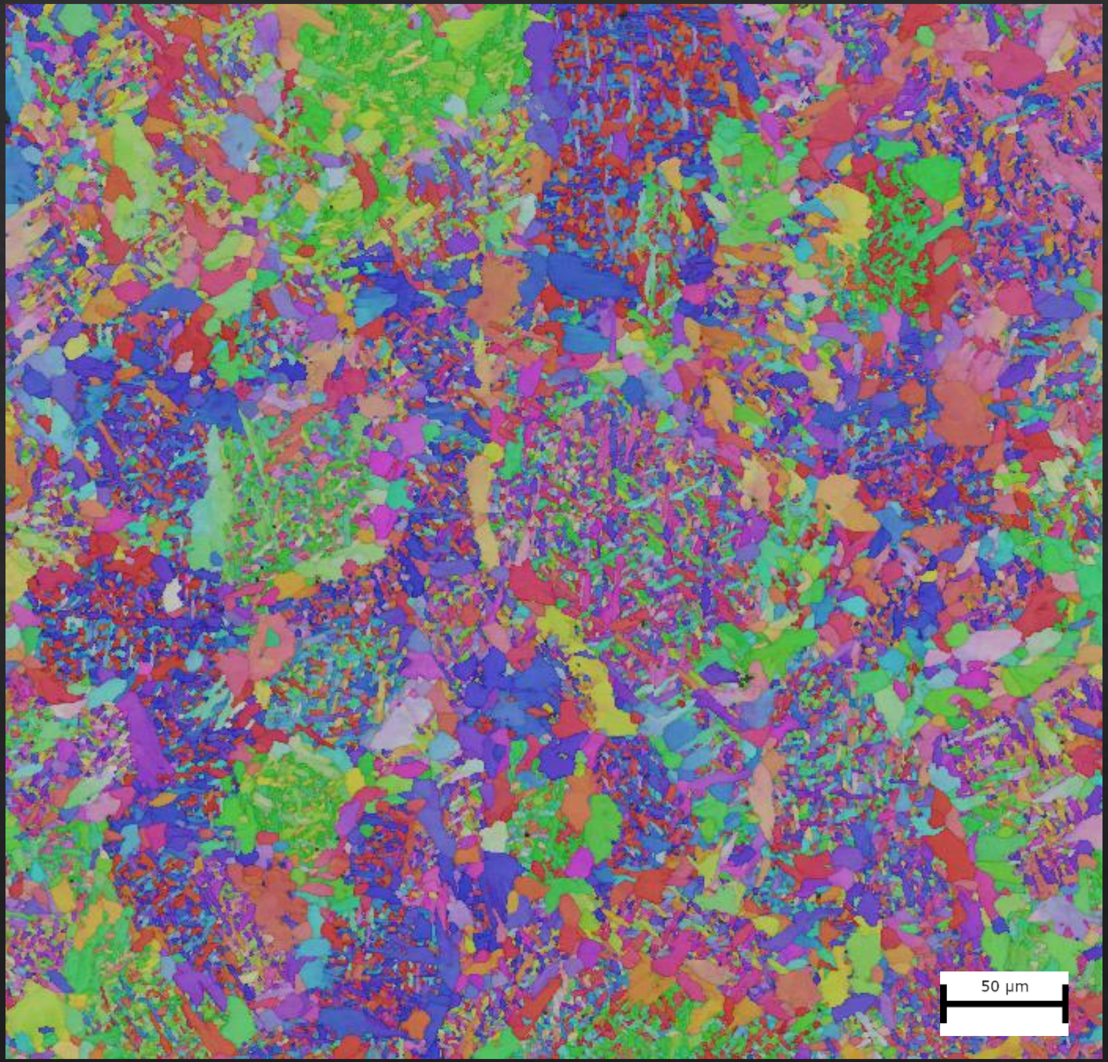
EBSD – O & W (Charpy notch area CGHAZ)





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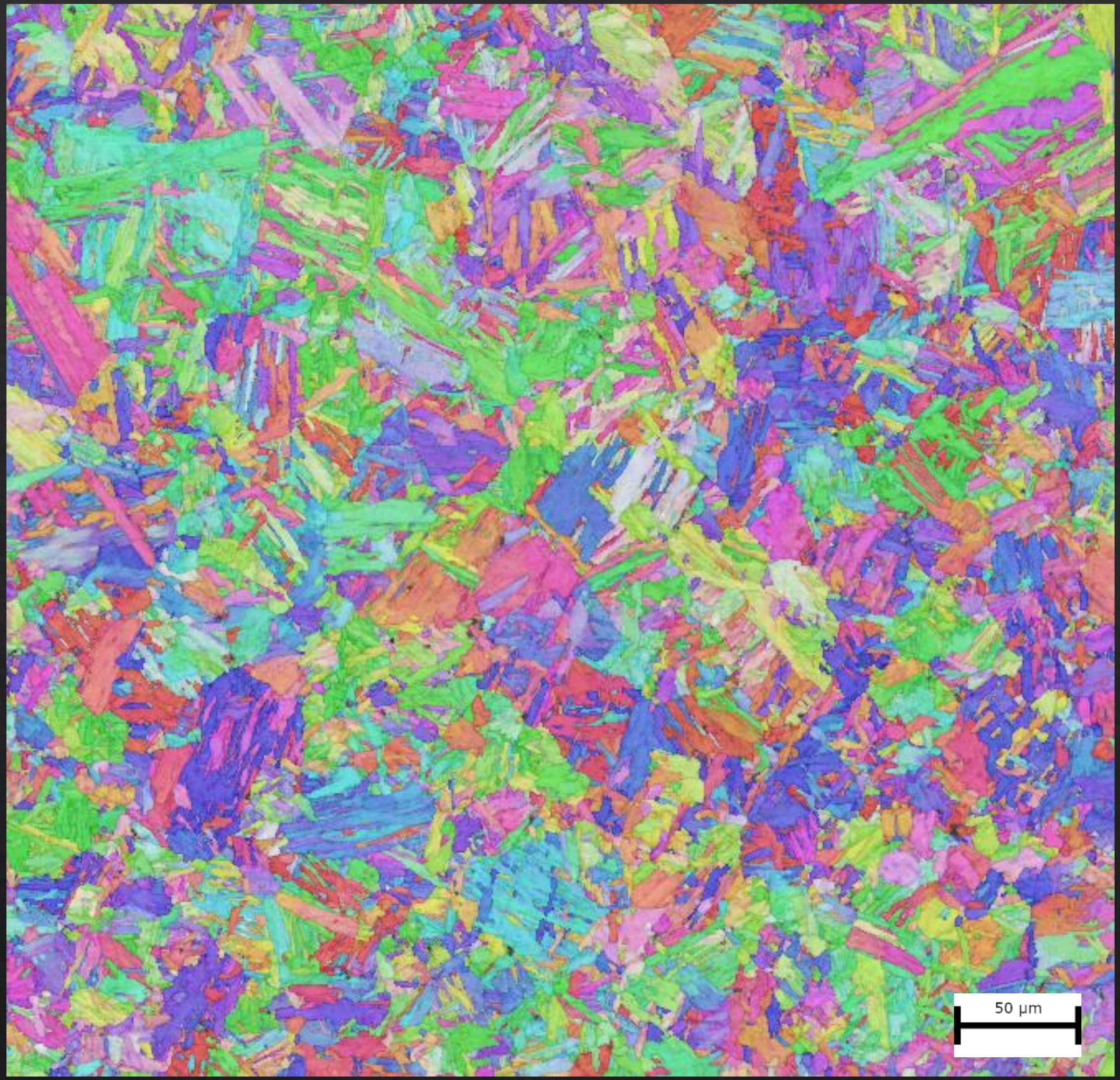
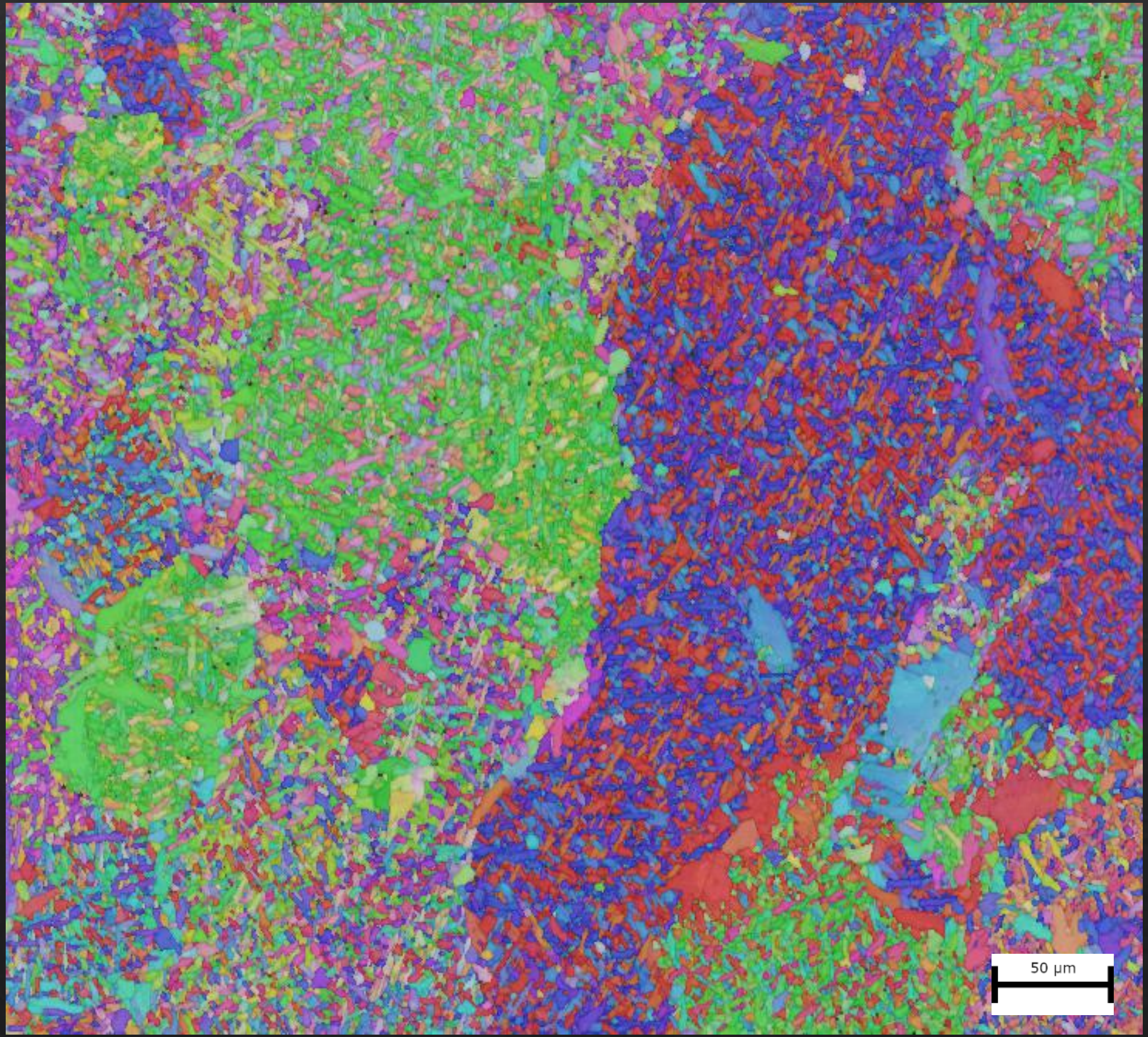
EBSD – V & Z (Charpy notch area CGHAZ)





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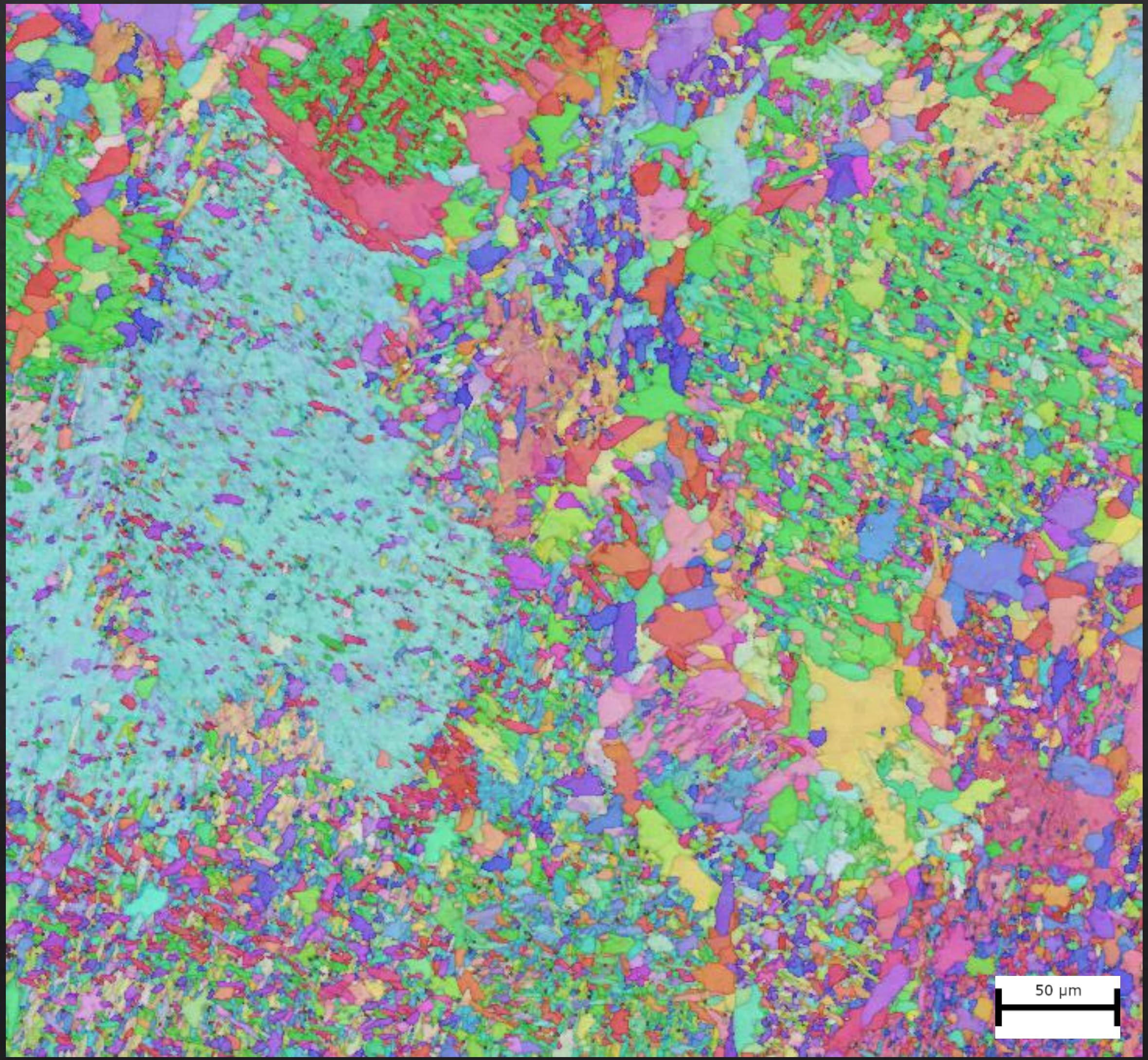
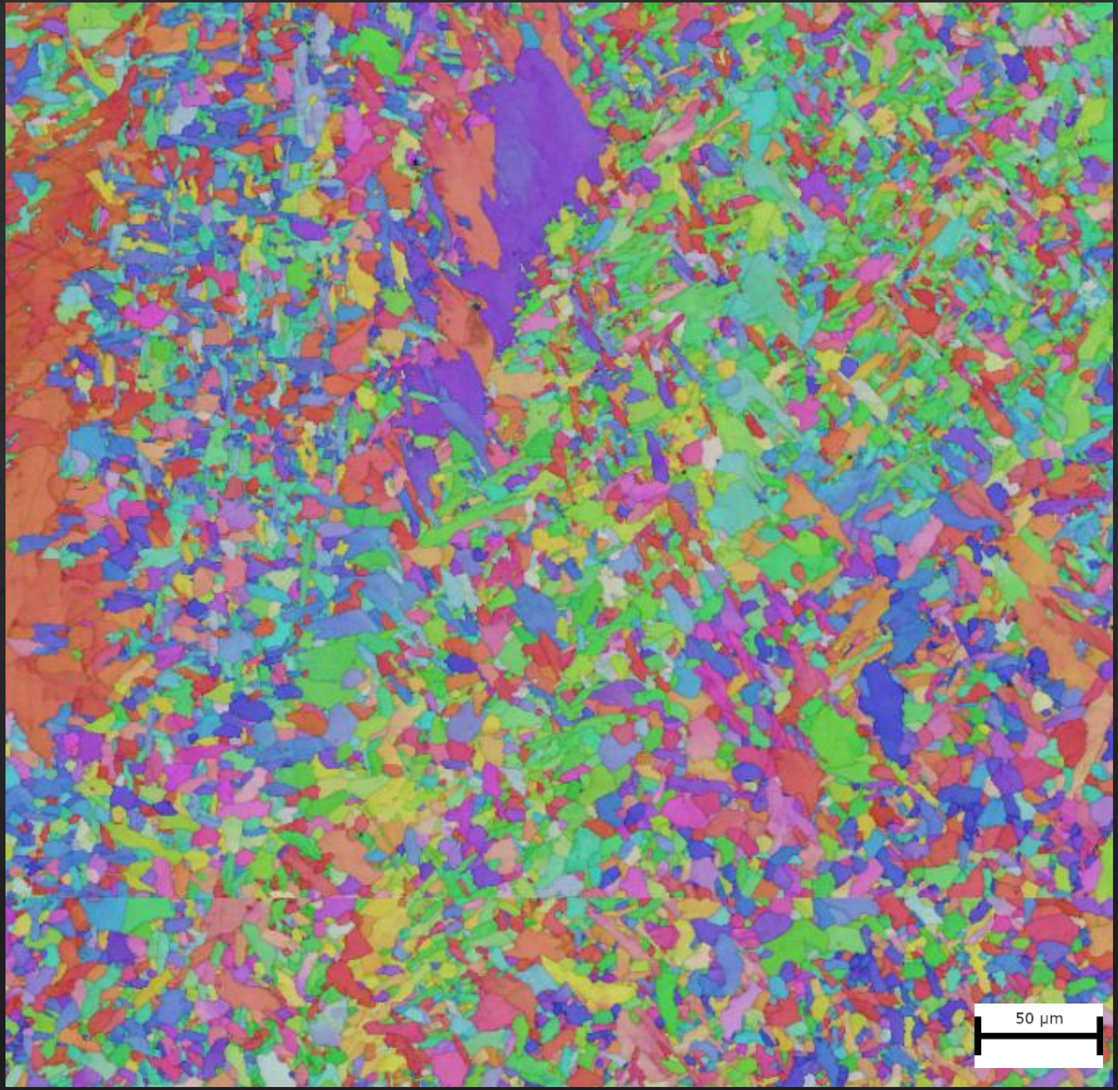
EBSD – Z2 & V2 (Charpy notch area CGHAZ)





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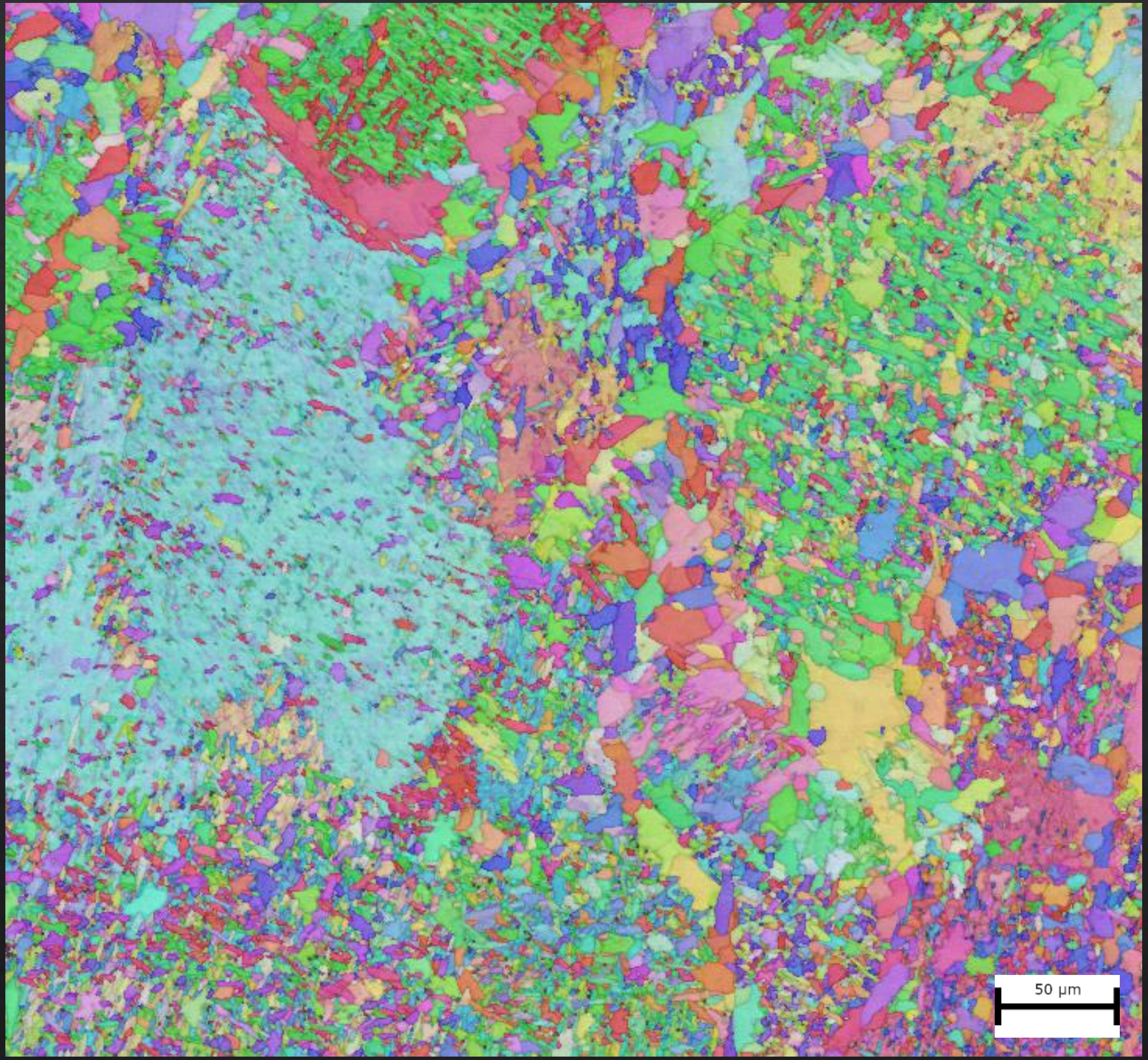
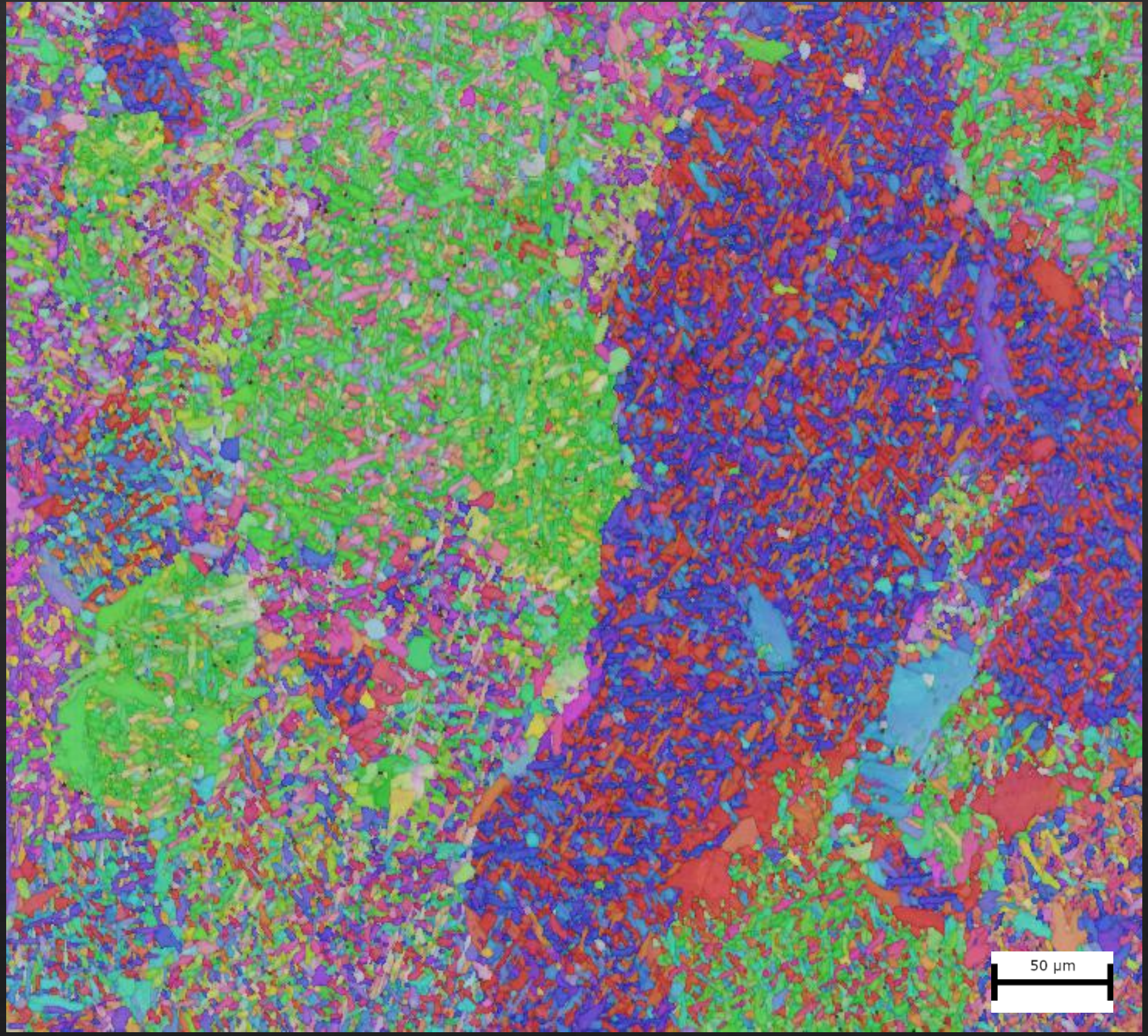
EBSD – Z2 & Z (Charpy notch area CGHAZ)





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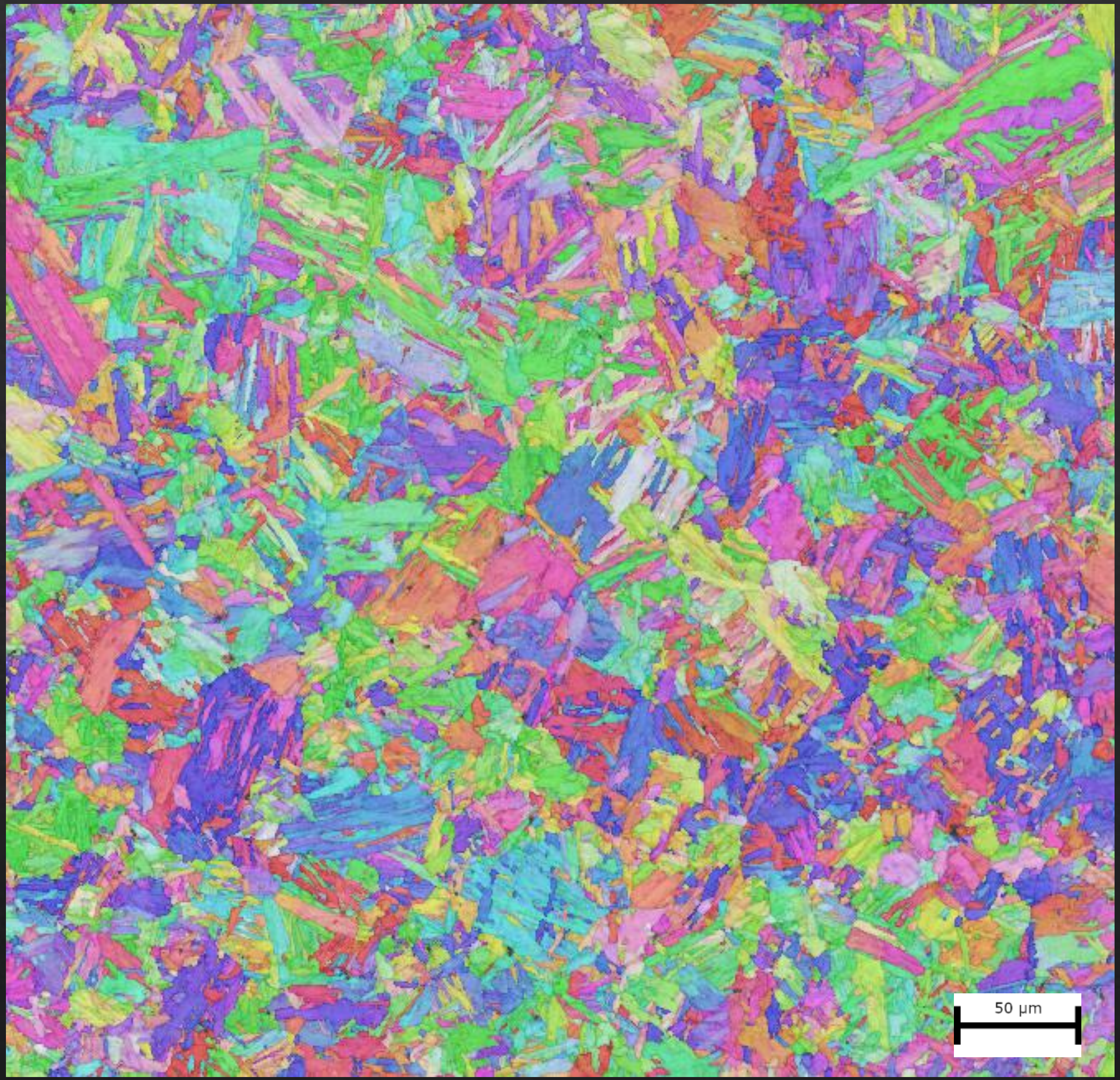
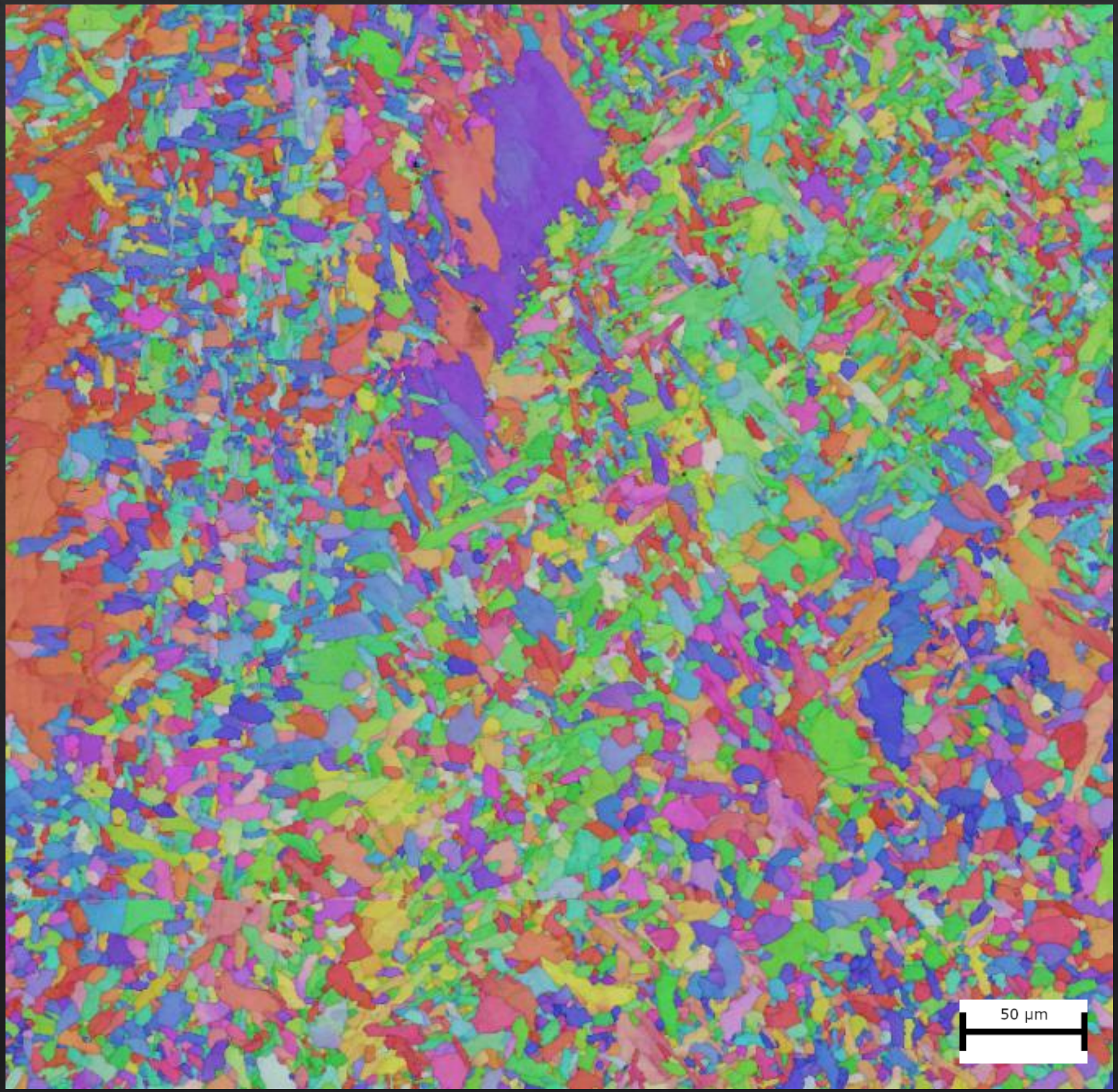
EBSD – V & V2 (Charpy notch area CGHAZ)





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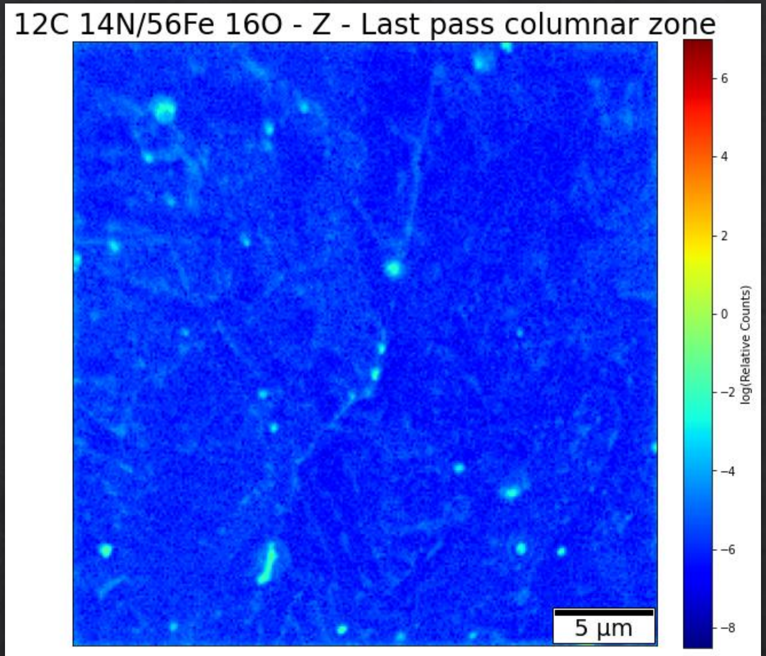
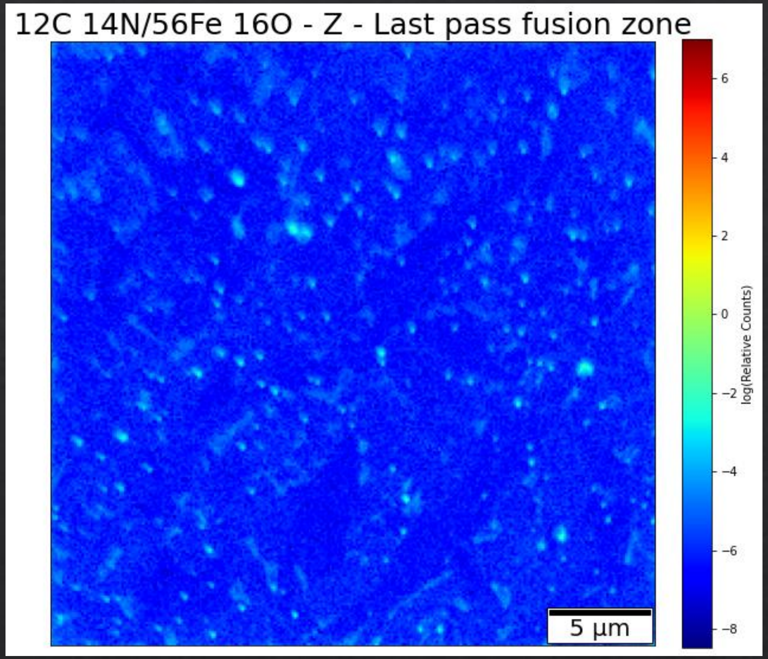
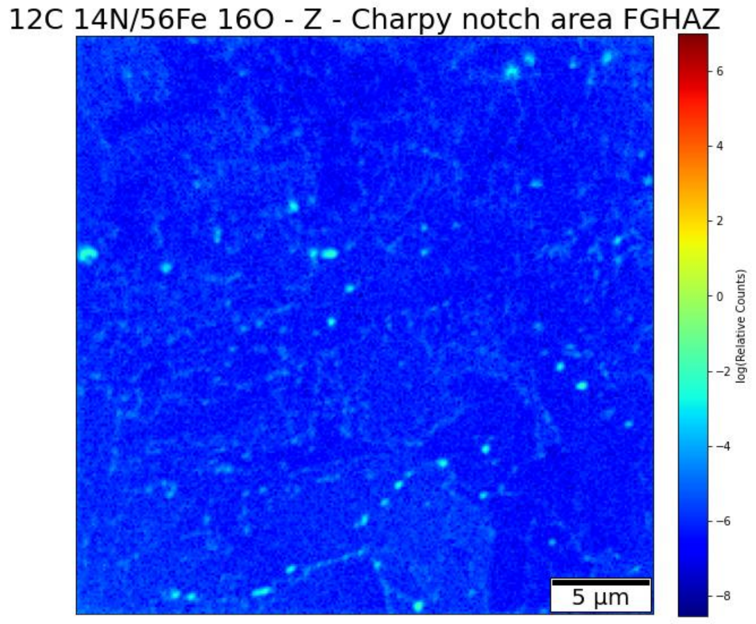
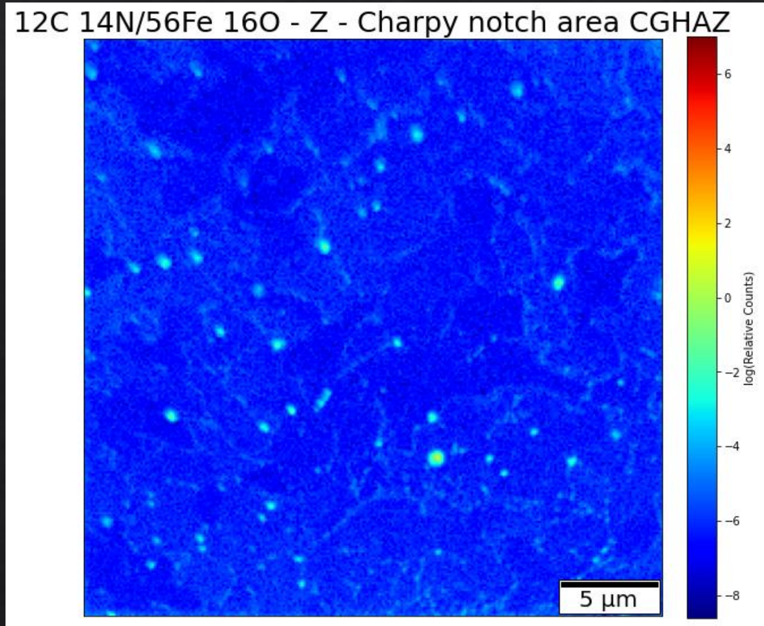
NanoSIMS - Nitrogen (Sample Z)

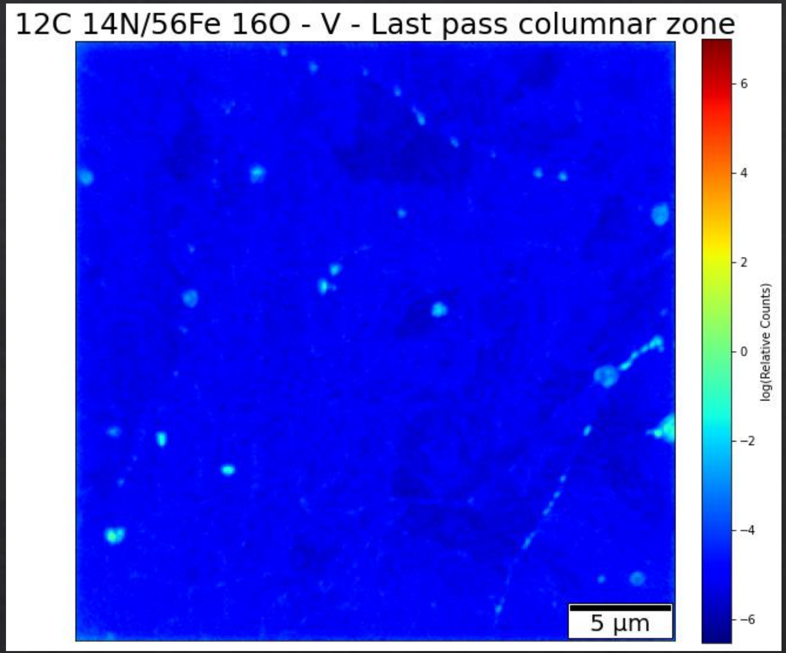


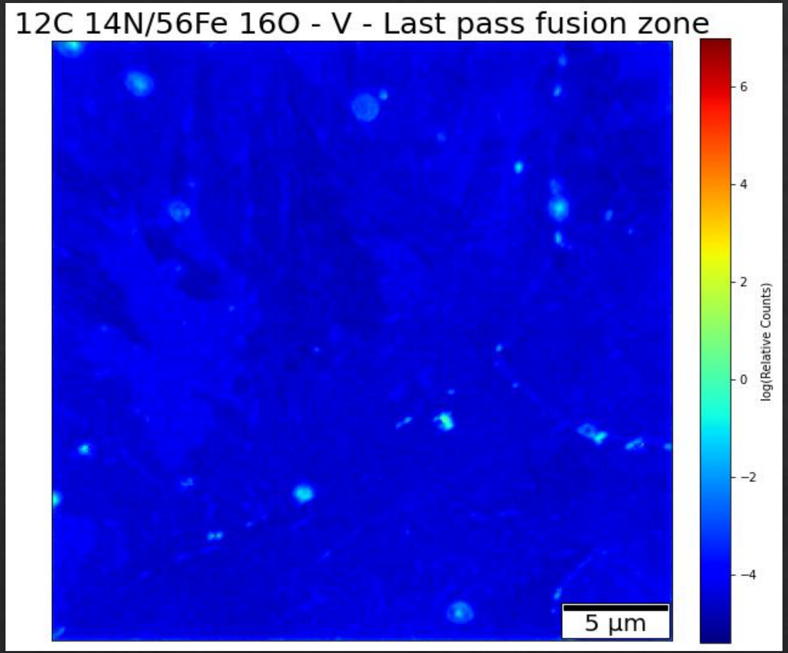


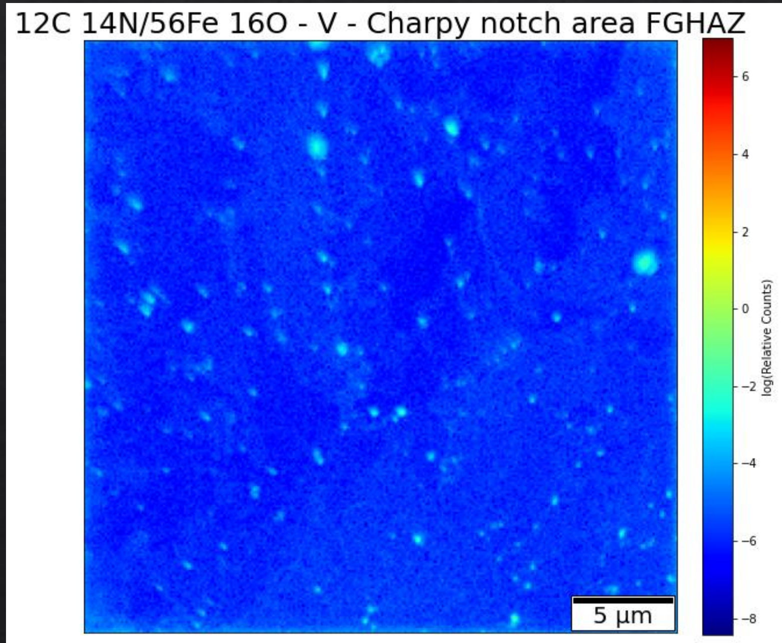


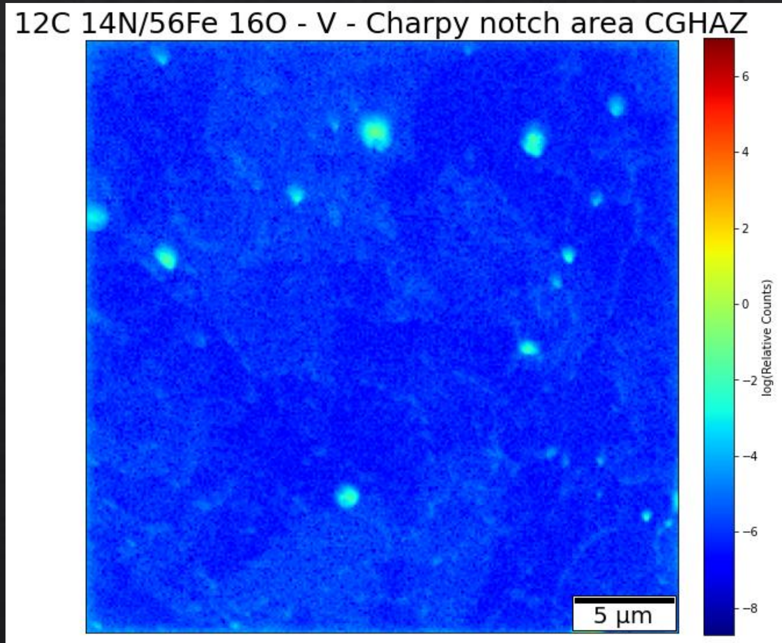


NanoSIMS - Nitrogen (Sample V)

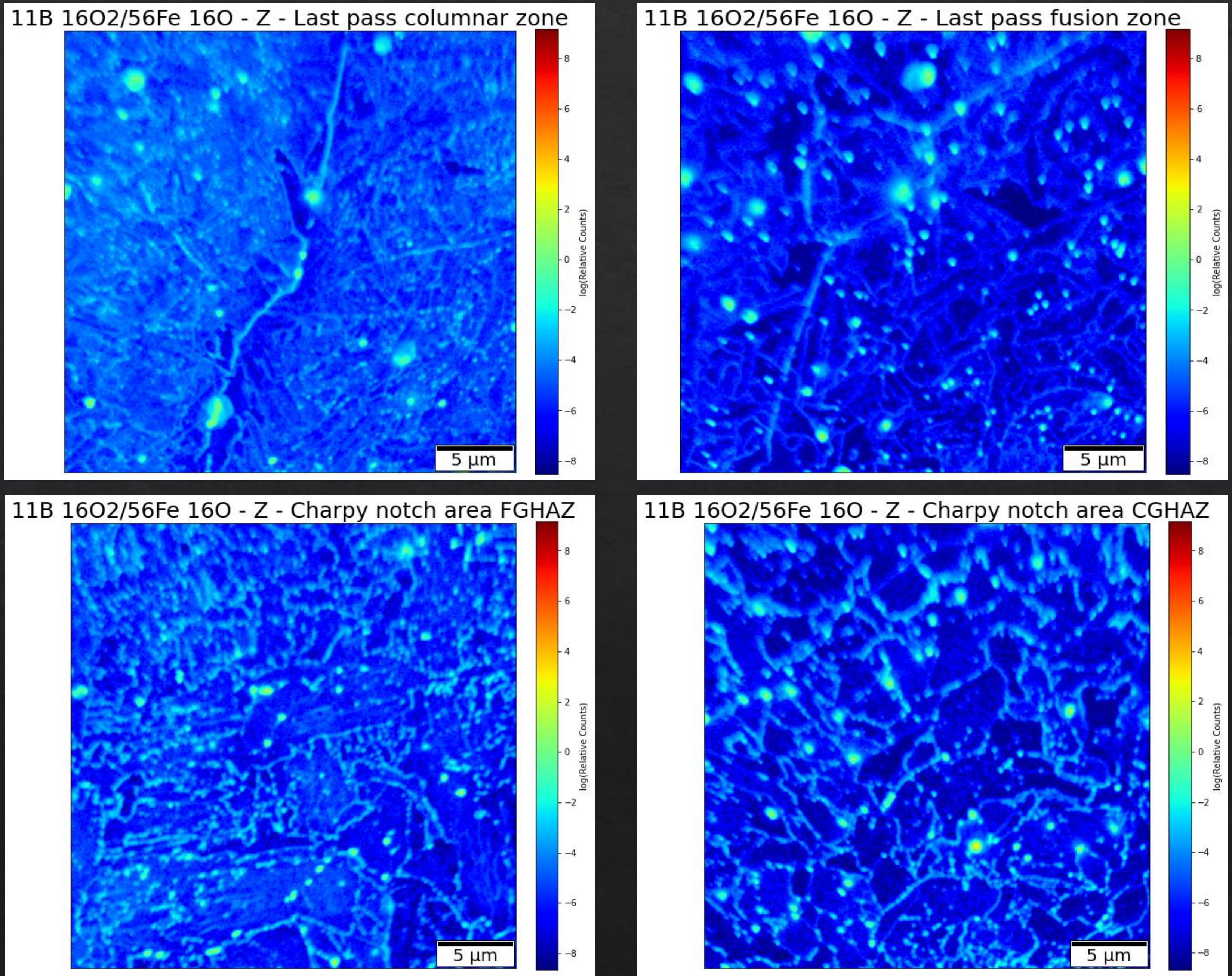




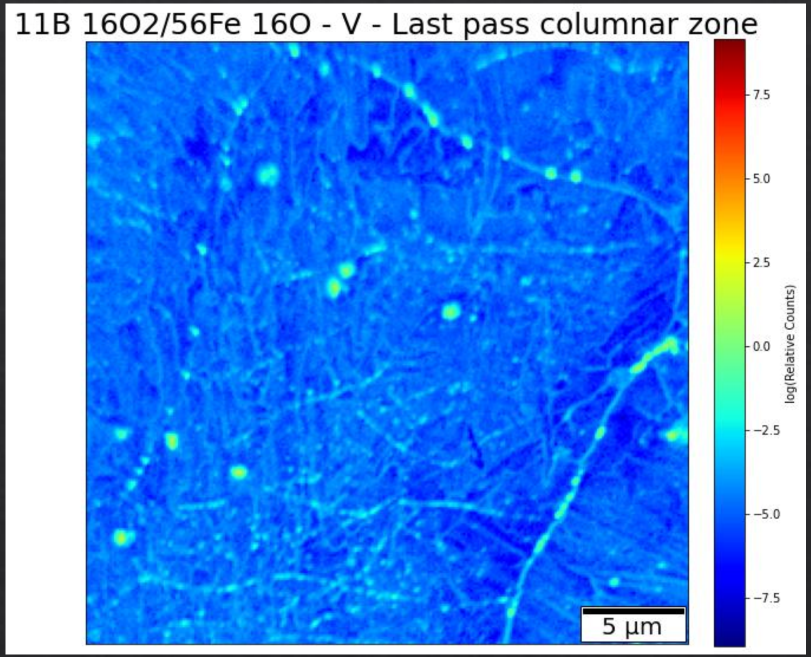


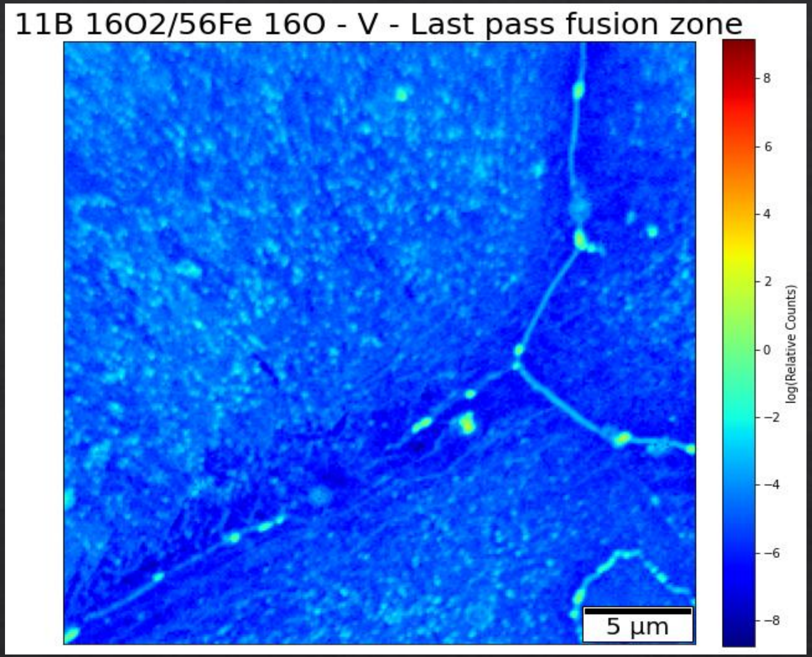


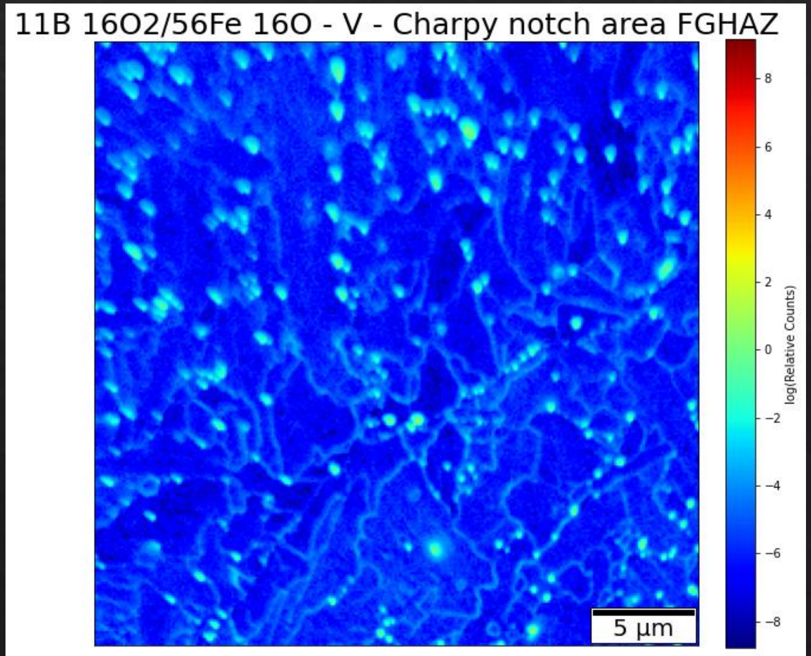
NanoSIMS - Boron (Sample Z)

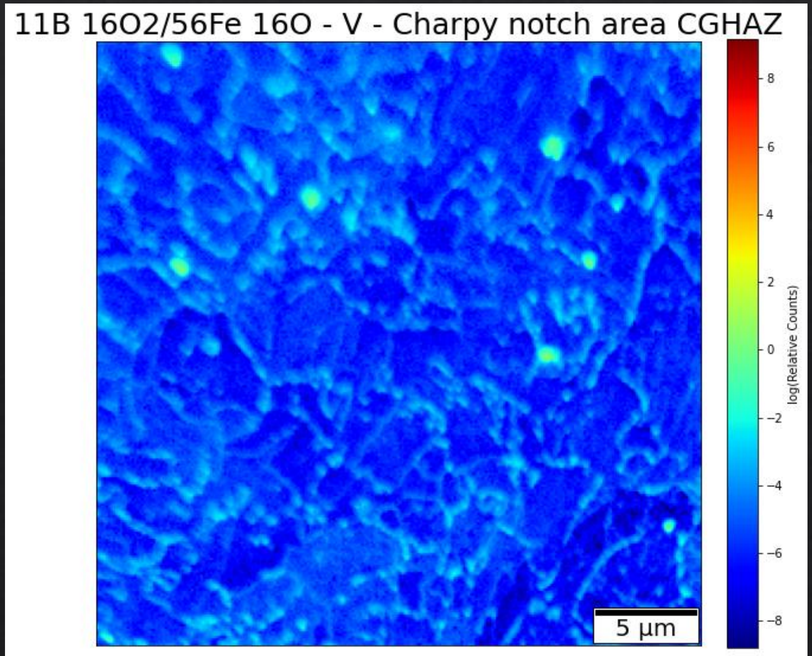


NanoSIMS - Boron (Sample V)

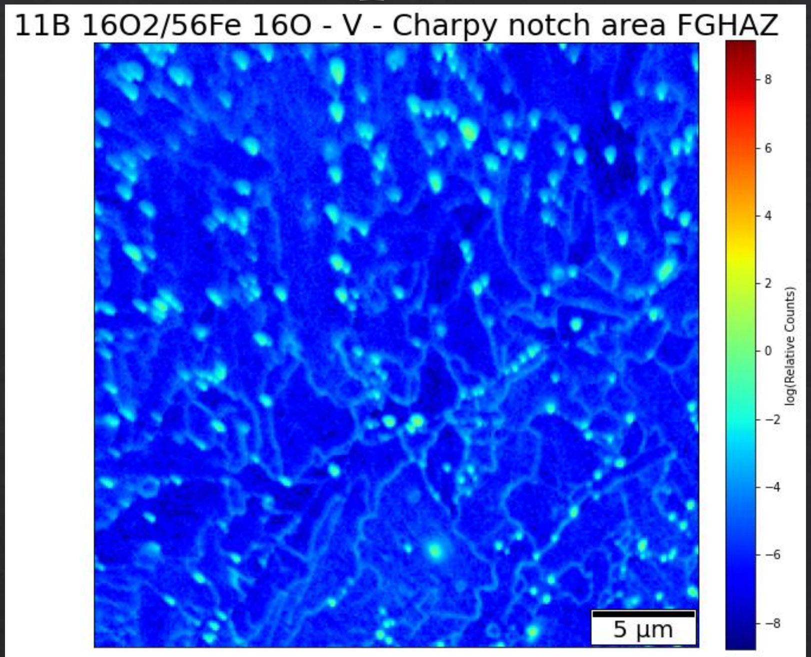


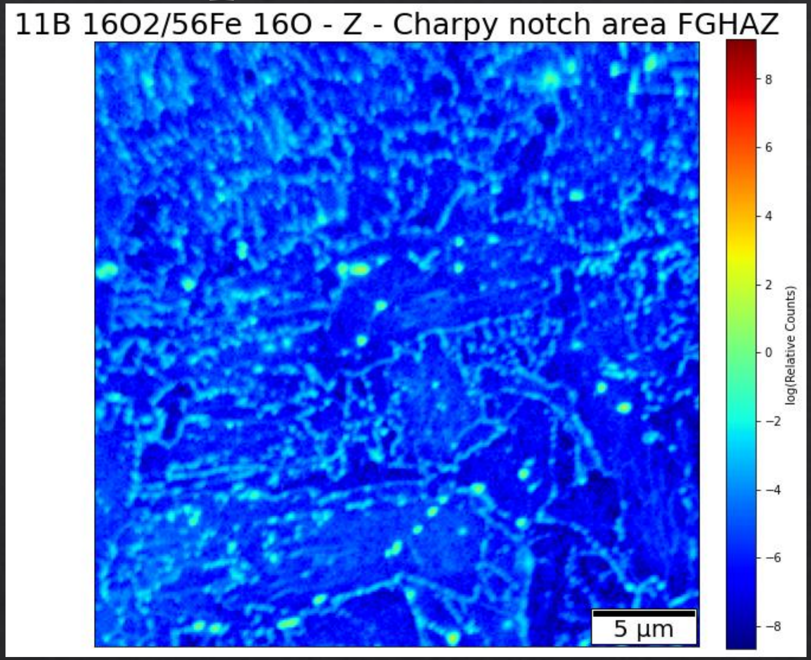


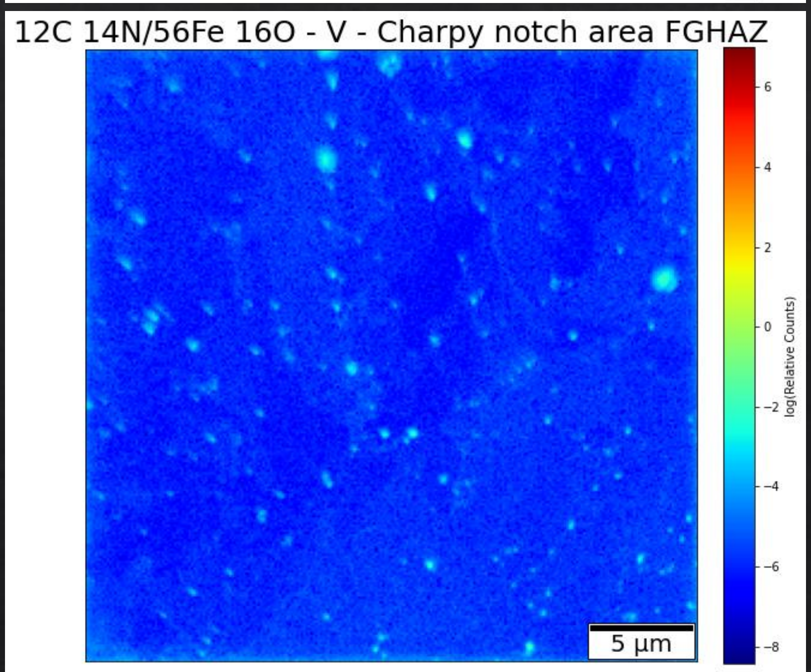


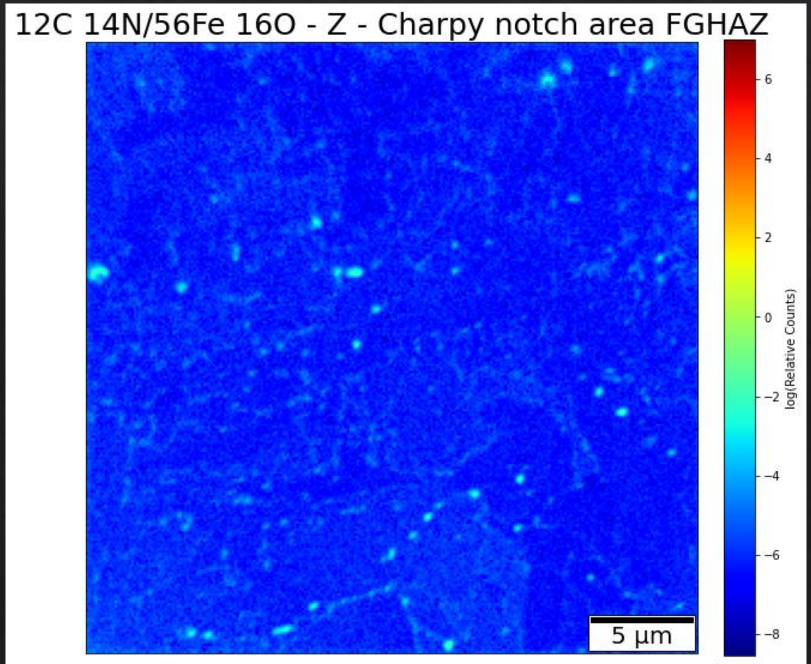


NanoSIMS - Sample V vs. Z (Charpy notch area FGHAZ)









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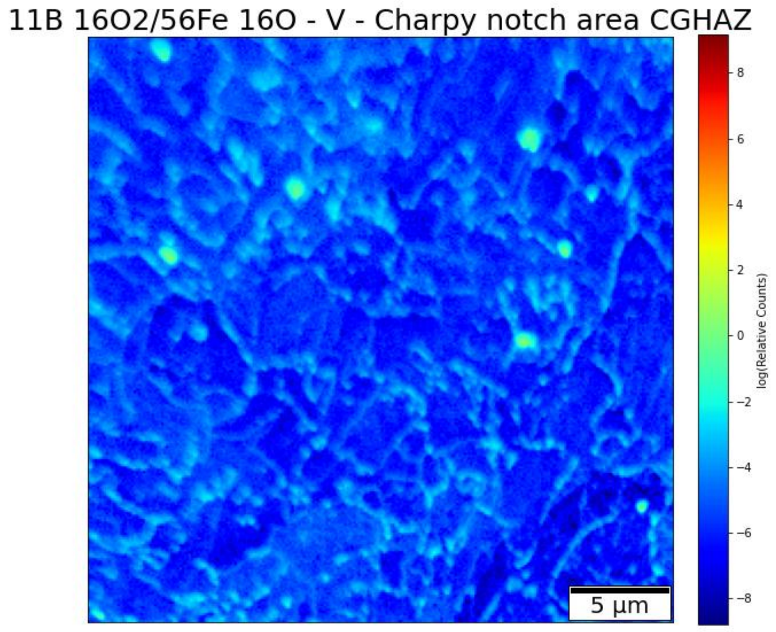

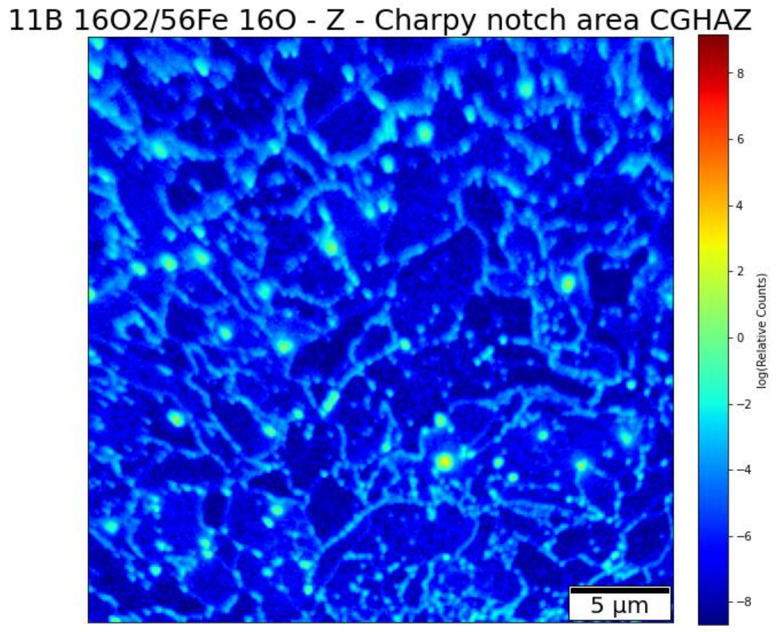

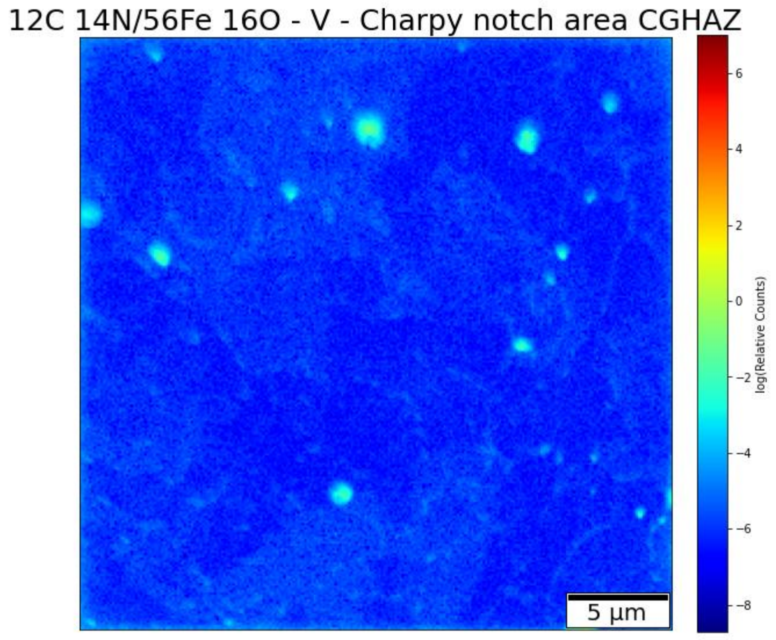

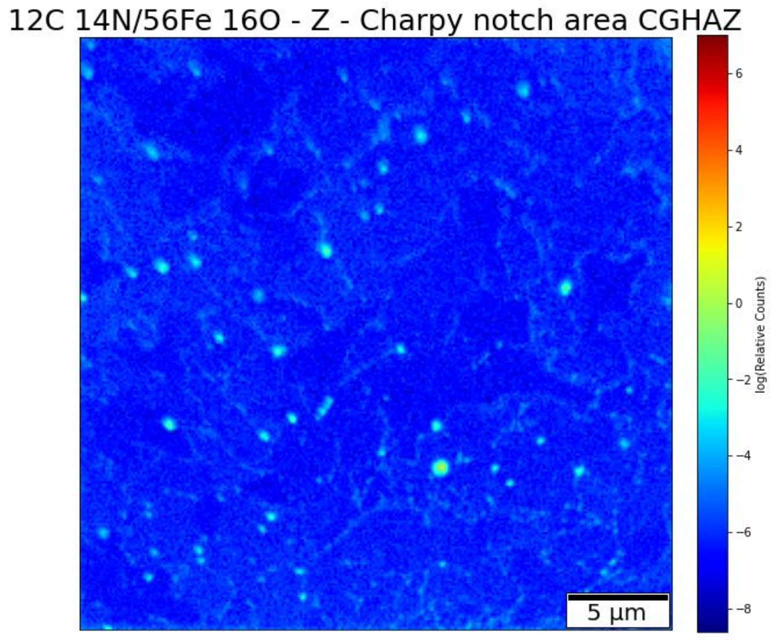

Conclusion

- Reheated microstructures of low-alloy C-Mn steel weld metal appear to be:
  - Either nearly indistinguishable across different compositions (FGHAZ)
  - Or present two relatively distinct grain structures (CGHAZ)
    - Poorer performing samples appear to have a sheave-like bainitic structure
    - Better performing samples appear to have an acicular structure with some/none polygonal or Widmanstätten ferrite
- Local chemical variations appear to be relatively inconsequential to Charpy behaviour in terms of dissolved light elements or their agglomeration
  - Nitrogen does not seem to diffuse significantly due to thermal cycling
  - Boron diffuses greatly from the matrix of the last pass to grain boundaries and second phase particles
  - However, further study is needed into the nature of the second phase particles present across different compositions

Thank you for listening!