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STEPS TOWARDS SUSTAINABILITY AND DECARBONISATION –

IMPACT OF HIGH RECYCLED CONTENT ON HIGH FORMABILITY PRODUCTS

UNDEB EWROPEAIDD EUROPEAN UNION
Llywodraeth Cymru Welsh Government
Cronfa Gymdeithasol Ewrop
European Social Fund
TATA STEEL
M2A COATED
Swansea University Prifysgol Abertawe
UKRI Engineering and Physical Sciences Research Council

Project Overview

Proposed Research:

Key Points:

- A shift away from BF/BOF towards EAFs steel manufacturing with increased scrap proportions
- Challenges and issues: undesirable residual elements leading to cracking, grain boundary segregation
- End Goal: IF steel manufactured at lower slab reheat temperatures coupled with residual elements

The Various Impacts of Residual Elements: Cr, Cu & Sn

- High concentrations of residual elements have detrimental effects: grain boundary segregation, hot shortness, cracking
- Sn- Segregate towards the grain boundary due to their solubility, reducing binding strength of bonds between grains and impeding the movement/recrystallisation.
- Cu- Inhibits ferrite growth and leads to hot shortness due to formation of precipitates at the austenite grain boundaries leading to solute drag
- Cr- Longer recovery times during the start of recrystallisation.

Residual Elements

Research Avenues

PLANT MATERIAL

High Cr IF steel cold rolled and annealed at a range of temperatures. R-value found through tensile testing

INTRAP STUDY

2 pass hot rolling schedule at lower slab reheat temperatures focusing on residual elements individually

VIM CAST

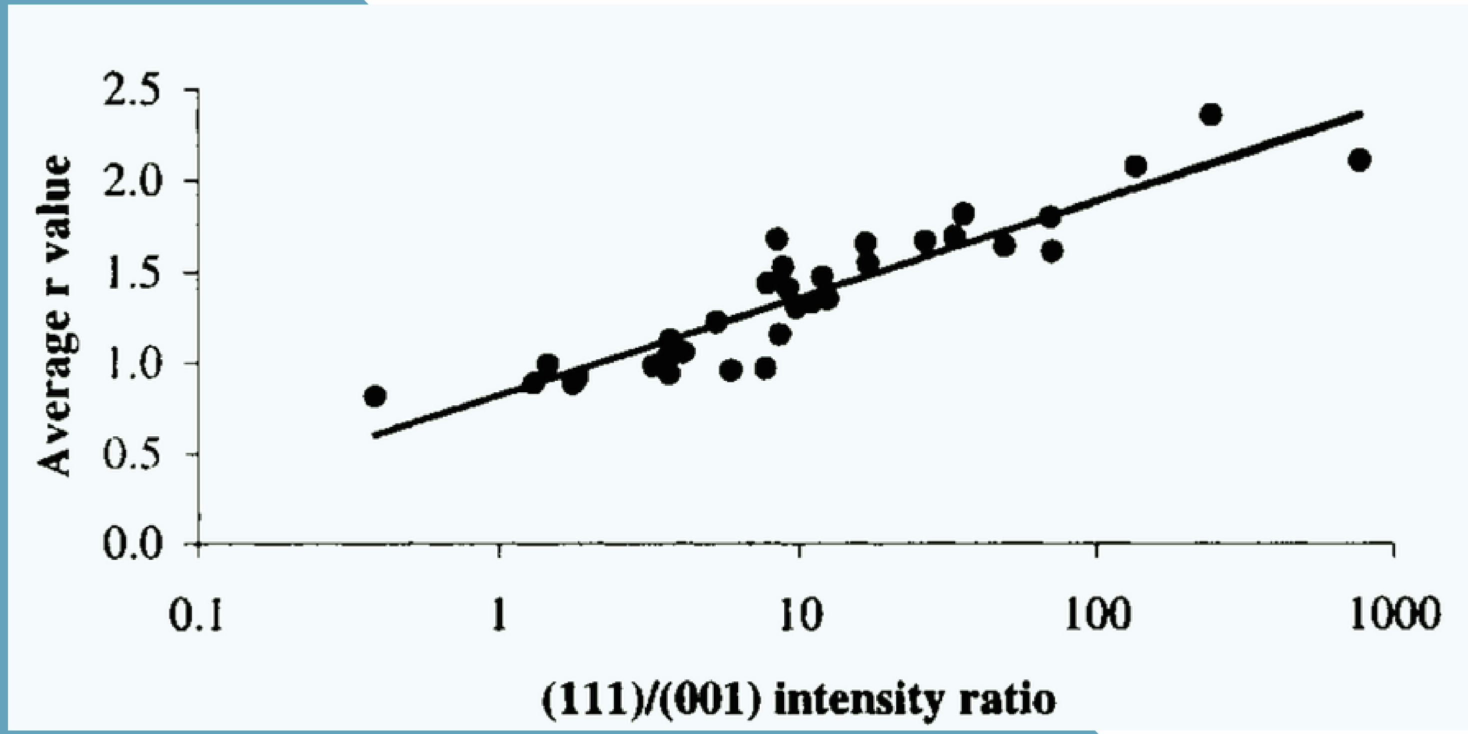
5 VIM casts- combination of additional Cu, Sn, Cr & Ni. Lower slab reheat temperatures closer to industry standard- 7 passes

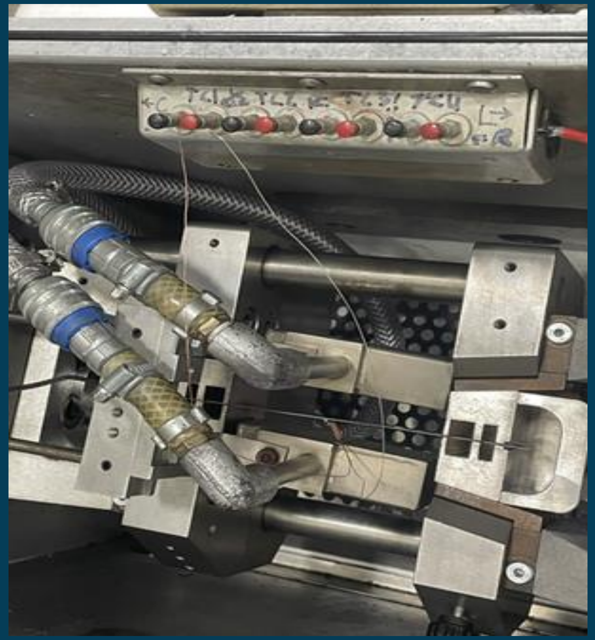
VIM CAST

Combination study- Higher annealing temperatures (static recrystallisation) and lower slab reheat temperatures (dynamic recrystallisation)

Relationship between r-Value and Crystallographic Texture:

- Deep drawability and r-value dependent on crystallographic texture
- Ideal grains to produce these properties are grains with {111} parallel to strip surface and similar, includes {554} (tilted)
- Crucial for IF steels to have a high r-value in order to generate deep drawn components





HOT ROLLING

-SLAB REHEAT TEMPERATURE
-ROUGHING
-FINISHING ROLLING
-RUNOUT TABLE PRACTICE
-COILING TEMPERATURE

COLD ROLLING

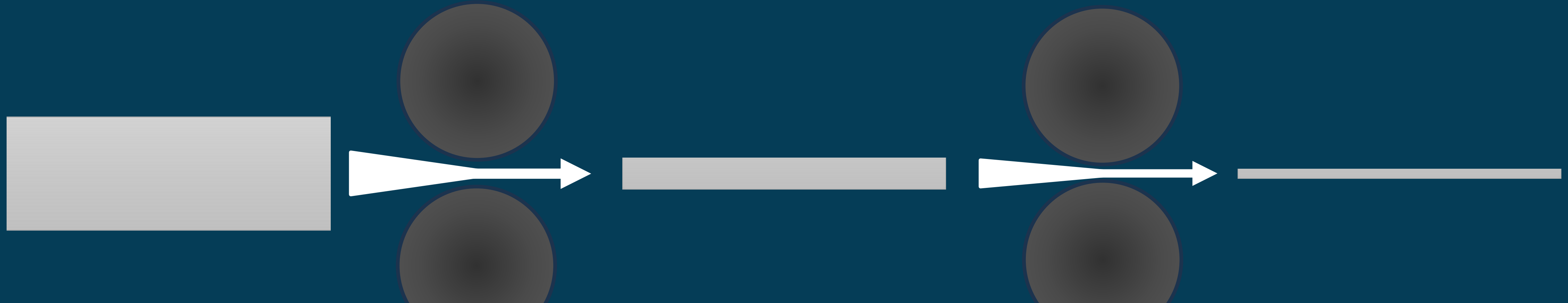
-REDUCTION PROFILE

ANNEALING & RECRYSTALLISATION

-GLEEBLE
-TENSILE TESTING & R-VALUE

R-Value

Thermomechanical Processing



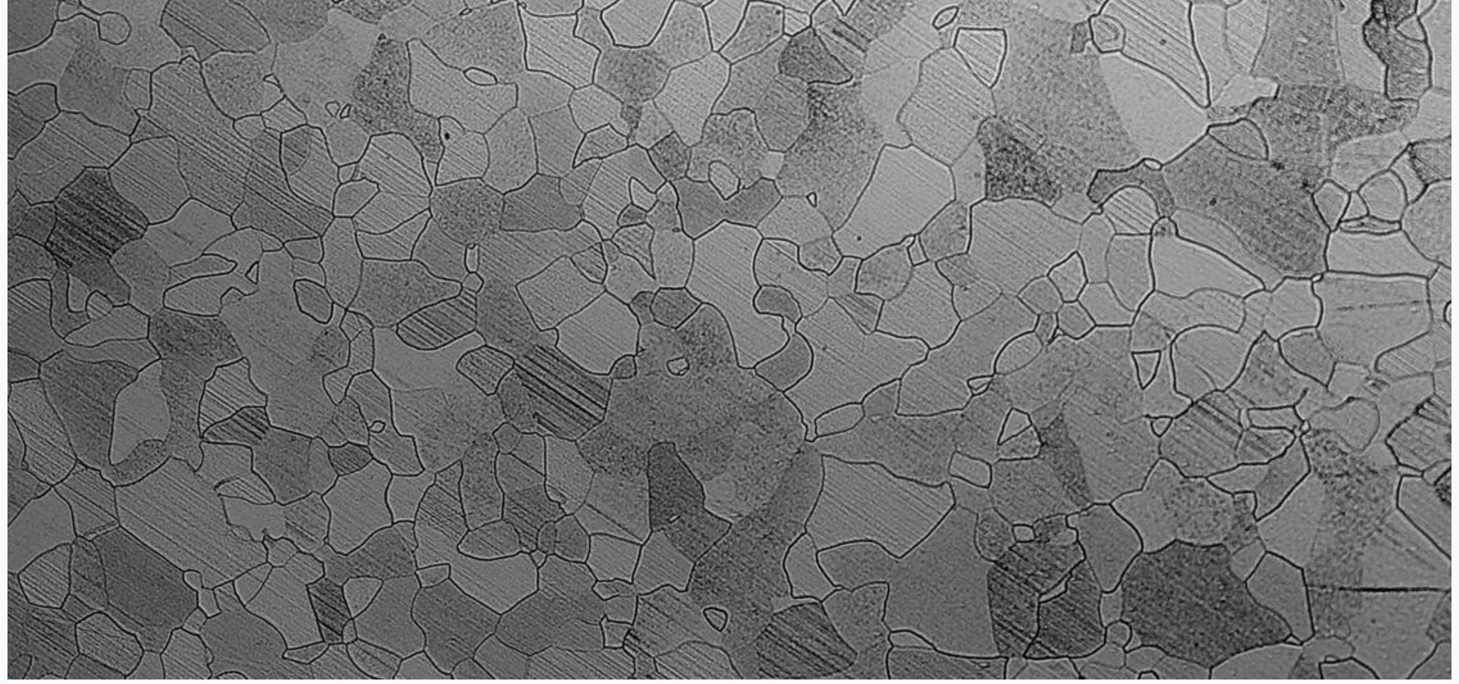
Hot band Microstructure

-Factors affecting hot band microstructure:

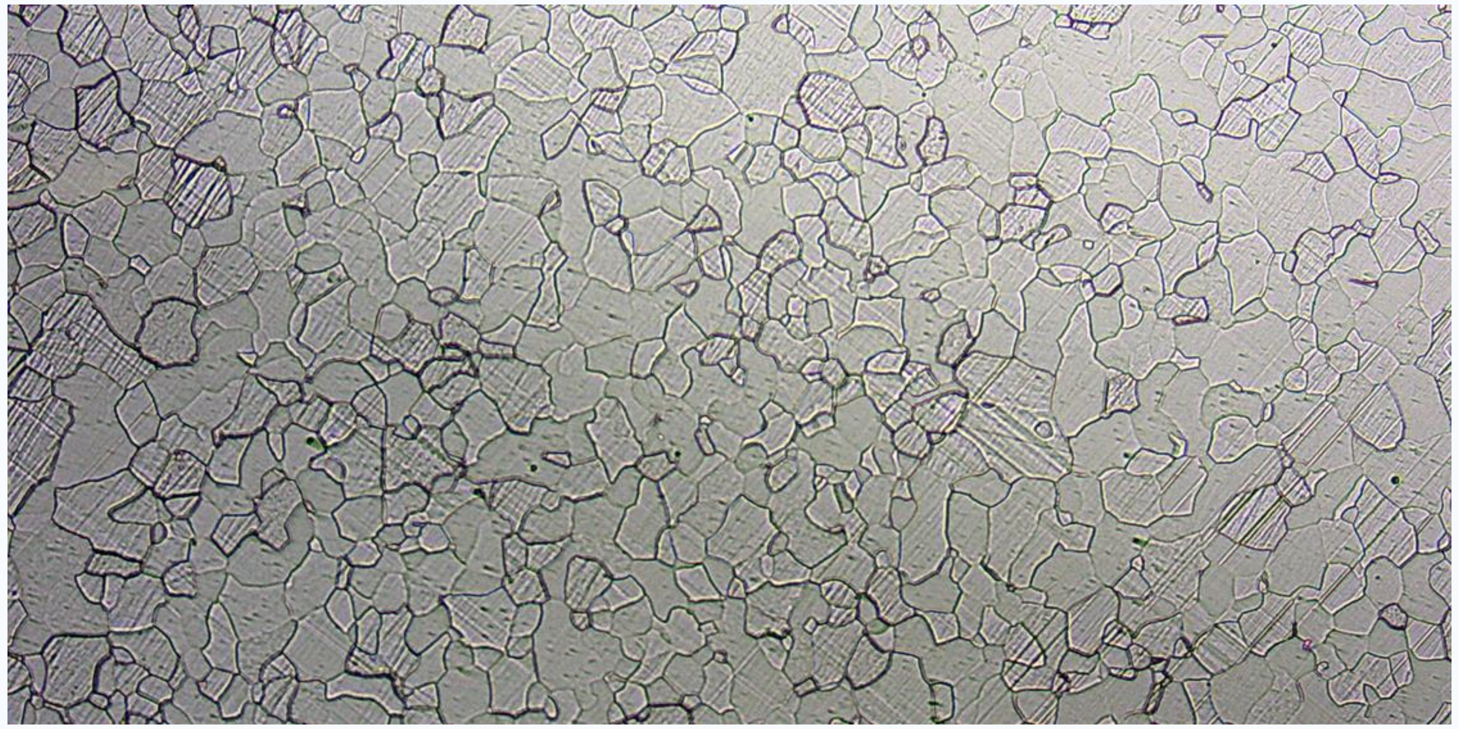
- Increased coarseness of precipitates
- Smaller grain size

-Plant material containing varying Cr content

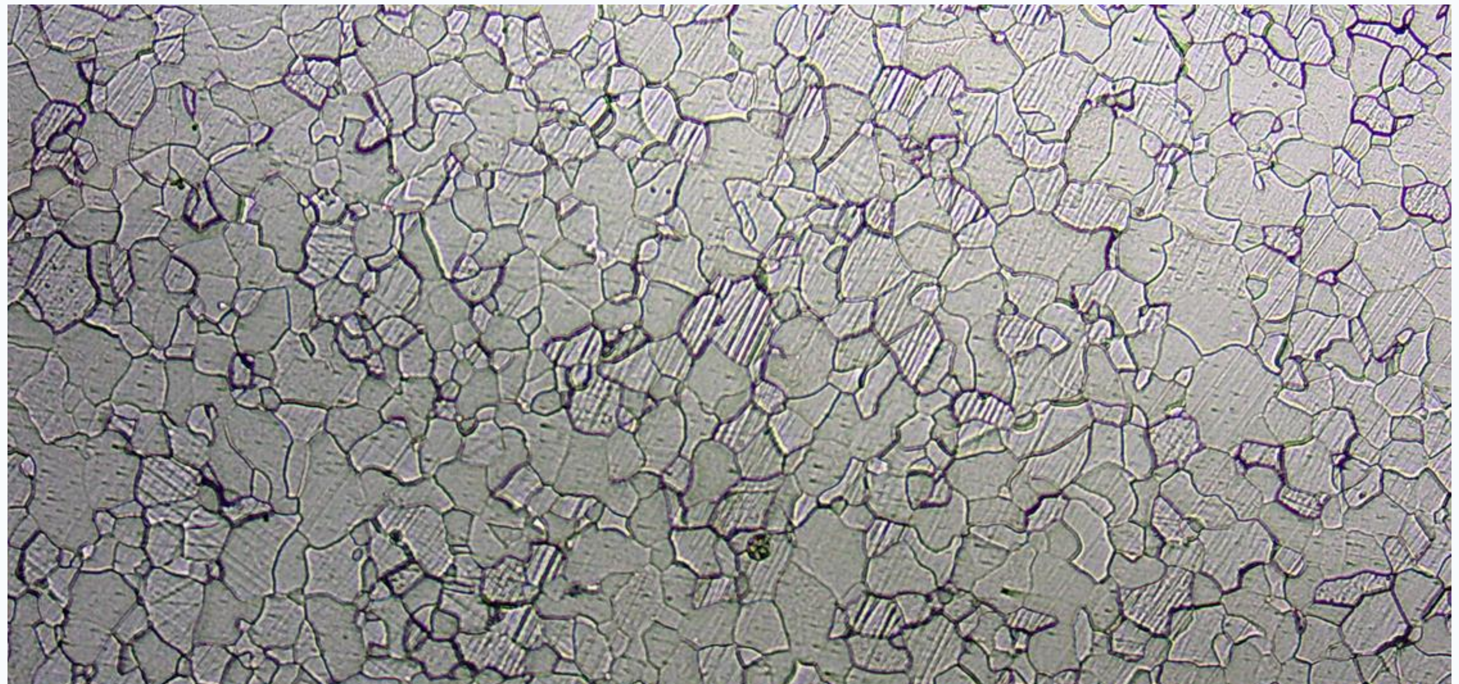
Cr Content (wt.%)	Grain size (μm)
0.017	19.7
0.06	23.1
0.07	24.5



0.017 wt.% Cr

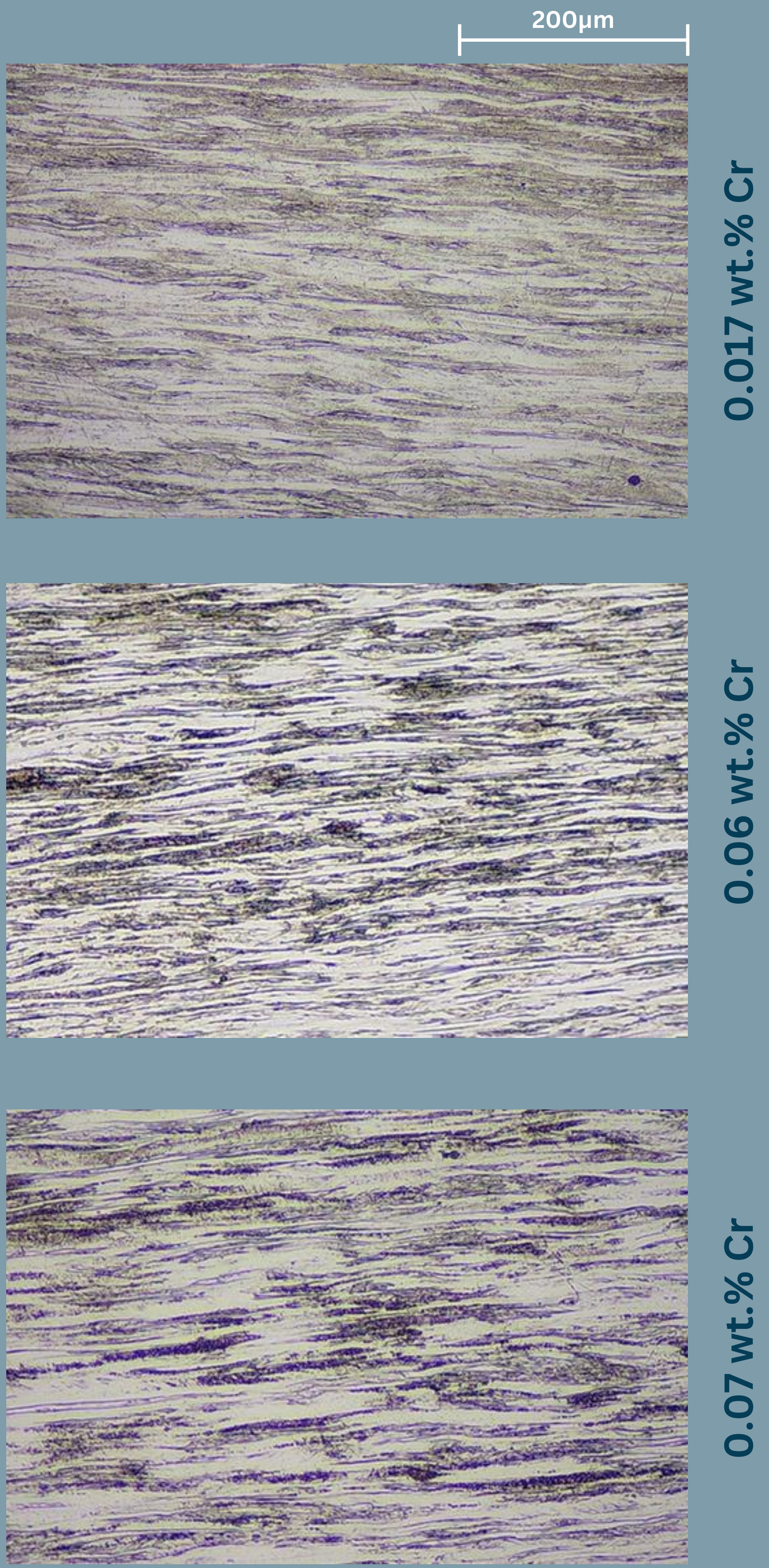


0.06 wt.% Cr



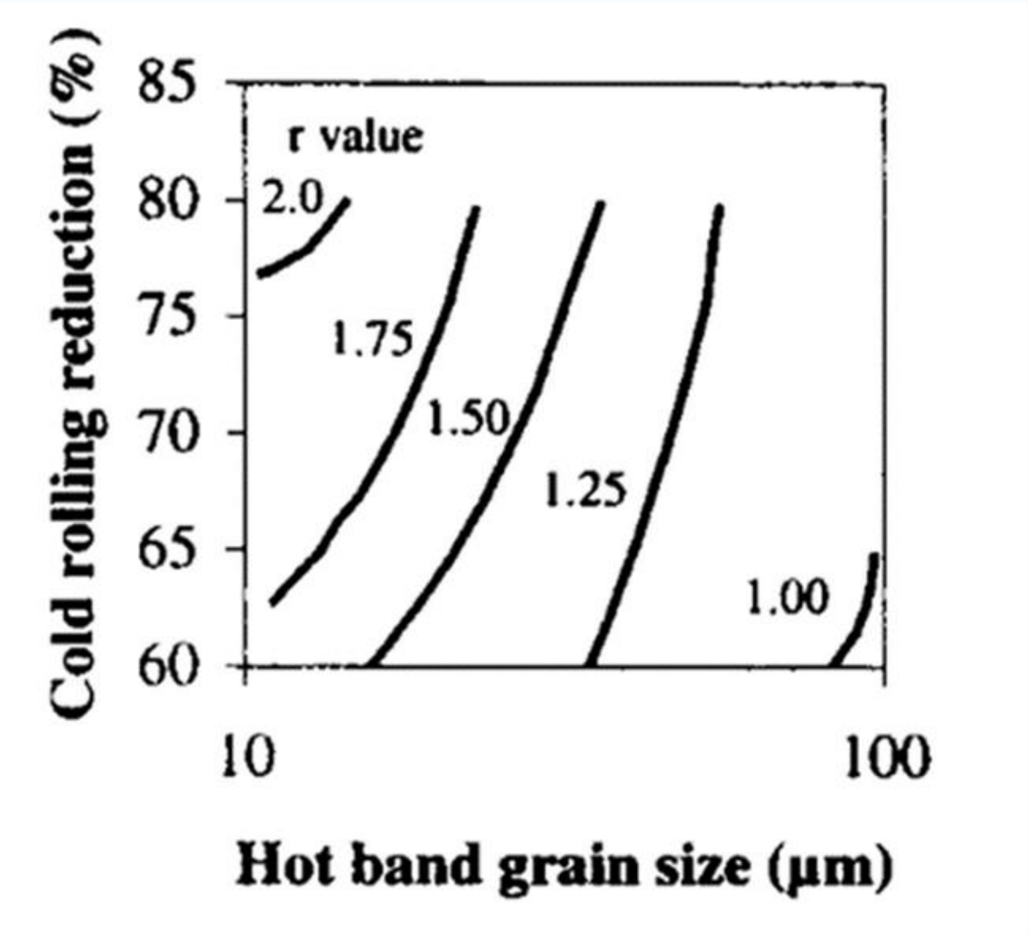
0.07 wt.% Cr

Cold Rolling:



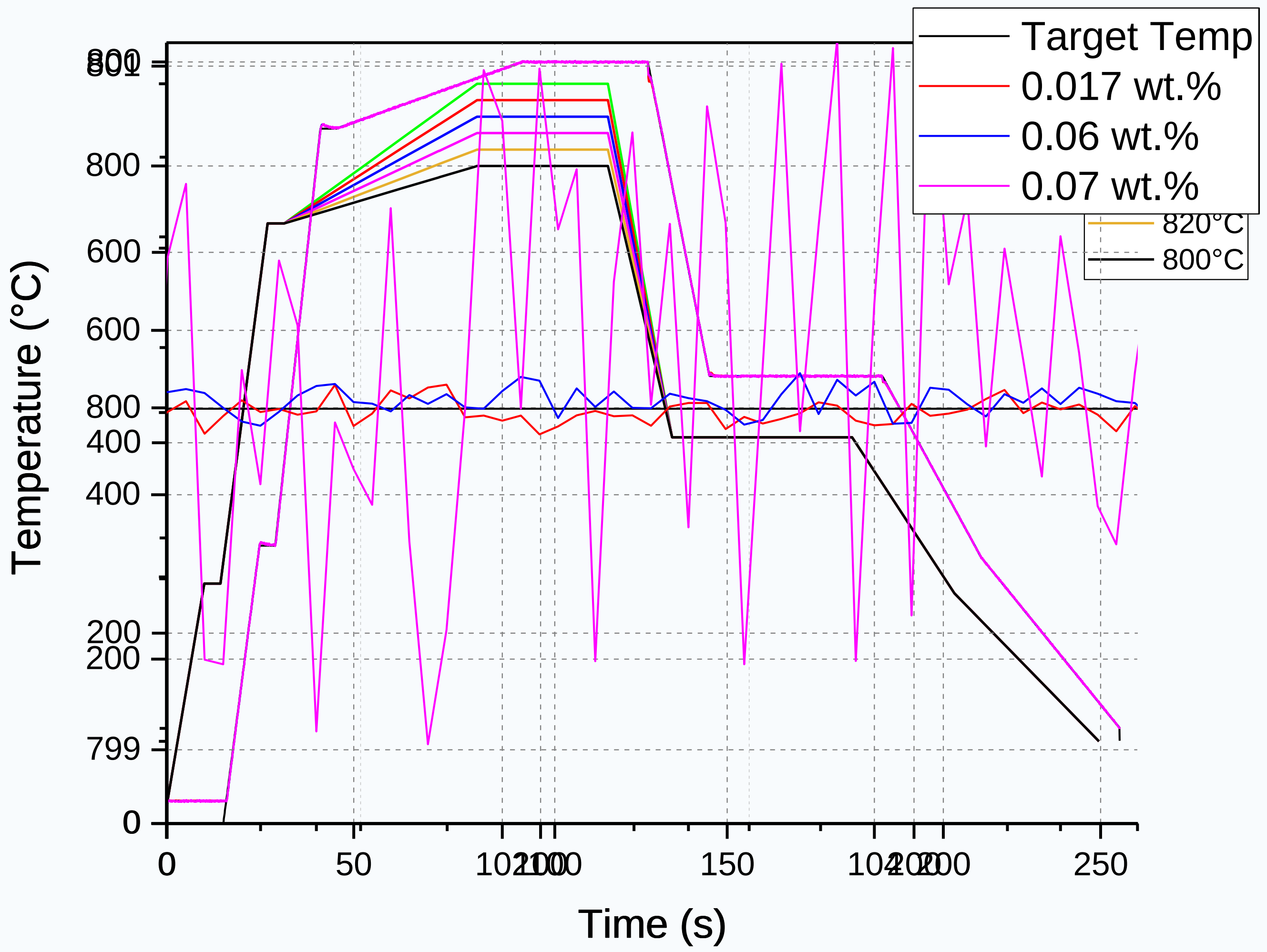
The Effect of Higher Cold Rolling Profiles

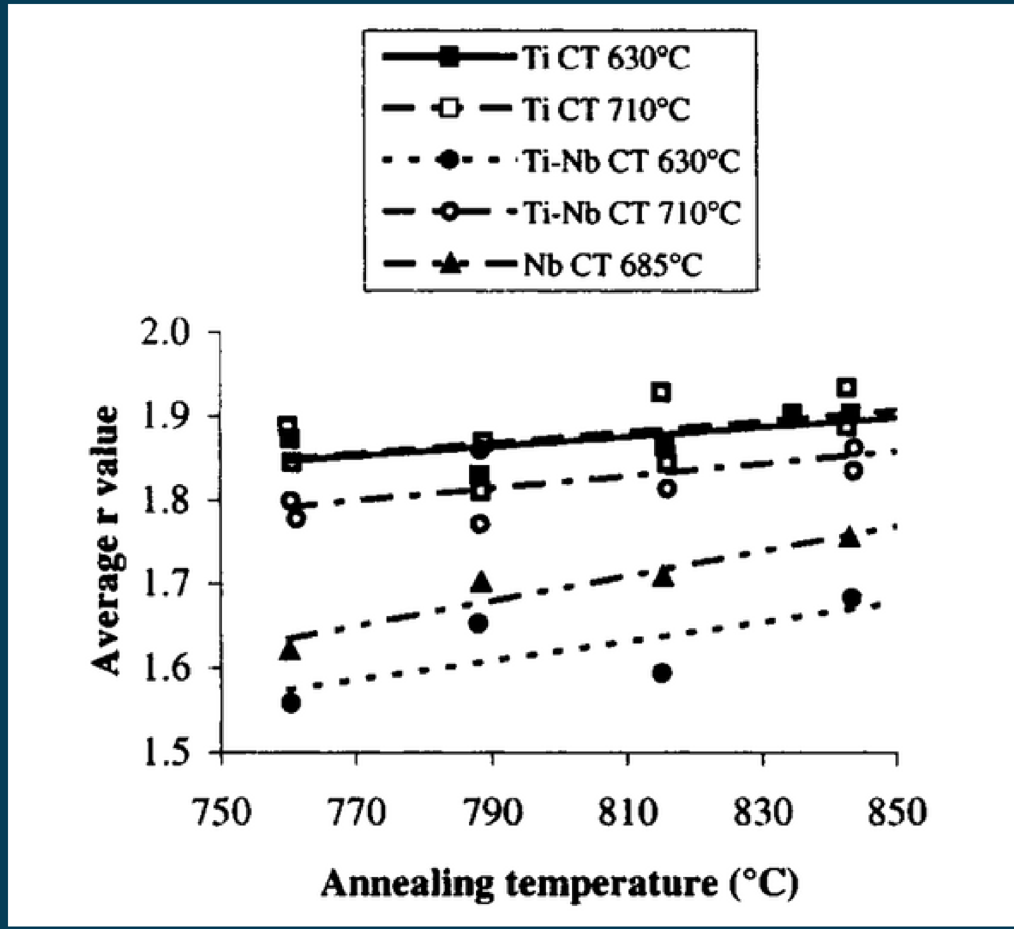
- 80% Reduction Profile
- Challenges: Limited to 80% reduction profile in industry due to line speed & cold rolling mill power

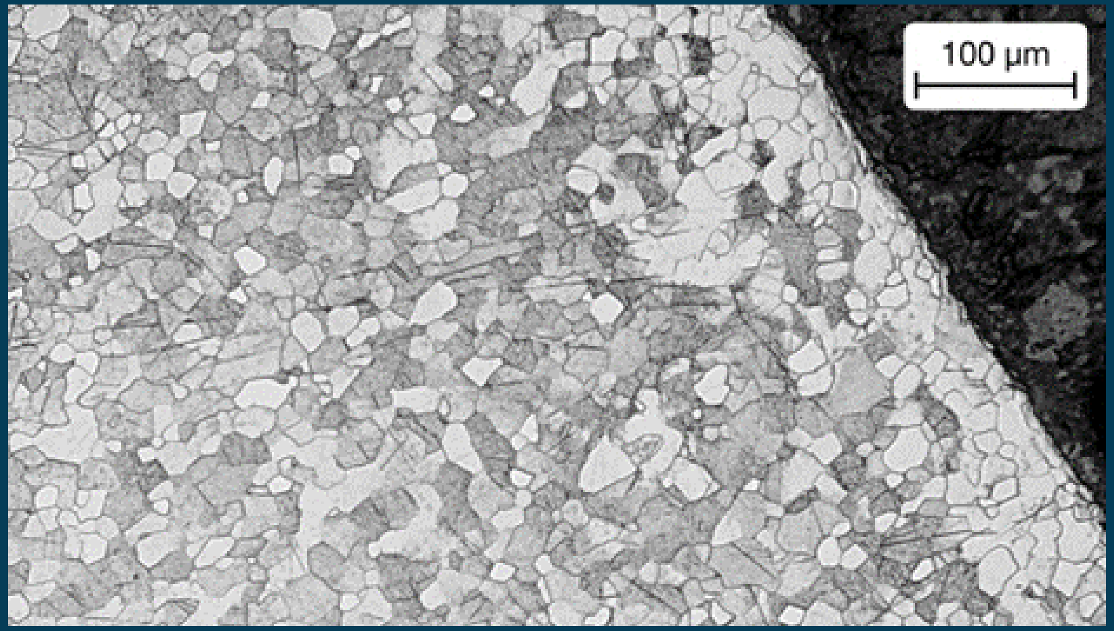


ANNEALING

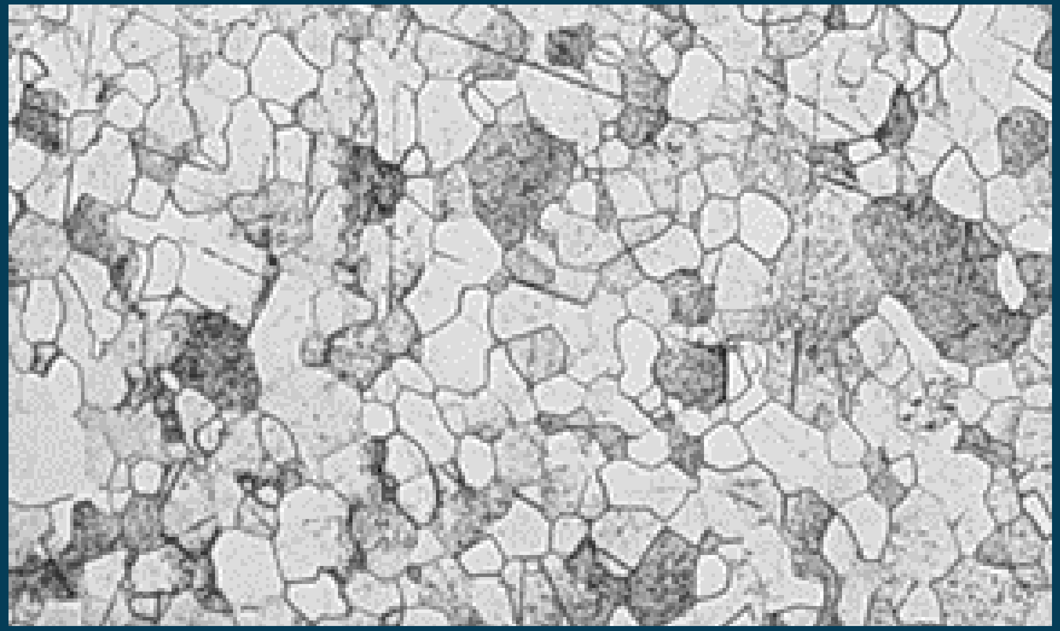
- Simulations via the Gleeble 3500
- Allows texture control through primary recrystallisation
- Higher annealing temperatures provide more grain growth and in turn a stronger {111} texture
- Factors explored: Line Speed (industrial view) & increased temperature



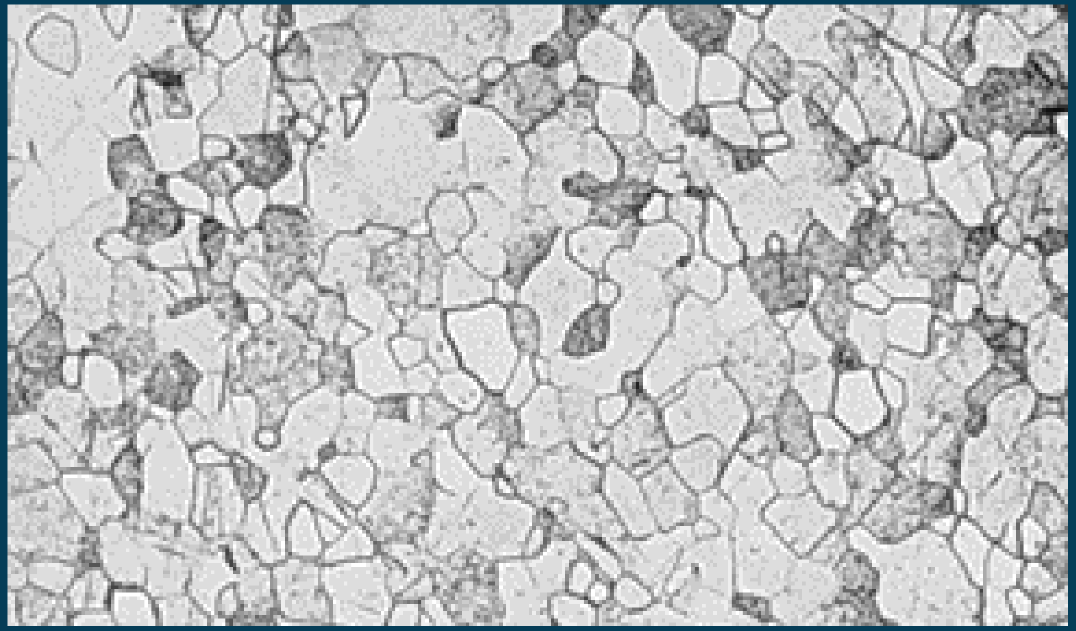




0.017 wt.% Cr



0.06 wt.% Cr



0.07 wt.% Cr

Cr Content (wt.%)	Hot band Grain size (µm)	Annealed Grain size (µm)	Vickers Hardness	R-value
0.017	19.7	13.6	88	2.17
0.06	23.1	17.4	86	2.13
0.07	24.5	19.9	85	2.07

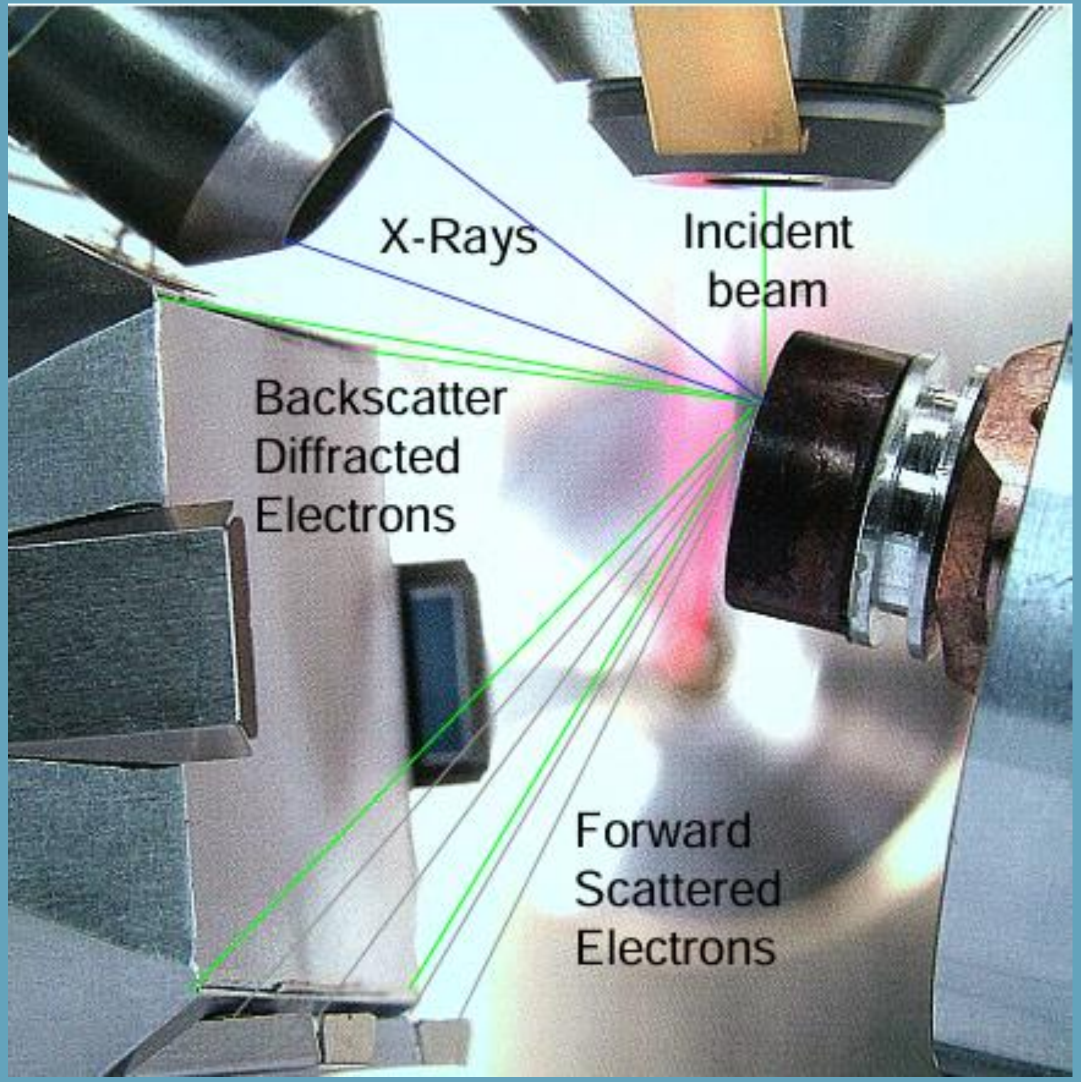
	R-value R-20%		
Cr Composition wt.%	0.017	0.06	0.07
Annealing Temp. C			
800	2.17	2.13	2.07
820	2.28	2.24	2.18
840	2.37	2.3	2.26
860	1.8	2.16	2.13
880	1.97	1.92	1.89
900	1.67	1.56	1.54

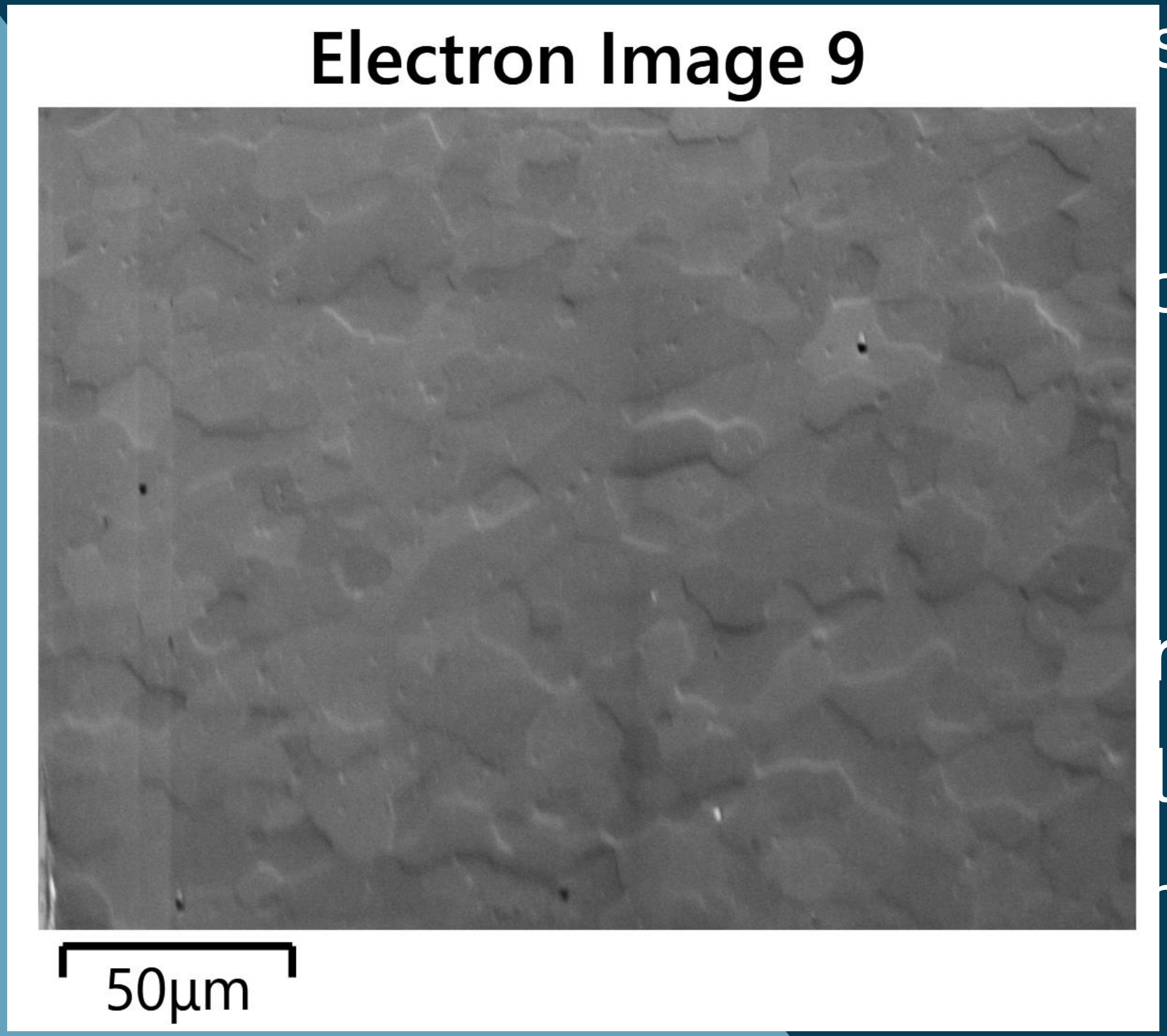
Final Microstructure

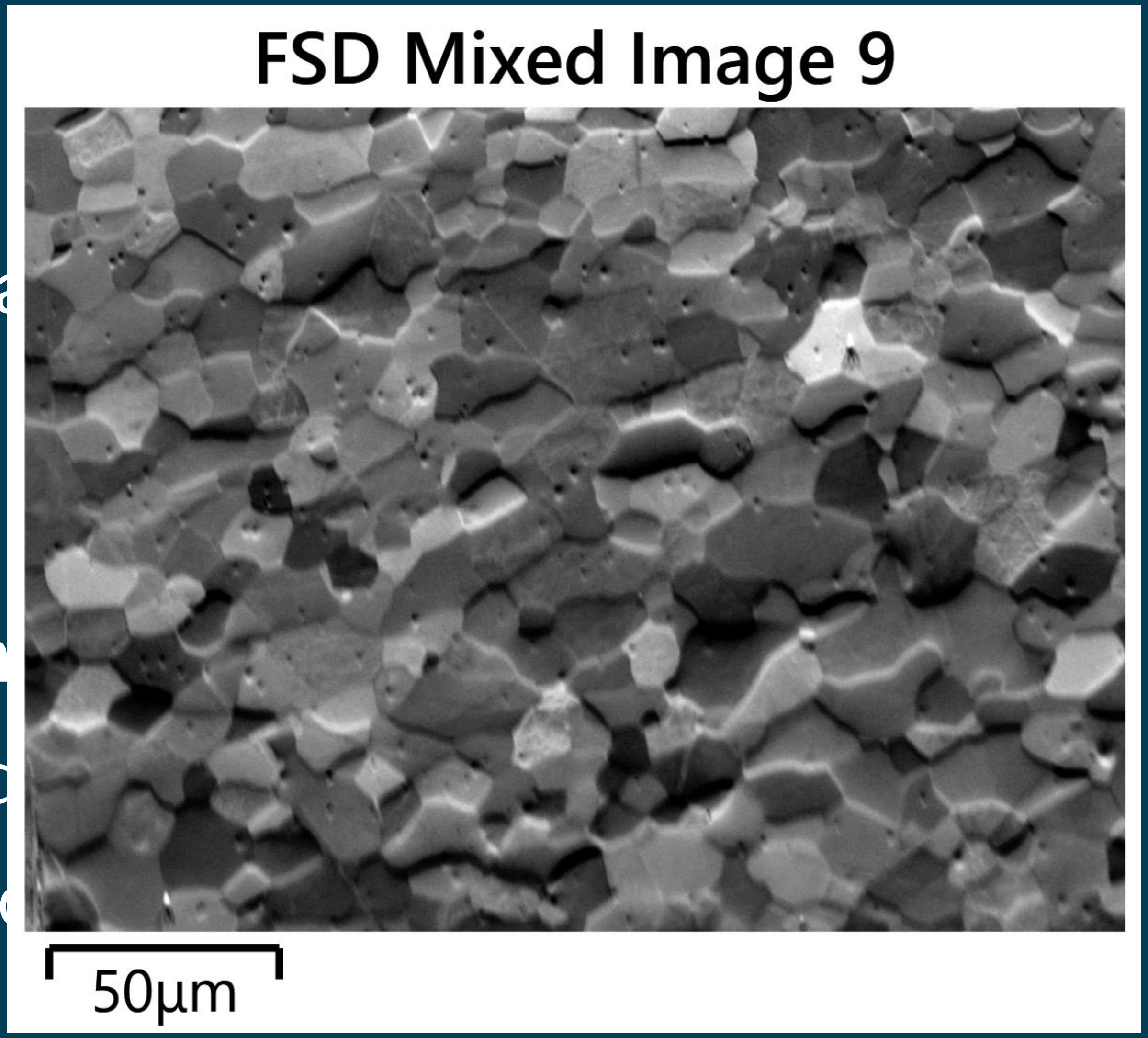
& R-value

Texture Analysis-EBSD

EBSD technique provides:



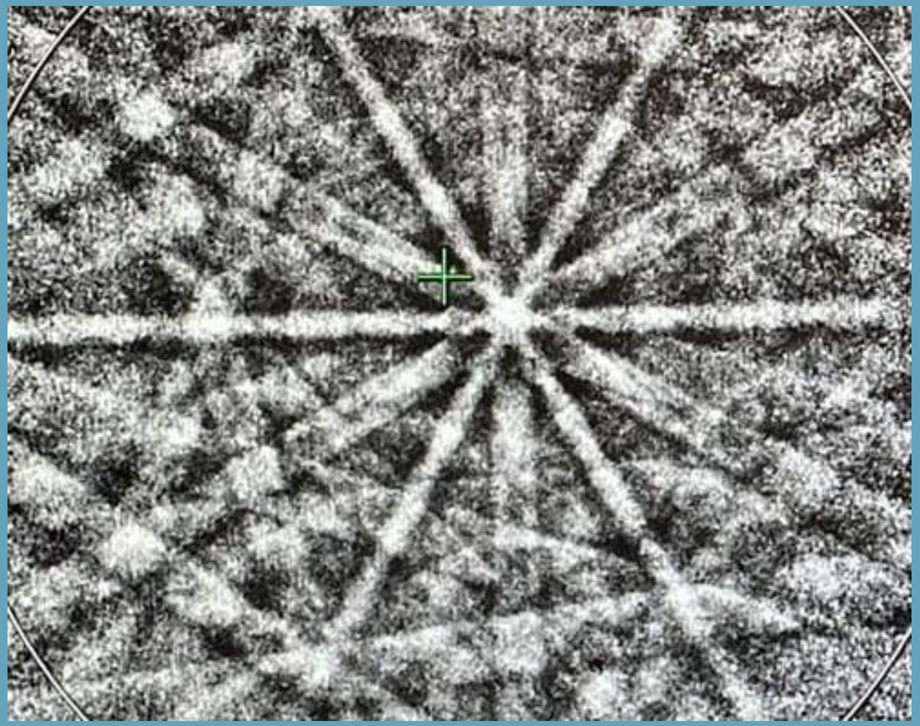


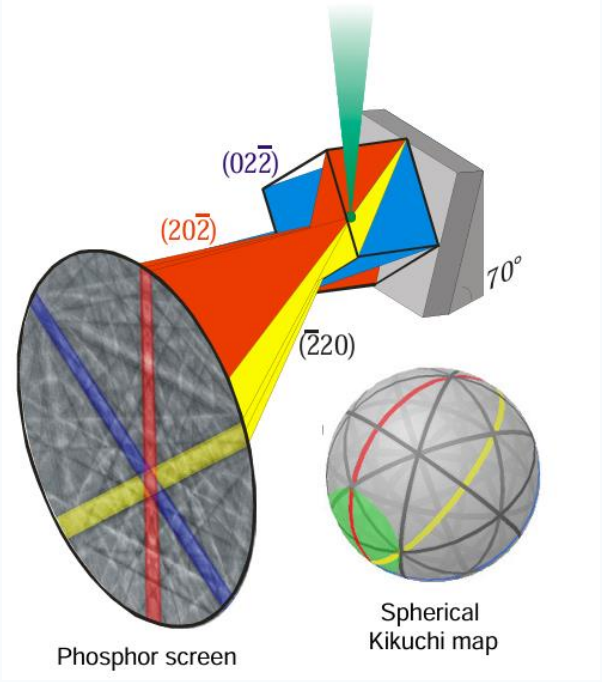


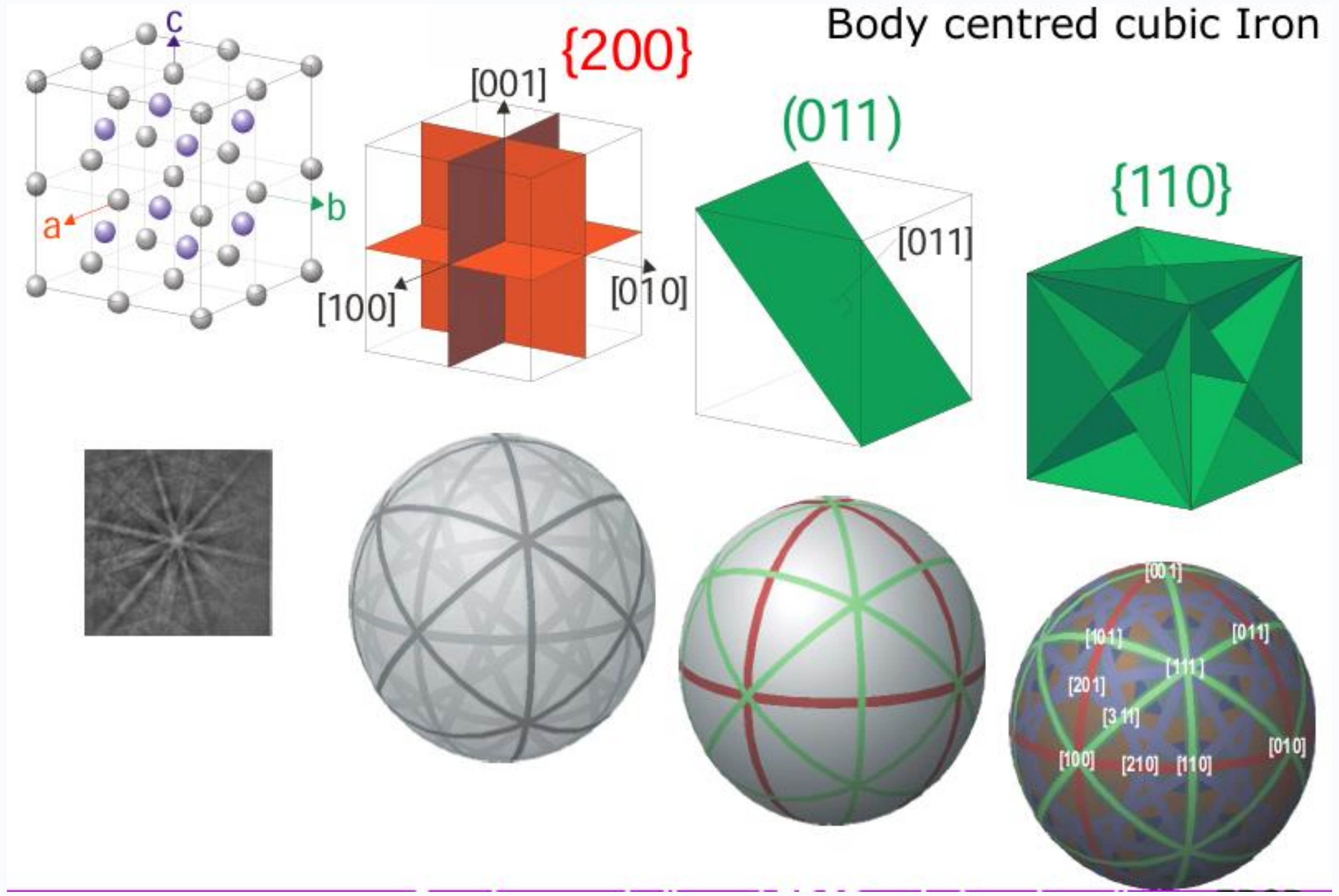
- Forward Scattered electrons increases diffraction contrast in imaging
- Grain boundaries and grains become easily identifiable

EBS Pattern Formation and Orientation

- Kikuchi bands are form when electrons travel along a crystallographic plane
- Widths are determined by Bragg's law and the specimen to screen distance
- Challenges: Limited to 80% reduction profile in industry due to line speed & cold rolling mill power

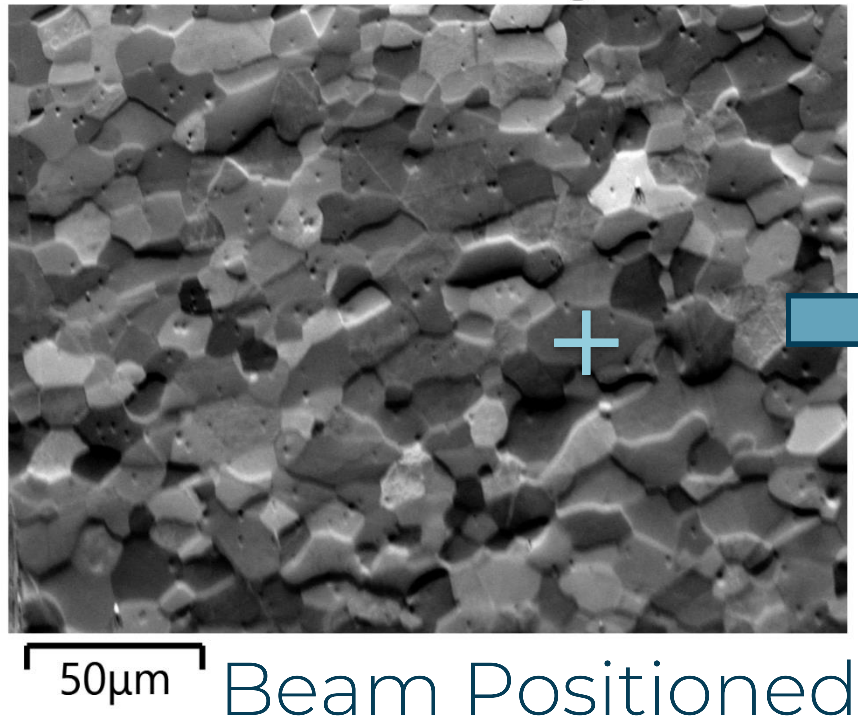




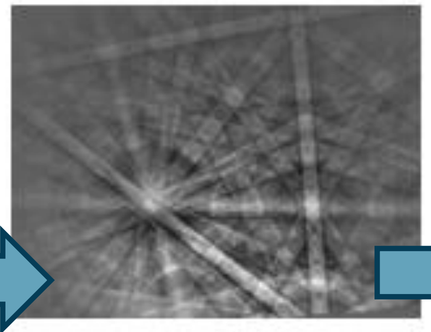


Indexing Cycle

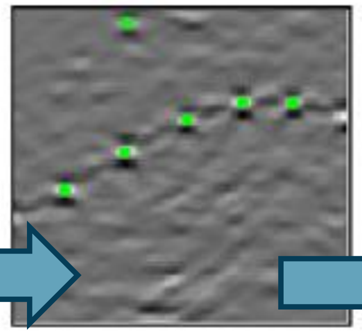
FSD Mixed Image 9



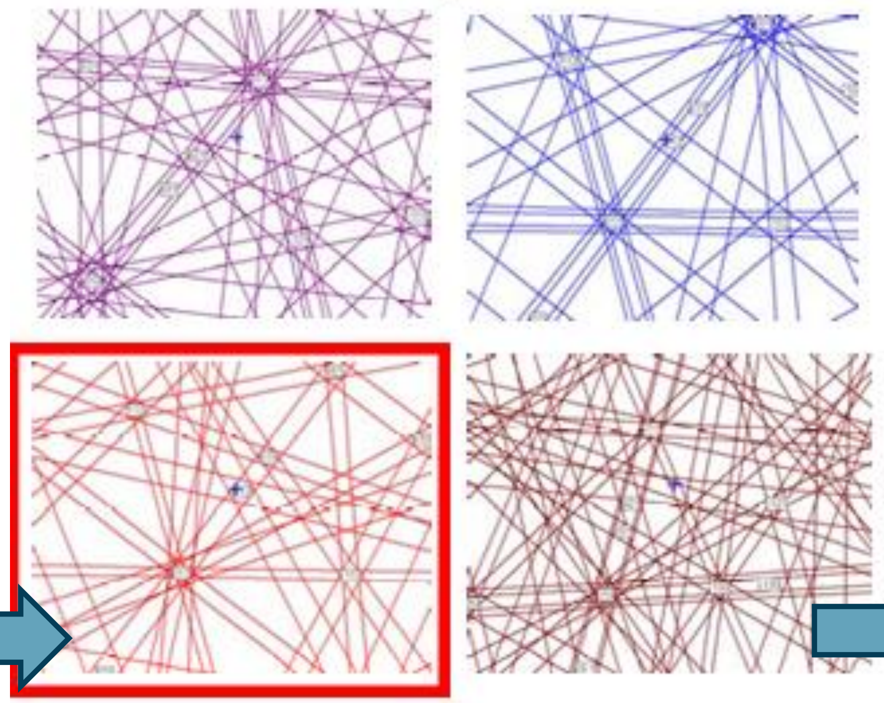
Beam Positioned



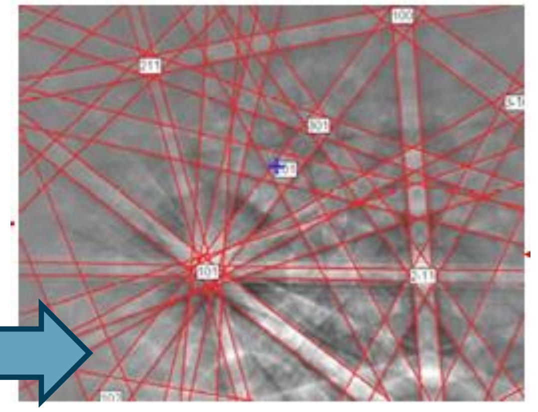
EBSP Collected



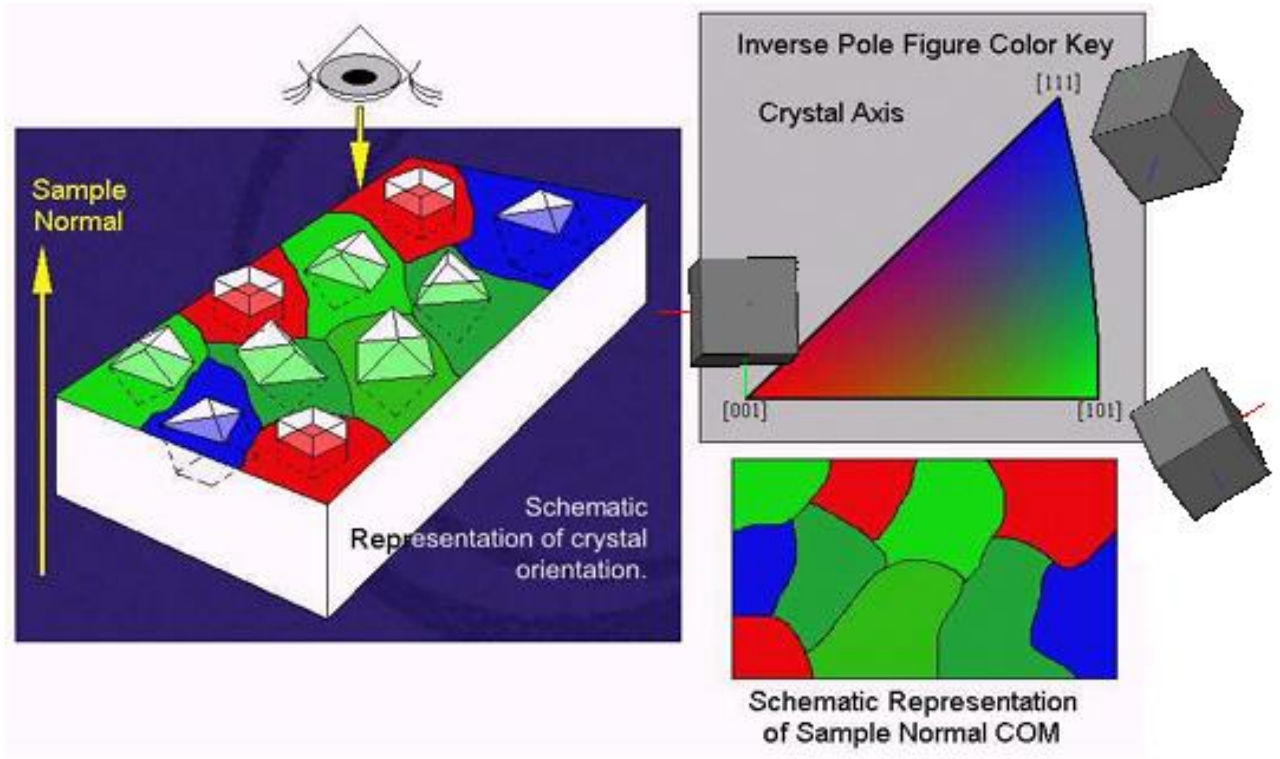
Hough Transformation

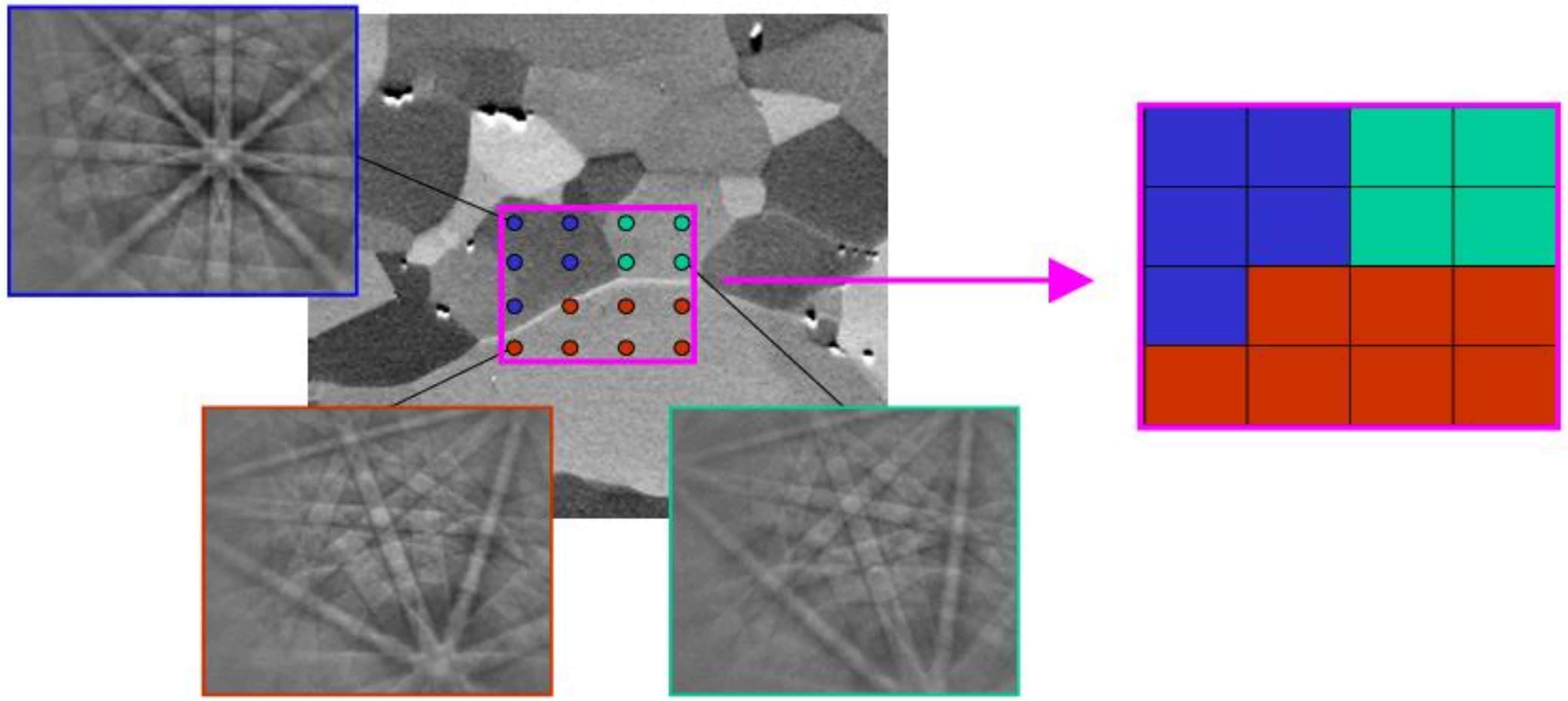


Phase and Orientation Matching

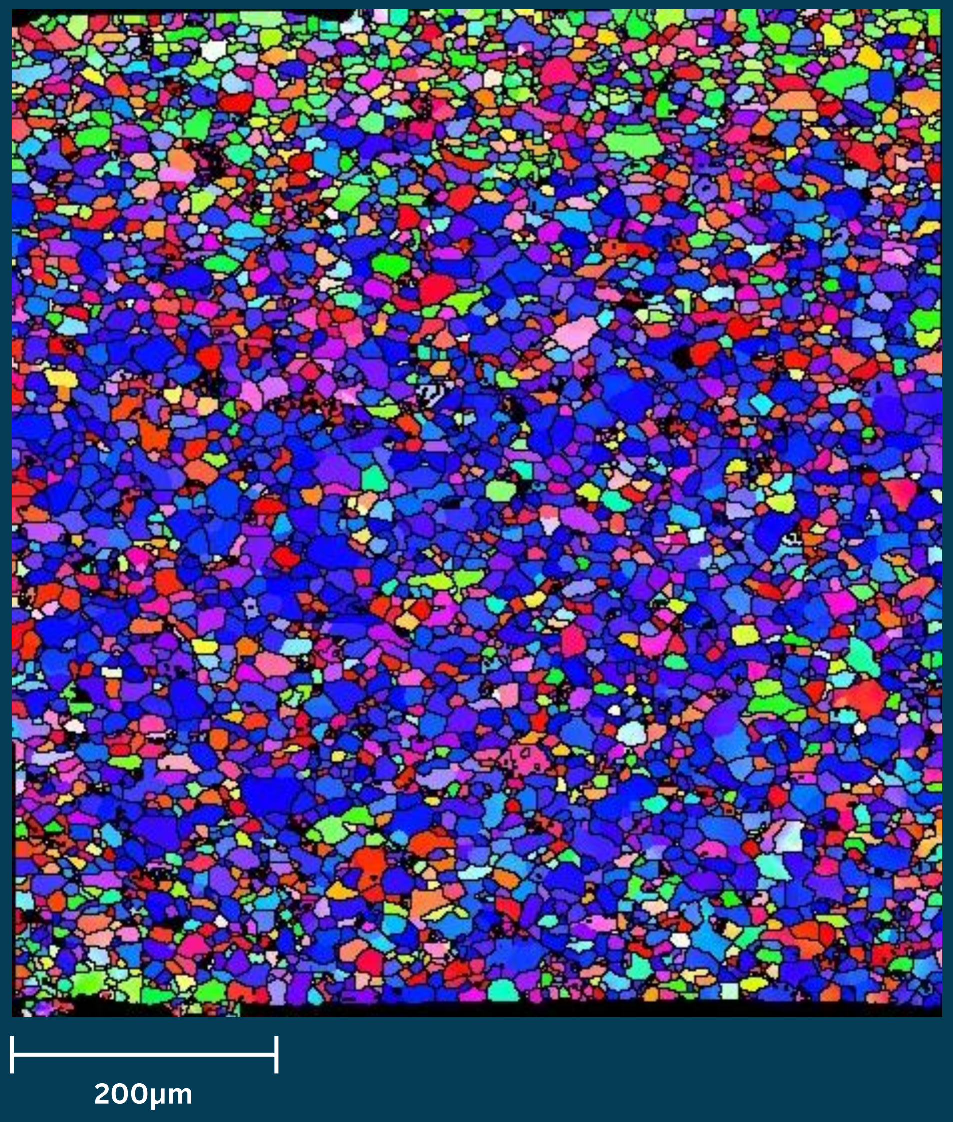


Verification of Match

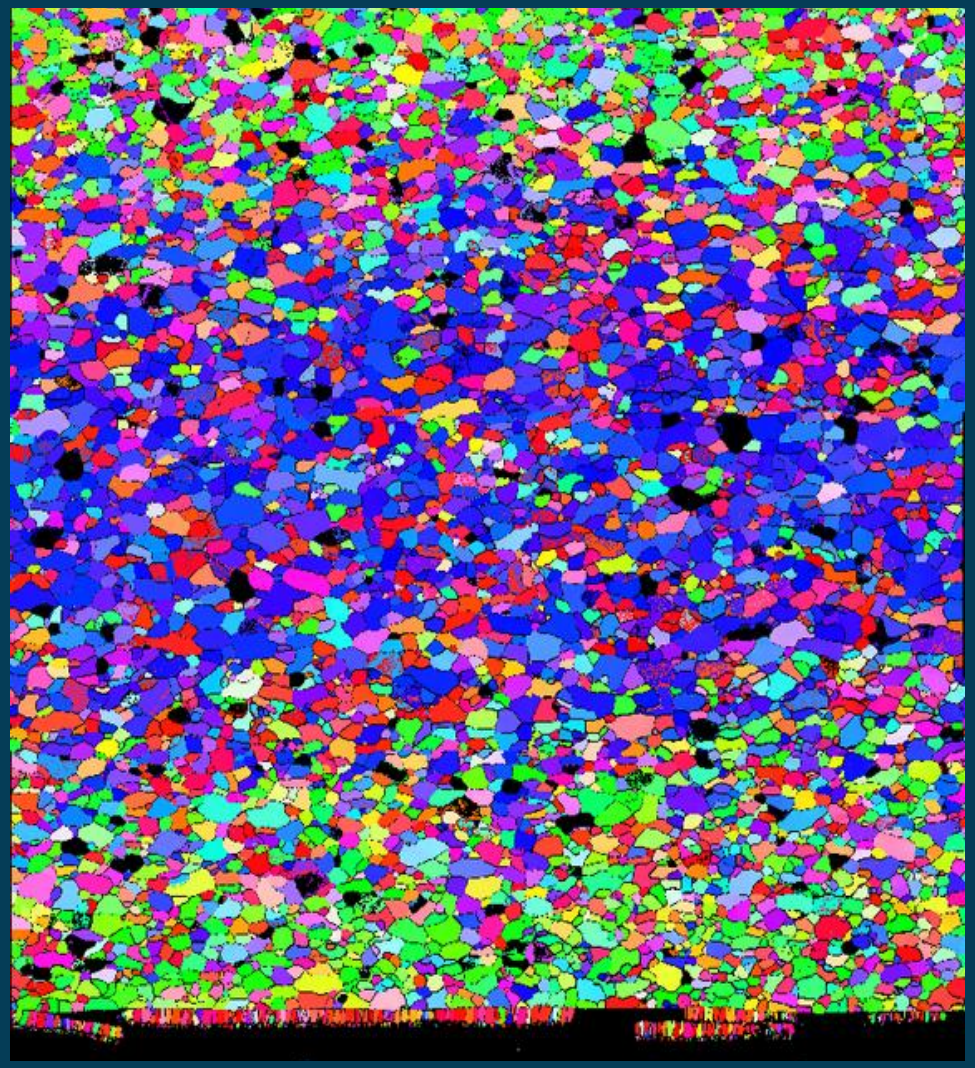




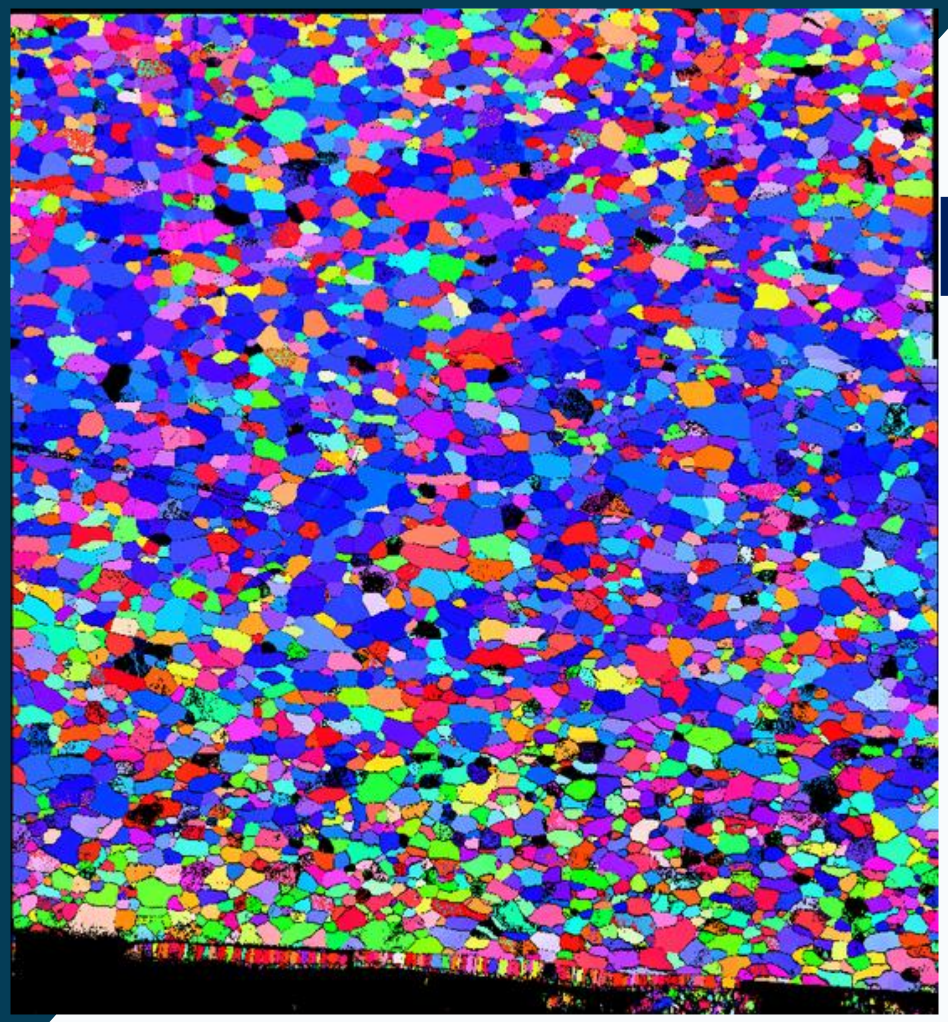
Texture- Inverse Pole Figures



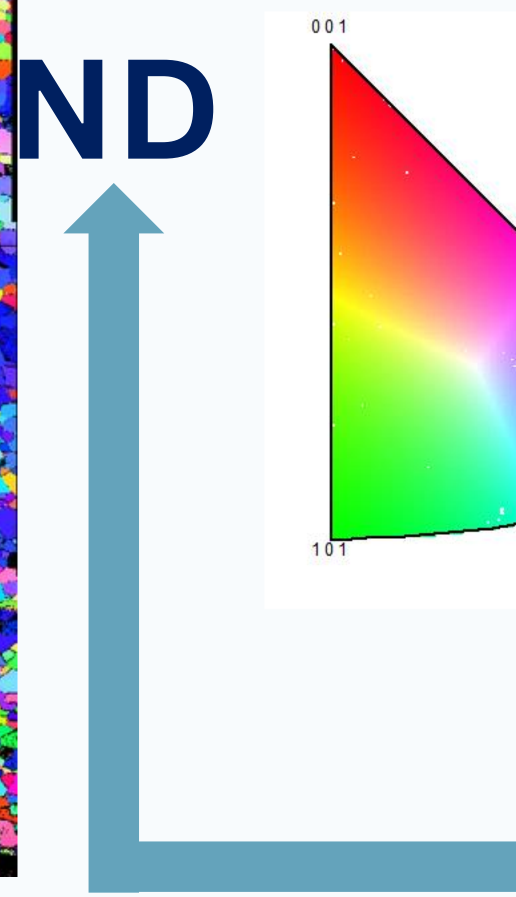
0.017 wt.%



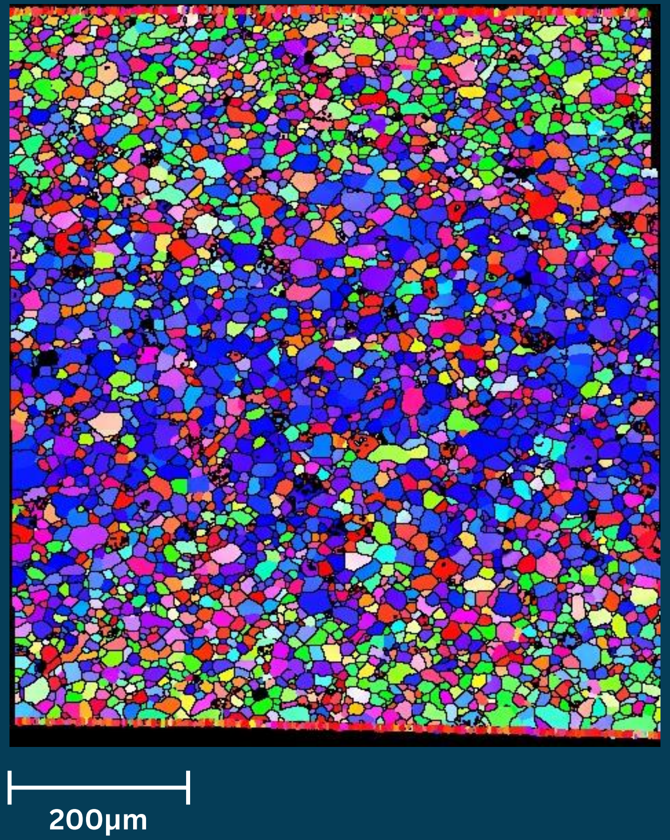
0.06 wt.%



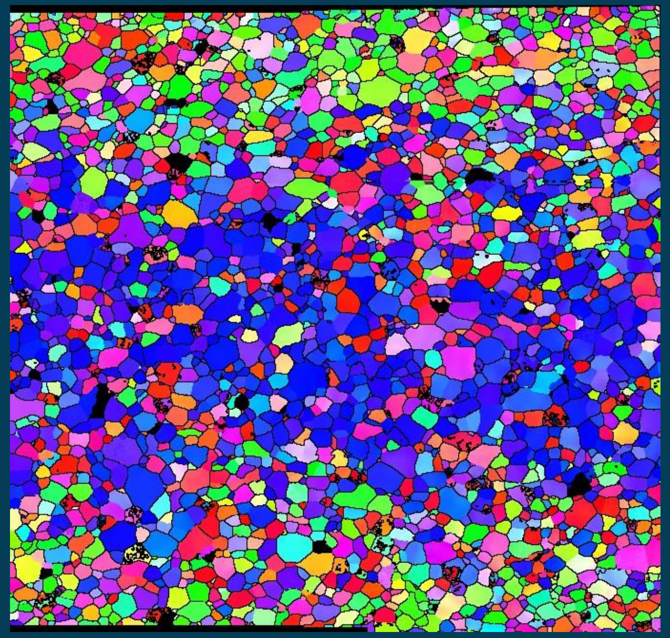
0.07 wt.%



Increasing the Annealing Temperature

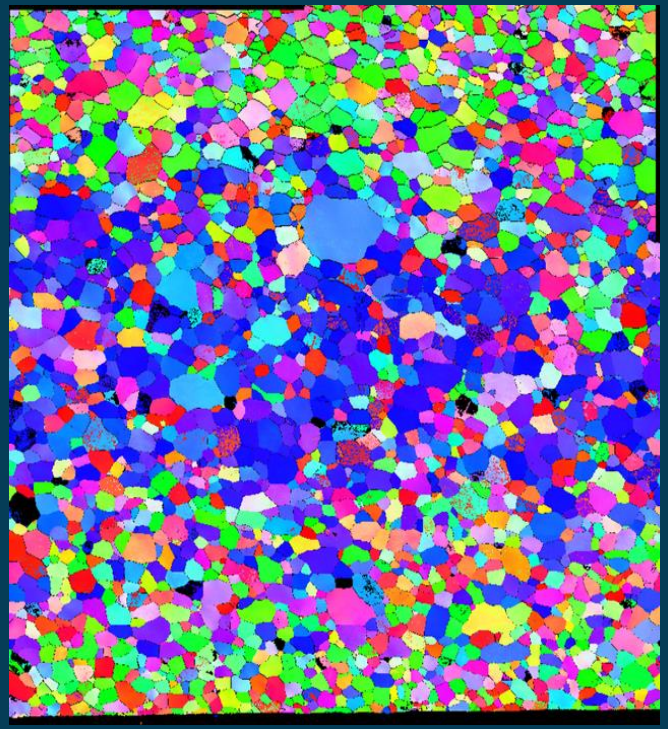


820 °C

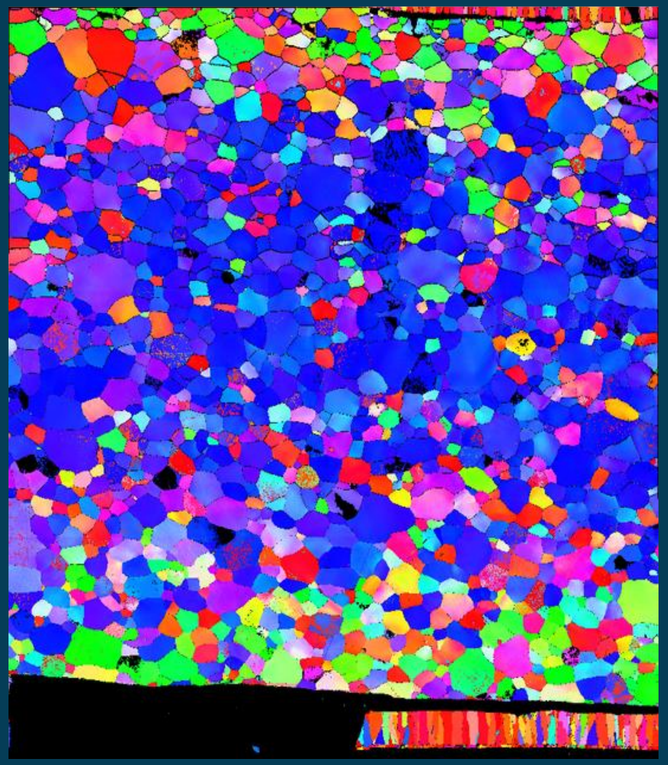


840 °C

860 °C



880 °C



900 °C

VIM CASTS

Future Work

- Lower slab reheat temperature: 1050C
- Hot rolling schedule tests using simulations and pure iron
- 7 pass schedule on VIM casts
- Cold rolling
- Annealing

IF Steel with High Scrap Content

- Lower Temperatures = higher loading force
- Number of passes
- Tnr: no-recrystalisation temperature
- Simulations and Phase Diagrams via ThermoCalc and JMatPro

VIM Casts

Conclusions:

Key Points:

- No significant change in r-value based on the chromium additions
- Significant decrease in r-value as annealing temperature increases
- Preferential 111 texture at 900°C may be due to partial recrystallisation and residual stress within the grains

Thank you for listening:

Any questions please email:
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References

- Odenthal H.J, Kemminger A, Krause F, Sankowski L, Uebber N, Vogl N, Review on Modelling and Simulation of the Electric Arc Furnace (EAF), Steel Research International, 2018;89;1700098
- Kapoor I, Davis C, Li Z, Effects of Residual Elements During the Casting Process of Steel Production: A Critical Review, Ironmaking & Steelmaking, 2021;48;6;712-727
- Iron and Steel Recycling: Review, Conceptual Model, Irreducible Mining Requirements, and Energy Implications, L.D. Danny Harvey, Renewable and Sustainable Energy Reviews, Vol. 138, 2021
- Campbell P, Blejde W, Mahapatra R, Wechsler R, Recent Progress on Commercialization of CASTRIP Direct Strip Casting Technology at Nucor Crawfordsville, Metallurgist, Vol. 48, Nos. 9-10, 2004, Pages 507-14
- Klinkenberg C, Kintscher B, Hoen K, Reifferscheid M, More than 25 Years of Experience in Thin Slab Casting and Rolling Current State of the Art and Future Developments, Steel Research International, Vol. 88, Iss. 10, 2017
- Effect of steelmaking dust characteristics on suitable recycling process determining: Ferrochrome converter (CRC) and electric arc furnace (EAF) dusts, Mamdouth Omran, Timo Fabritius, Powder Technology, Vol. 308, 2017, Pages 47-60
- Holie S., 'Processing and Properties of Mild Interstitial Free Steels, Materials Science and Technology, Vol. 16, Issue 10, 2000, Pages 1079-93