Interim Report I

5 Inch Thick 2219-T87 Plate Low Ductility Investigation
– Material analysis on broken tensile samples

EM31 Investigation Team

EM31/NASA-Marshall Space Flight Center

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2219-T87 Plate Low Ductility Investigation Support

Investigation planning & coordination: Po Chen, Ben Rupp

Metallography & optical microscopy: Matt Medders, Sam Mcleroy, Po Chen

SEM/fractography: Ellen Rabenberg

DSC: Ching-Hua Su, Jeff Quick, Po Chen

Electrical conductivity (EC): Ching-Hua Su

1. DSC is intended to compare incipient melting temperature and mass % of Al-Cu eutectic phase
2. EC is an indirect way to compare precipitate size and distribution.
    - In general, the material that has larger precipitate size and wider spacing between precipitate particles has higher EC

Samples Received from EM21 for Low Ductility Investigation

Broken tensile samples

Specimen ID, Test temperature	Fracture elongation (%)
9492854 720-4, RT	6.67%
9492854 720-2, LN2	7.23%
9492854 720-23, LH2	2.55%
930071 722C-3, RT	1.70%
930071 722C-5, LN2	1.00%
930071 722C-10, LH2	1.15%
930082 723C-2, RT	1.33%
930082 723C-6, LN2	1.25%
930082 723C-10, LH2	1.10%

Investigation on-going

+

5” plate block

1. One from lot 9492854
2. Two from lot 930071
3. Two from lot 930082

Broken Tensile Samples

1. Two from lot 930081 (ductility ≈ 0.8% in LN_2)

To be investigated

Sample Preparation and Analysis Status for Broken Tensile Samples

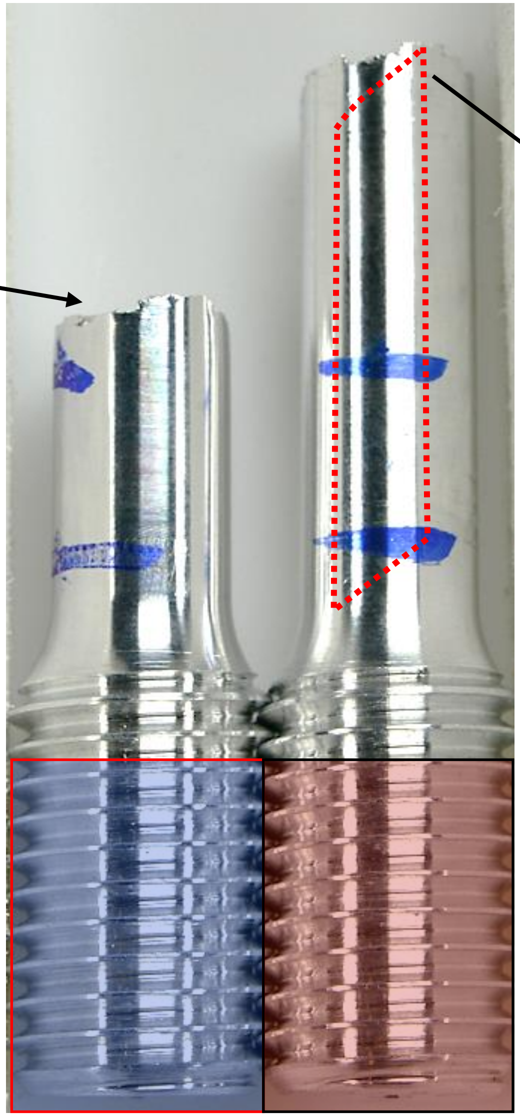
Specimen ID	% EL	Priority	Sample preparation		Metallurgical Analysis		DSC/EC Analyses	
			Met samples	DSC/EC samples	Optical microscopy	SEM	DSC	EC
9492854 720-4, RT	6.67%	2	√	√	√			
9492854 720-2, LN2	7.23%	1	√	√	√	√	√	√
9492854 720-23, LH2	2.55%	1	√	√	√			
930071 722C-3, RT	1.70%	2						
930071 722C-5, LN2	1.00%	1	√	√	√	√	√	√
930071 722C-10, LH2	1.15%	2						
930082 723C-2, RT	1.33%	2						
930082 723C-6, LN2	1.25%	1	√	√	√	√	√	√
930082 723C-10, LH2	1.10%	2						

√: denotes completion of sample preparation or metallurgical analysis

1. Divide the broken tensile samples into two groups, priority 1 & 2
2. Focus on 3 LN_2 samples from 3 different lots to determine root cause of low ductility in a timely fashion

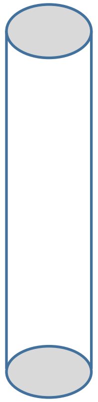
Material Analysis Plan for Thick 2219 Plate Samples

SEM analysis on fracture surface to determine fracture mode, amount and distribution of Cu-rich precipitates

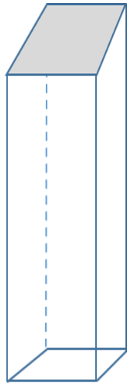


Section sample along rolling direction. Analyze grain structure and GB precipitation near the fracture surface using OM and SEM. The focus is on size & distribution of coarse GB Cu-rich precipitates

DSC sample (4.5 mm d. x 10 mm



EC sample (2.5 mm x 2.5 mm x 15 mm)



Extract DSC & EC samples from the threaded section

Extract met samples from the threaded section to determine "L" direction

Key Findings after the Material Analysis on Three Broken Tensile Samples

		Key Findings						
Specimen ID, Test T	Ductility	Grain size	% Rx	Remnant dendrite cells	**Fracture mode**	**Density of coarse Cu-rich θ phase (Al_2Cu) at GB**	Incipient melting temperature (DSC)	EC
9492854 720-2, LN2	7.23%	smaller	higher	fewer	**TG**	**low**	≈ 548 °C	lower
930071 722C-5, LN2	1.00%	larger	lower	more	**IG**	**high**	≈ 548 °C	higher
930082 723C-6, LN2	1.25%	larger	lower	more	**IG**	**high**	≈ 548 °C	higher

Rx: Recrystallization; TG: Transgranular fracture; IG: Intergranular fracture
GB: Grain boundary; EC: Electricity conductivity, DSC: Differential Scanning Calorimetry

Detrimental effects of coarse Cu-rich particles (θ phase - Al_2Cu):

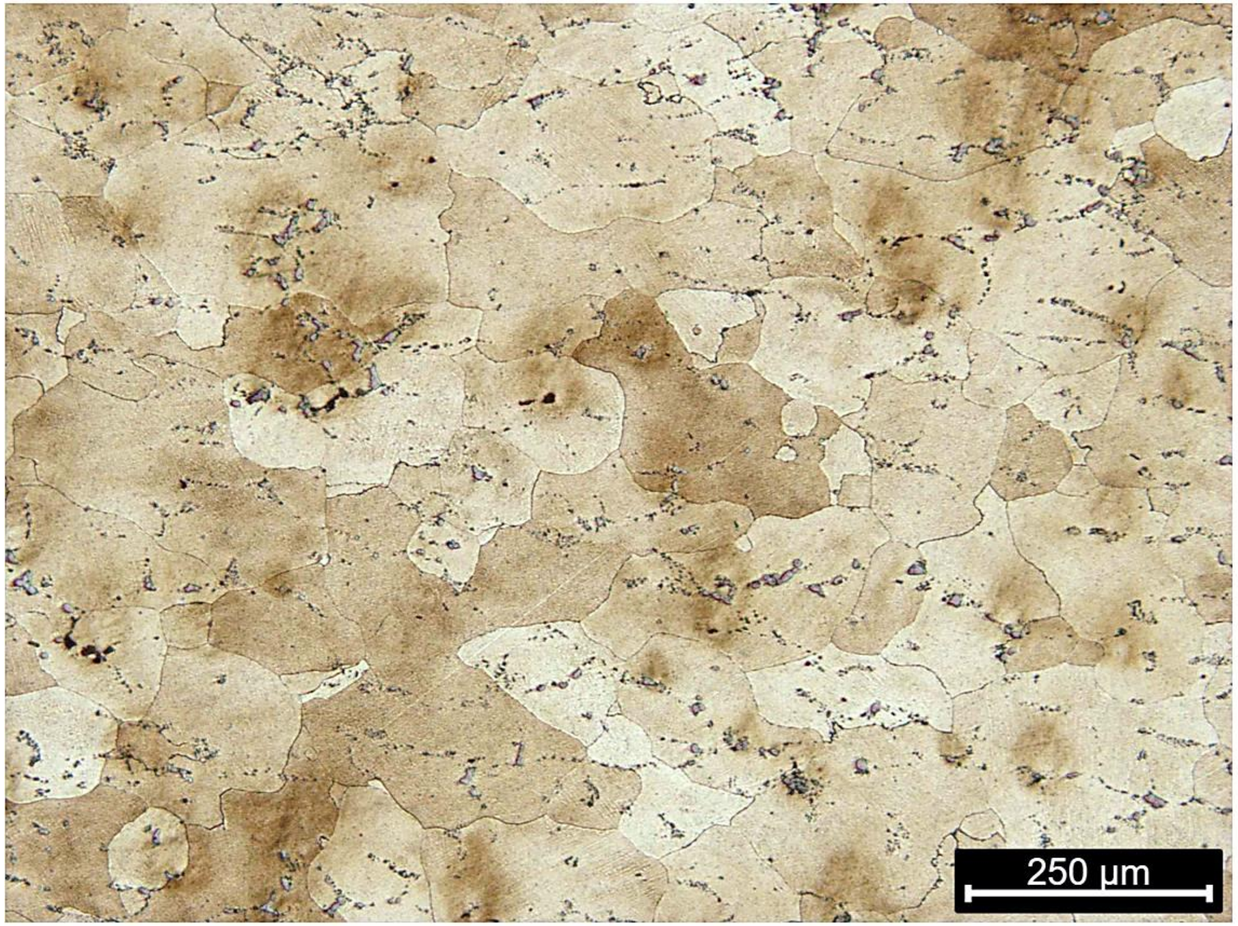
1. They are stress risers and will increase K_t during tensile testing and promote crack initiation
2. The greater the number of coarse Cu-rich particles, the easier for micro-cracks to connect
3. Many connected micro-cracks lead to larger cracks and a drastic reduction in fracture elongation

Optical Microscopy Results - Charts 8 – 18

OM lead: Matt Medders

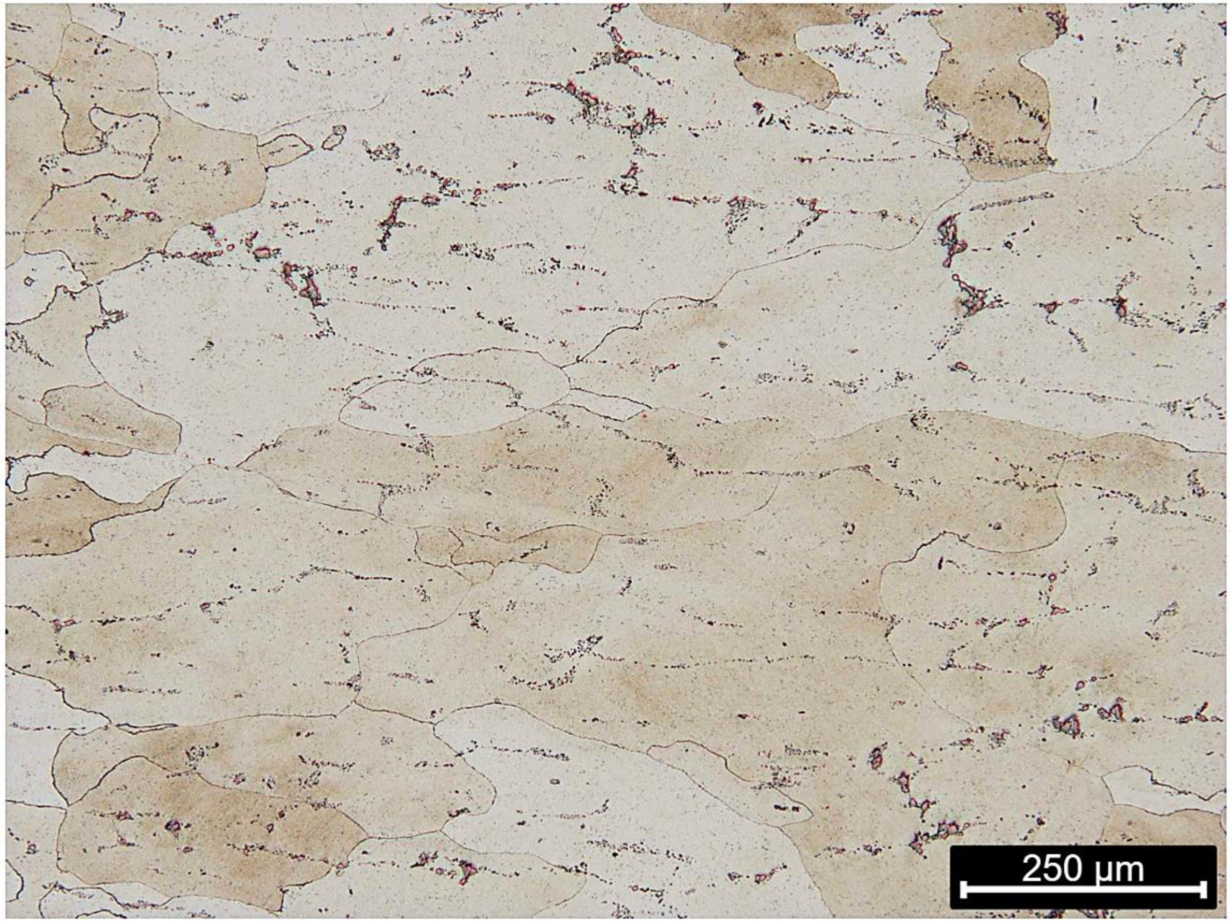
Grain Structure Comparison – 720-2 vs. 723C-6

Higher Rx, smaller GS, fewer dendritic cells



720-2 LN2 – 7.23%

Lower Rx, larger GS, distinct prior dendritic structure

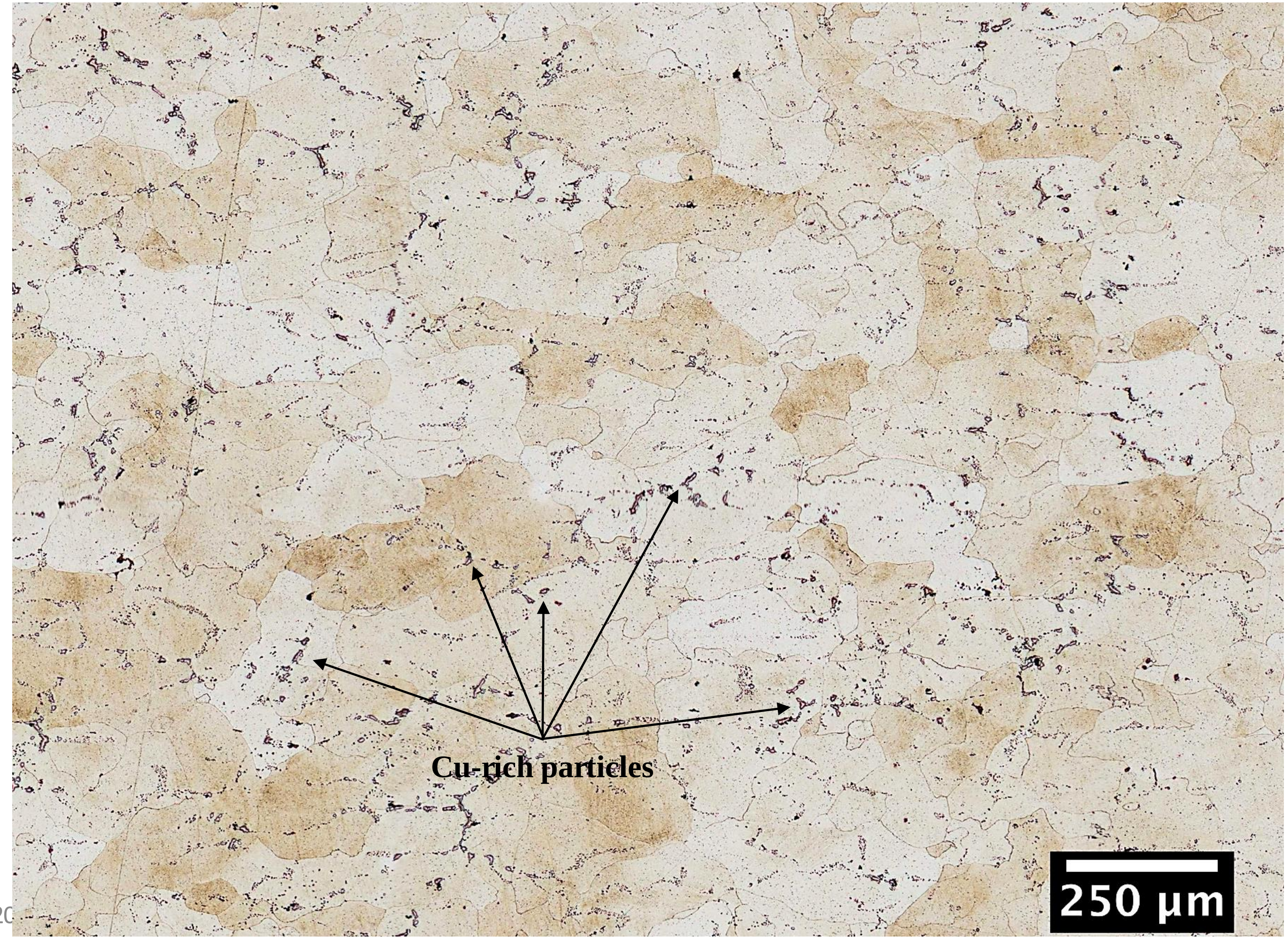


723C-6 LN2 – 1.25%

The small (pinkish) particles are Cu-rich θ phase, Al_2Cu

Coarse Cu-Rich Particles Size & Distribution in Sample 720-2

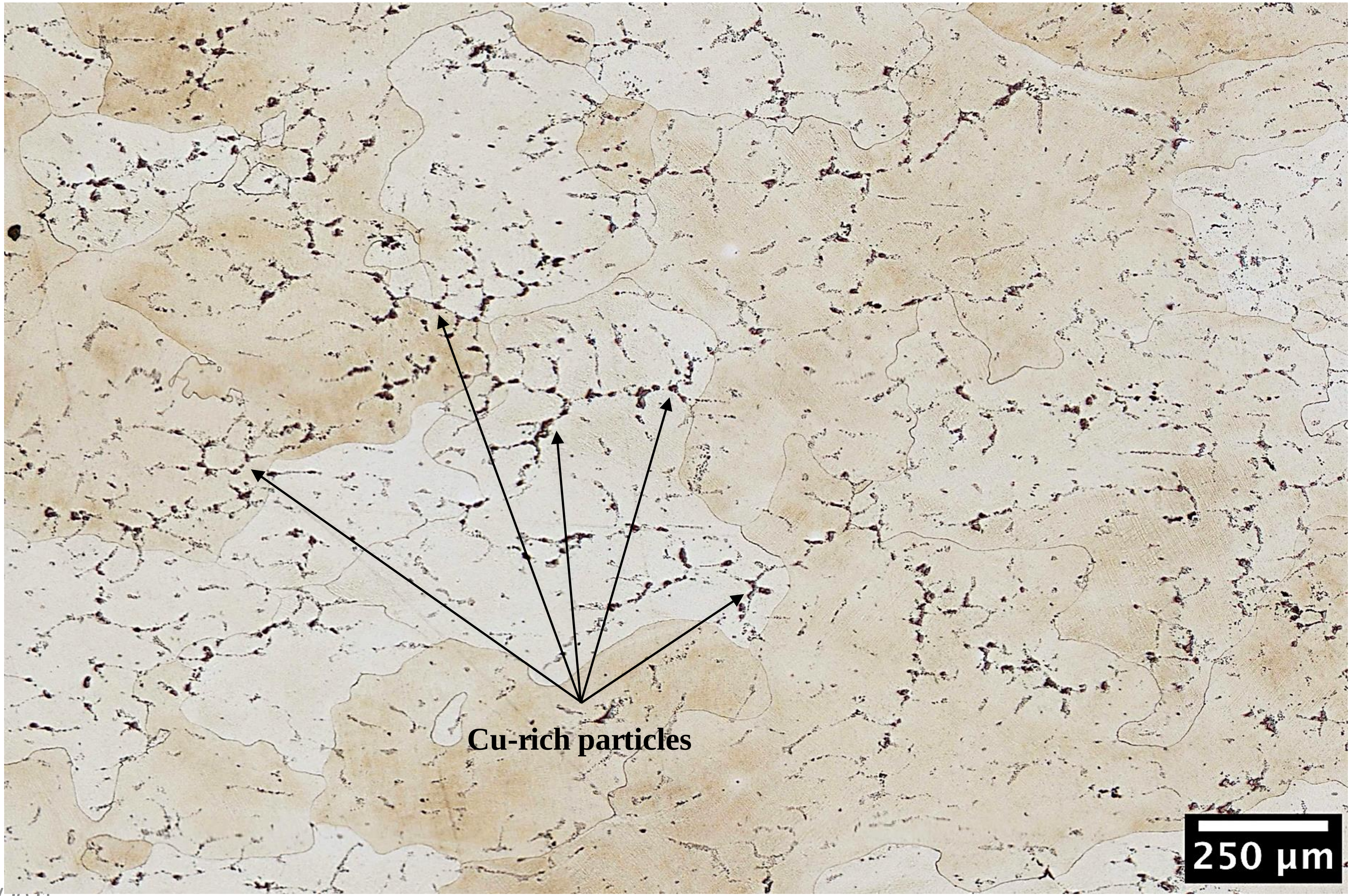
720-2 LN2 – 7.23%



1. The small (pinkish) particles are Cu-rich θ phase, Al_2Cu
2. More uniform distribution of Cu-rich particles (Al_2Cu-θ phase)
3. No clear sign of coarse Cu-rich particles at prior dendritic boundaries

Coarse Cu-Rich Particles Size & Distribution in Sample 722C-5

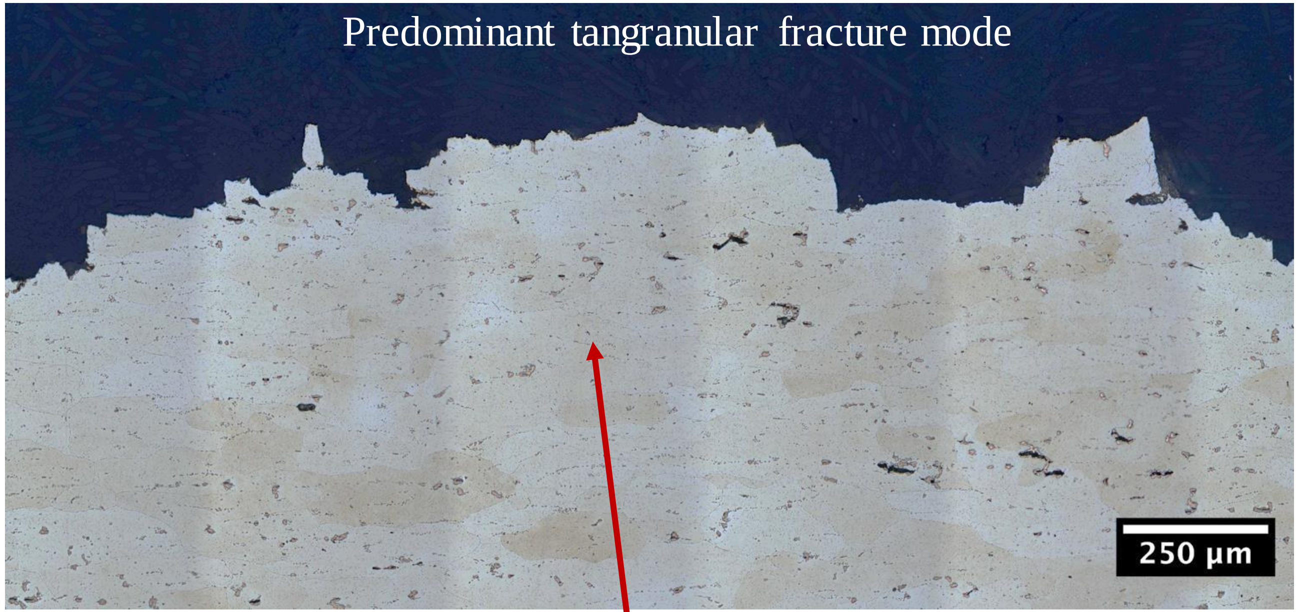
722C-5 LN2 – 1.0%

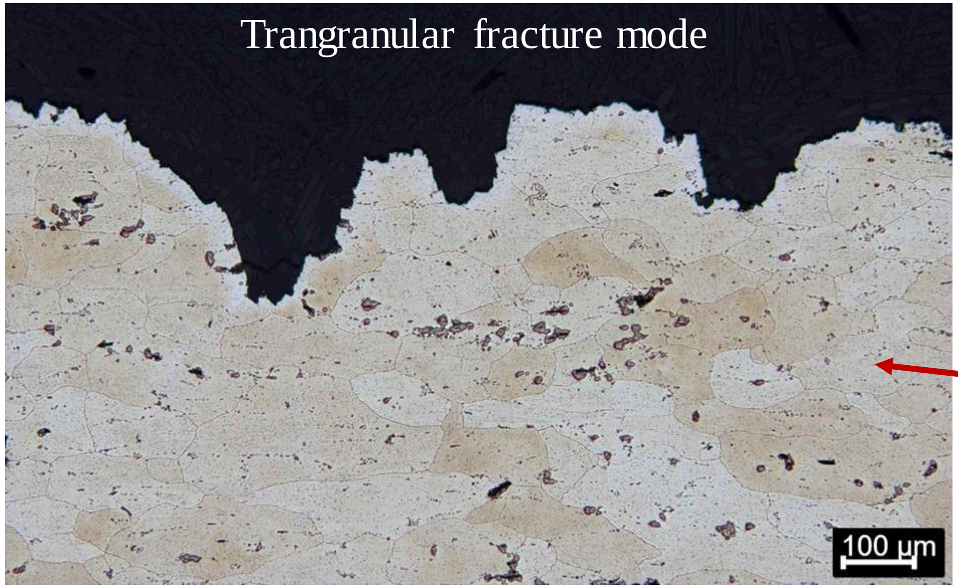


1. The small (pinkish) particles are Cu-rich θ phase, Al_2Cu
2. Non-uniform distribution of Cu-rich particles (Al_2Cu-θ phase)
3. More coarse Cu-rich particles are present along the prior dendritic boundaries

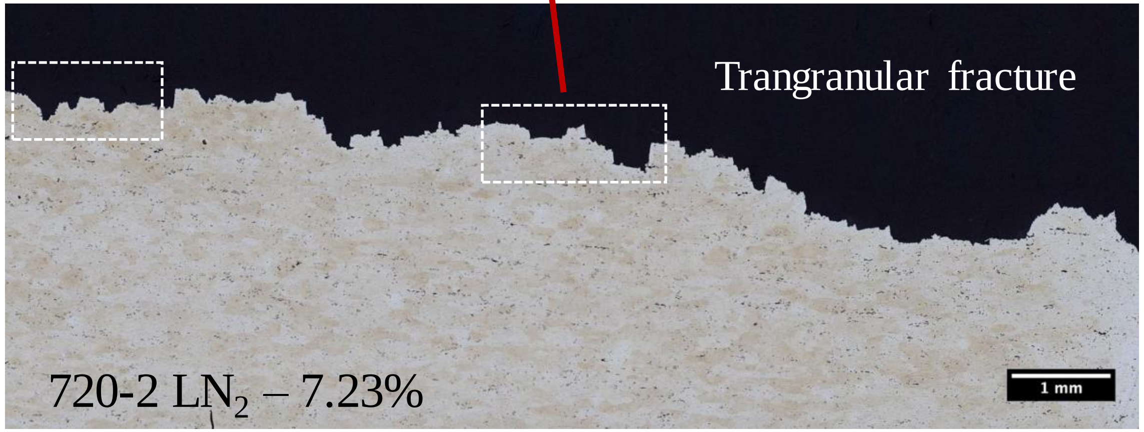
Cross-Sectional View of Fracture Surface - 720-2 LN_2 – 7.23%

1. Predominant transgranular fracture mode
2. No sign of continuous cracking along grain boundaries



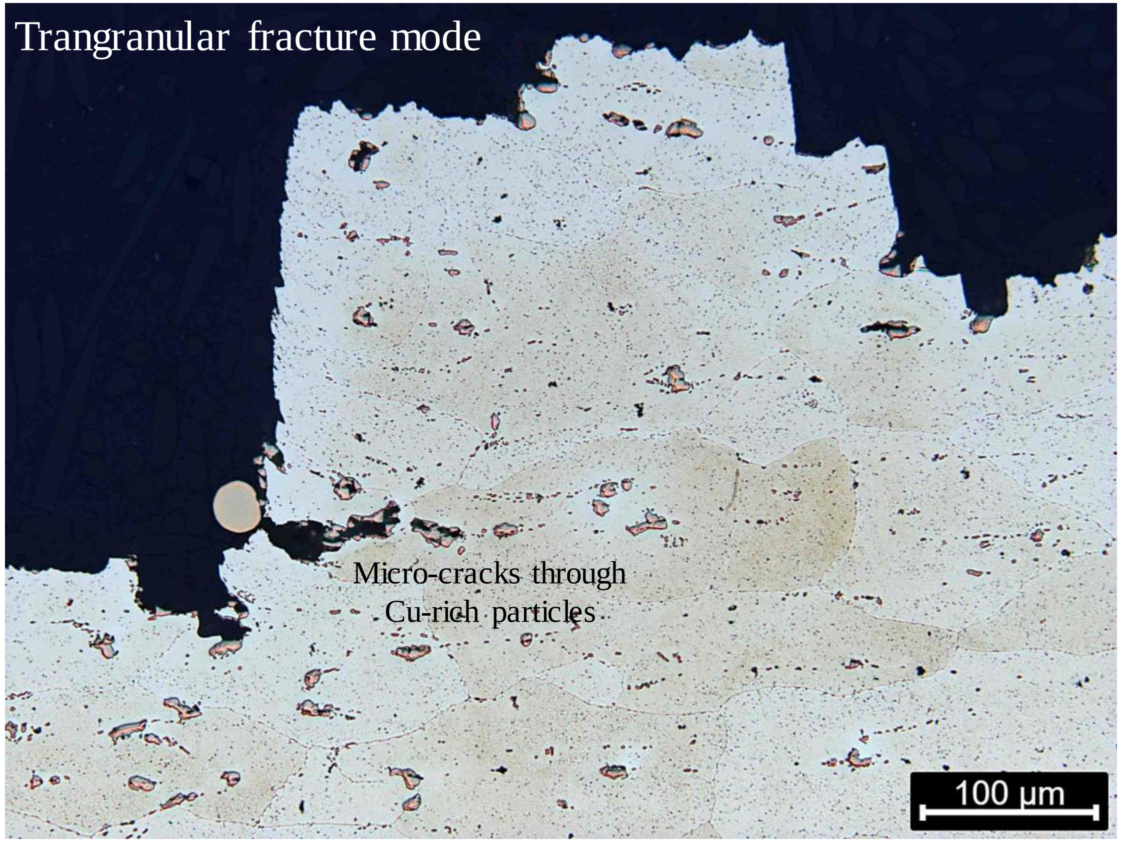


No sign of brittle fracture

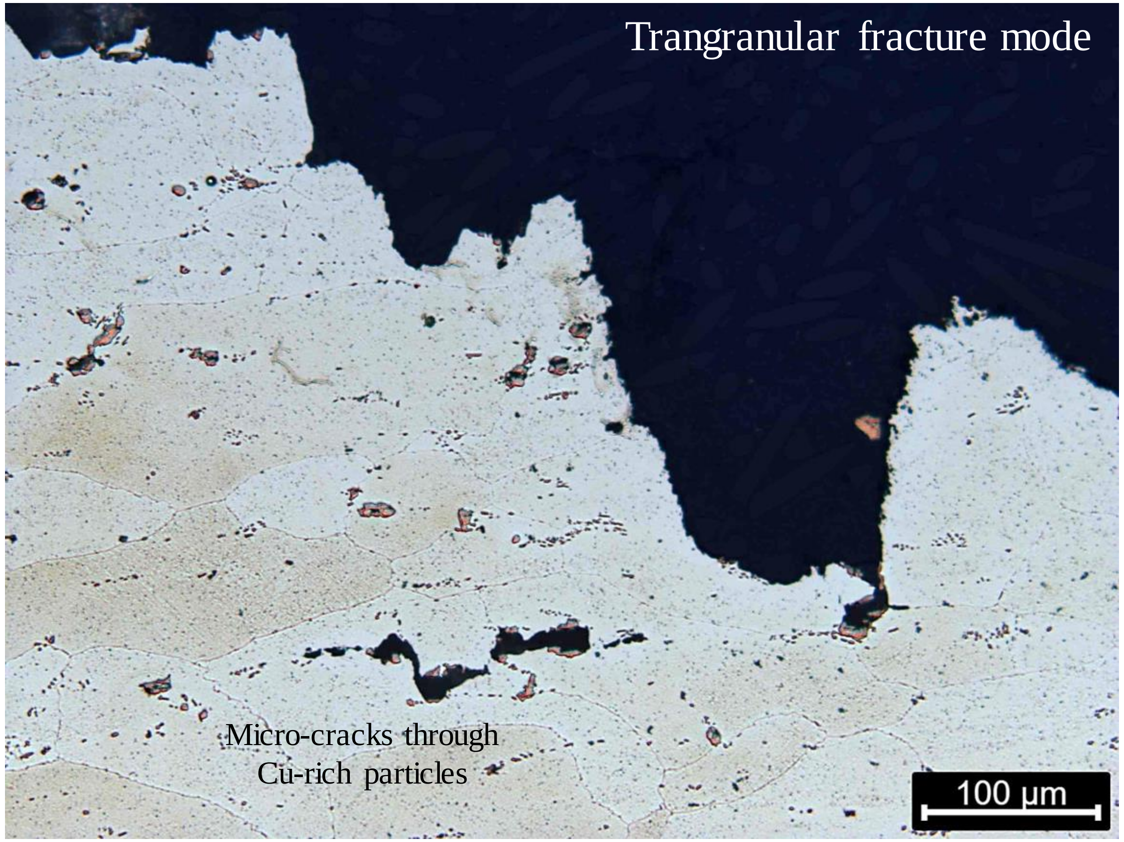


Close-up View of Fracture Surface - 720-2 LN_2 – 7.23%

720-2 LN_2 – 7.23%



Signs of ductile fracture

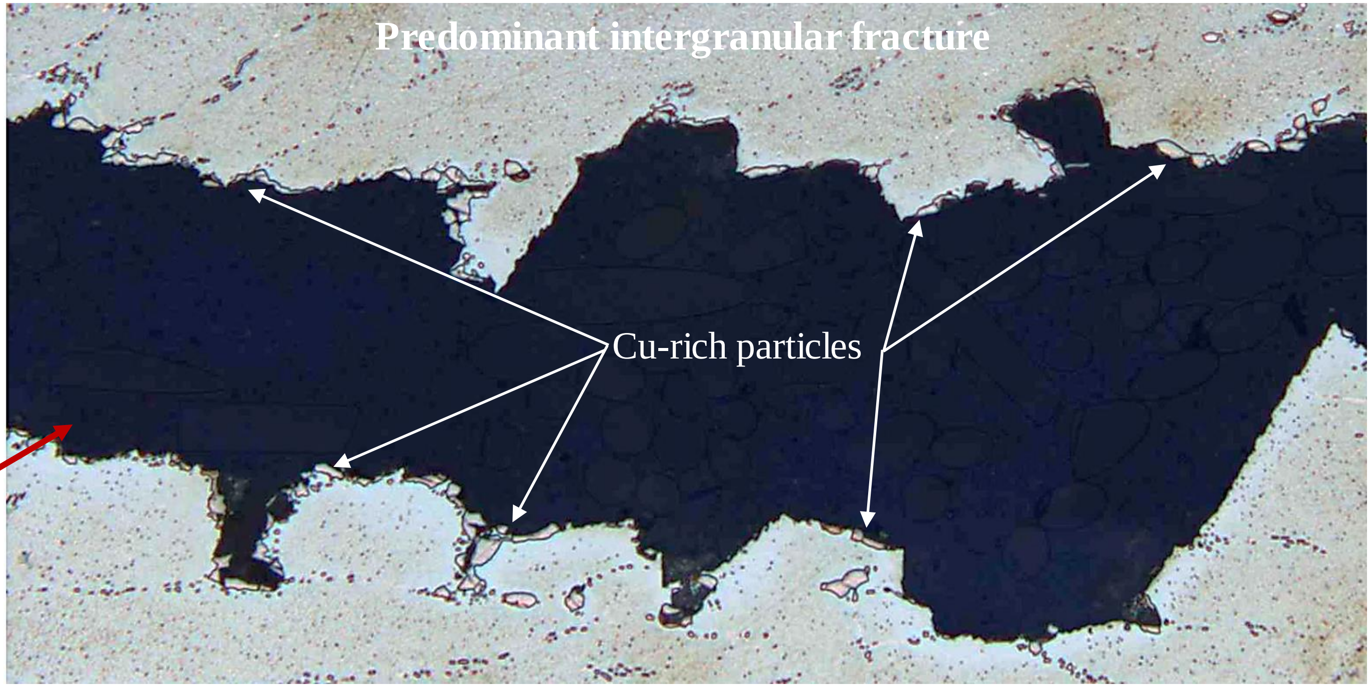


Signs of ductile fracture

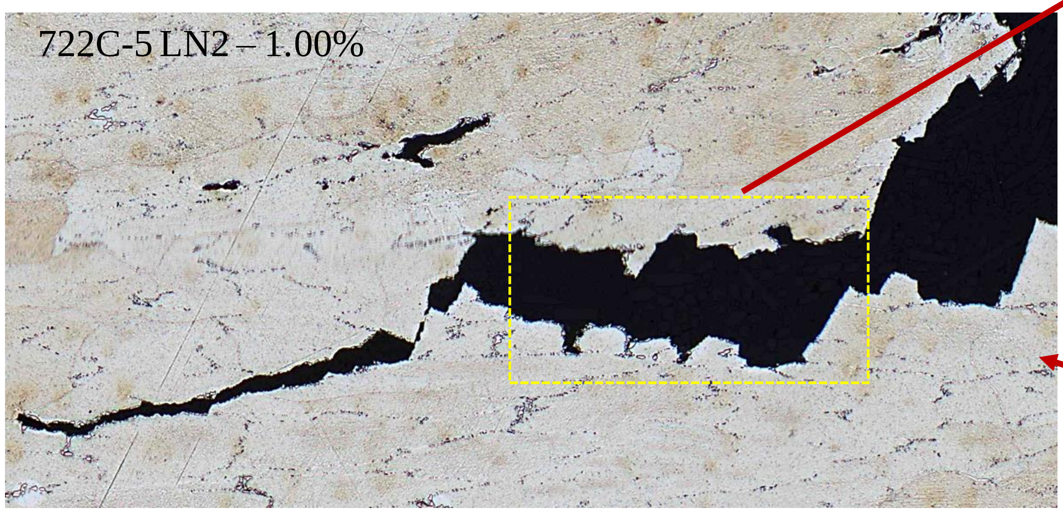
1. Predominant transgranular fracture mode, No sign of continuous cracking along grain boundaries
2. Some isolated micro-cracks, but micro-cracks do not connect through broken Cu-rich particles

Cross-Sectional View of Fracture Surface - 722C-5 LN_2 – 1.0%

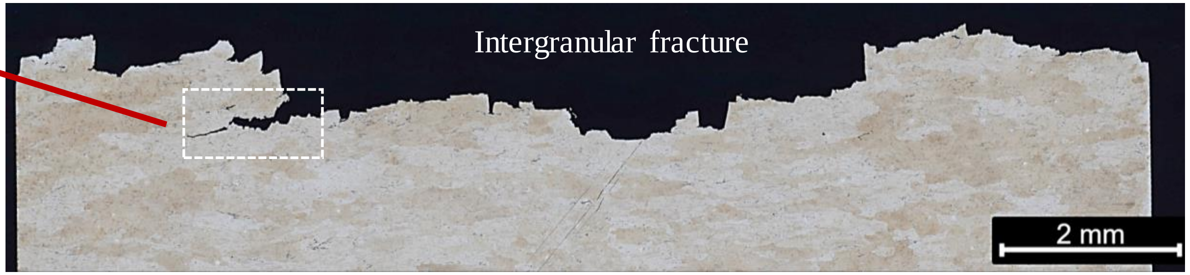
1. Predominant Intergranular fracture mode
2. Clear signs of continuous cracking on Cu-rich particles along grain boundaries



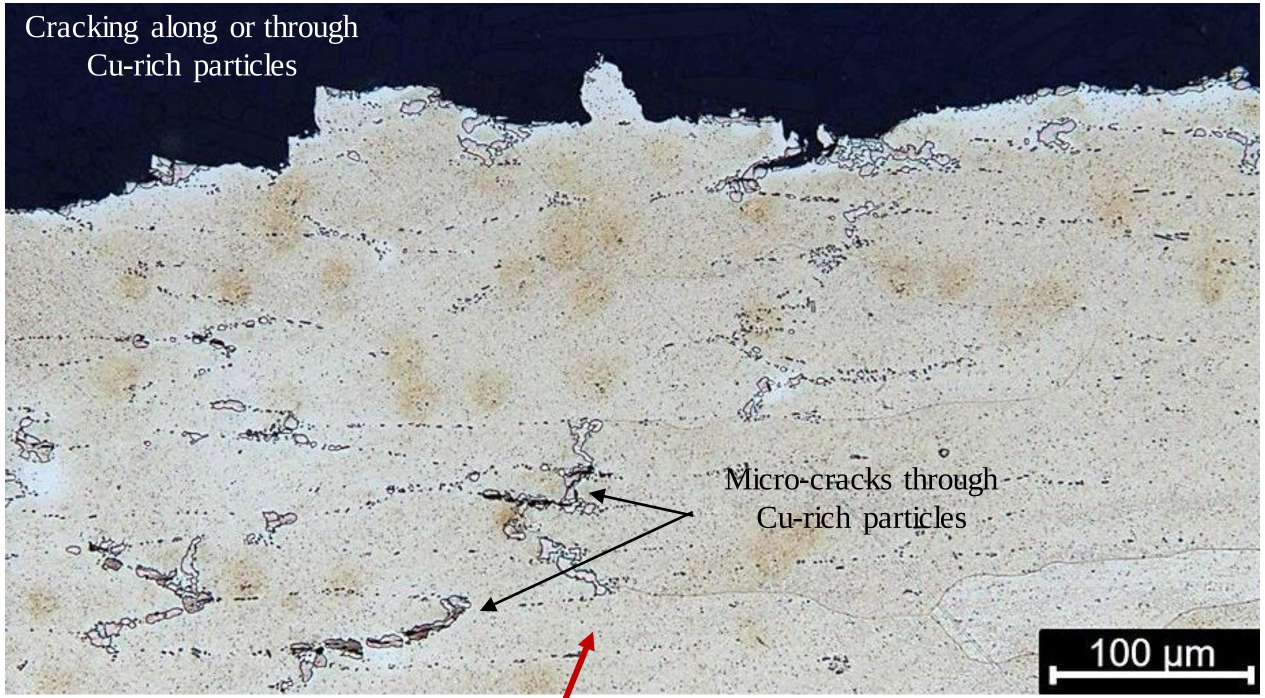
Fracture path along Cu-rich particle boundary



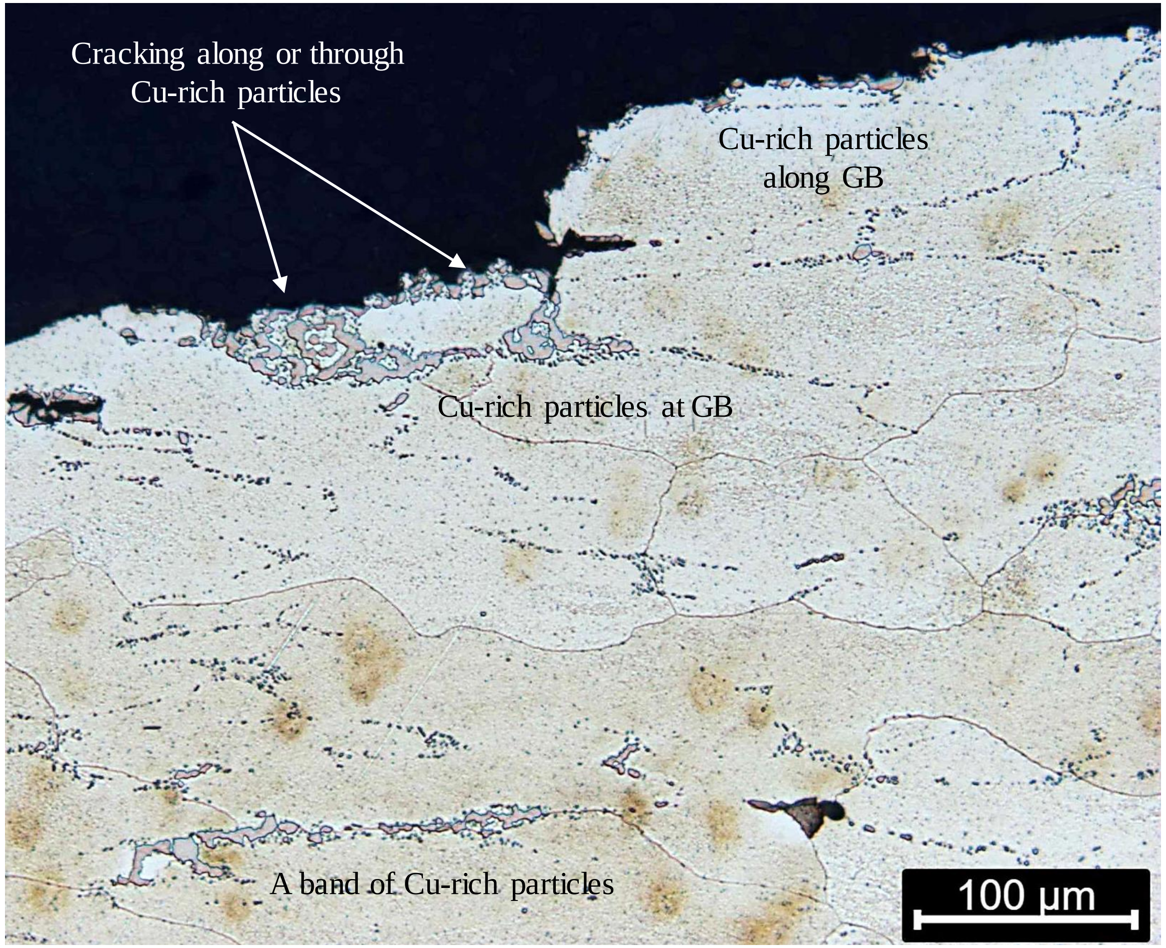
Signs of brittle fracture



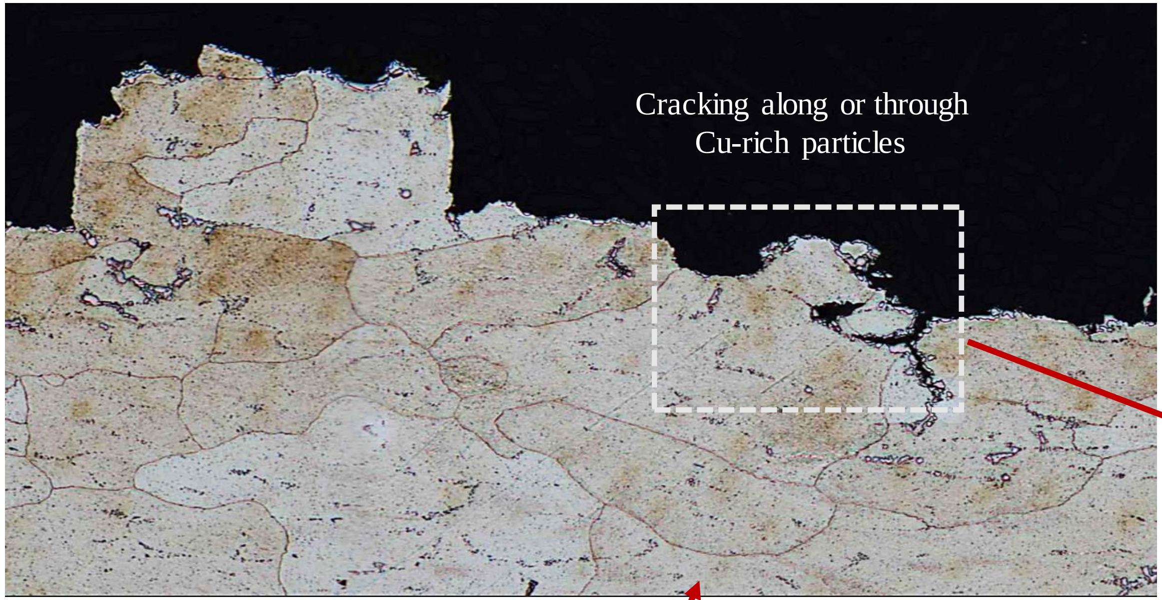
Cross-Sectional View of Fracture Surface - 722C-5 LN_2 – 1.0%

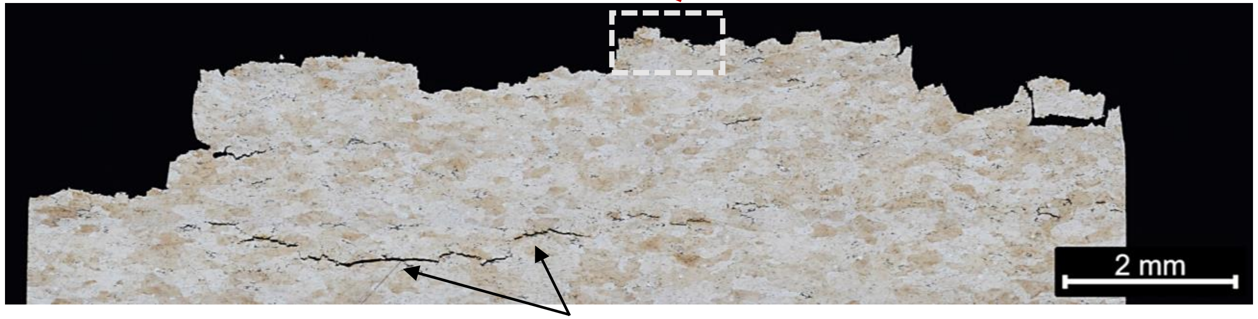


Signs of brittle fracture



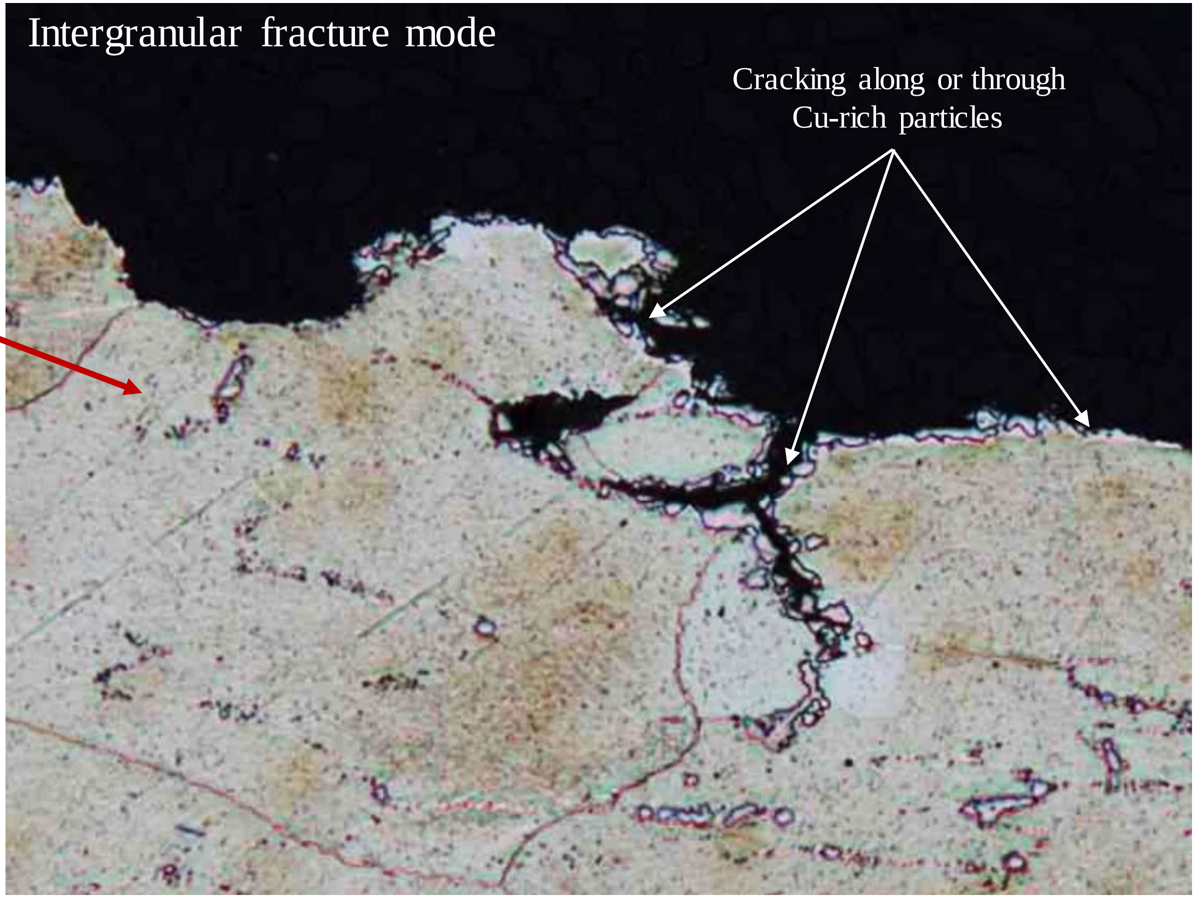
Cross-Sectional View of Fracture Surface - 723C-6 LN_2 – 1.25%





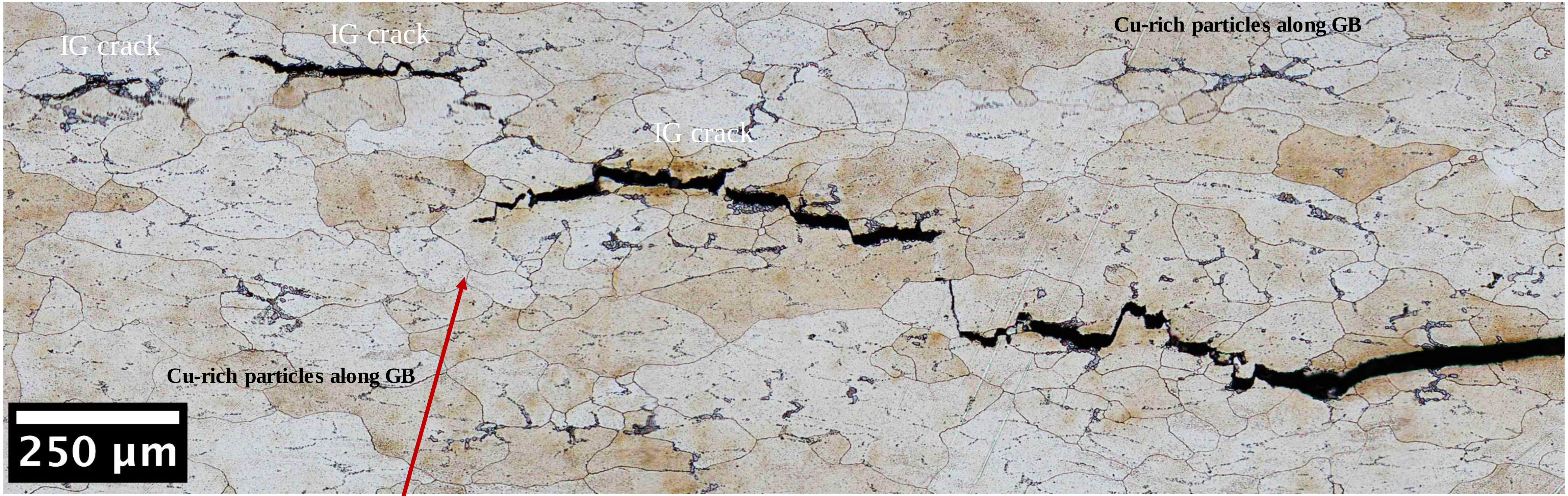
Long subsurface cracks ⊥
to the tensile direction

Signs of brittle fracture

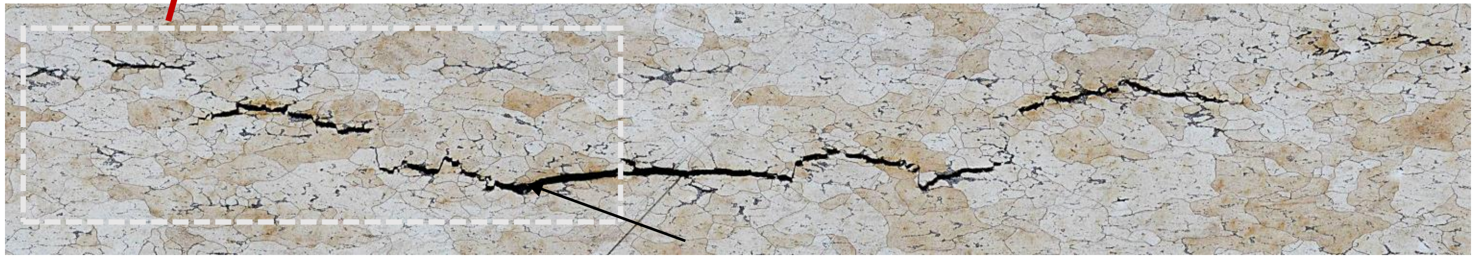


Cross-up View of Subsurface Cracks - 723C-6 LN_2 – 1.25%

Predominant intergranular fracture mode



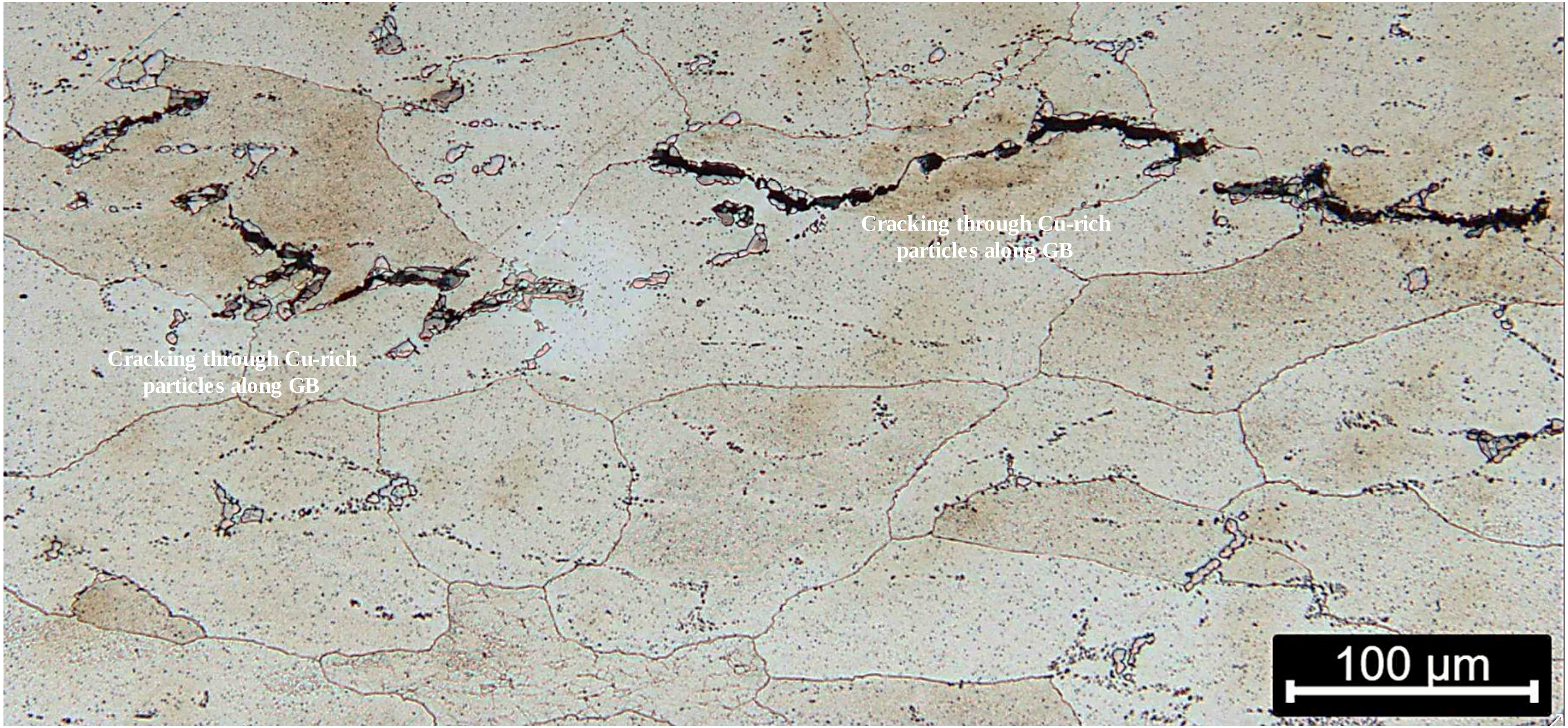
Cracking through GB and Cu-rich particles



Long subsurface cracks ⊥ to the tensile direction

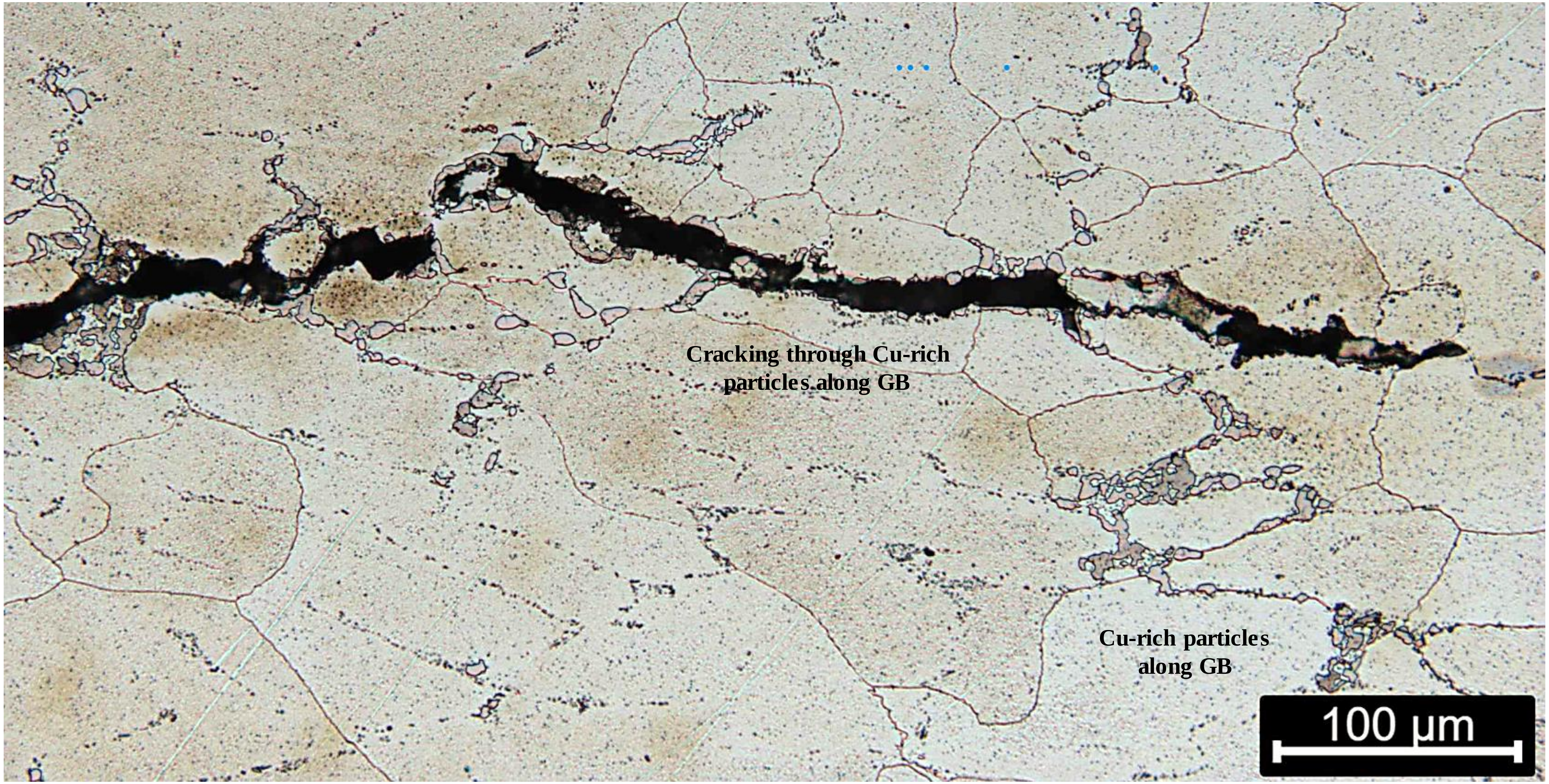
Cross-up View of Subsurface Cracks - 723C-6 LN_2 – 1.25%

Predominant intergranular fracture mode



Cross-up View of Subsurface Cracks - 723C-6 LN_2 – 1.25%

Predominant intergranular fracture mode



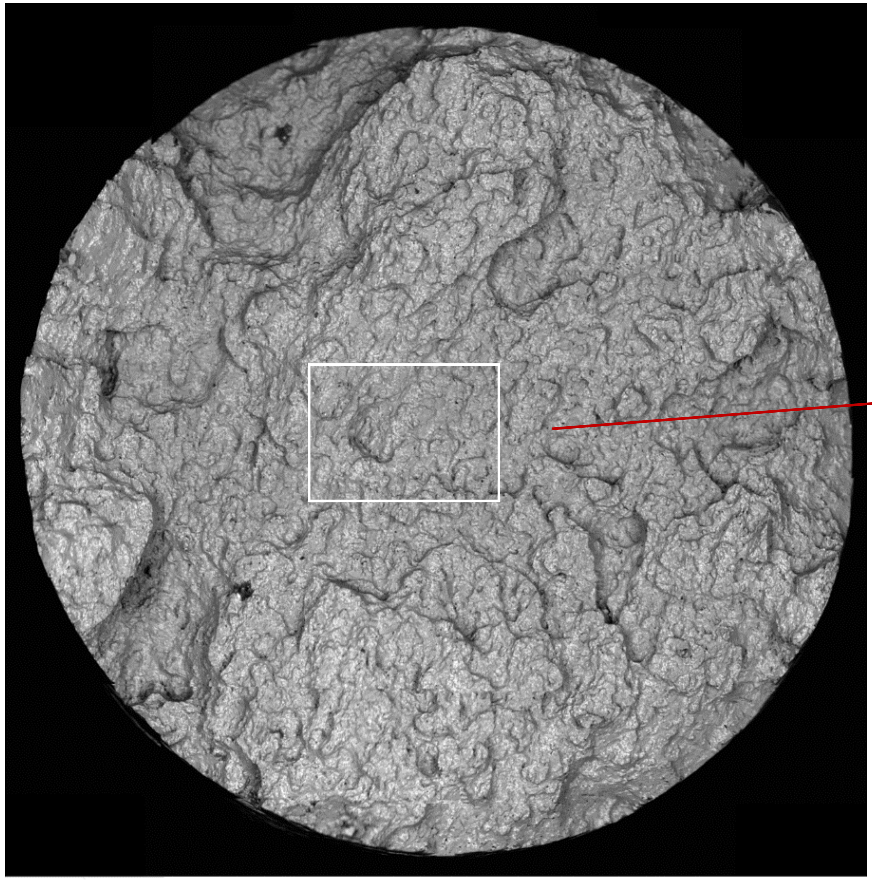
SEM/X-ray Map Results - Charts 20 - 31

SEM lead: Ellen Rabenberg

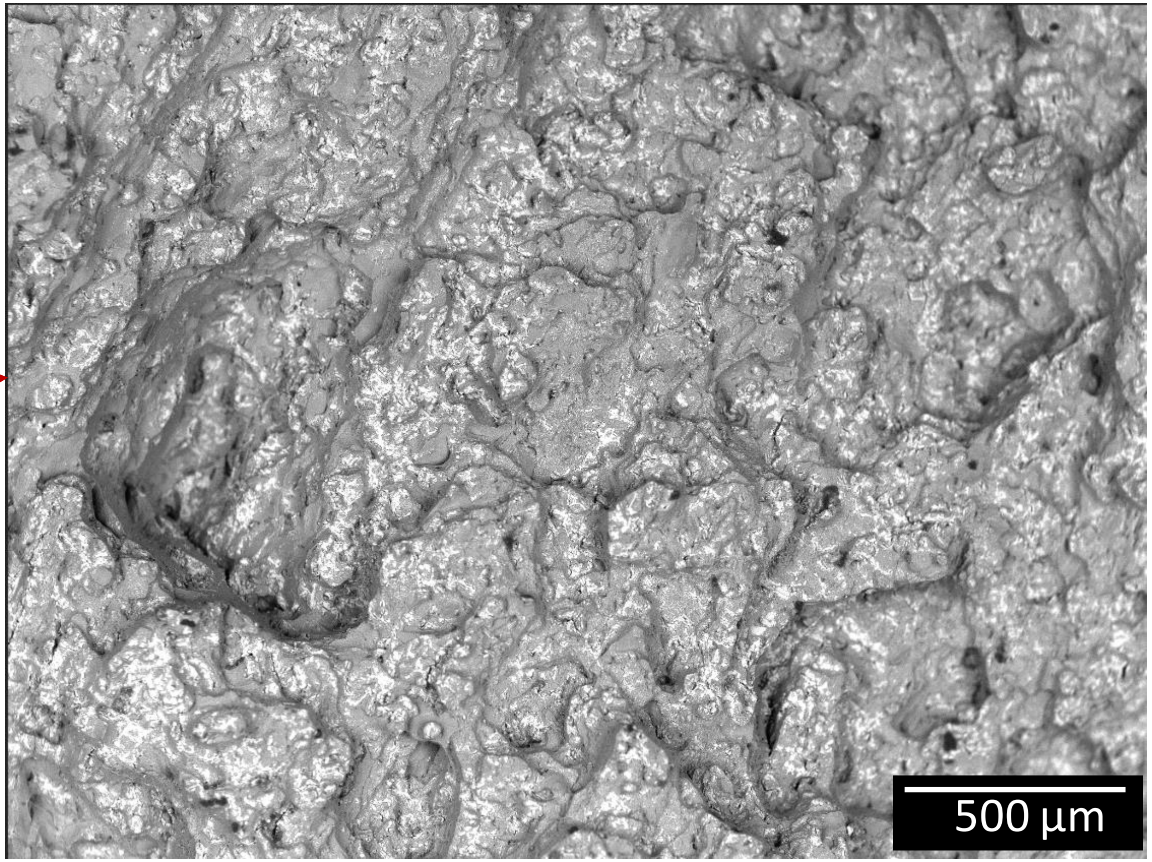
SEM Fractography of Sample 720-2

720-2 LN2 – 7.23%

White particles are Cu-rich precipitates



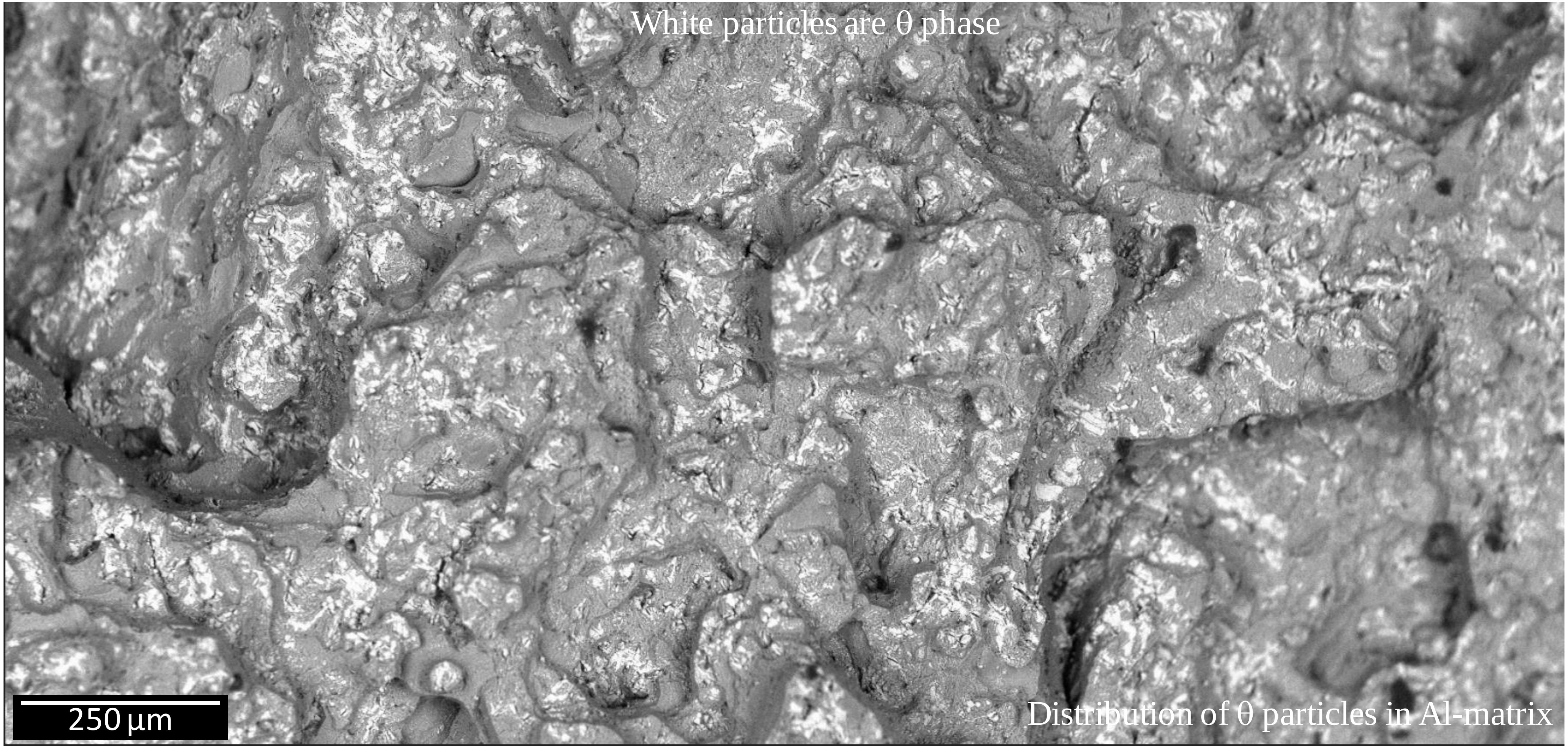
SEM image – entire fracture surface



Distribution of Cu-rich particles in Al-matrix

Cu-rich particles are finer and have more uniform distribution

SEM Fractography of Sample 720-2, LN2 – 7.23%

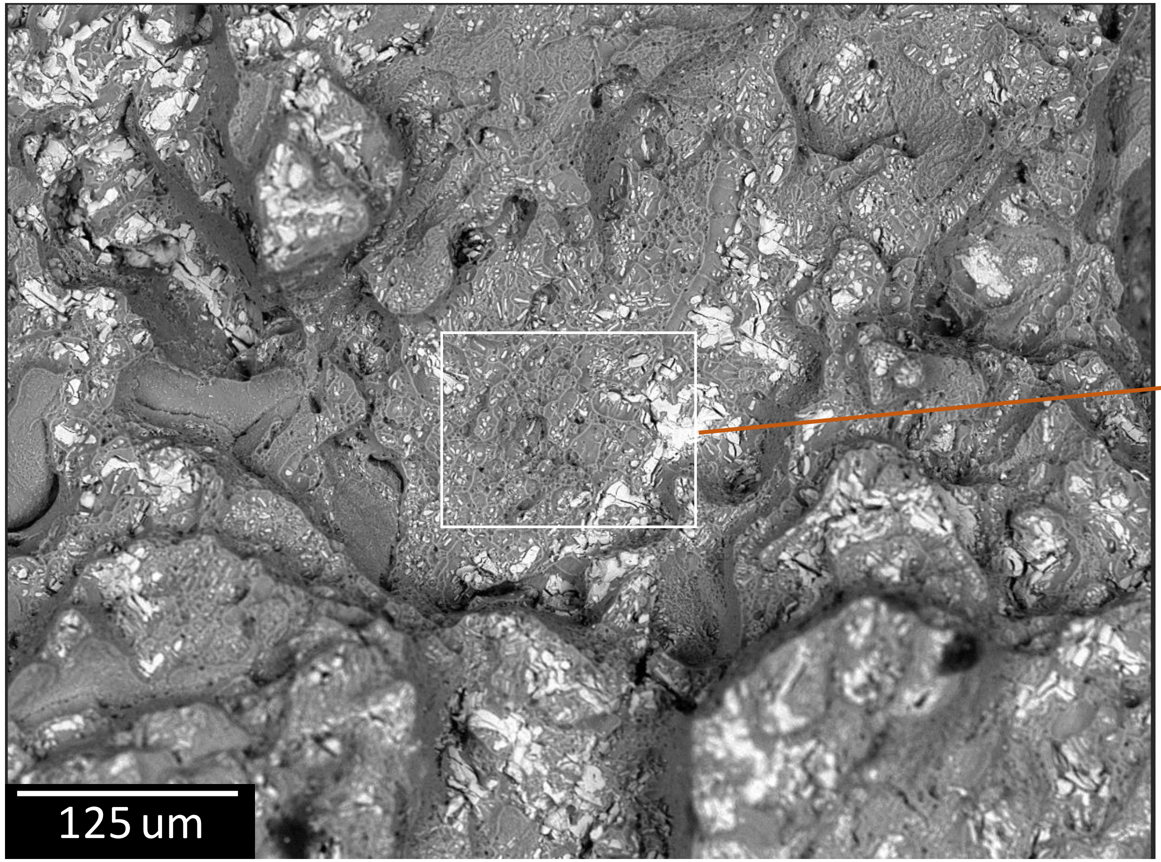


Cu-rich particles have more uniform distribution

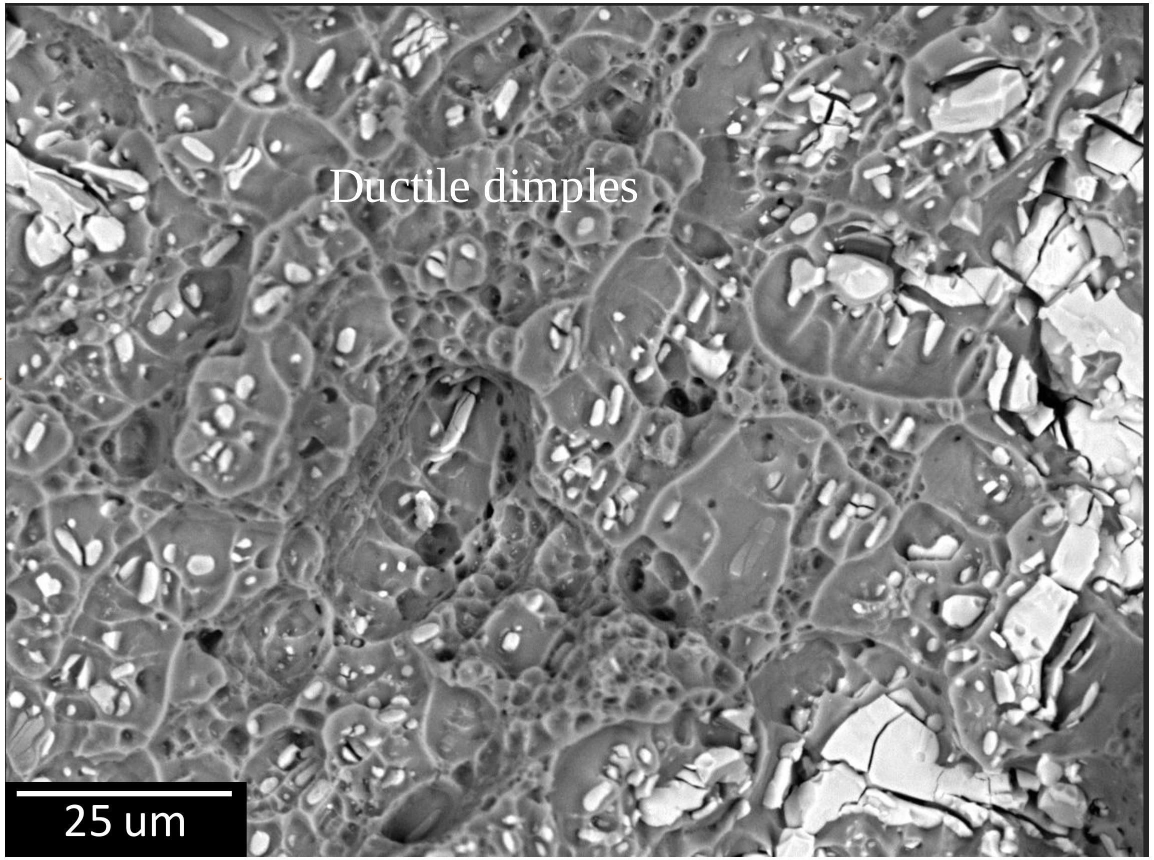
SEM Fractography of Sample 720-2

720-2 LN2 – 7.23%

White particles are Cu-rich precipitates



Distribution of Cu-rich particles in AL-matrix

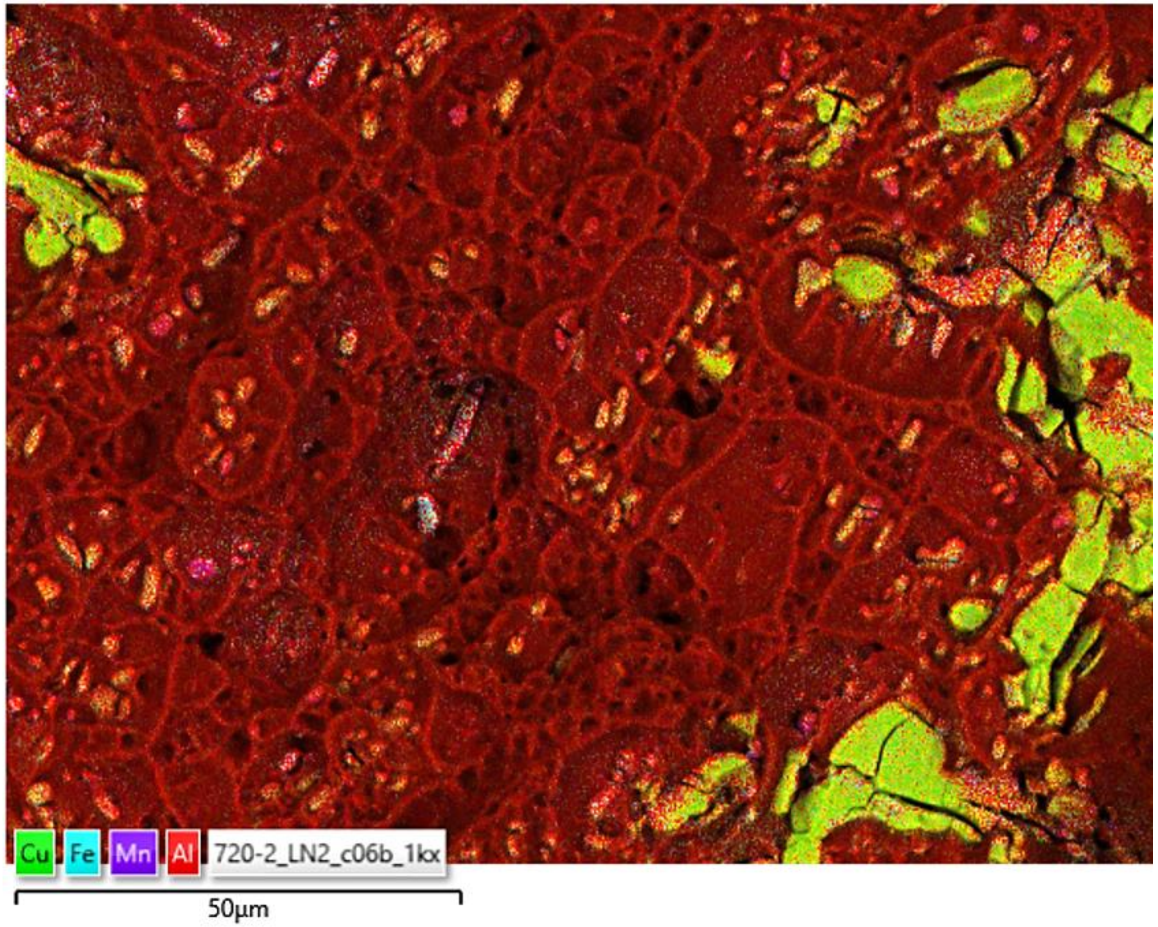


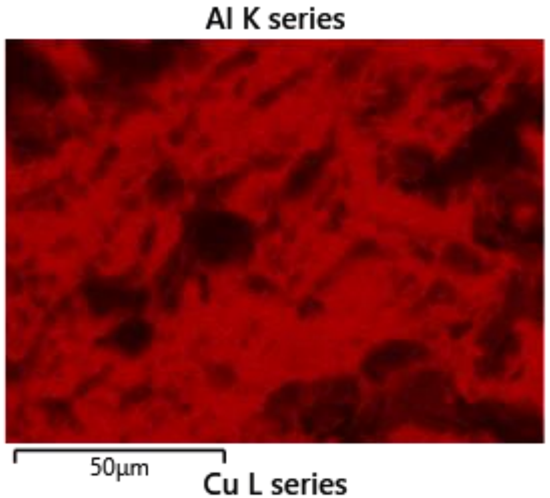
Most Cu-rich particles are in dimples

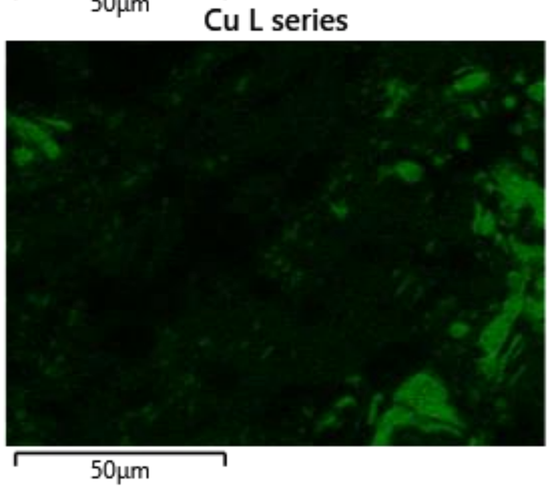
1. Cu-rich particles are finer and have more uniform distribution, signs of ductile fracture
2. Fine Cu-rich particles are in the middle of dimples, indicative of higher ductility

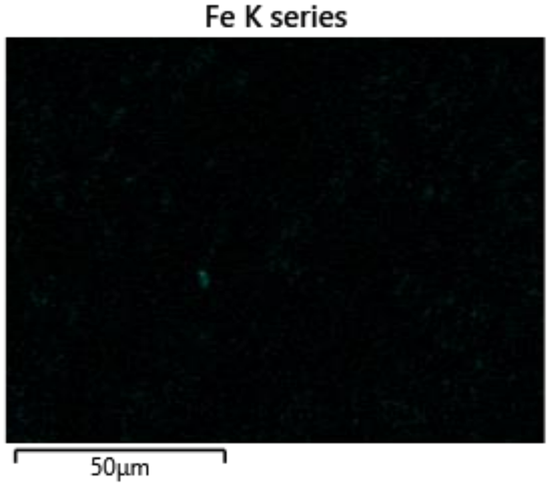
SEM/X-ray Map for Sample 720-2

720-2 LN2 – 7.23%





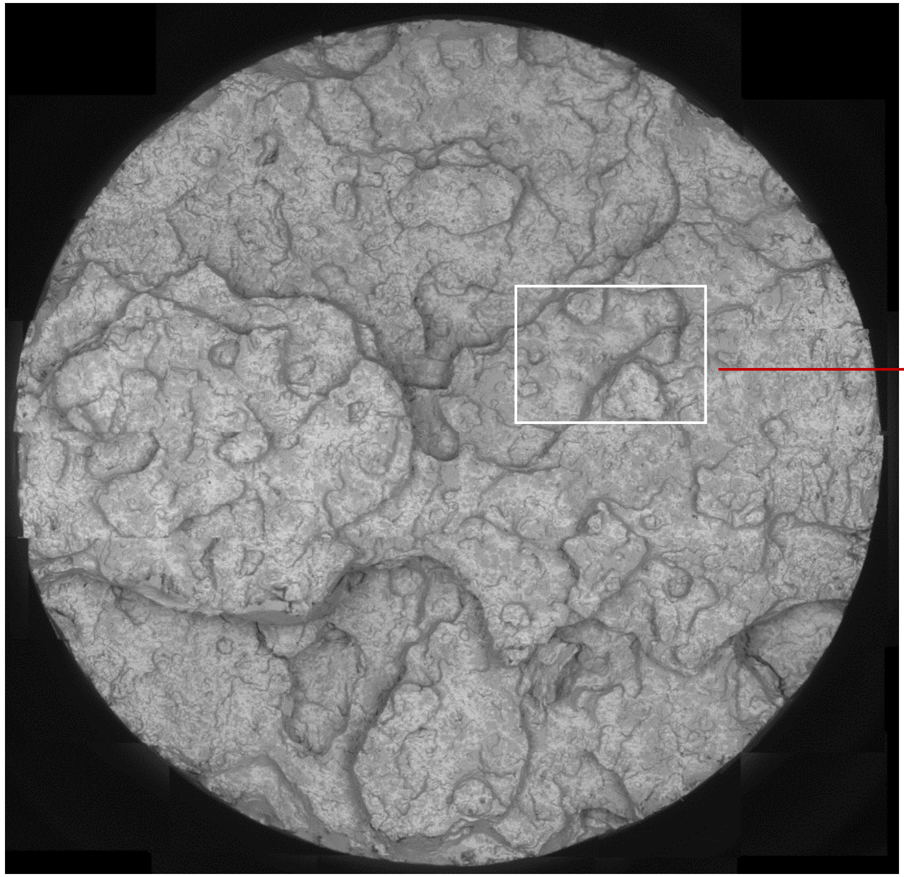




EDS confirms the white particles in SEM image (green color on x-ray map) are Cu-rich

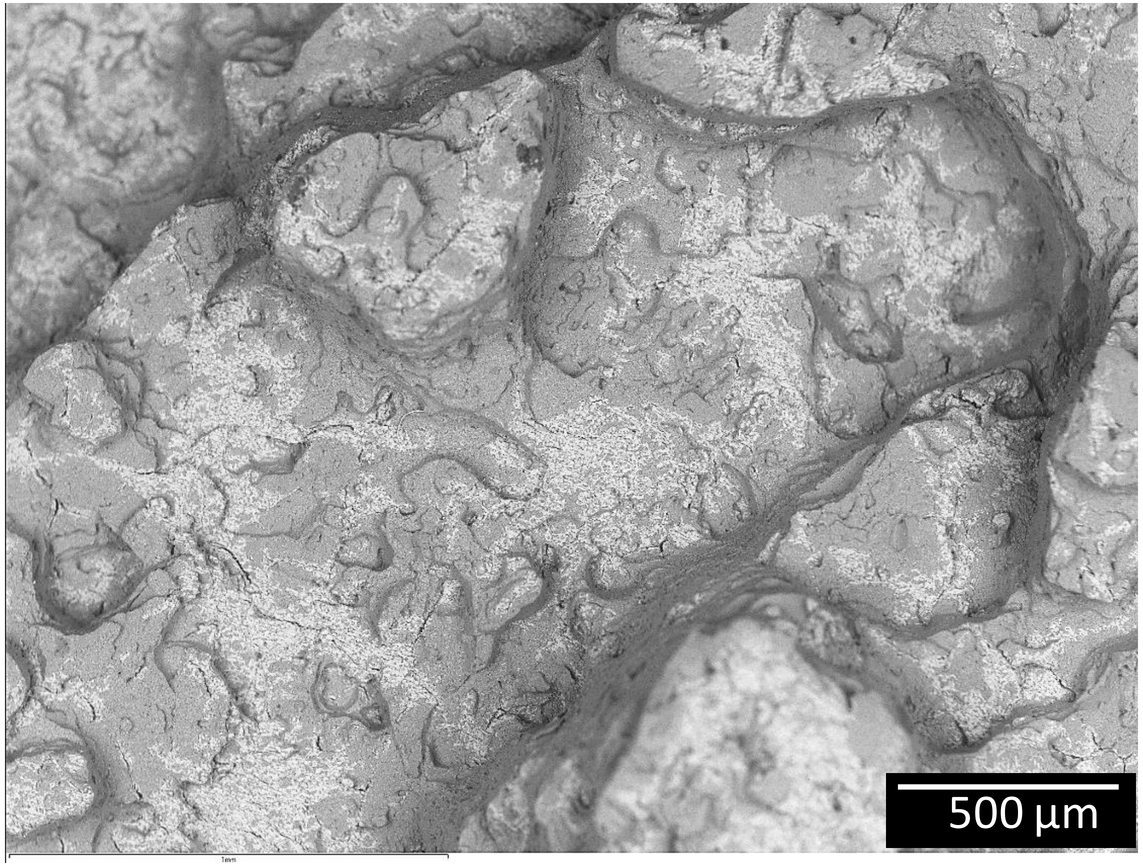
SEM Fractography of Sample 722C-5

722C-5 LN2 – 1.00%



SEM image – entire fracture surface

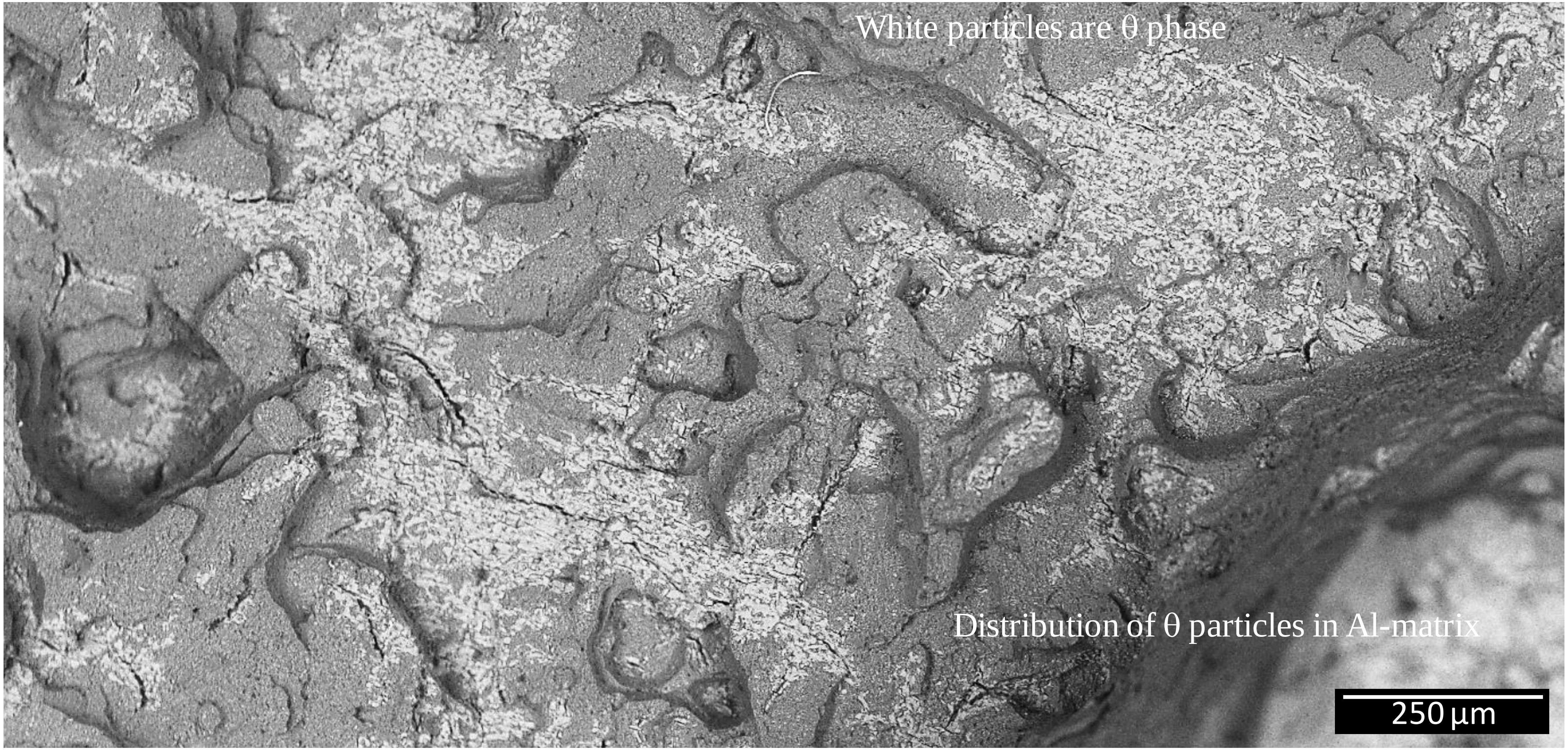
White particles are Cu-rich precipitates



Distribution of Cu-rich particles in AL-matrix

Cu-rich particles are coarser and have non-uniform distribution

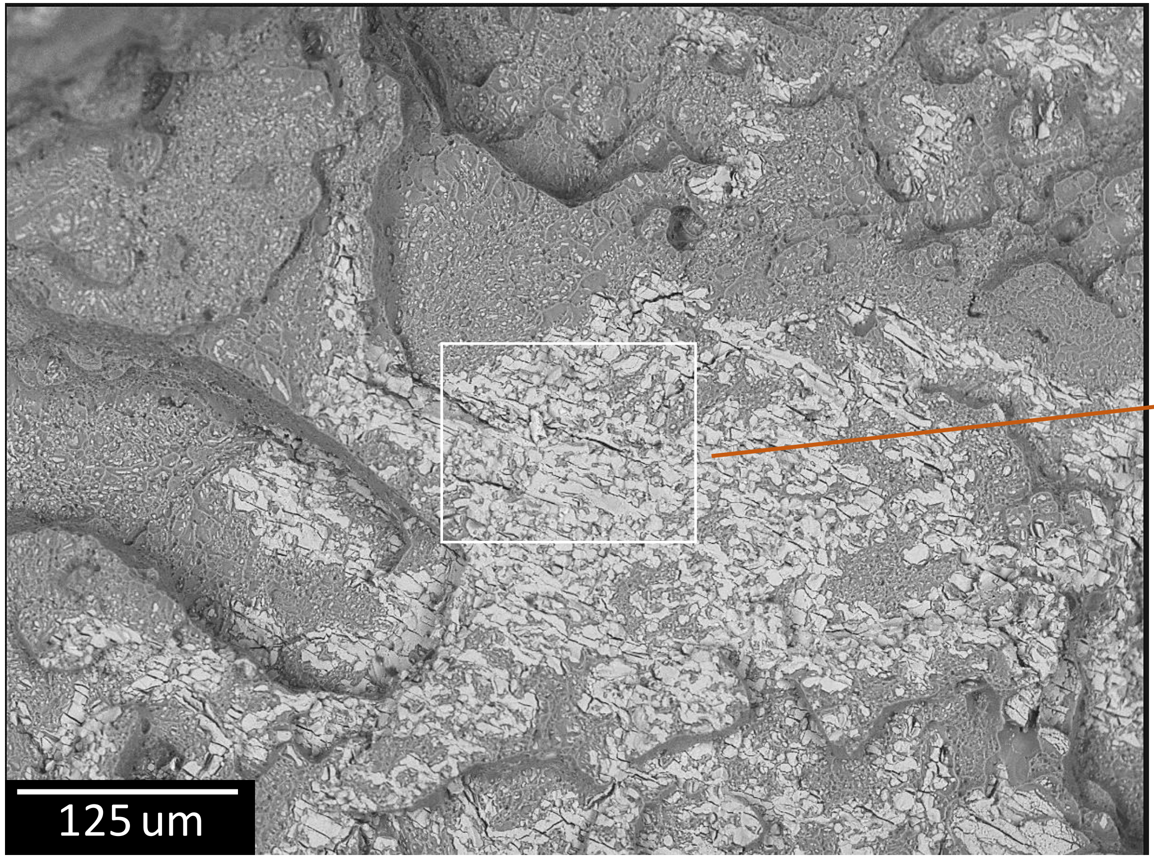
SEM Fractography of Sample 722C-5 LN2 – 1.00%



Cu-rich particles have non-uniform distribution

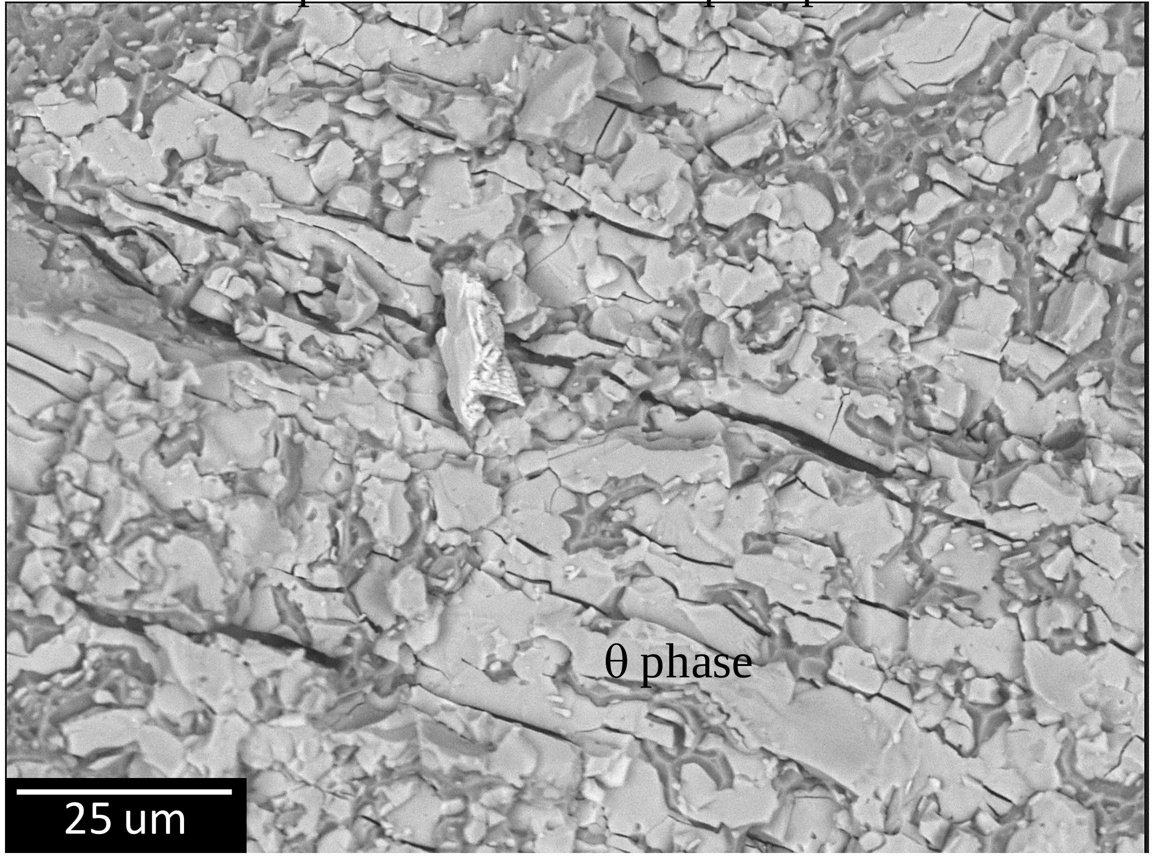
SEM Fractography of Sample 722C-5

722C-5 LN2 – 1.00%



Clusters of Cu-rich particles with micro-cracks

White particles are Cu-rich precipitates

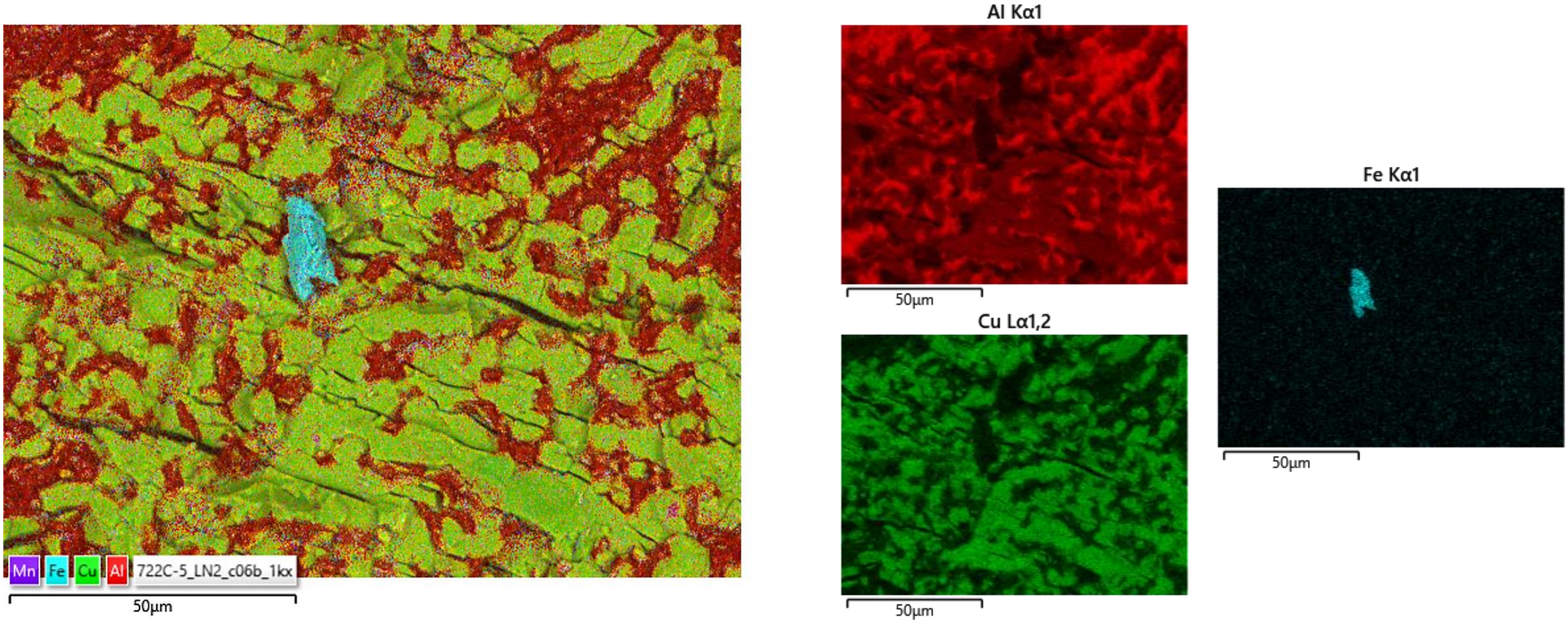


Cracking along or through Cu-rich particles

1. Cu-rich particles are coarser and have a tendency to aggregate together
2. Cu-rich particles are hard and brittle, acting as stress risers during tensile deformation
3. Many micro-cracks are present in the regions that have numerous Cu-rich particles

SEM/X-ray Map for Sample 722C-5

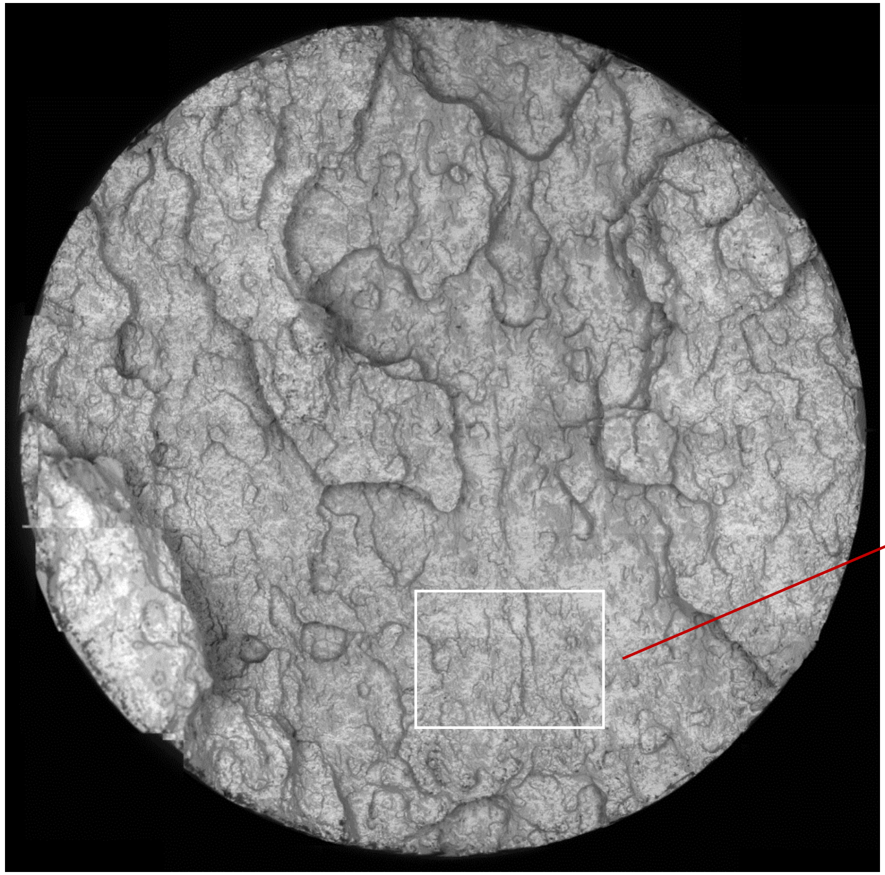
722C-5 LN2 – 1.00%



EDS confirms the white particles in SEM image (green color on x-ray map) are Cu-rich

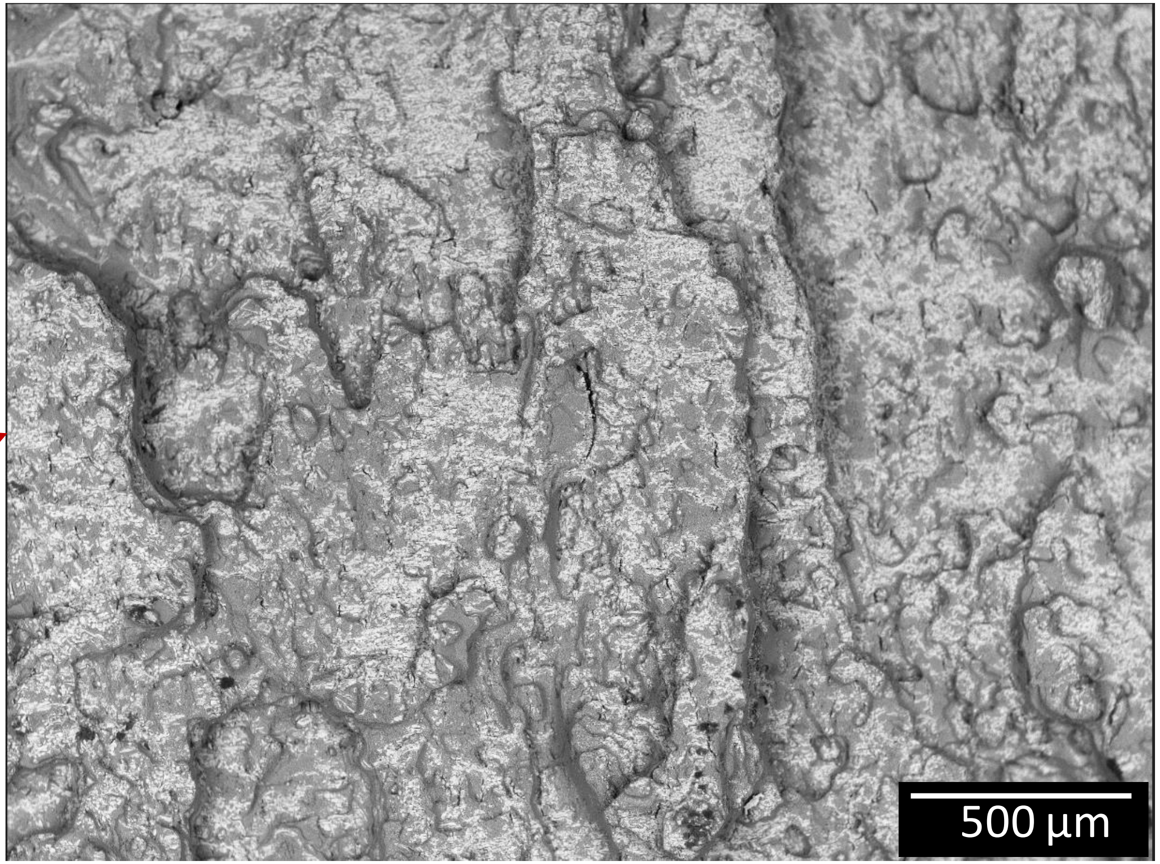
SEM Fractography of Sample 723C-6

723C-6 LN2 – 1.25%



SEM image – entire fracture surface

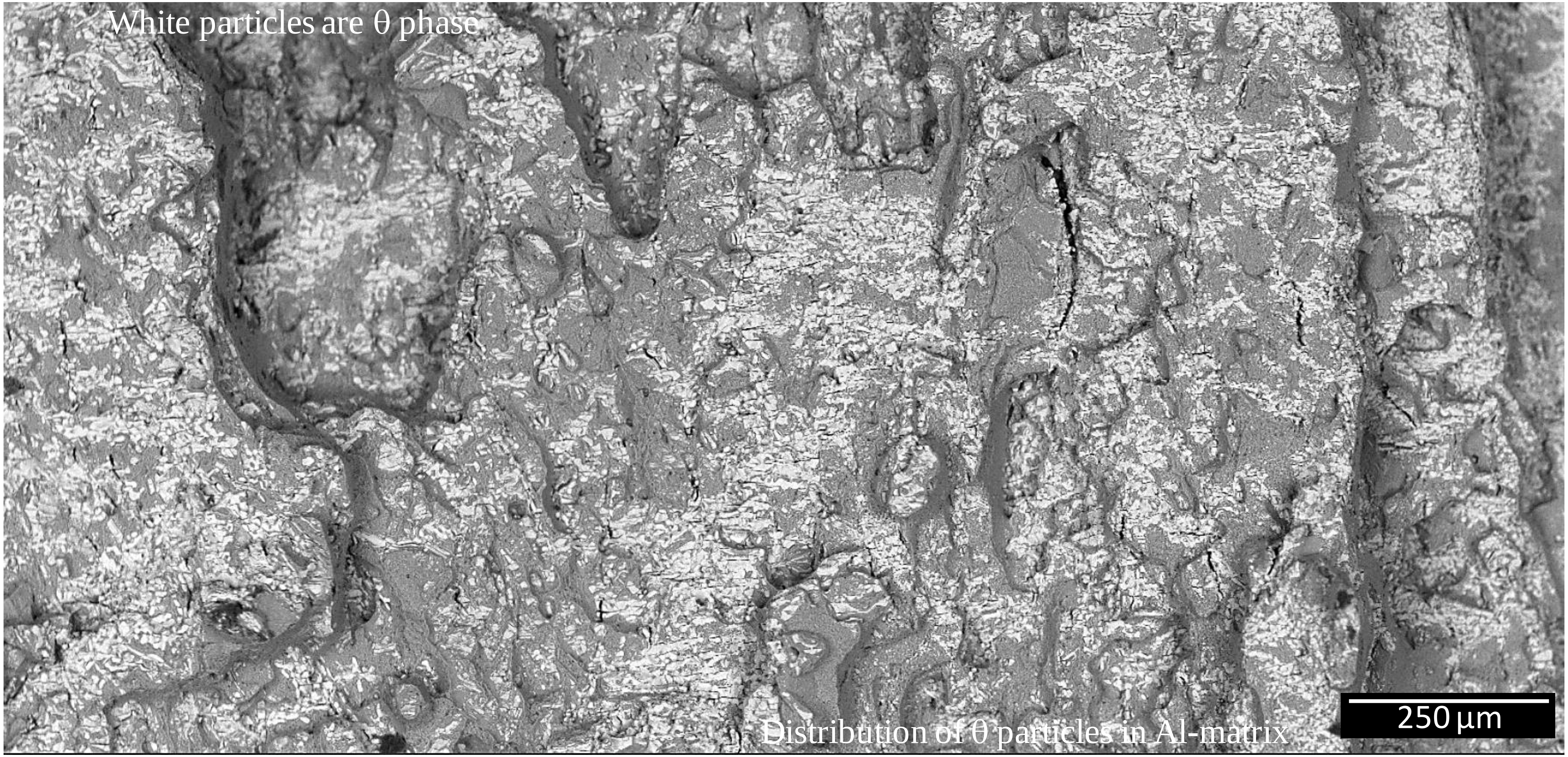
White particles are Cu-rich precipitates



Distribution of Cu-rich particles in AL-matrix

Cu-rich particles are coarser and have non-uniform distribution

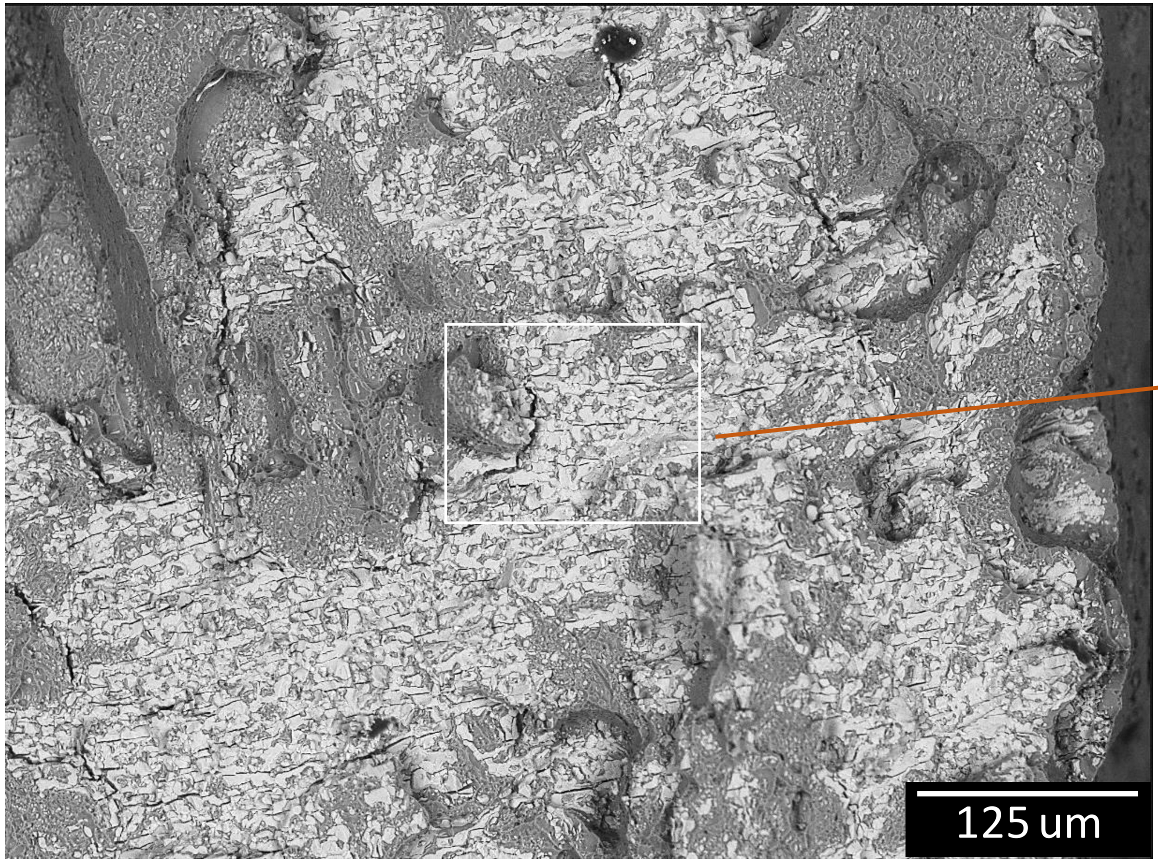
SEM Fractography of Sample 723C-6 LN2 – 1.25%



Density of Cu-rich particles is unusually high in this region

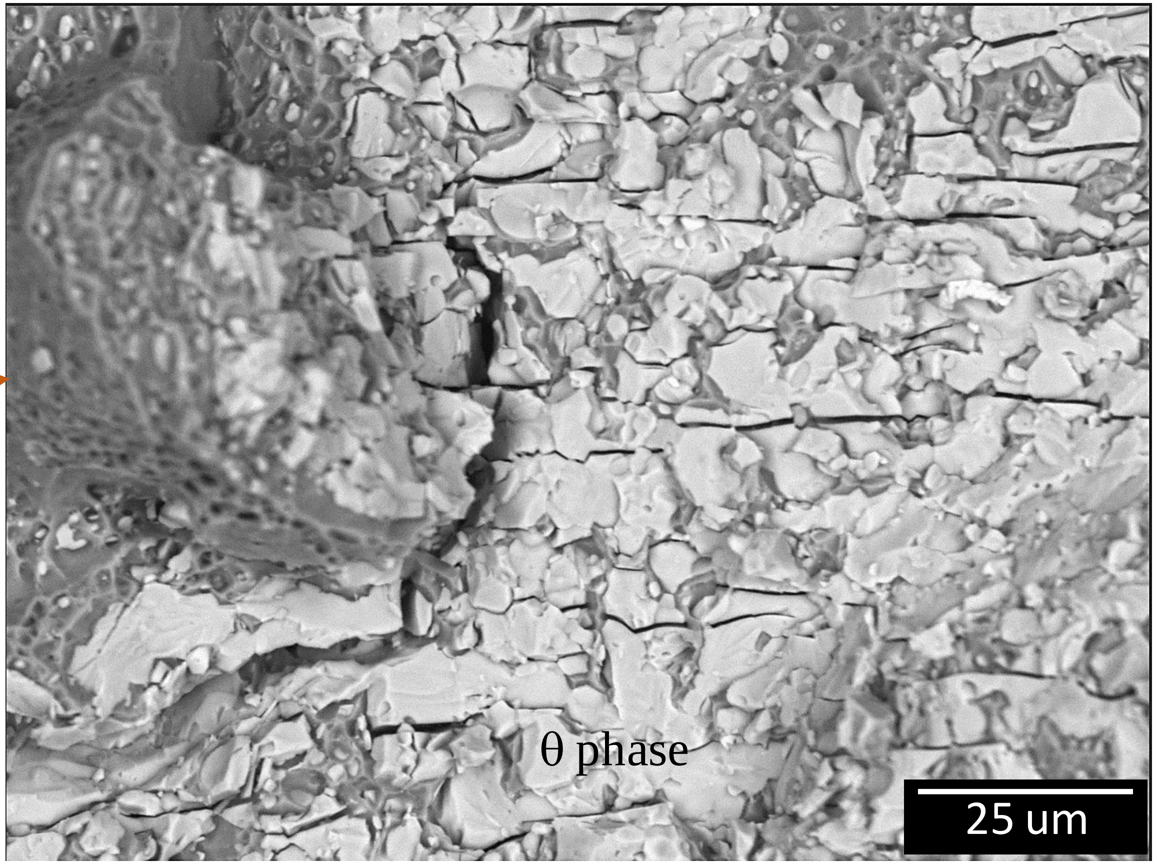
SEM Fractography of Sample 723C-6

723C-6 LN2 – 1.25%



Clusters of Cu-rich particles with micro-cracks

White particles are Cu-rich precipitates

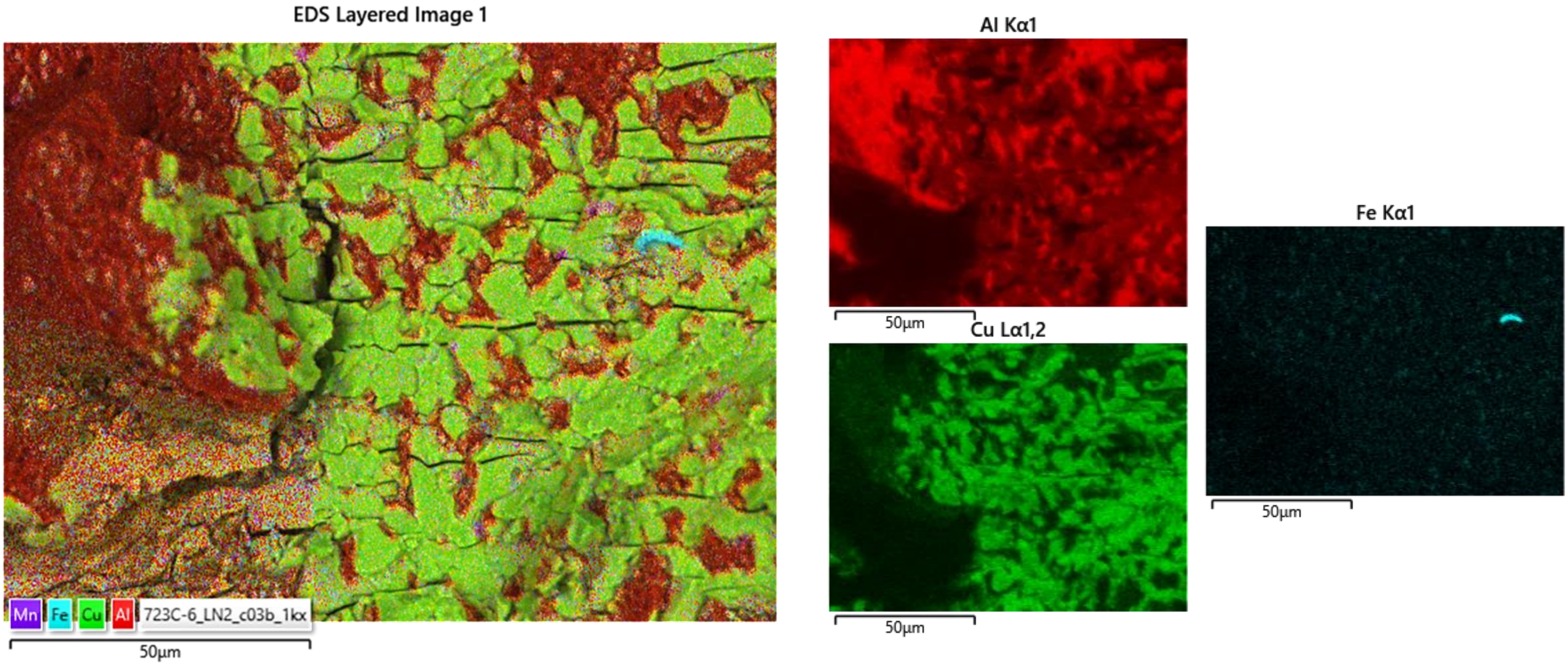


Cracking along or through Cu-rich particles

1. Cu-rich particles are coarser and have a tendency to aggregate together
2. Cu-rich particles are hard and brittle, acting as stress risers during tensile deformation
3. Many micro-cracks are present in the regions that have numerous Cu-rich particles

SEM/X-ray Map for Sample 723C-6

723C-6 LN2 – 1.25%



EDS confirms the white particles in SEM image (green color on x-ray map) are Cu-rich

Summary of Key Findings

The high ductility sample (9492854-720-2, LN2) has the following microstructural features:

- Higher degree of recrystallization, smaller grain size,
- Transgranular fracture, lower area fraction of coarse particles (qualitative analysis)
- Lower electricity conductivity that can be attributed smaller Cu-rich particles and smaller spacing between them

The low ductility samples (930071-720C-5, 930082-723C-6 LN2) has the following microstructural features:

- Lower degree of recrystallization, distinct signs of prior dendritic structure, large grain size
- Intergranular fracture, higher area fraction of coarse particles (qualitative analysis)
- Higher electricity conductivity that can be attributed larger Cu-rich particles and wider spacing between them

The drastic reduction in tensile ductility can be attributed to the following factors:

- The presence of numerous coarse Cu-rich particles (Al_2Cu, θ phase) at grain boundaries
- They are stress risers and will increase K_t during tensile testing and promote crack initiation
- The greater the number of coarse Cu-rich particles, the easier for micro-cracks to connect
- Many connected micro-cracks lead to larger cracks and a drastic reduction in tensile fracture elongation