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Enhancing grain refinement of austenitic steel with Ti additions by melt treatment sequence optimization

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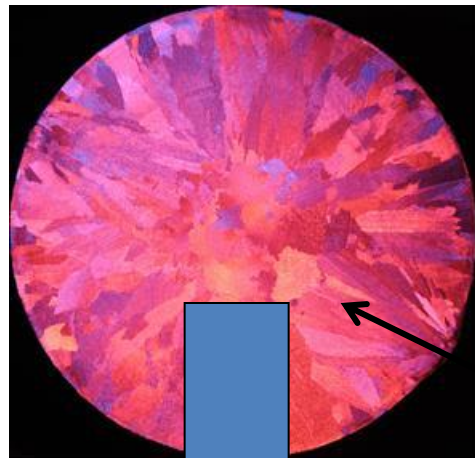




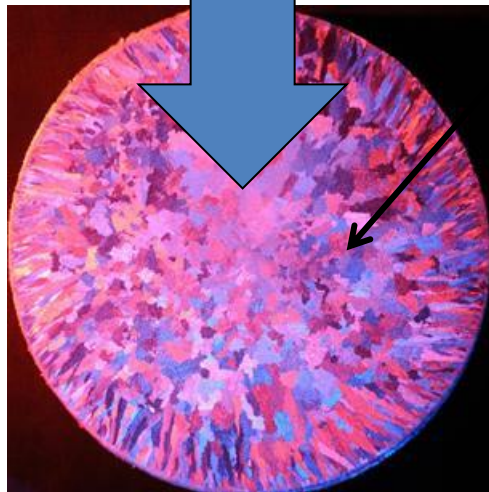
Objective

Grain size control is one of the most important aspects in the cast alloys processing

Objective: To develop an advanced solidification process for controlling the crystallization structure of austenitic grades of cast steels in heavy sections



Columnar structure



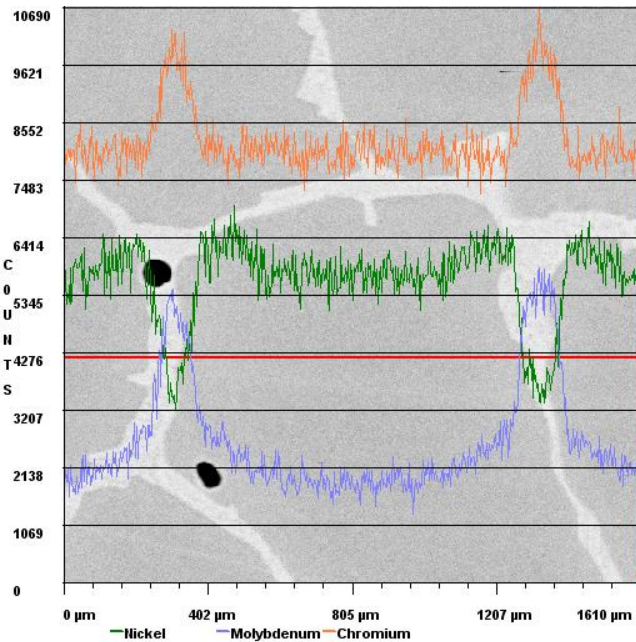
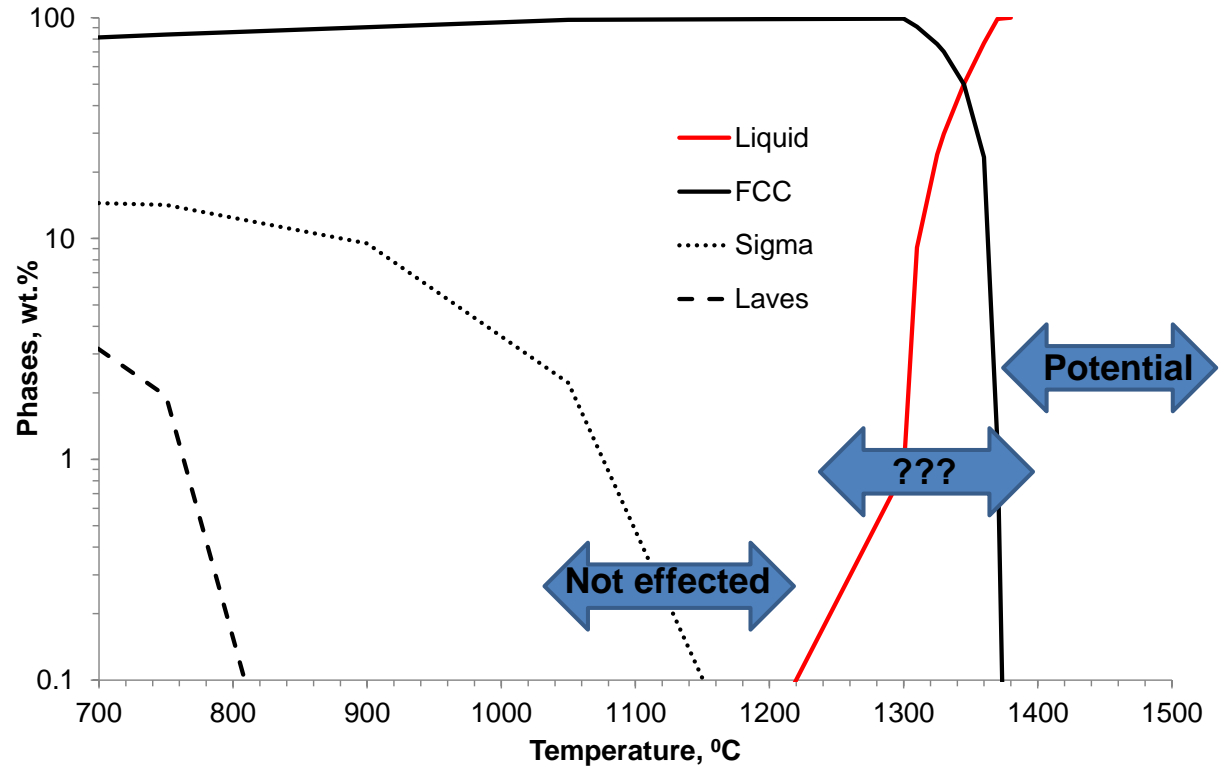
Equiaxed structure

- High alloyed austenitic steels are used in both the as-cast condition and heat treated conditions
- The as cast grain size is important for all applications as it determines the minimum grain size achievable in these cast alloys



Potential heterogeneous nuclei in base steel

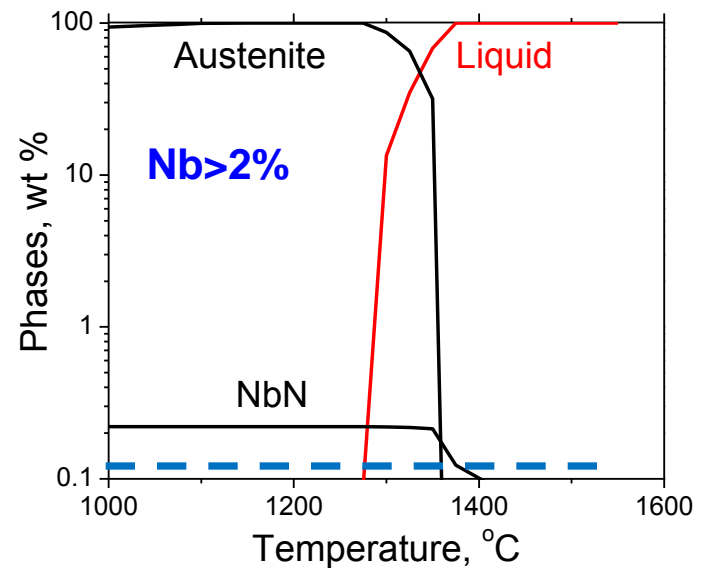
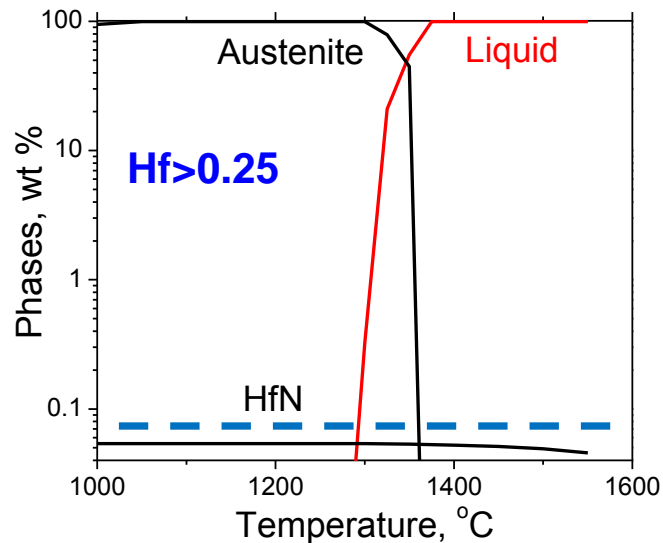
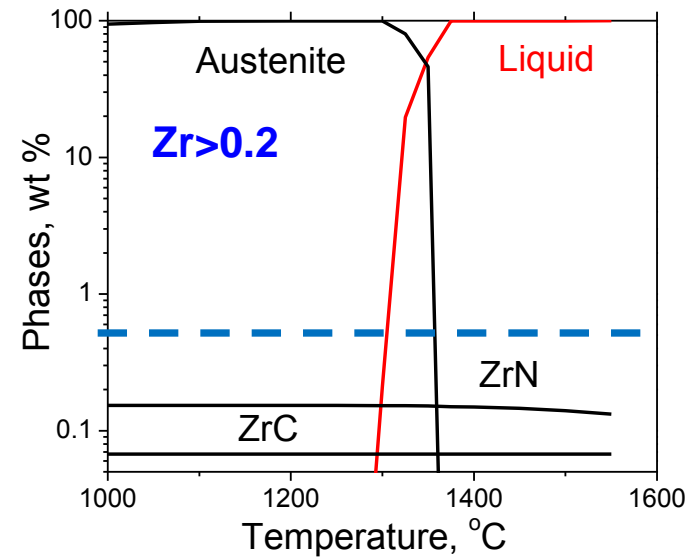
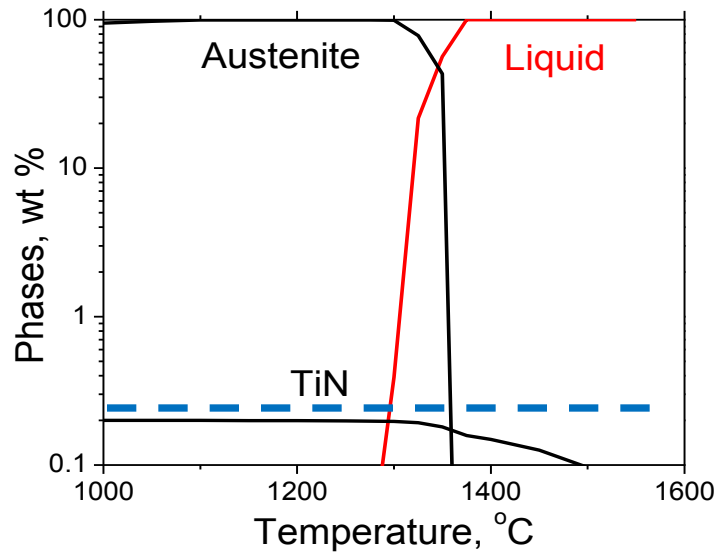
Factor stability in the melt



19Cr18Ni superaustenitic stainless steel



Calculated stability of potential nuclei



--- Oxides



Effect of additional de-oxidation

- What is the sequence of reactions during processing?
- How sequence of treatment will change composition of reaction products?
- What will be optimal sequence of melt treatment?

One step

Refiner

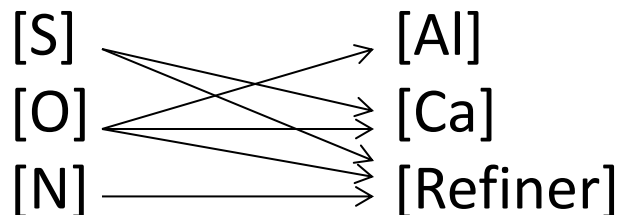
Complex

De-ox
+Refiner

Sequential

De-ox

Refiner



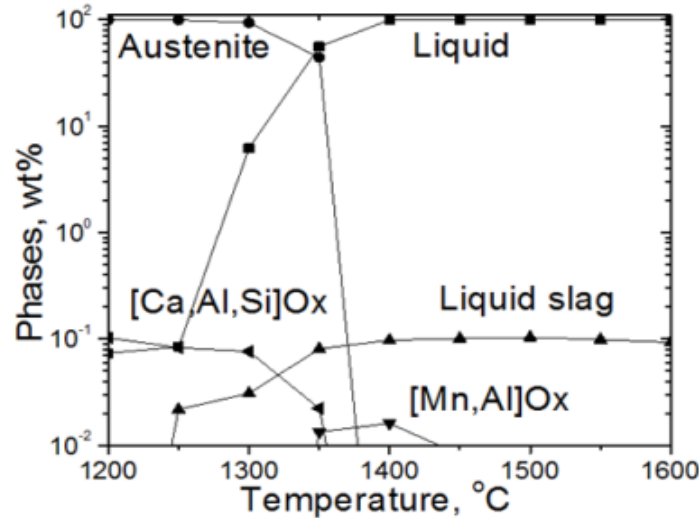


Simulated cases and experimental heats

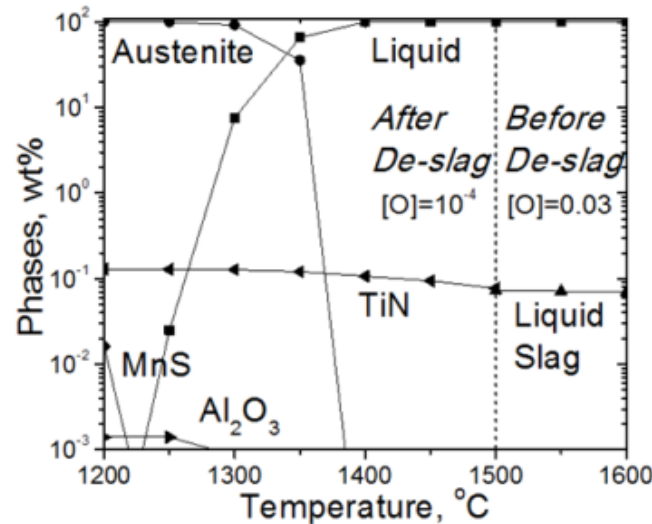
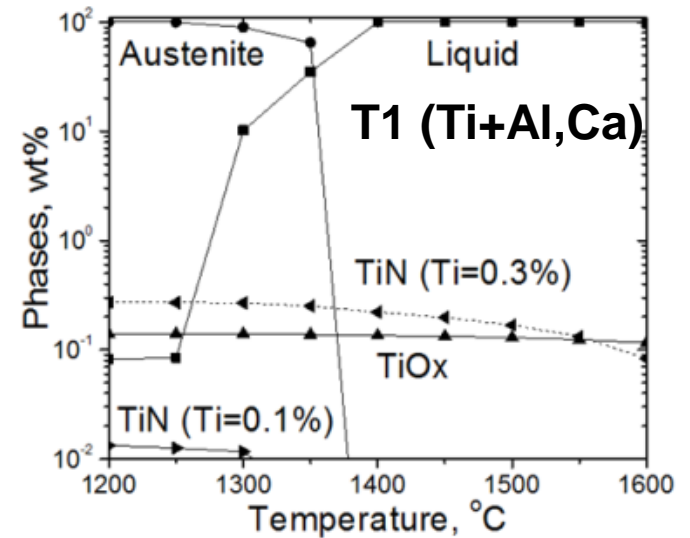
Heat #	Treatment	
	First	Second
B	-	Al, Ca
T1	Ti	Al, Ca
T2	Al, Ca	Ti
T3	Ca	Al, Mg, Ti



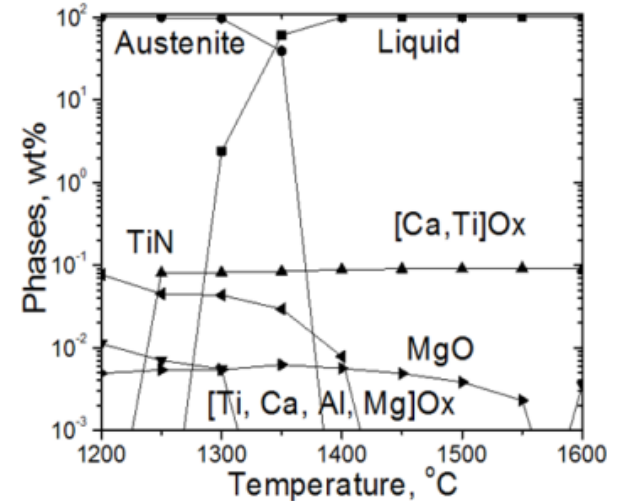
Effect of treatment sequences on precipitations



B0 (Al+Ca)



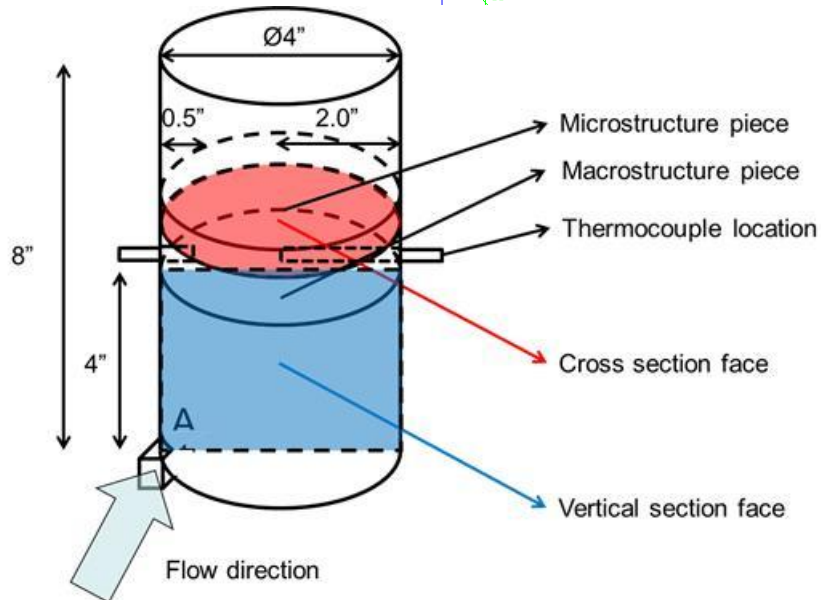
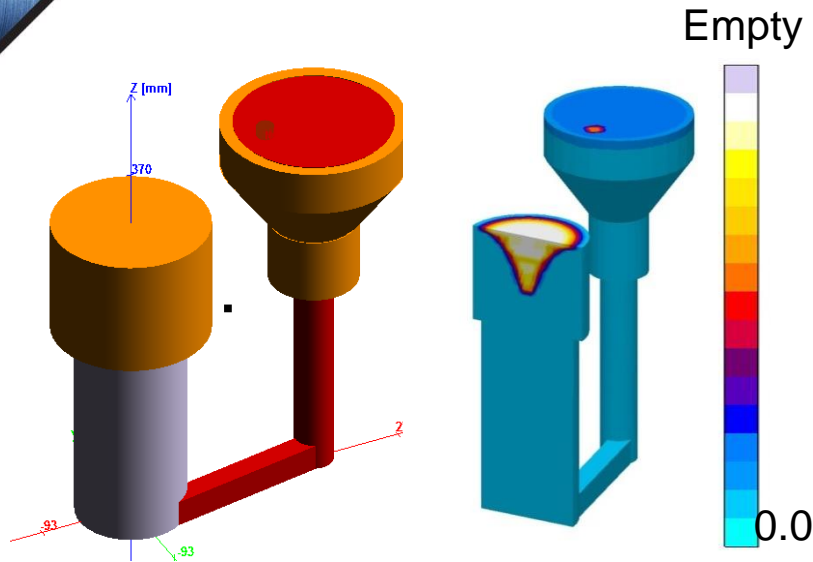
T2 (Ti+Al,Ca)



T3 (Ca+Al,Mg,Ti)



Experimental procedure: heavy section casting



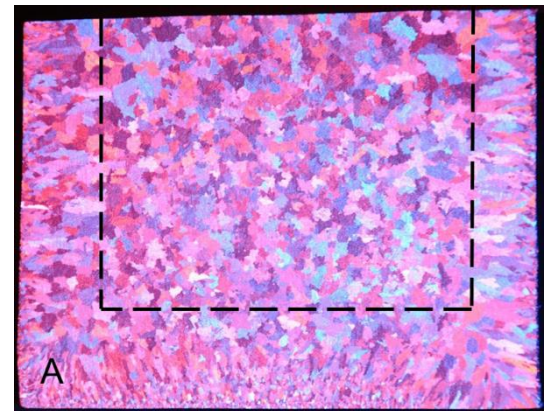
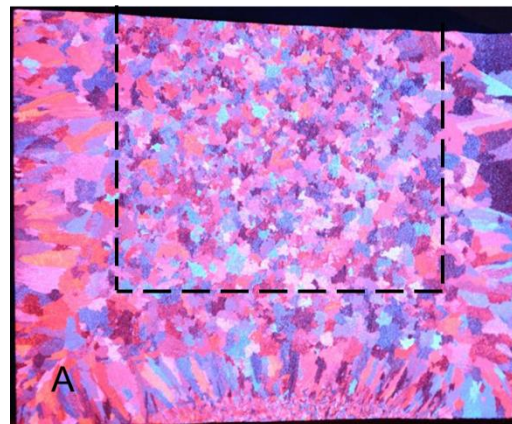
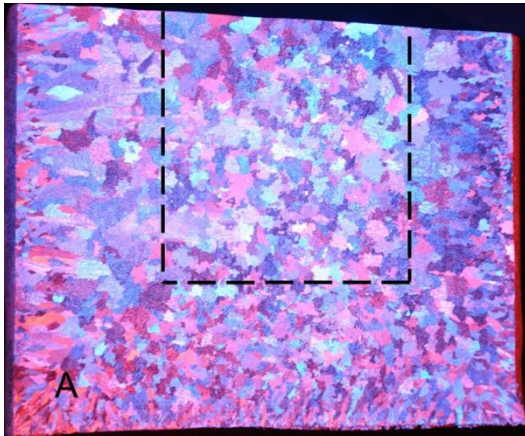
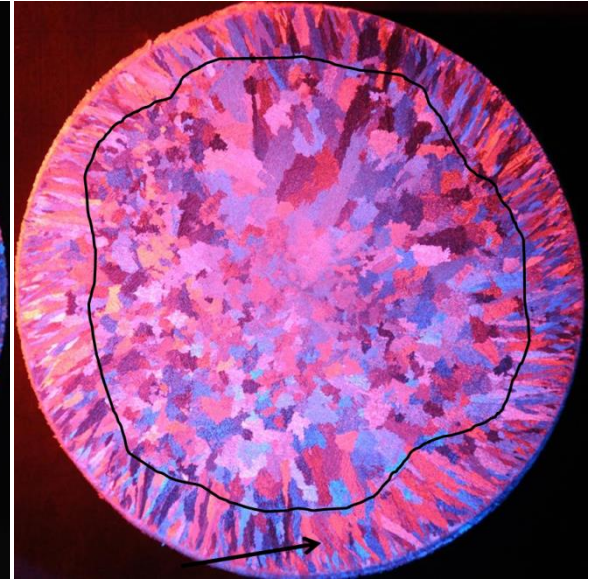
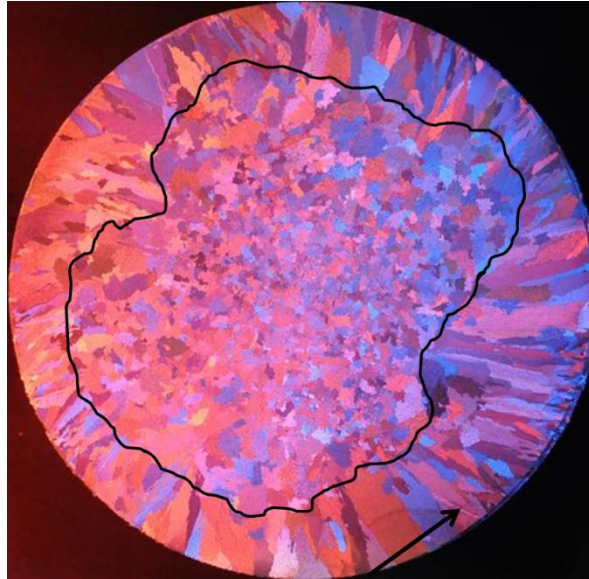
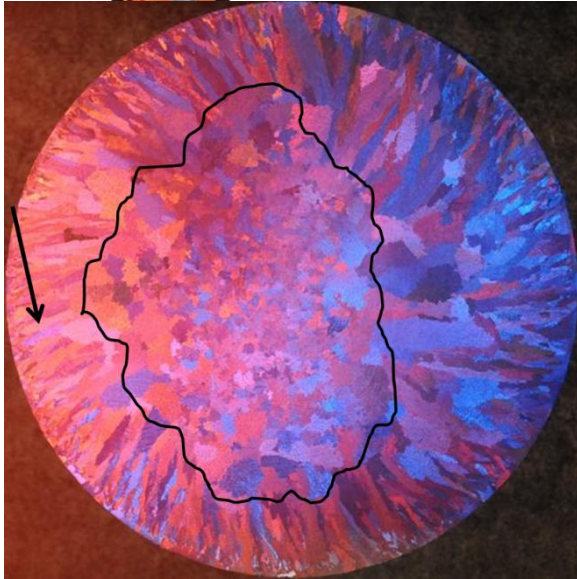


Macrostructure

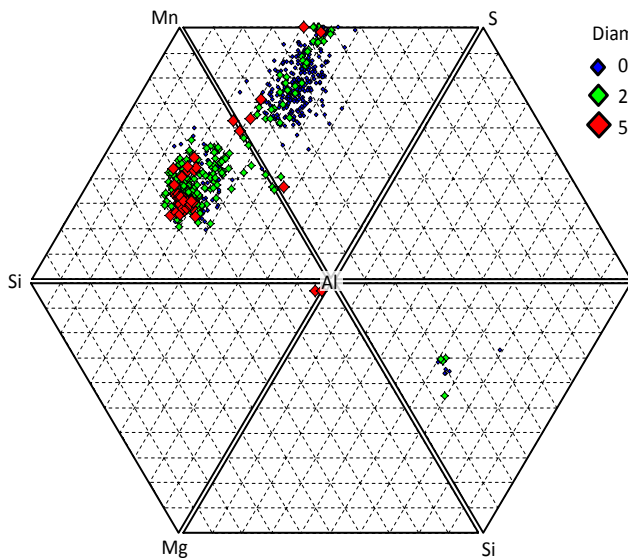
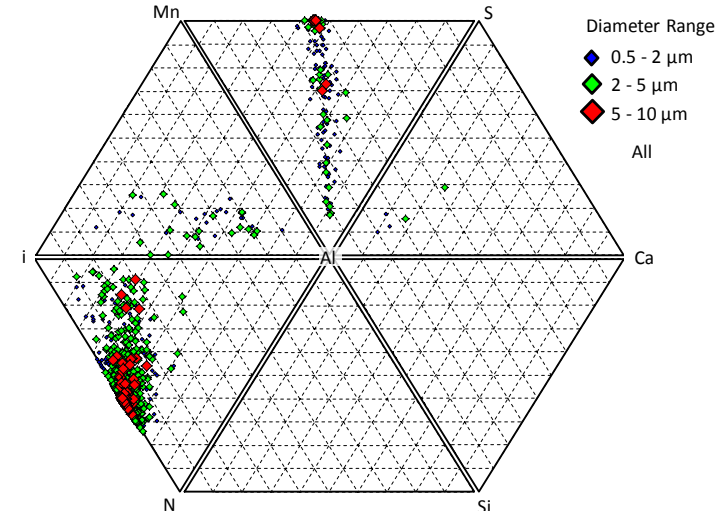
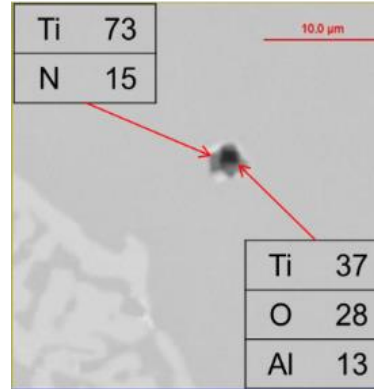
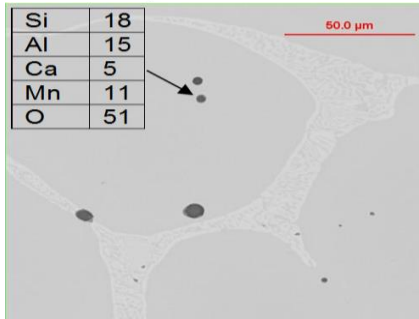
B2 base

T1 (IF: Ti, Ladle: deox)

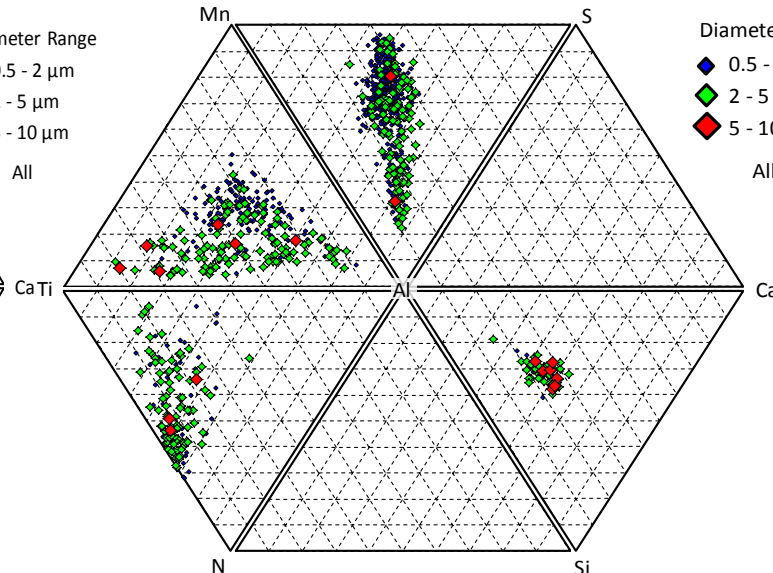
T2 (Ladle: deox + Ti)



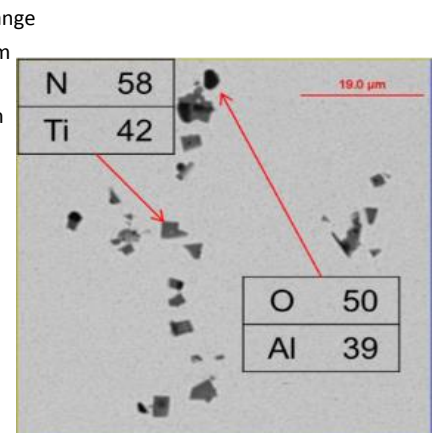
Chemistry of precipitates



B2 base



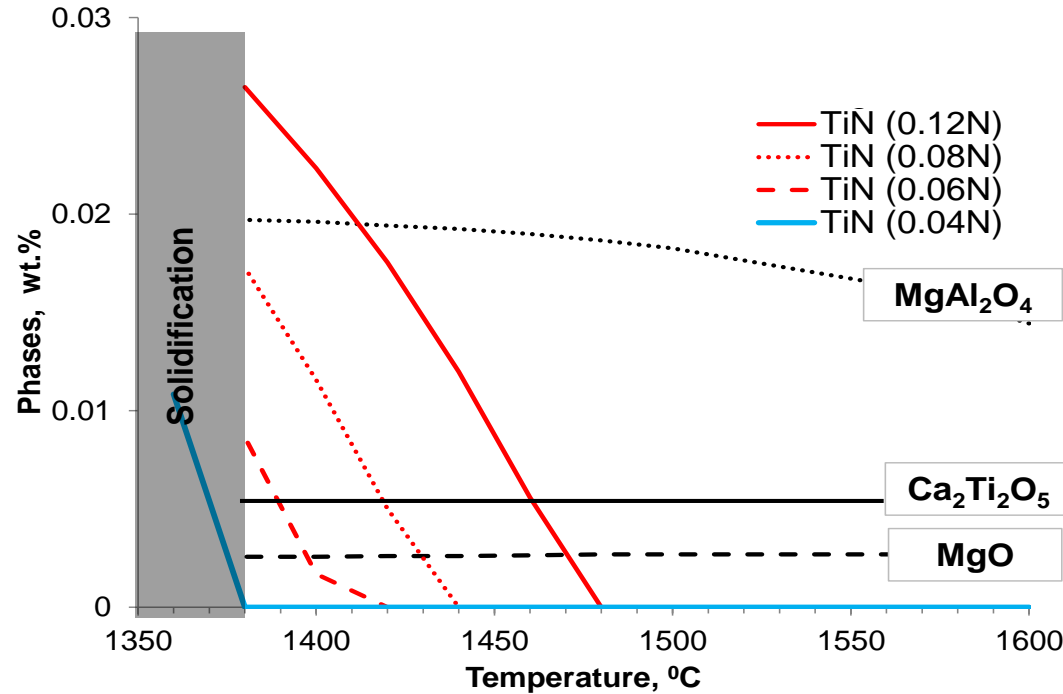
T1 (Ti + deox)



T2 (Deox + Ti)



Co-precipitation grain refinement approach



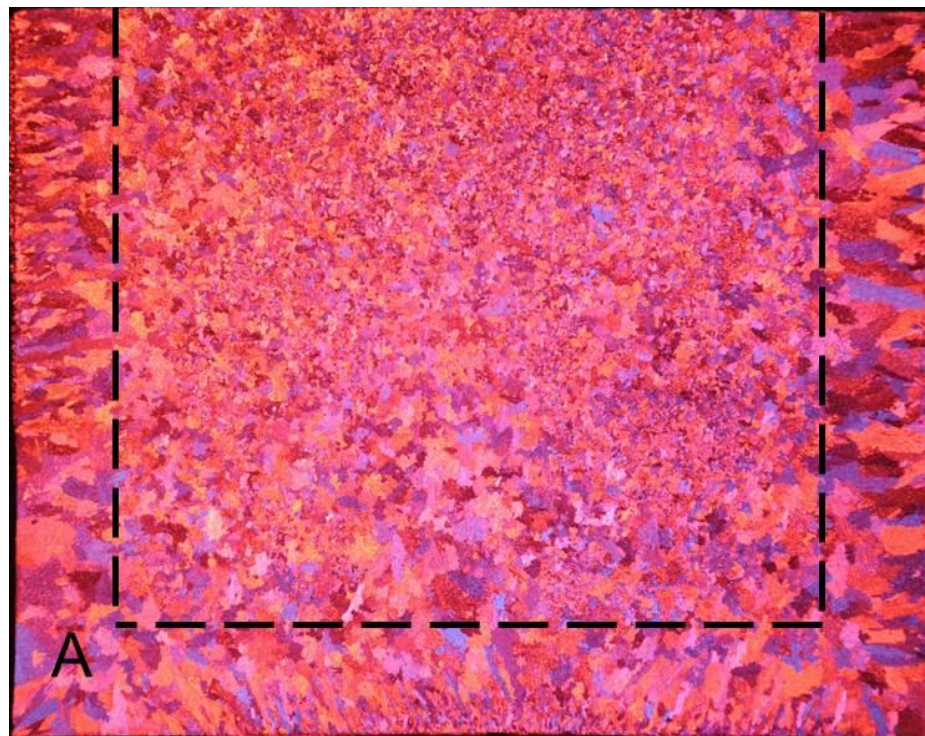
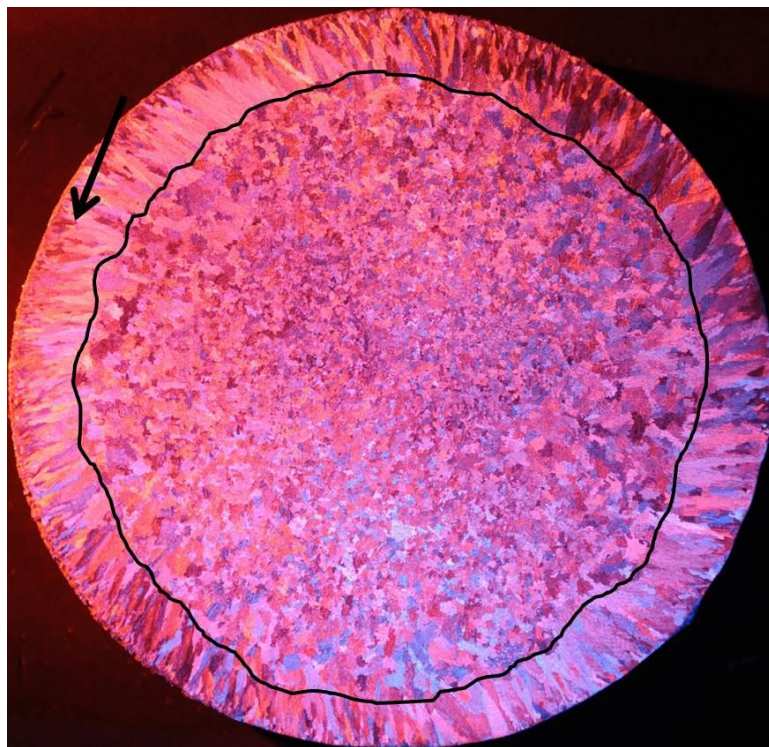
CET

Compound	Lattice parameter a_0 at 2800 °F, Å	Planar disregistry with TiN, %
TiN	4.308	-
MgAl_2O_4	4.098	4.9
MgO	4.310	0.0053
Ti_2O_3	5.225	16.2
Al_2O_3	4.825	17.48



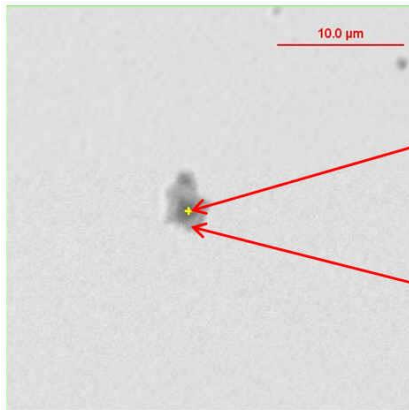
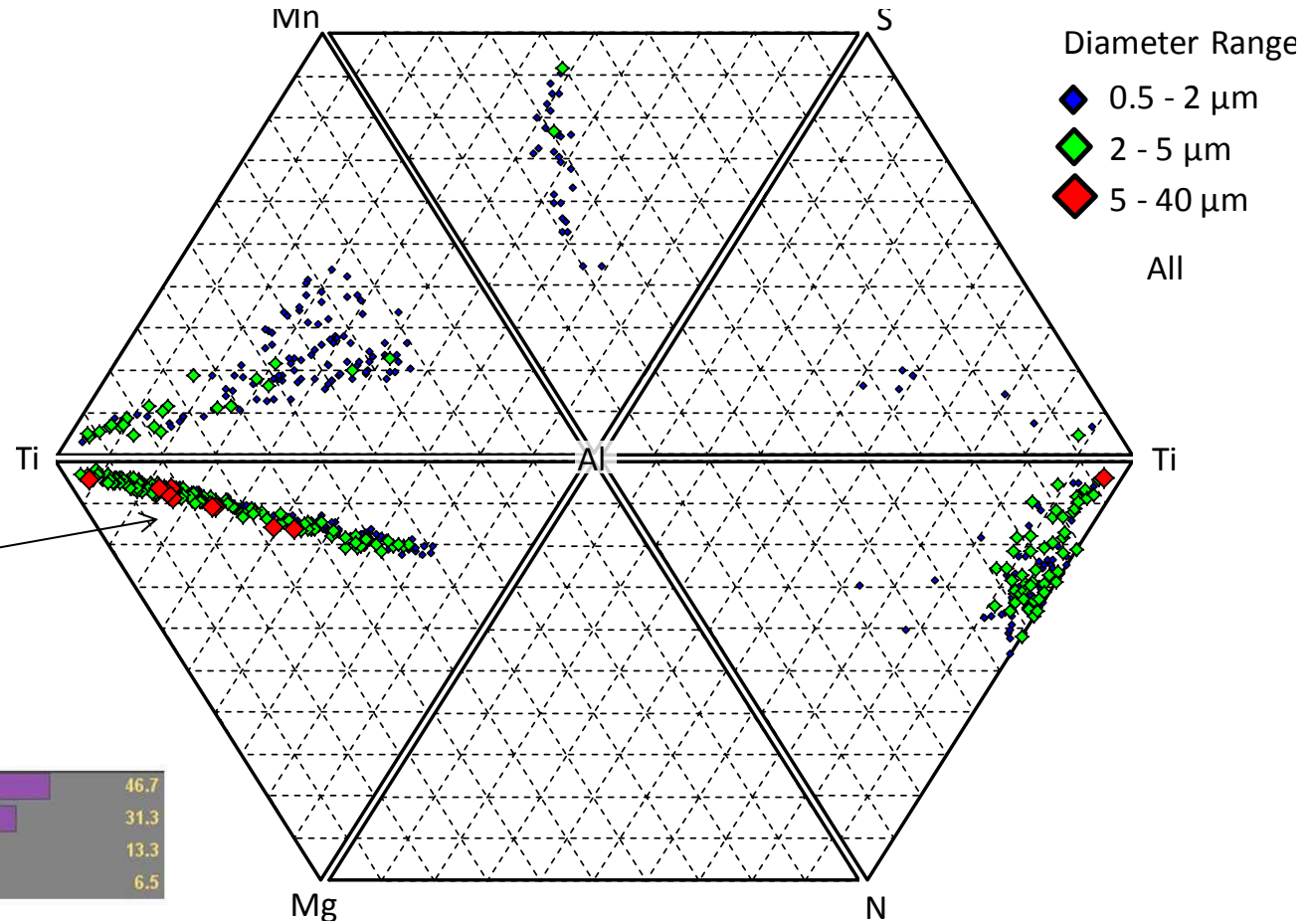
Experimental heat T3 for concept verification

Heat #	Treatment	
	IF	Ladle
T3	Ca	Al, Mg, Ti





Precipitations - Heat T3

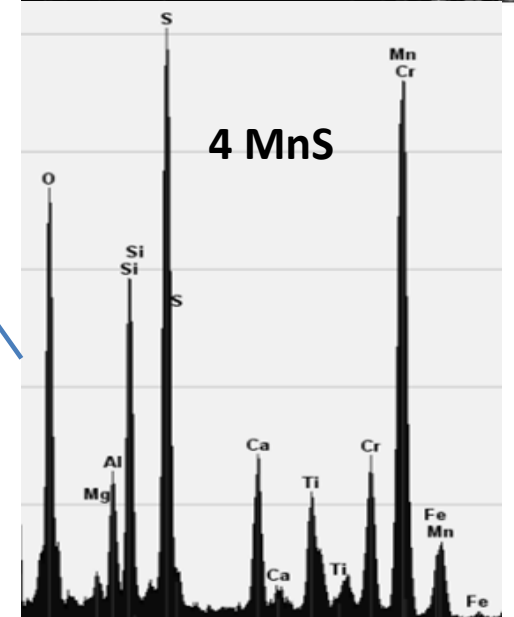
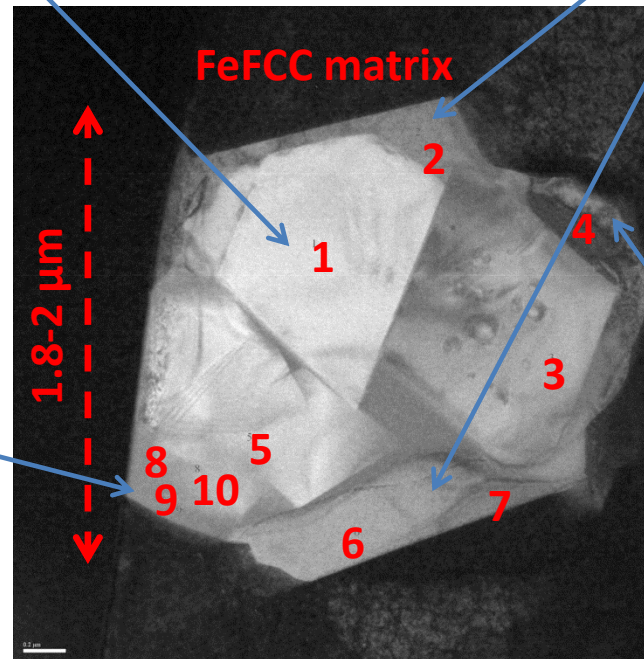
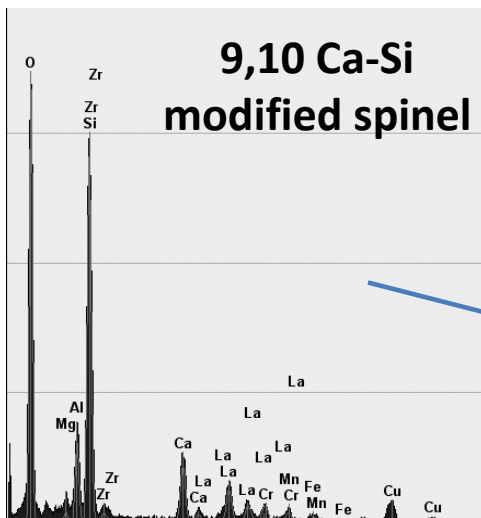
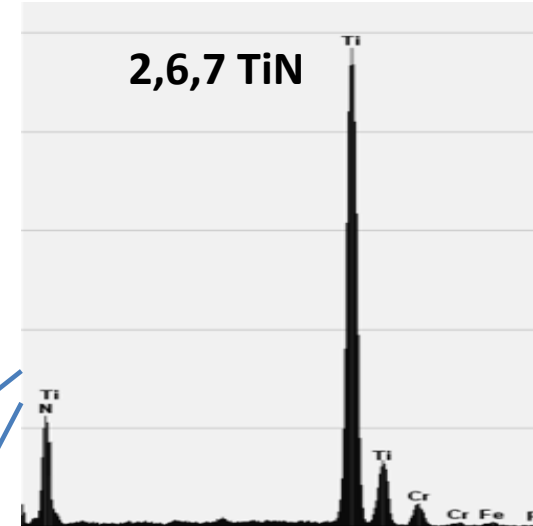
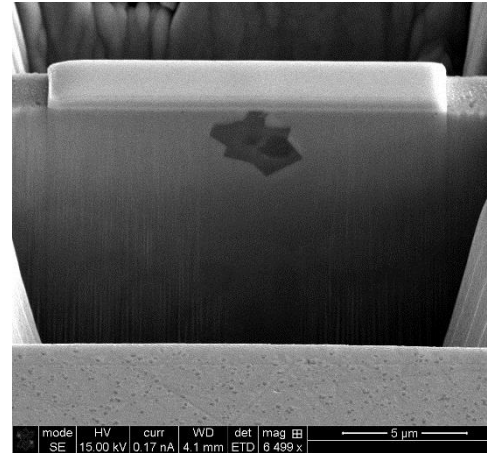
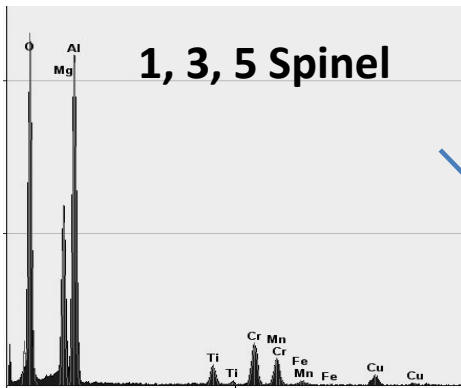


O	46.7
Ti	31.3
Al	13.3
Mg	6.5

Ti	54.5
N	32.4

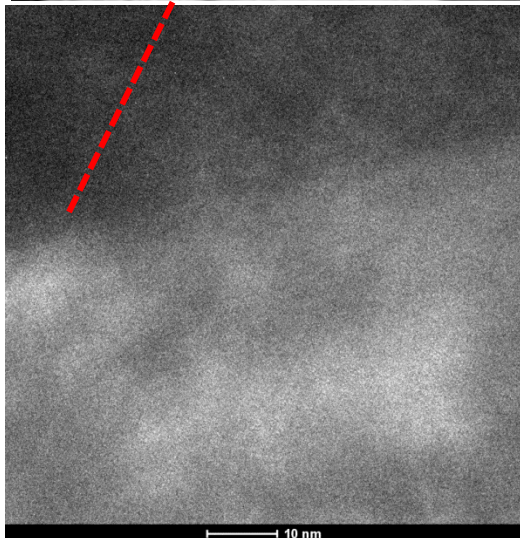
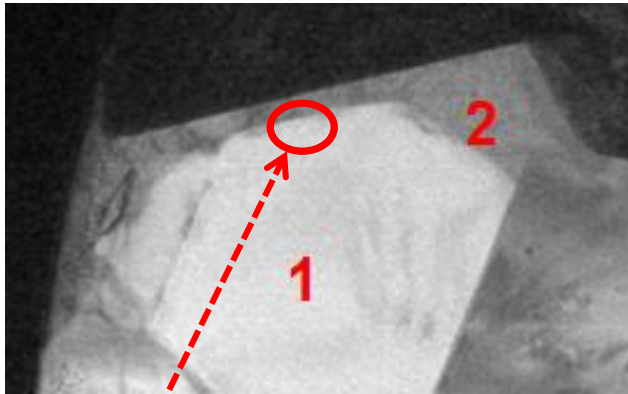


TEM of complex precipitate





Spinel – TiN boundary

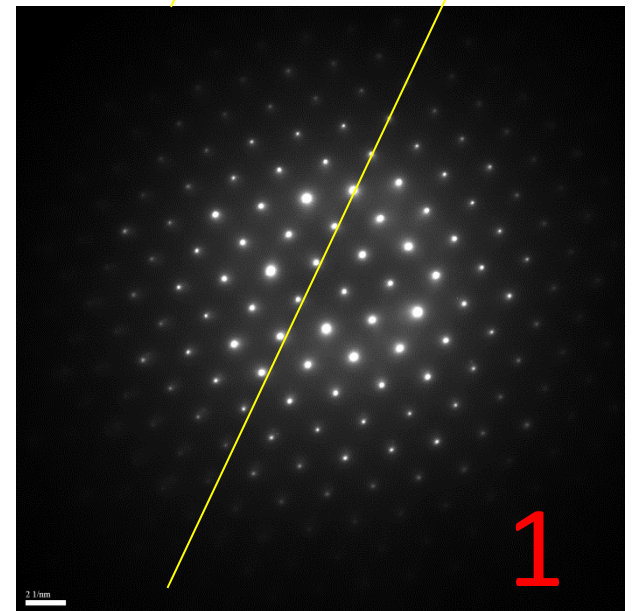
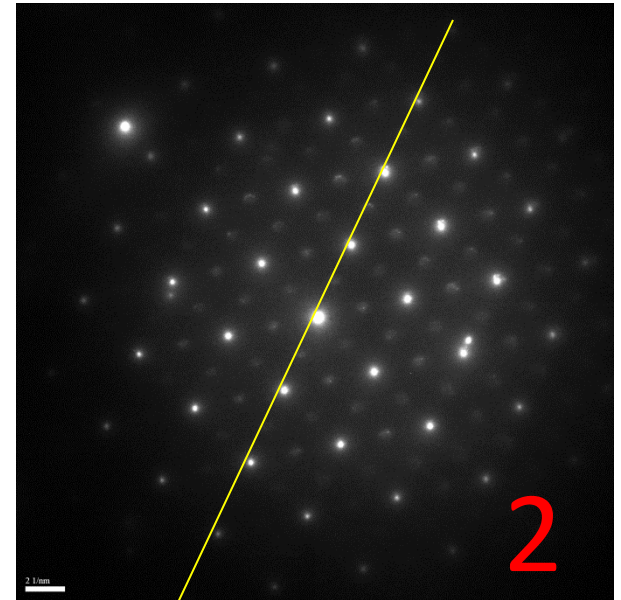


Bulk:

- Constant zone axes angles
- The same [011] planes in beam direction
- Very close orientation

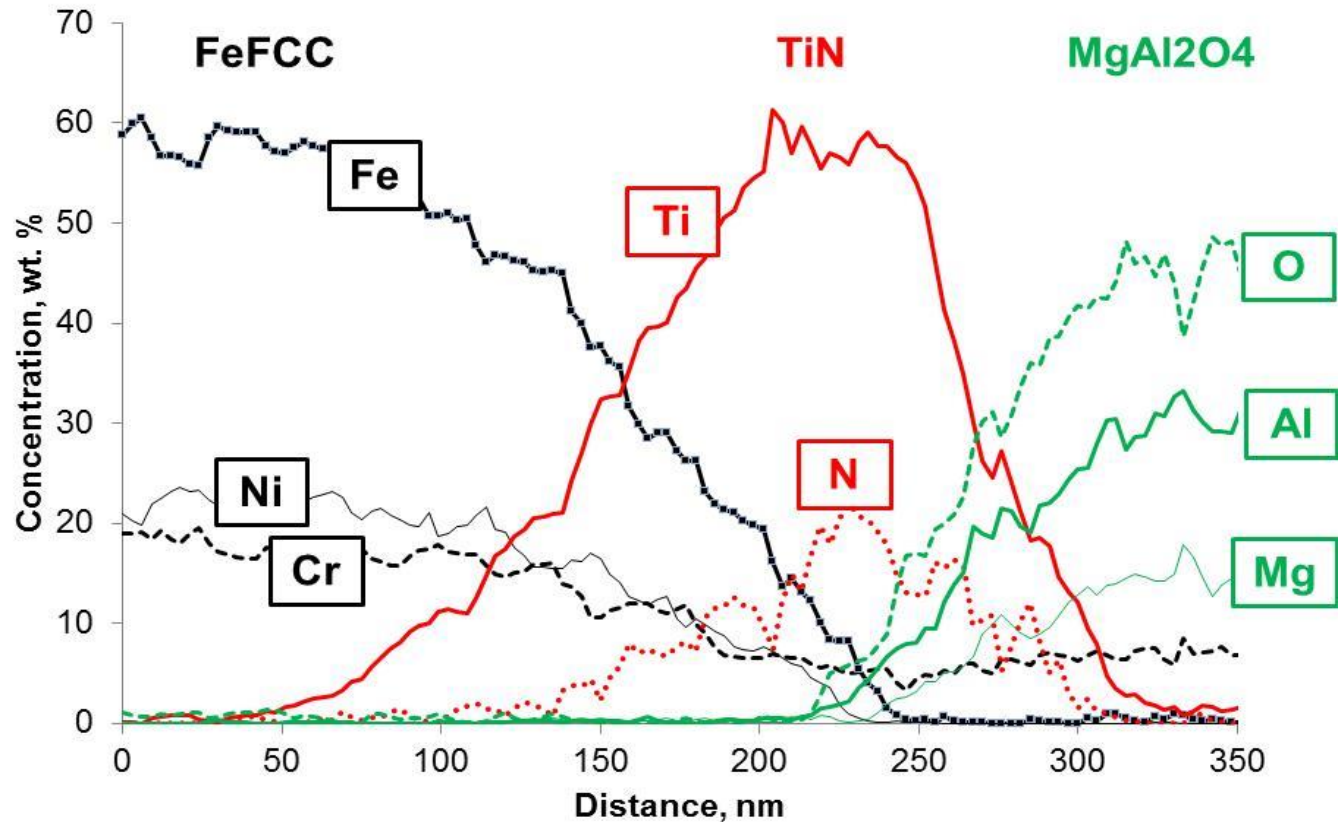
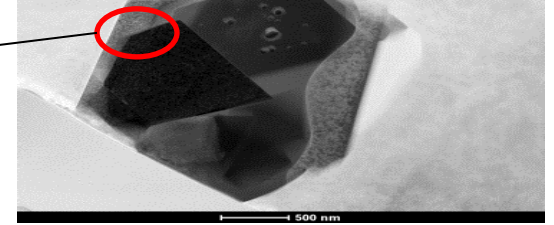
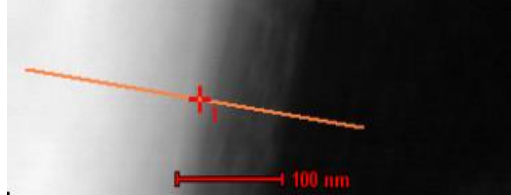
Boundary:

- Flat topology
- Almost epitaxial





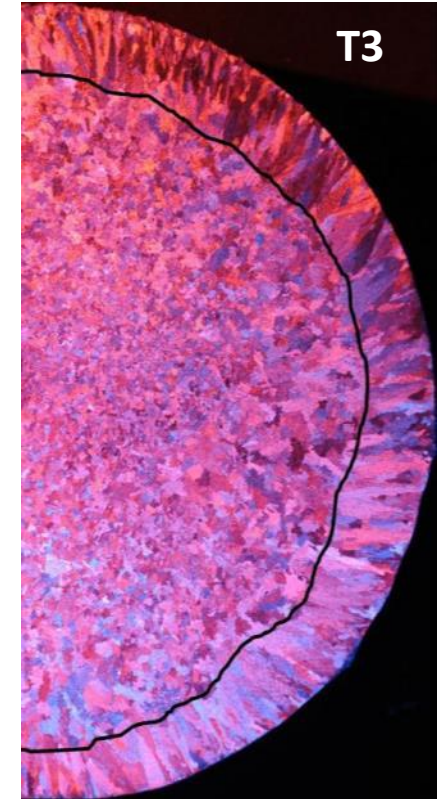
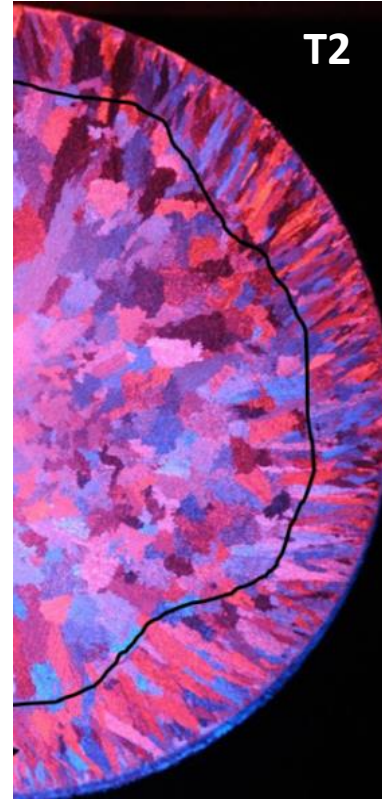
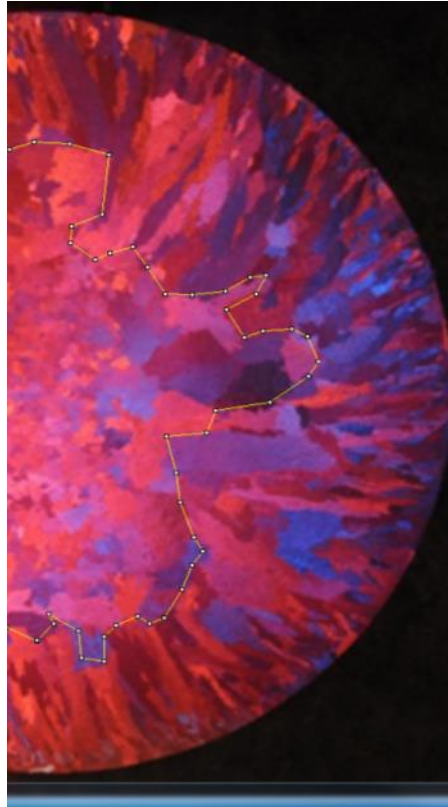
High resolution Matrix-TiN-Spinel line scan



Step size – 5 nm, spot size ≈ 10 nm



Comparison of achieved grain refinement



	R	Equiaxed grains, , mm
G2 (base)	0.57	2.4
T2 (N+Deox+Ti)	0.78	2.2
T3 (Al+Mg+Ti)	0.82	0.5



Findings

- Optimized sequence of de-oxidation and refinement provides increase grain refinement efficiency
- Co-precipitation of targeted nucleation sites by inclusion engineering is the effective way to enhance heterogeneous nucleation
- The well-refined as-cast structure was achieved in experimental heavy section castings



Acknowledgements

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Thank You



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Presenter Simon N. Lekakh
Research Professor
Missouri University of Science and Technology
Kent Peaslee Steel Manufacturing Research Center