Characterization of Alloys 690 to 52-Type Welds, Weld Interfaces, and Base Metal Microstructures

NRC-Industry 2011 Meeting on Alloy 690 Research

June 6-7, 2011

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imagination at work

Background

- First measurements made of residual plastic strains in Alloy 690 base metal welded to Alloys 52 or 152 showed very low residual plastic strains, at or near those of the as-received base metals.
- This was in contrast to stainless steel base metals welded with Alloys 52 or 152 where the highest residual plastic strains were measured in the fine grain base metal.
- Detailed measurements of the chemical and microstructural interfaces between Alloy 690 and Alloy 52 show that the highest residual plastic strains occur in the Unmixed Zone (UMZ) / Partially Melted Zone (PMZ) of the chemically identified Alloy 690.

Background

- **Multiple microstructural and factors determine the magnitude and location of weld residual strains.**

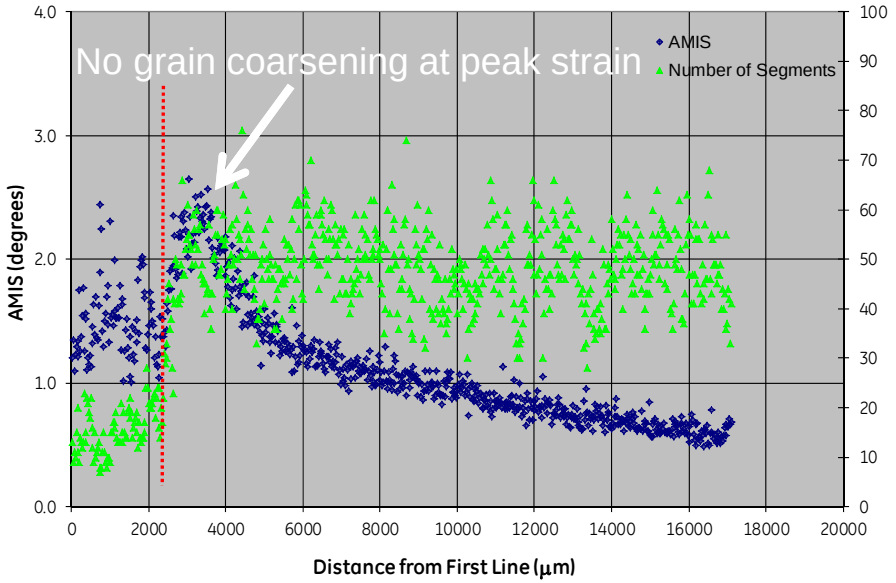
- **Microstructure: Starting grain size, residual strains in base metal, carbide precipitation, etc. influence yield strength which determine the location of highest residual plastic strain in base metals at the weld interface.**

Background

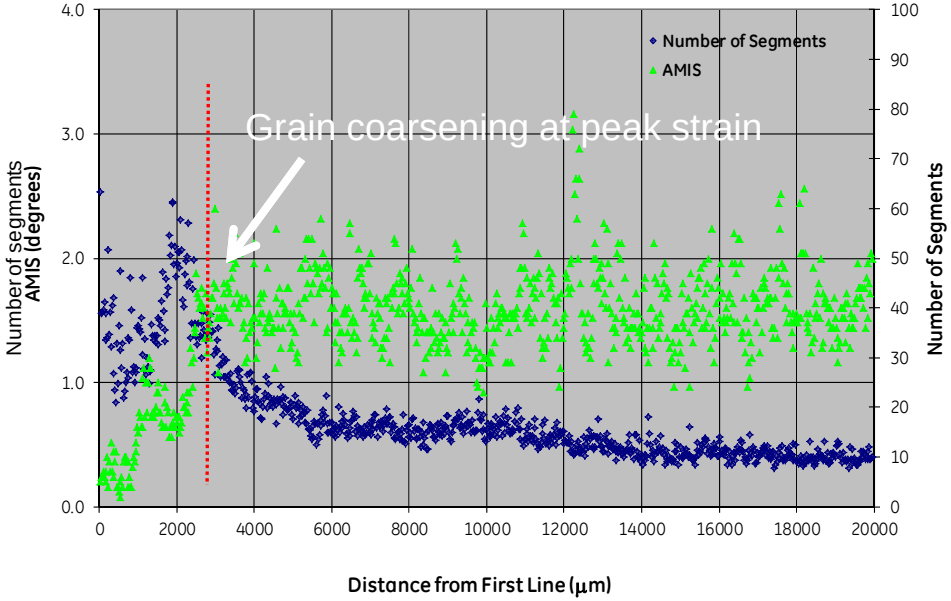
Peak Residual Plastic Strains

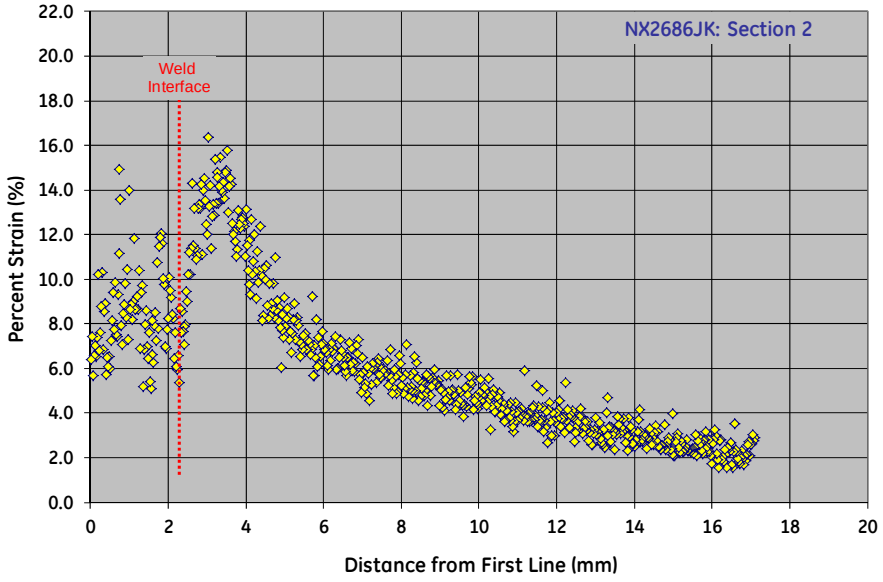
Stainless Steel versus Alloy 690

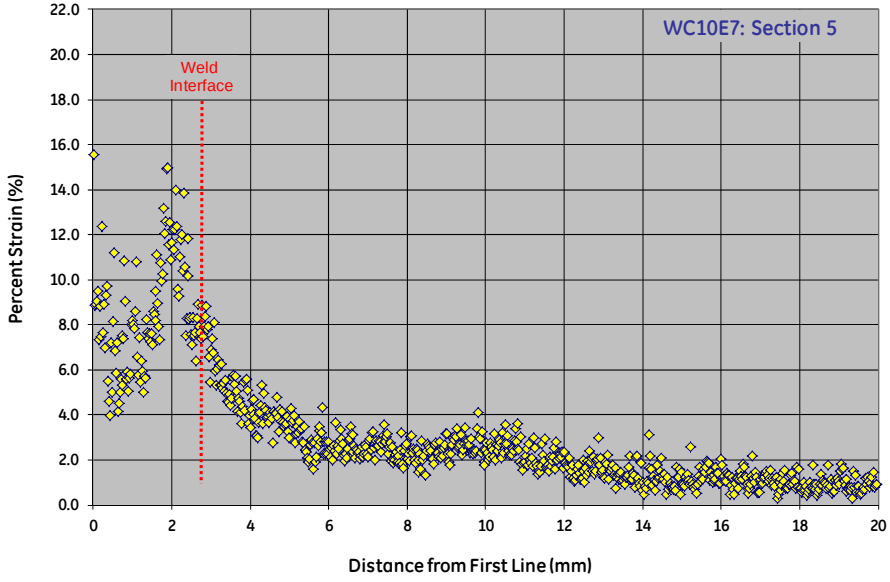
304 SS to Alloy 152 Weld Interface



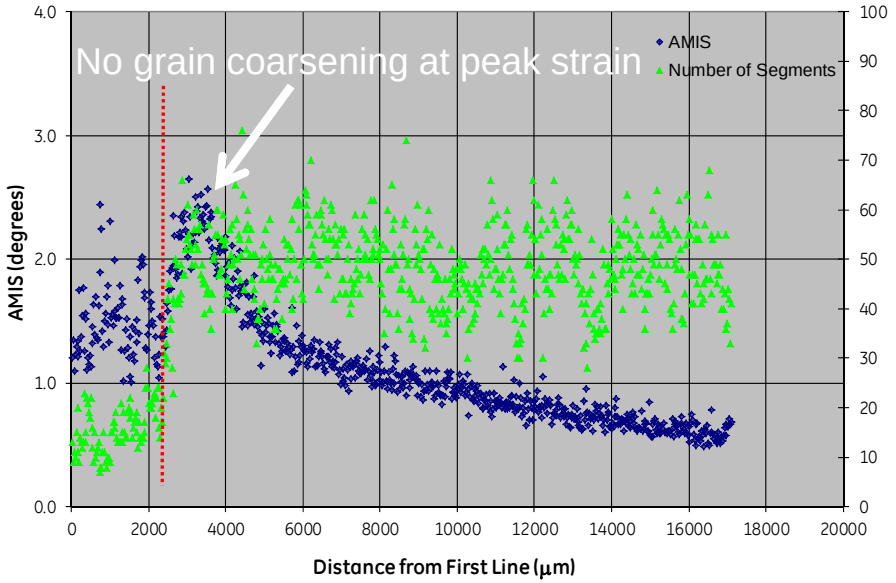
Alloy 690 to Alloy 152 Weld Interface



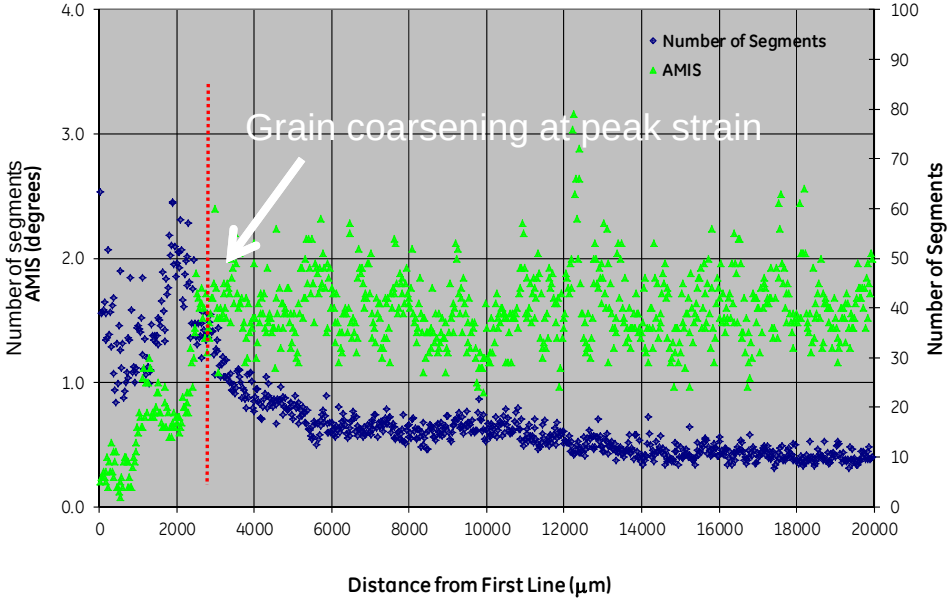


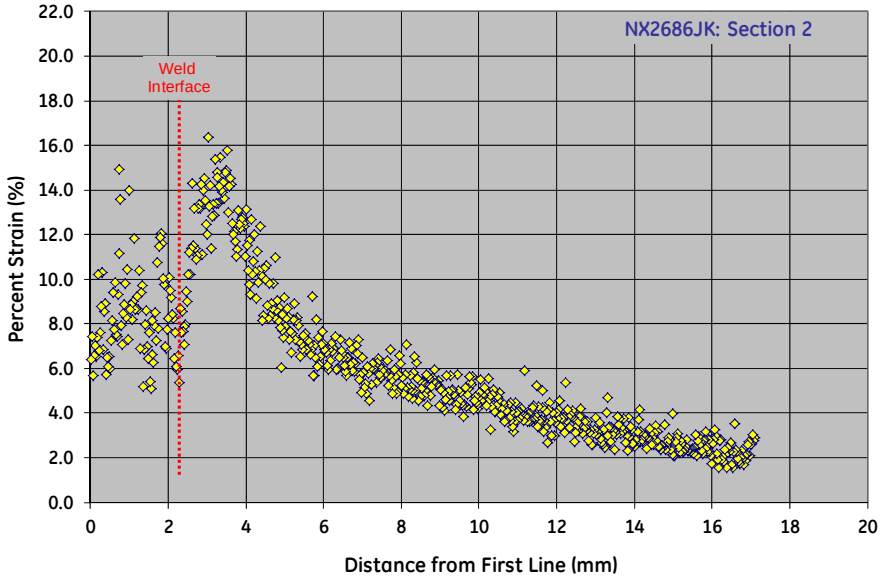


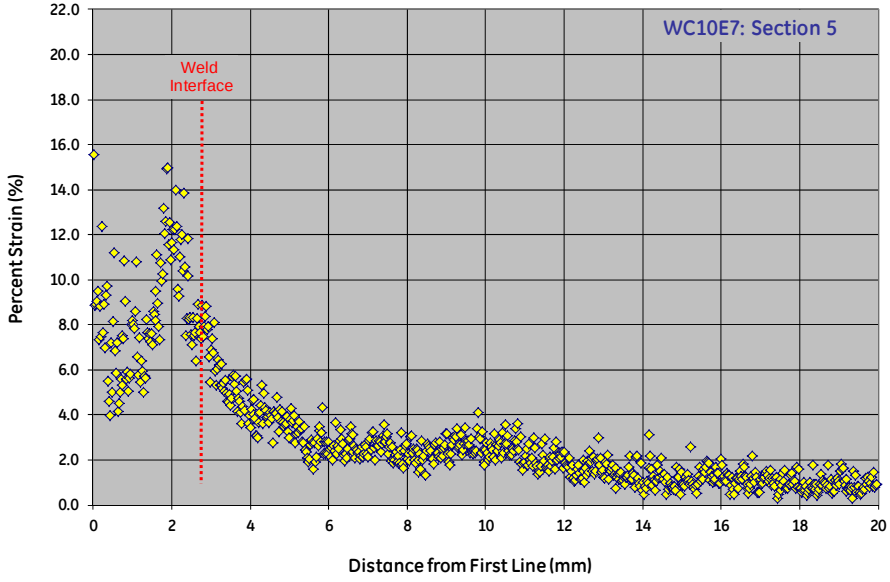
304 SS to Alloy 152 Weld Interface



Alloy 690 to Alloy 152 Weld Interface







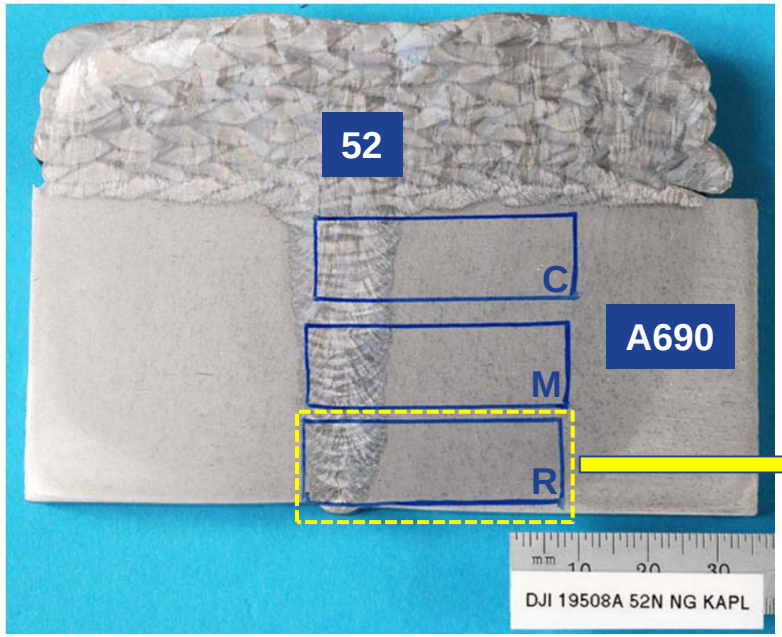
Background

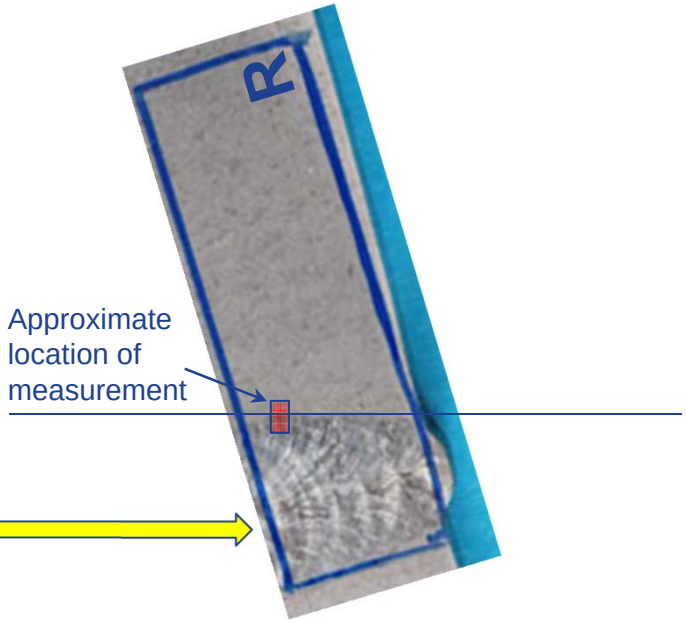
Microstructure Basis for Interface

Alloy 52-A690 Weld Interface Microstructure Versus EPMA Comparison

19508A 52M Narrow Groove Weld

Alloy 52 to Alloy 690 weld DJI 19508A 52M NG - Root (Location 3) Setup

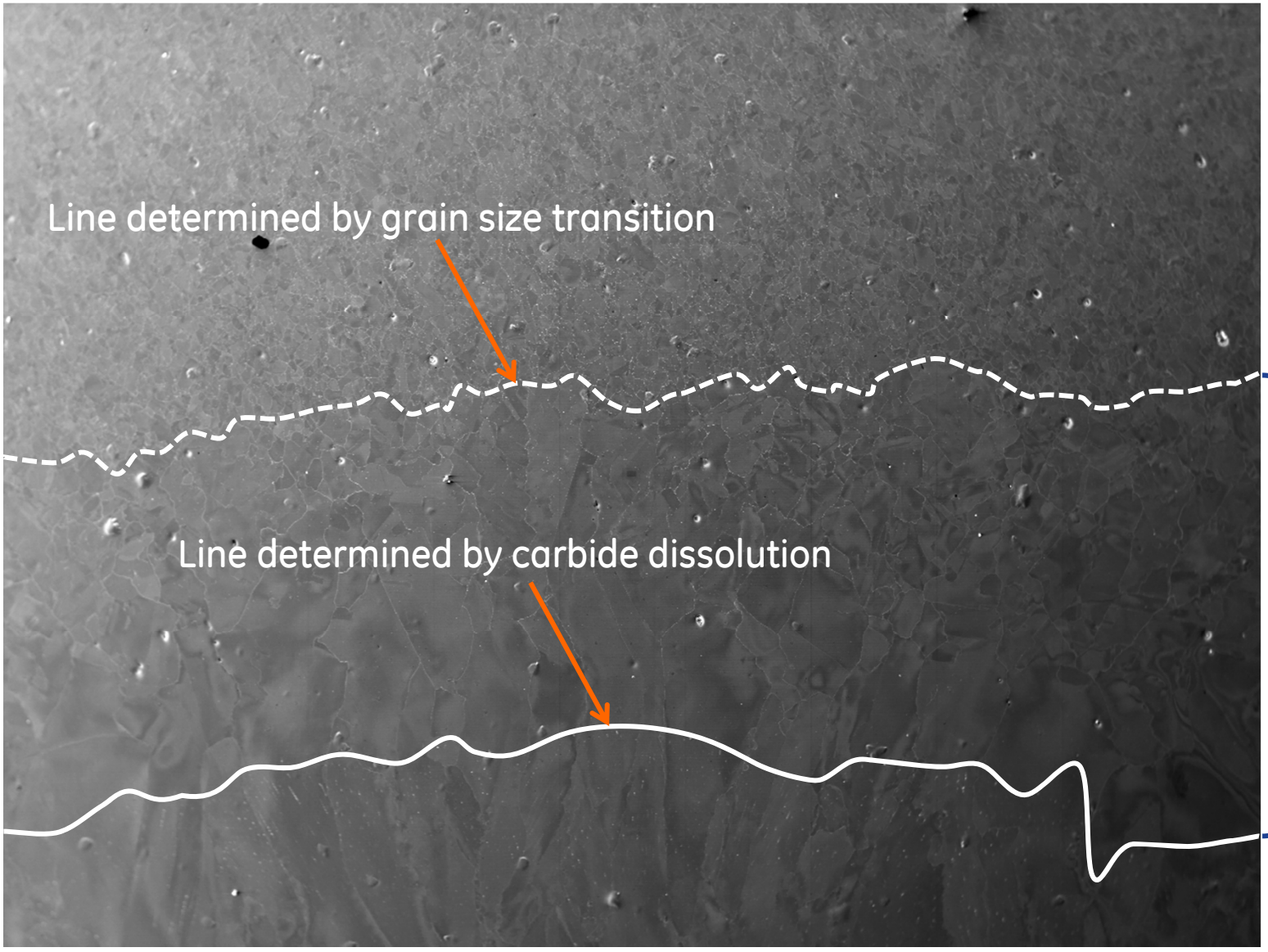




The section was rotated in an effort to have a horizontal Weld/PMZ+UMZ interface.
(The resulting plastic strain data will have better representation from each individual region this way.)

Microstructural Basis for Alloy 690 PMZ at Interface

SE Image: 50x



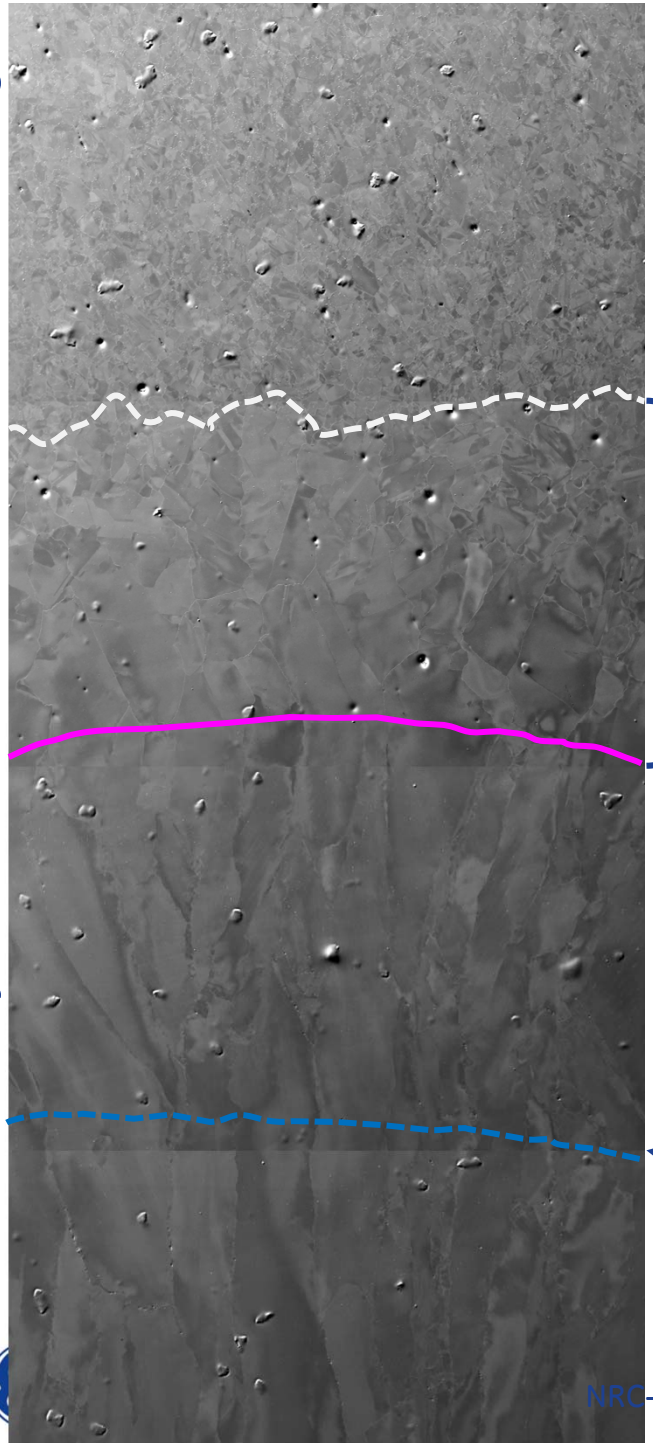
Approximation of PMZ is based on the following:

- Carbides precipitated along the dendrites cores (according to EPMA data, this is an indication of the transition to the PMZ from the weld)
- Grain size change (transition from PMZ to base material)

Approximate region of the PMZ based on dissolution of carbides.

SE Image

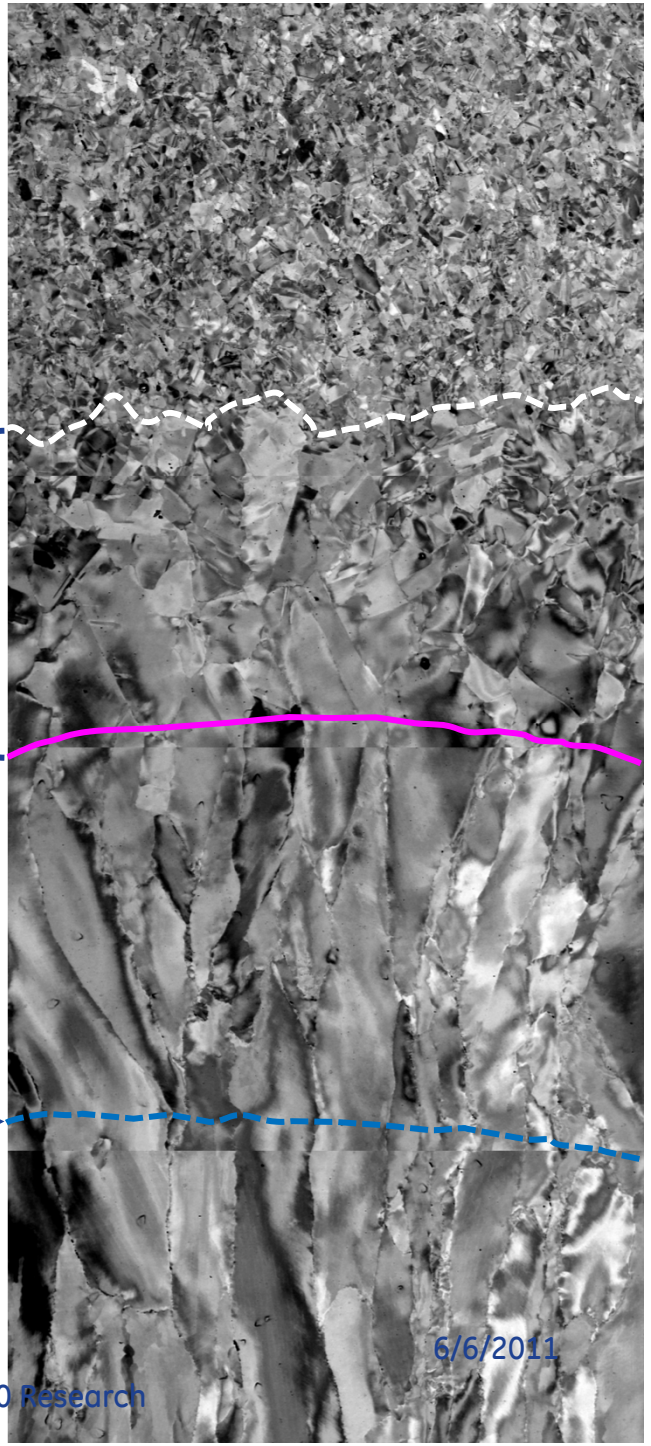
Area Measured by EBSD



PMZ+UMZ. (Purple line confirmed by EPMA data.)

The dotted blue line represents the end of the 1st pass weld dilution zone. (Confirmed by EPMA data.)

— 100 μm

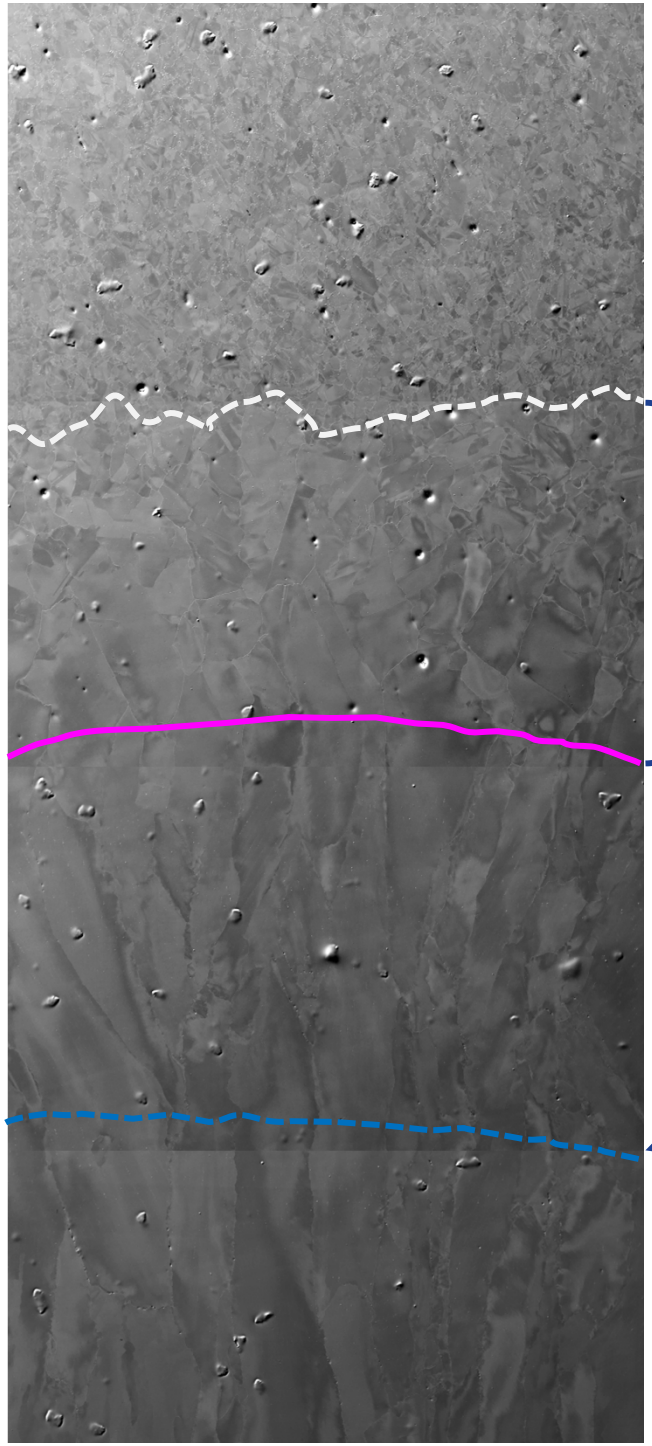


Area Measured by EBSD

BSE Image

SE Image

Area Measured by EBSD

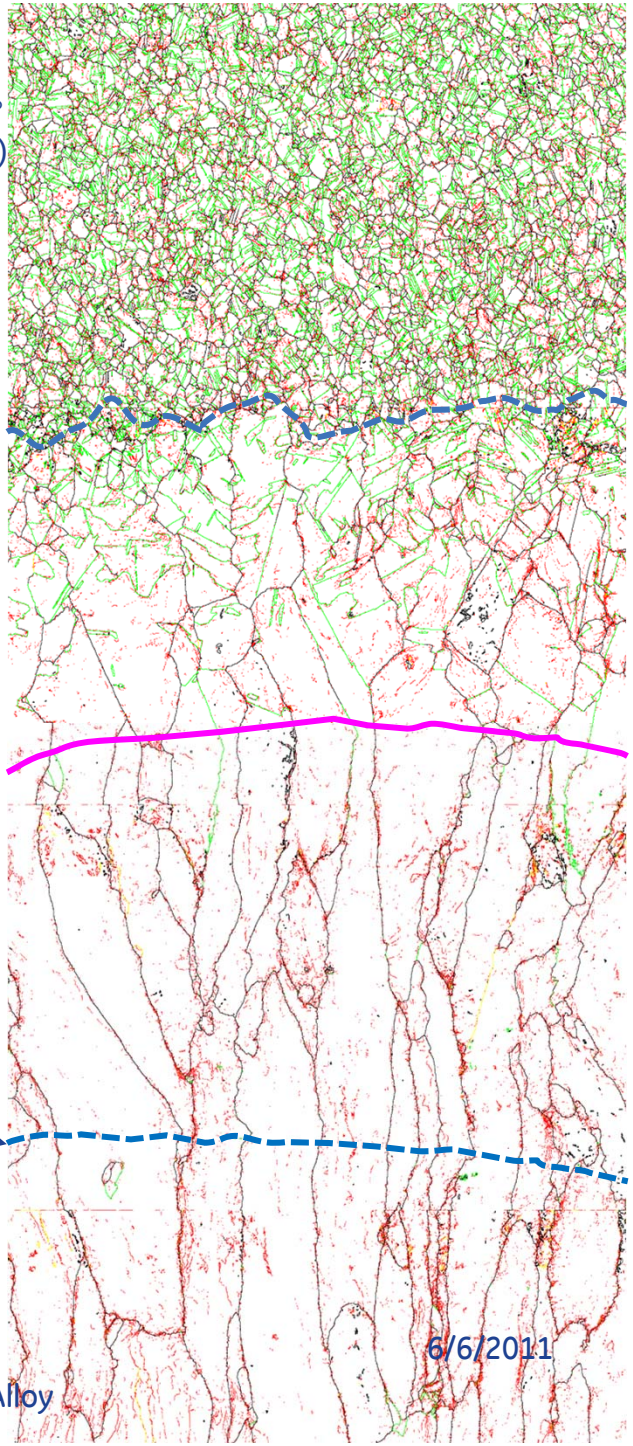


Region of the PMZ+UMZ. (Purple line confirmed by EPMA data.)

The dotted blue line represents the end of the 1st weld pass dilution zone. (Confirmed by EPMA data.)

— 100 μm

Red = 1.5°<θ<3°
Yellow = 3°<θ<10°
Black = 10°<θ<60°
Green = Twin (60°)

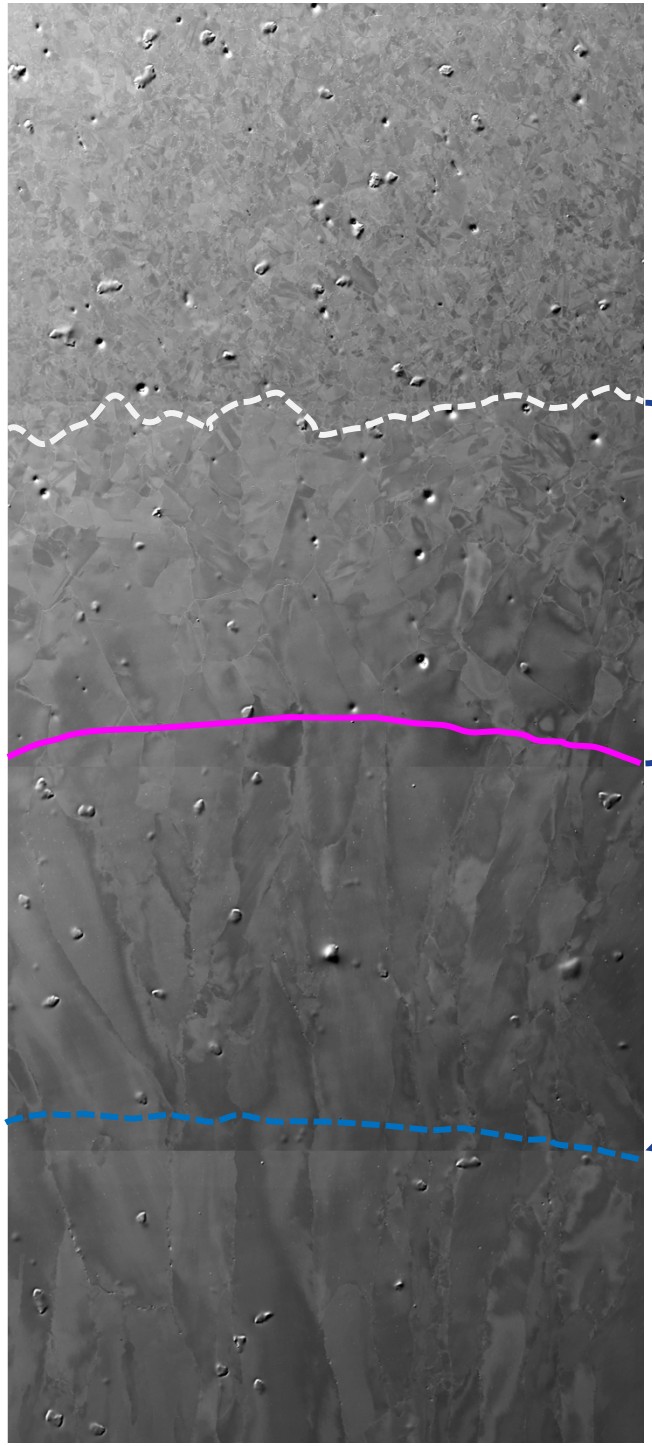


Area Measured by EBSD

Boundary Map

SE Image

Area Measured by EBSD



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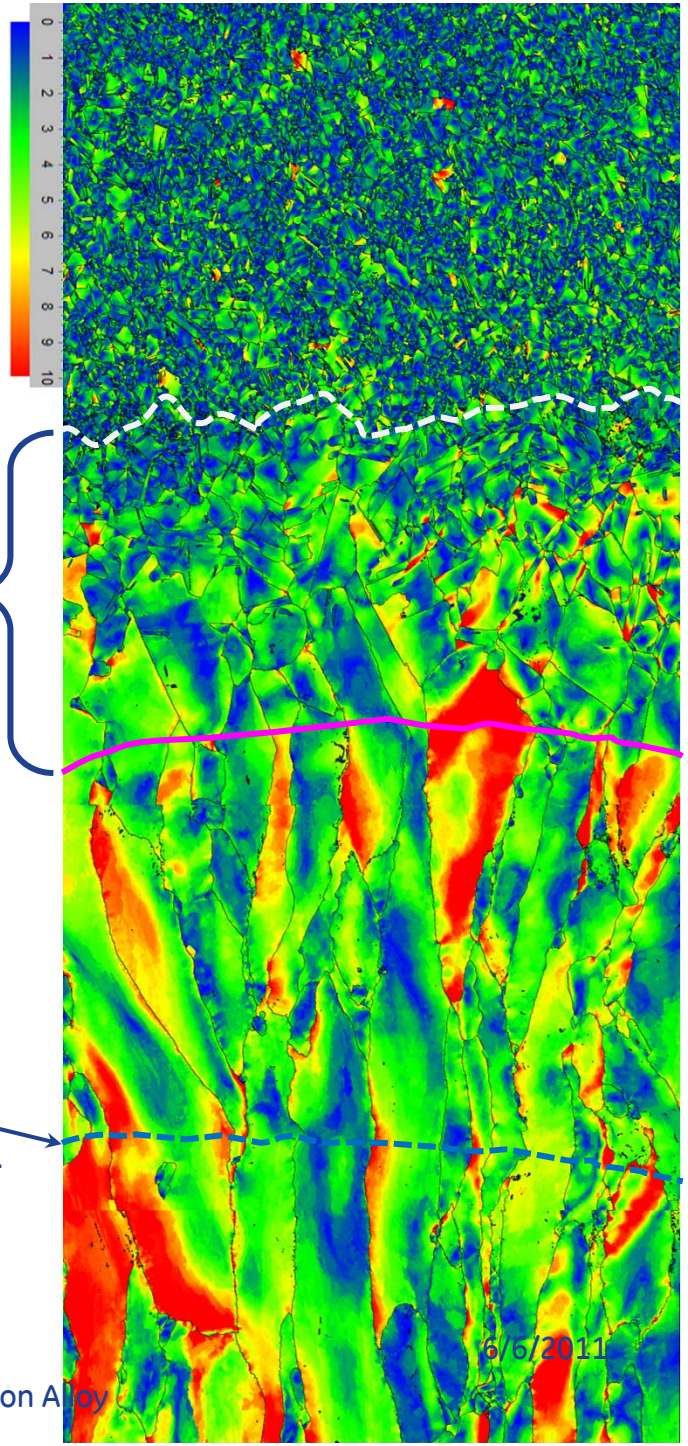
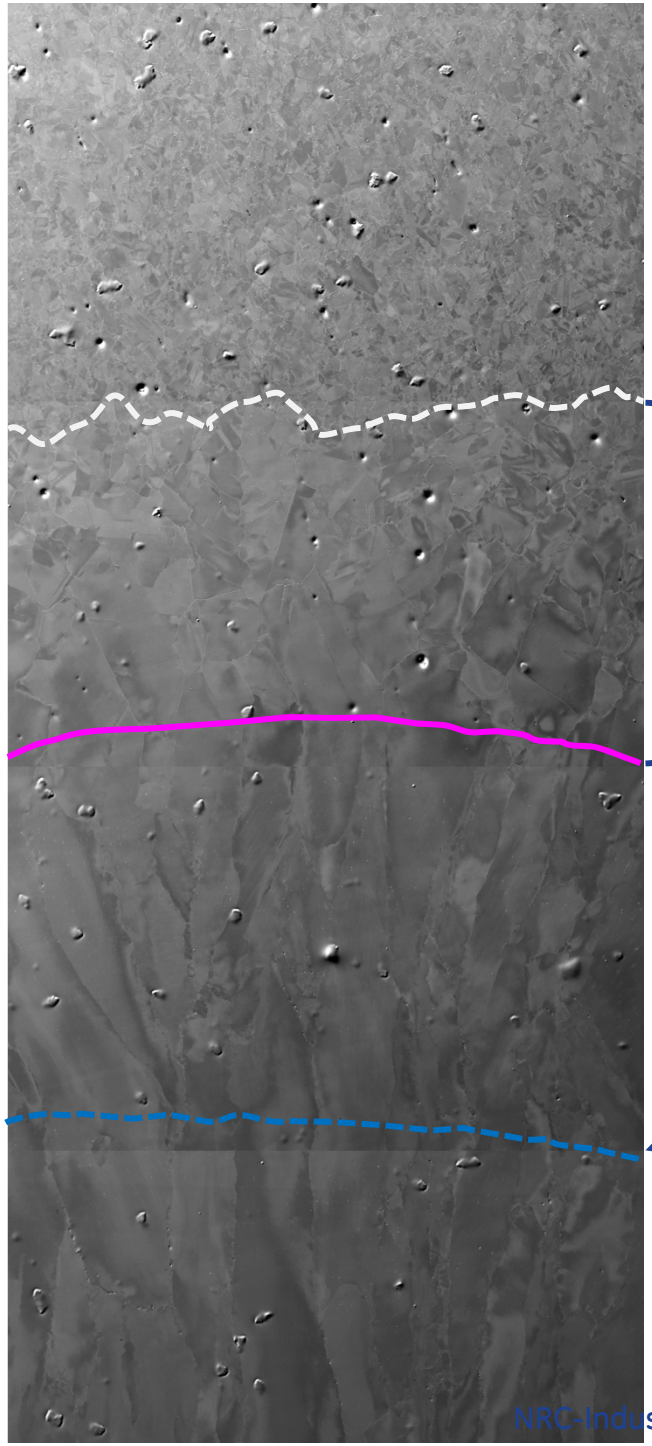


Area Measured by EBSD

10° Misorientation Map

SE Image

Area Measured by EBSD



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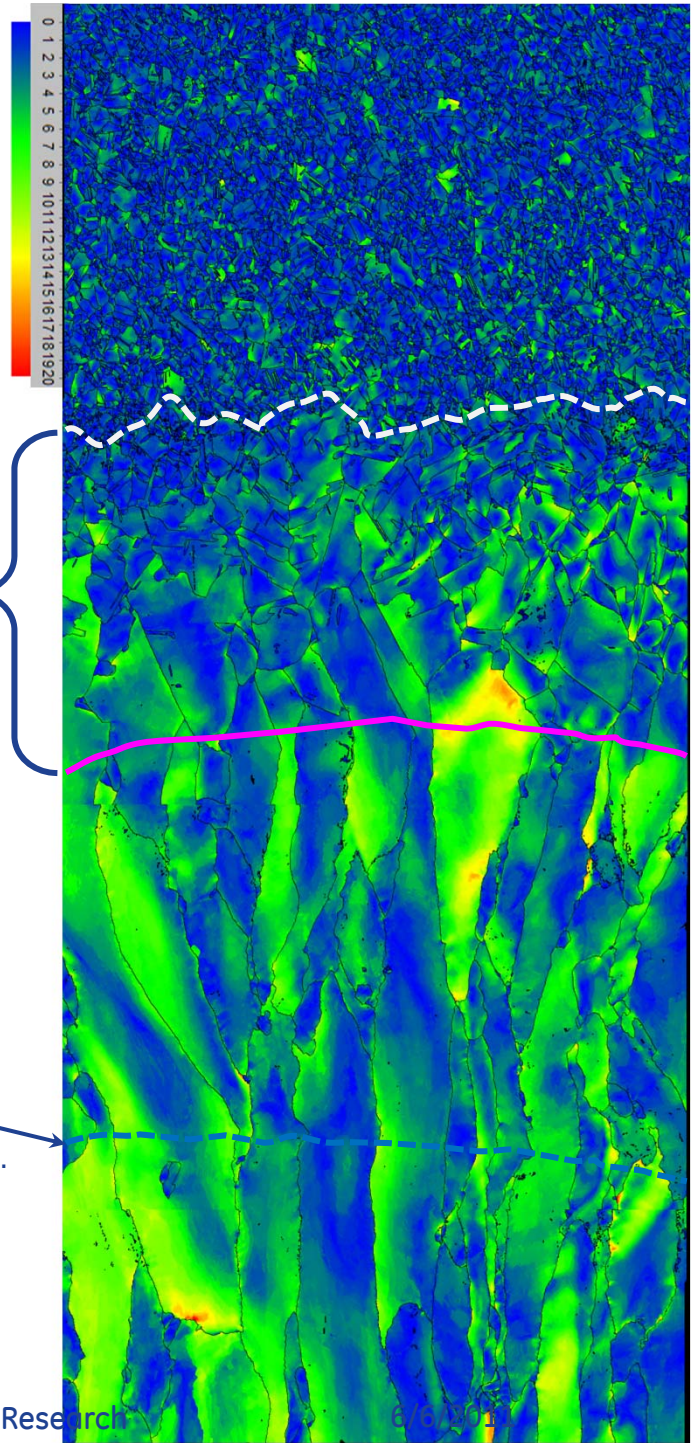
The dotted blue line represents the end of the 1st weld pass dilution zone. (Confirmed by EPMA data.)

— 100 μm



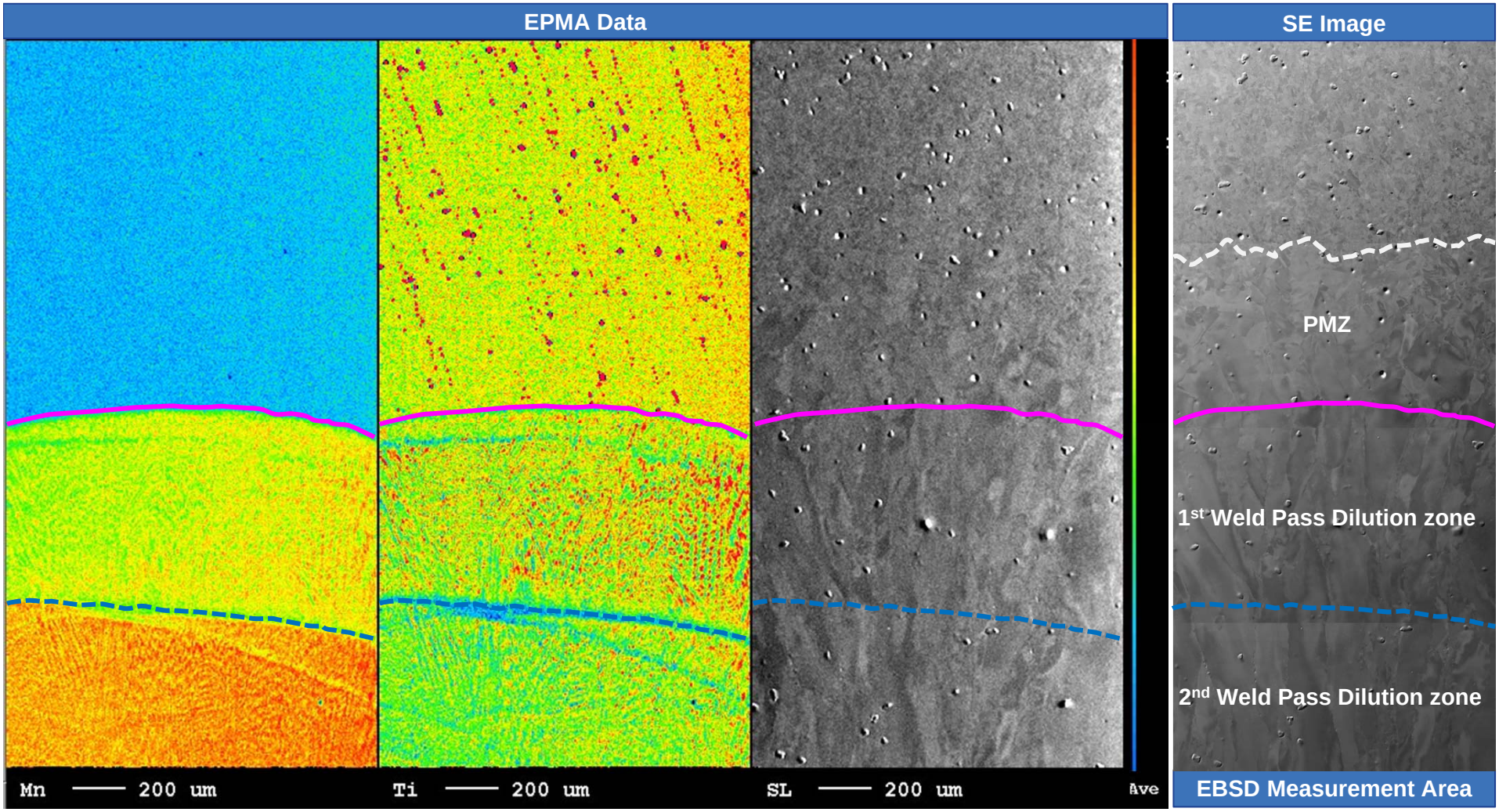
Area Measured by EBSD

20° Misorientation Map

Background

Chemical Basis for Interface

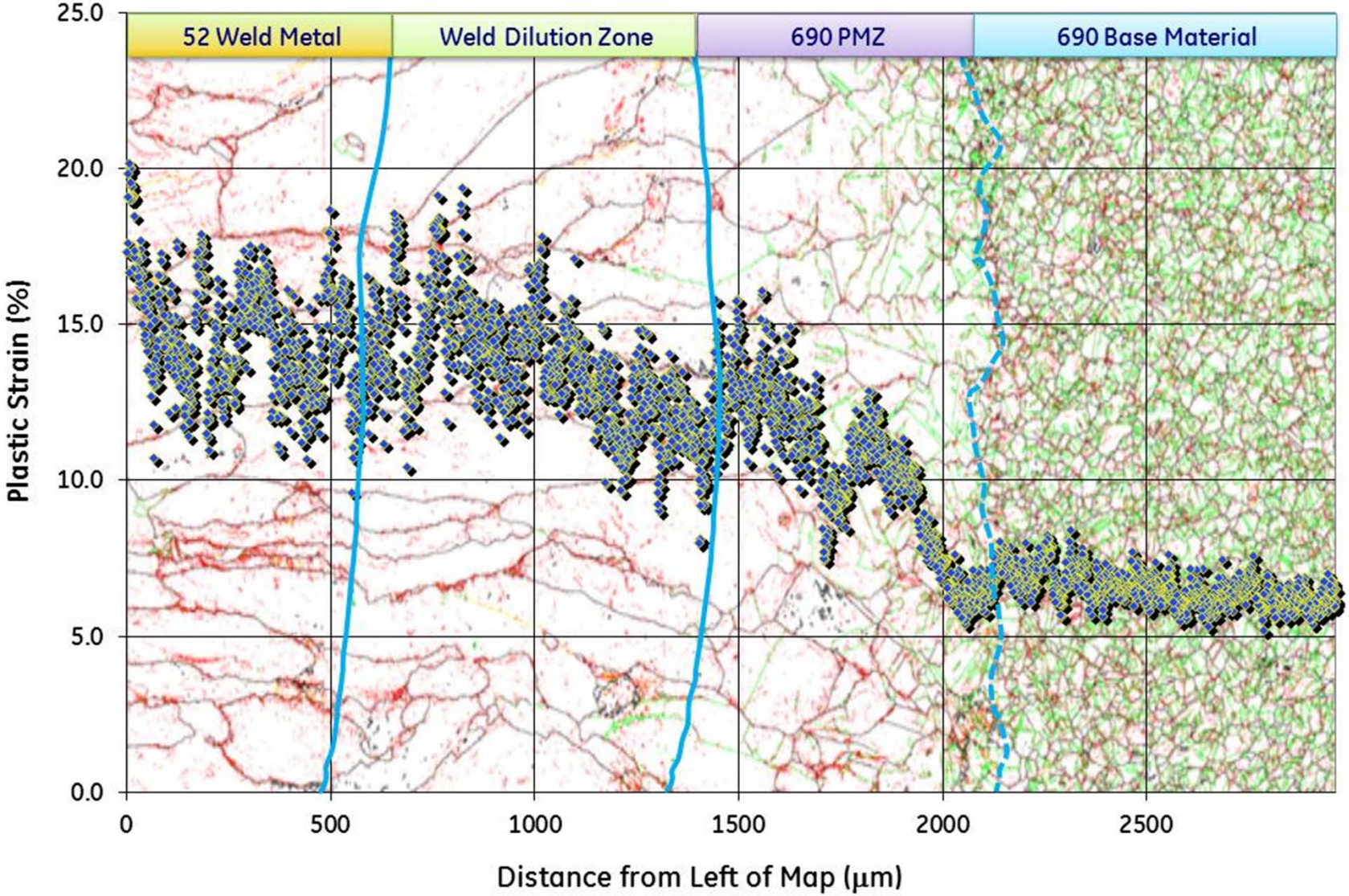
Chemical Basis for Alloy 690 UMZ+PMZ at Interface EPMA Data



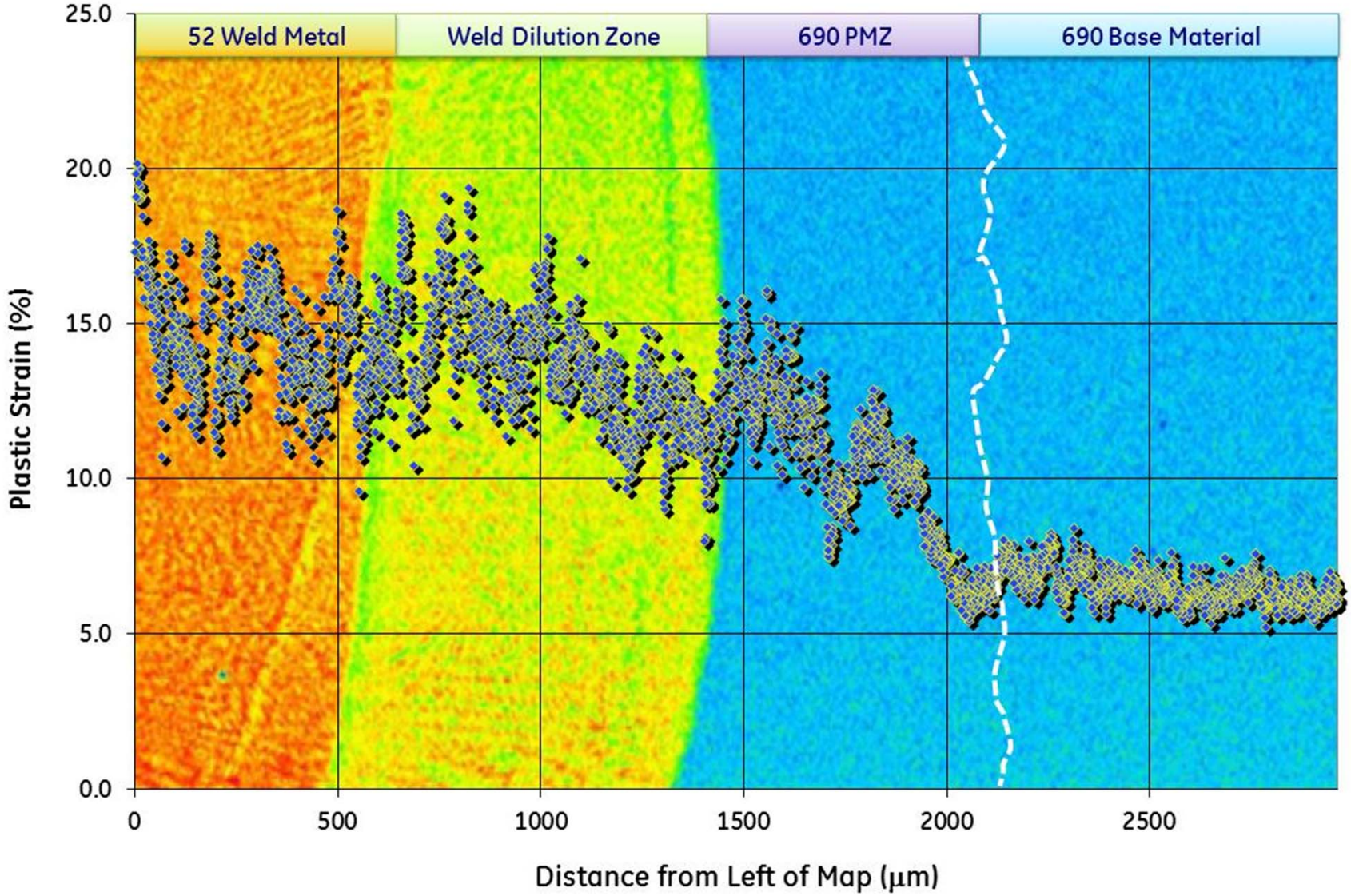
- Purple lines are drawn on the EPMA maps to indicate the chemical interface from the 1st weld pass dilution zone to the base Alloy 690 PMZ+UMZ.
- Dotted blue lines are indicate the end of the 1st weld pass dilution zone.

The dotted white line shows where the grain size changes, end of the UMZ+PMZ.

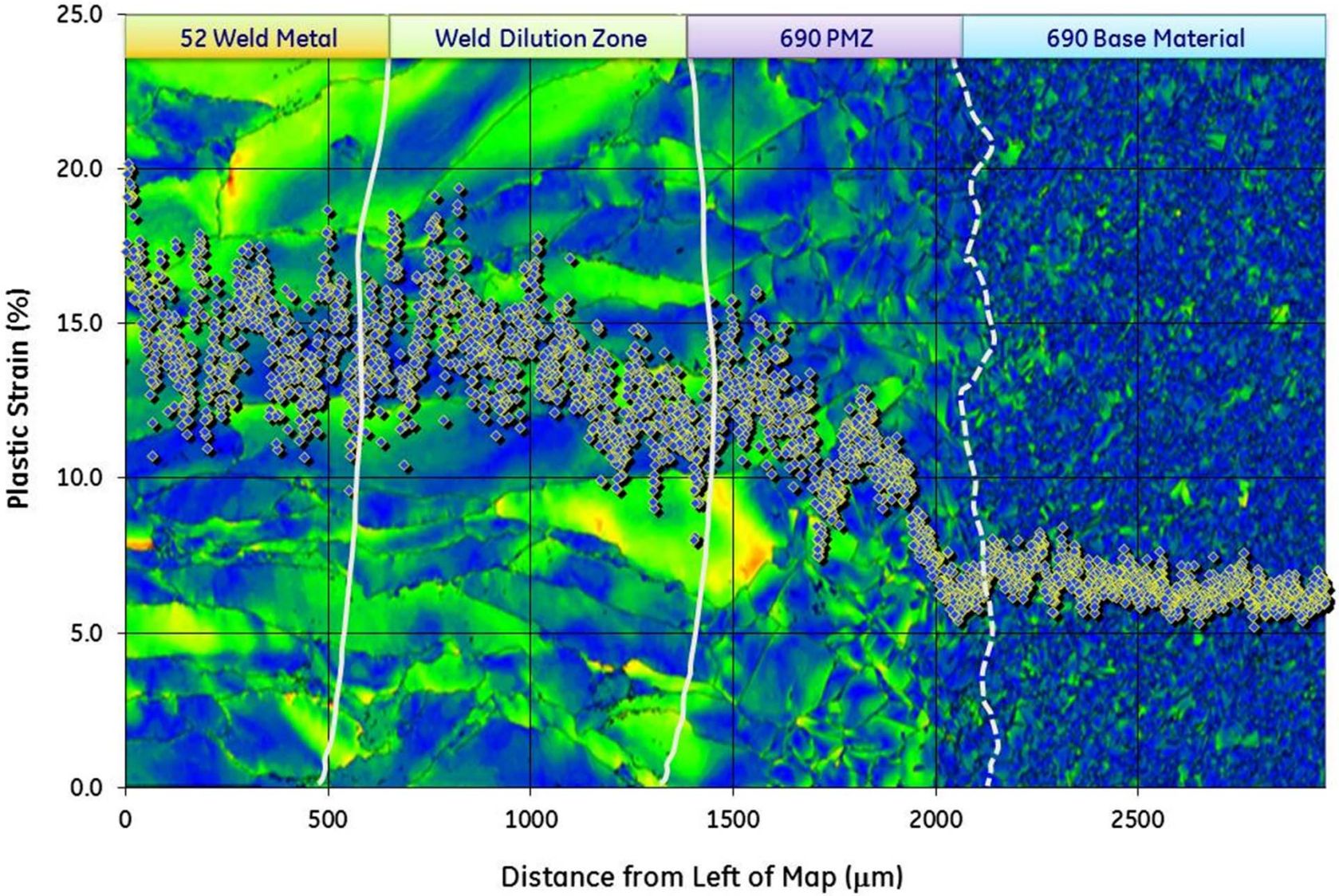
Residual plastic strain plot overlaid onto grain boundary character map, note twin boundary (green) density in Alloy 690 base metal versus PMZ+UMZ.

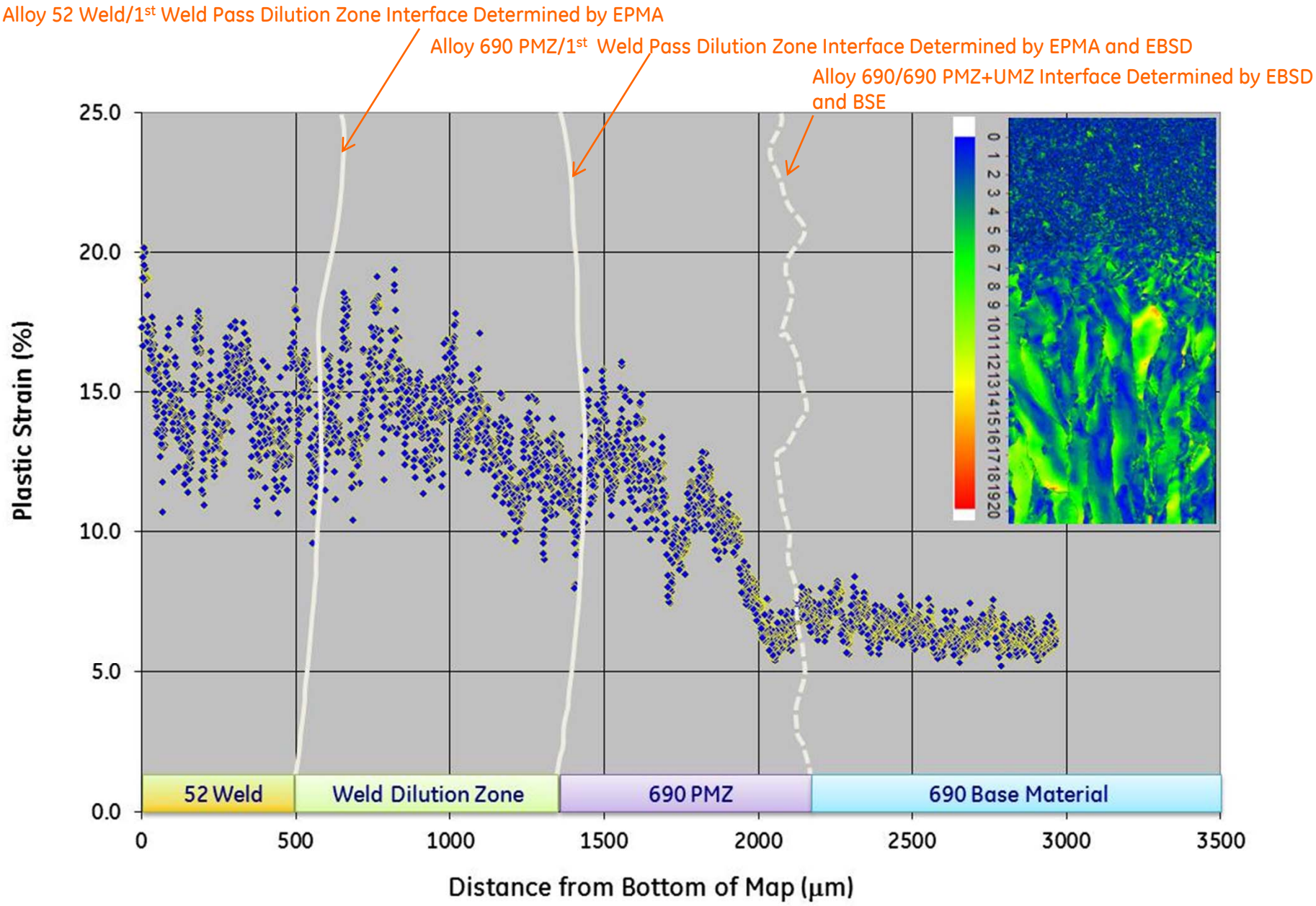


Residual plastic strain plot overlaid onto EPMA Mn map. Note peak in residual plastic strain in Alloy 690 occurs in chemically identifiable Alloy 690 PMZ+UMZ.



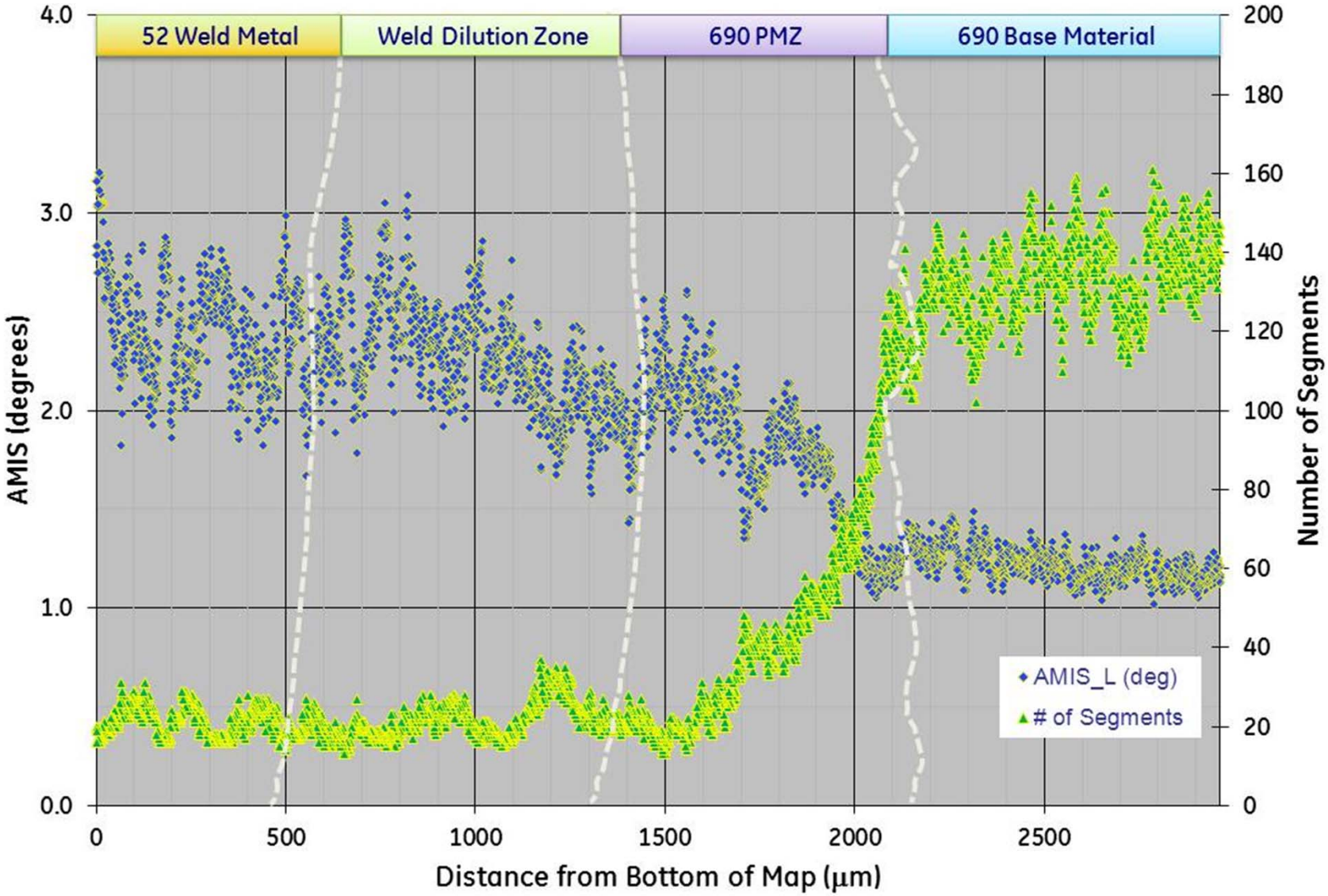
Residual plastic strain plot overlaid onto misorientation map. Note highest misorientation in Alloy 690 occurs in chemically identifiable Alloy 690 PMZ+UMZ.



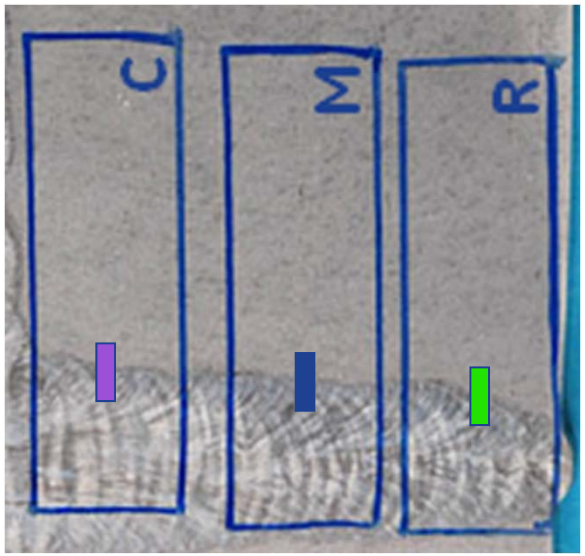


Residual plastic strain plot as a function of position across the weld interface

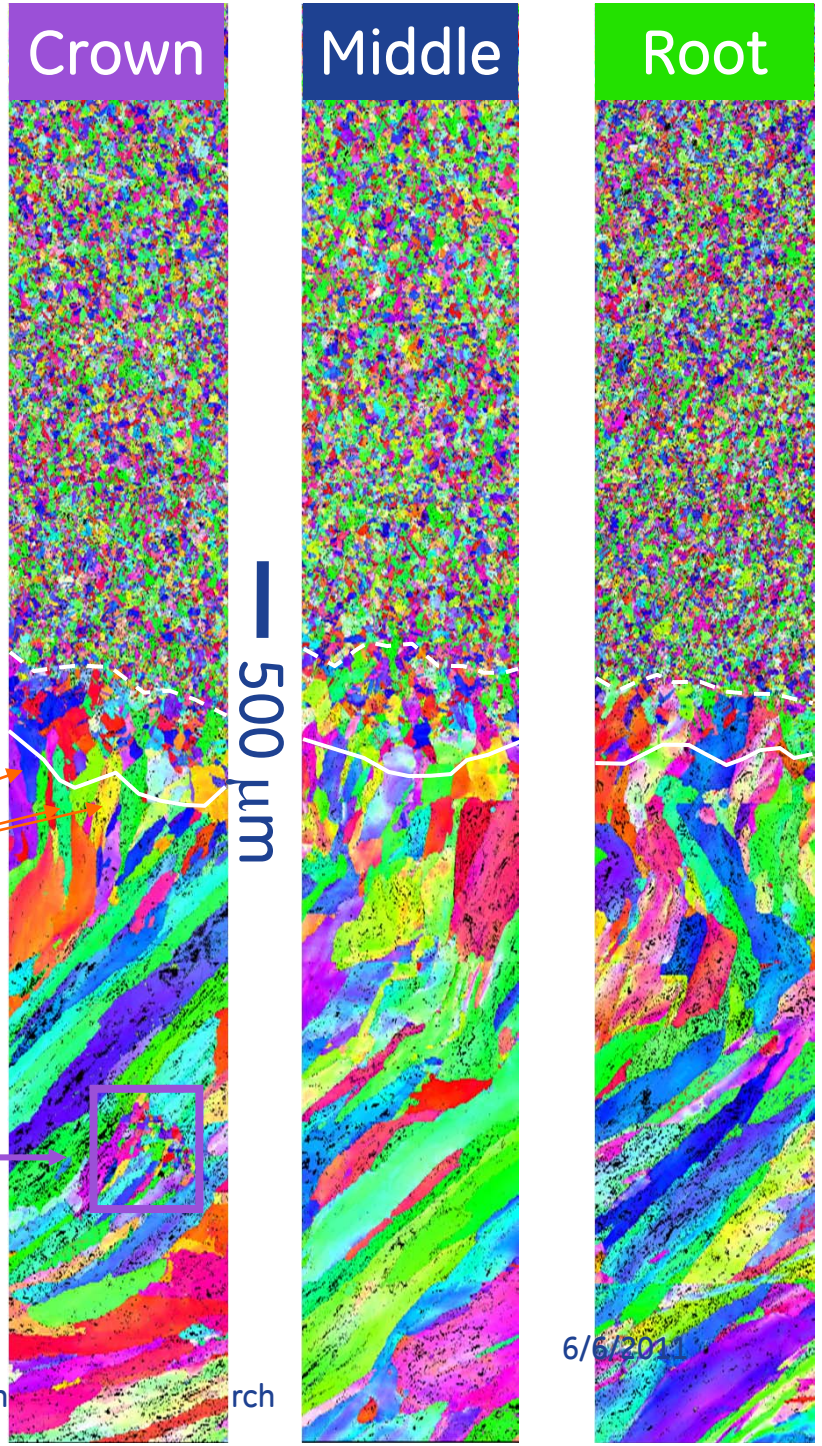
AMIS and Number of Segments (inverse of grain size) plots as a function of position across the weld interface. PMZ+UMZ transitions from mixed equiaxed fine and coarse grains to mixed coarse epitaxial dendrites and coarse equiaxed grains.



19508A 52M – Interface Study
IPF Maps of Entire Measurement Area



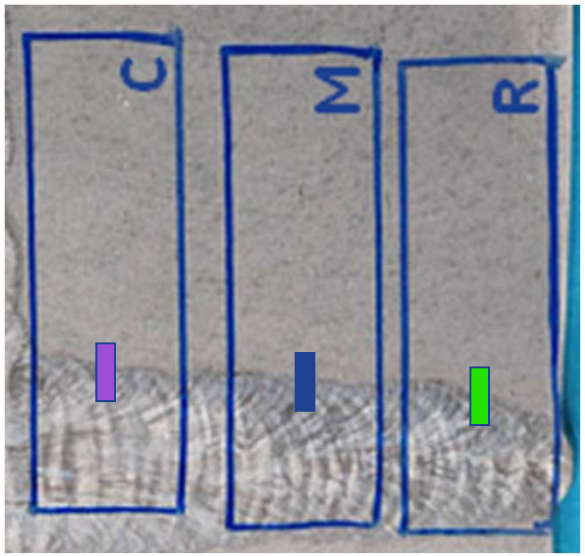
— Possible interface
····· End of "transition" zone



Middle: Epitaxial dendrites.

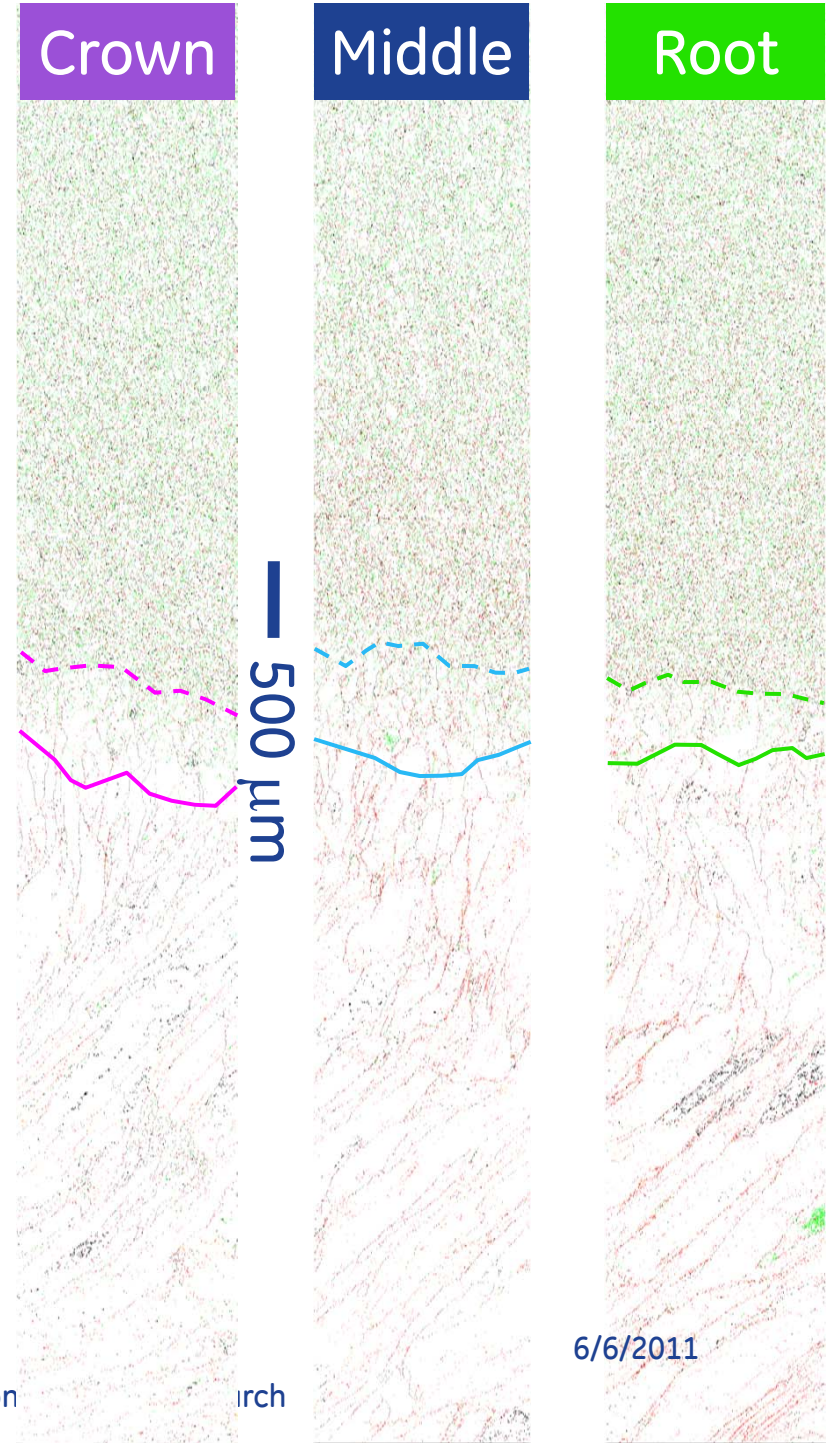
The weld portion has a region of recrystallized grains.

19508A 52N – Interface Study
BSE Images of Entire Measurement Area



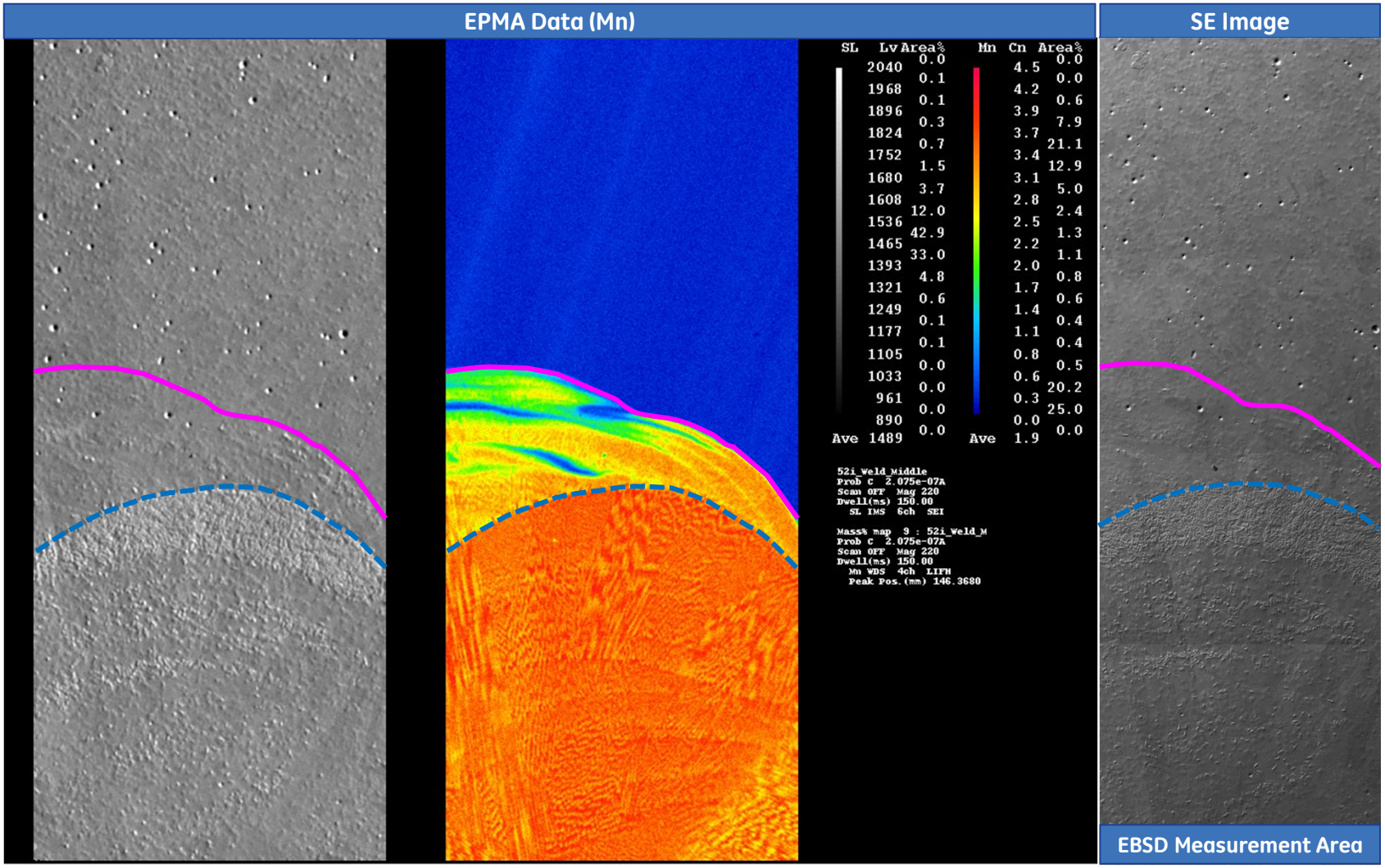
Chemical 52/690 interface

End of "transition" zone



Comparison 52i V-Groove Weld Mid-Plane Alloy 690

COMPARISON: 52i V-Groove Weld Mid-Plane EPMA Data

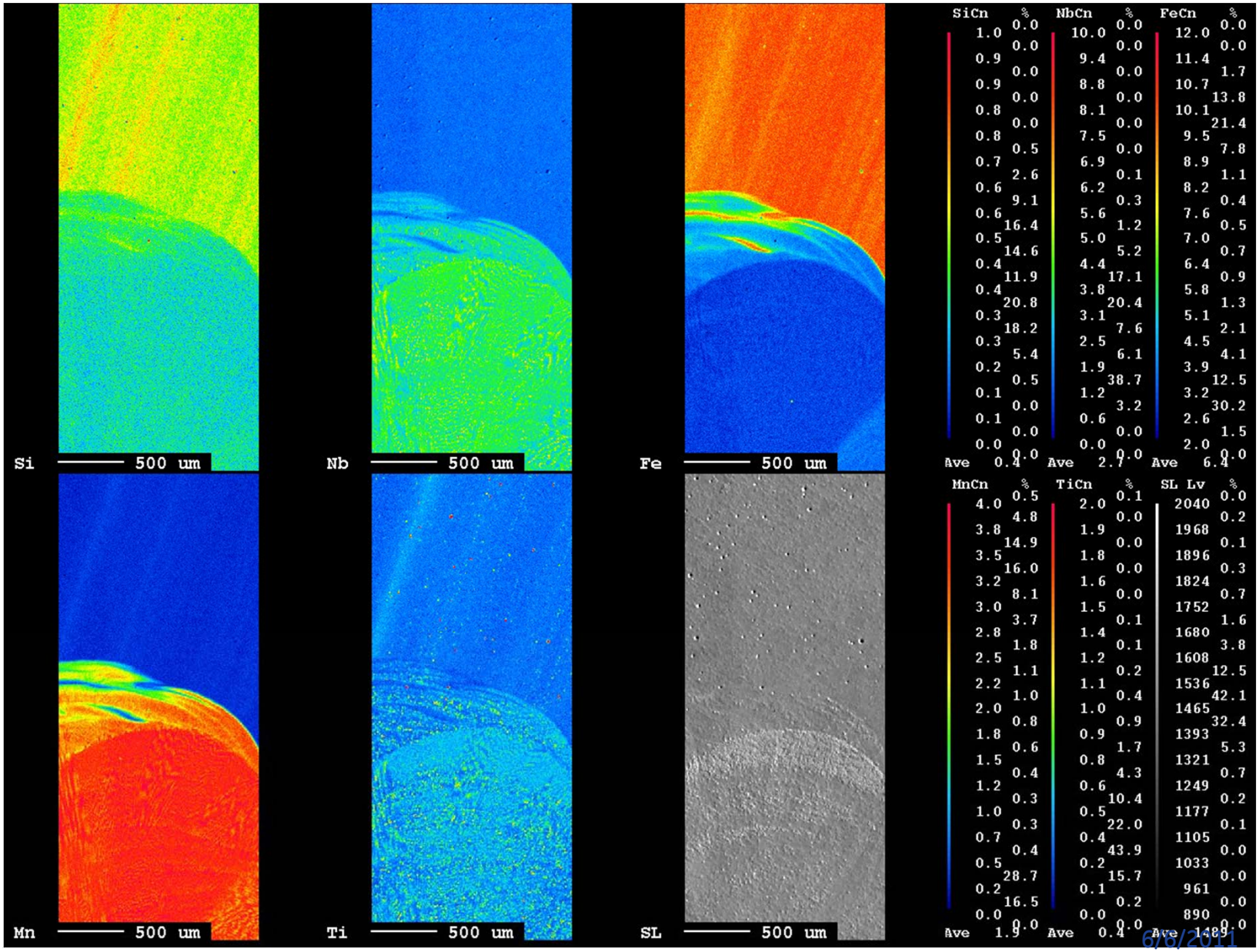


- Purple lines are drawn on the EPMA maps to indicate the chemical interface from the PMZ to the base material (690).
- The PMZ is chemically diluted with the 52i weld metal.

6/6/2011

COMPARISON: 52i V-Groove Weld Mid-Plane

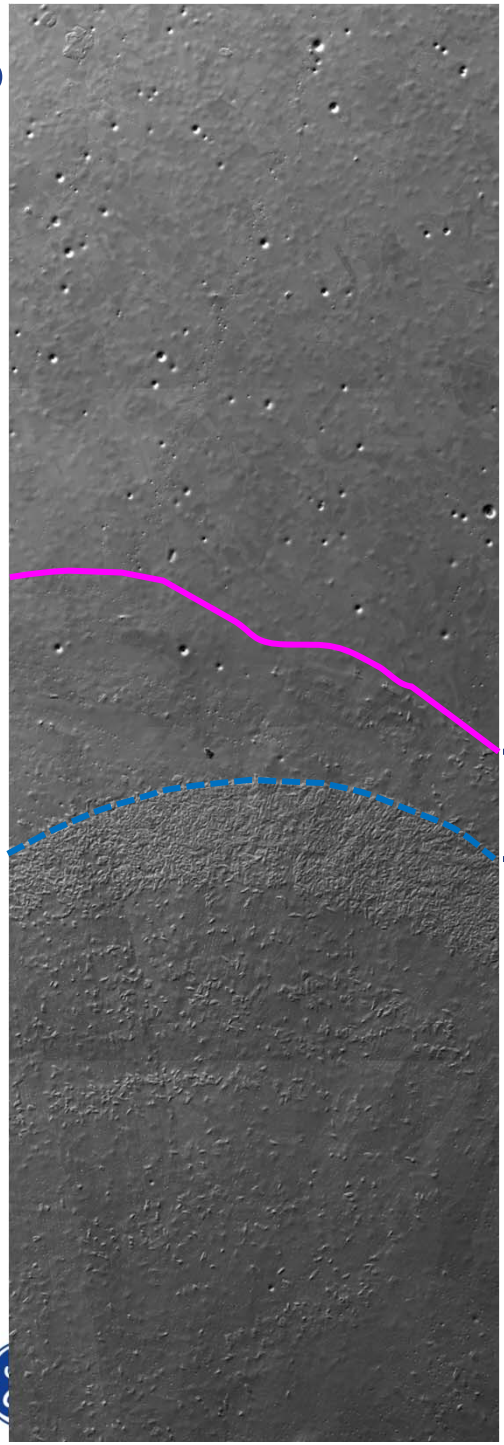
EPMA Data



6/8/2011

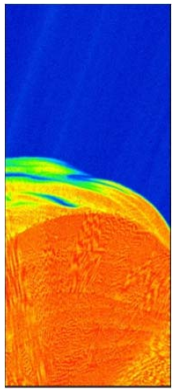
SE Image

52i Left of Weld: Mid



Grain size and morphology in the base metal is very different than the 52/690 systems.

Partial Melt defined by EPMA and EBSD data.

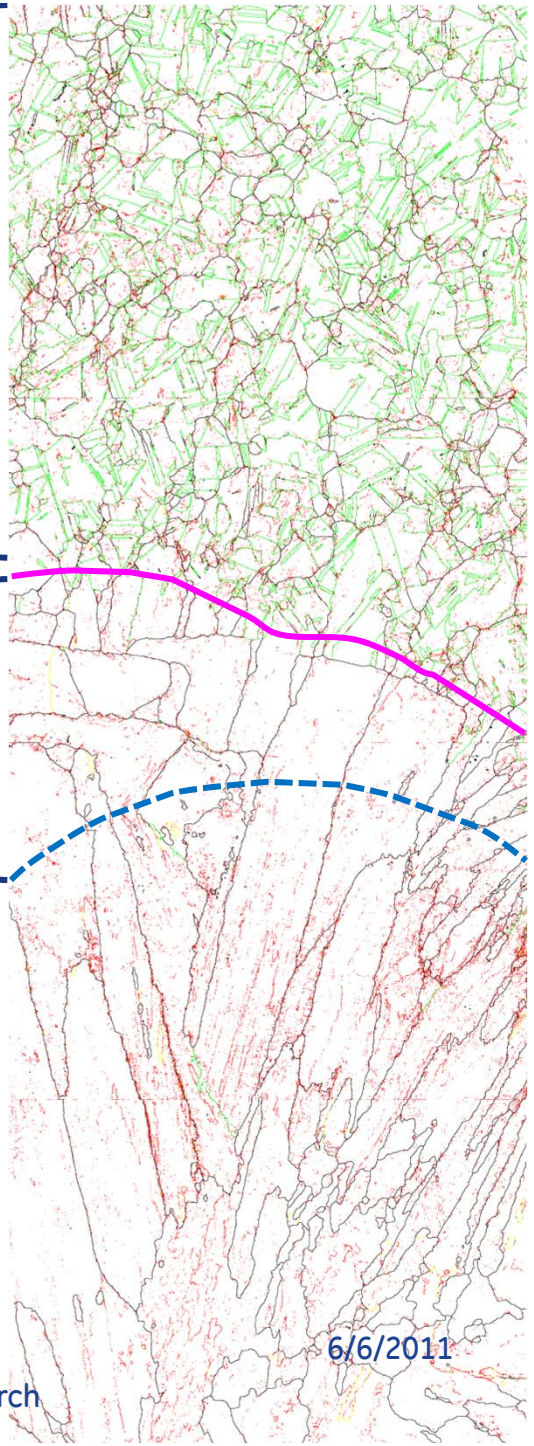


Mn Map (EPMA)

Red = 1.5°<θ<3°
Yellow = 3°<θ<10°
Black = 10°<θ<60°
Green = Twin (60°)

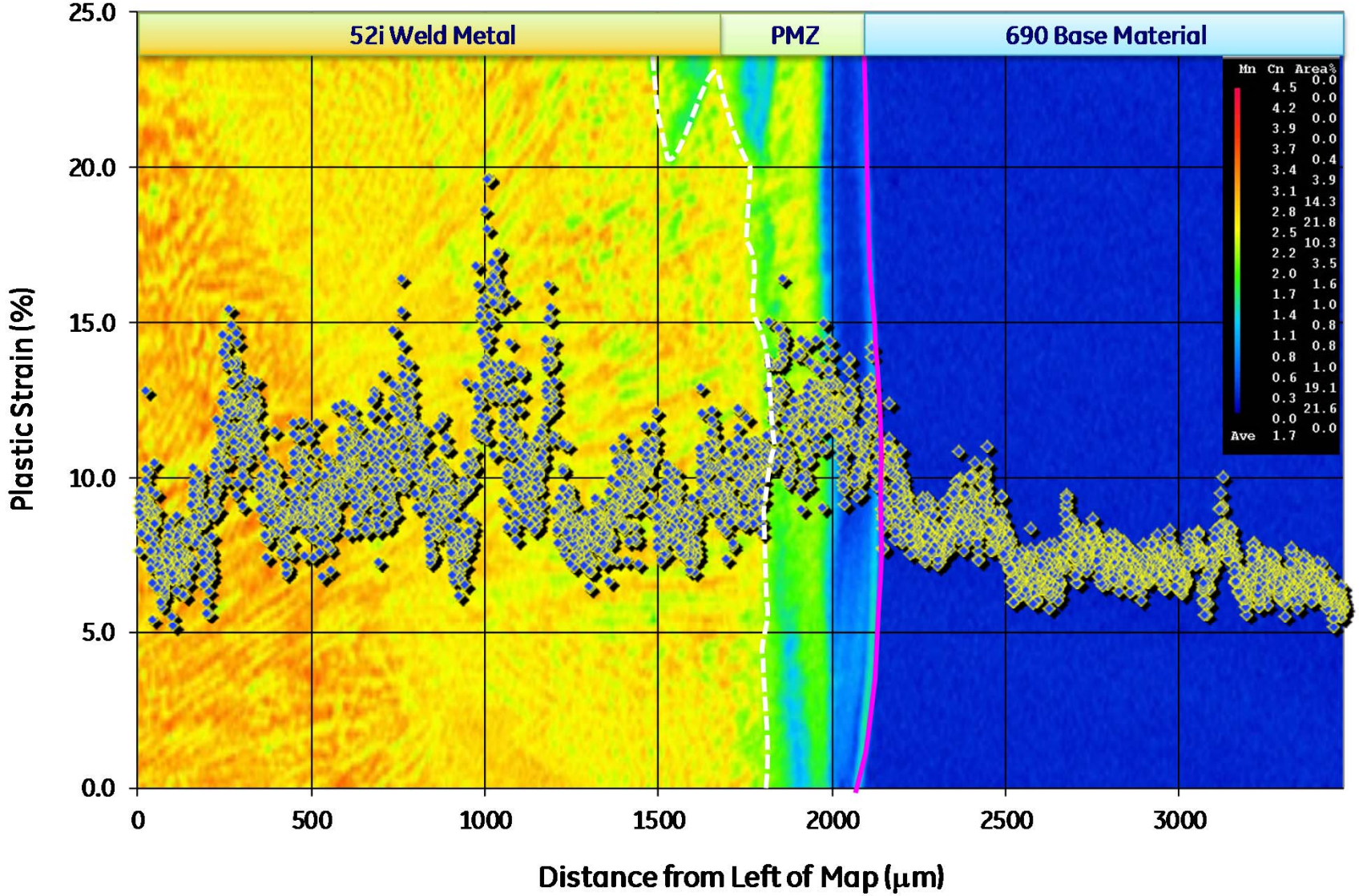
250 μm

52i Left of Weld: Mid

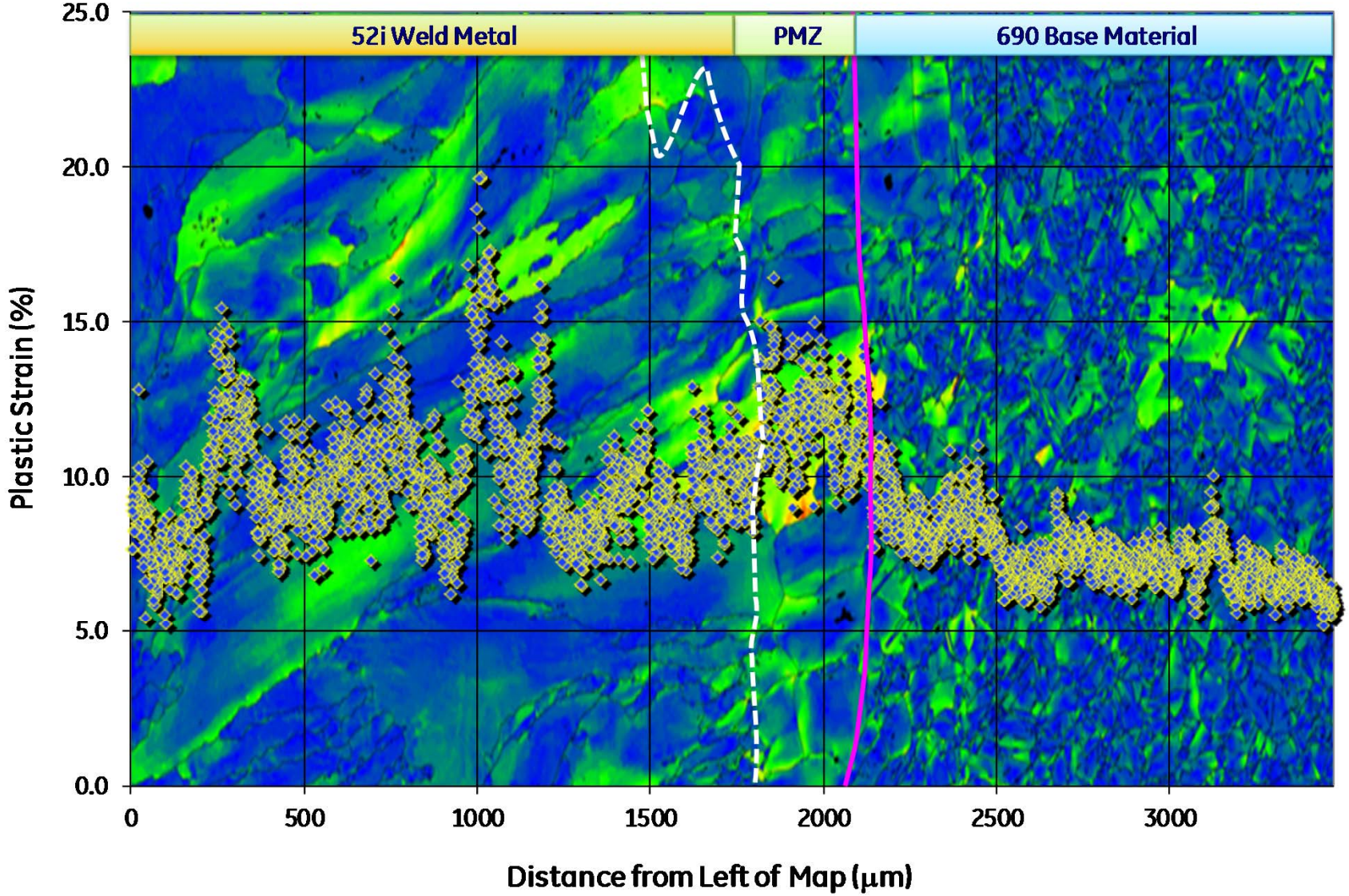


Boundary Map

COMPARISON: 52i V-Groove Weld Mid-Plane Strain versus EPMA Data



COMPARISON: 52i V-Groove Weld Mid-Plane Strain versus Misorientation



Summary – Alloy 690 PMZ

- After reviewing prior data from an Alloy 52 to Alloy 690 weld DJI 19508A 53N NG we confirmed that the Alloy 52 weld to Alloy 690 interface was structured as follows:

  Alloy 52 Weld Passes / Alloy 52 1st Weld Pass Dilution Zone / Alloy 690 PMZ +UMZ/ Alloy 690 Base metal

- The Alloy 690 PMZ+UMZ has a mixed microstructure consisting of large epitaxial dendrites, coarsened equiaxed grains, and fine recrystallized grains. **The Alloy 690 PMZ+UMZ is chemically Alloy 690** and varies in width, 670 microns wide in the region investigated.
- The Alloy 690 PMZ+UMZ consists of epitaxial dendrites, coarse grains, and fine recrystallized grains and is on average of much coarser grain size than the Alloy 690 base metal.
- While the Alloy 52 weld metal has the highest residual plastic strain in the weldment the highest residual plastic strains in the chemically identified Alloy 690 occur in the Alloy 690 PMZ.
- A very different interface chemistry has been observed in Alloy 52i to Alloy 690 weld interfaces

Summary – Alloy 690 PMZ

- **Residual strain is located in the region of lowest yield strength at the time of weld solidification and cool down**

  - Base metal if lowest YS

  - Base metal true HAZ

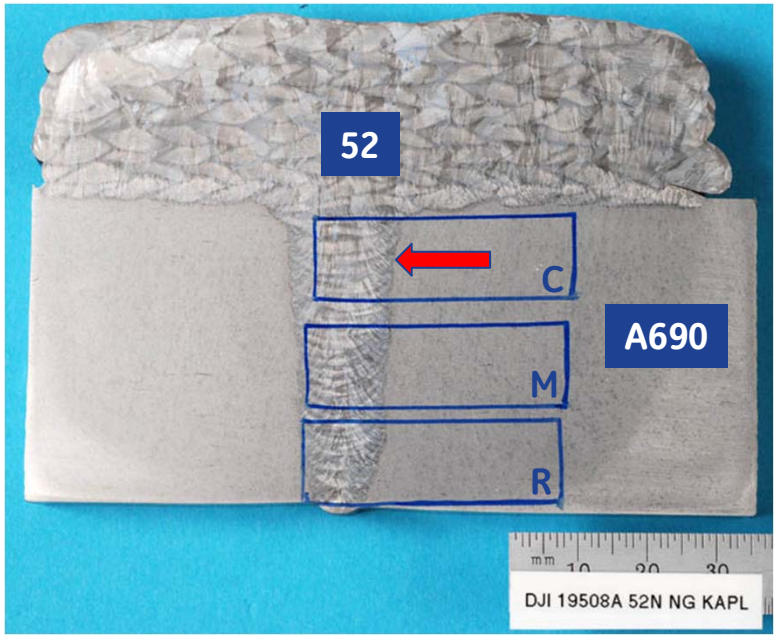
  - PMZ Alloy 690

  - Surrounding defects if dynamic recrystallization has not occurred.

Weld Defects and Dynamic Recrystallization in Alloy 52 Weld Metal

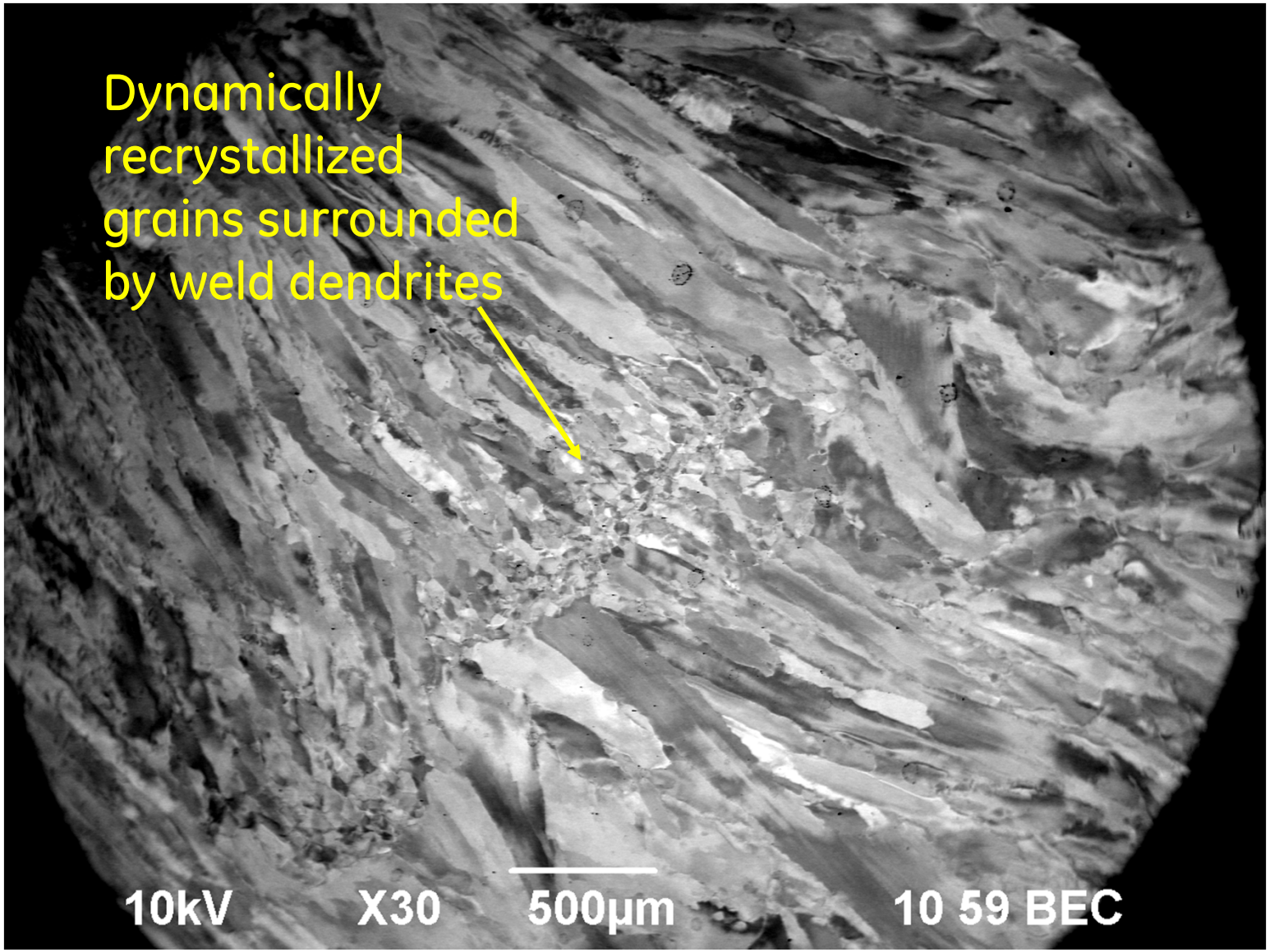
EBSD Map of Dynamically Recrystallized Grains in 52 Weld

Weld: DJI 19508A 52M



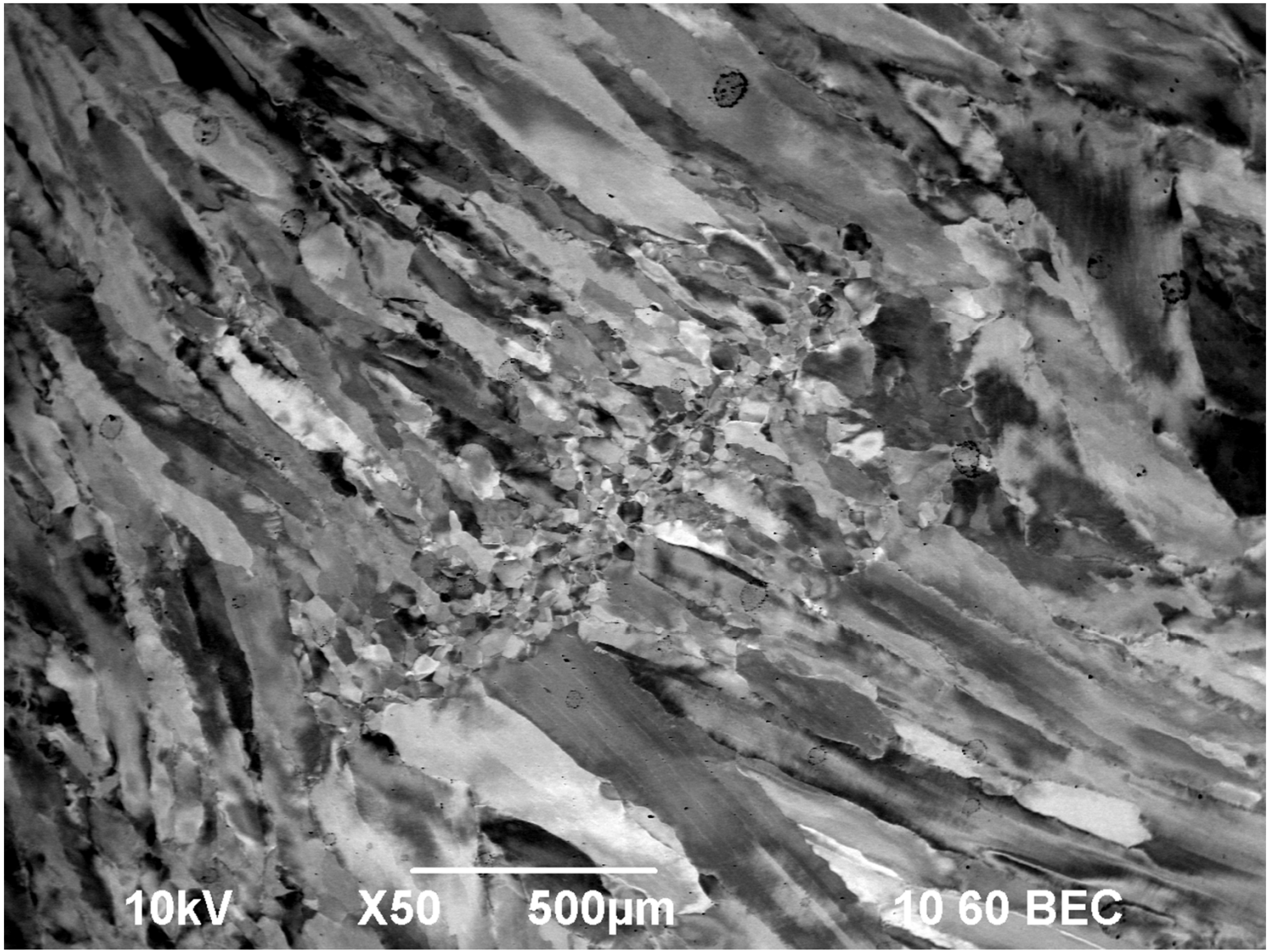
Dynamically Recrystallized Grains

BSE Image: 30x



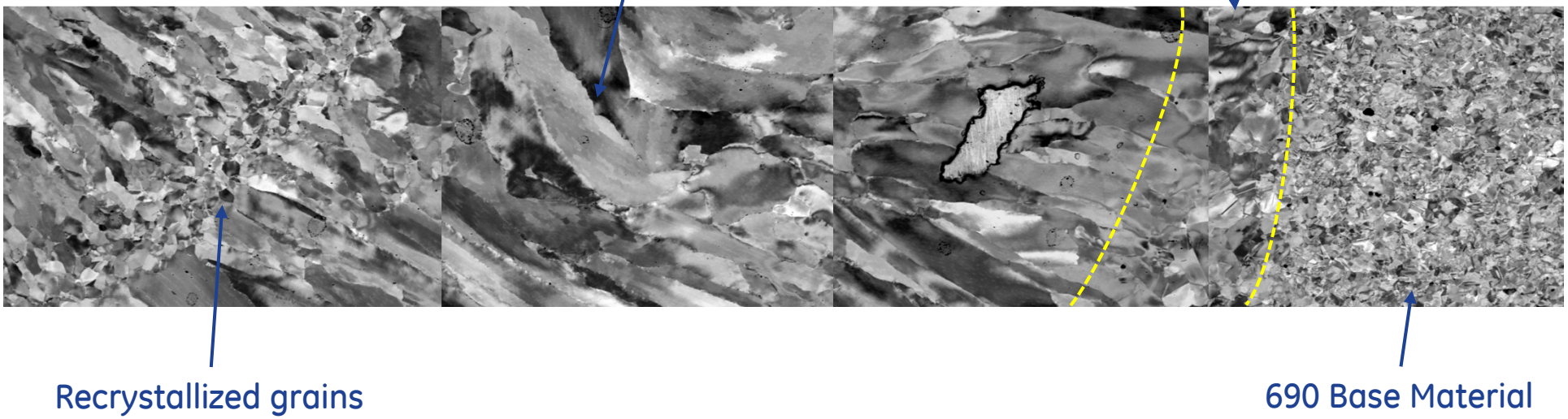
Dynamically Recrystallized Grains

BSE Image: 50x



Dynamically Recrystallized Grains

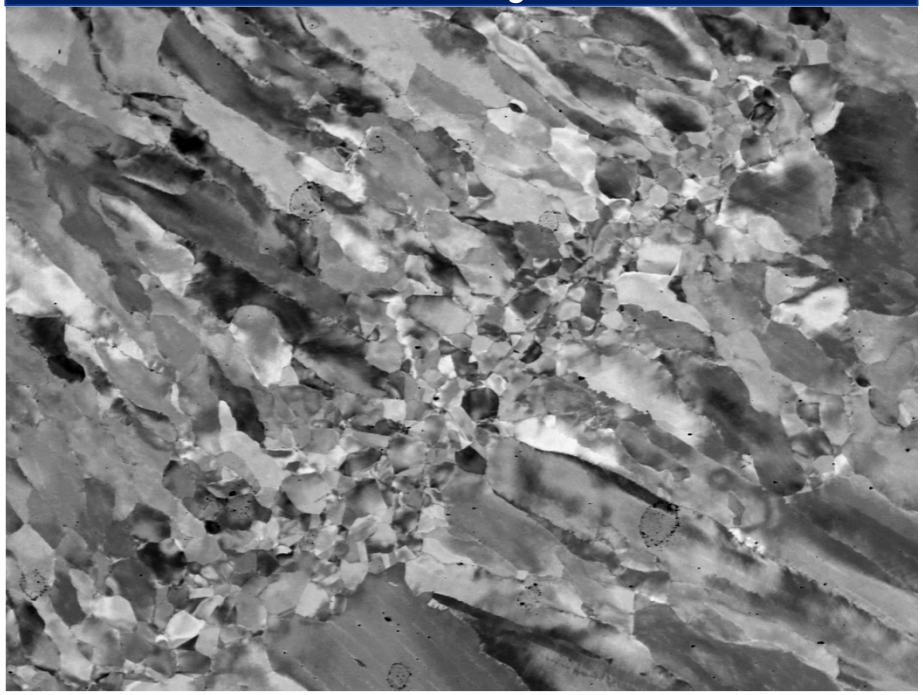
BSE Images: 100x



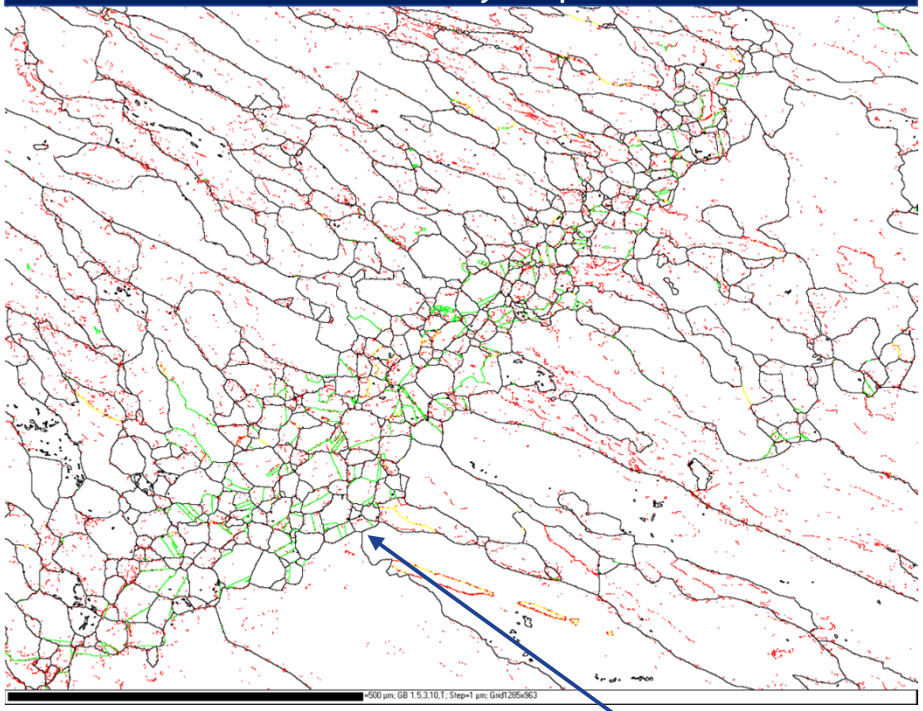
Dynamically recrystallized grains

Boundary Map

BSE Image



Boundary Map



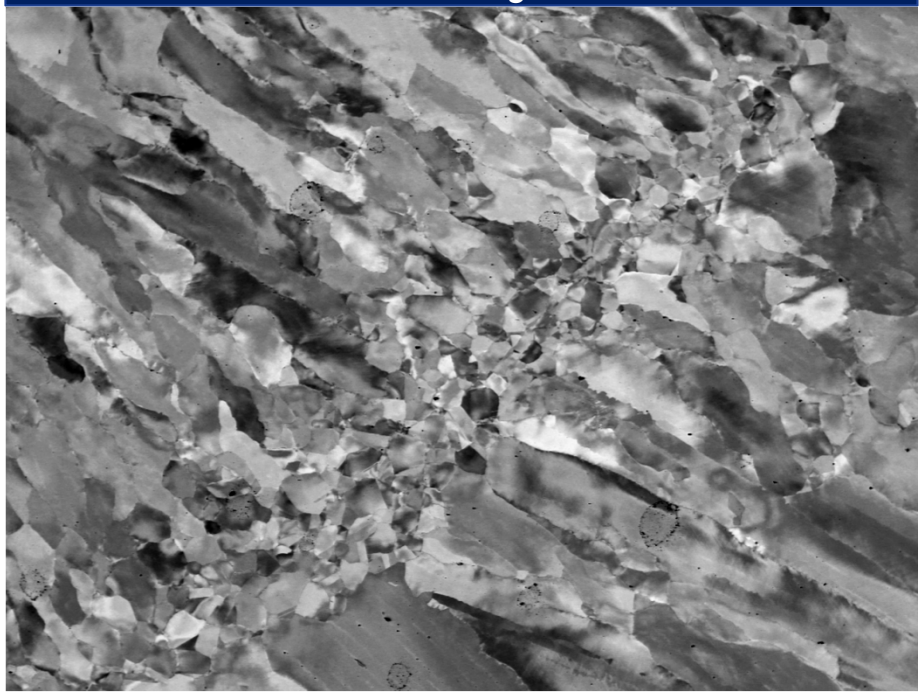
Red = 1.5°<θ<3°
Yellow = 3°<θ<10°
Black = 10°<θ<60°
Green = Twin (60°)

Twins (green lines) present in recrystallized grains.

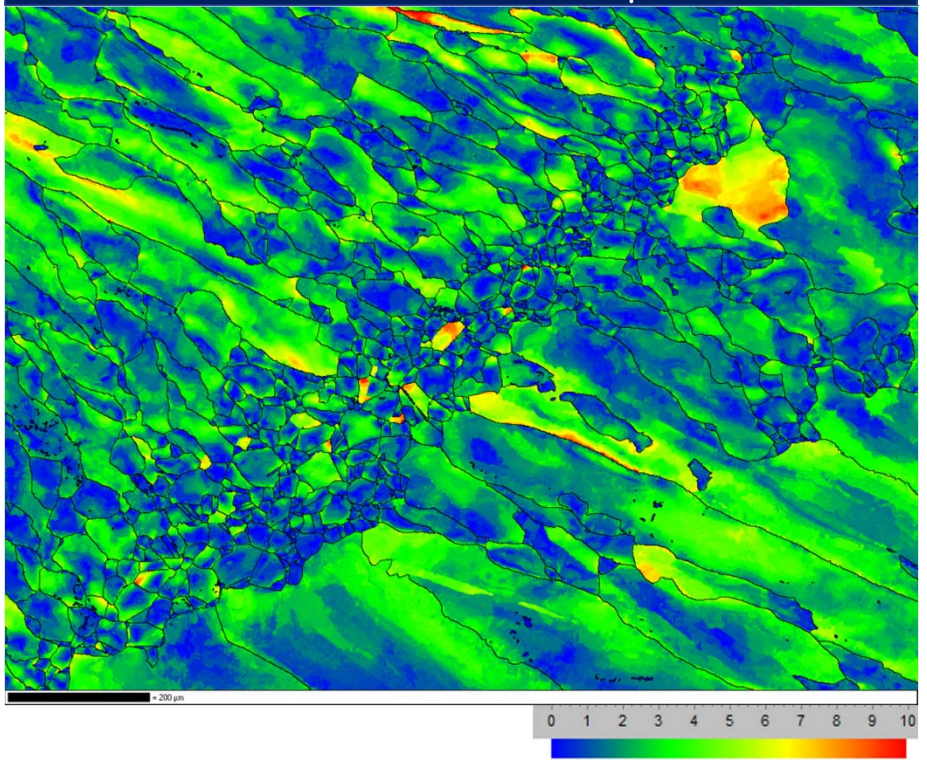
Dynamically Recrystallized Grains

10° Misorientation Map

BSE Image



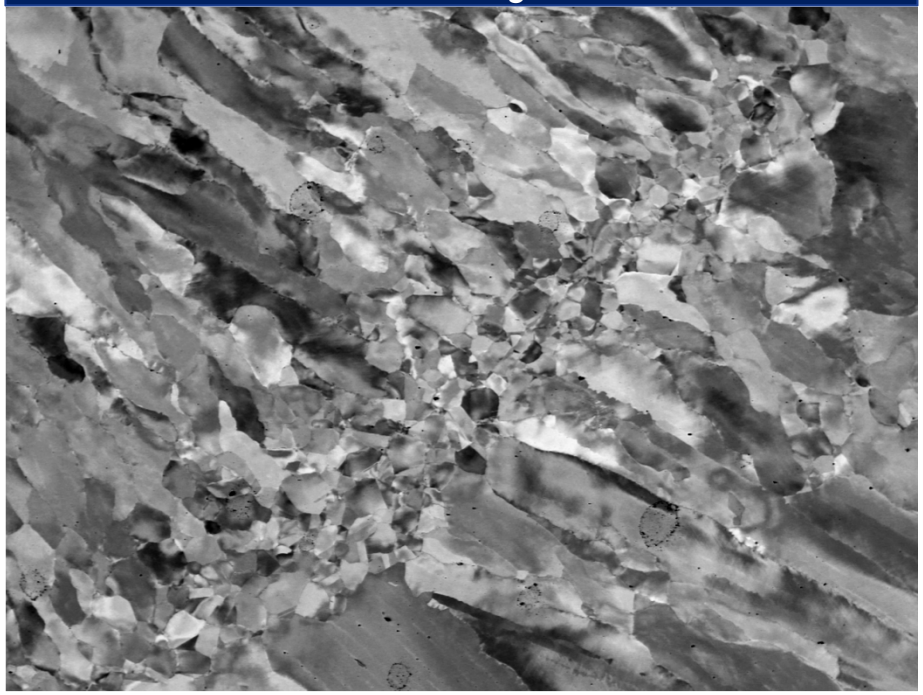
10° Misorientation Map



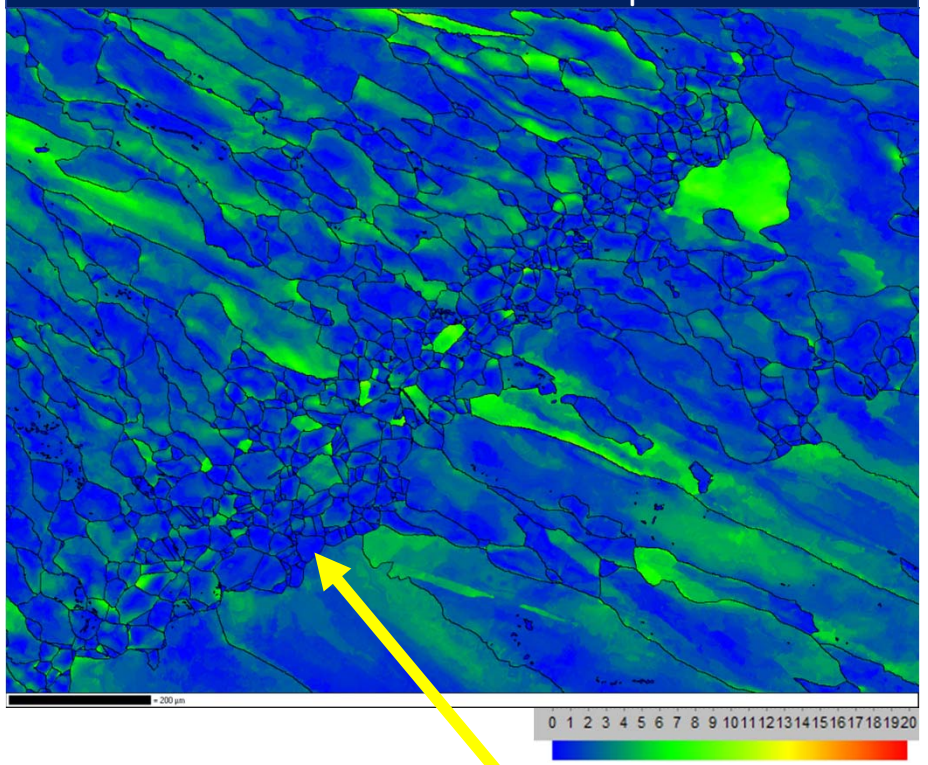
Dynamically Recrystallized Grains

20° Misorientation Map

BSE Image

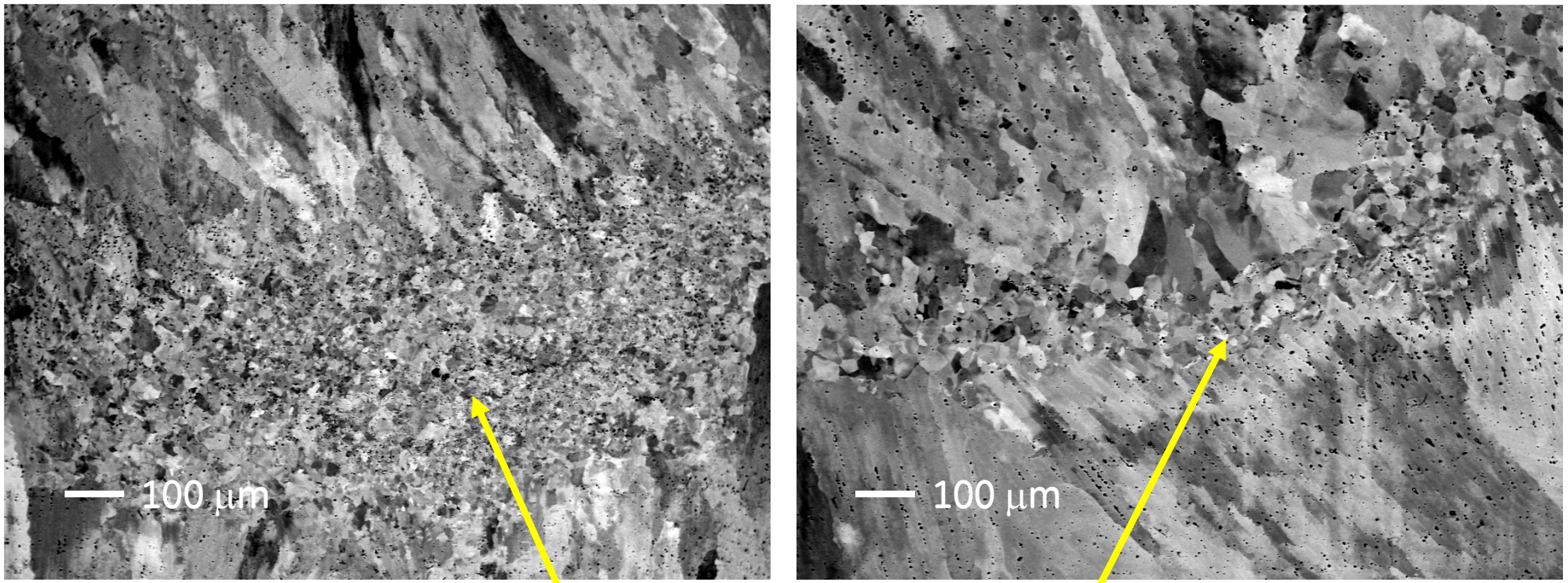


20° Misorientation Map



Recrystallized grains are relatively strain free in comparison to the surrounding dendrites.

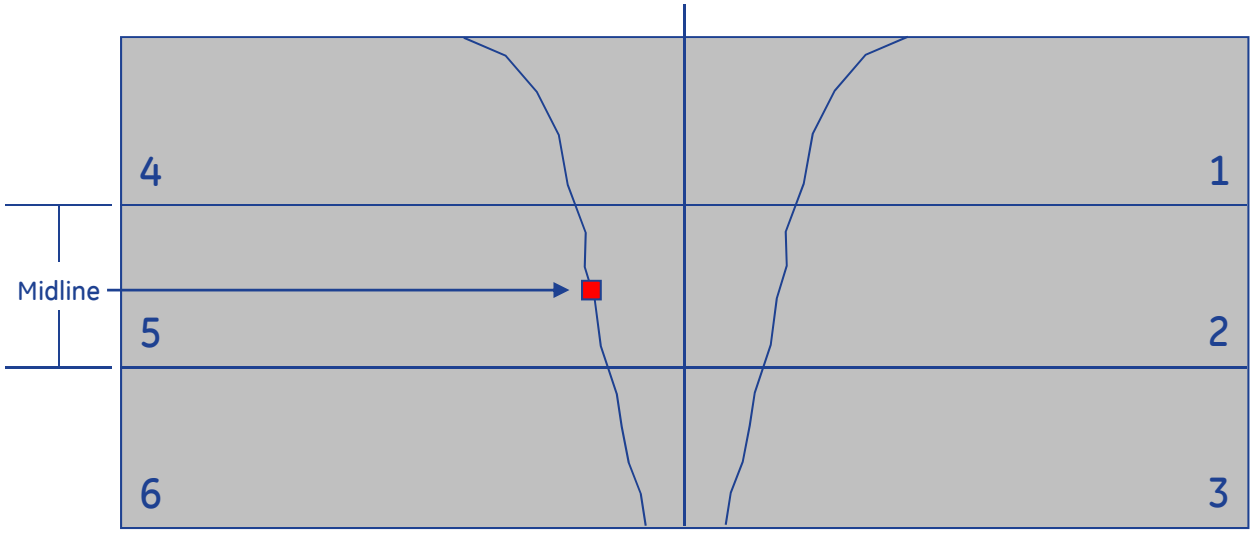
Other Examples of Dynamically Recrystallized Grains in Alloy 52-Type Welds BSE Images



Dynamically recrystallized grains

Alloy 52 Weld / 690 Base Metal – NX2579JK

Location of Images

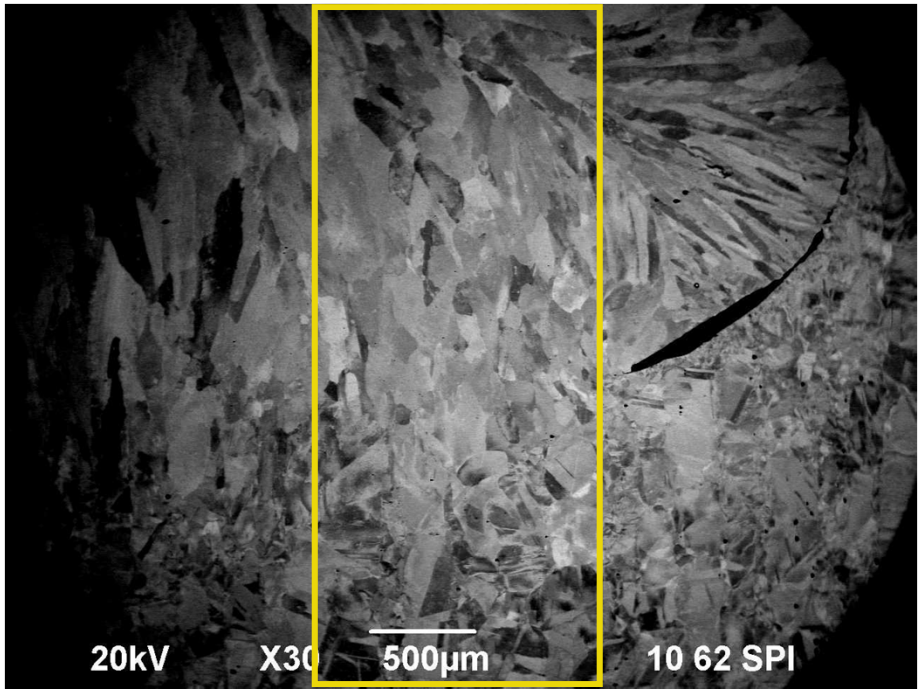


Weld defect observed at the interface in Sample 5

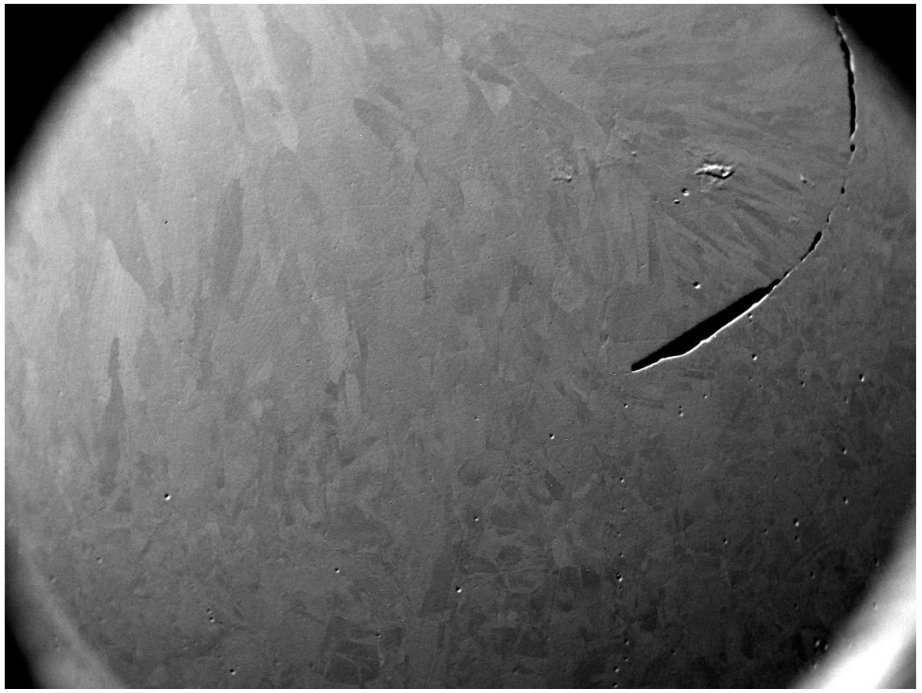
This feature was ~0.5 mm from the AMIS measurements taken at the midline of the short axis of the sample

Alloy 52 Weld / 690 Base Metal – NX2579JK

BSE, SE Images of weld defect

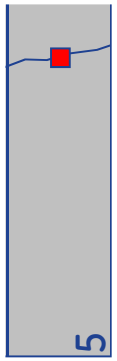


BSE Image



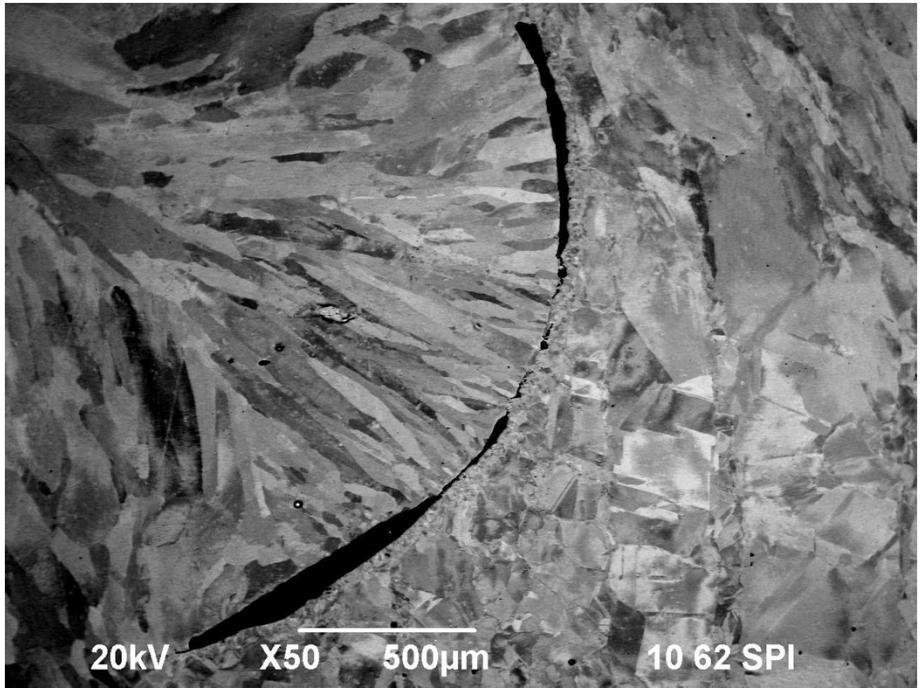
SE Image

Area inside the yellow box indicates the area measured by the Linescan measurements to produce AMIS data.

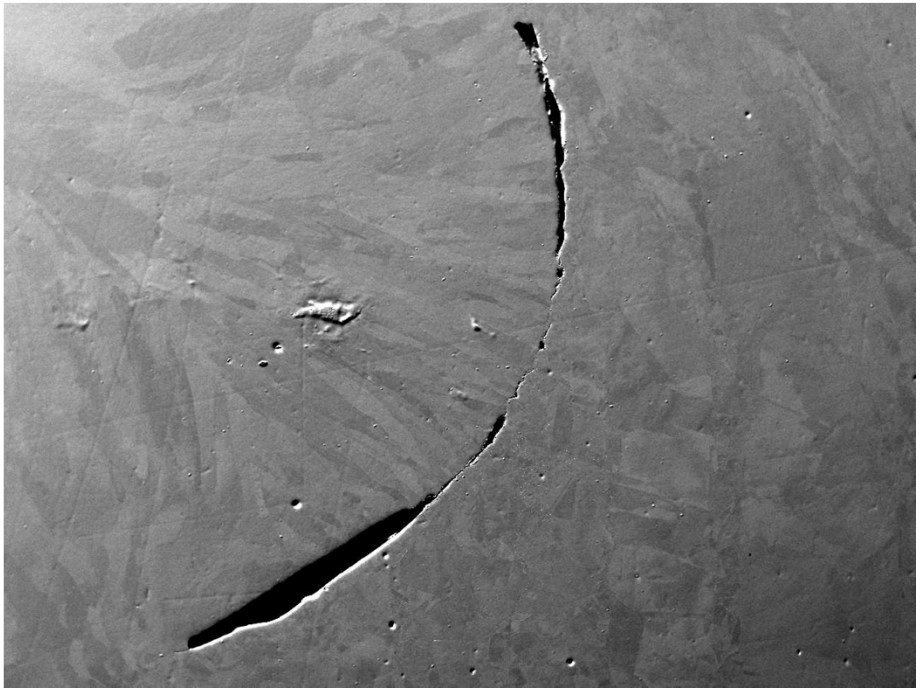


Alloy 52 Weld / 690 Base Metal – NX2579JK

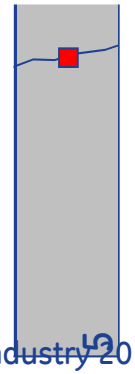
BSE, SE Images of weld defect



BSE Image

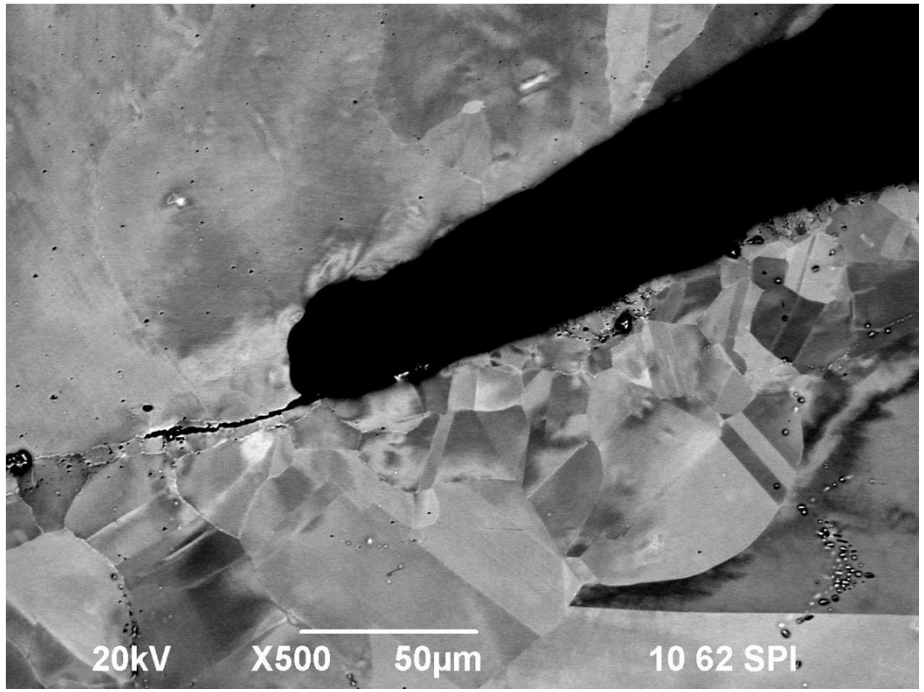


SE Image

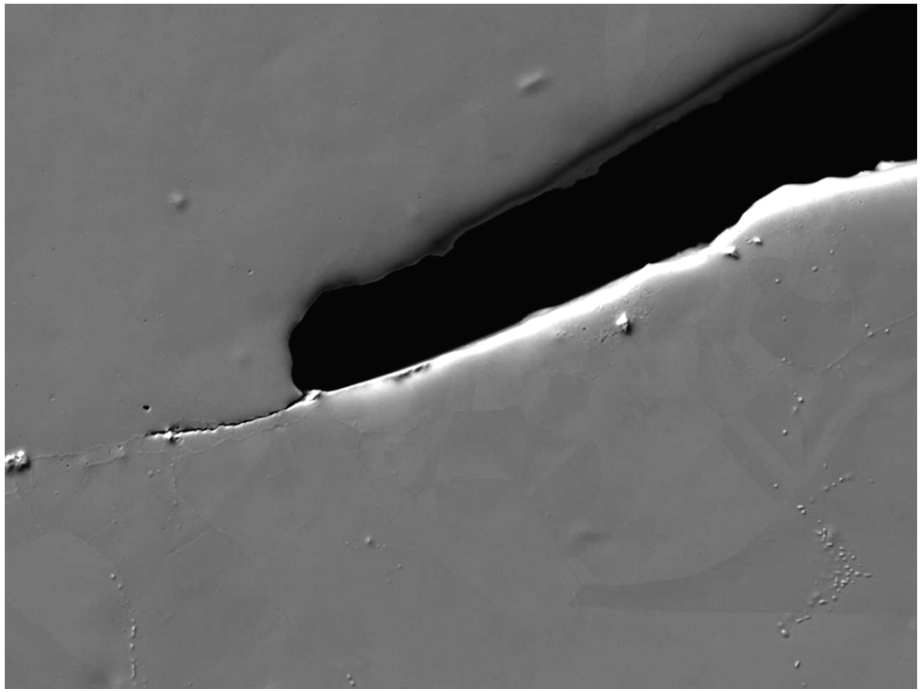


Alloy 52 Weld / 690 Base Metal – NX2579JK

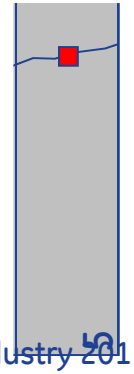
BSE, SE Images of weld defect



BSE Image



SE Image



19508A 52M – Interface Study:

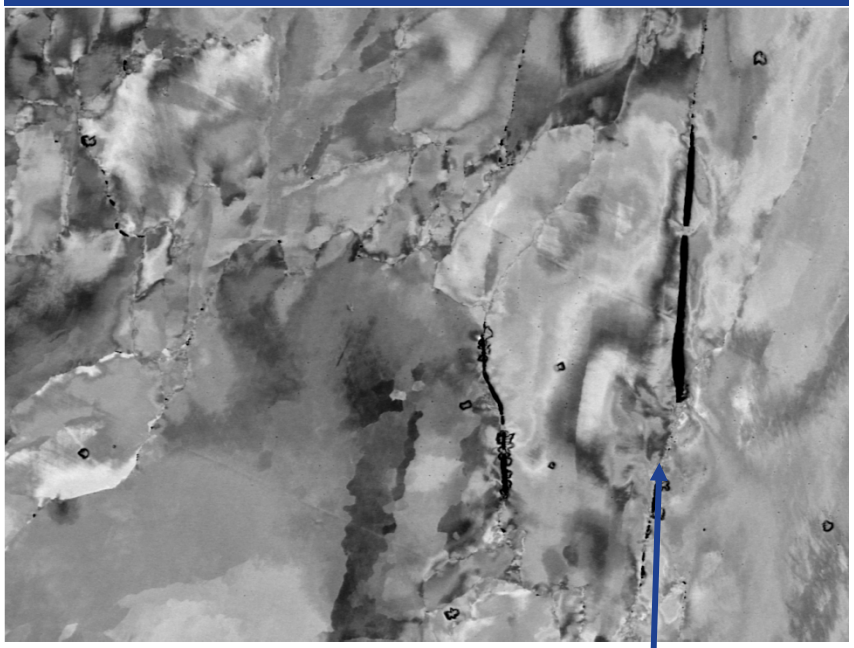
Middle

BSE/SE Images: 150x

SE Image

100 μm

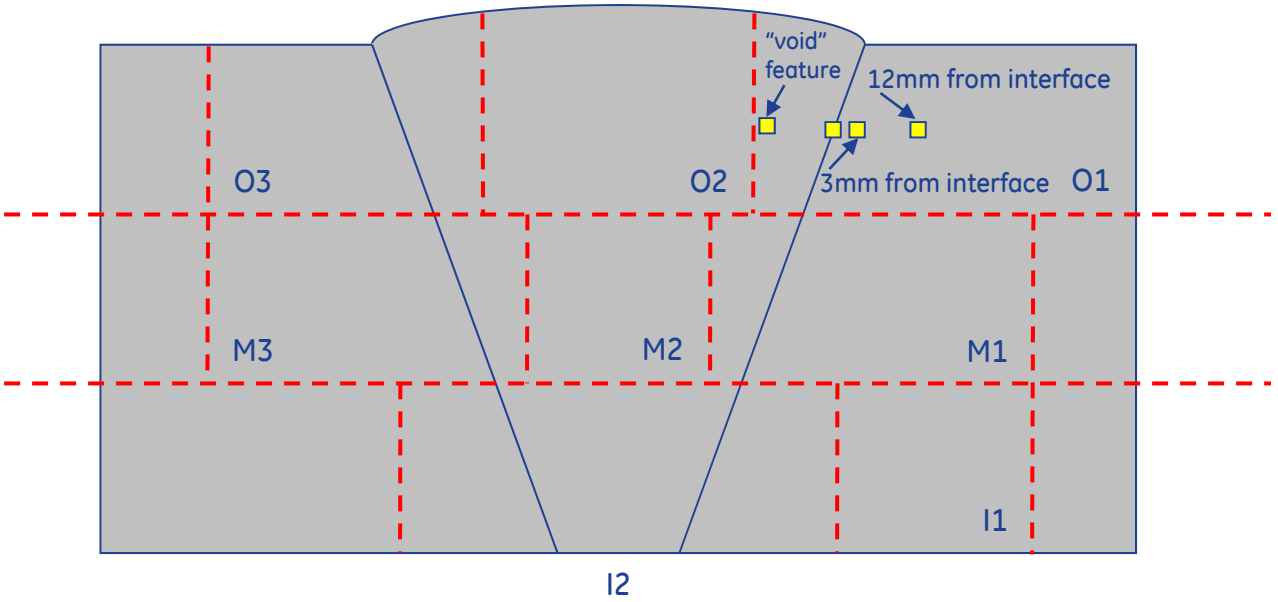
BSE Image



Plumes of plastic strain

Weld Slice 82WJ

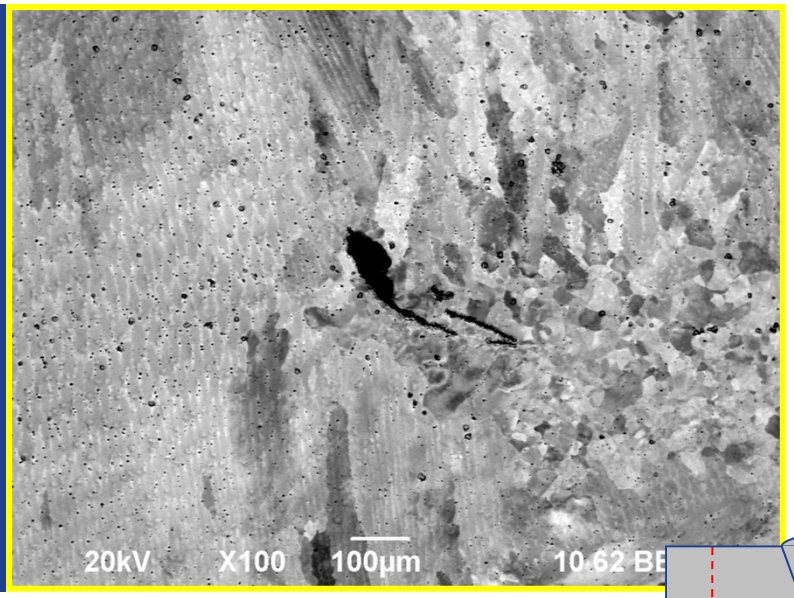
Section O1

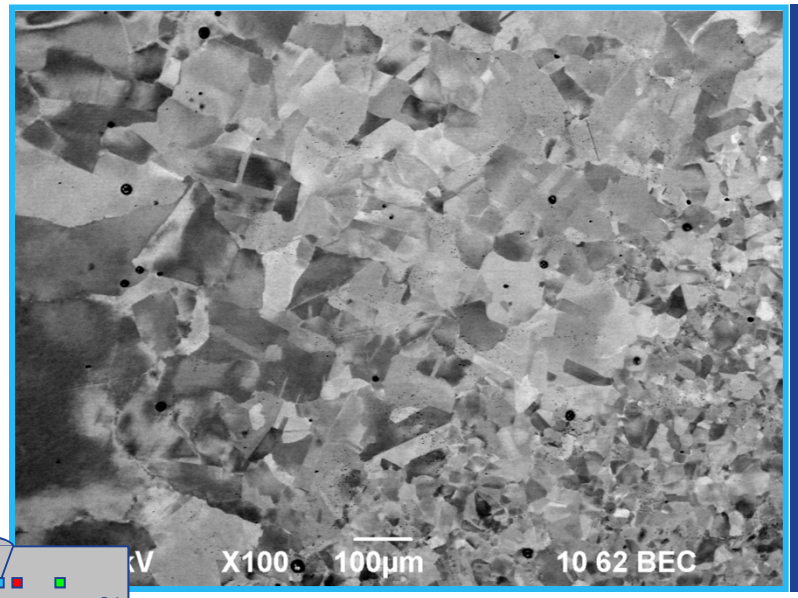


Section O1

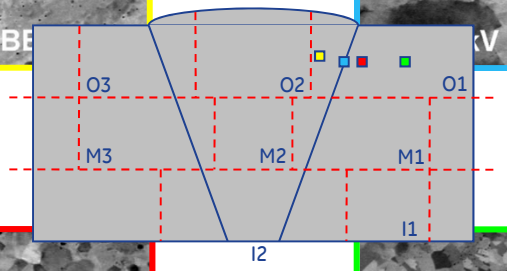
BSE Images: 100x

O1: Void in Weld

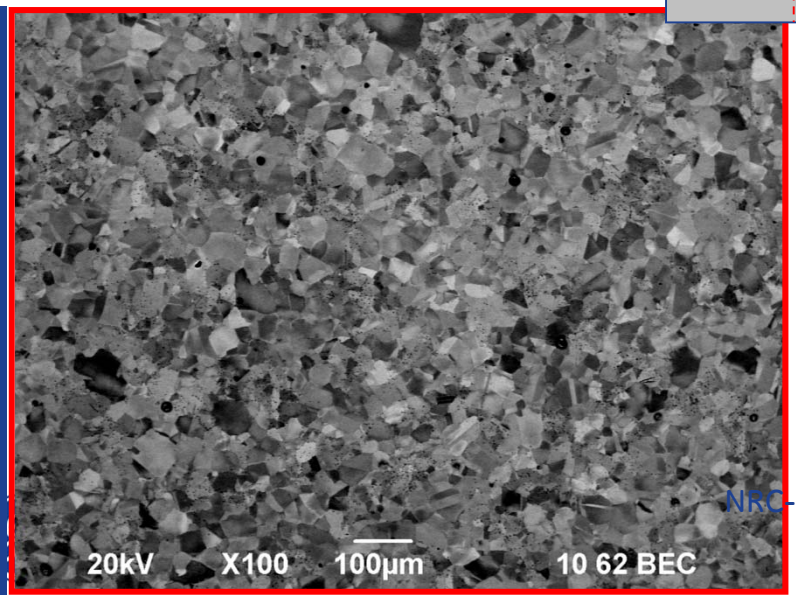


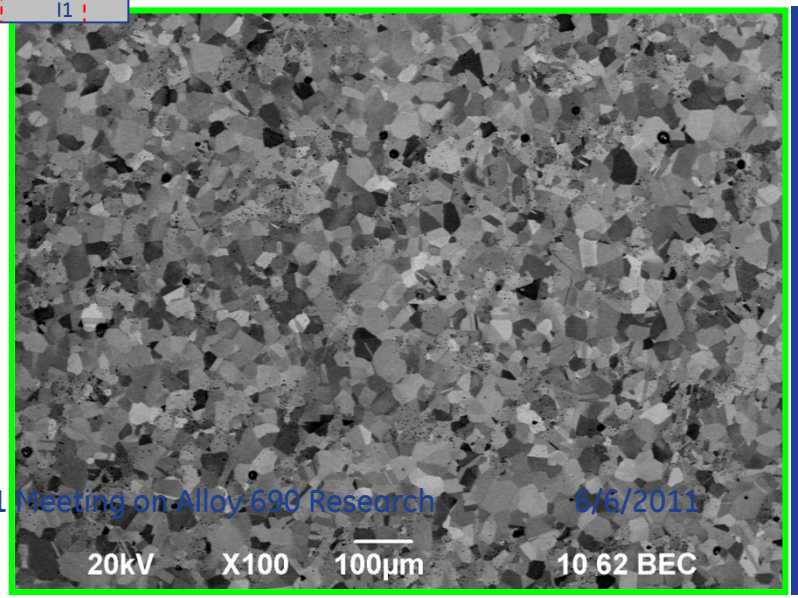


O1: "Mid" interface



O1: 3mm from interface



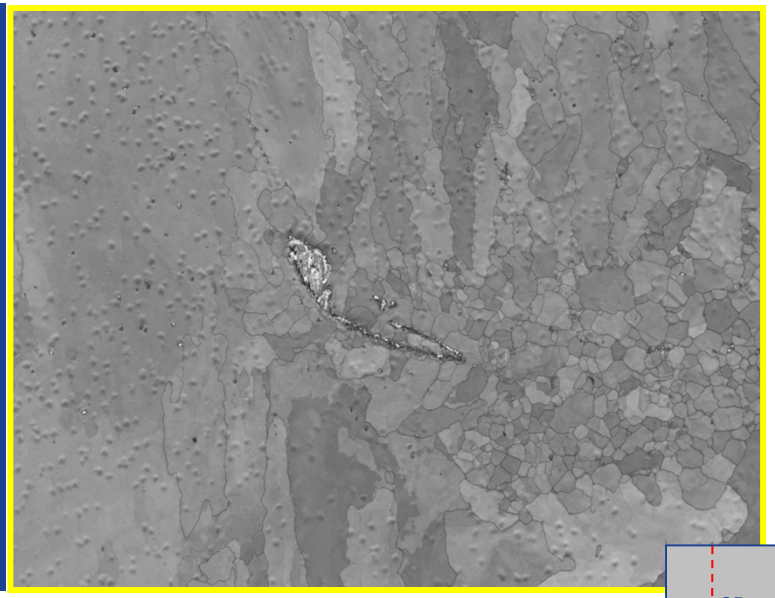


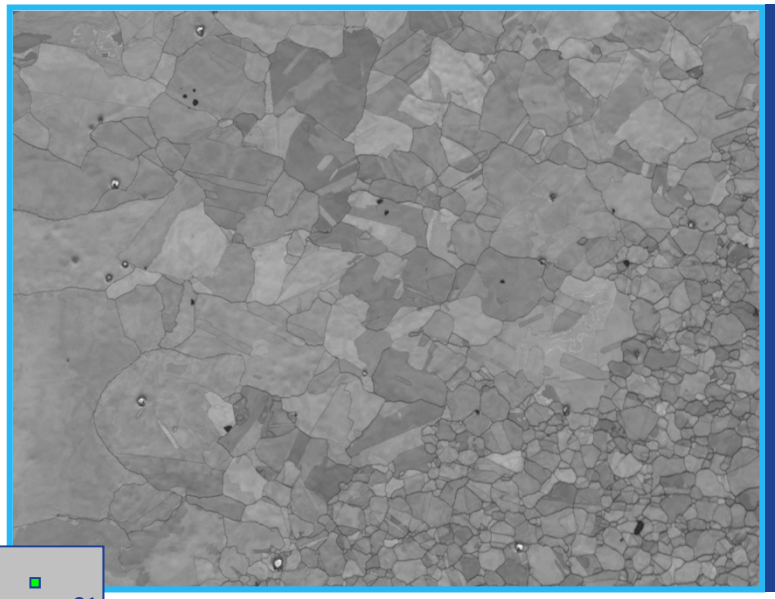
O1: 12mm from interface

Section O1

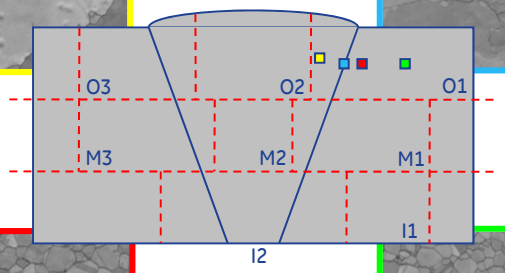
Band Contrast Maps

O1: Void in Weld

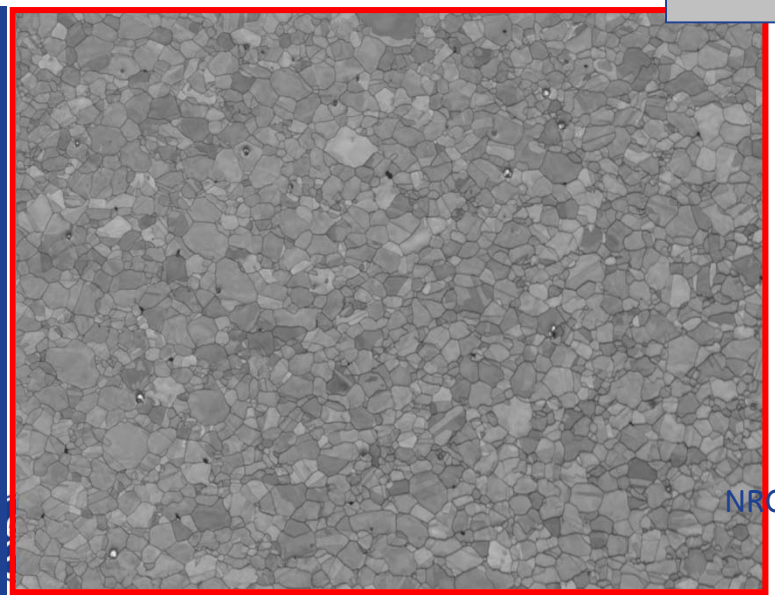


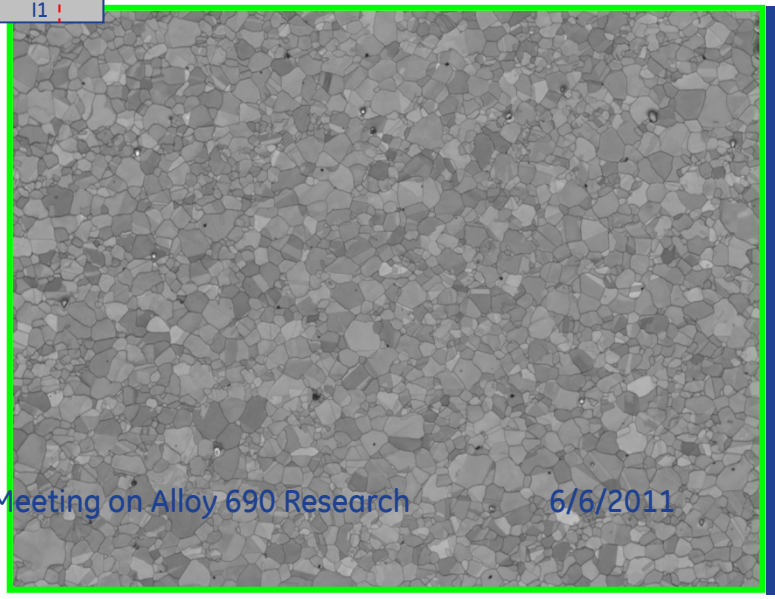


O1: "Mid" interface



O1: 3mm from interface



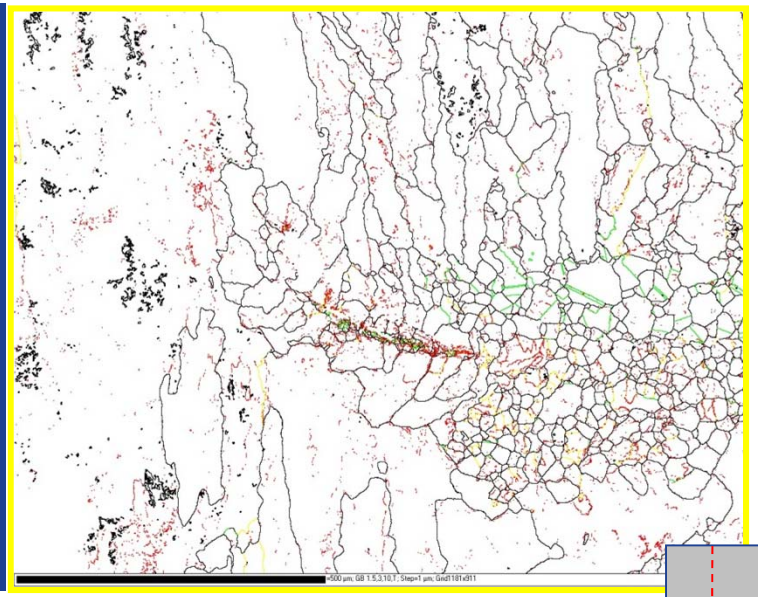


O1: 12mm from interface

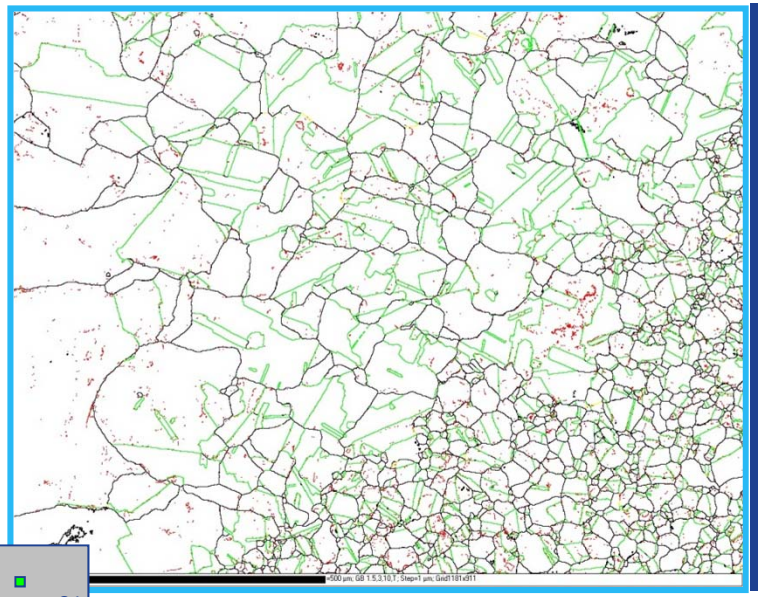
Section O1

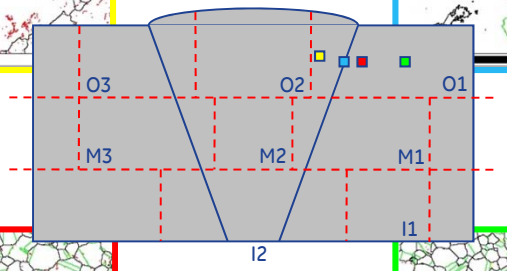
Boundary Maps

O1: Void in Weld

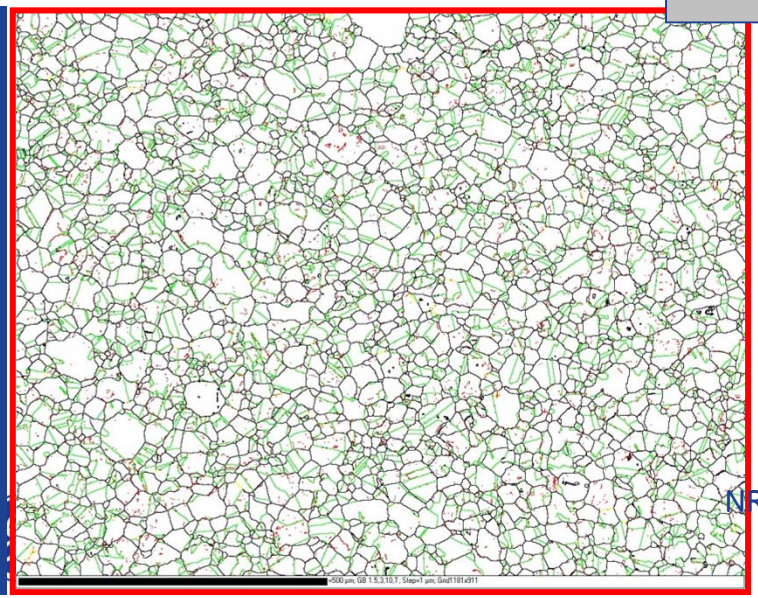


O1: "Mid" interface

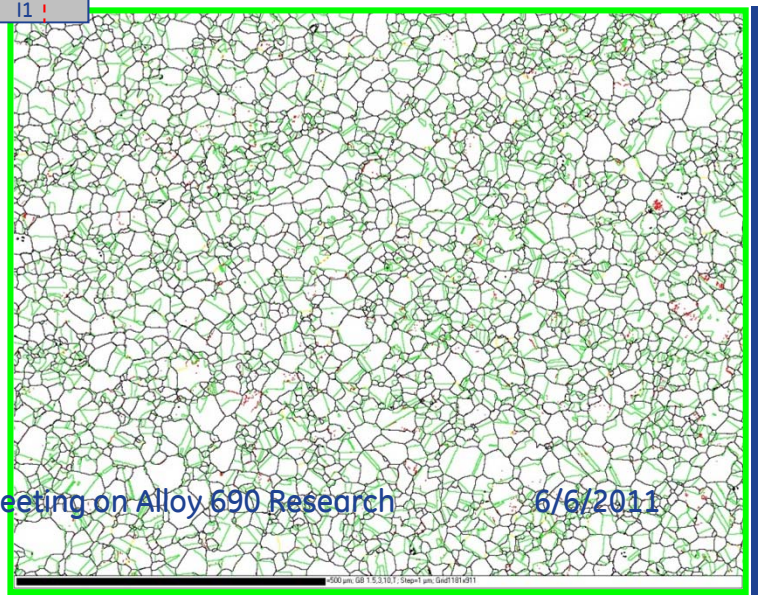




O1: 3mm from interface



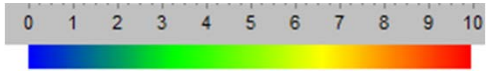
O1: 12mm from interface



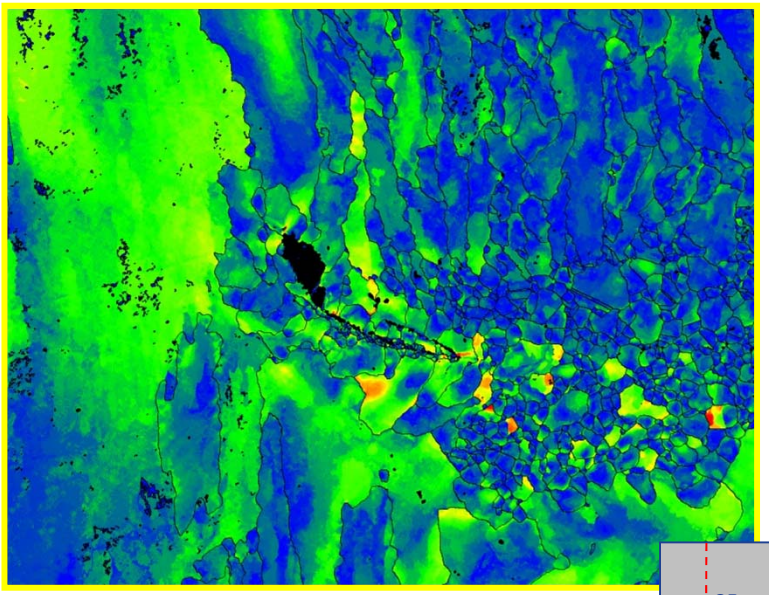
Red = 1.5°<θ<3°
Yellow = 3°<θ<10°
Black = 10°<θ<60°
Green = Twin (60°)

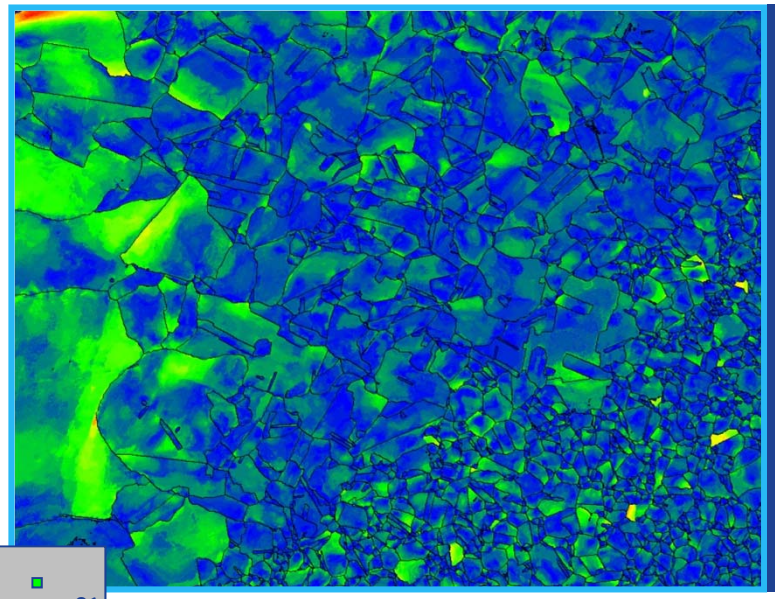
Section O1

10° Misorientation Maps

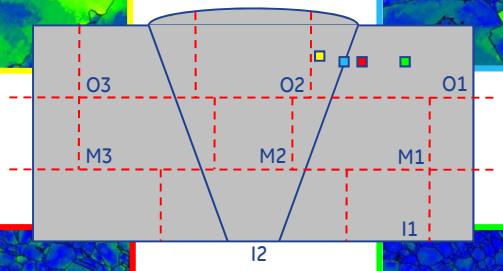


O1: Void in Weld

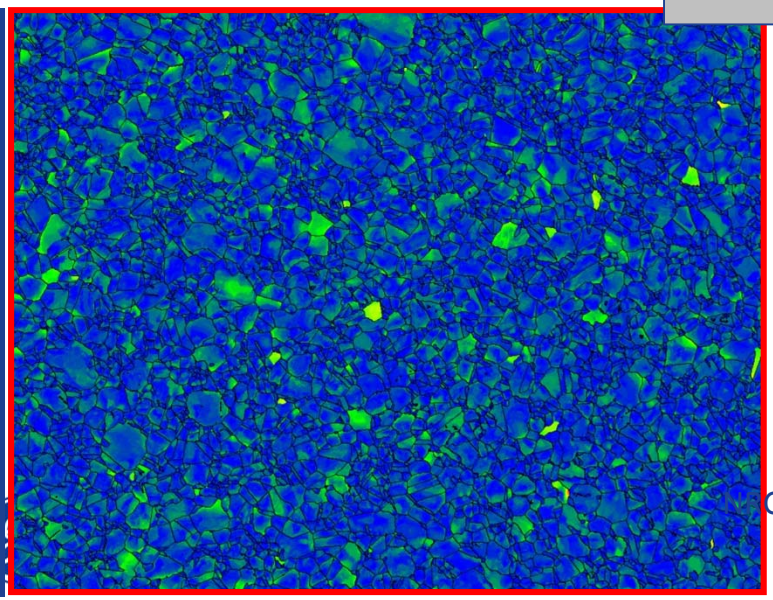


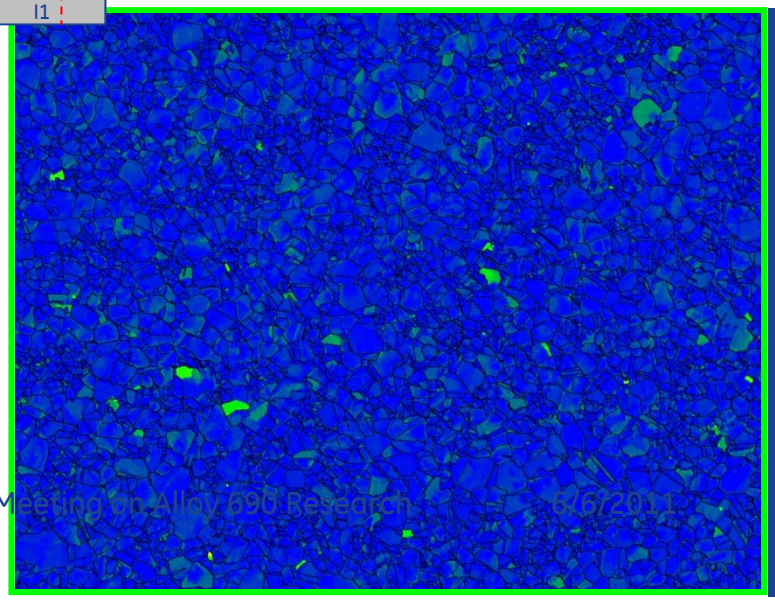


O1: "Mid" interface



O1: 3mm from interface

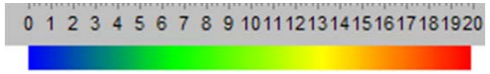




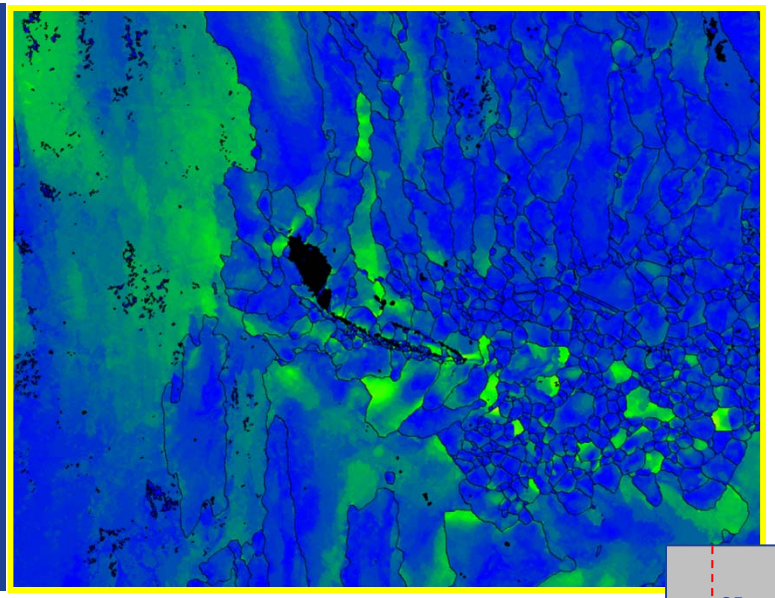
O1: 12mm from interface

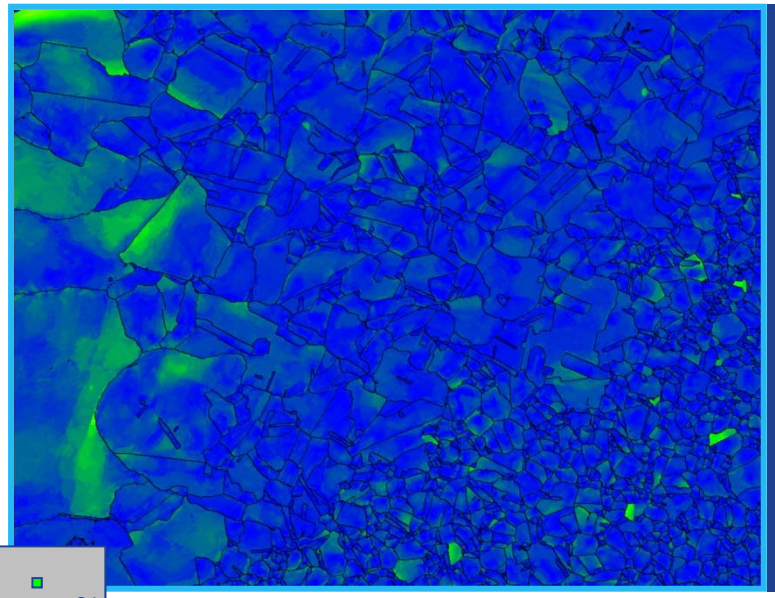
Section O1

10° Misorientation Maps

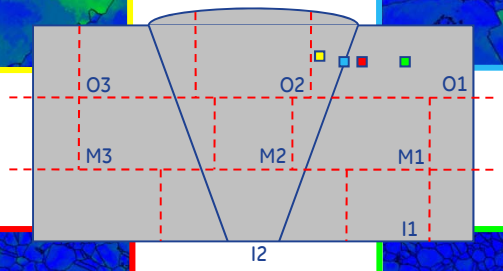


O1: Void in Weld

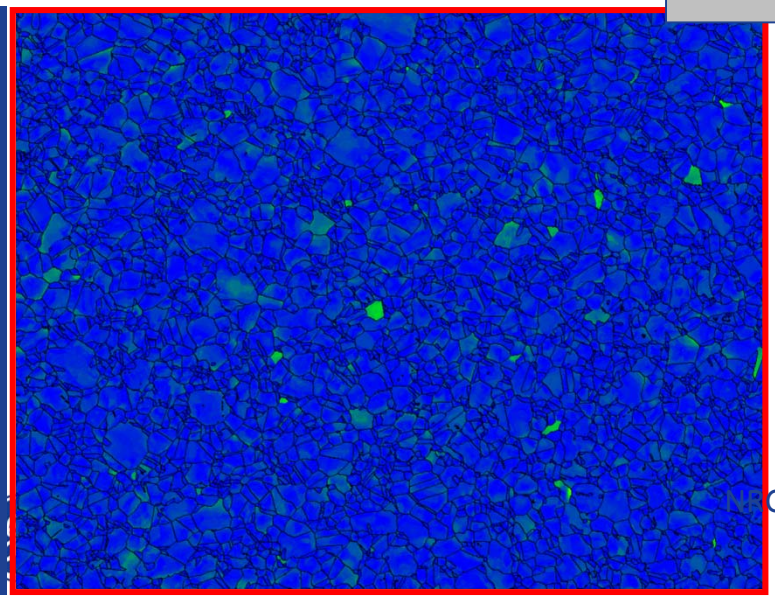


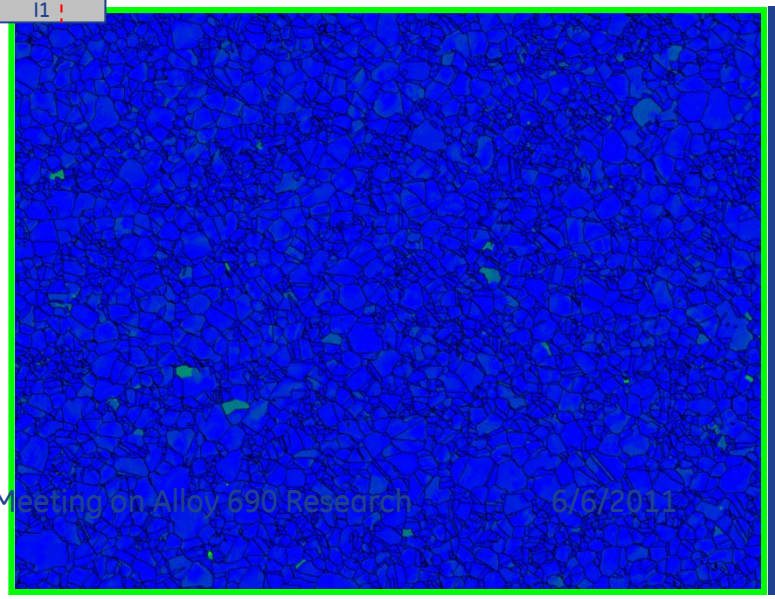


O1: "Mid" interface



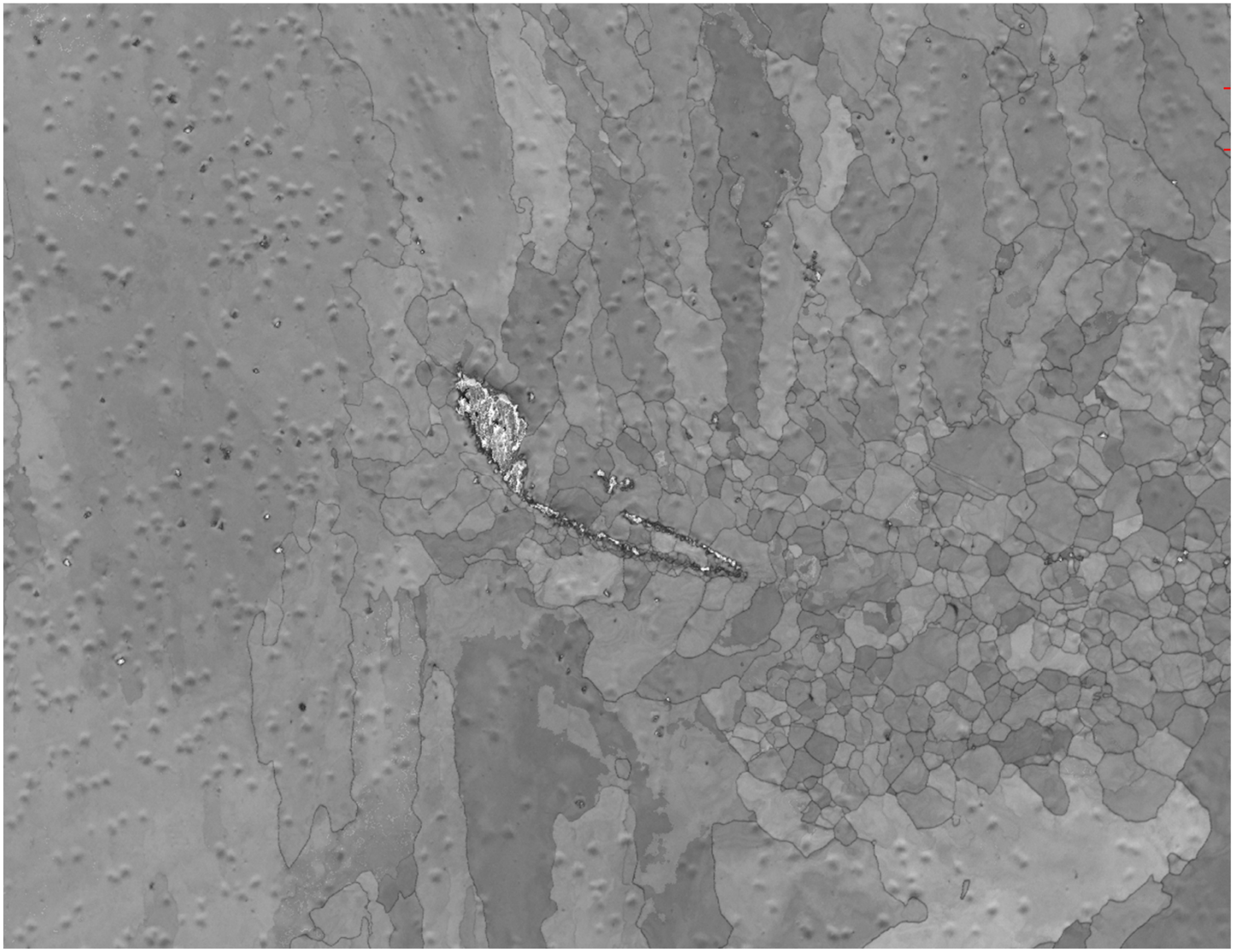
O1: 3mm from interface



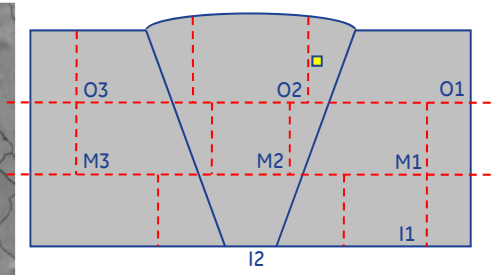


O1: 12mm from interface

Section O1: Void



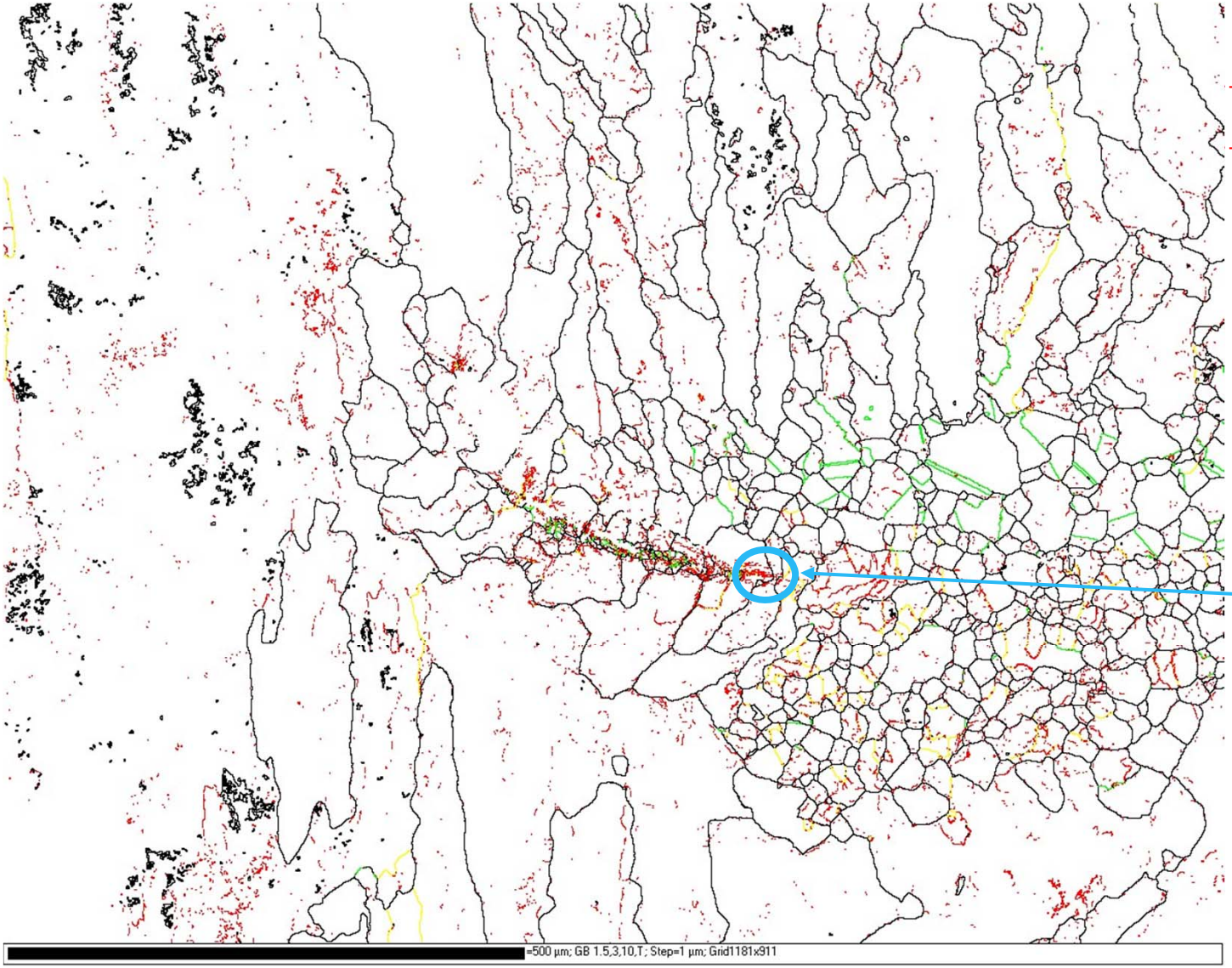
Band Contrast Map

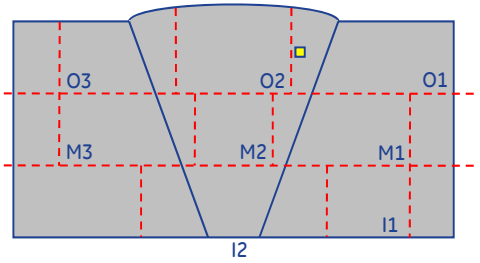


This feature is ~13.3 mm from the interface. Recrystallized grains are seen to the right of the feature, and very small recrystallized grains are observed at the bottom edge of the feature.

Section O1: Void

Band Contrast Map



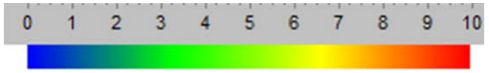


Some of the recrystallized grains on the right and at the bottom edge have formed twin boundaries (shown in green).

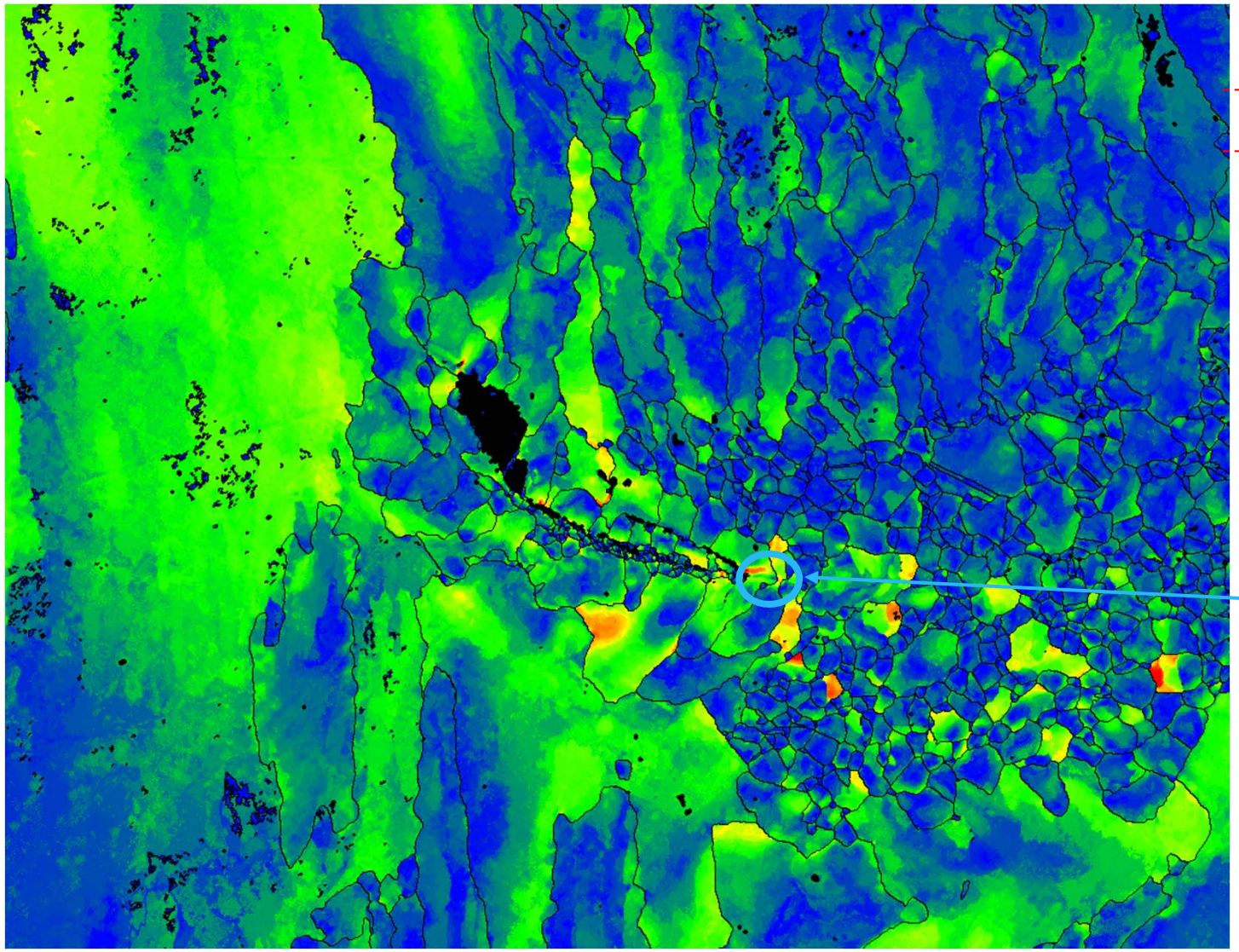
A small "plume" of low angle boundaries can be seen at the edge of the feature. This plume is nicely visualized in the misorientation map on the following slide.

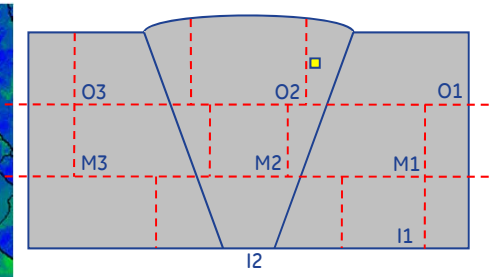
Red = 1.5°<θ<3°
Yellow = 3°<θ<10°
Black = 10°<θ<60°
Green = Twin (60°)

Section O1: Void



10° Misorientation Map





Zoom in to the area defined by the blue circle to see the "plume" of low angle boundaries at the edge of the feature.

Alloy 52 Weld / 690 Base Metal – NX2579JK
Summary

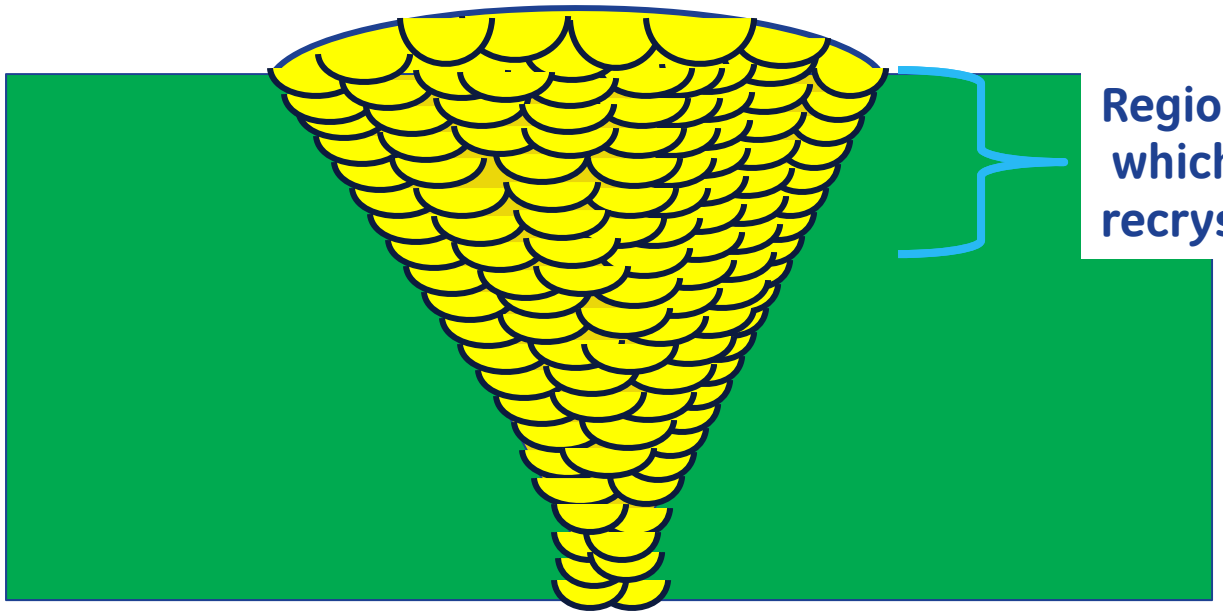
Large circular gap defect at weld interface - section 5

Small grains surround the gap on base metal side

High deformation around entire gap

Dynamic recrystallization around many weld defects in 52-type And 82 welds

Map of Dynamically Recrystallized Grains in 52-Type Weld Metals



Region of 52-type welds in which dynamically recrystallized grains are found

Summary Dynamic Recrystallization in Alloy 52 Weld Metal

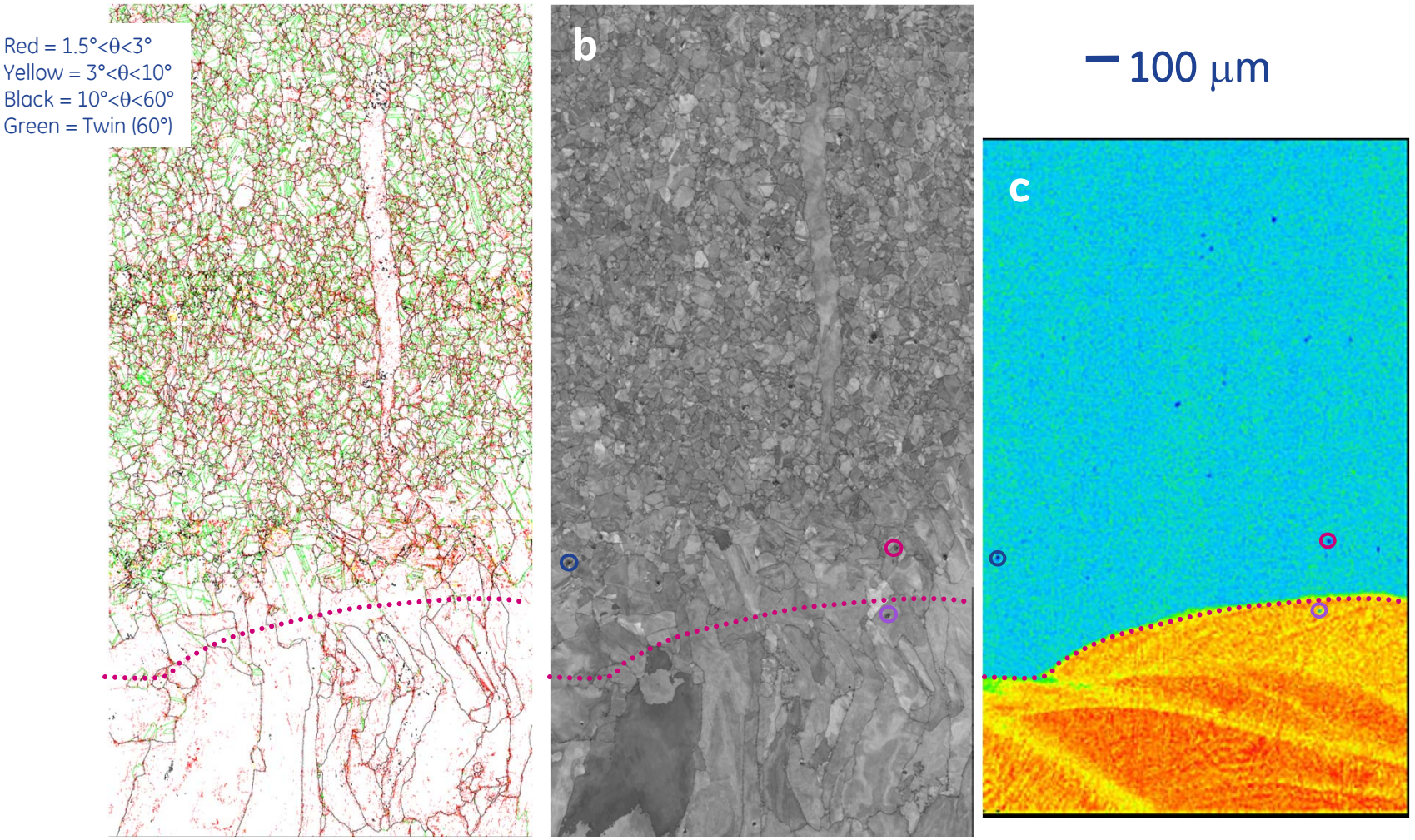
- Structure of Alloy 52 weld metal is not purely dendritic
- Regions of fine, low strain, equiaxed grains are present due to dynamic recrystallization.
- Dynamic recrystallization has been found to be localized to the upper third of the weld, presumably due to the slower cooling and higher strain rates there.
- Since dynamic recrystallization annihilates plastic strain it may be associated with the lower residual plastic strains found at weld interfaces in regions under weld caps.
- There is evidence that it occurs in regions between weld passes and in association with weld defects – association with regions of high residual plastic strain.
- Dynamic recrystallization has been observed in Alloy 82-type compositions but appears to be more prevalent in Alloy 52-type chemistries.

Alloy 690

Residual strain in base metal

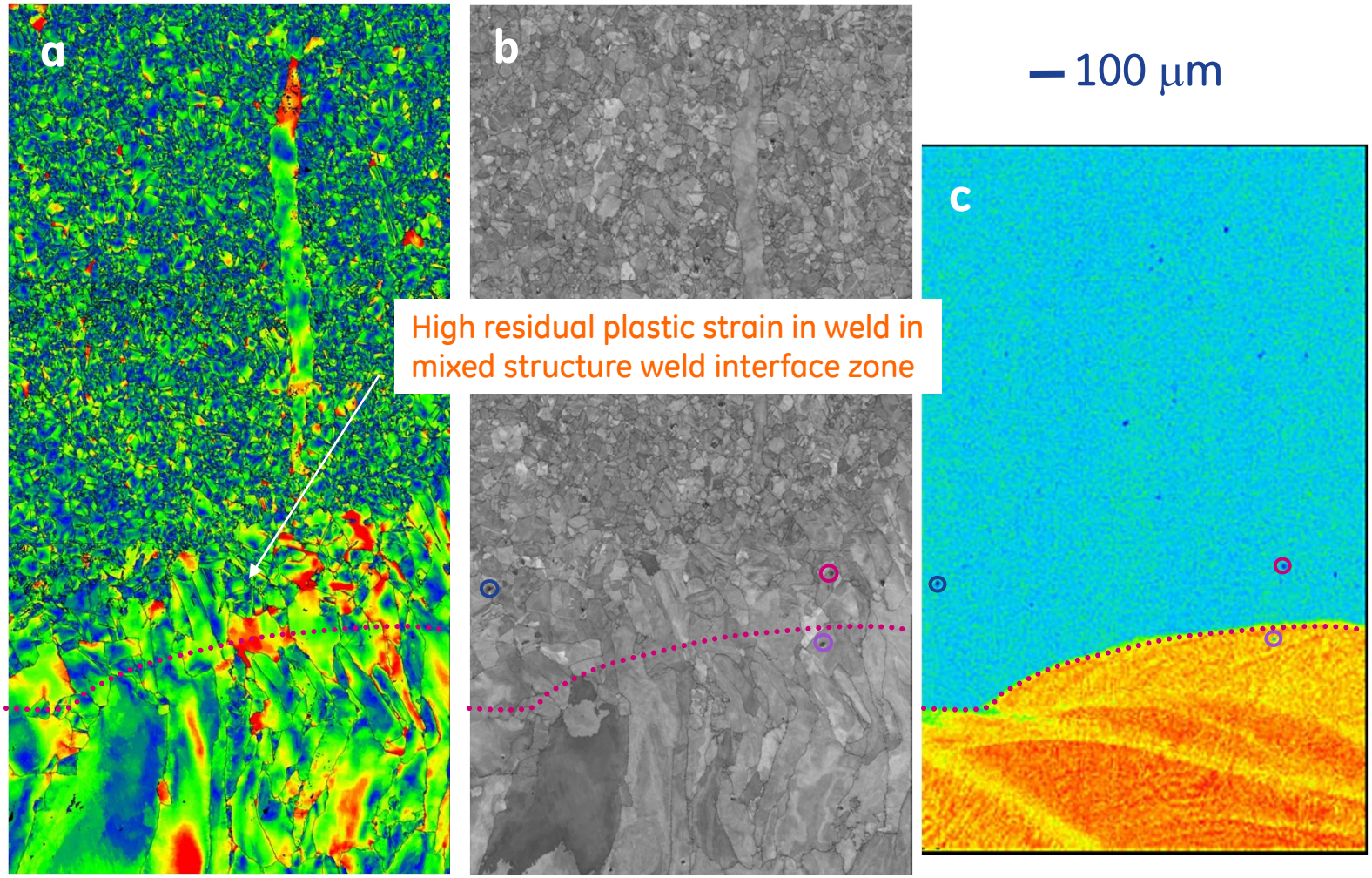
Microstructural features in base metal

19508A 52M – Middle Weld Interface Sample
(a) Grain Boundary Map, (b) Band Contrast Map, and (c) EPMA Mn Map



Postulate epitaxial growth of dendrites into the alloy 690 base metal interfacial Zone – no chemical composition change in 690 where dendrites growth from 52 into 690

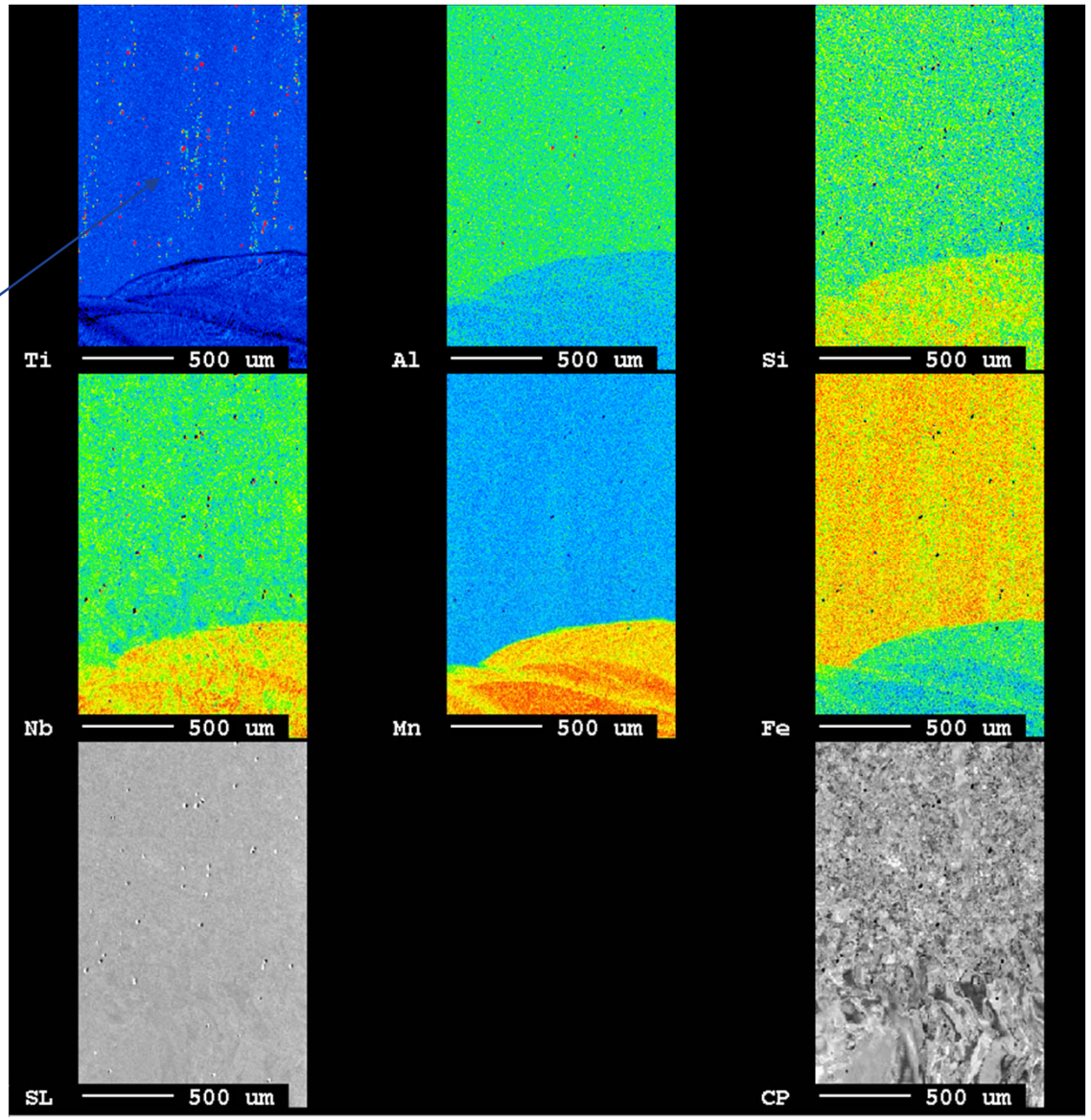
19508A 52M – Middle Weld Interface Sample
(a) Misorientation Map, (b) Band Contrast Map, and (c) EPMA Mn Map

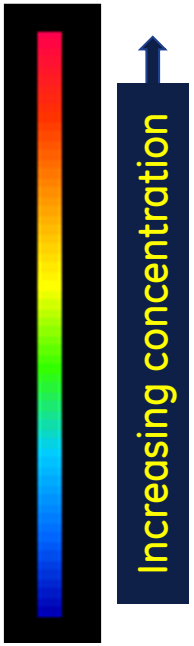


Postulate epitaxial growth of dendrites into the alloy 690 base metal interfacial zone – no chemical composition change in 690 where dendrites growth from 52 into 690

19508A 52M – Middle Weld Interface Sample
EPMA Maps

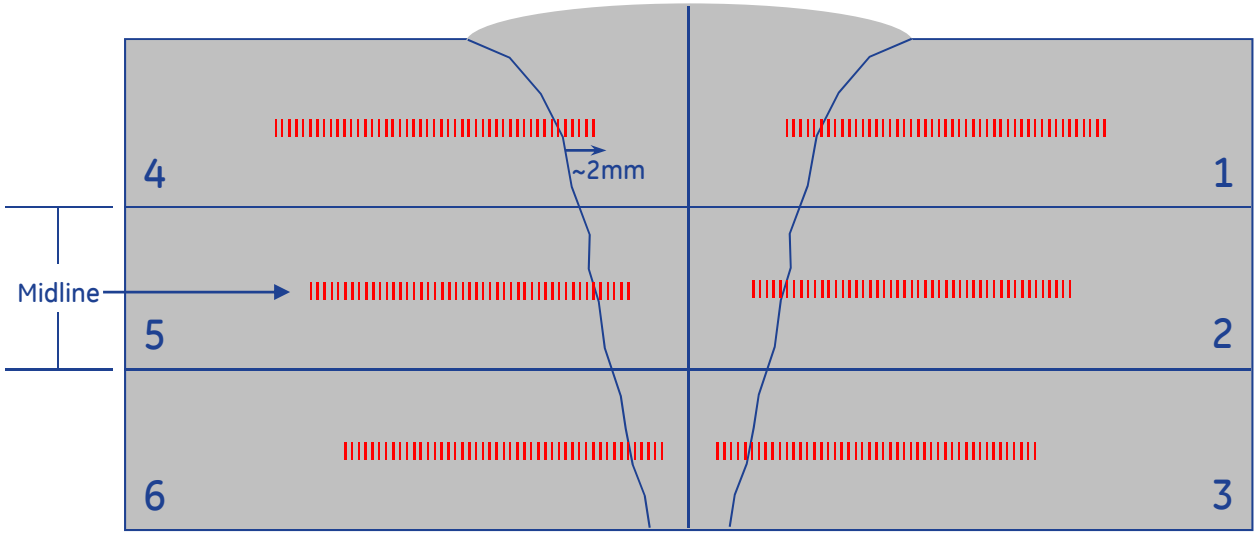
TiC carbide banding





Comparison MLTS-3-Cr Alloy 690 with 52 Filler Metal

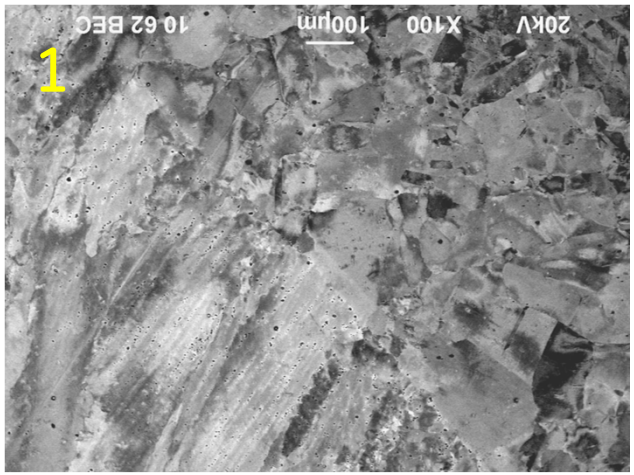
Sample MLTS-3-Cr Description of Measurements

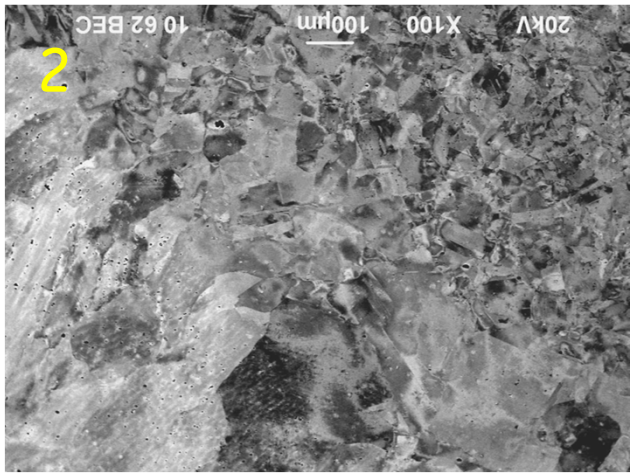


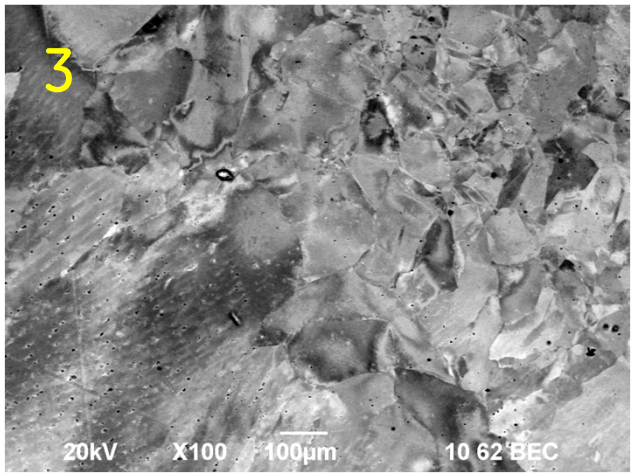
- The slice was cut into 6 individual samples (labeled 1 – 6 above)
- Linescan measurements were taken at the midline of the short axis of each sample
- Each measurement was started ~2mm below the weld interface to include a small amount of data from the weld region
- Measurements were taken as far into the base material as was allowed by the geometry of the microscope chamber or as far as the electropolished edge would allow

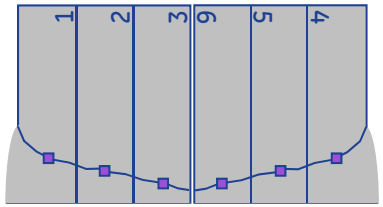
Sample MLTS-3-Cr Images

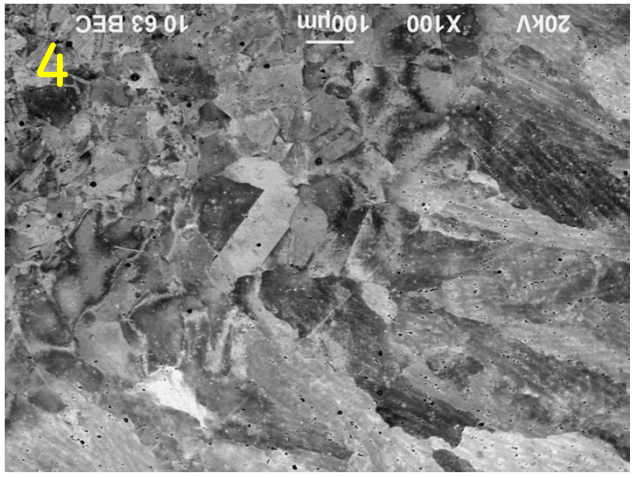
Interface: 100x

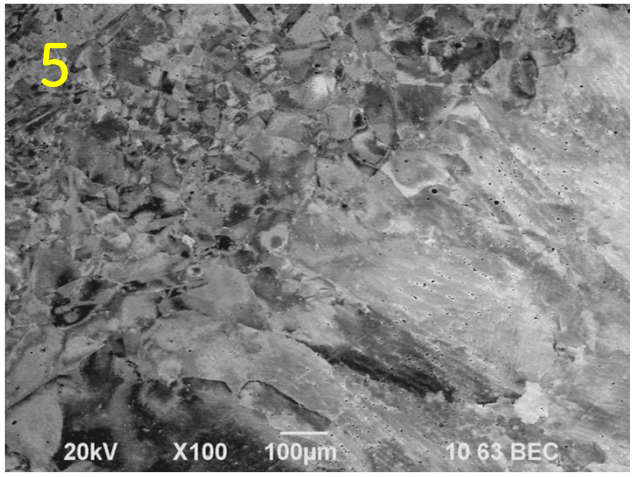


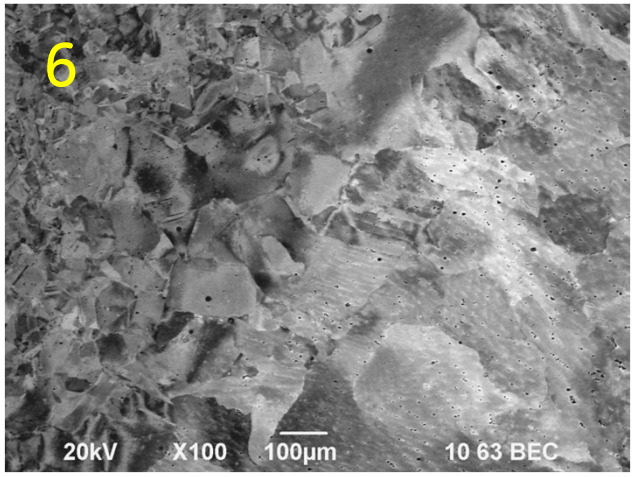






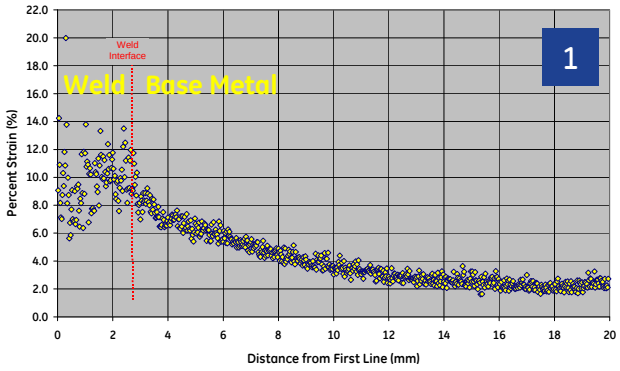


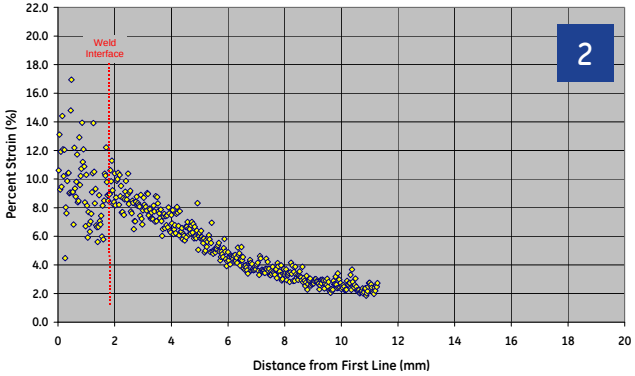


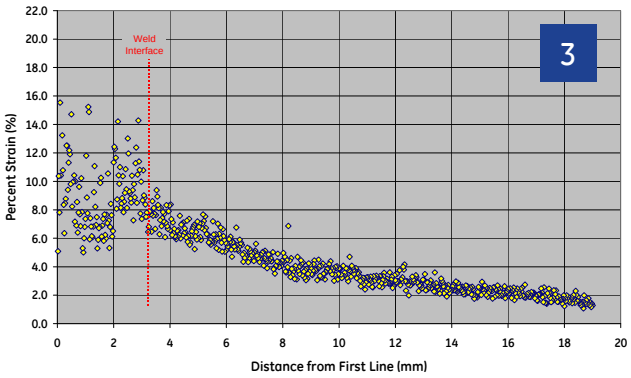


Alloy 52 Weld / 690 Base Metal – MLTS-3-Cr

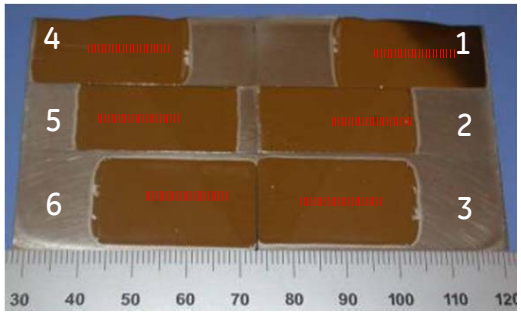
Plastic Strain Plots

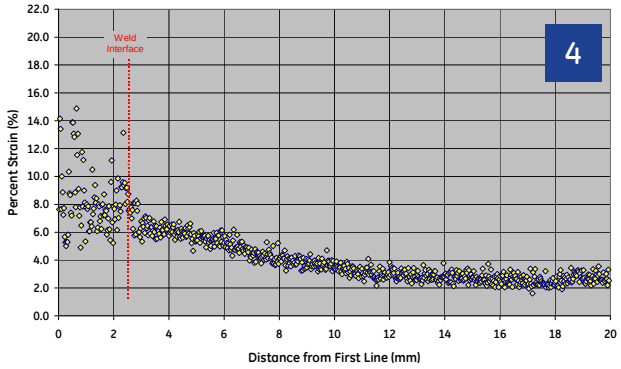


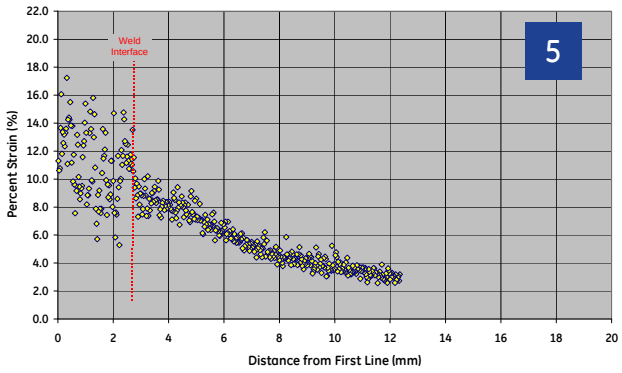


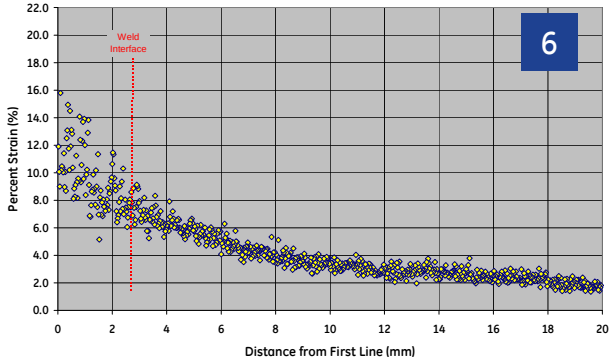


The vertical red dotted lines indicate the approximate locations of the weld interface



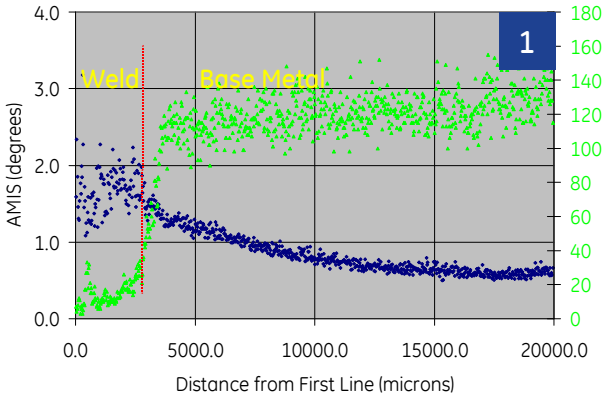


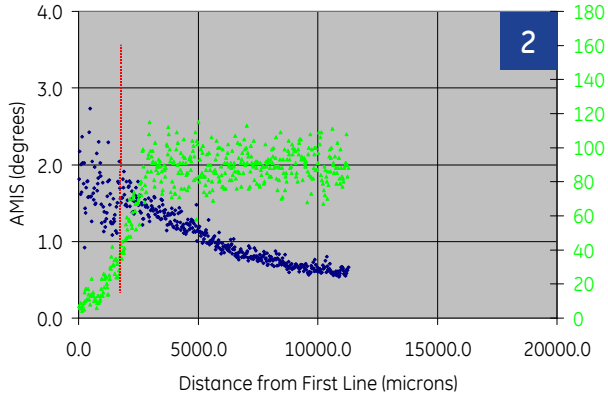


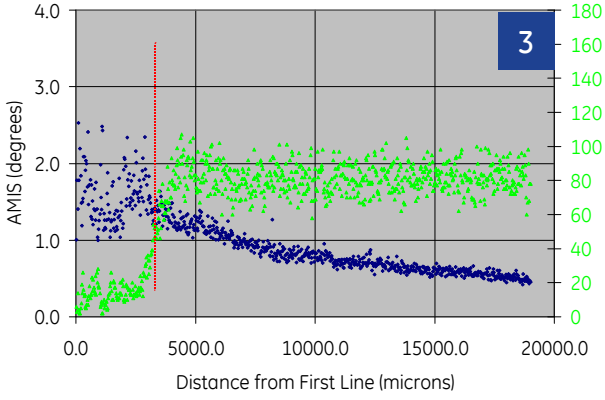


Alloy 52 Weld / 690 Base Metal – MLTS-3-Cr

AMIS and No. of Segments Plots



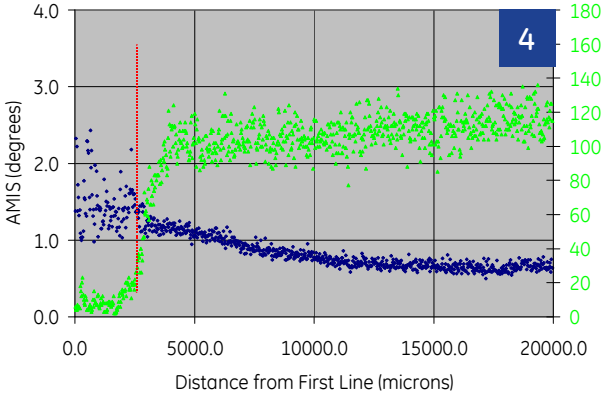


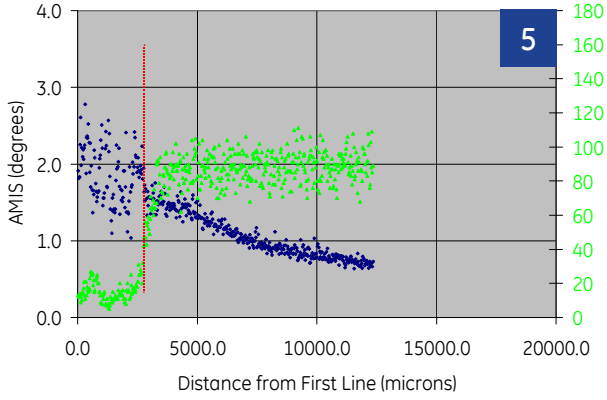


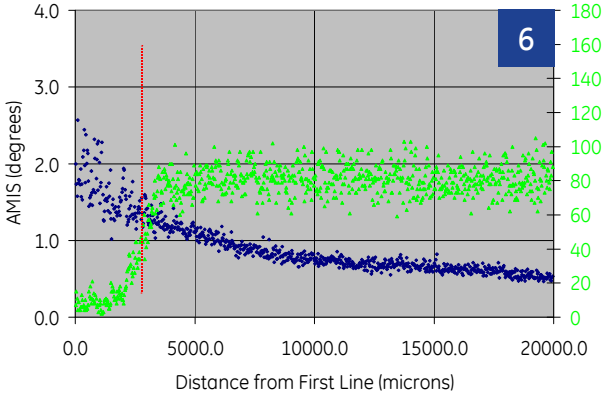
Number of segments – inversely related to grain size

Weld top → Root

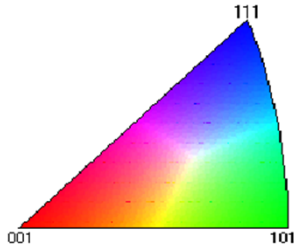
AMIS
Number of Segments





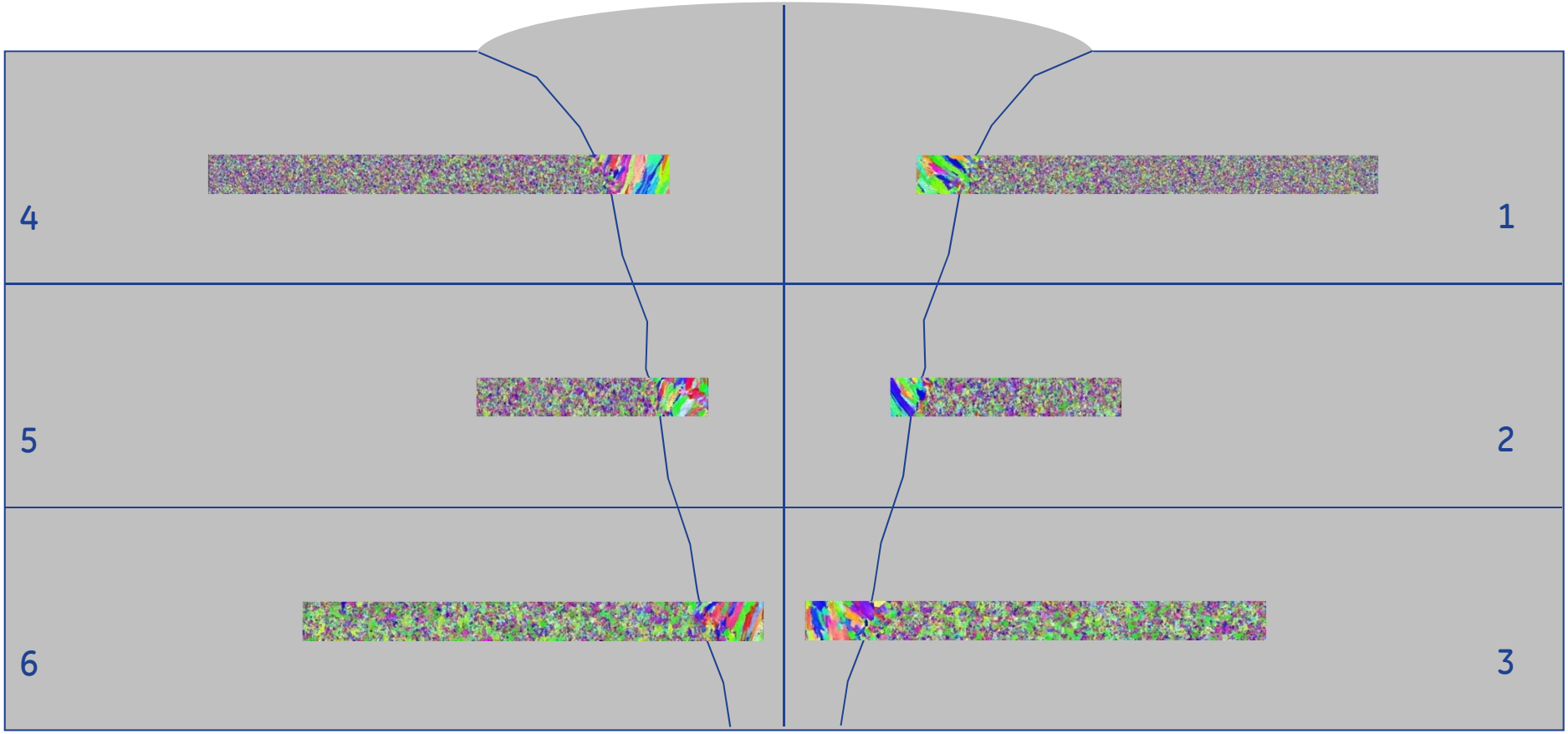


Sample MLTS-3-Cr



IPFx Maps

COLORED ORIENTATION || X AXIS



Sample MLTS-3-Cr

IPFy Maps

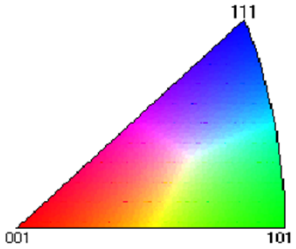
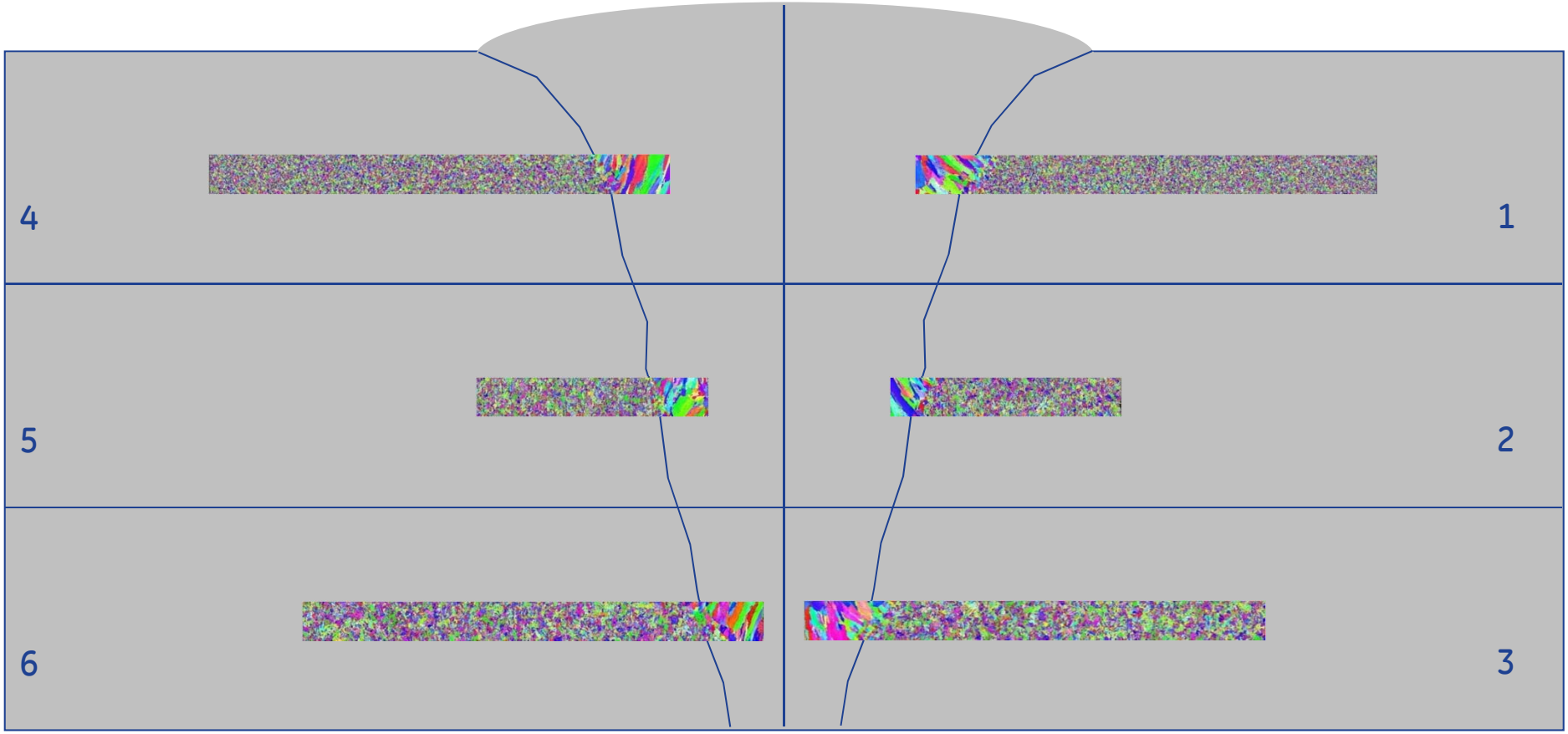
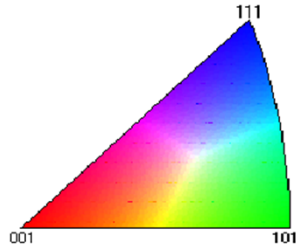


Plate microstructure Changes through thickness

COLORED ORIENTATION || Y AXIS

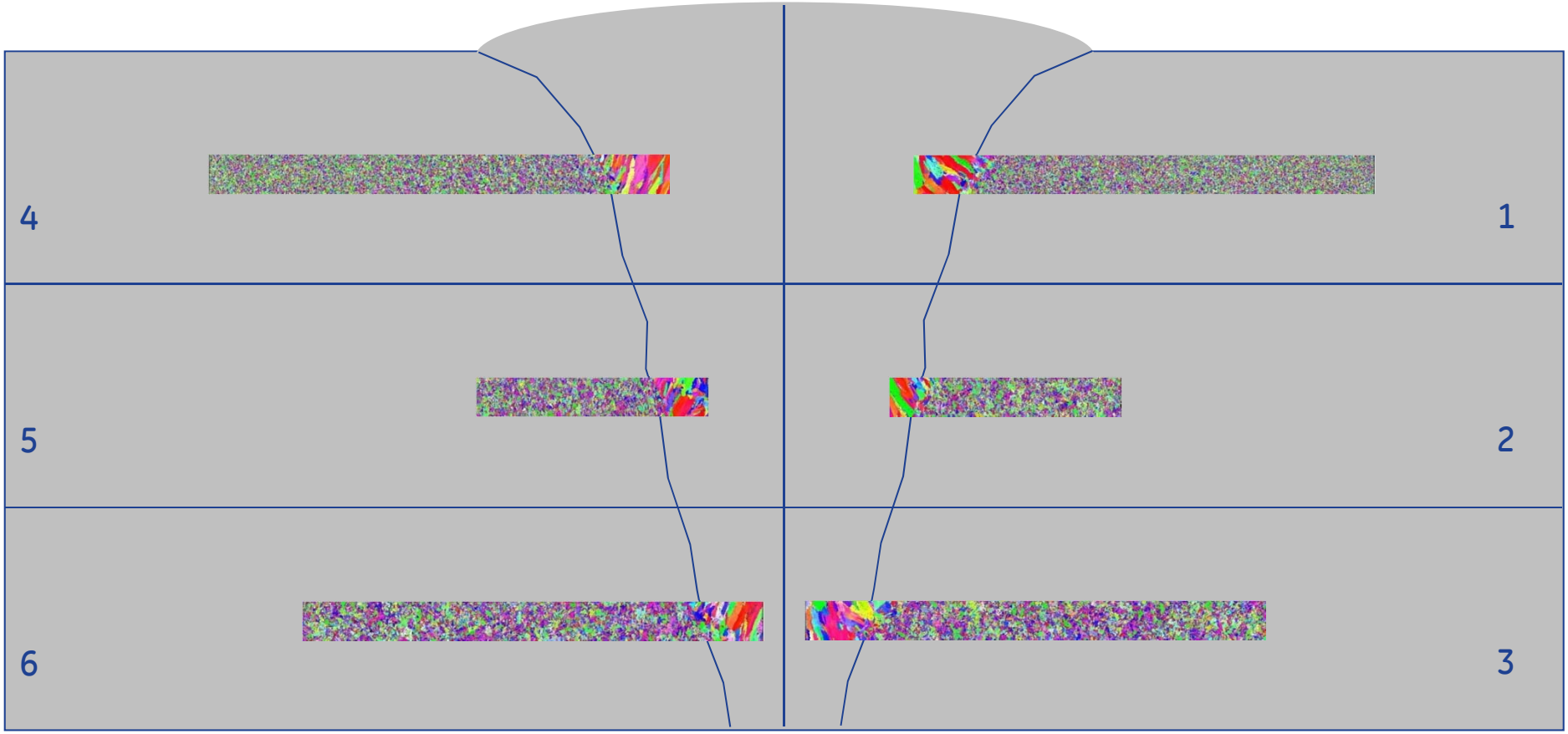


Sample MLTS-3-Cr



IPFz Maps

COLORED ORIENTATION || Z AXIS



Alloy 52 Weld / 690 Base Metal – MLTS-3-Cr
Summary

No banding in any of the sections

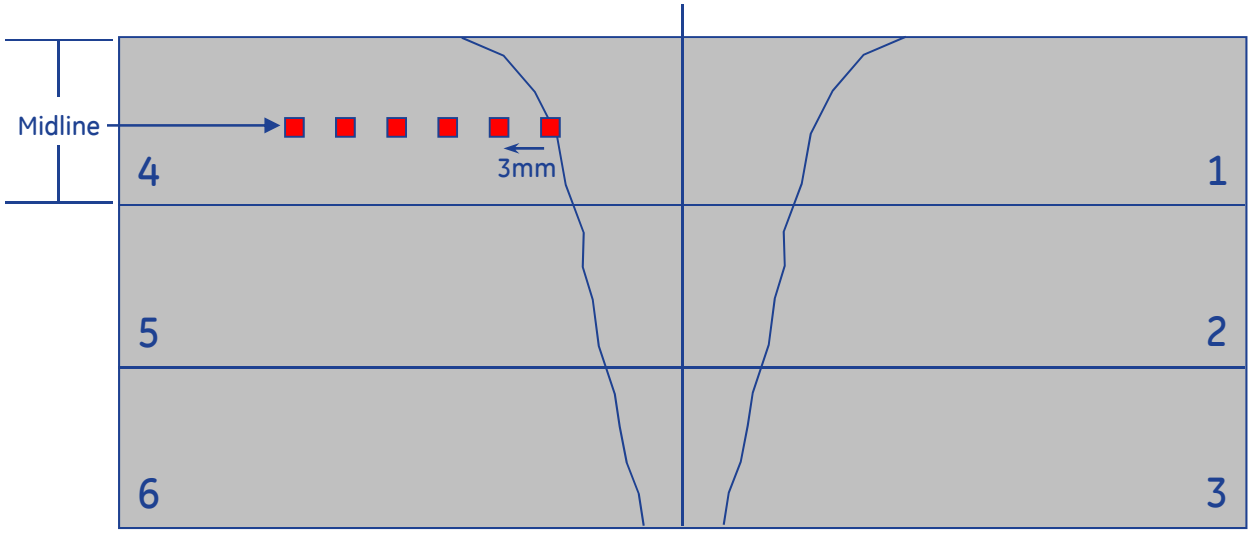
Grain size larger at the root of weld than at the top

Some texture in sections 3 and 6

Comparison Weldment Sample WC10E7 Alloy 690/152

Sample WC10E7-4

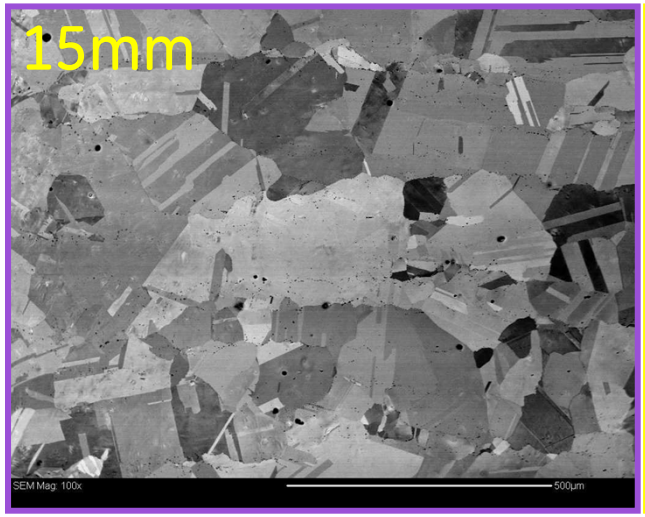
Description of Map Measurements

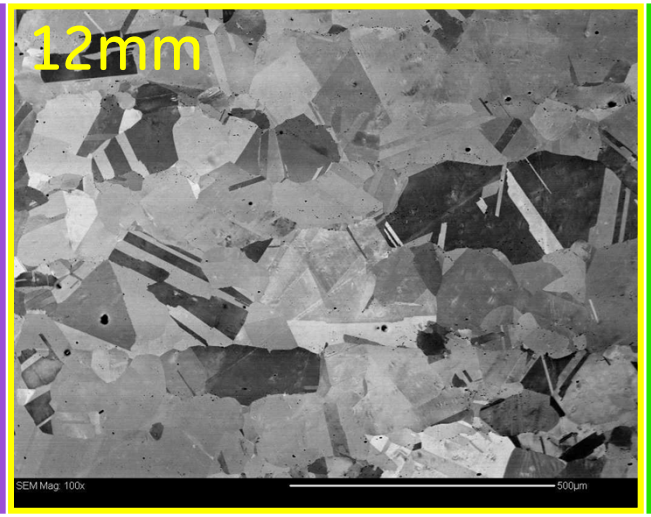


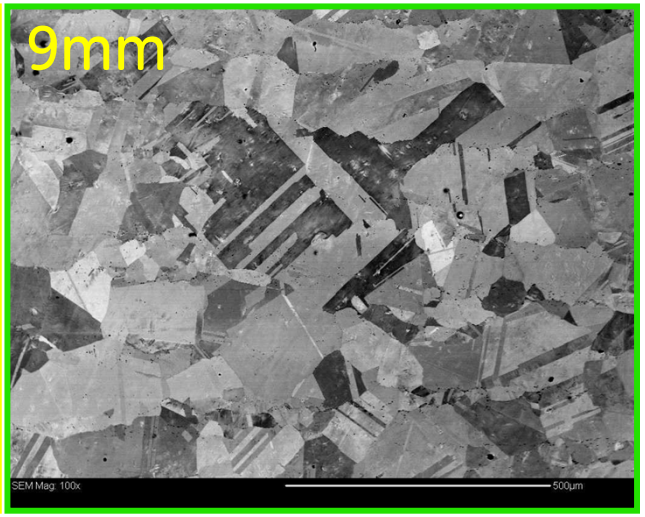
- Section 4 was measured in 6 locations: Interface, and 3mm, 6mm, 9mm, 12mm, 15mm from the interface
- Map measurements were taken at the midline of the short axis of each sample

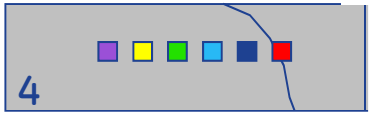
Sample WC10E7-4

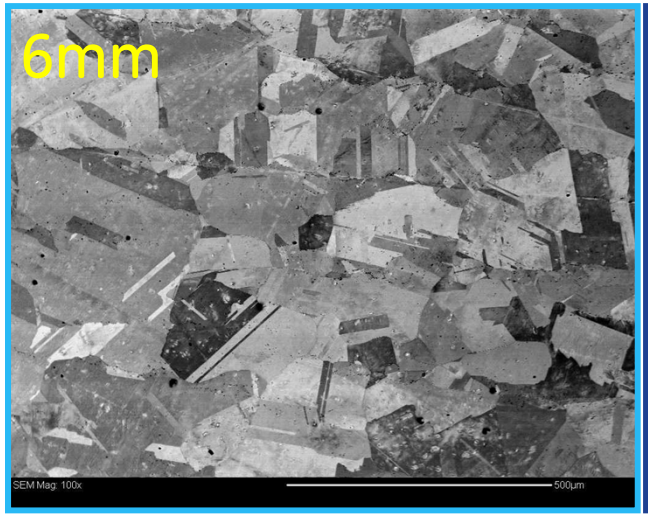
BSE Images: 100x

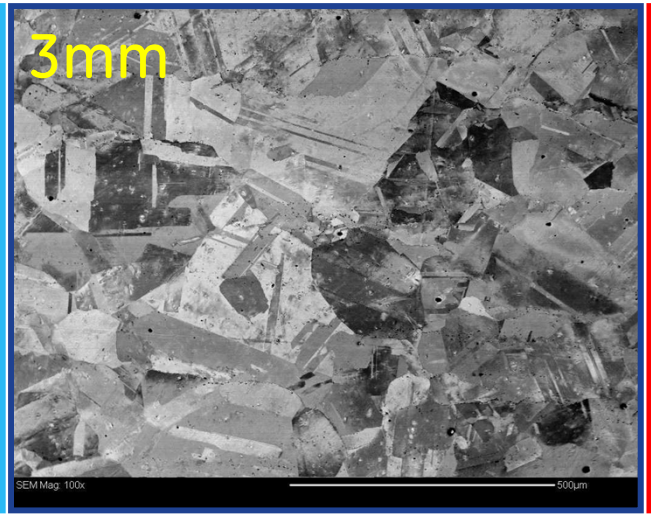






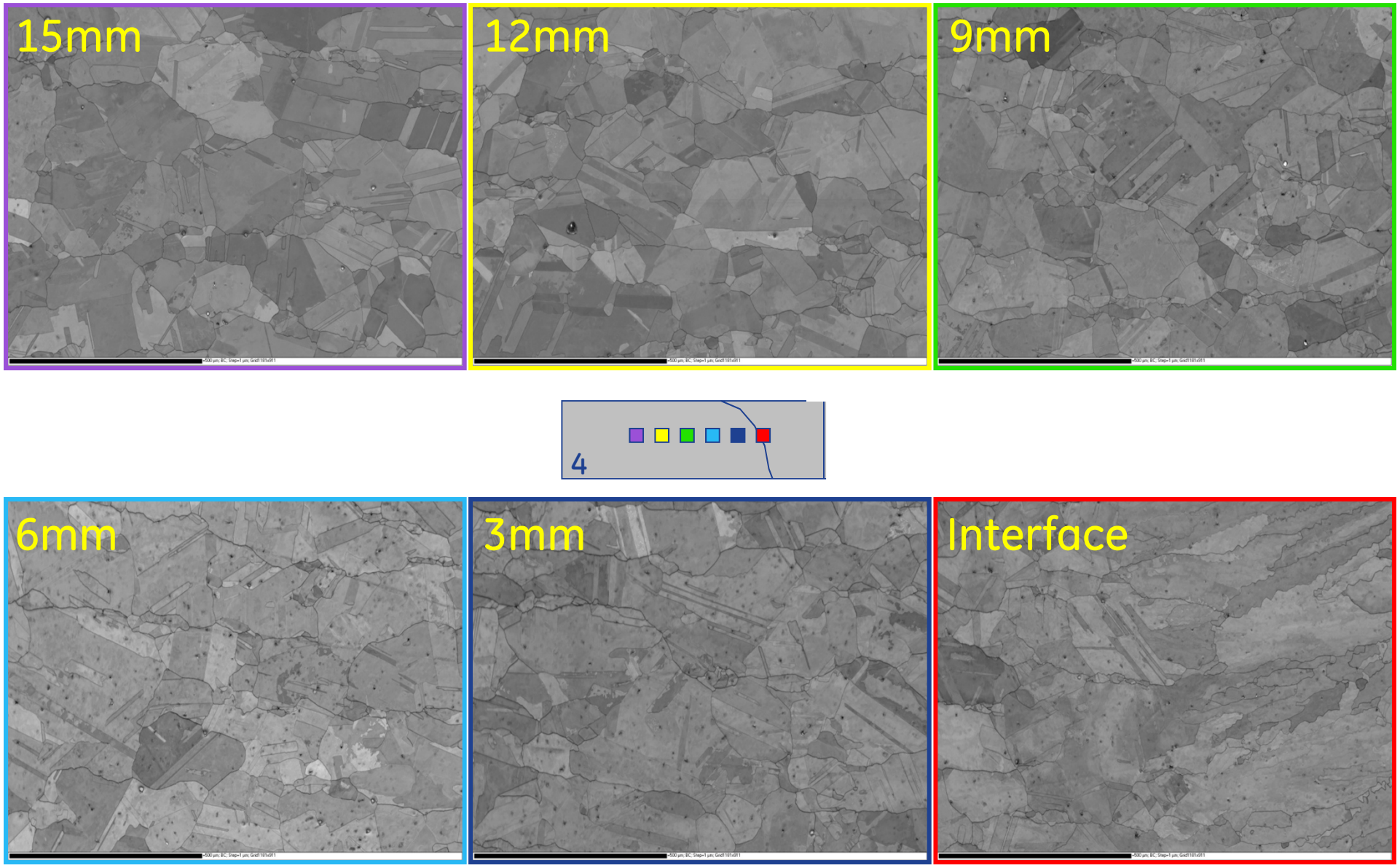






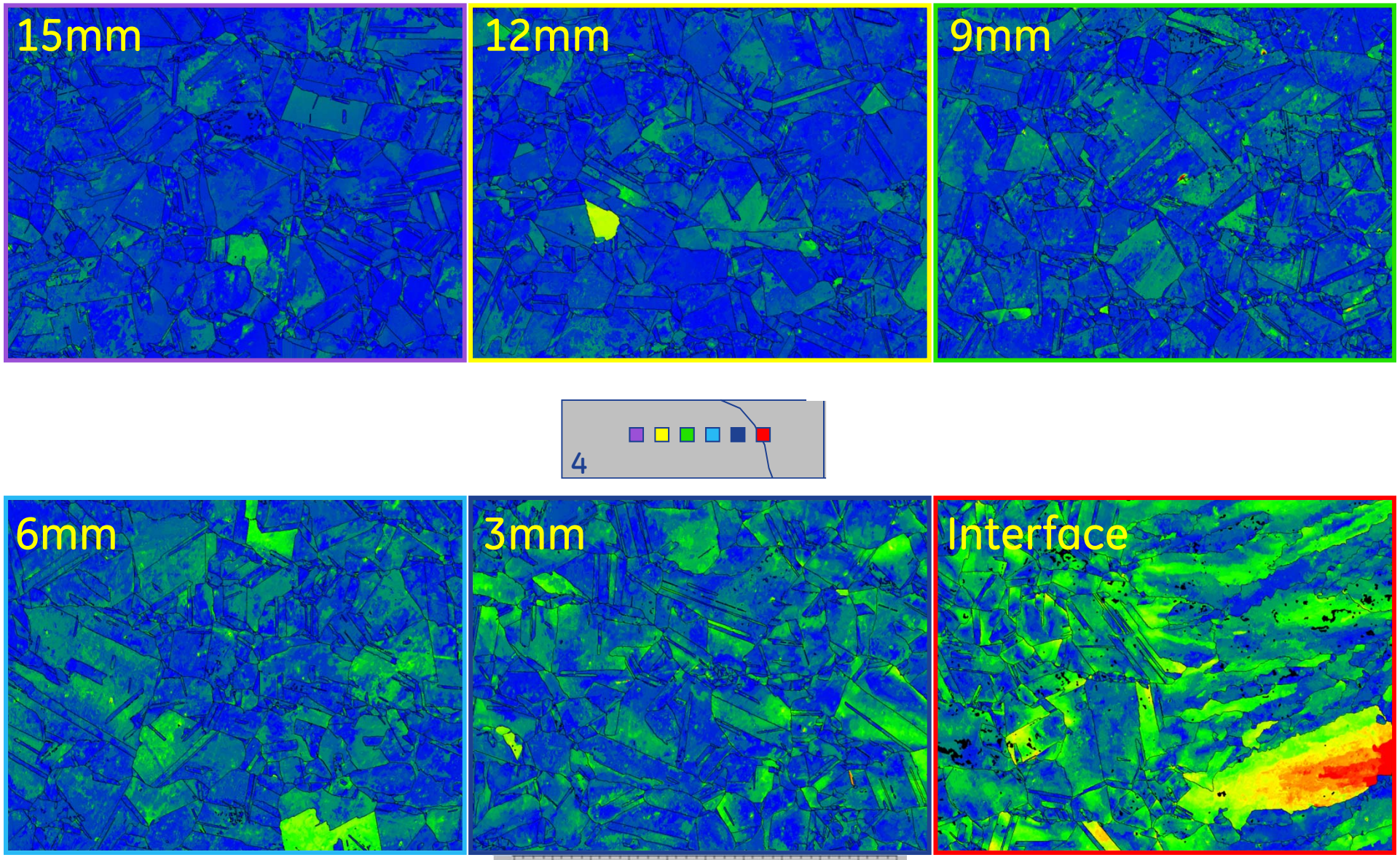
Sample WC10E7-4

Band Contrast Maps



Sample WC10E7-4

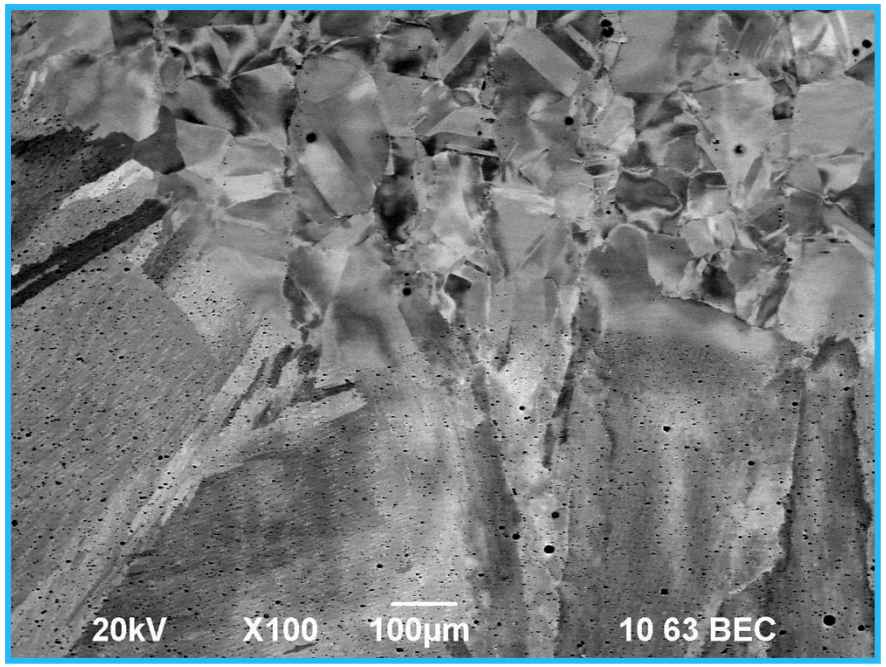
10° Misorientation Maps

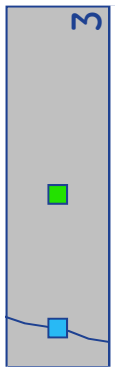


Sample WC10E7-3

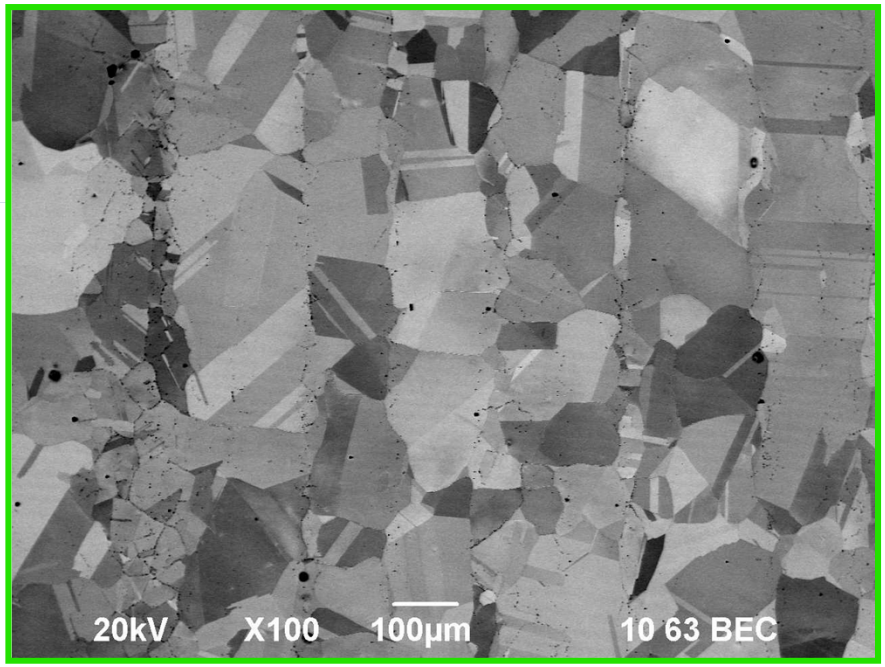
BSE Images: 100x

Interface





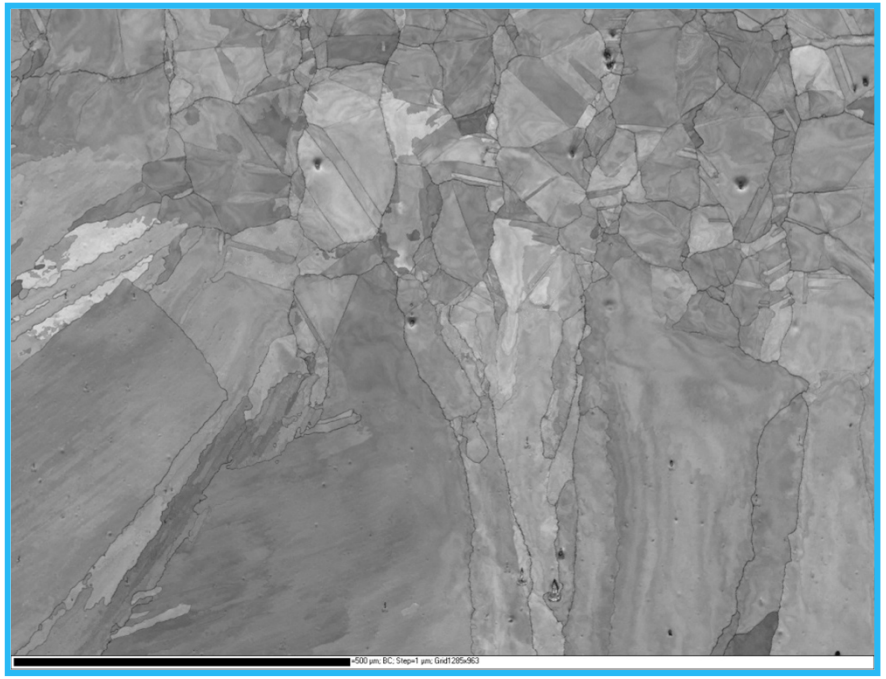
12mm

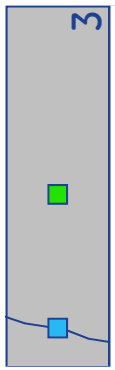


Sample WC10E7-3

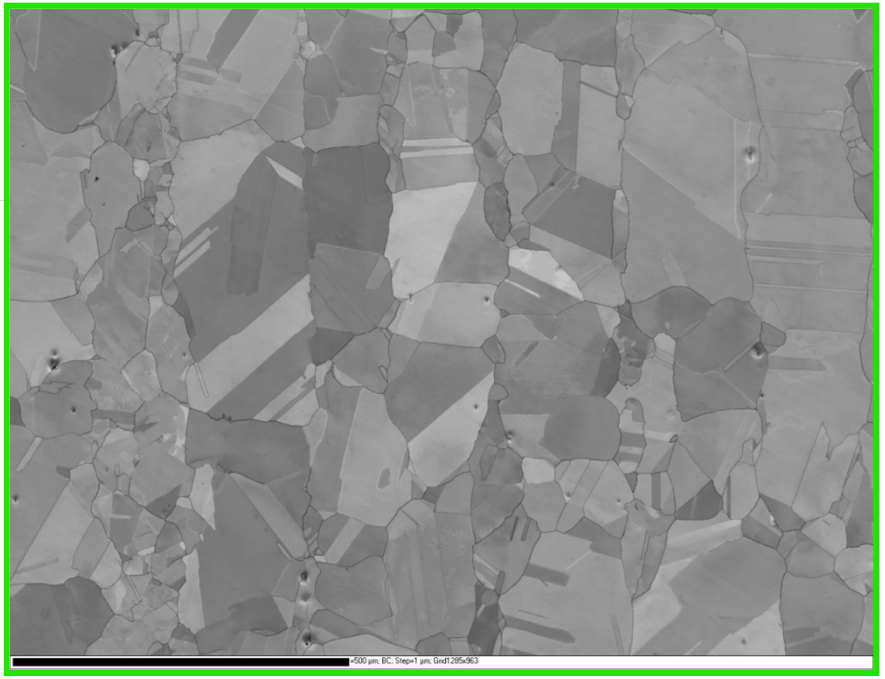
Band Contrast Maps

Interface





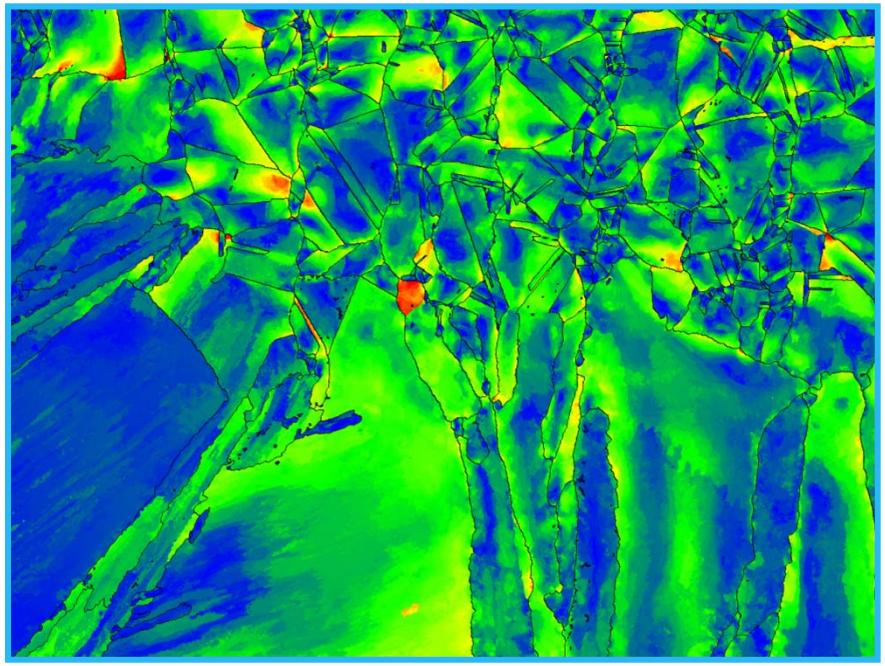
12mm

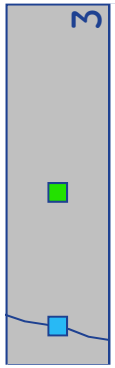


Sample WC10E7-3

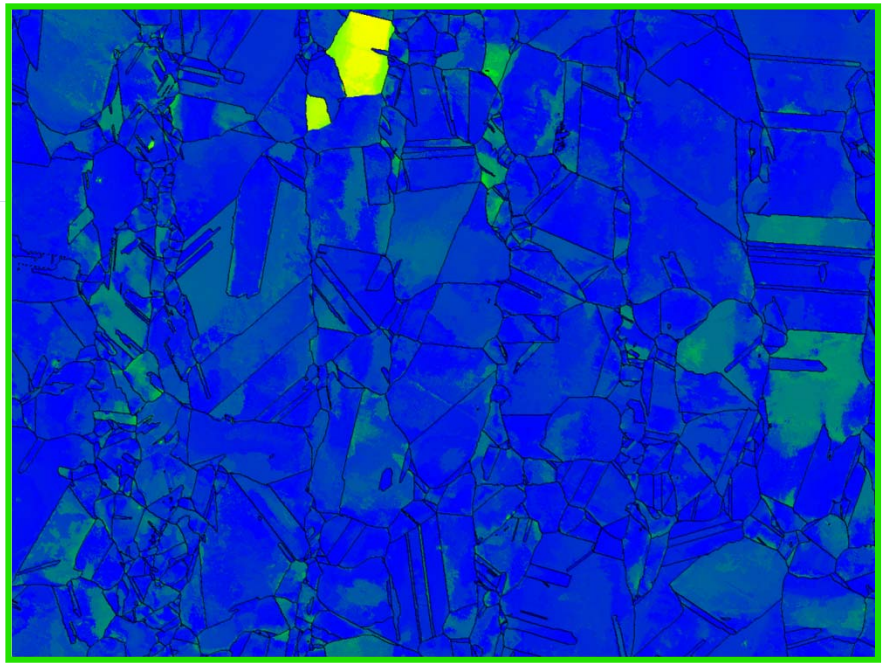
10° Misorientation Maps

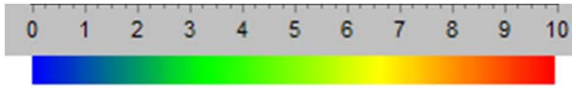
Interface





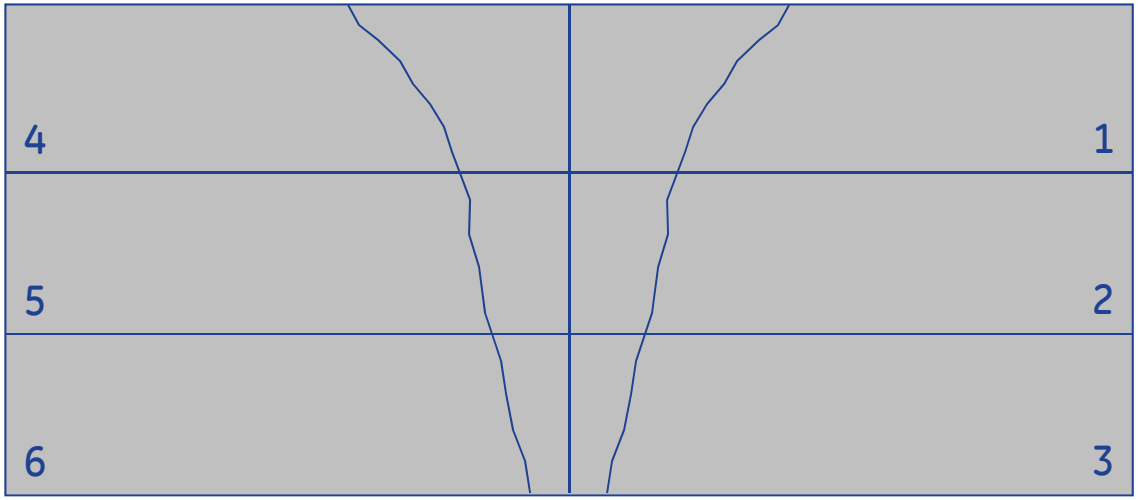
12mm





Sample WC10E7

Base Metal = 690
Weld = B&W Alloy 152

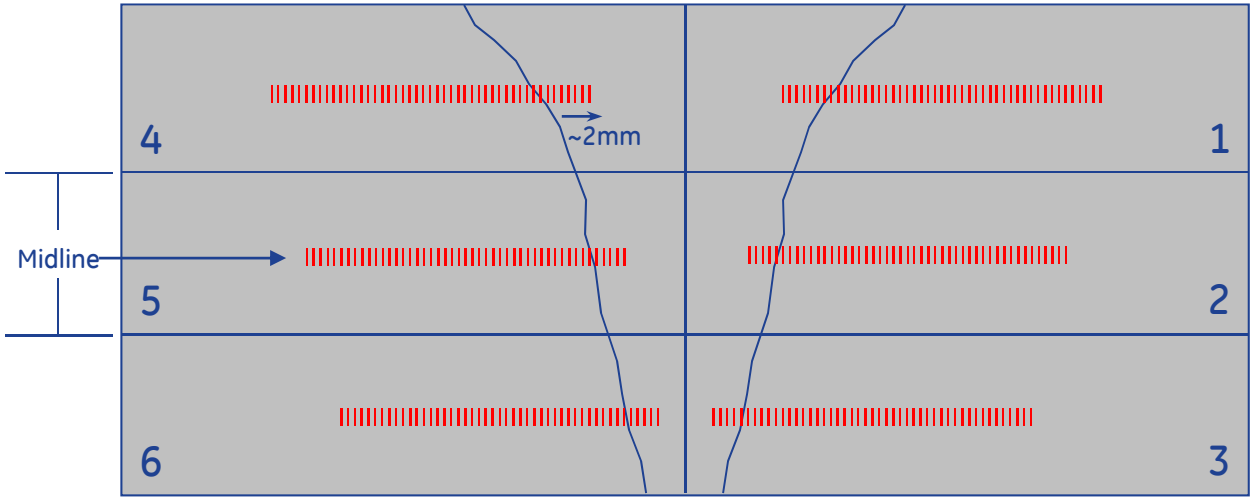


AMIS Analysis

imagination at work

Sample WC10E7

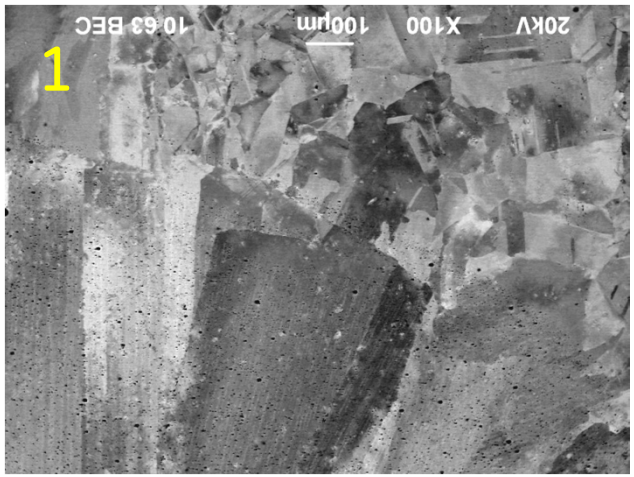
Description of Measurements

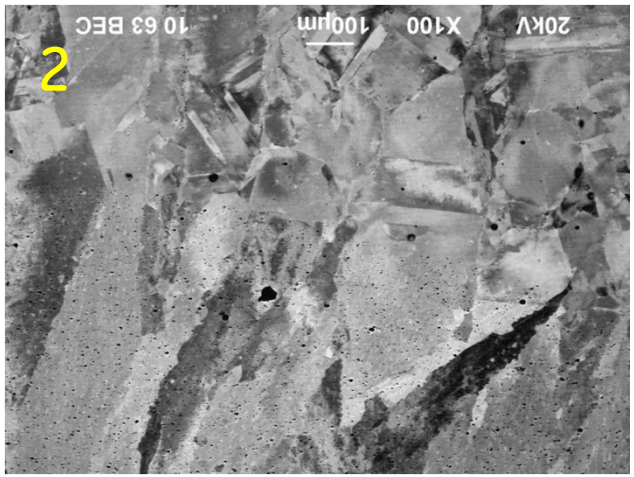


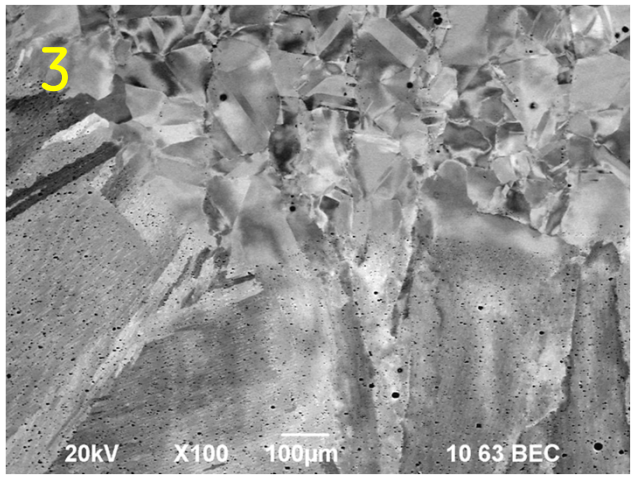
- The slice was cut into 6 individual samples (labeled 1 – 6 above)
- Linescan measurements were taken at the midline of the short axis of each sample
- Each measurement was started ~2mm below the weld interface to include a small amount of data from the weld region
- Measurements were taken as far into the base material as was allowed by the geometry of the microscope chamber, or as far as the electropolished edge would allow

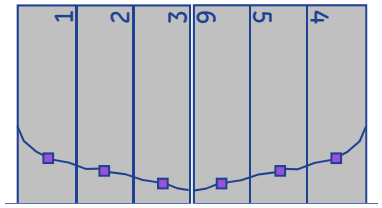
Sample WC10E7 BSE Images

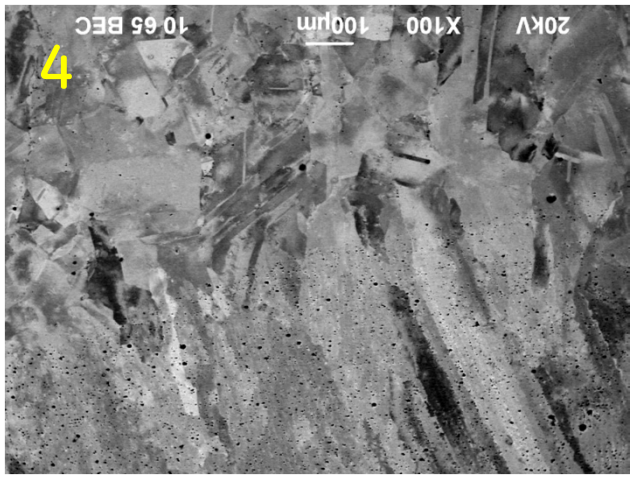
Interface: 100x

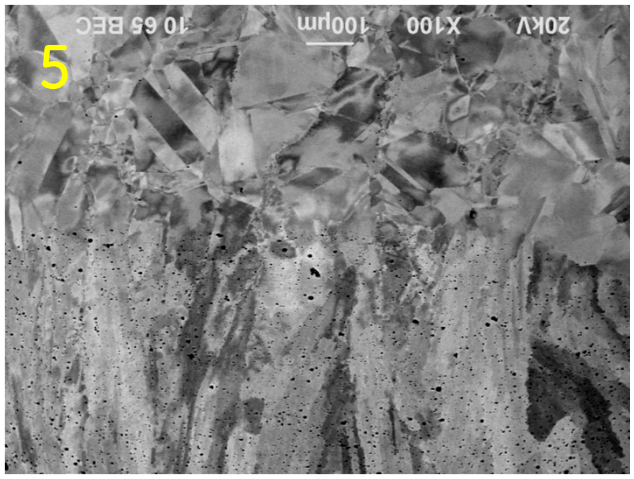


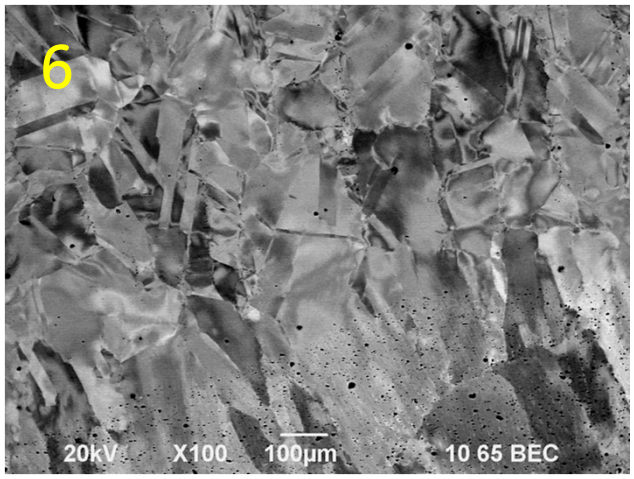






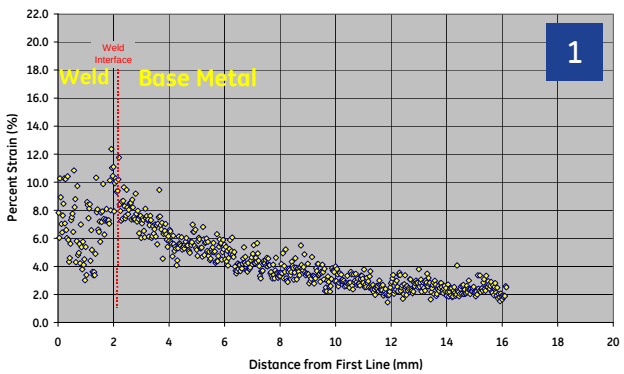


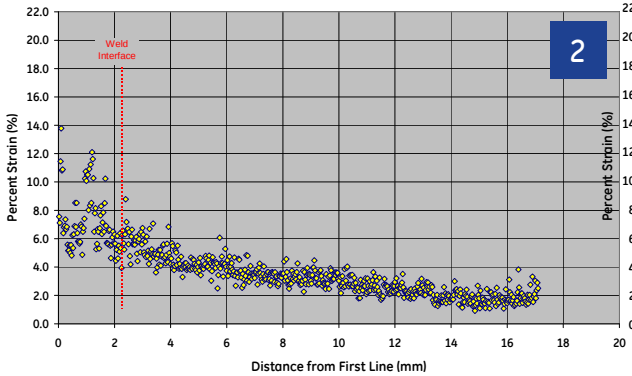


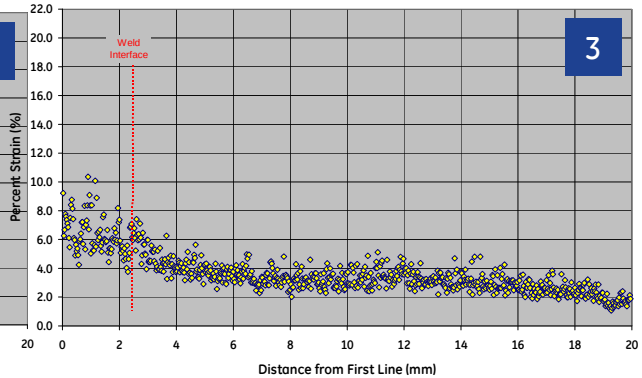


Alloy 52 Weld / 690 Base Metal – NX2579JK

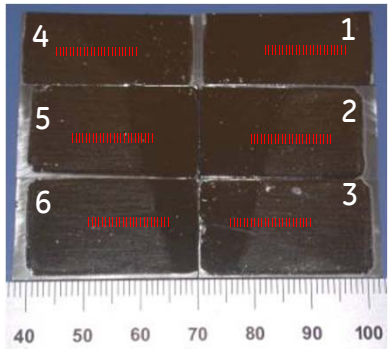
Plastic Strain Plots

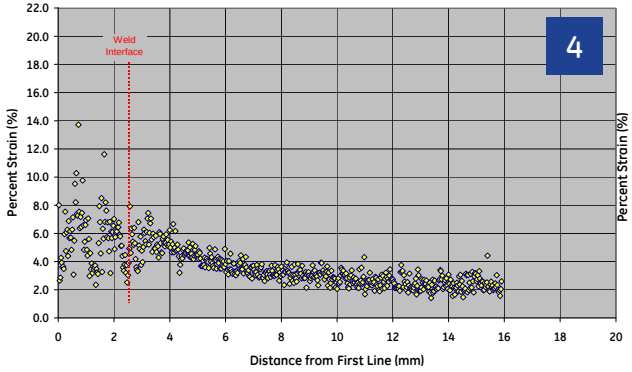


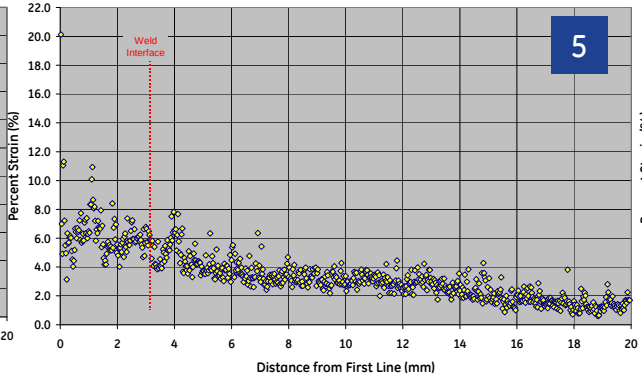


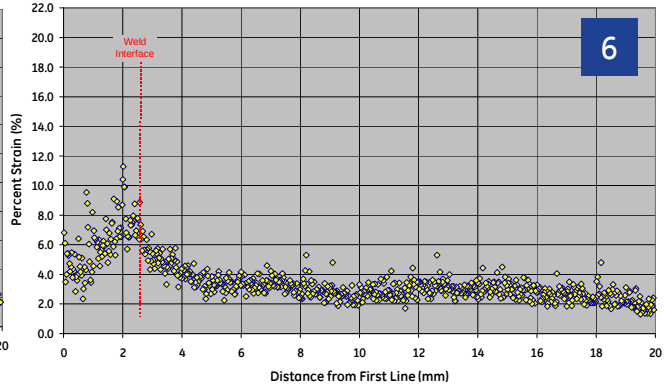


The vertical red dotted lines indicate the approximate locations of the weld interface

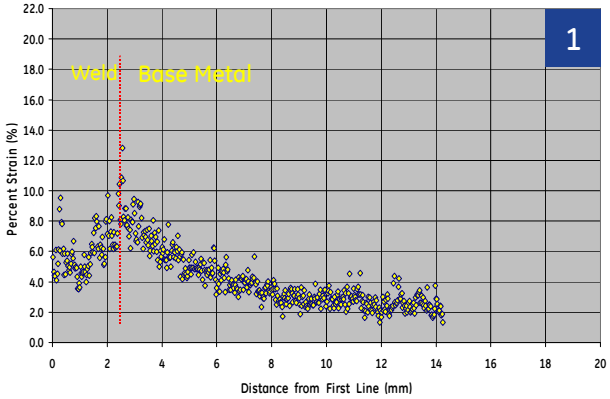


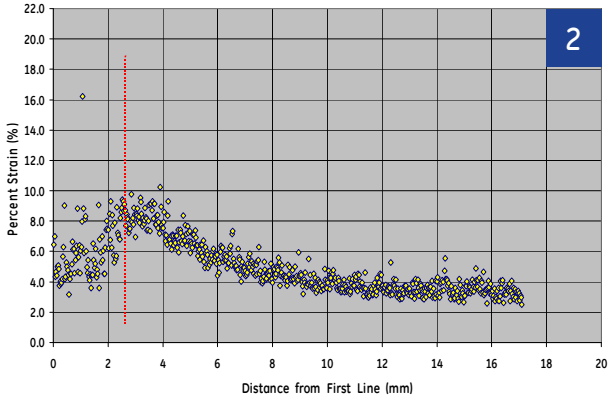


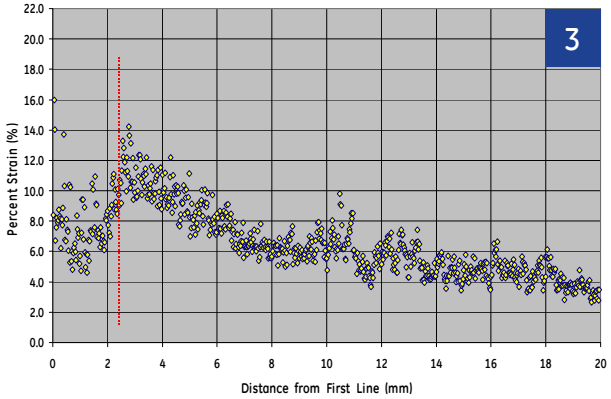




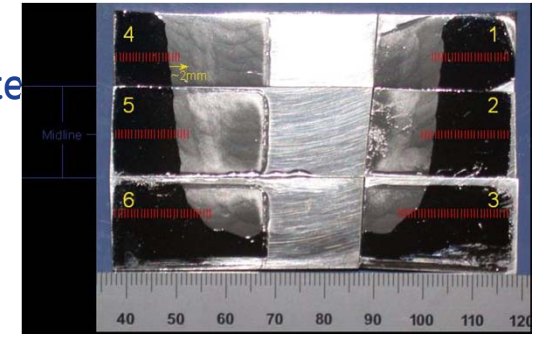
Alloy 152 Weld / 304 Base Metal – 307380 Percent Strain Plots

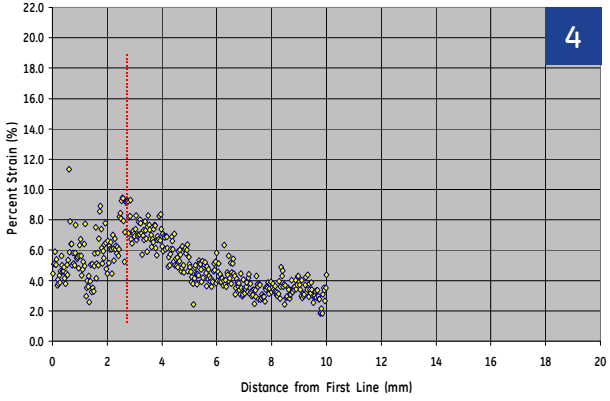


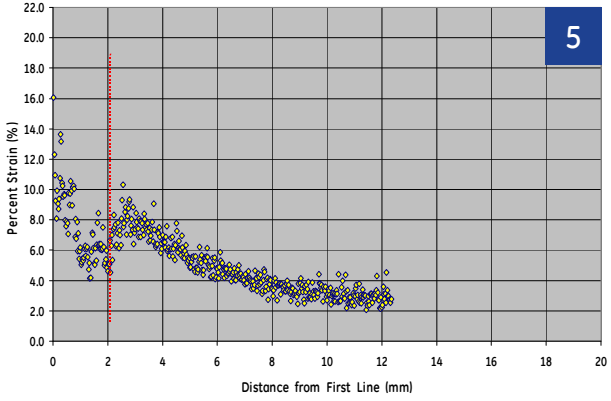


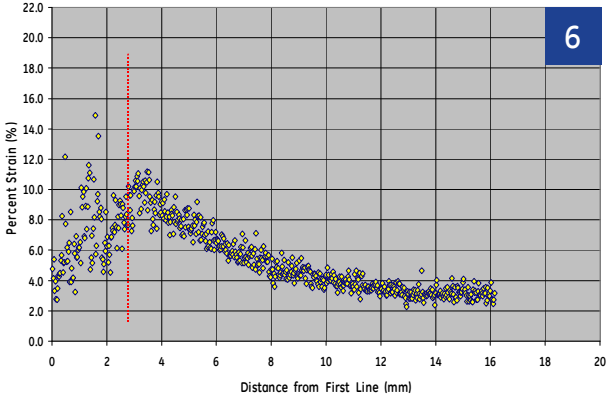


The vertical red dotted lines indicate the approximate locations of the weld interface



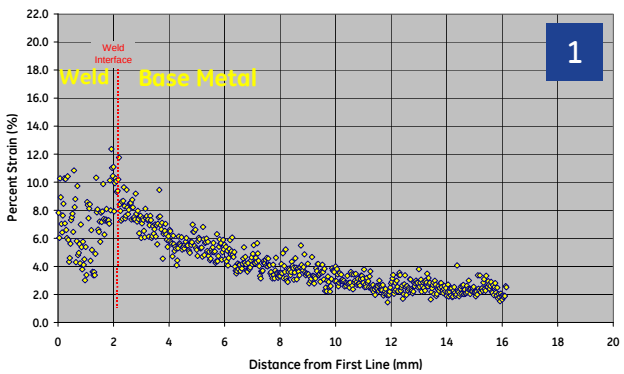


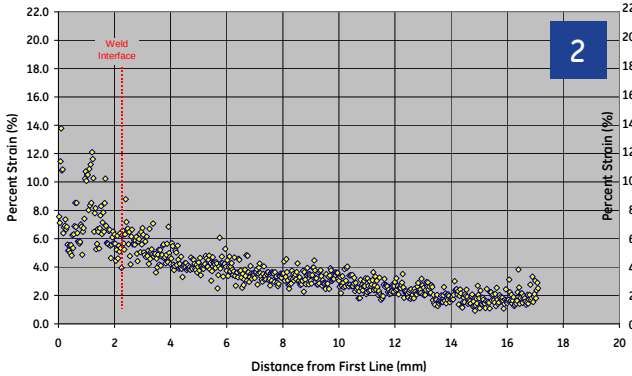


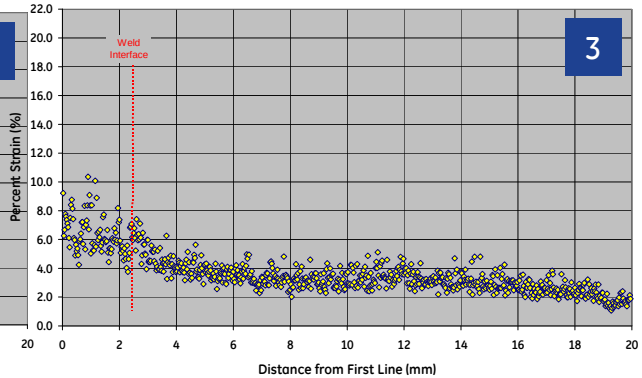


Alloy 52 Weld / 690 Base Metal – NX2579JK

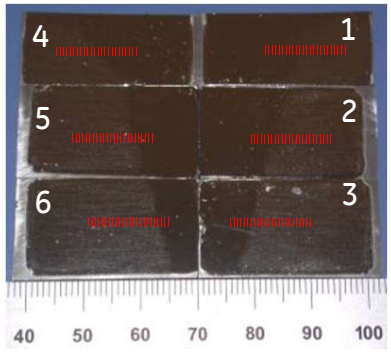
Plastic Strain Plots

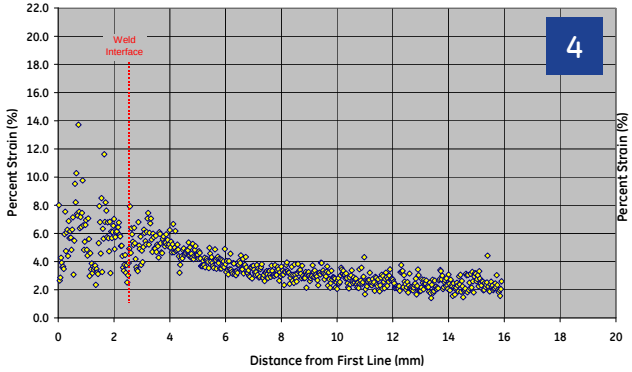


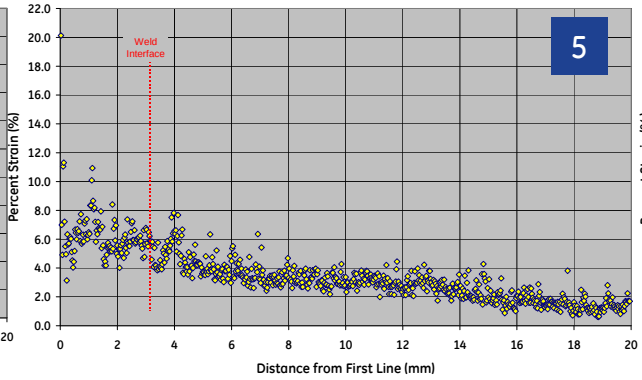


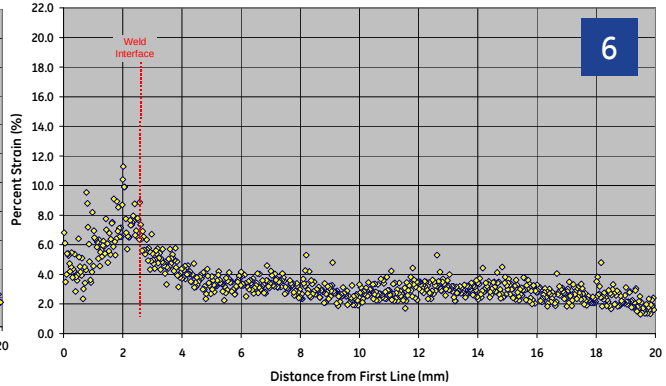


The vertical red dotted lines indicate the approximate locations of the weld interface

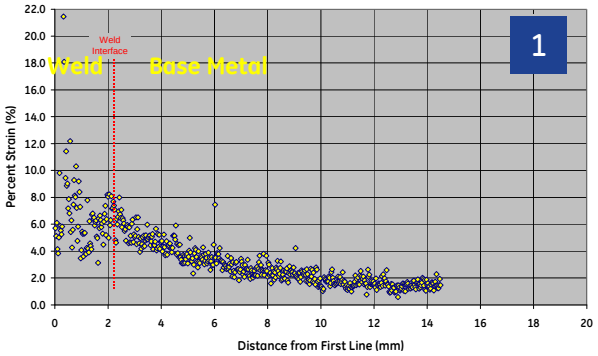


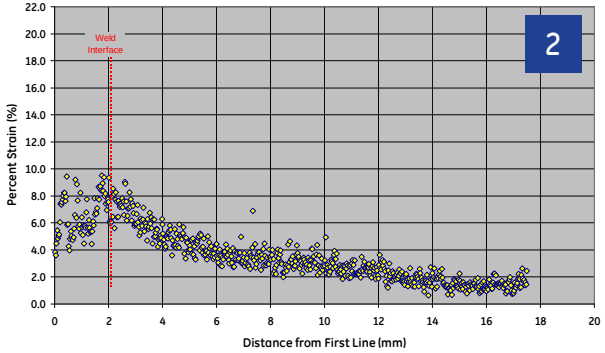


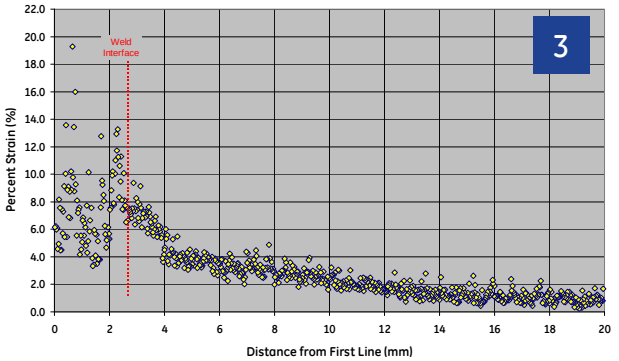




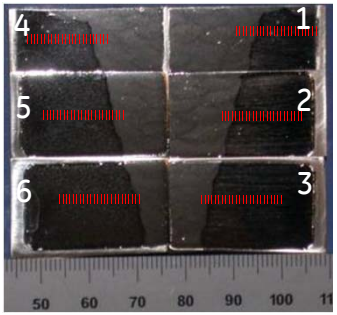
Alloy 152 Weld / 690 Base Metal - WC10E7 Strain Plots

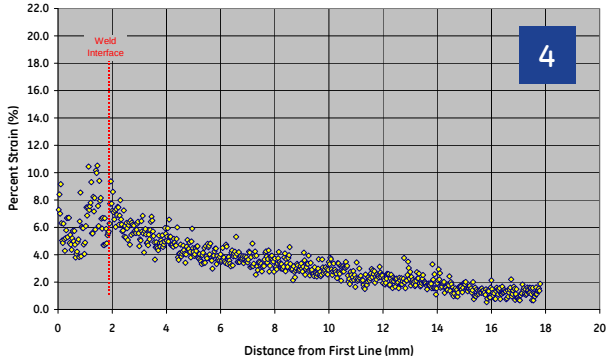


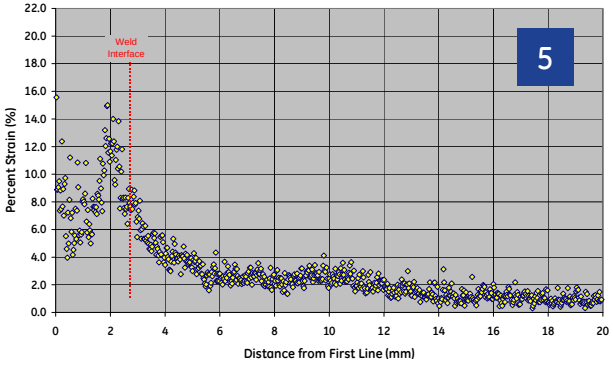


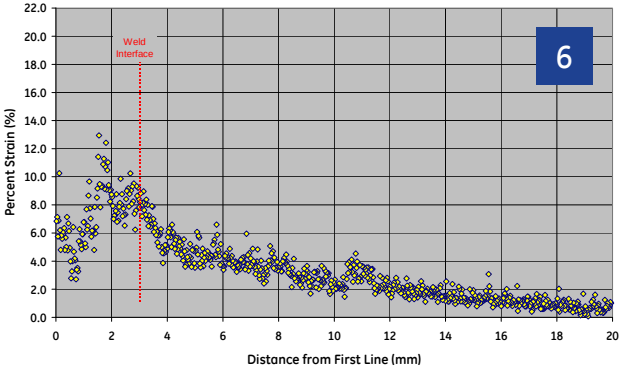


The vertical red dotted lines indicate the approximate locations of the weld interface

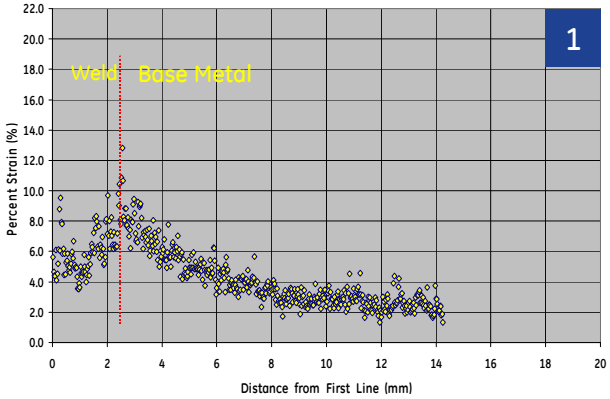


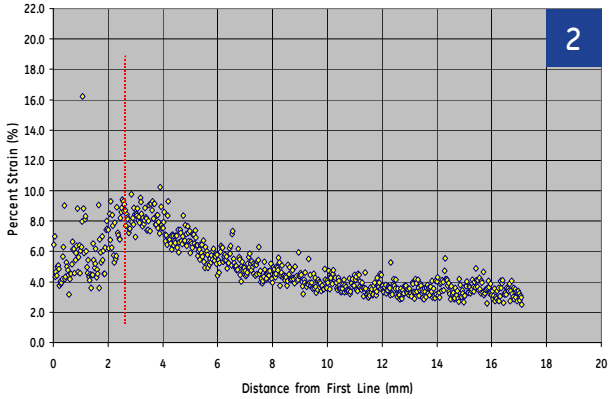


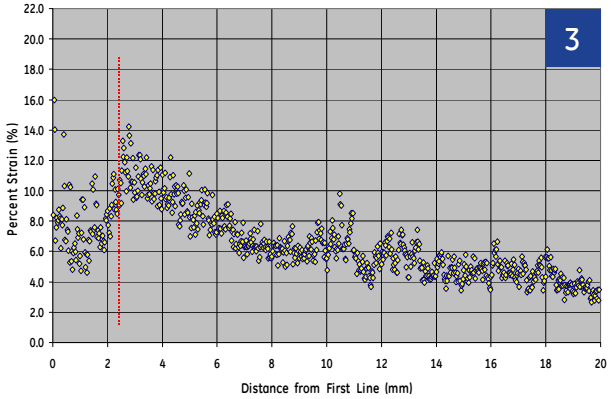




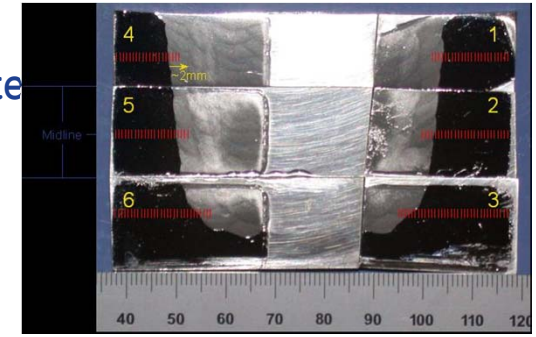
Alloy 152 Weld / 304 Base Metal – 307380 Percent Strain Plots

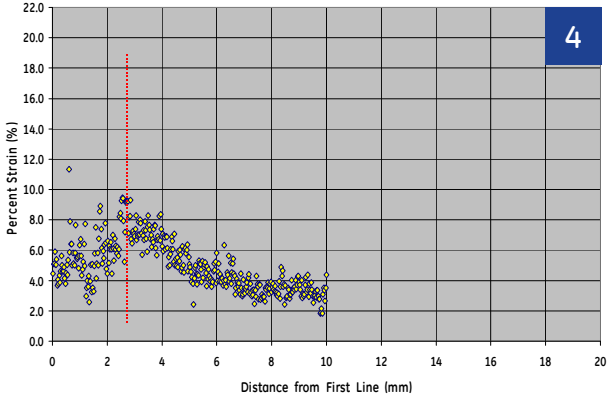


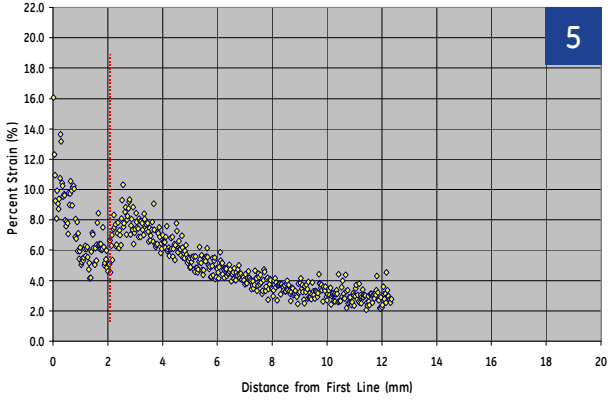


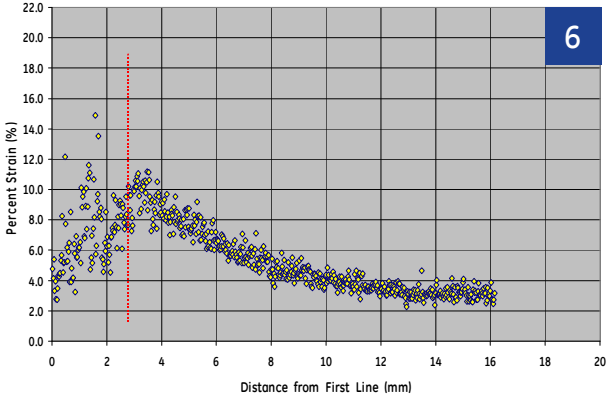


The vertical red dotted lines indicate the approximate locations of the weld interface



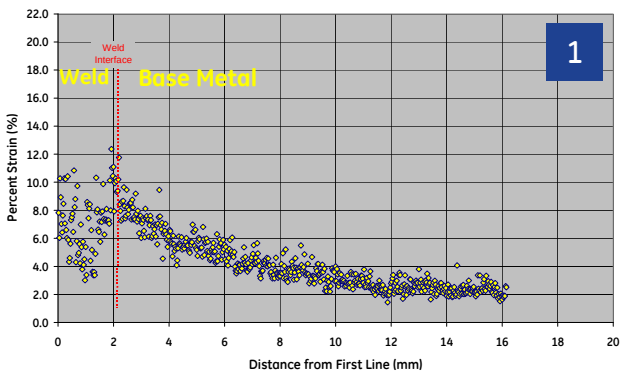


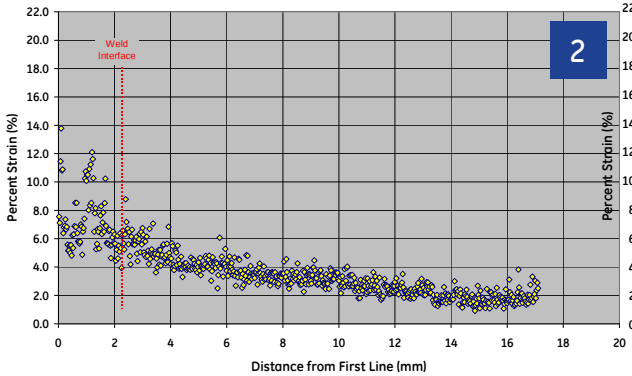


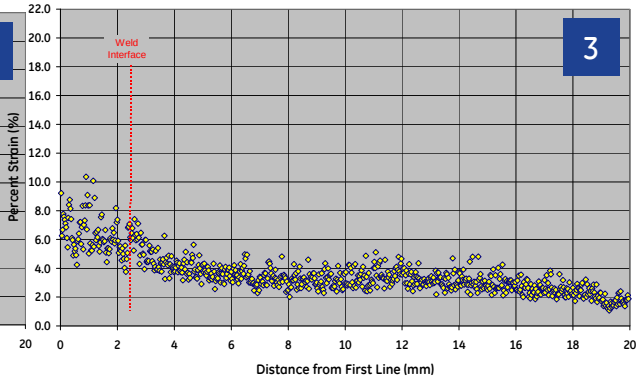


Alloy 52 Weld / 690 Base Metal – NX2579JK

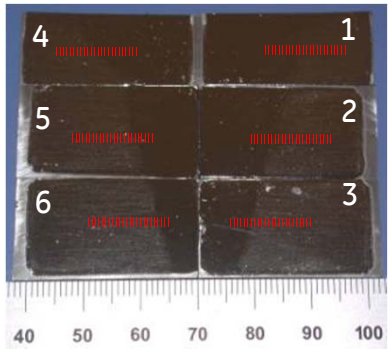
Plastic Strain Plots

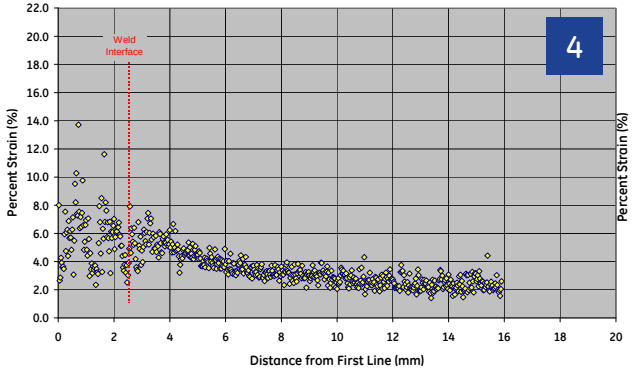


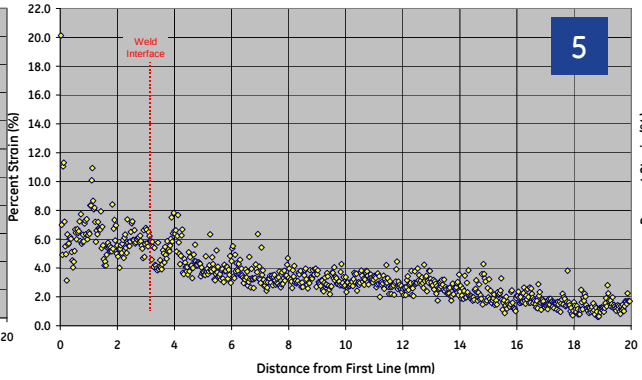


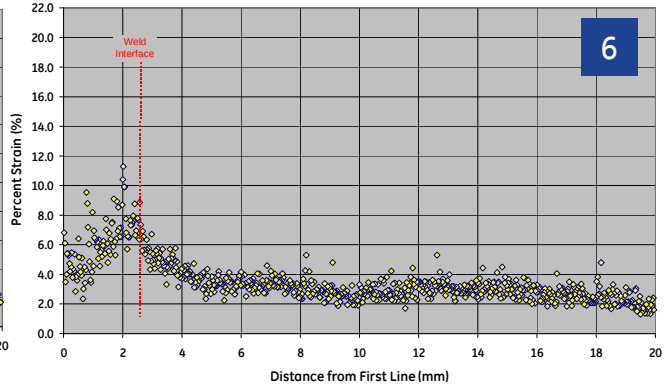


The vertical red dotted lines indicate the approximate locations of the weld interface

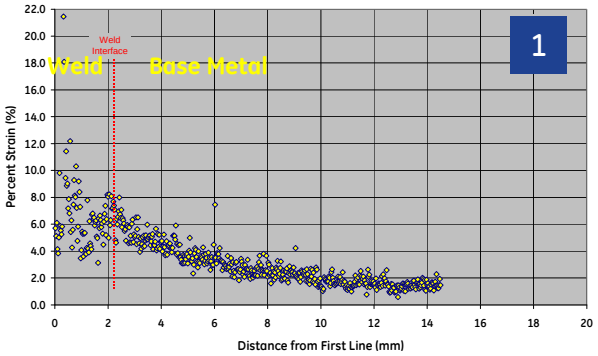


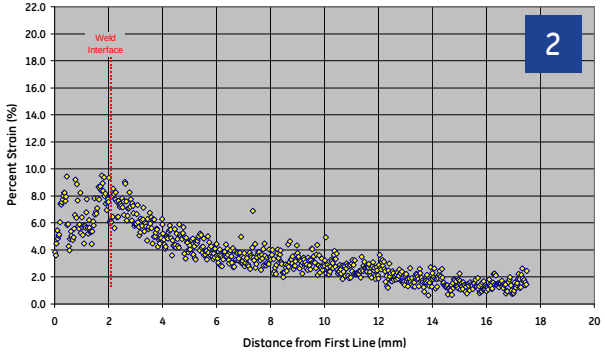


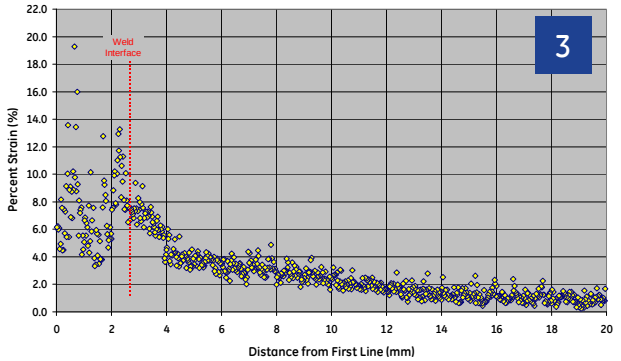




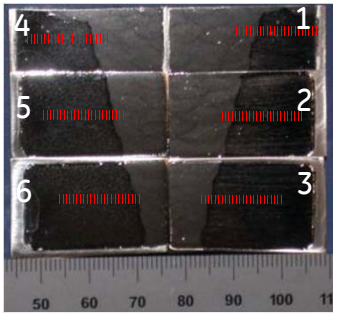
Alloy 152 Weld / 690 Base Metal - WC10E7 Strain Plots

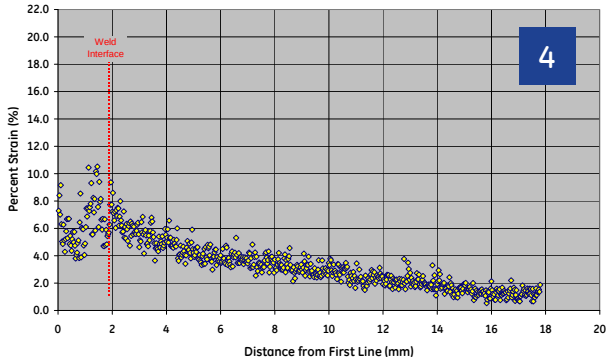


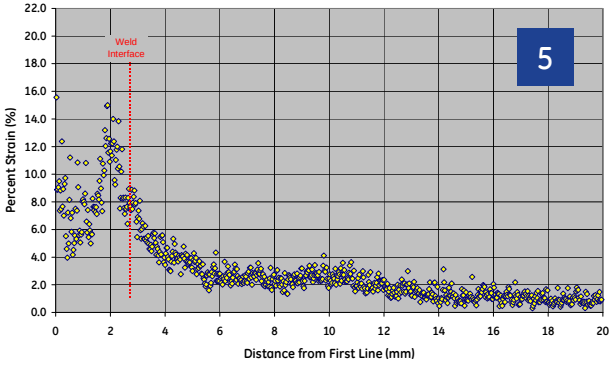


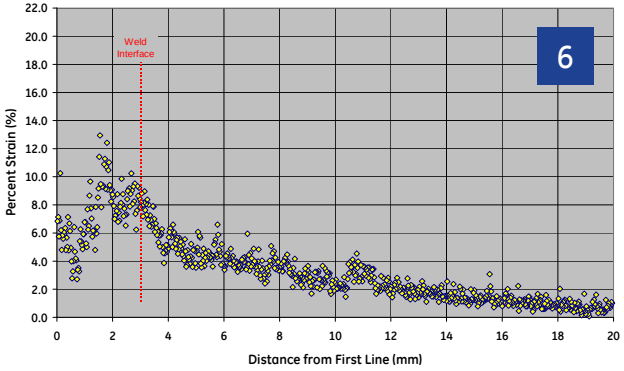


The vertical red dotted lines indicate the approximate locations of the weld interface

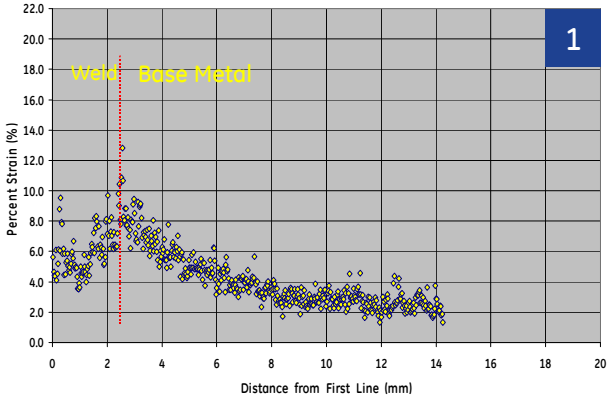


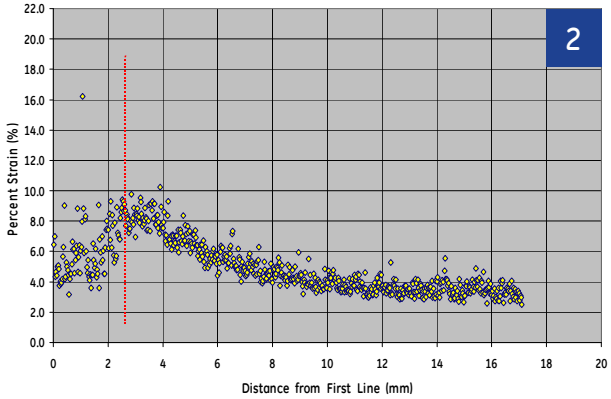


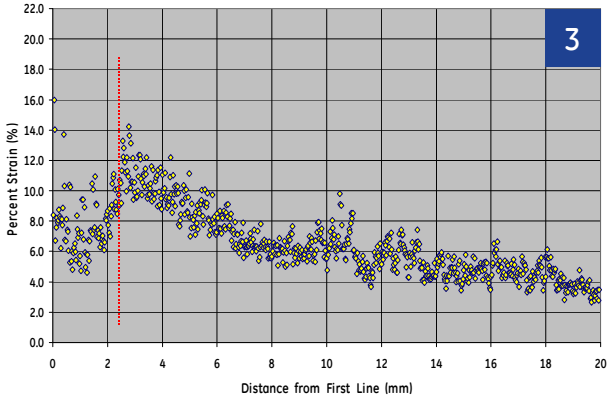




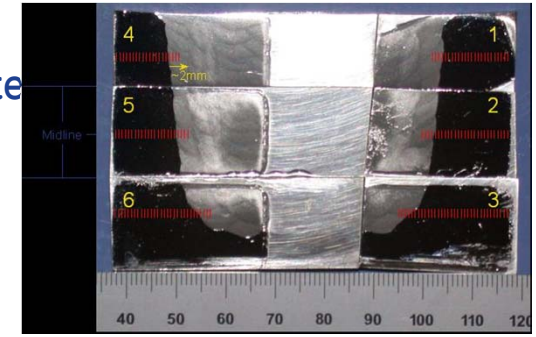
Alloy 152 Weld / 304 Base Metal – 307380 Percent Strain Plots

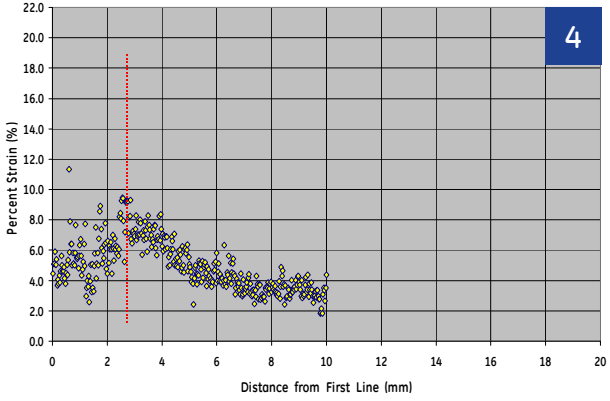


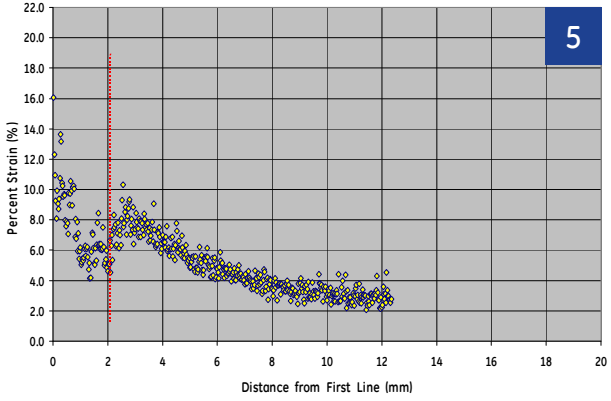


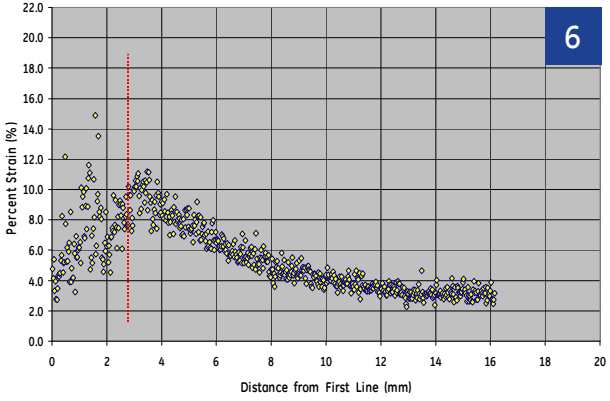


The vertical red dotted lines indicate the approximate locations of the weld interface



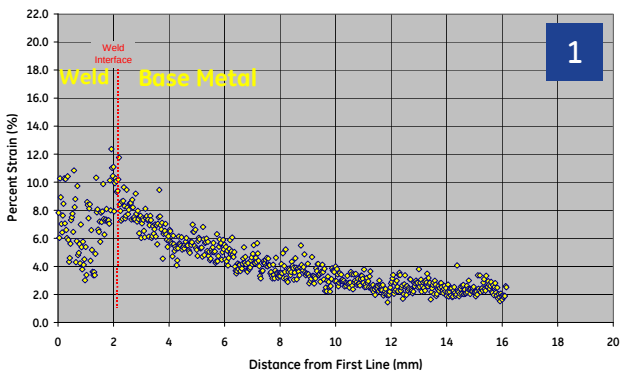


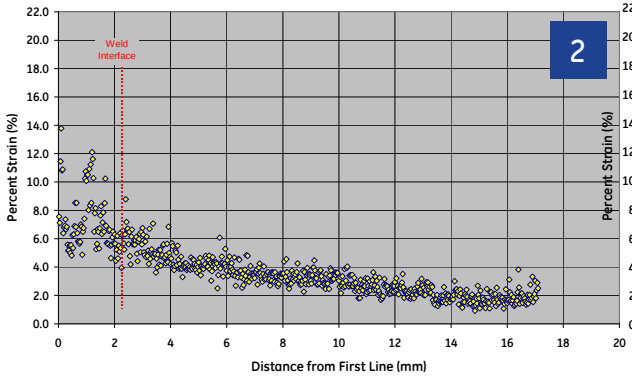


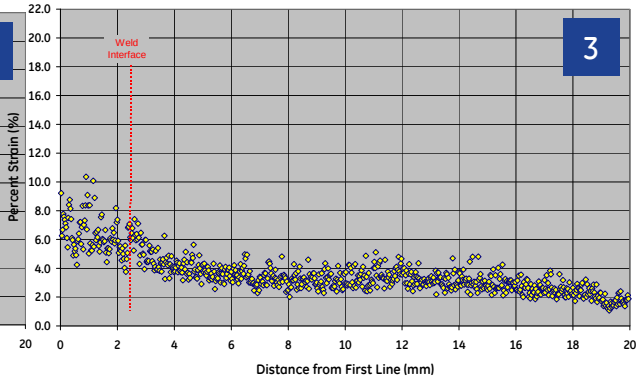


Alloy 52 Weld / 690 Base Metal – NX2579JK

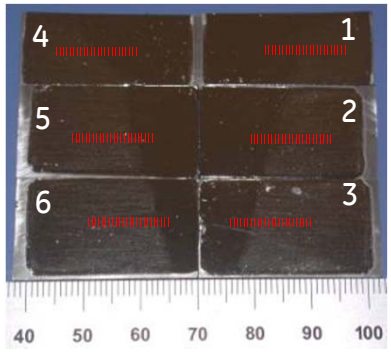
Plastic Strain Plots

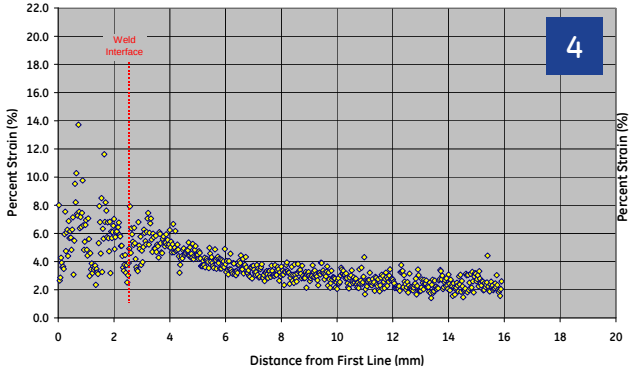


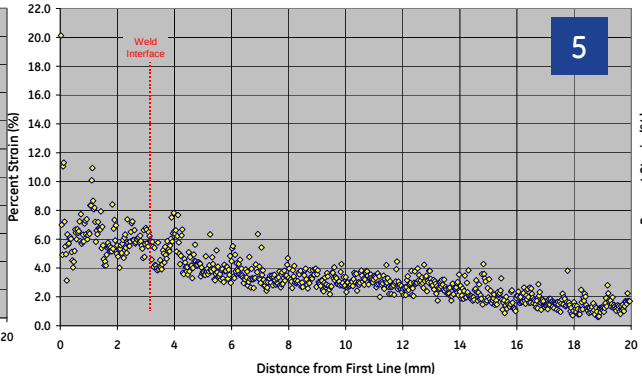


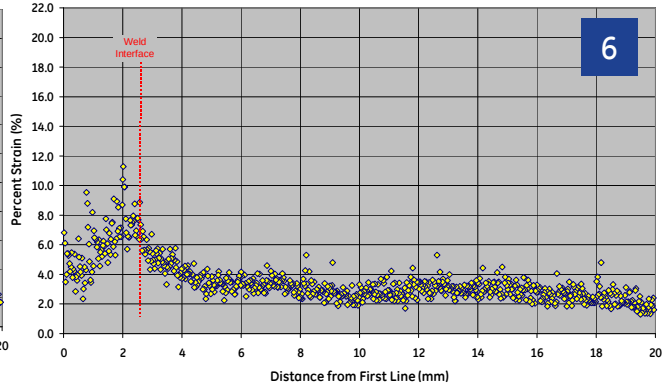


The vertical red dotted lines indicate the approximate locations of the weld interface



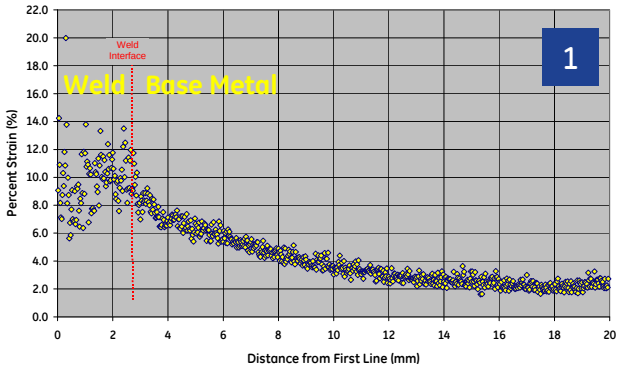


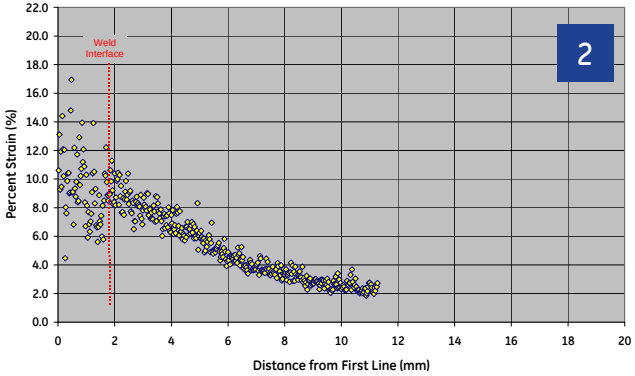


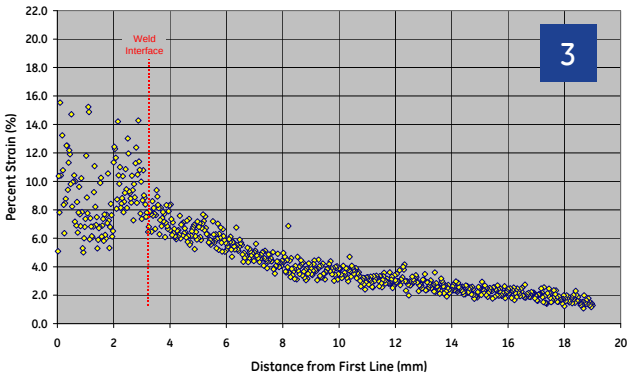


Alloy 52 Weld / 690 Base Metal – MLTS-3-Cr

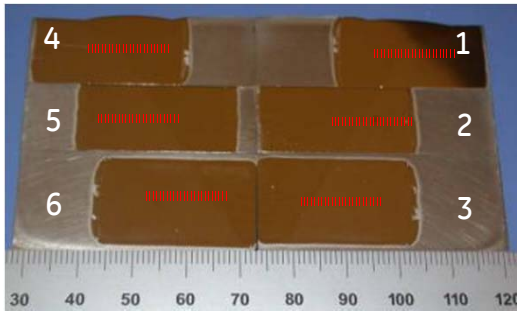
Plastic Strain Plots

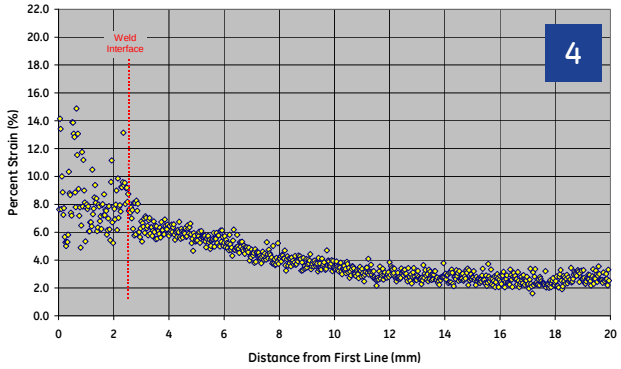


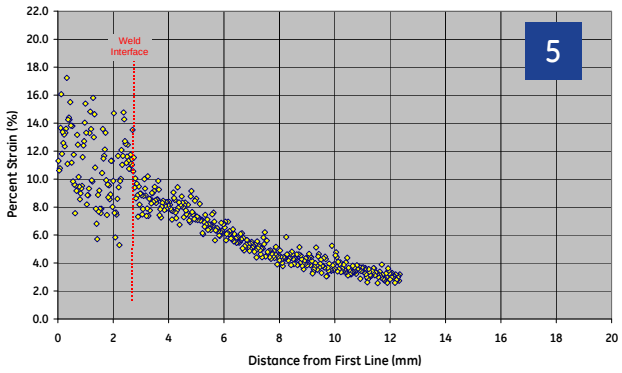


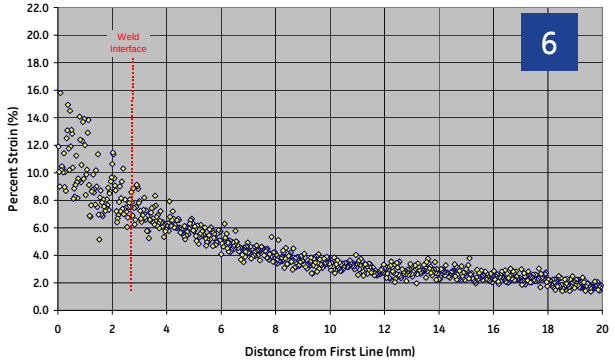


The vertical red dotted lines indicate the approximate locations of the weld interface









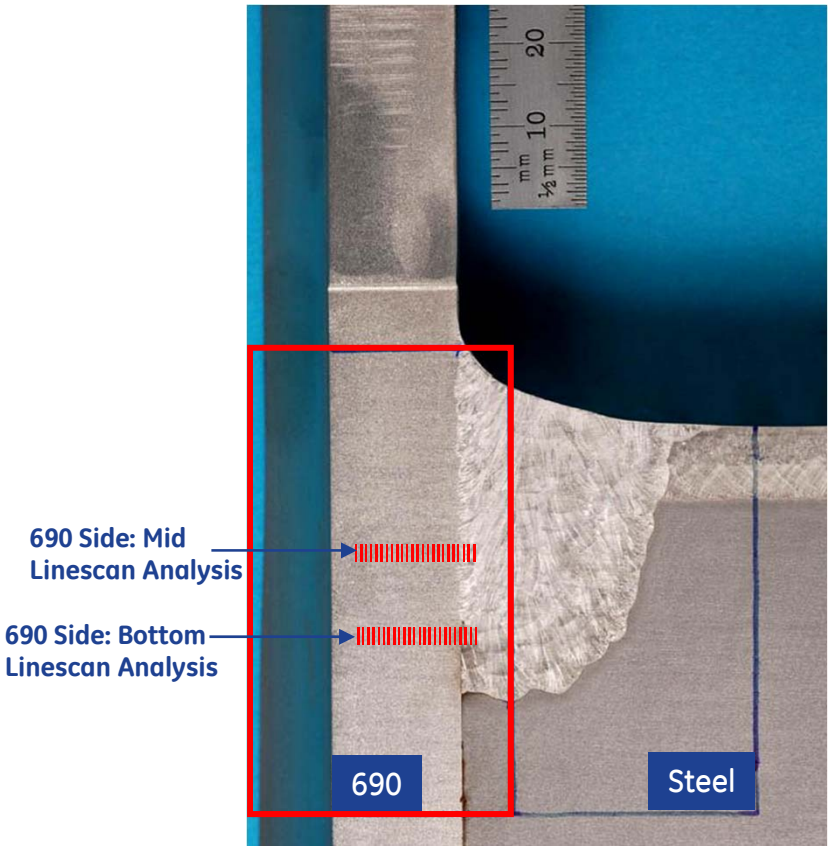
Comparison PG&E CRDM J weld mockup Valinox 690 Side

J-Groove Mock Up

EBSD Strain Analysis

imagination at work

J-Groove Mock Up

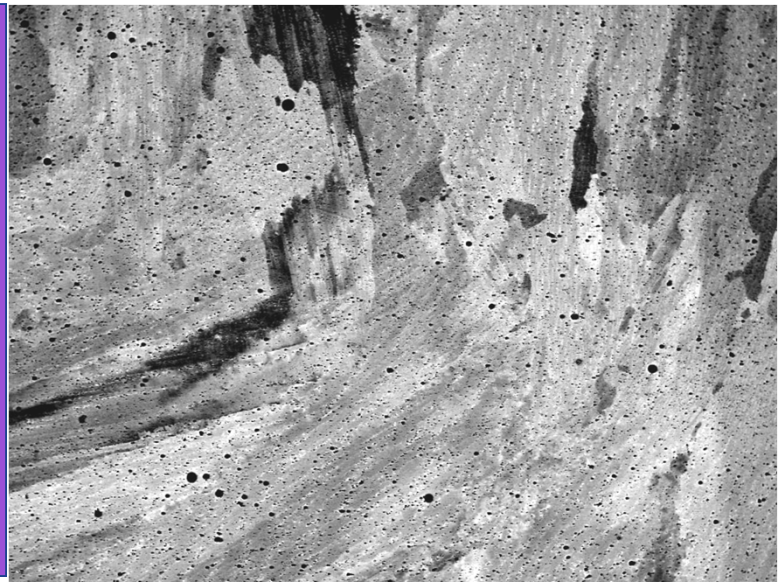


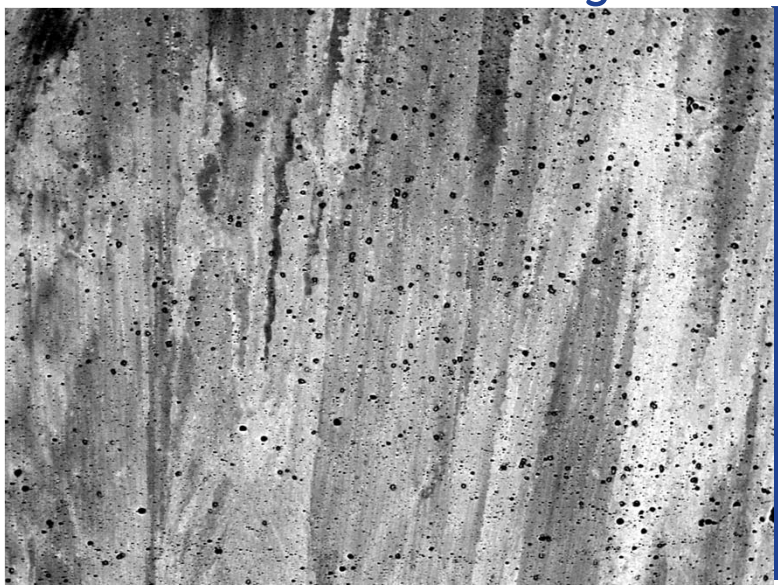
EBSD Strain Analysis – 690 Side

J-Groove Weld - 690 Side: 2mm Before Interface

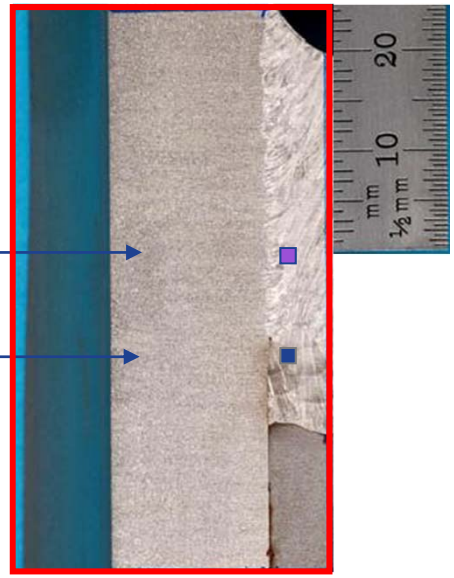
BSE Images: 100x

690: Mid Section





690: Bottom Section



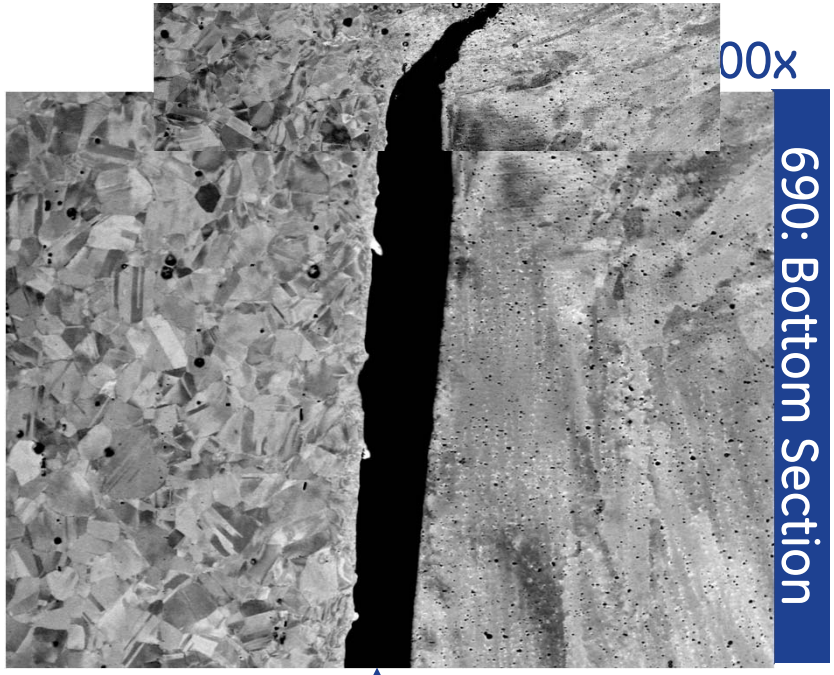
690 Side: Mid
Linescan Analysis

690 Side: Bottom
Linescan Analysis

— 100 μm

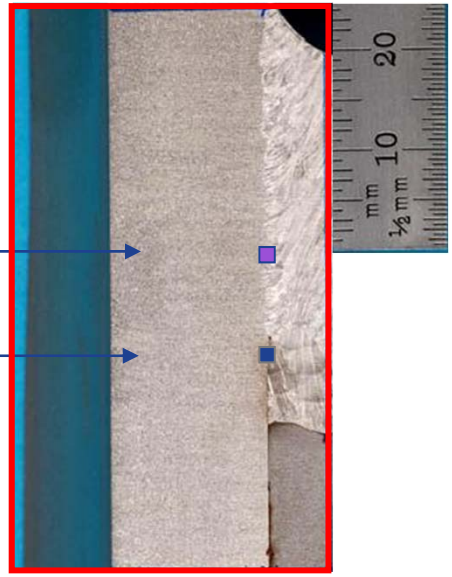
J-Groove Weld - 690 Side: Interface

690: Mid Section



690: Bottom Section

Gap in the material at the interface.



690 Side: Mid Linescan Analysis

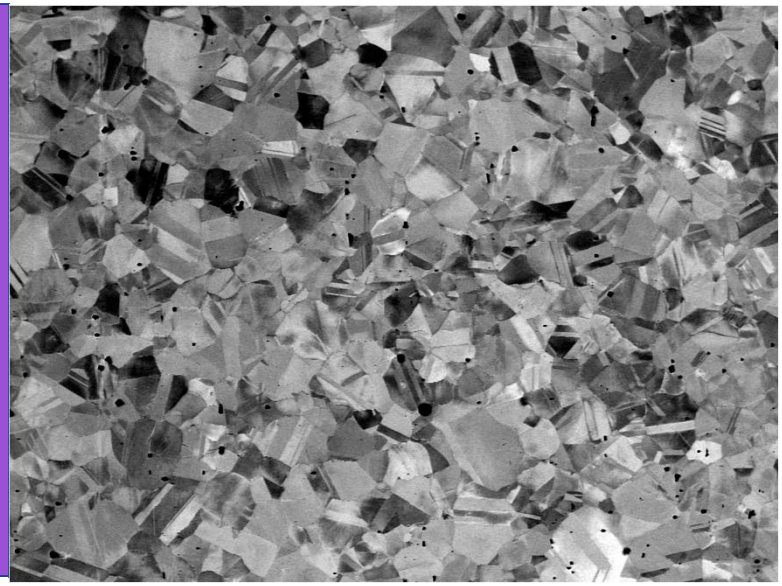
690 Side: Bottom Linescan Analysis

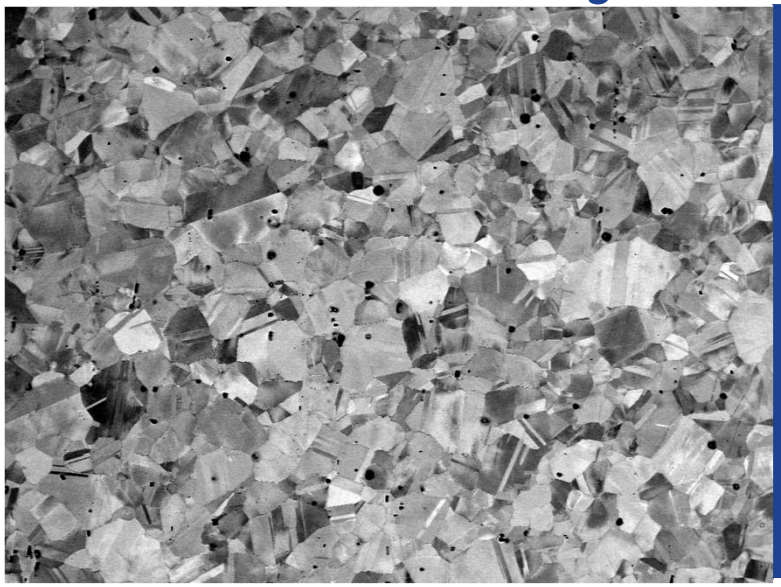
— 100 μm

J-Groove Weld - 690 Side: 2mm After Interface

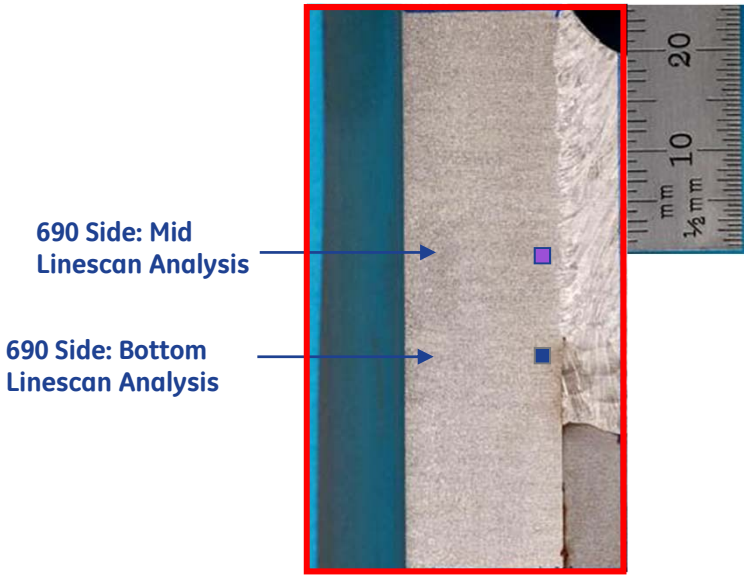
BSE Images: 100x

690: Mid Section





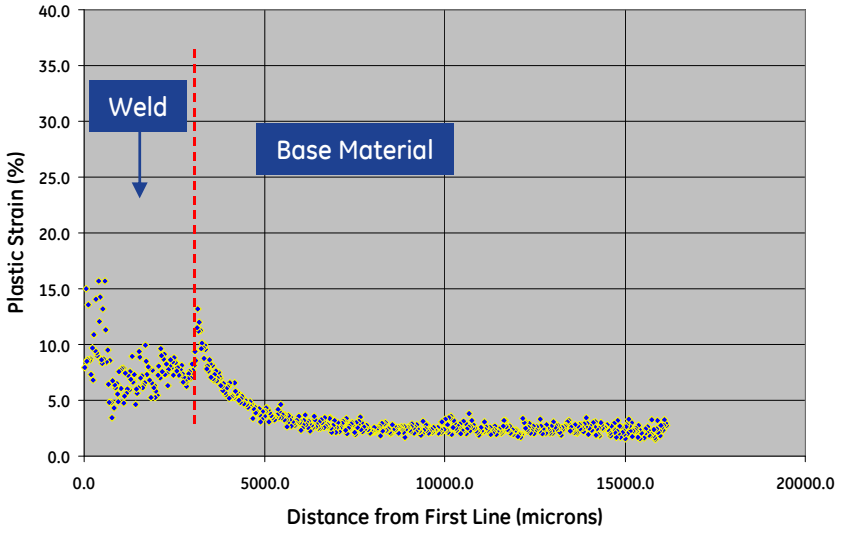
690: Bottom Section



— 100 μm

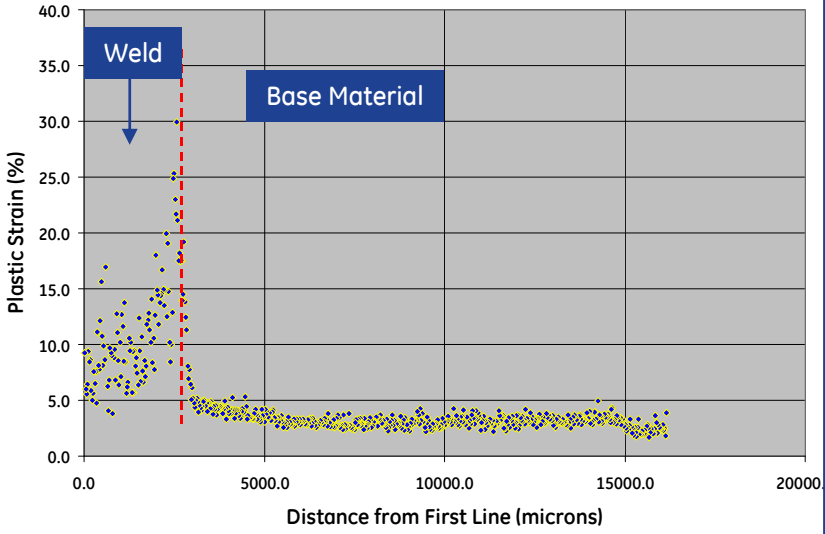
J-Groove Weld - 690 Side

690: Mid Section

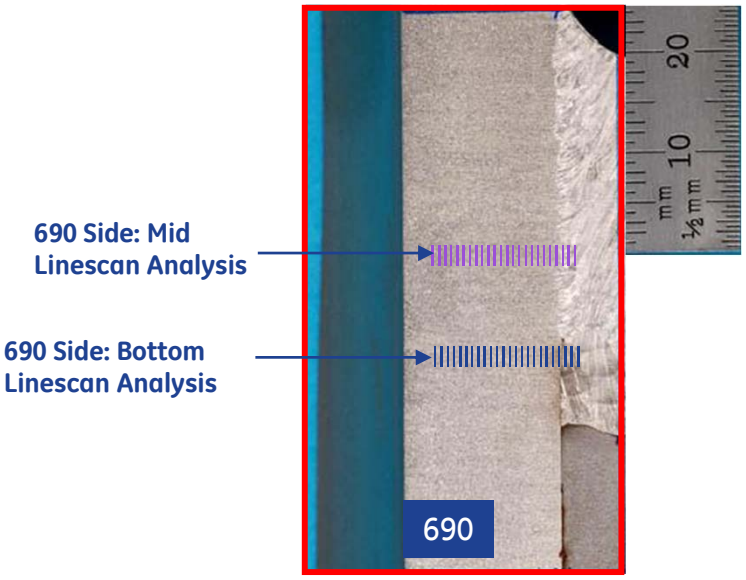


Plastic Strain vs. Distance

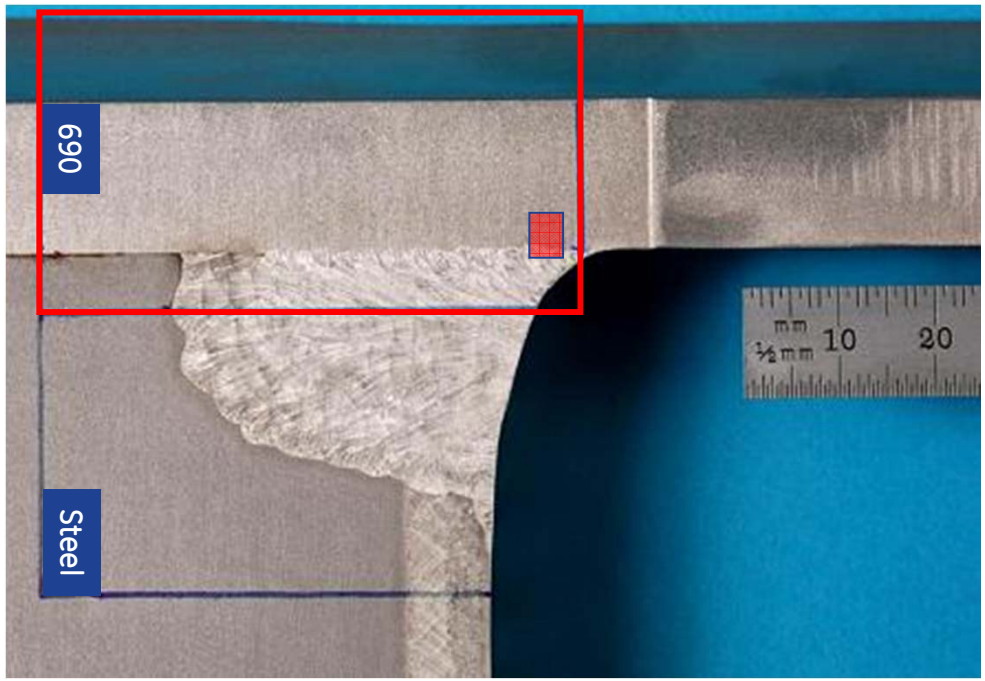
690: Bottom Section



Sharp rise in plastic strain in alloy 690 (30%) at the interface near lack of fusion region.



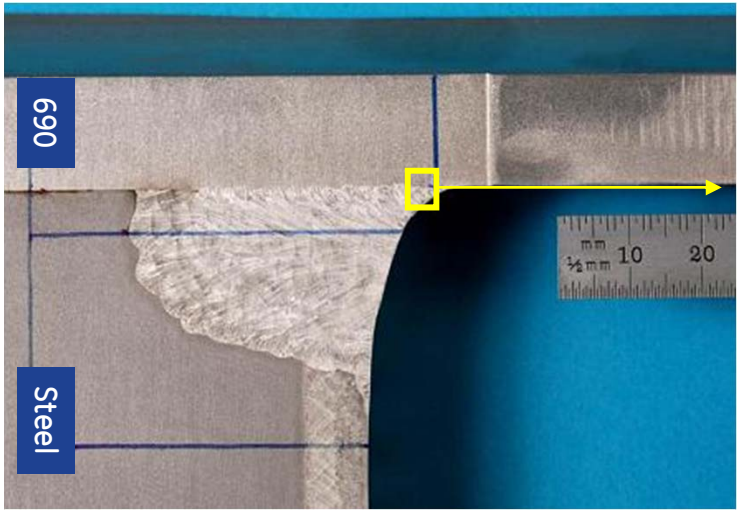
J-Groove Weld

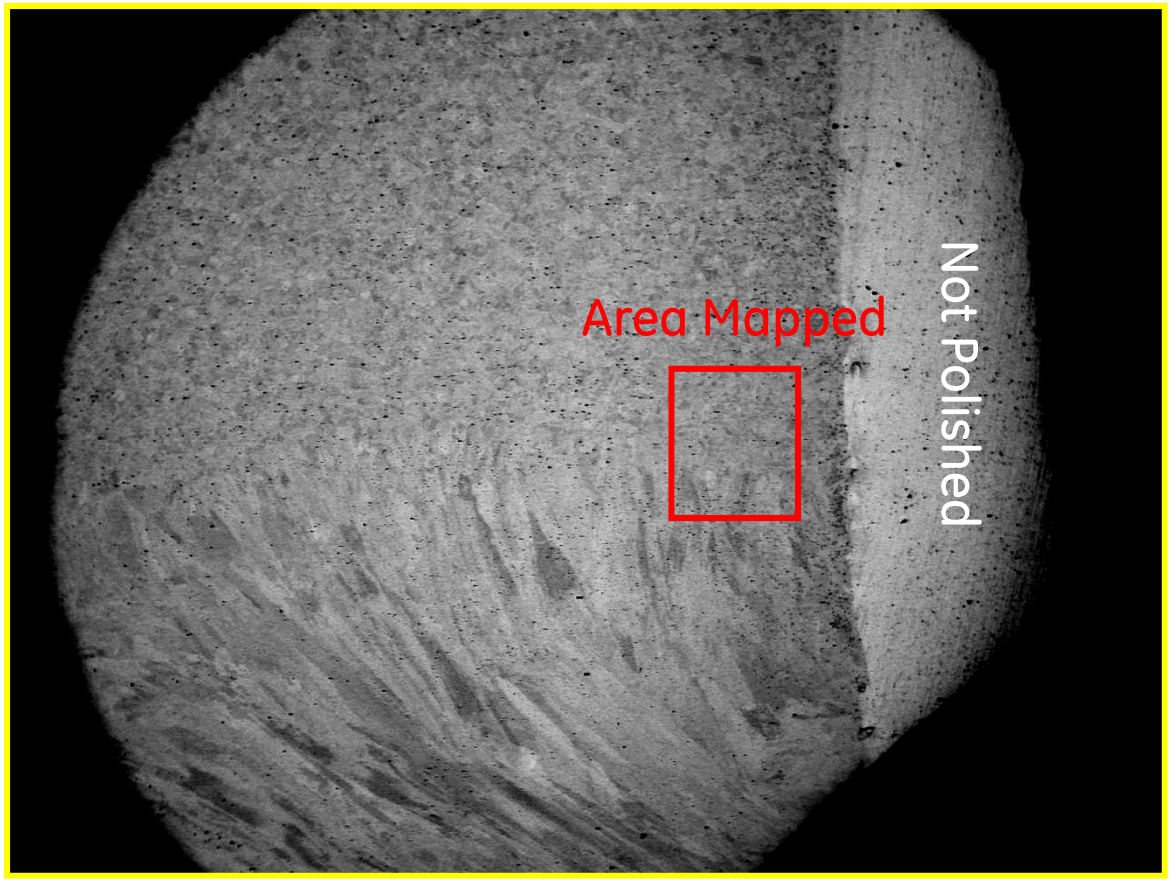


EBSD Map Analysis – 690 Side

J-Groove Weld - 690 Side: Mapped Region

BSE Images: 15x

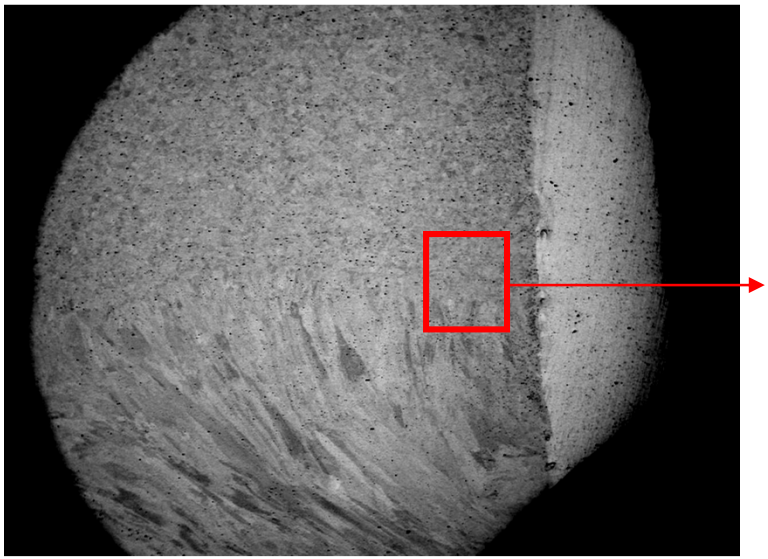


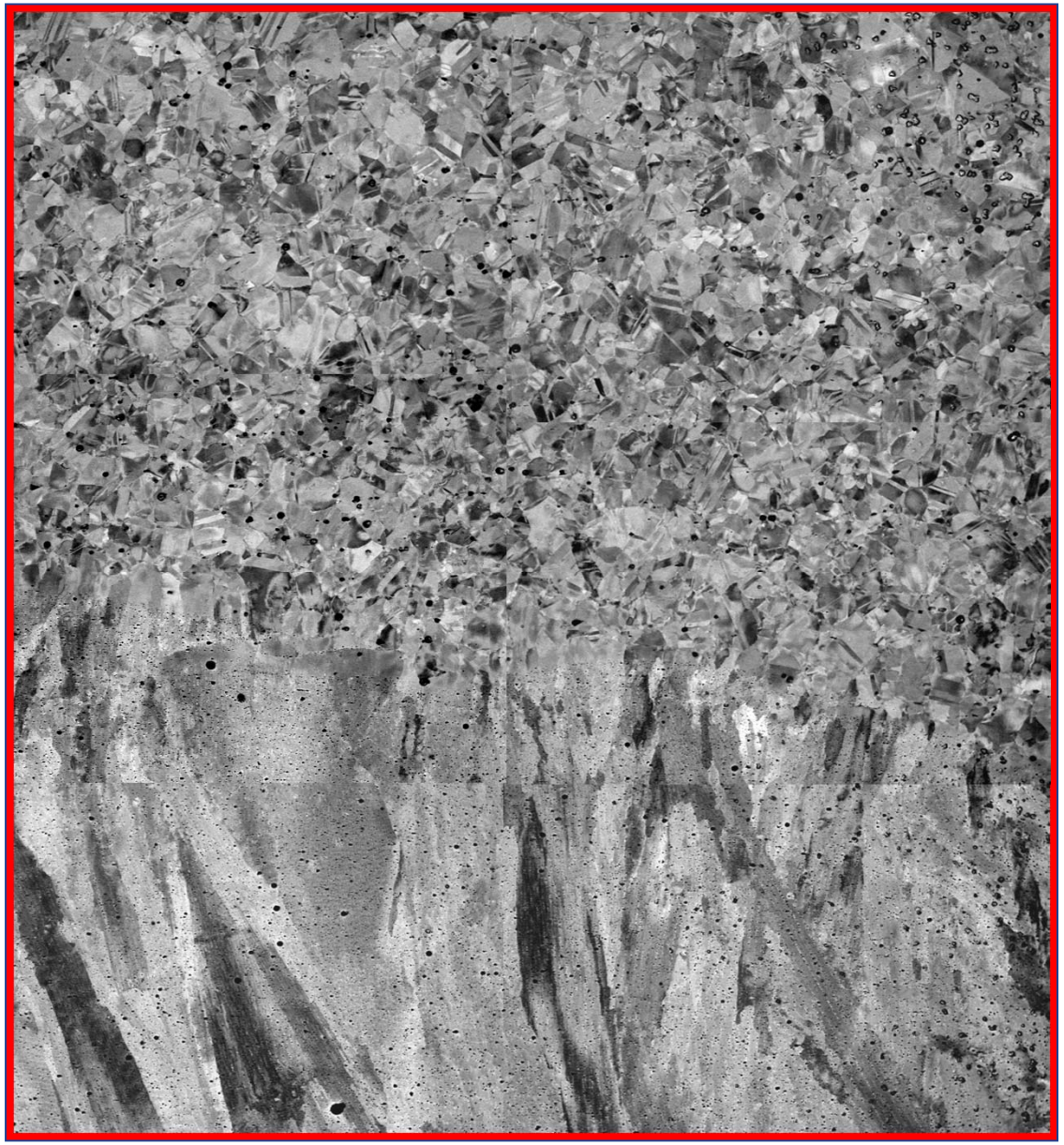


1 mm

J-Groove Weld - 690 Side: Mapped Region

BSE Images: 100x

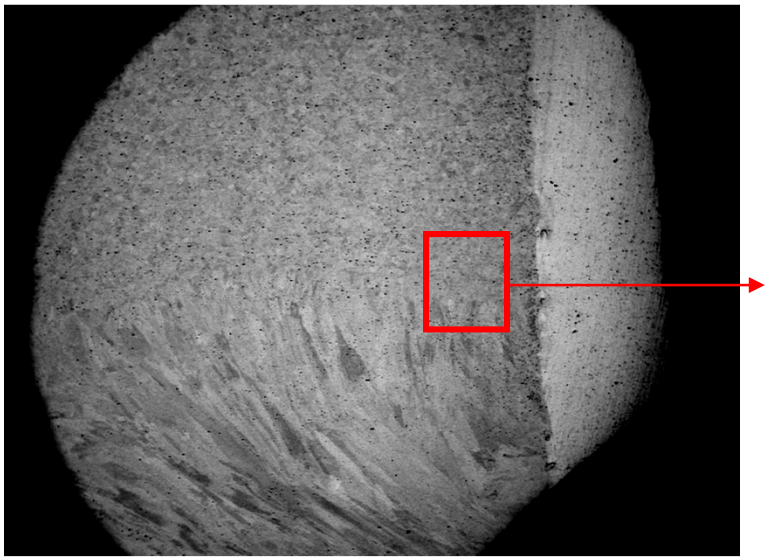


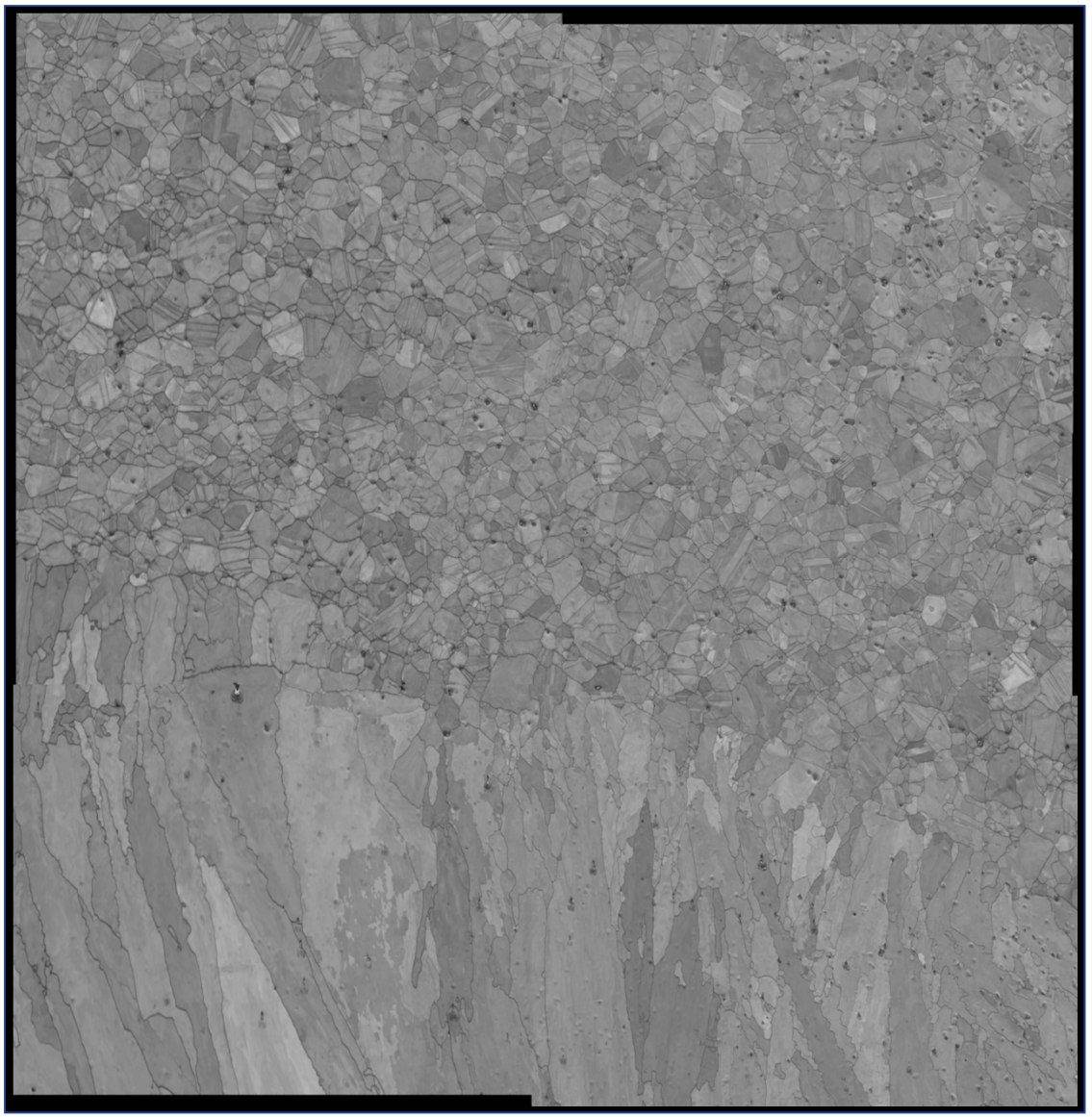


500 um

J-Groove Weld - 690 Side: Mapped Region

Band Contrast Map

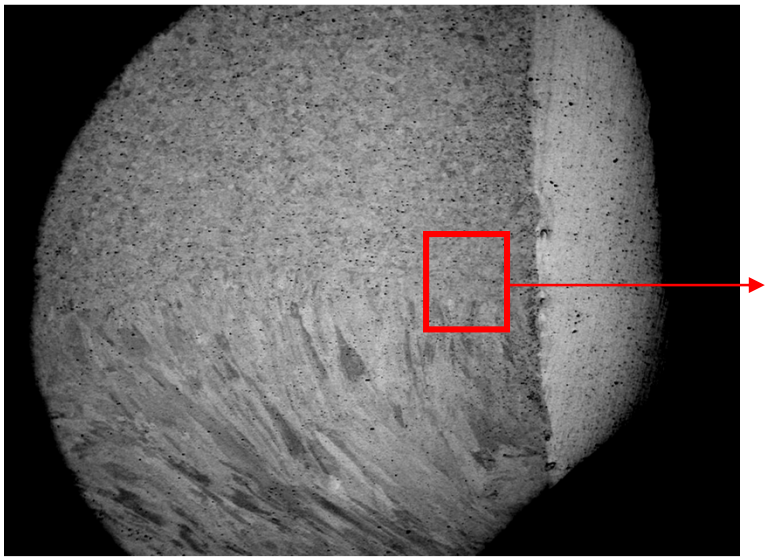




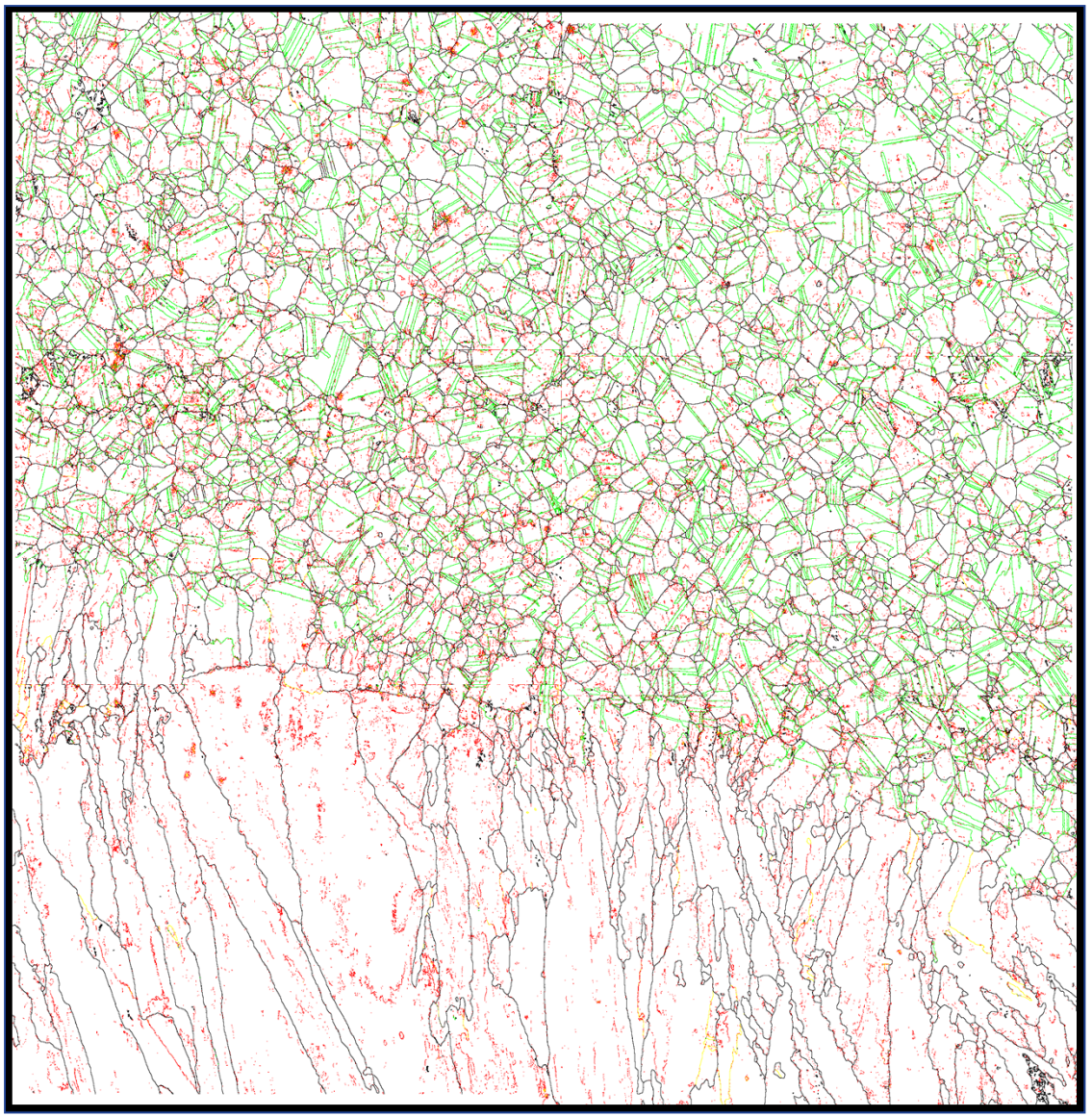
1 mm

J-Groove Weld - 690 Side: Mapped Region

Boundary Map



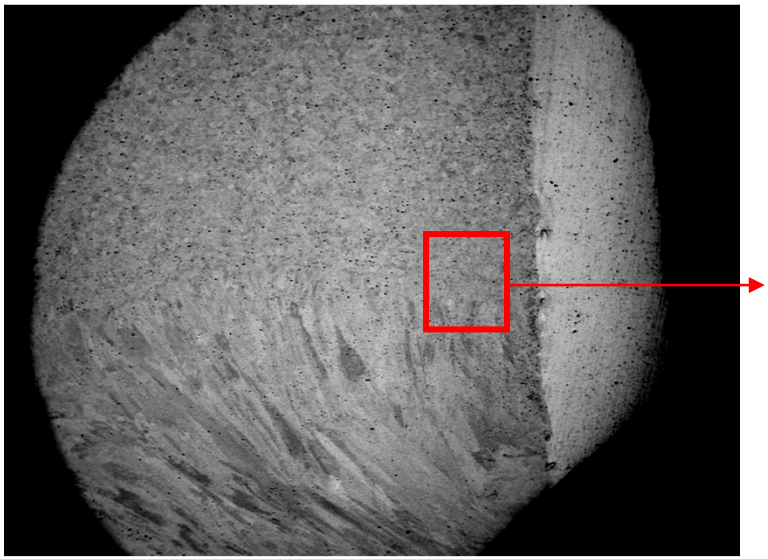
Red = 1.5°<θ<3°
Yellow = 3°<θ<10°
Black = 10°<θ<60°
Green = Twin (60°)

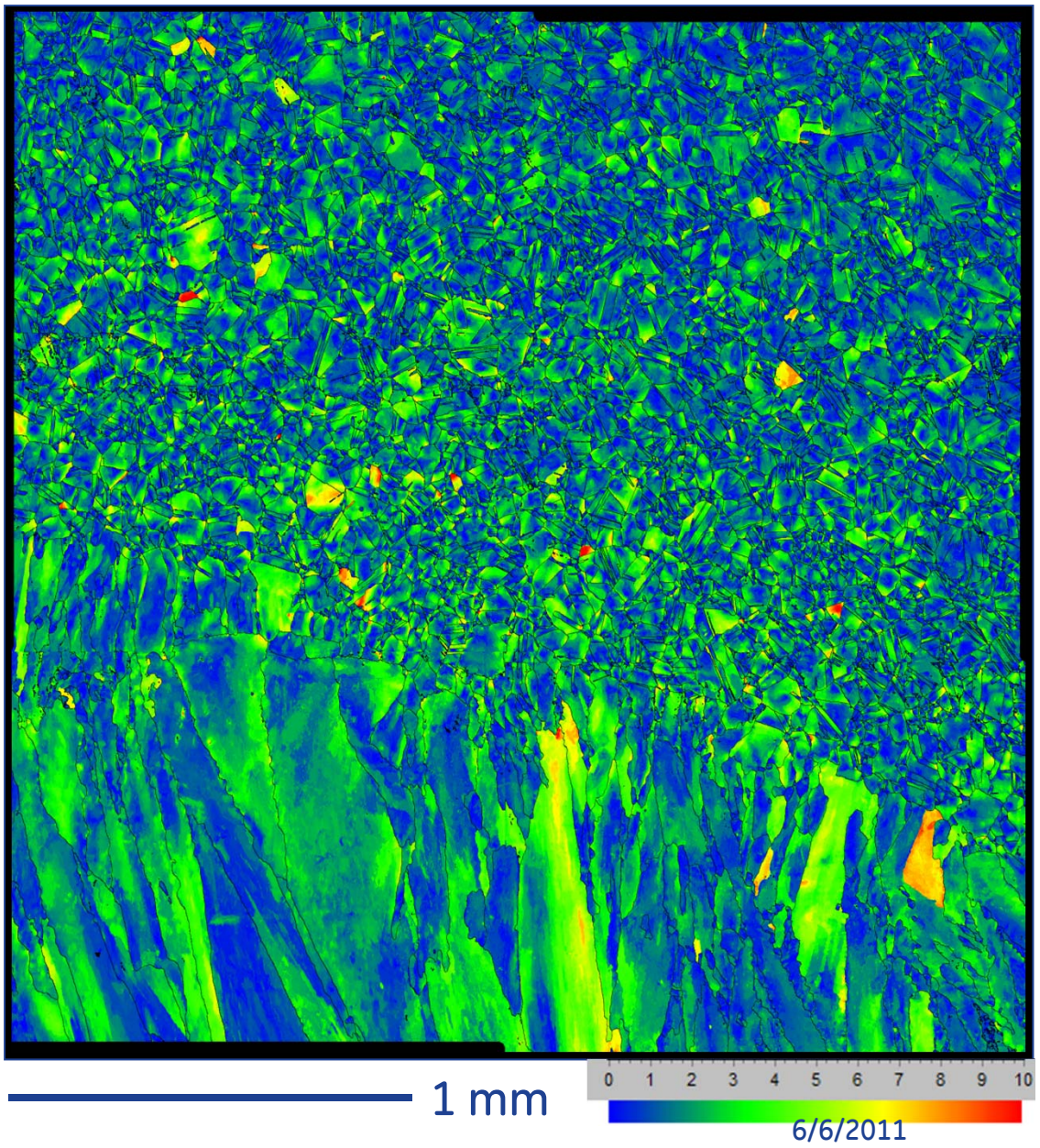


1 mm

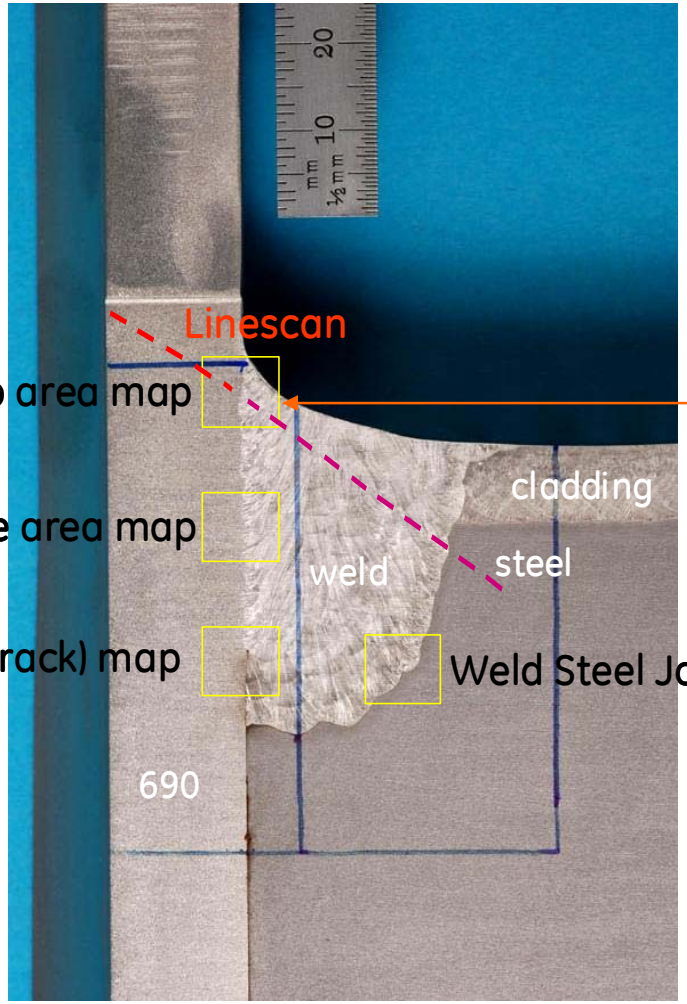
J-Groove Weld - 690 Side: Mapped Region

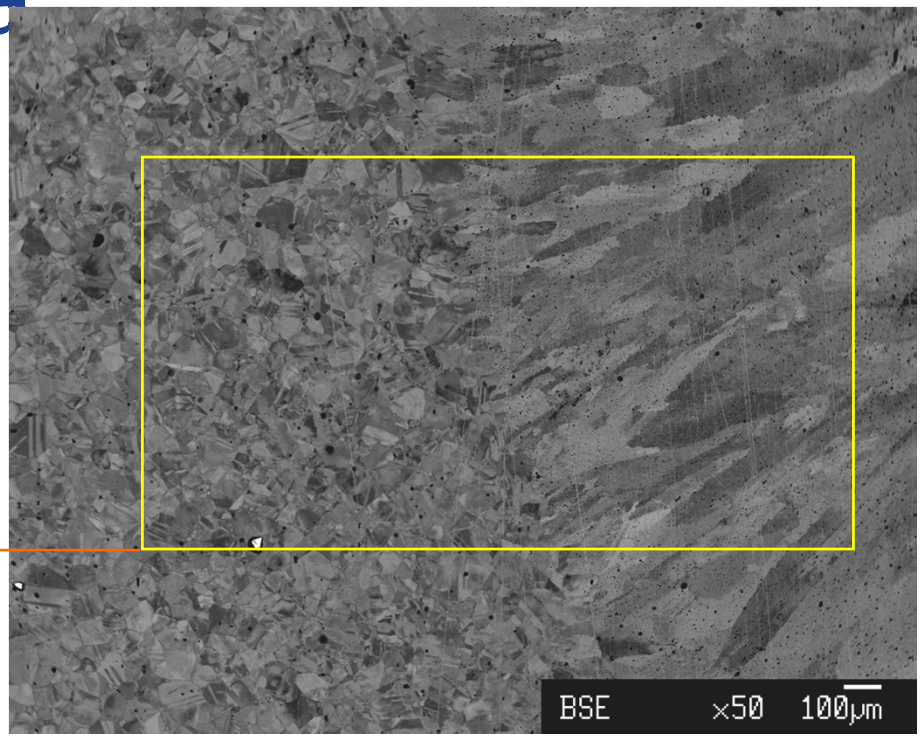
10° Misorientation Map



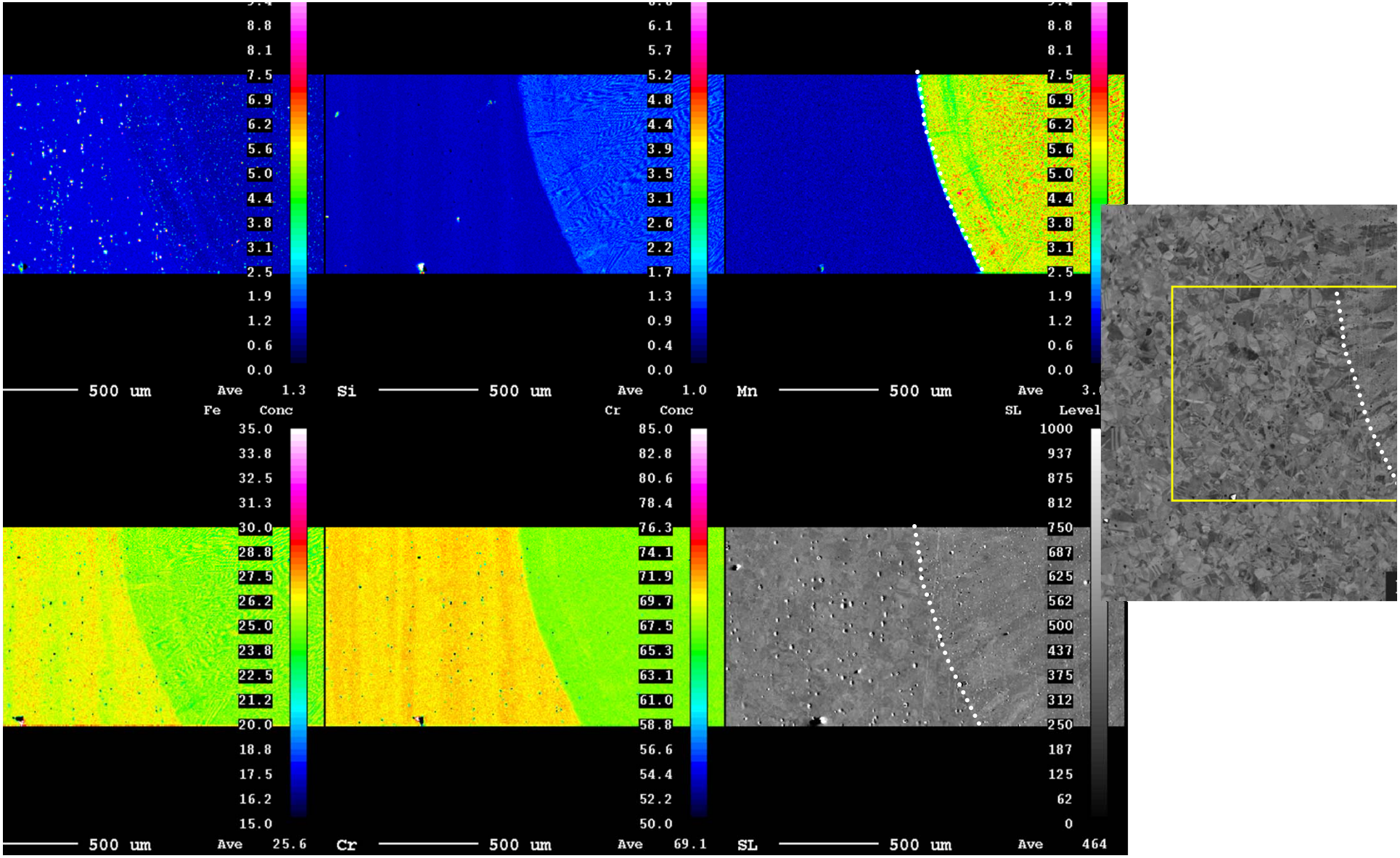


J-Groove- Top area

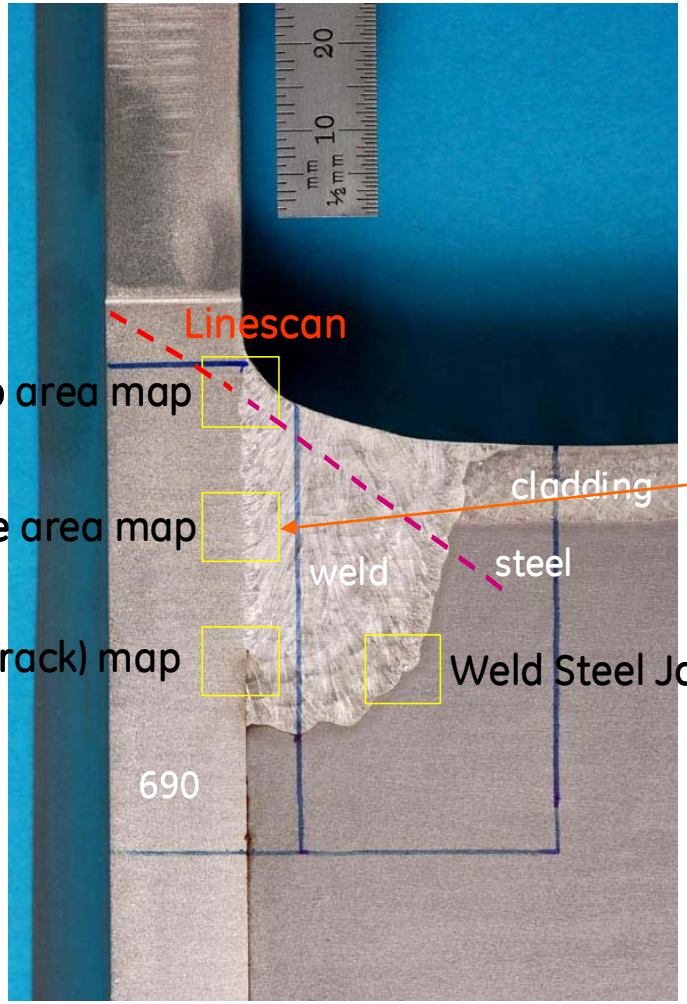


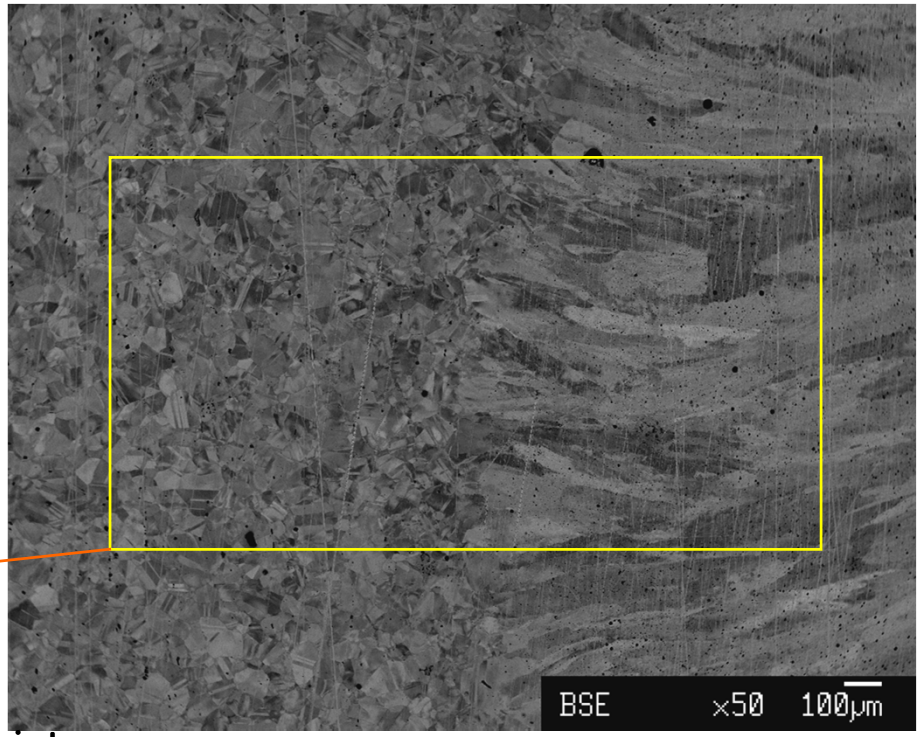


yellow box shows approximate area mapped


8.8
8.1
7.5
6.9
6.2
5.6
5.0
4.4
3.8
3.1
2.5
1.9
1.2
0.6
0.0
500 um
Ave 1.3
Fe Conc
6.1
5.7
5.2
4.8
4.4
3.9
3.5
3.1
2.6
2.2
1.7
1.3
0.9
0.4
0.0
Si
500 um
Ave 1.0
Cr Conc
Mn
500 um
Ave 3.
SL Level
35.0
33.8
32.5
31.3
30.0
28.8
27.5
26.2
25.0
23.8
22.5
21.2
20.0
18.8
17.5
16.2
15.0
500 um
Ave 25.6
Cr
85.0
82.8
80.6
78.4
76.3
74.1
71.9
69.7
67.5
65.3
63.1
61.0
58.8
56.6
54.4
52.2
50.0
500 um
Ave 69.1
SL
1000
937
875
812
750
687
625
562
500
437
375
312
250
187
125
62
0
500 um
Ave 464

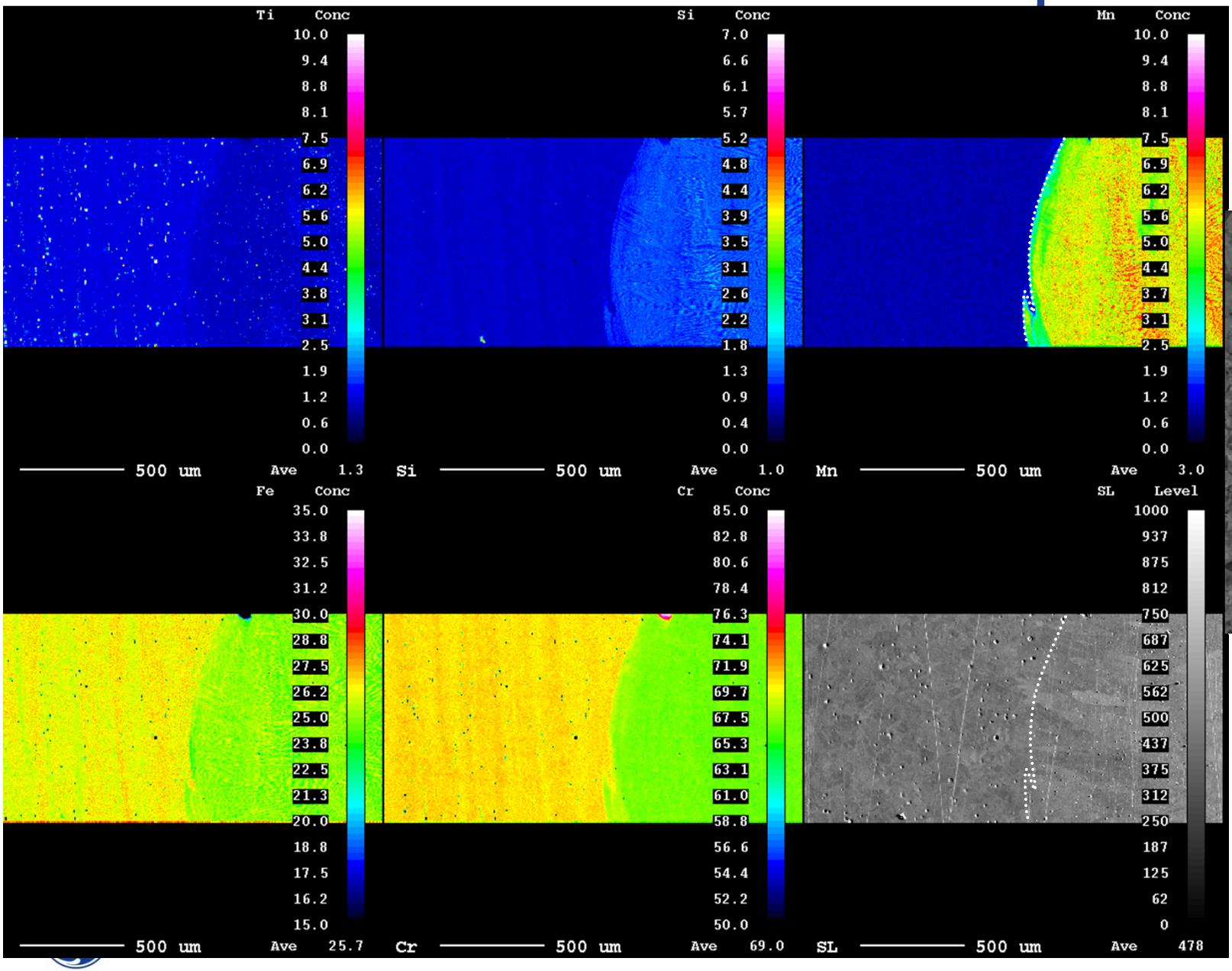
J-Groove- Middle area- Map

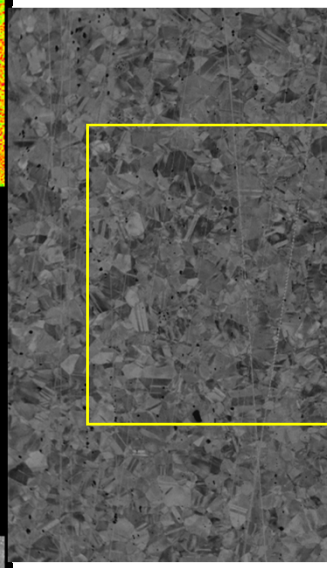




yellow box shows
approximate area mapped

J-Groove- Middle area- Map





J-Groove Weld

EBSD Strain Analysis – Steel Side

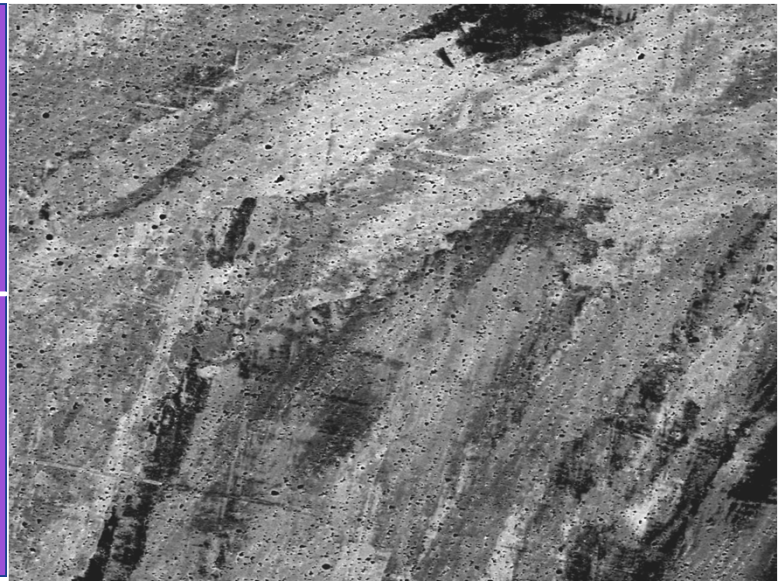
imagination at work

Images

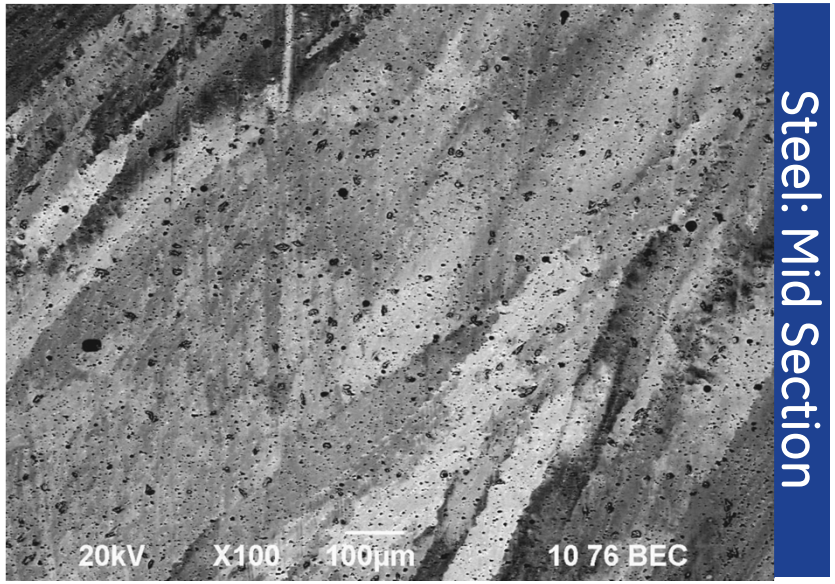
J-Groove Weld - Steel Side: 2mm Before Interface

BSE Images: 100x

Steel: Top Section

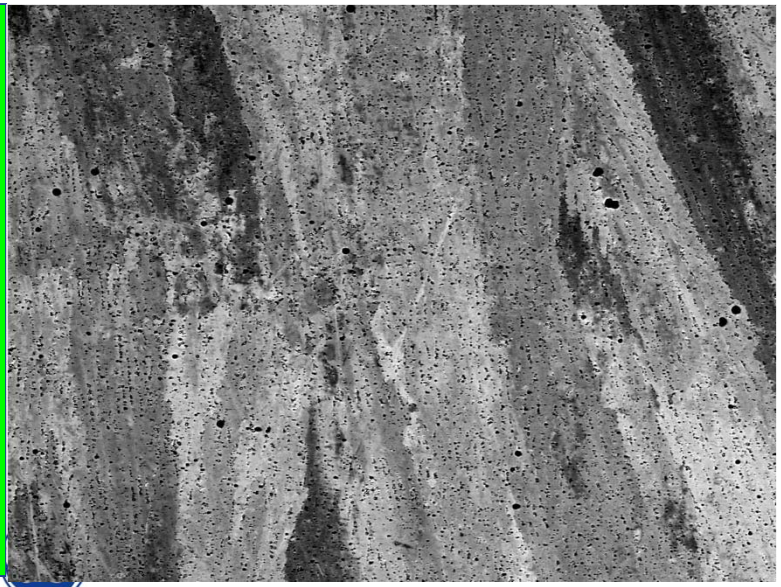


Steel: Mid Section

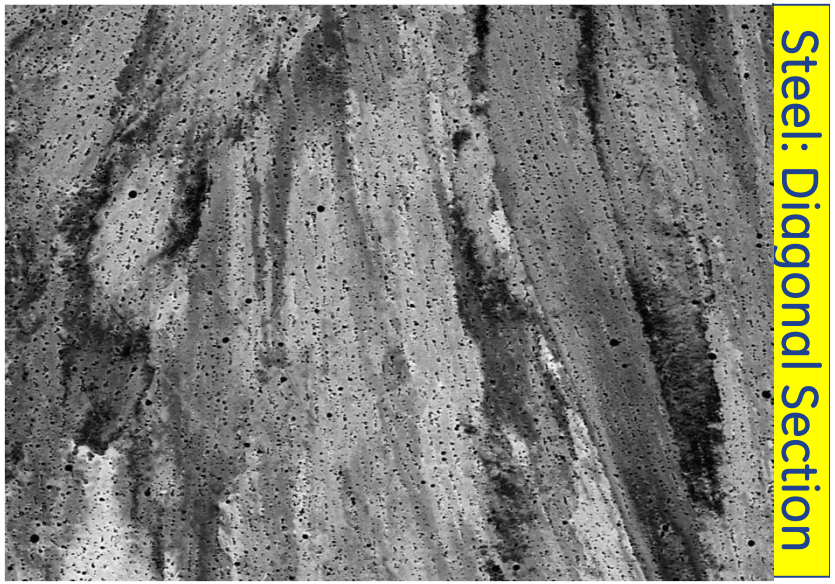


— 100 mm

Steel: Bottom Section



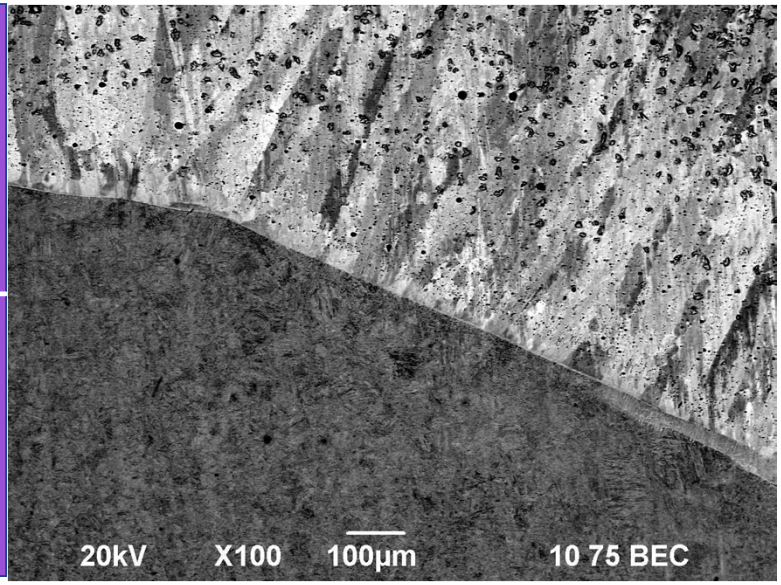
Steel: Diagonal Section



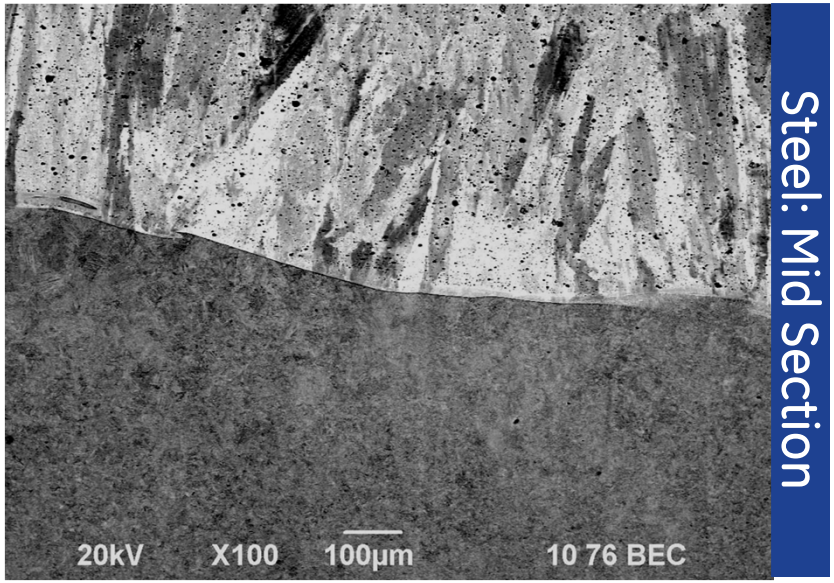
J-Groove Weld - Steel Side: Interface

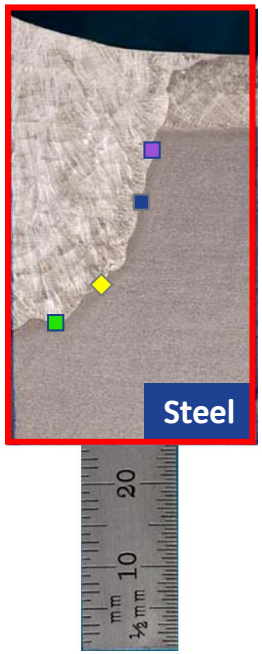
BSE Images: 100x

Steel: Top Section



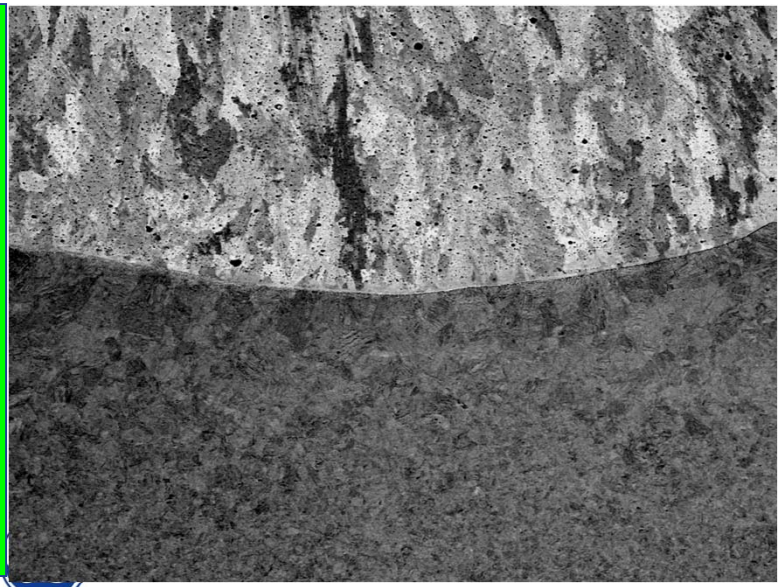
Steel: Mid Section



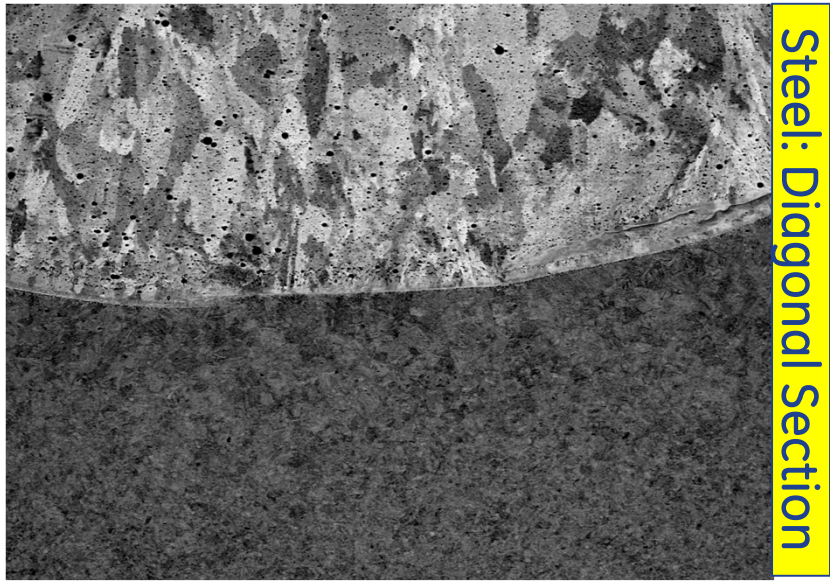


— 100 mm

Steel: Bottom Section



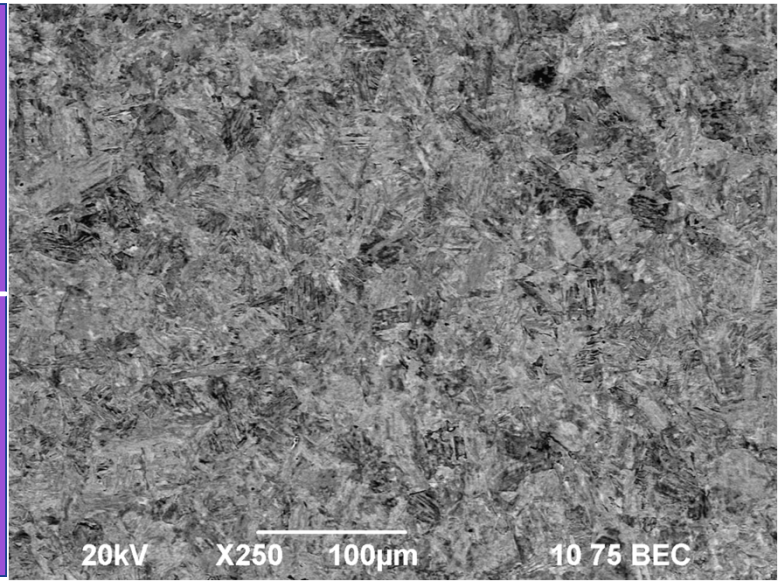
Steel: Diagonal Section



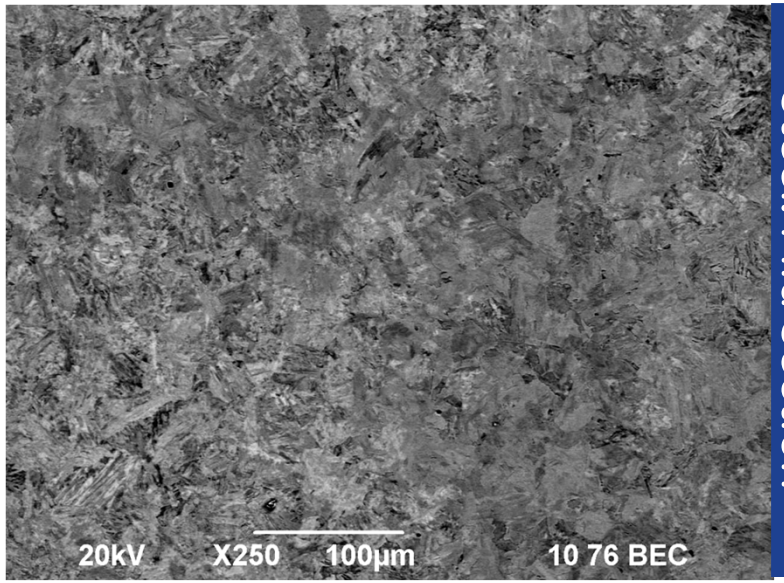
J-Groove Weld - Steel Side: 2mm After Interface

BSE Images: 250x

Steel: Top Section

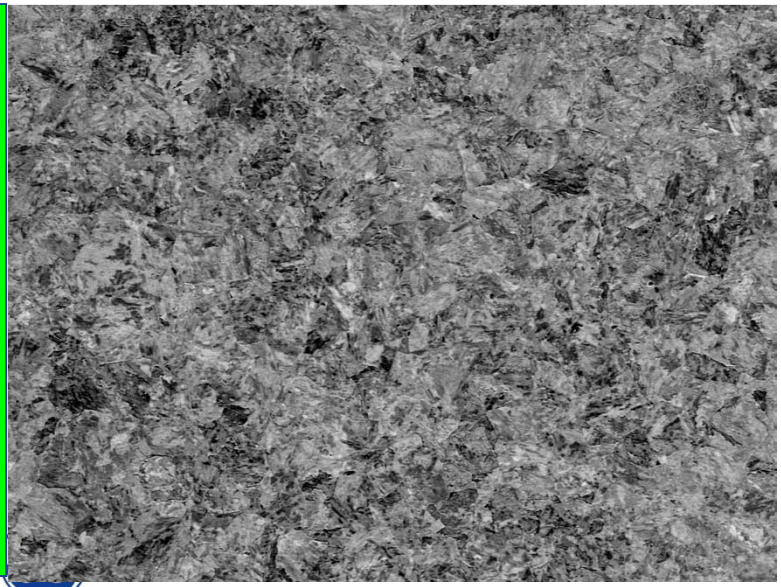


Steel: Mid Section

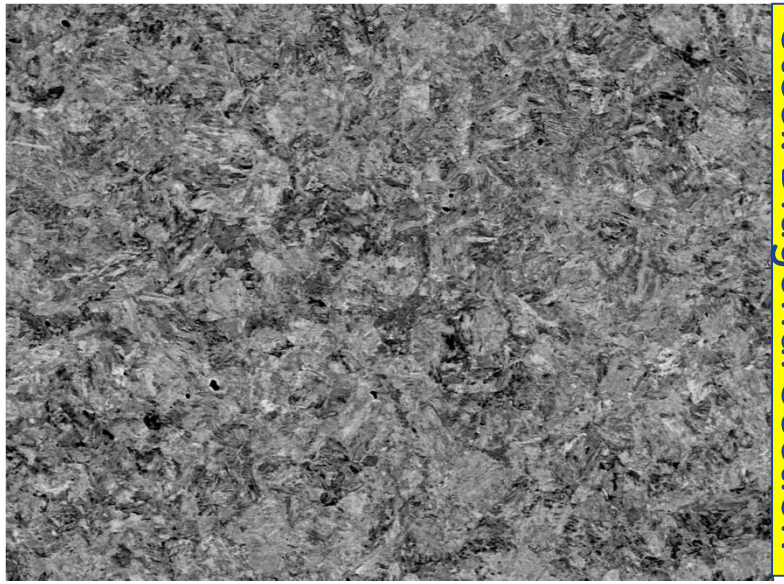


100 µm

Steel: Bottom Section



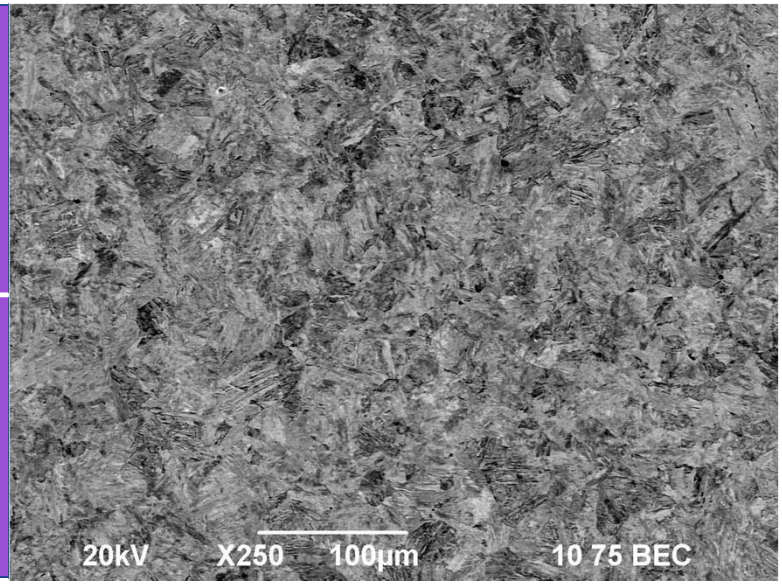
Steel: Diagonal Section



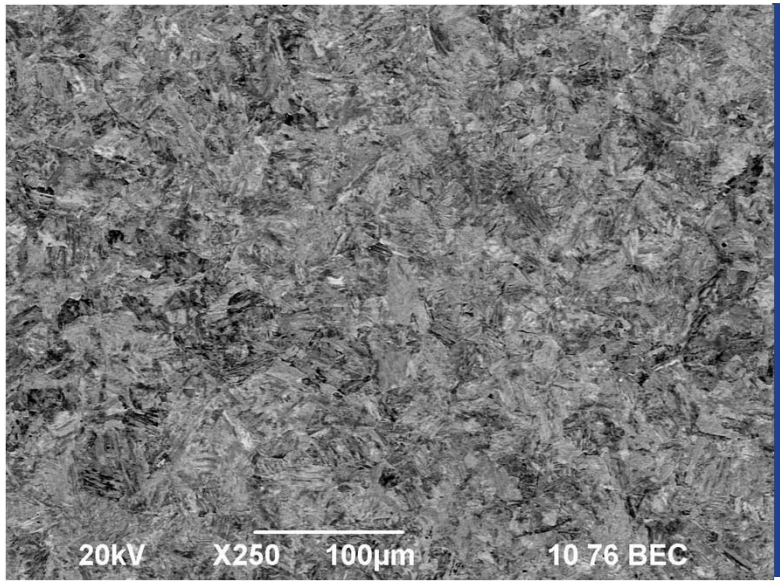
J-Groove Weld - Steel Side: 5mm After Interface

BSE Images: 250x

Steel: Top Section

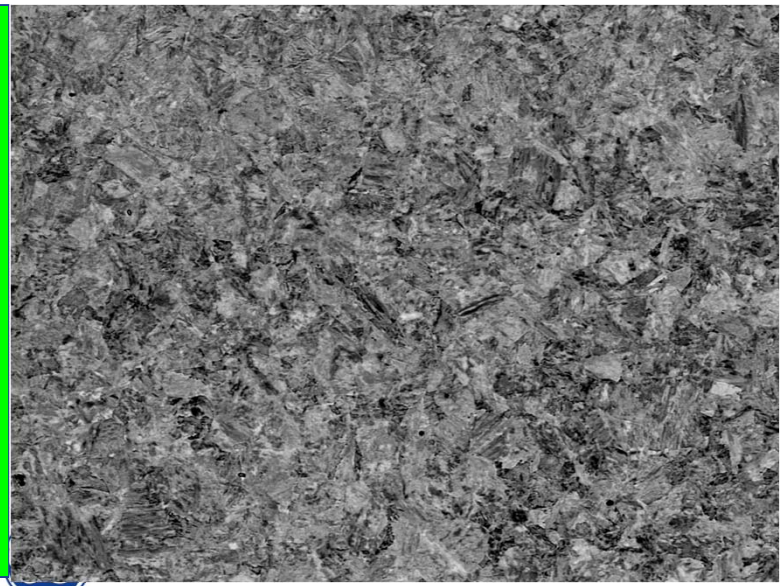


Steel: Mid Section

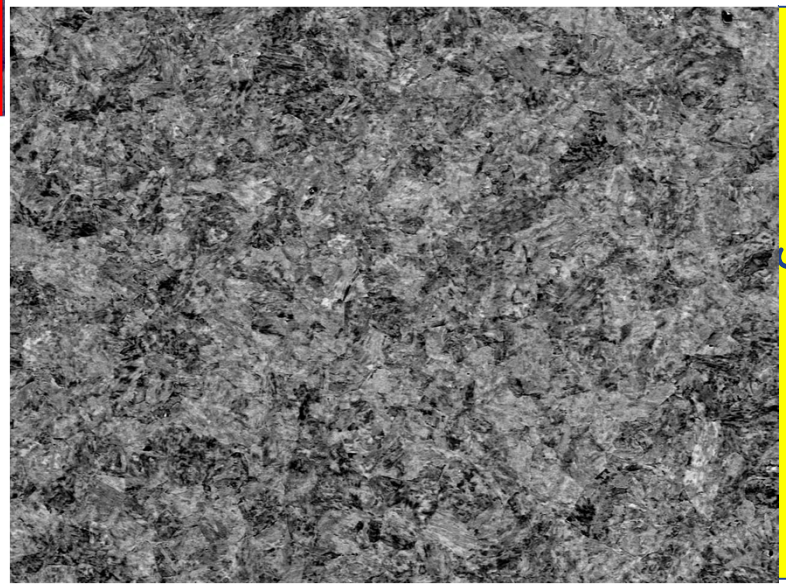


100 µm

Steel: Bottom Section



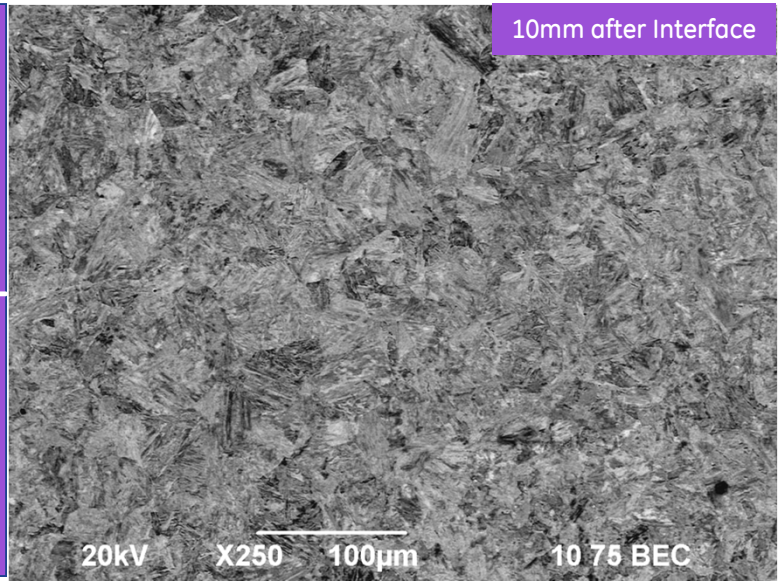
Steel: Diagonal Section

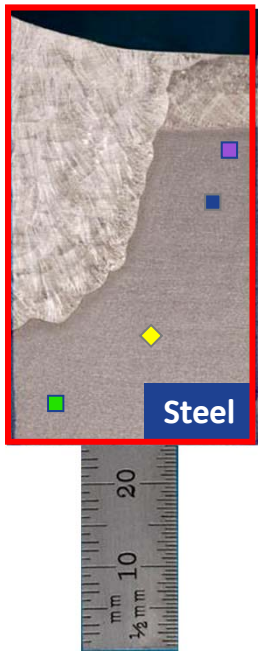


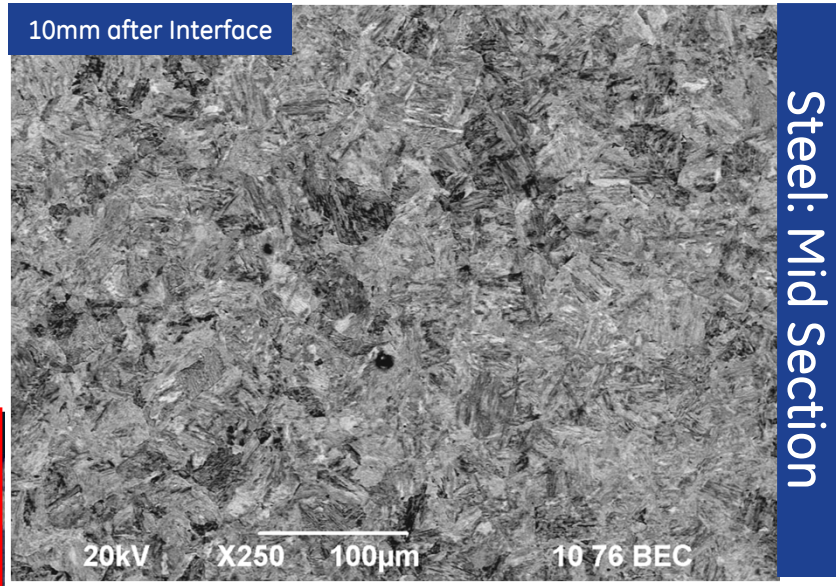
J-Groove Weld - Steel Side

BSE Images: 250x

Steel: Top Section



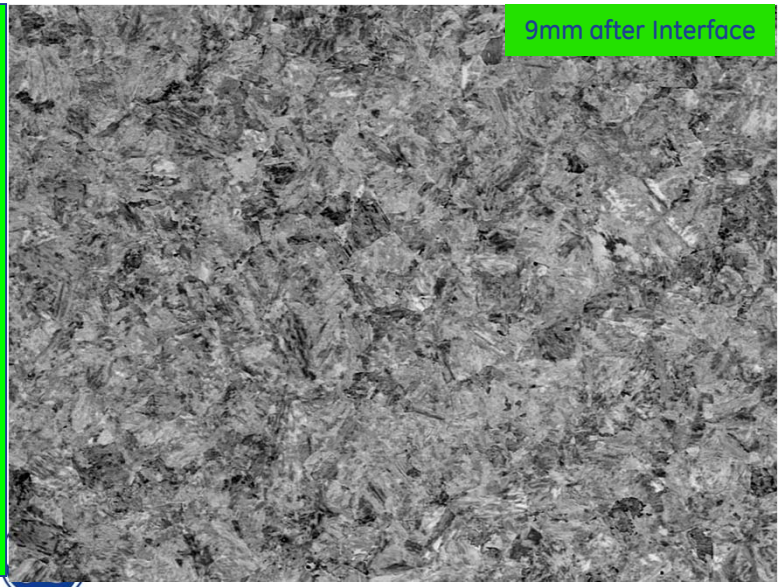


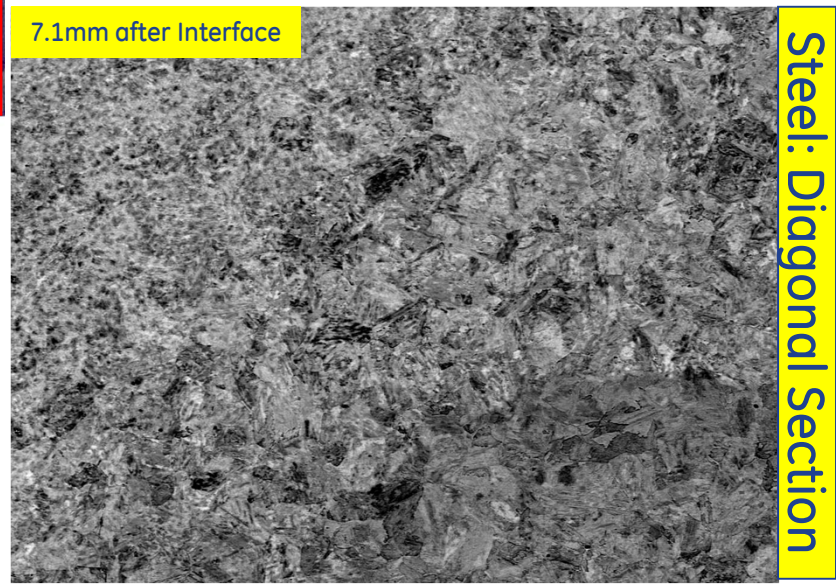


Steel: Mid Section

100 µm

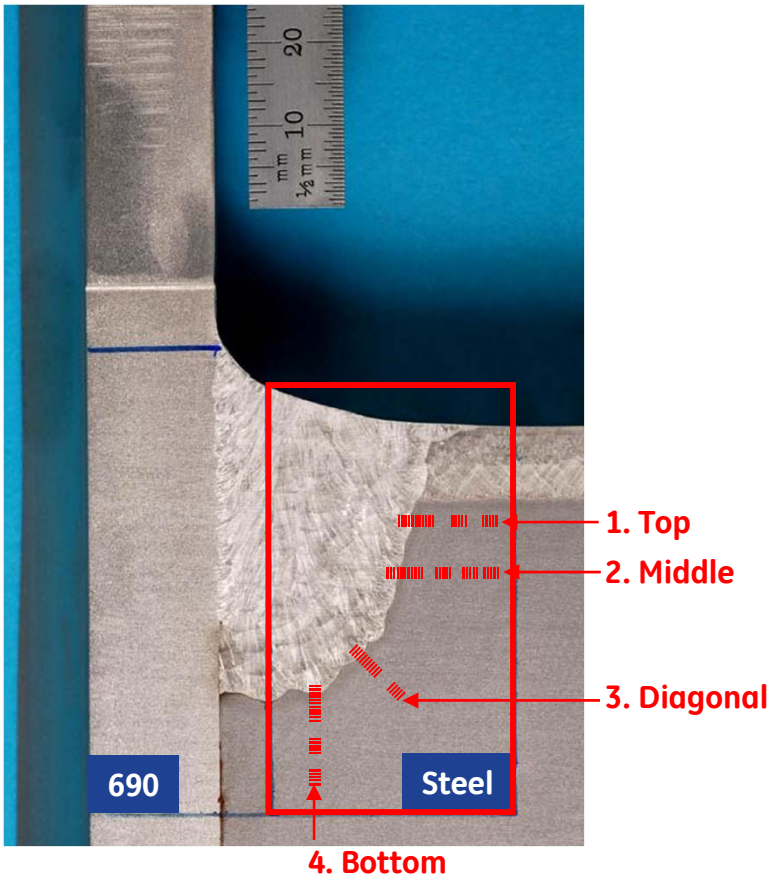
Steel: Bottom Section





Steel: Diagonal Section

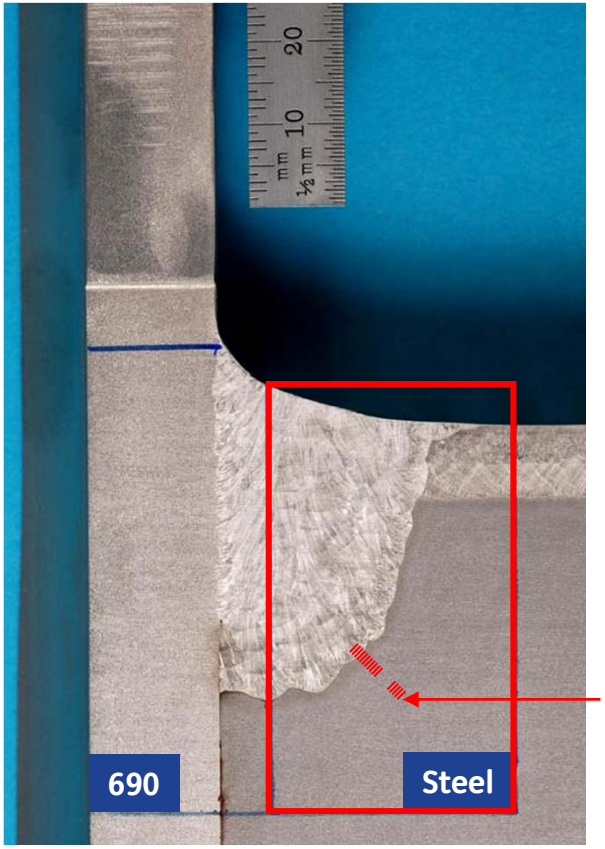
J-Groove Weld



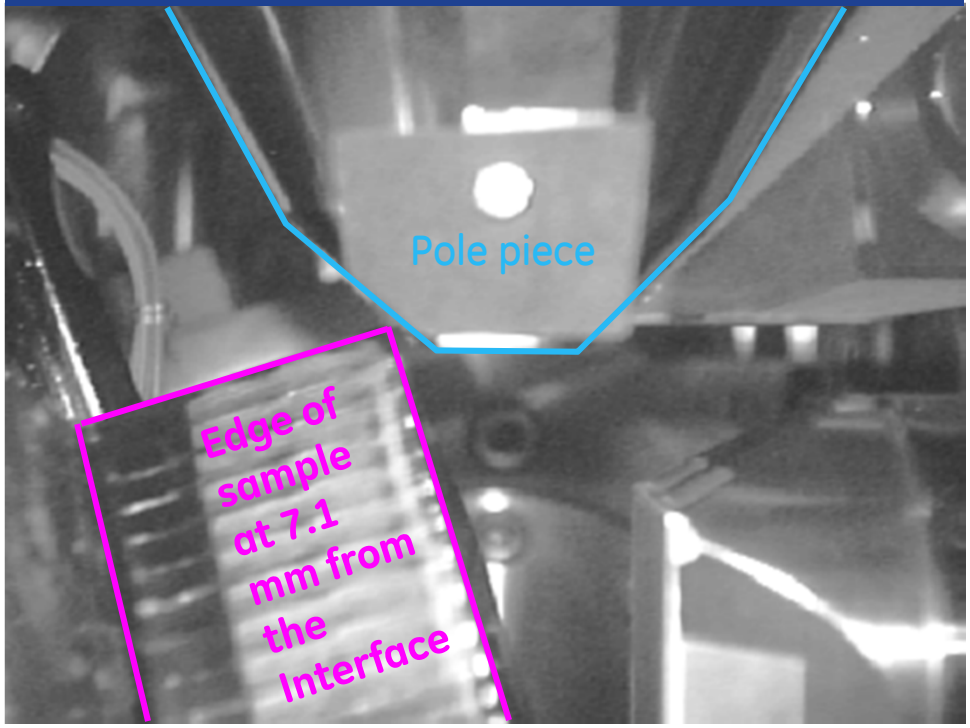
EBSD Strain Analysis – Steel Side

Linescan Data

Note regarding the Diagonal Section

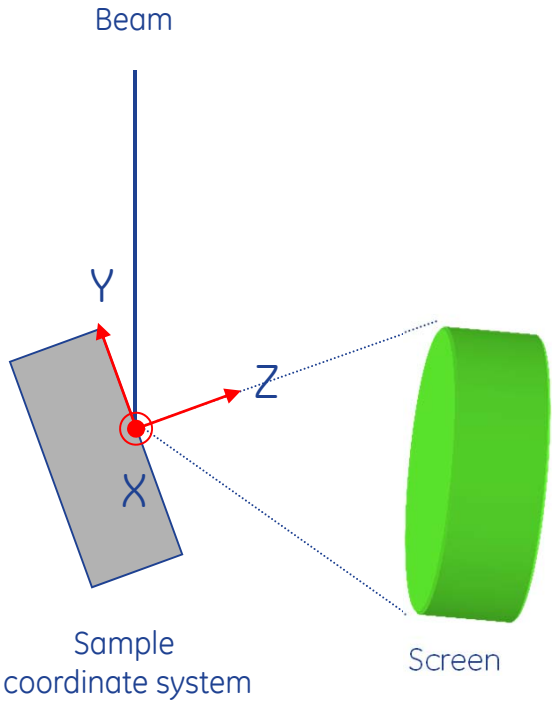


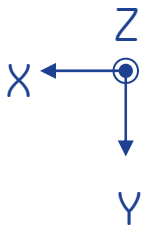
Chamber of SEM with Steel Section of J-Groove set up for Diagonal measurement



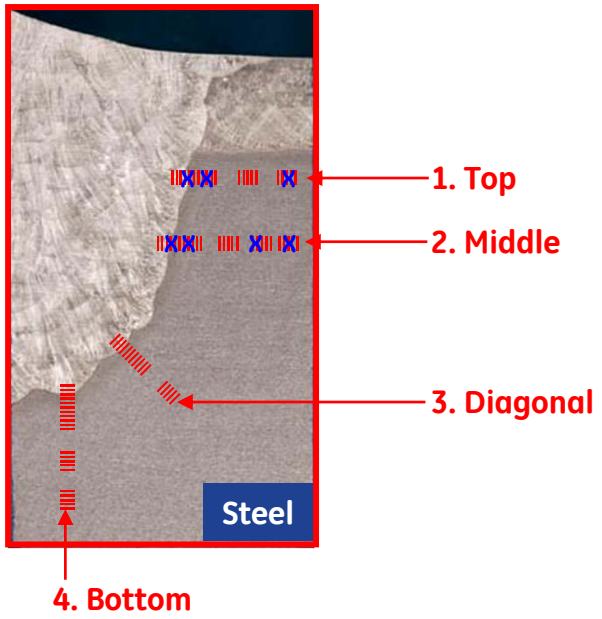
Due to the large physical size of the sample, measurement of the "Diagonal" section was limited to ~7.1mm from the interface.

Measurement Setup:





Sample coordinate system orientation



- Linescan locations indicated in red
- Map locations are indicated by a blue X

Sample prep:

- Samples were cut and ground down to 800 grit size at The M&P Lab
- Electropolished and measured by EBSD at GE-GRC

Linescan Measurement Conditions:

- Magnification = 100x
- 1.285 mm in the x direction
- Varies per location in the y direction
- 0.25 um steps in the x-direction
- 50 μm steps in the y-direction
- 20kV accelerating voltage (JEOL 6490)

Map Measurement Conditions:

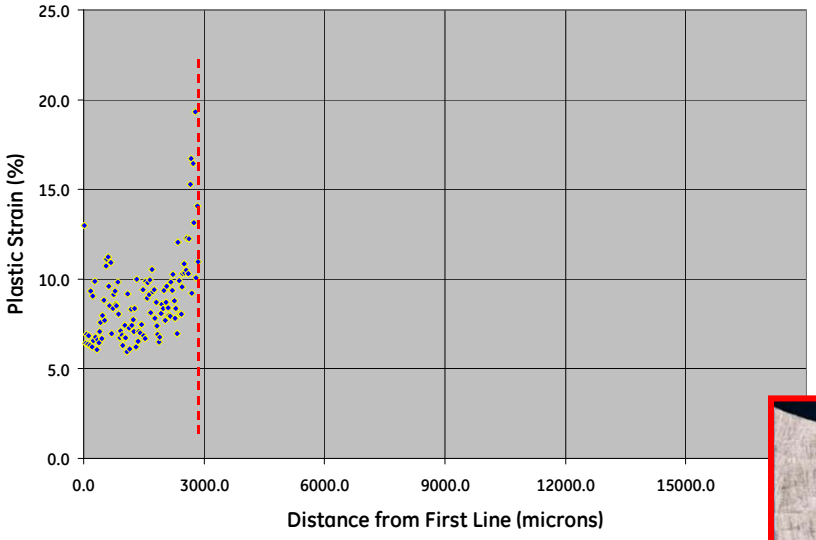
- Magnification = 100x
- 187.5 um in the x direction
- 187.5 um y direction
- 0.25 um steps in the x-direction
- 0.25 um steps in the y-direction
- 20kV accelerating voltage (JEOL 6490)

imagination at work

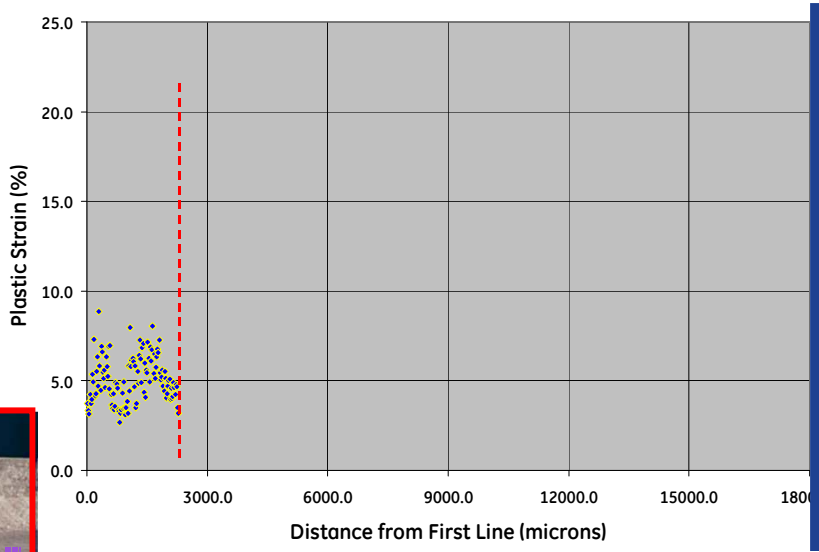
J-Groove Weld - Steel Side

Plastic Strain vs. Distance

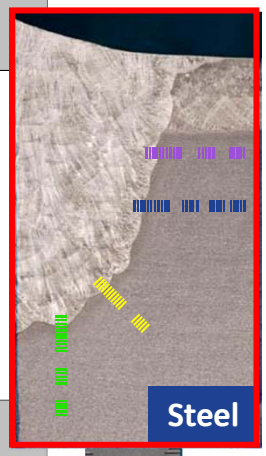
Steel: Top Section



Steel: Mid Section

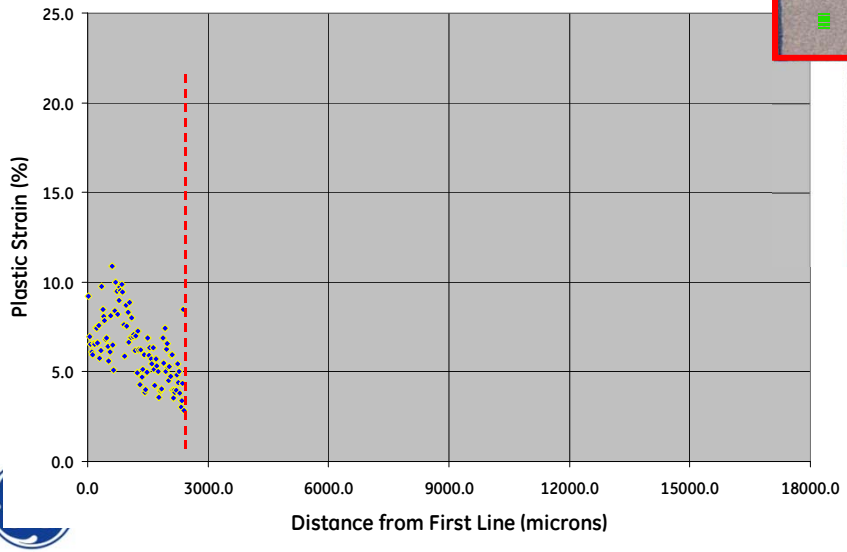


Plastic strain data is ONLY from the weld region.

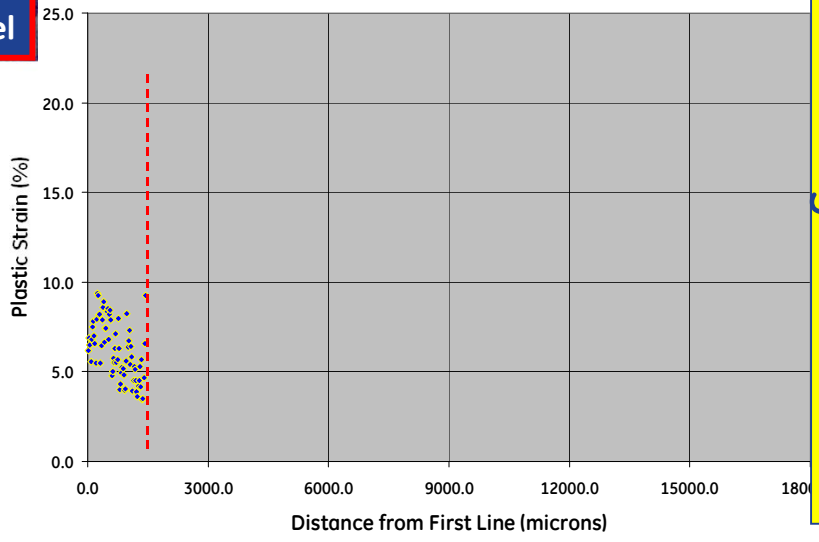


Plastic strain has not been calculated from the steel side of the interface since this material has not yet been calibrated for plastic strain.

Steel: Bottom Section



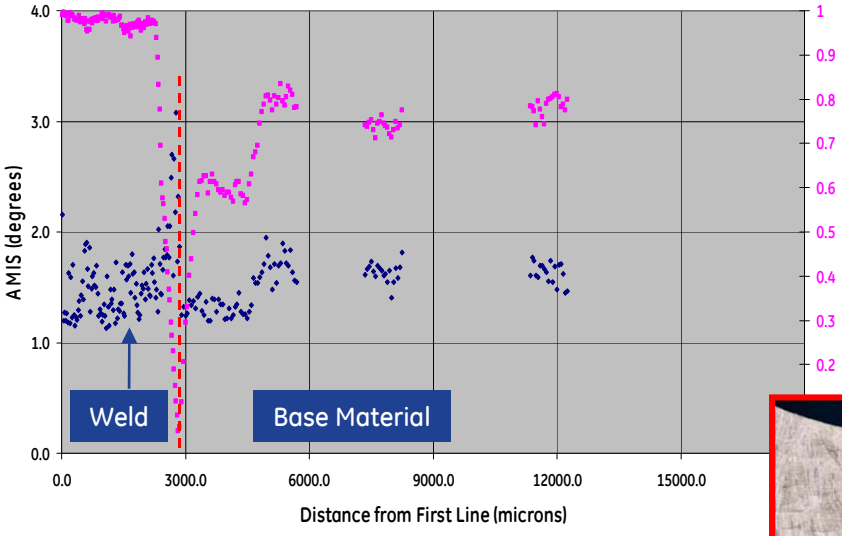
Steel: Diagonal Section



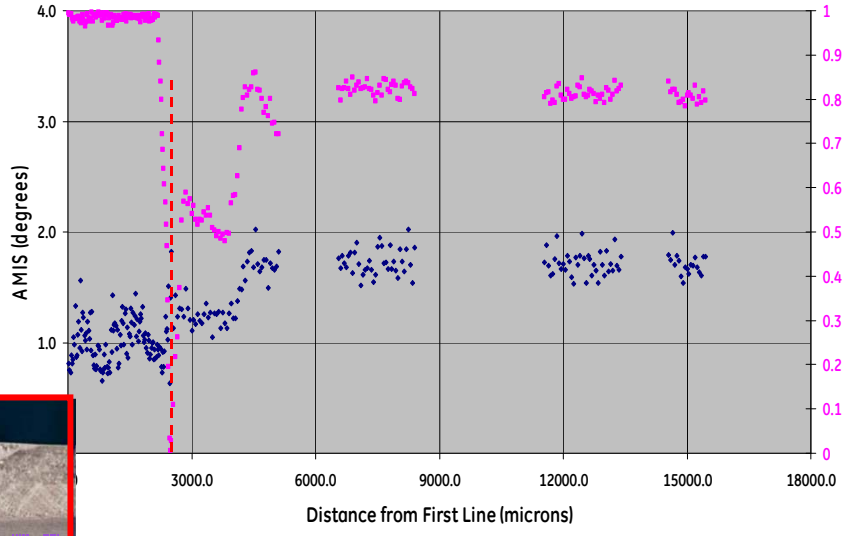
J-Groove Weld - Steel Side

AMIS/Hit Rate vs. Distance

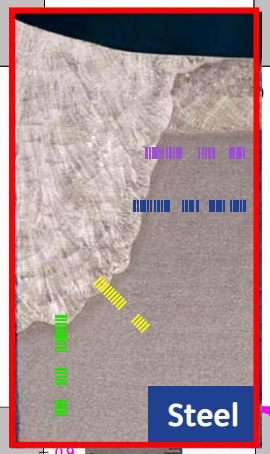
Steel: Top Section



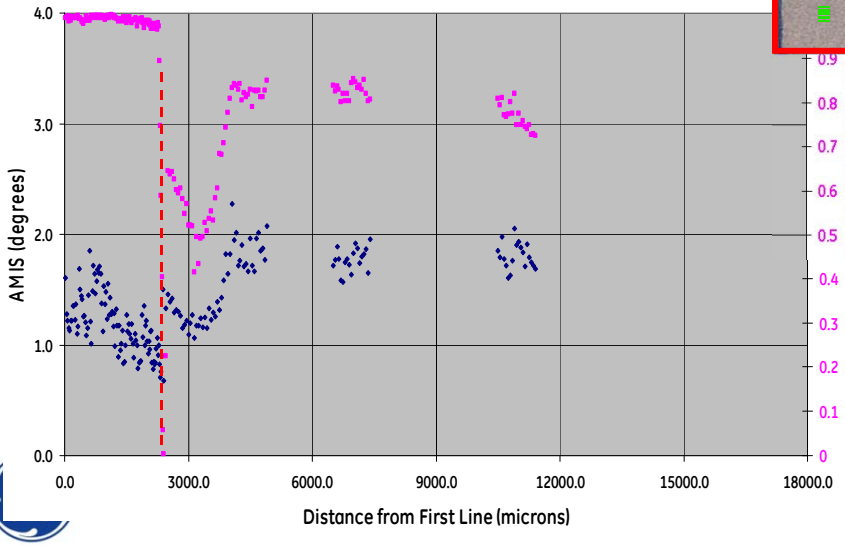
Steel: Mid Section



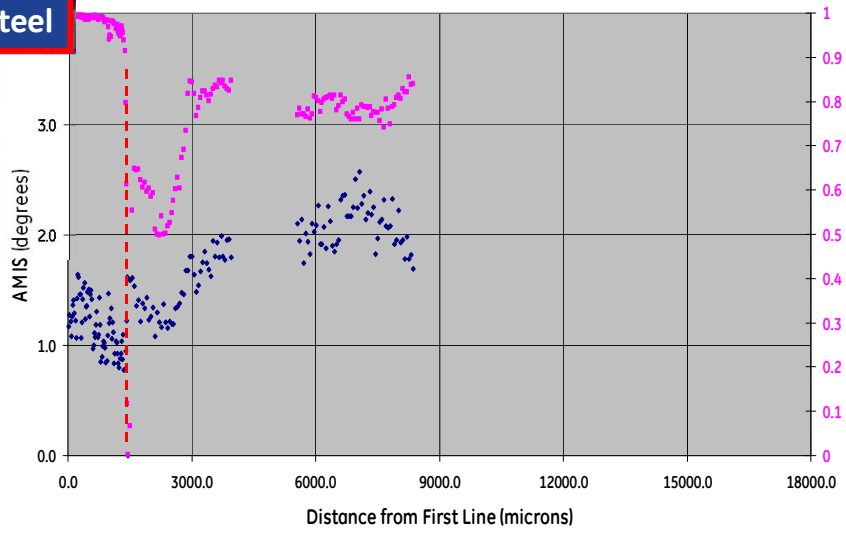
Hit Rate
AMIS



Steel: Bottom Section



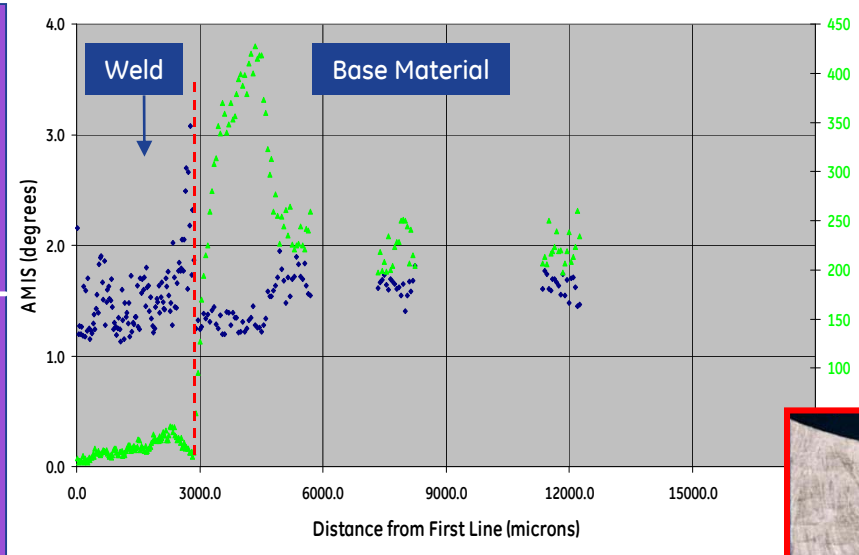
Steel: Diagonal Section



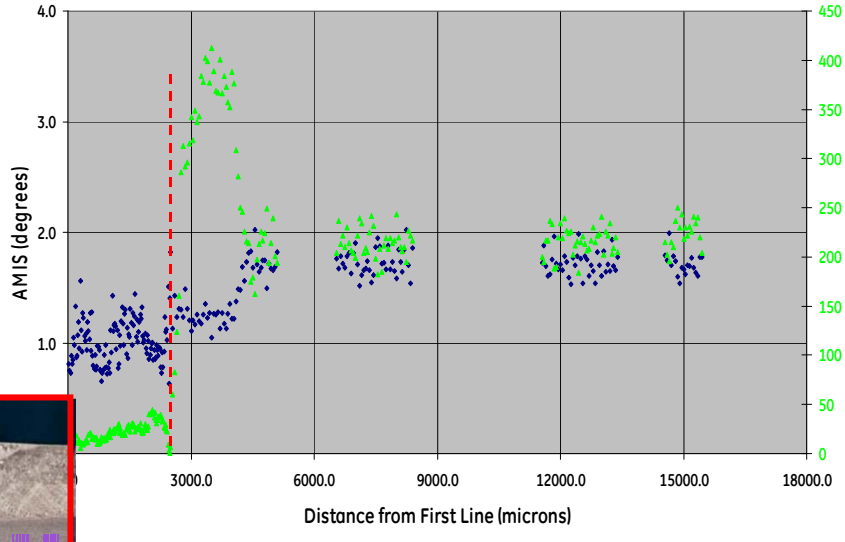
J-Groove Weld - Steel Side

AMIS/# of Segments vs. Distance

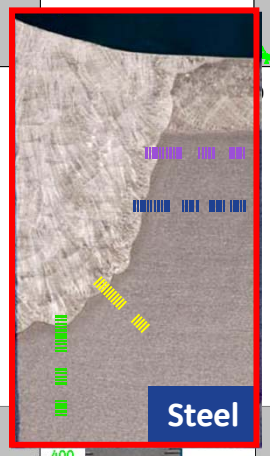
Steel: Top Section



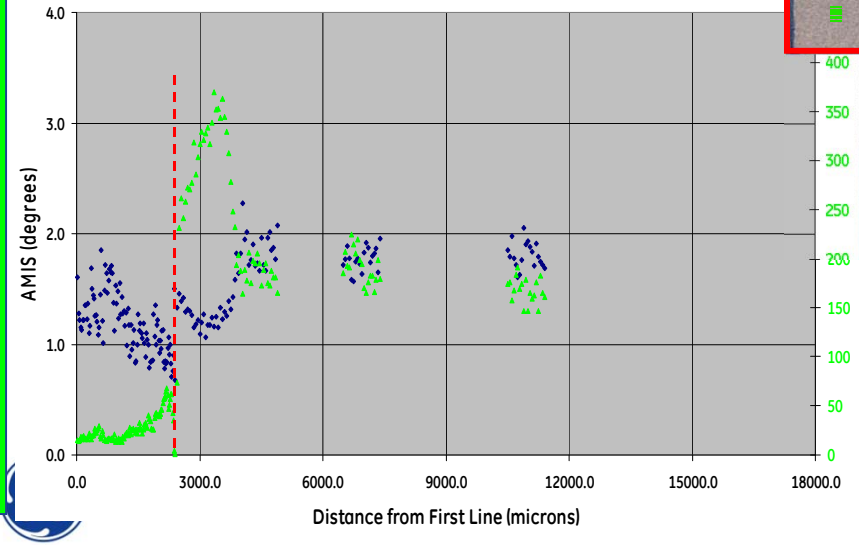
Steel: Mid Section



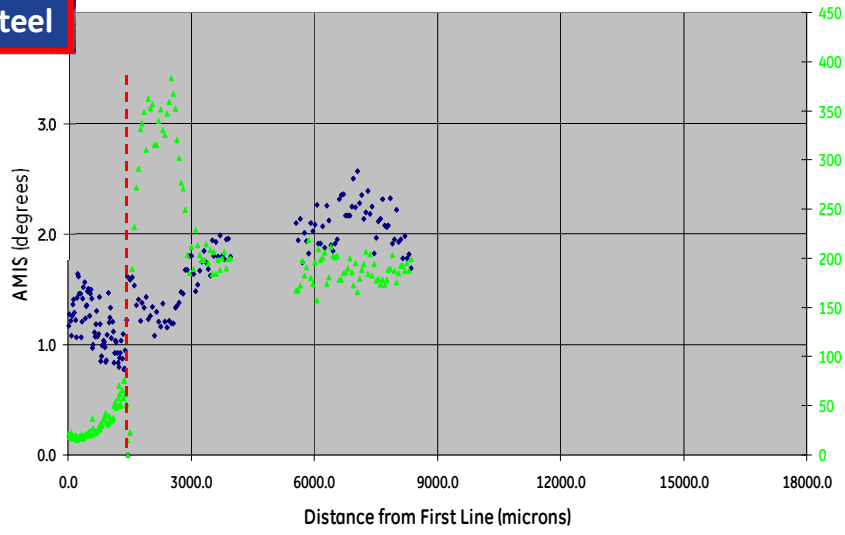
of Segments
AMIS



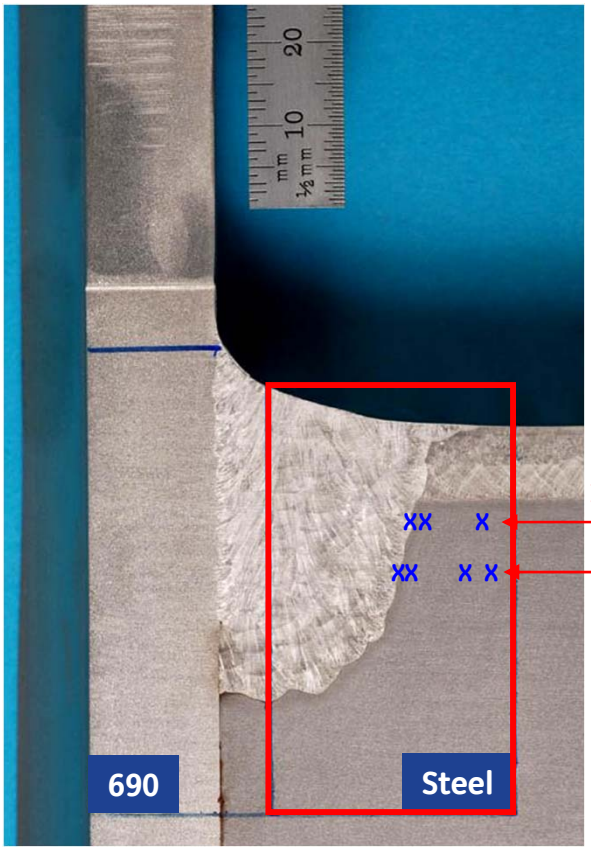
Steel: Bottom Section



Steel: Diagonal Section



J-Groove Weld



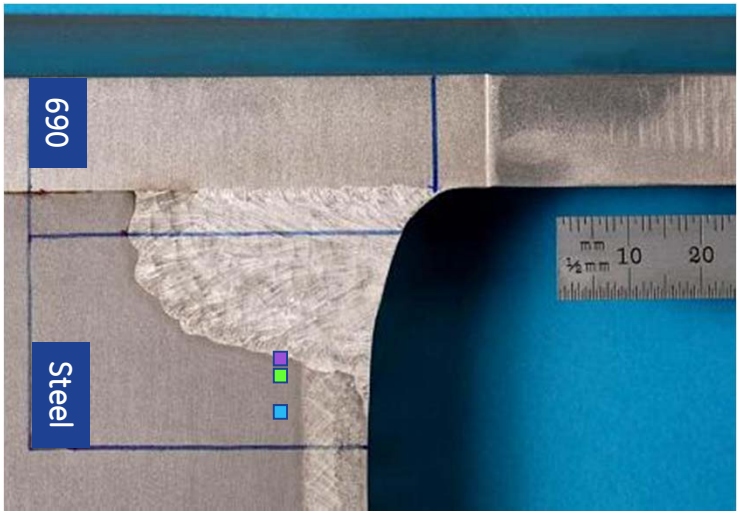
1. Top: Interface, 2mm from interface, 9mm from interface
2. Middle: Interface, 2mm from interface, 9mm from interface, 13mm from interface

Map locations are indicated by a blue X.

EBSD Strain Analysis – Steel Side

Map Analyses

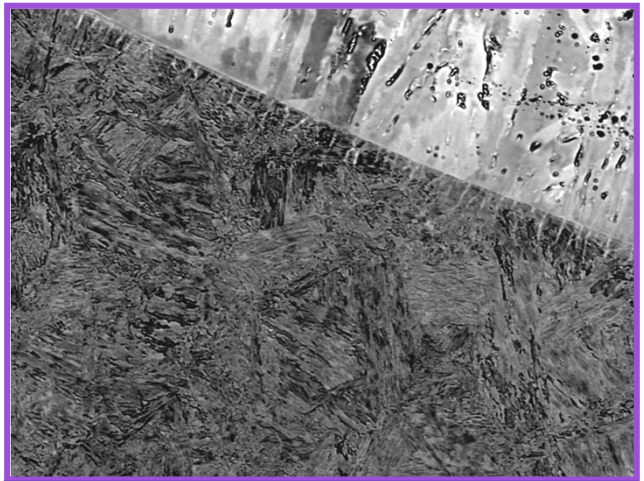
J-Groove Weld: Steel Side



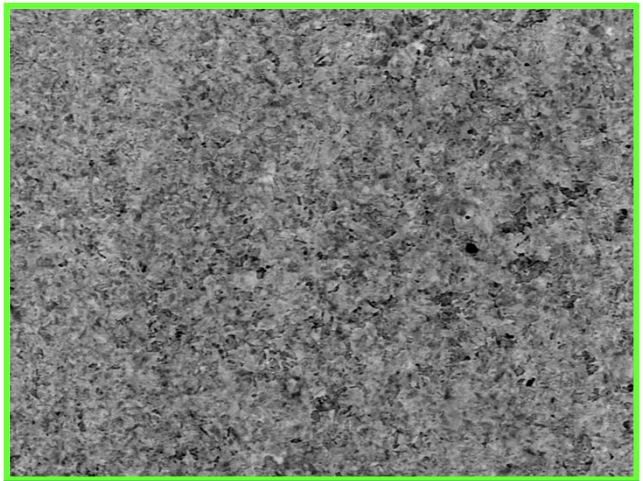
Map Analyses: Top Section

J-Groove Weld - Steel Side

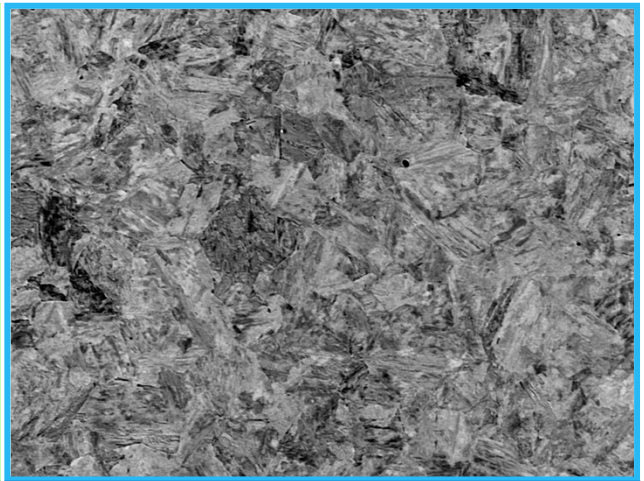
Top Section: BSE Images 500x



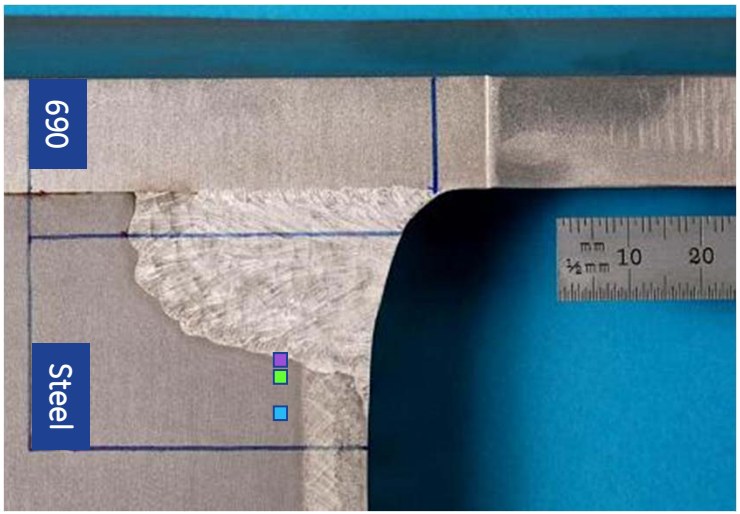
Interface



2 mm from Interface



9 mm from Interface

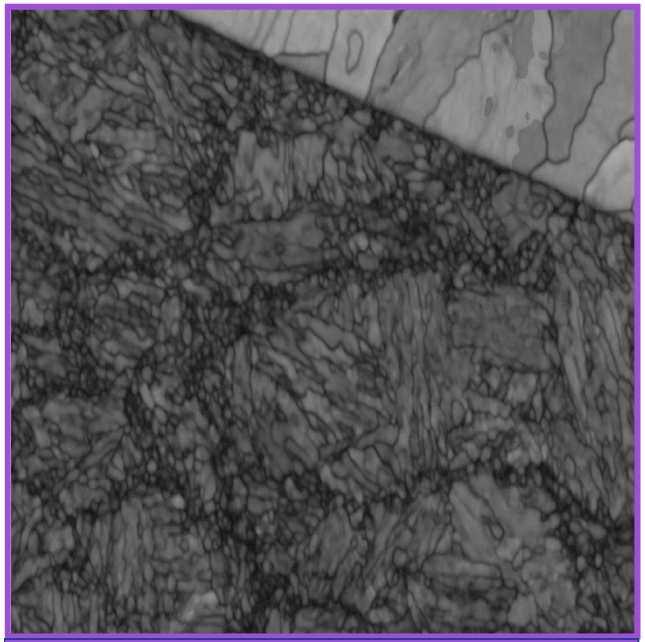


50 µm

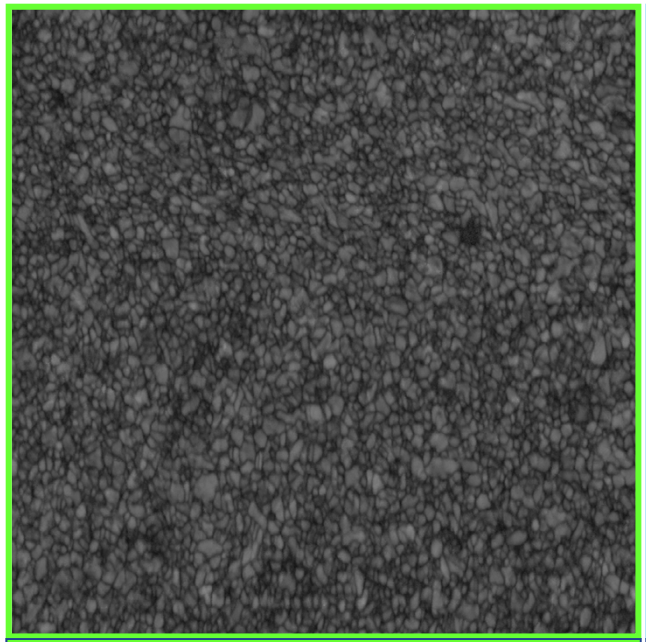
imagination at work

J-Groove Weld - Steel Side

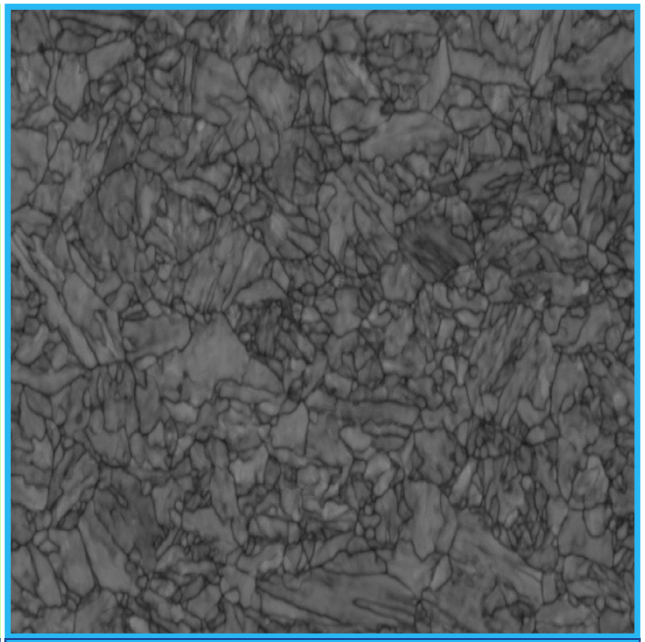
Top Section: Band Contrast Maps



Interface

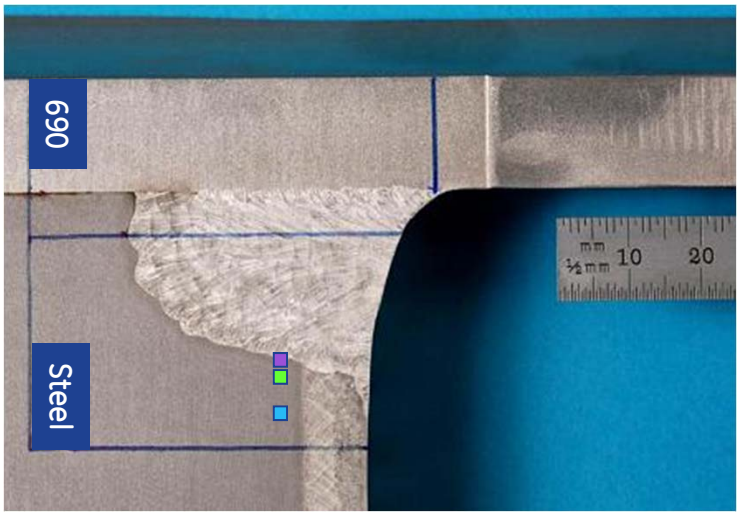


2 mm from Interface



9 mm from Interface

50 μm

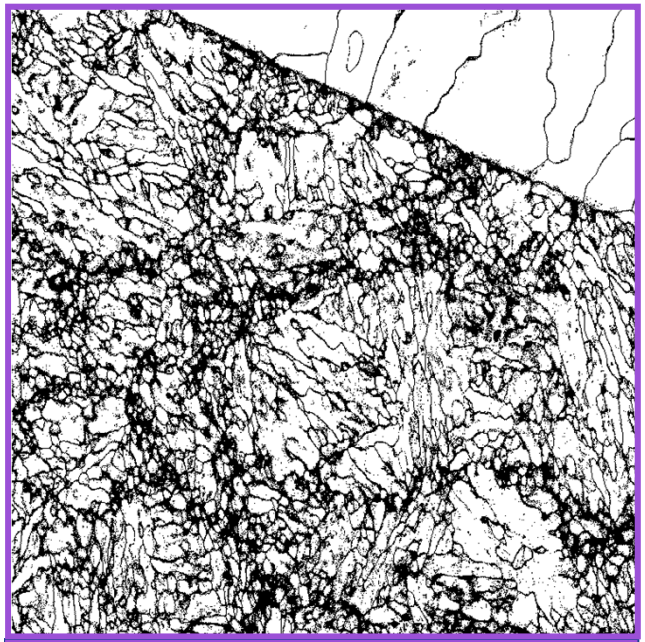


NOTE: Maps are processed from raw data only. (No noise reduction was performed.)

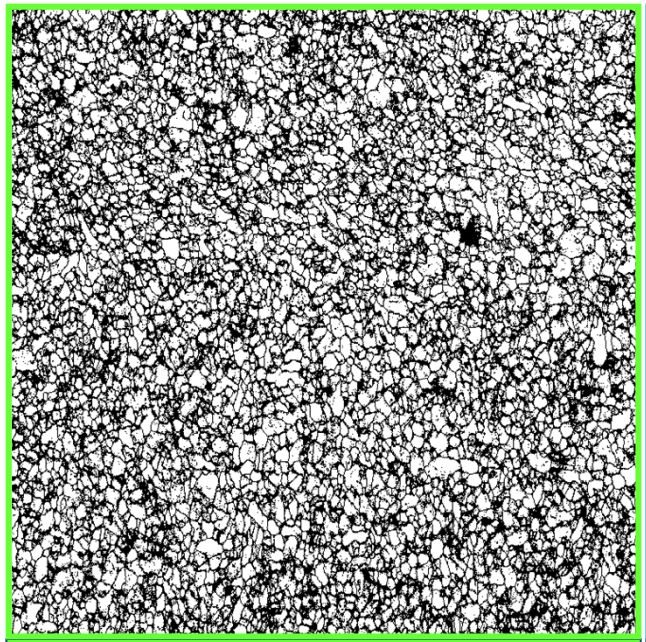
imagination at work

J-Groove Weld - Steel Side

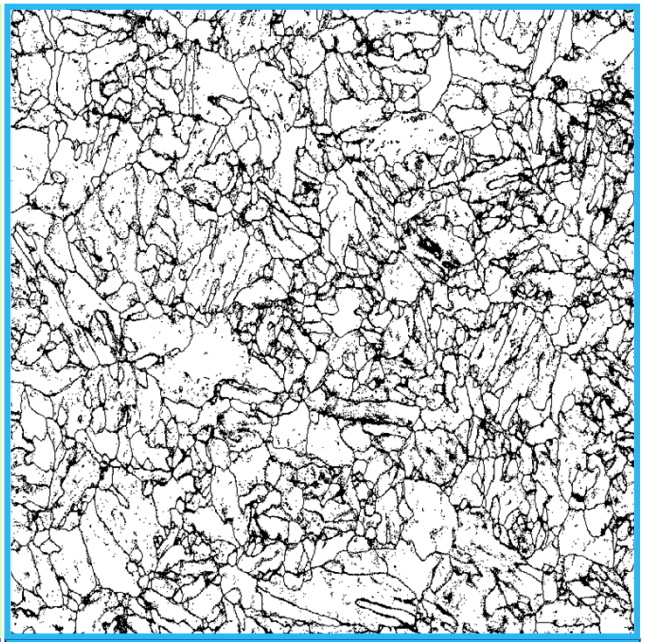
Top Section: Boundary Maps



Interface

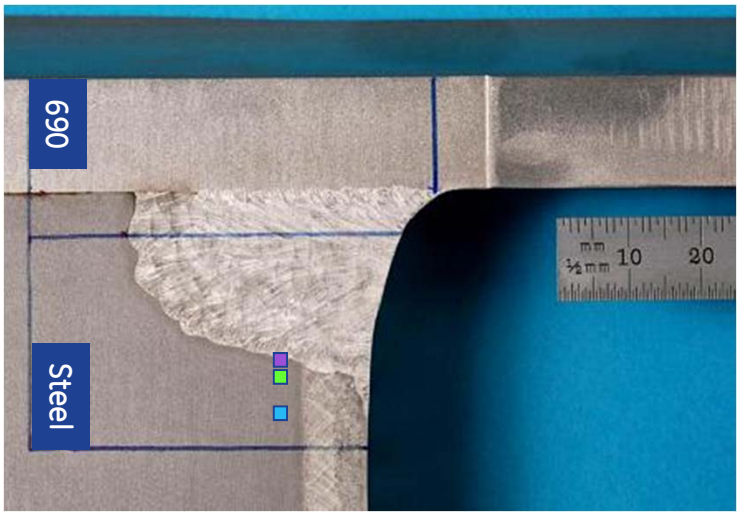


2 mm from Interface



9 mm from Interface

50 μm



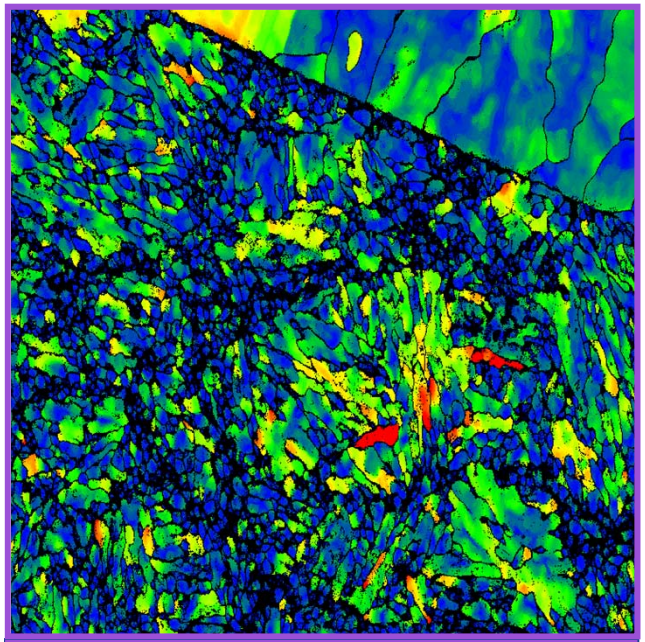
Black Lines = 10°<θ<60°

NOTE: Maps are processed from raw data only. (No noise reduction was performed.)

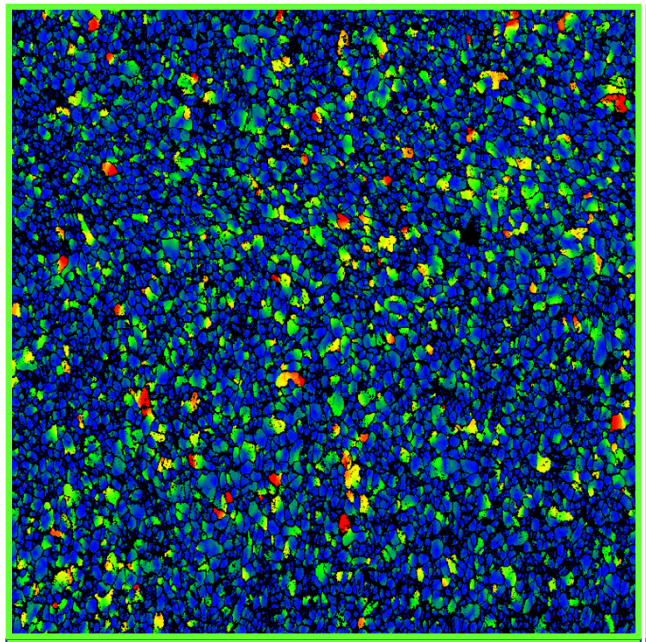
imagination at work

J-Groove Weld - Steel Side

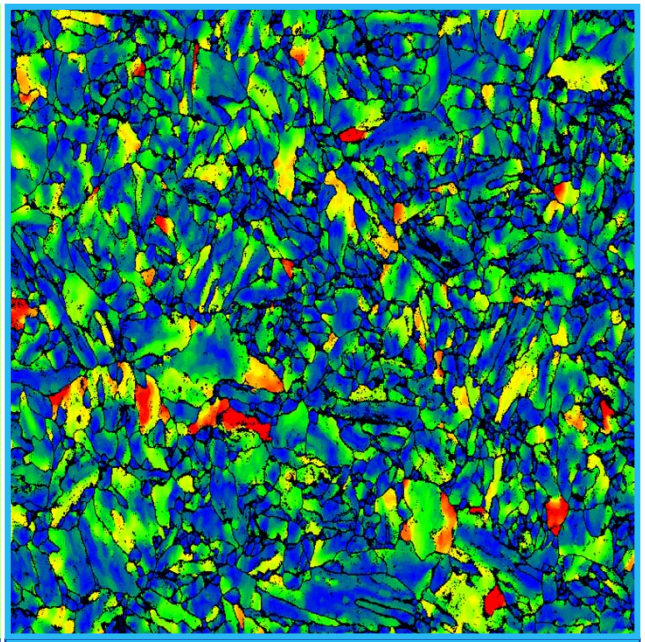
Top Section: 10° Misorientation Maps



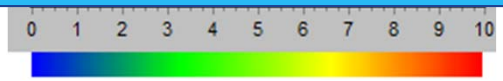
Interface



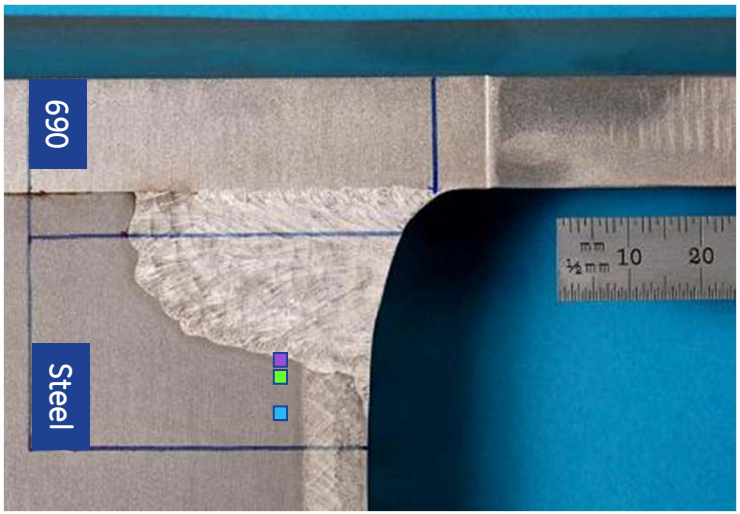
2 mm from Interface



9 mm from Interface



50 μm

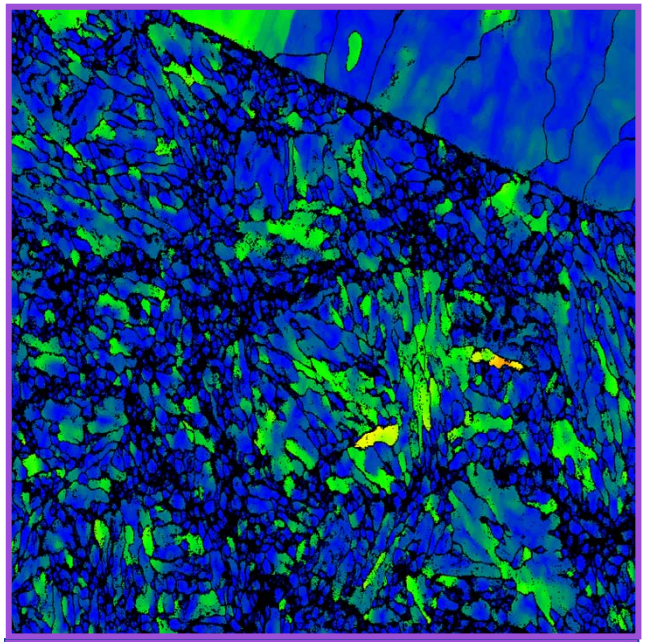


NOTE: Maps are processed from raw data only. (No noise reduction was performed.)

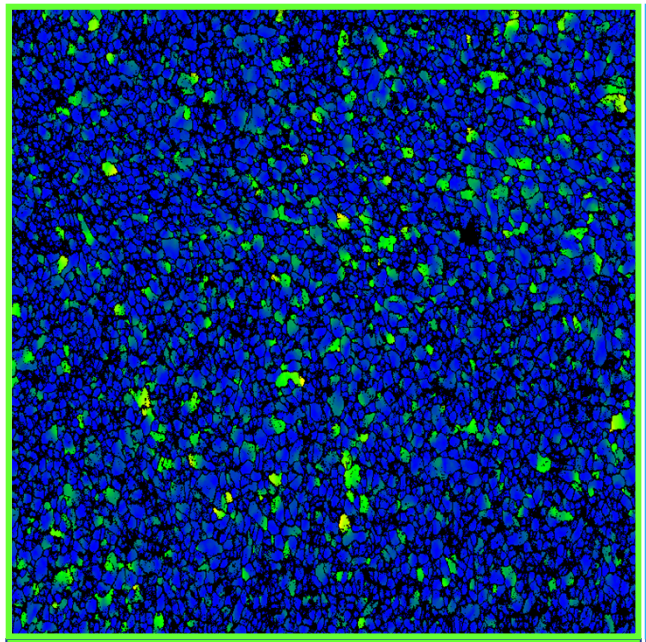
imagination at work

J-Groove Weld - Steel Side

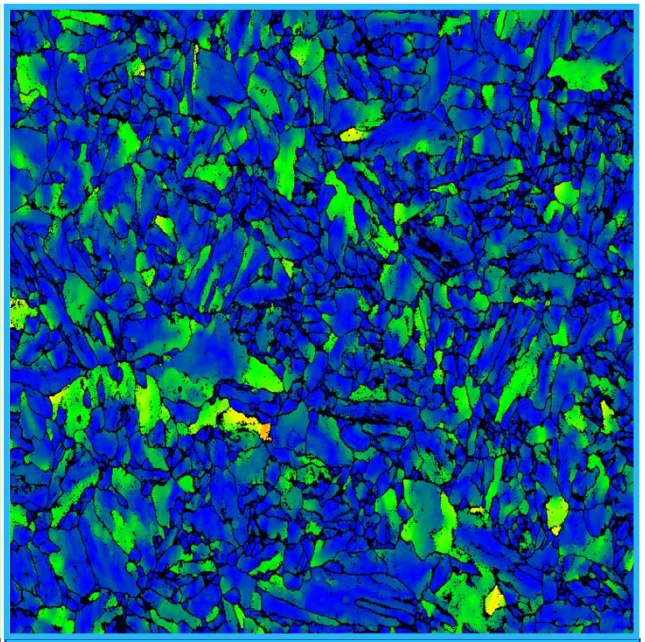
Top Section: 20° Misorientation Maps



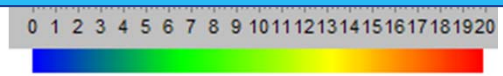
Interface



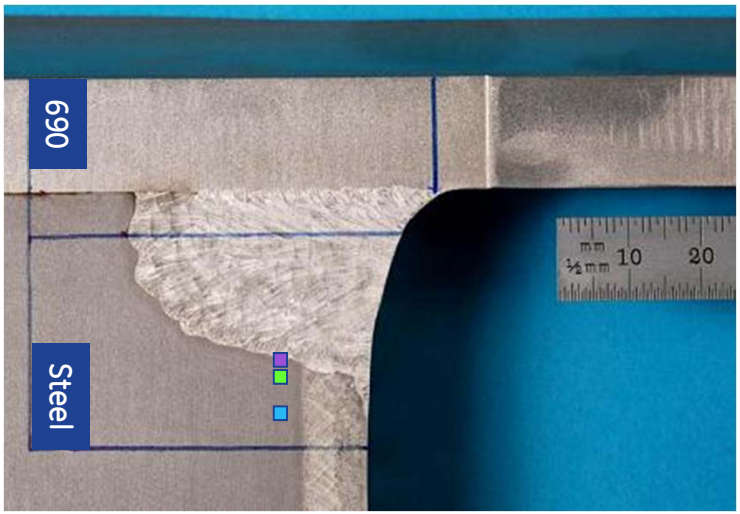
2 mm from Interface



9 mm from Interface



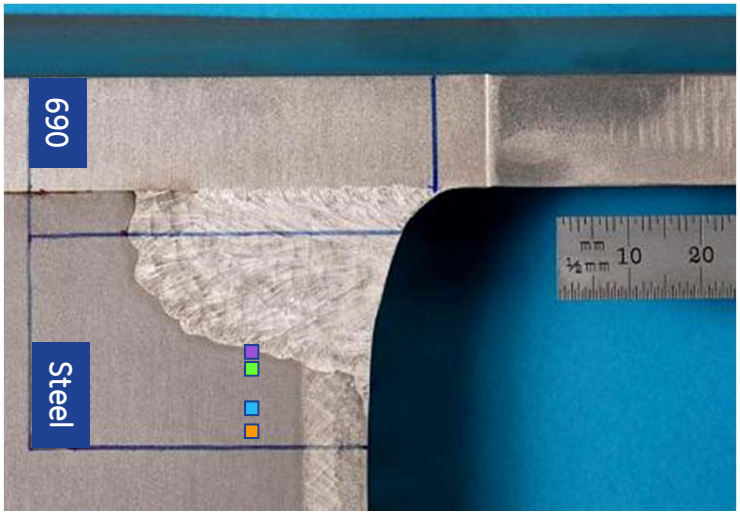
50 μm



NOTE: Maps are processed from raw data only. (No noise reduction was performed.)

imagination at work

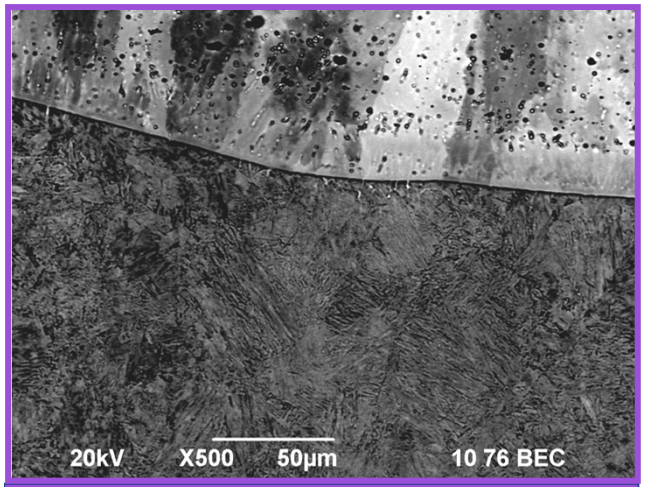
J-Groove Weld: Steel Side



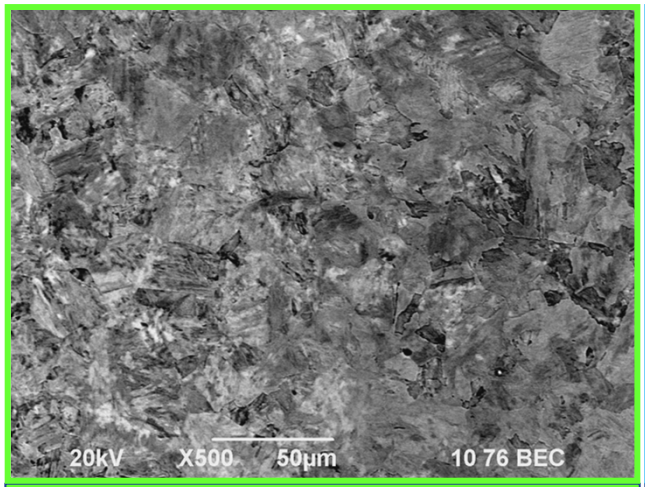
Map Analyses: Mid Section

J-Groove Weld - Steel Side

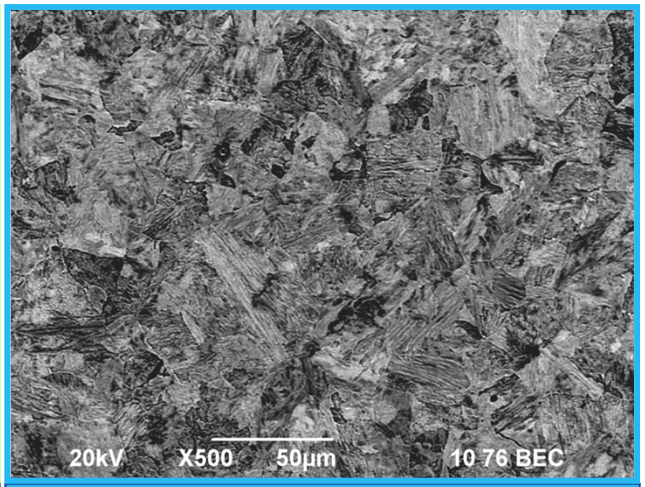
Mid Section: BSE Images 500x



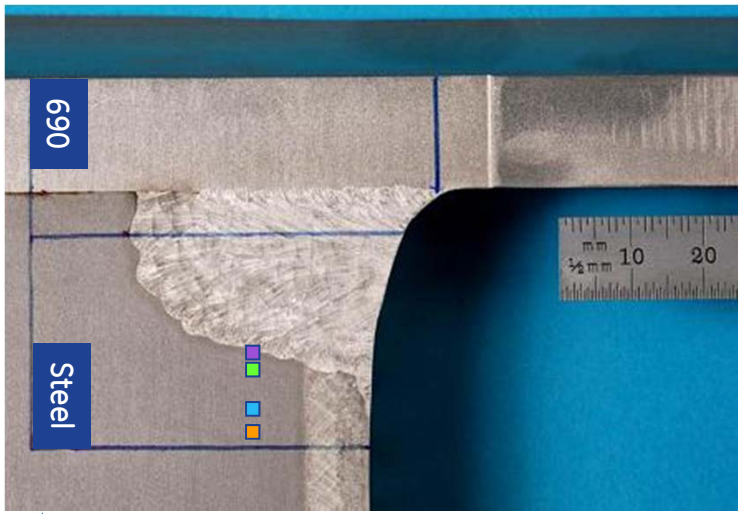
Interface



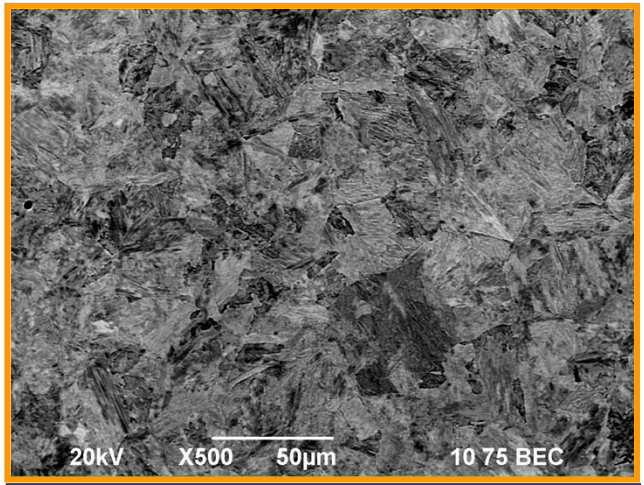
2 mm from Interface



9 mm from Interface



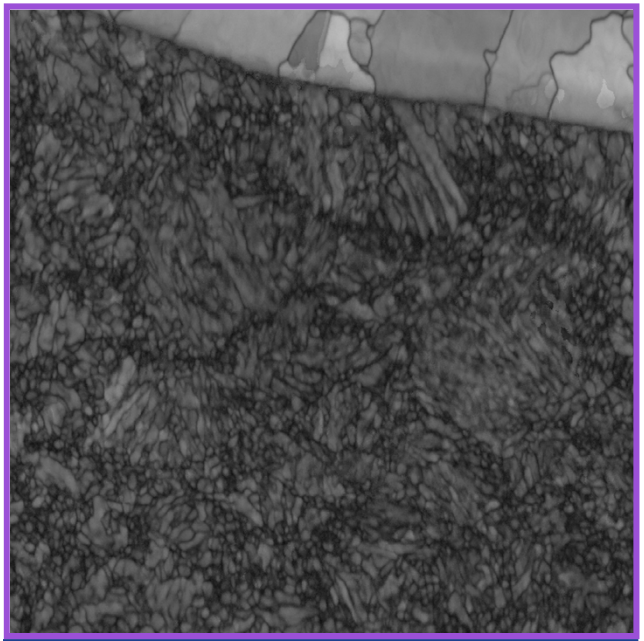
NOTE: Maps are processed from raw data only. (No noise reduction was performed.)



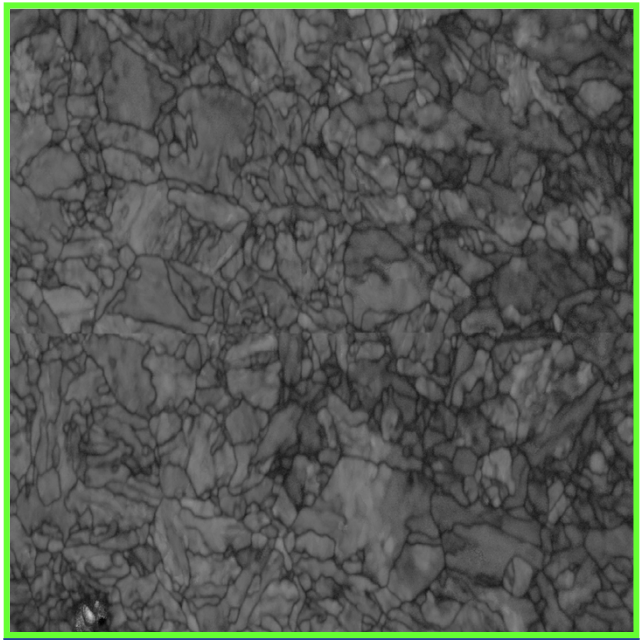
13 mm from Interface

J-Groove Weld - Steel Side

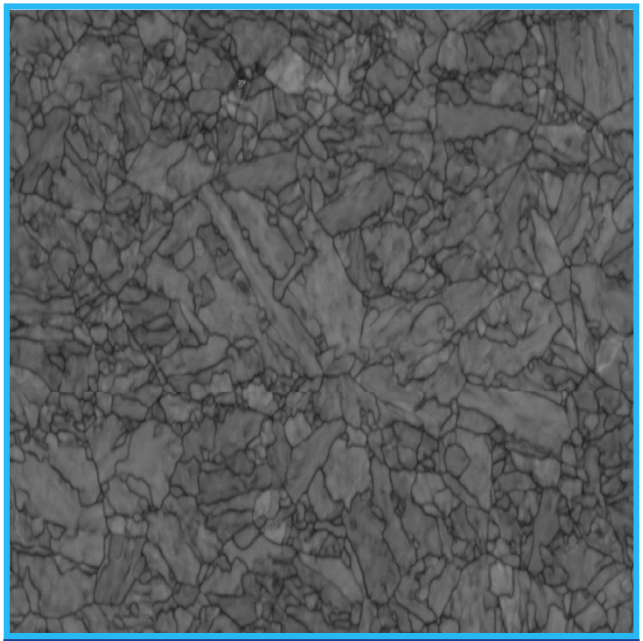
Mid Section: Band Contrast Maps



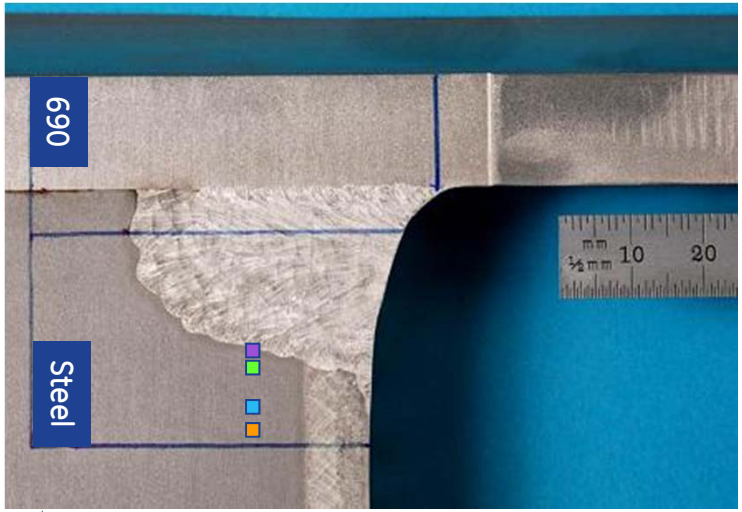
Interface



2 mm from Interface

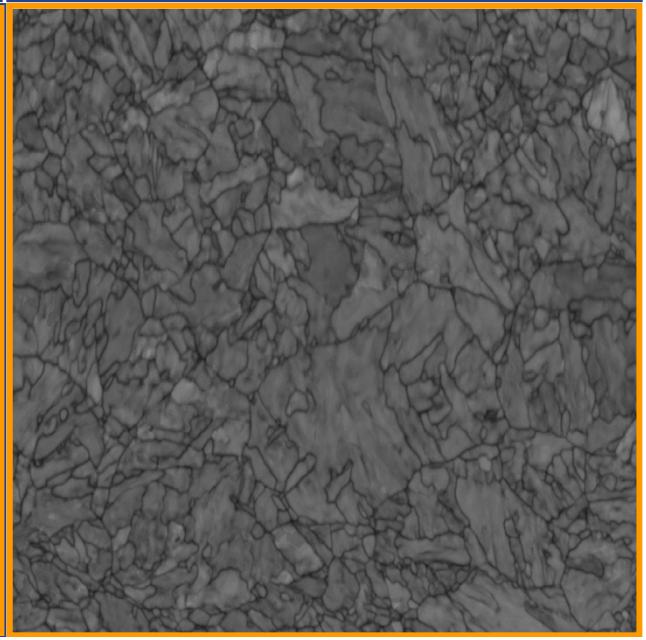


9 mm from Interface



50 μm

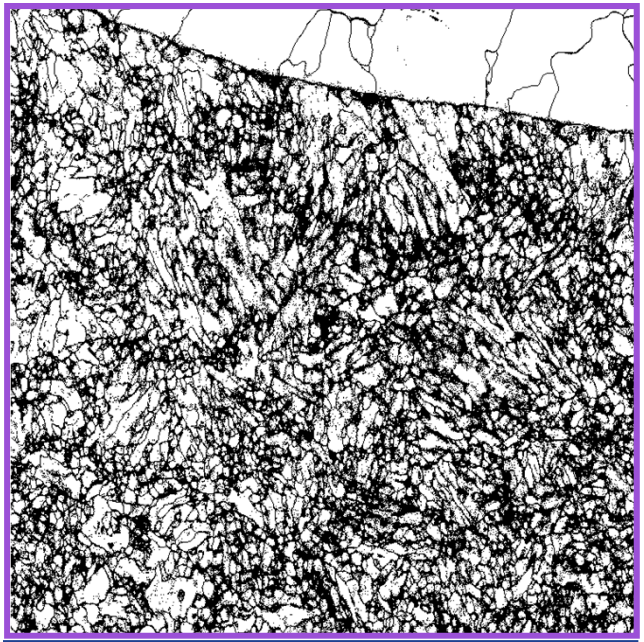
13 mm from Interface



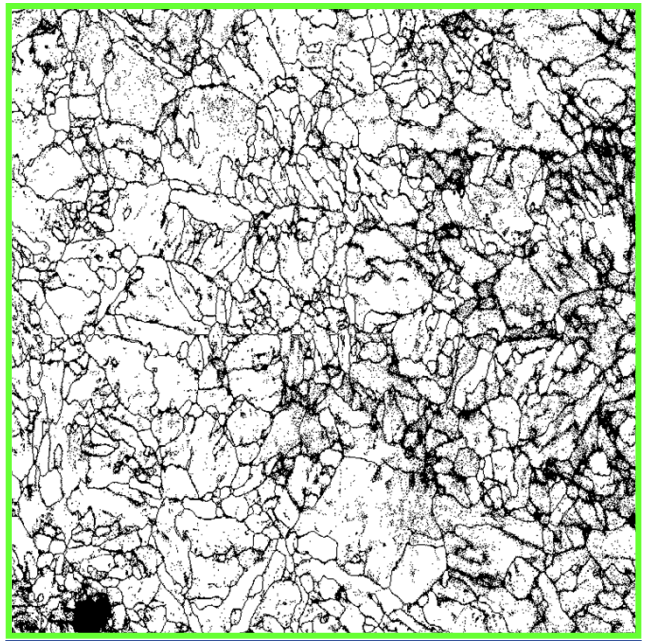
NOTE: Maps are processed from raw data only. (No noise reduction was performed.)

J-Groove Weld - Steel Side

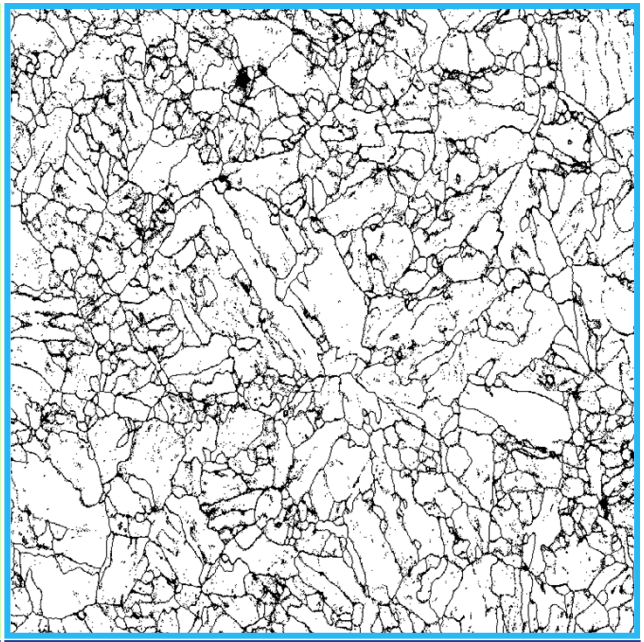
Mid Section: Boundary Maps



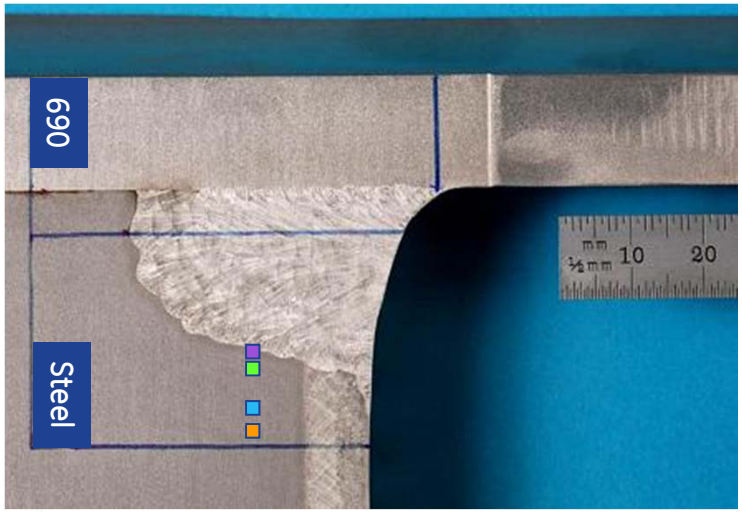
Interface



2 mm from Interface



9 mm from Interface

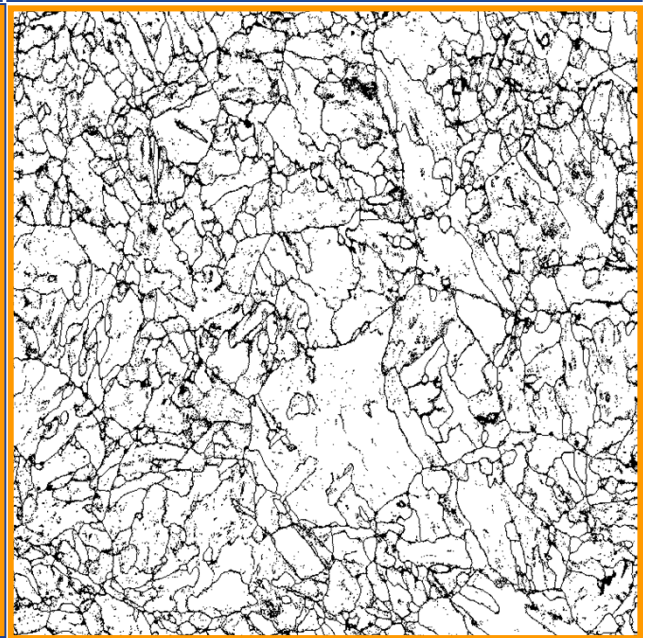


50 μm

Black Lines = 10°<θ<60°

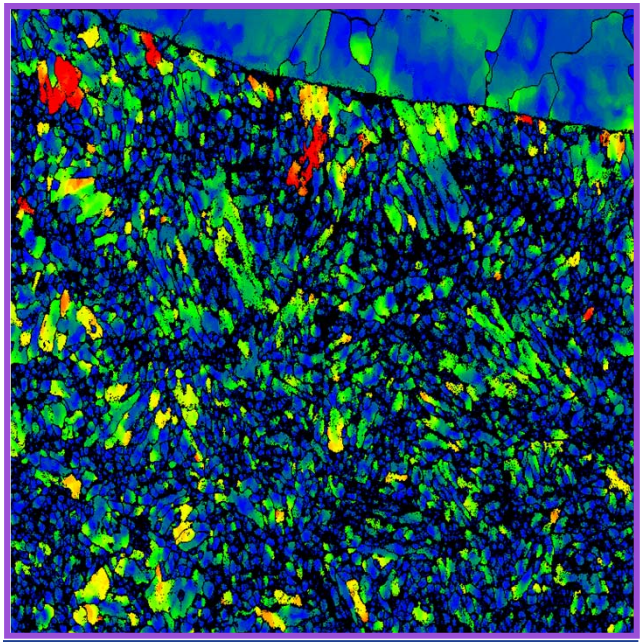
NOTE: Maps are processed from raw data only. (No noise reduction was performed.)

13 mm from Interface

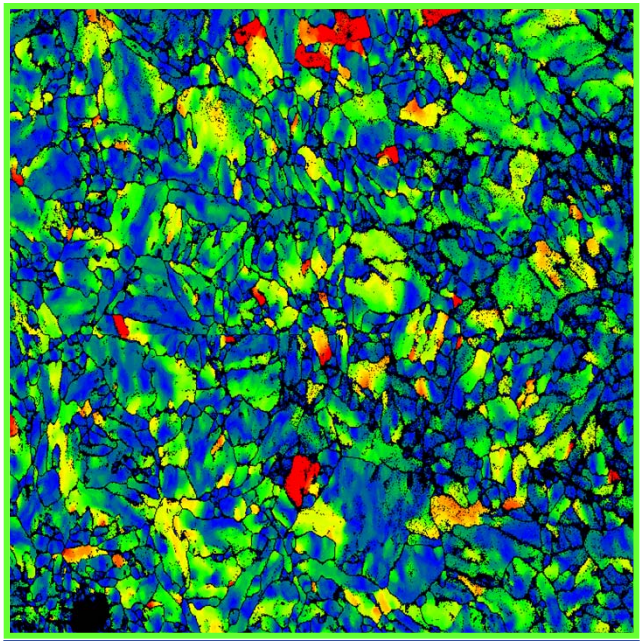


J-Groove Weld - Steel Side

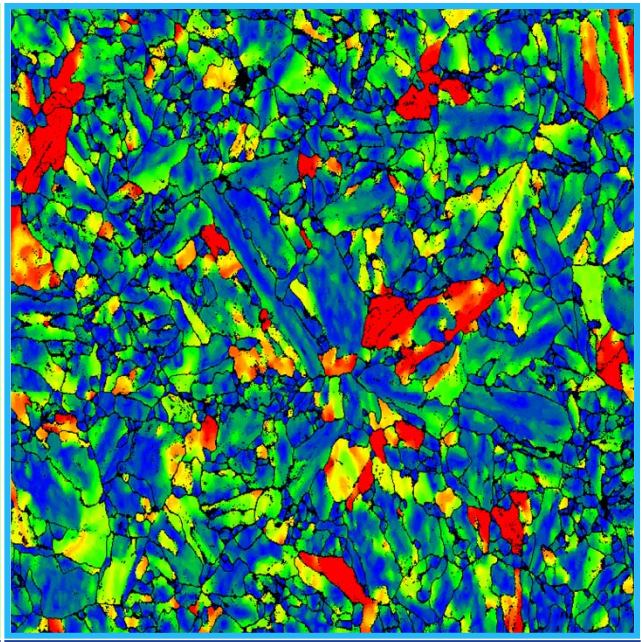
Mid Section: 10° Misorientation Maps



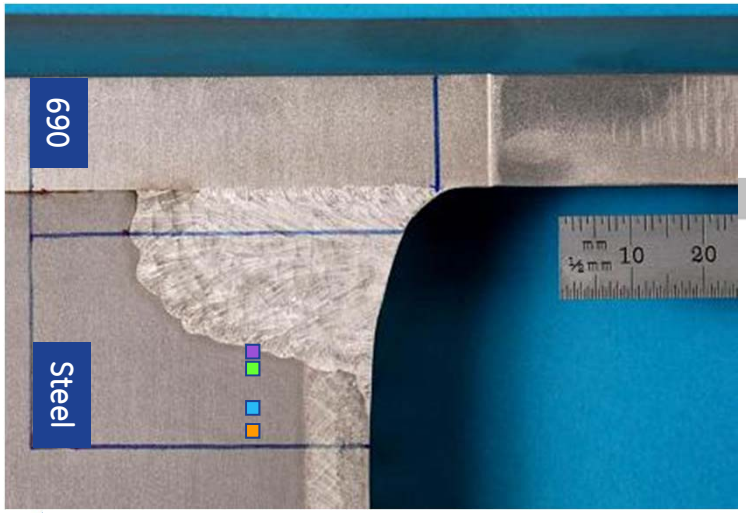
Interface



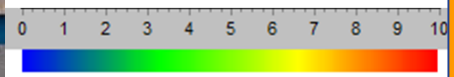
2 mm from Interface



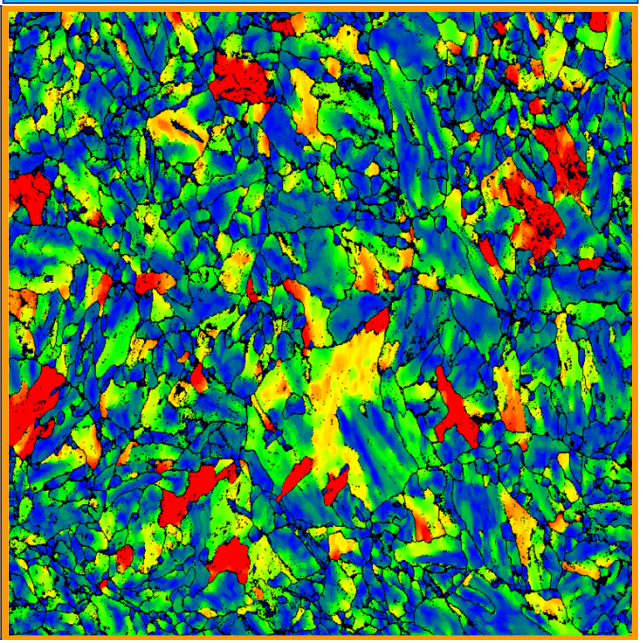
9 mm from Interface



50 μm



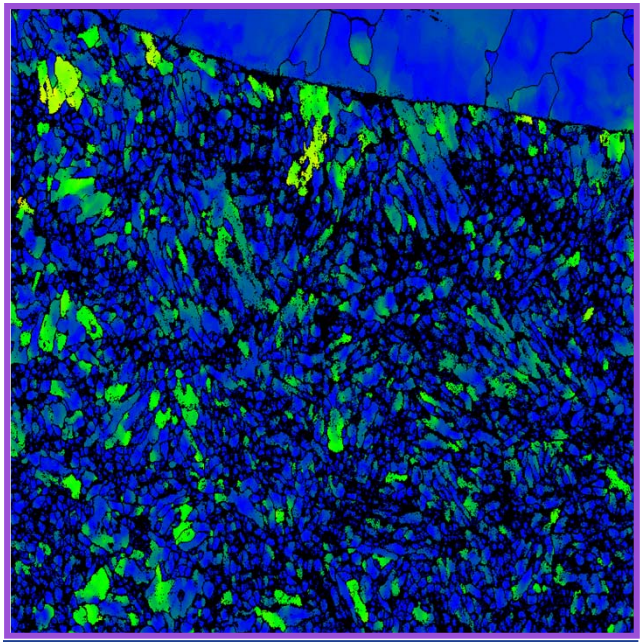
13 mm from Interface



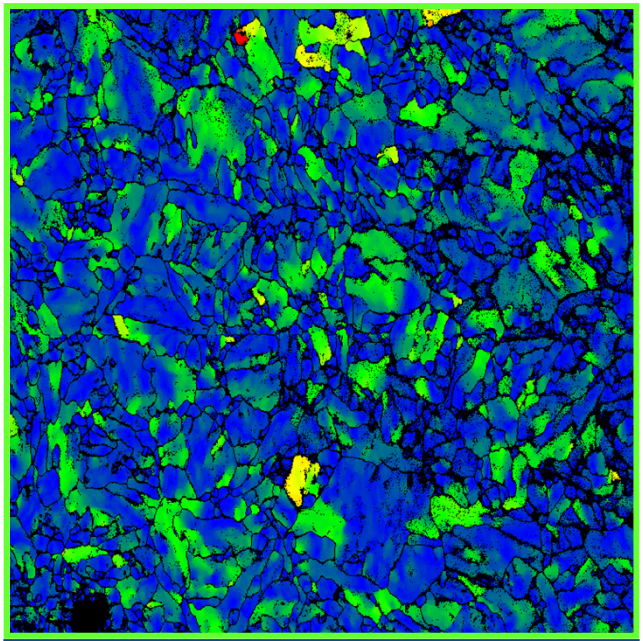
NOTE: Maps are processed from raw data only. (No noise reduction was performed.)

J-Groove Weld - Steel Side

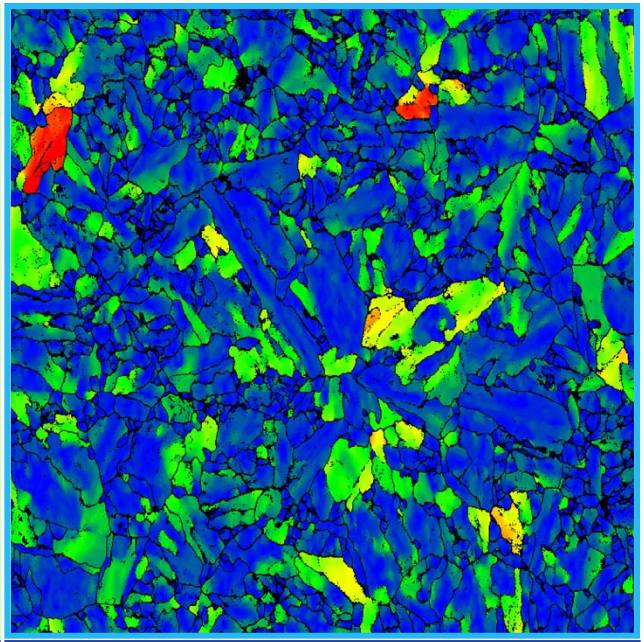
Mid Section: 20° Misorientation Maps



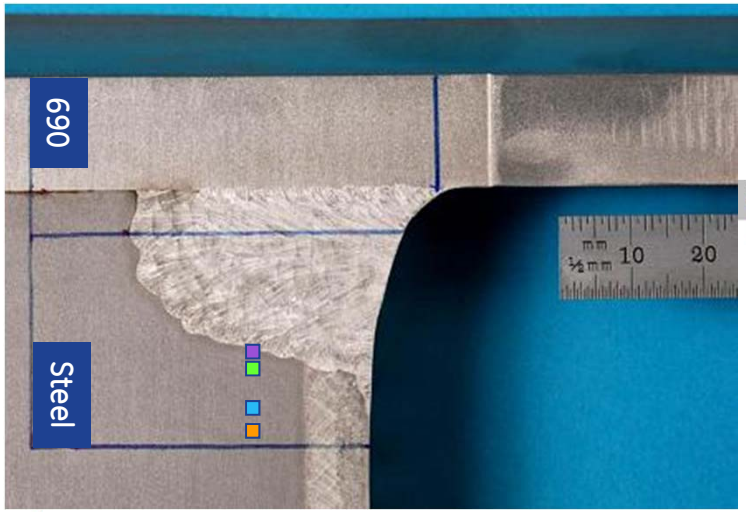
Interface



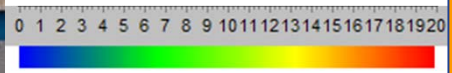
2 mm from Interface



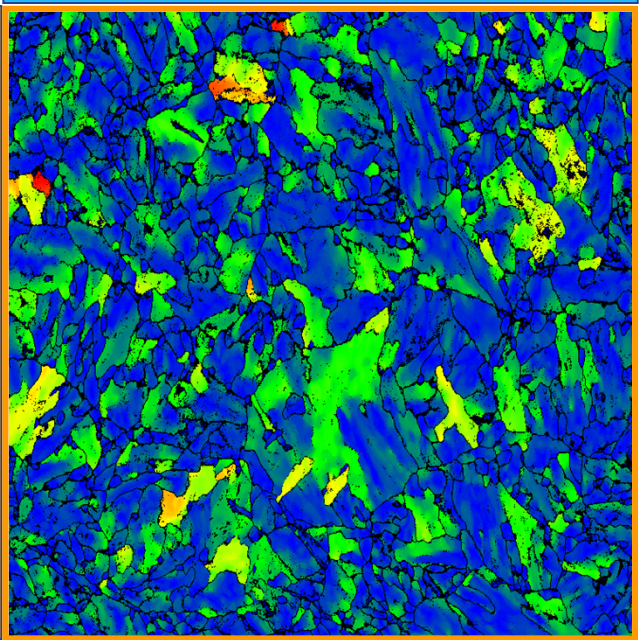
9 mm from Interface



50 μm

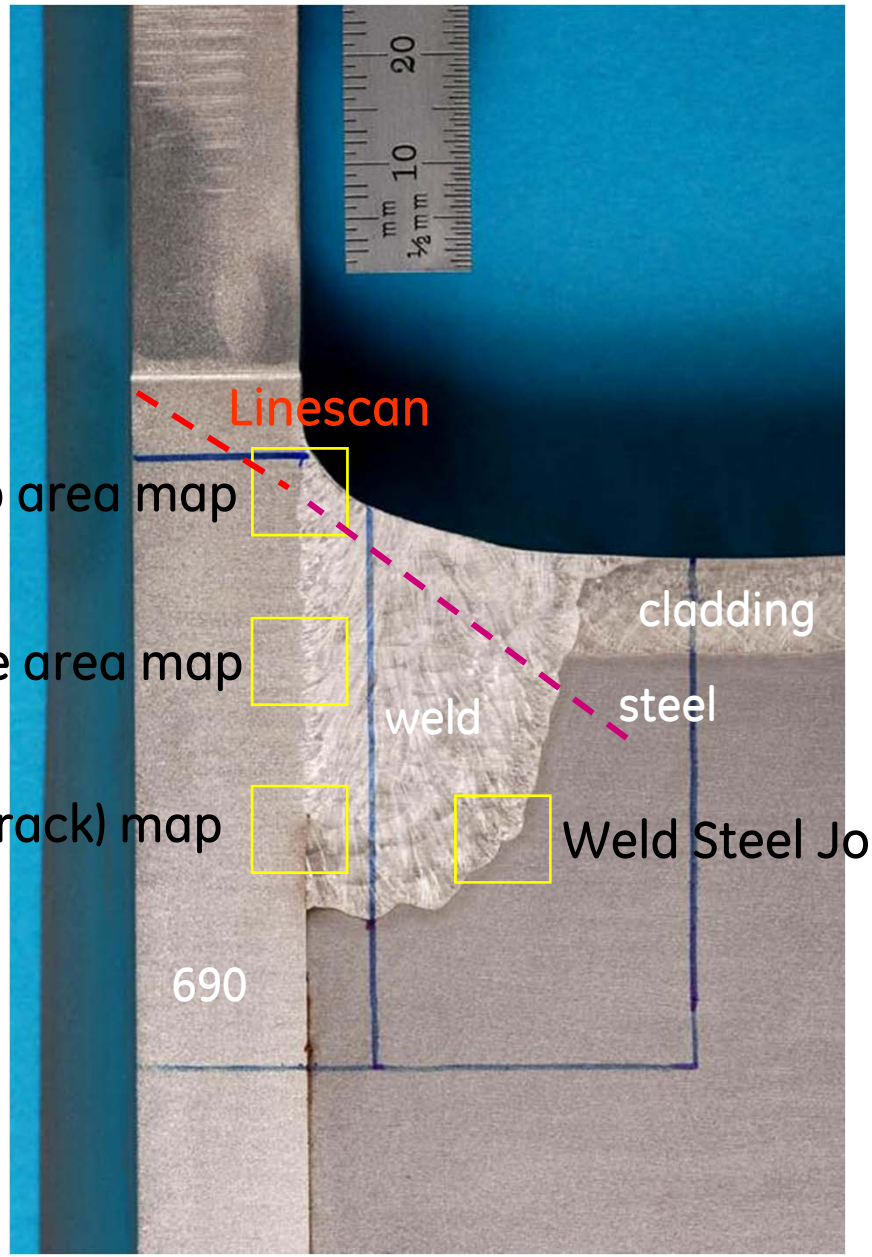


13 mm from Interface



NOTE: Maps are processed from raw data only. (No noise reduction was performed.)

J-Groove

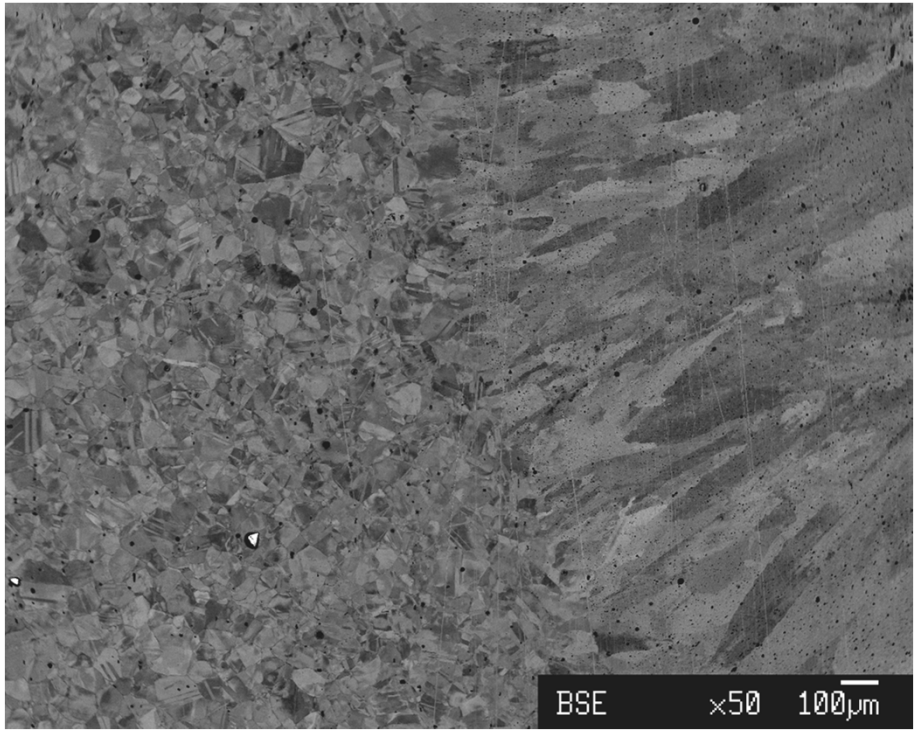


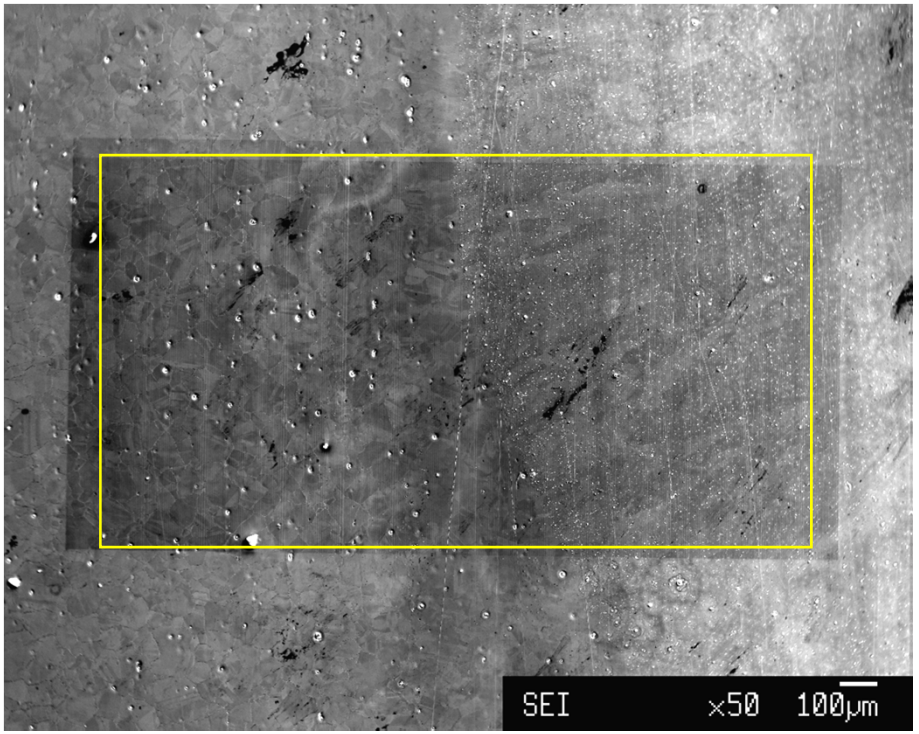
EPMA analyses of components

all values in wt%

	Mo	Al	Nb	Co	Ni	Ti	Cr	Si	Fe	Mn	Cu	Total
STEEL	0.3	(0.0)	(0.0)	0.2	0.6	(0.0)	0.2	0.1	97.3	1.6	0.1	100.2
STEEL	0.3	(0.0)	0.0	0.2	0.6	(0.1)	0.2	0.2	97.1	1.6	0.1	100.1
WELD	0.0	0.2	1.2	0.0	50.5	0.1	27.0	0.3	17.2	3.6	0.1	100.2
WELD	(0.0)	0.6	1.2	0.0	49.6	0.0	27.3	0.4	16.0	3.8	0.0	99.1
WELD	0.0	0.1	0.9	0.0	50.1	0.0	27.8	0.4	15.7	3.5	0.1	98.7
WELD	0.0	0.1	2.0	0.0	53.2	0.1	28.7	0.4	11.1	4.0	0.1	99.6
690	0.0	0.2	0.0	0.0	58.9	0.1	29.7	0.1	10.0	0.4	0.1	99.6
690	0.0	0.2	0.0	0.0	59.9	0.1	29.8	0.2	10.1	0.4	0.1	100.7
CLADDING	0.0	(0.0)	0.0	0.1	9.9	(0.0)	19.7	0.5	68.3	1.5	0.1	100.2
CLADDING	0.0	0.0	0.0	0.1	9.9	(0.1)	19.9	0.5	68.0	1.4	0.0	99.7
CLADDING	0.0	0.0	0.0	0.1	9.6	(0.0)	20.1	0.5	67.7	1.4	0.1	99.5

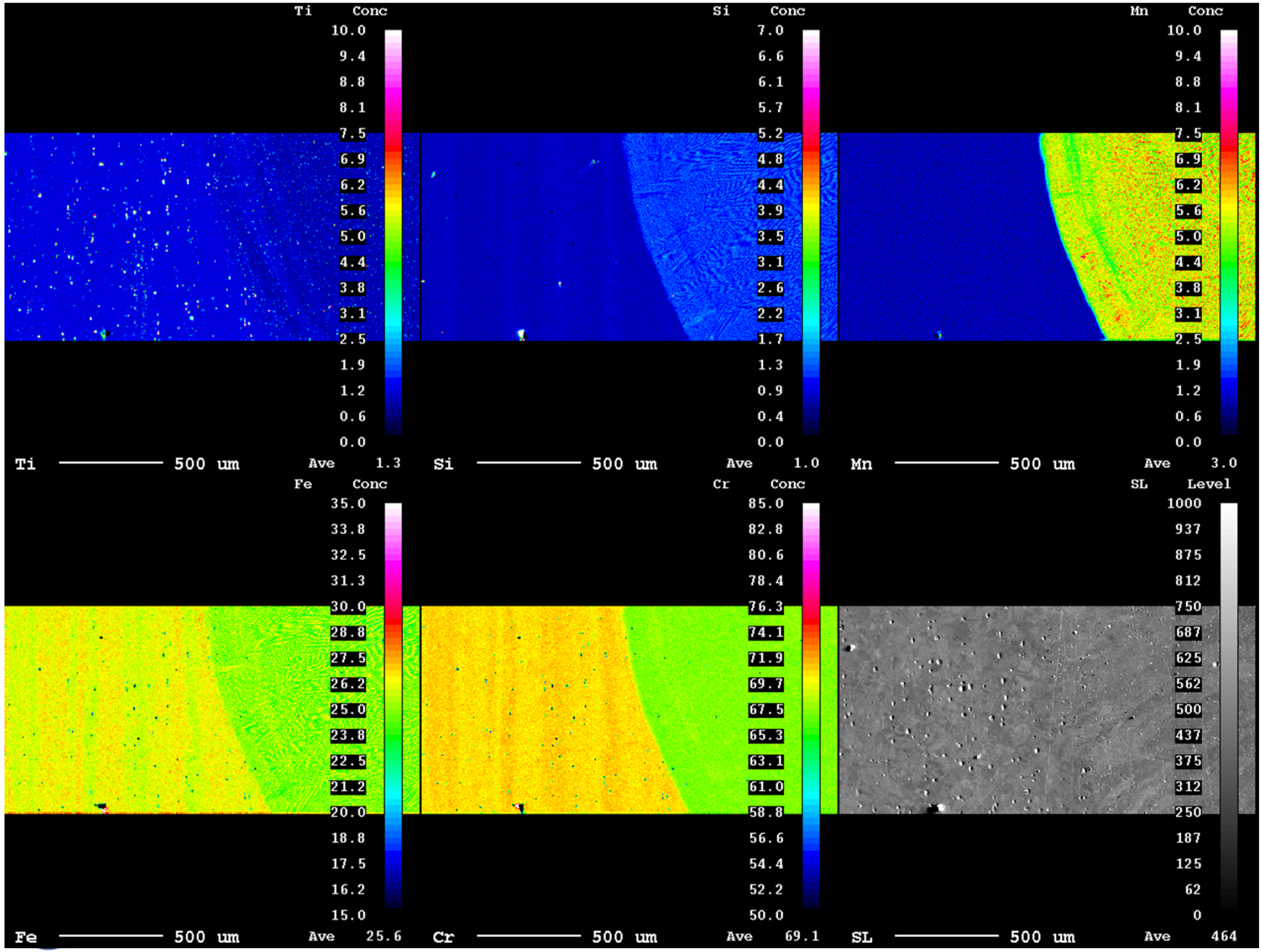
J-Groove- Top area



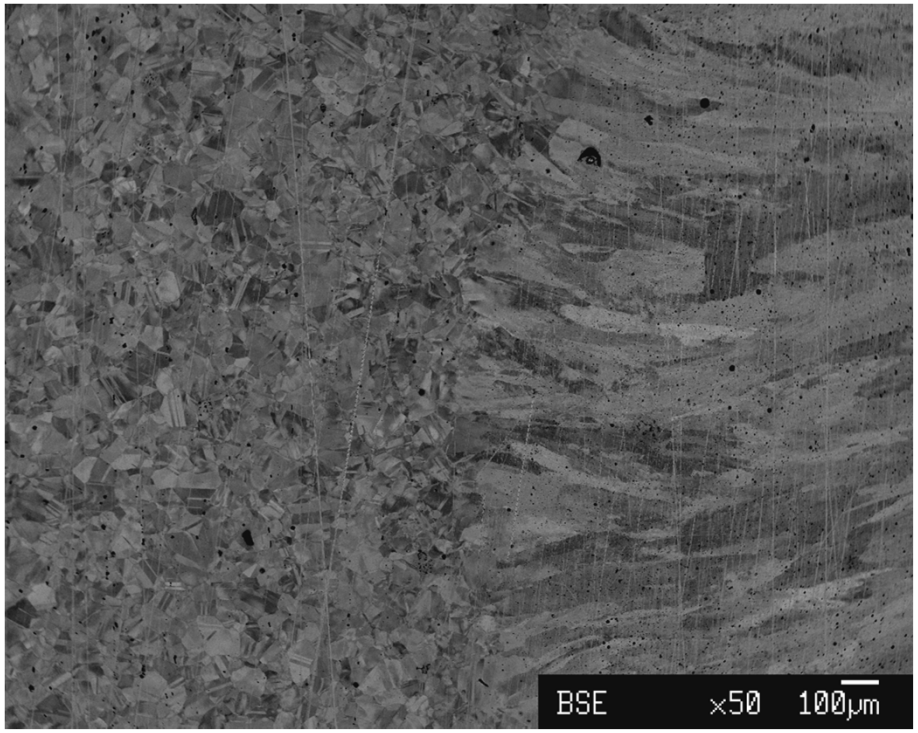


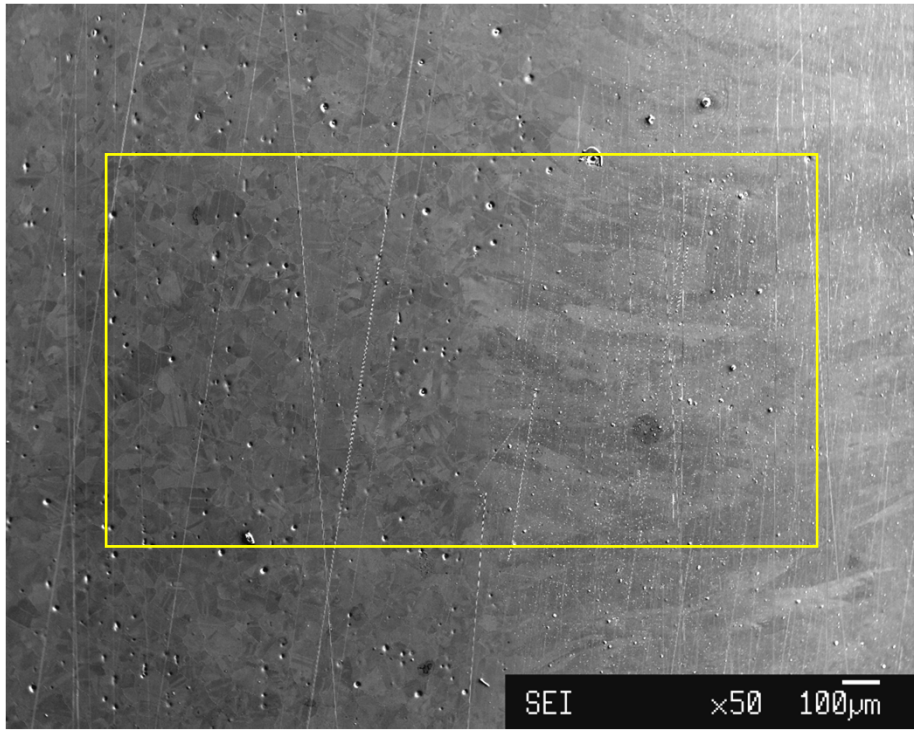
yellow box shows
approximate area mapped

J-Groove- Top area- Map



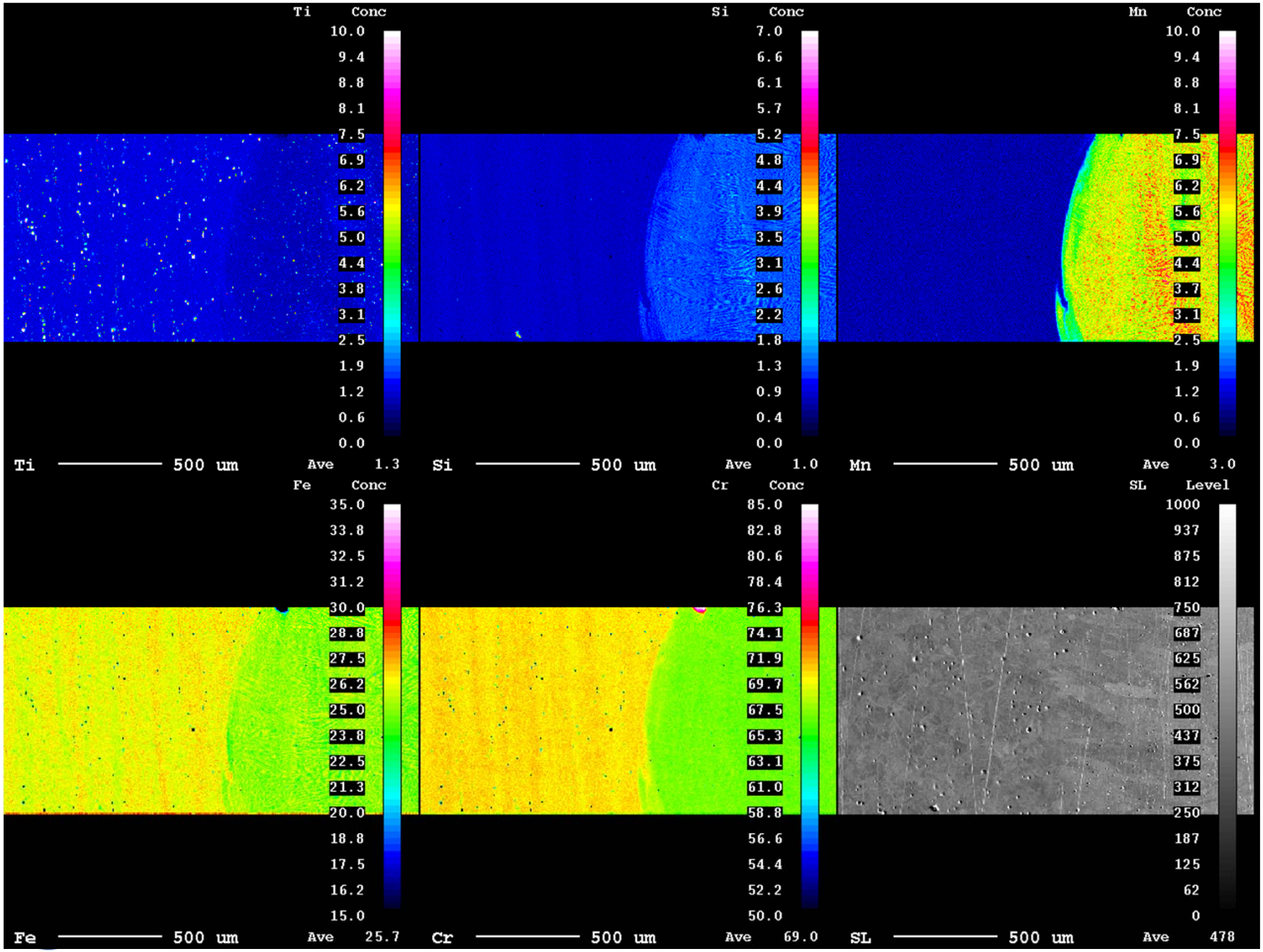
J-Groove- Middle area- Map



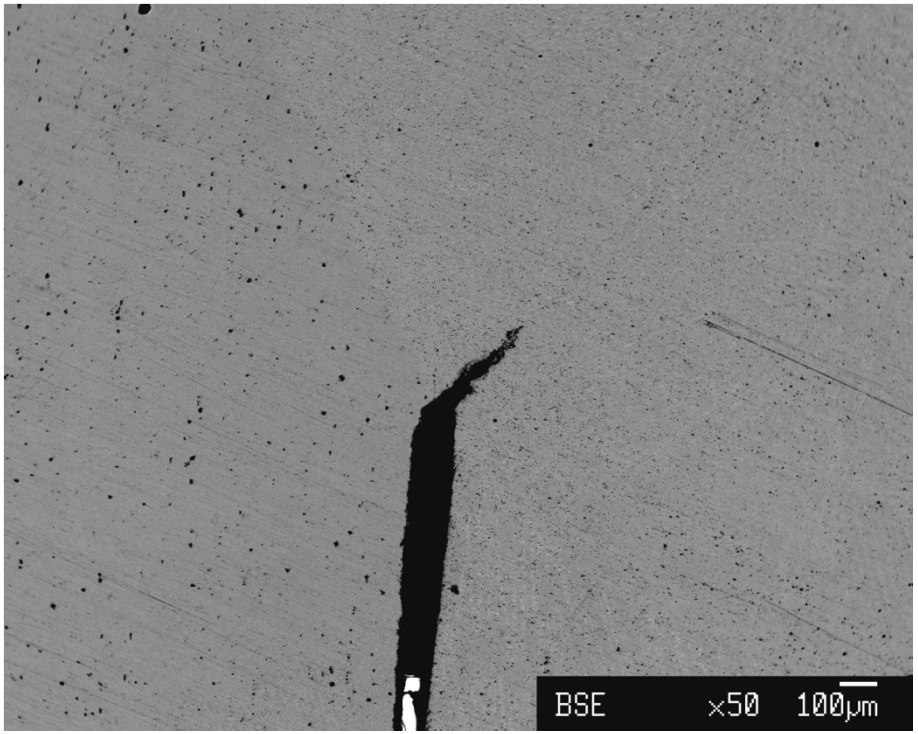


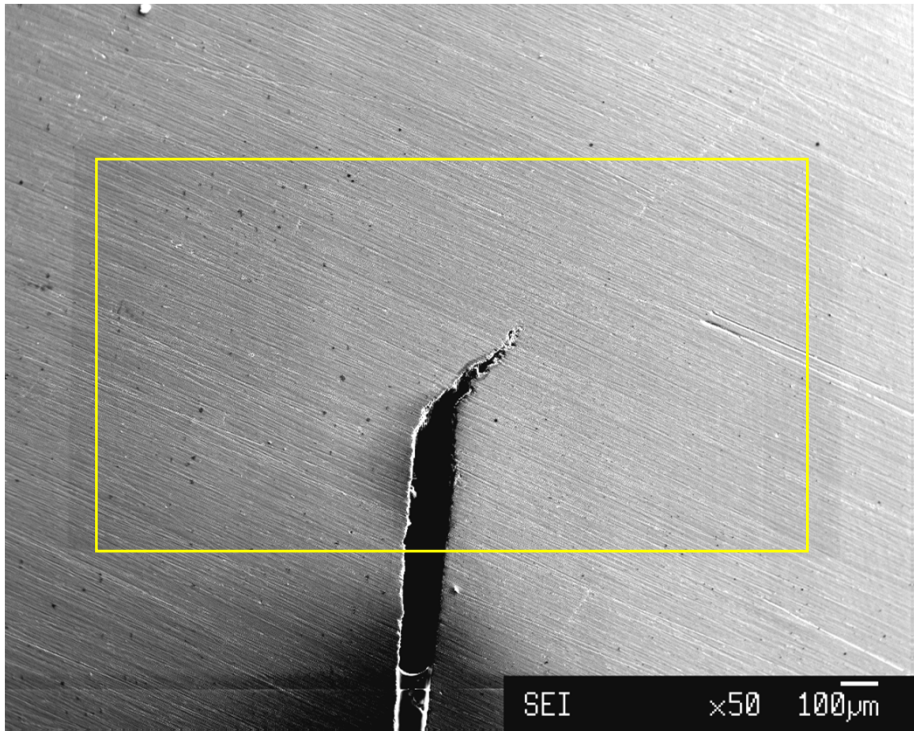
yellow box shows
approximate area mapped

J-Groove- Middle area- Map



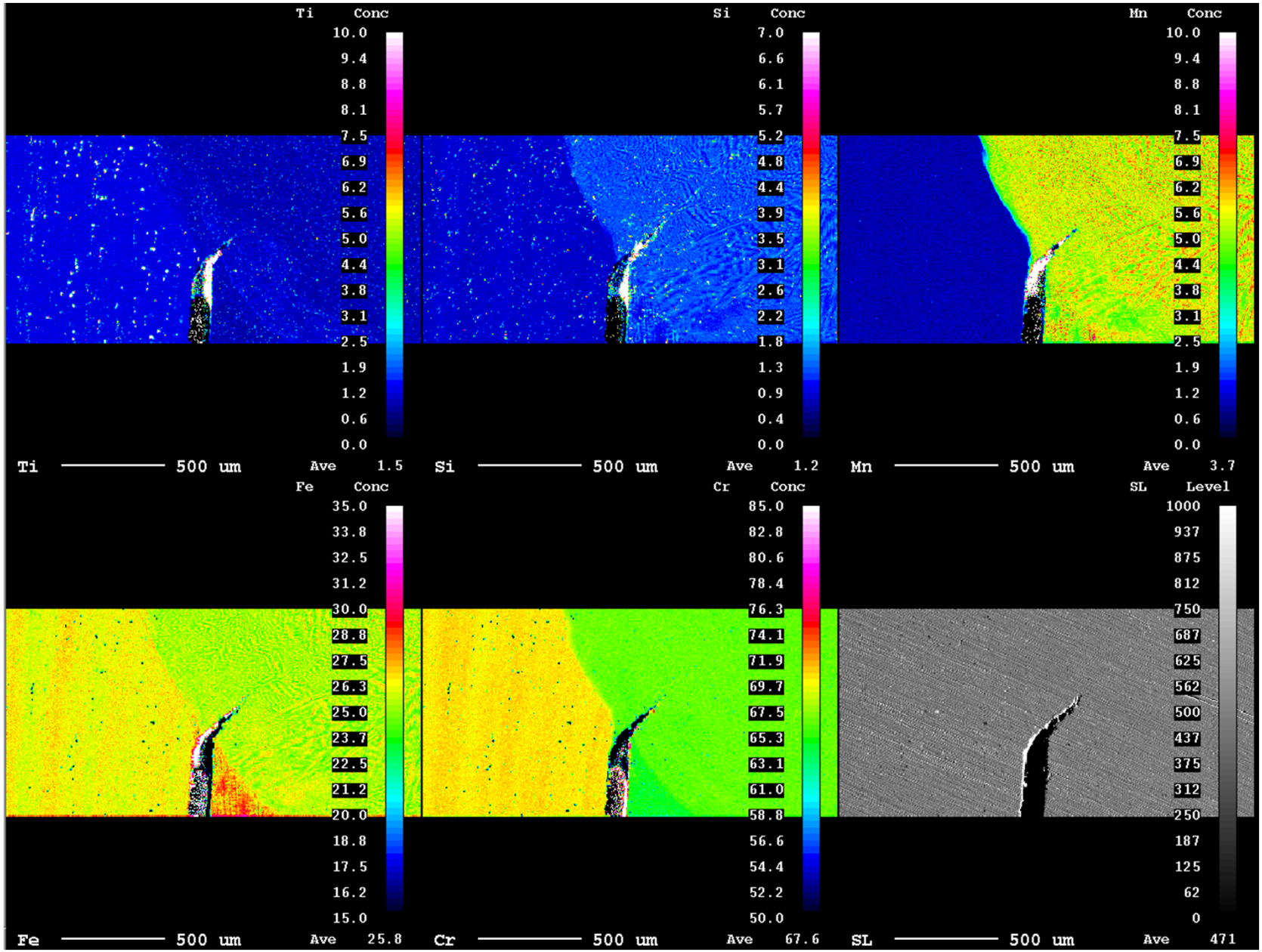
J-Groove- Bottom area (crack)



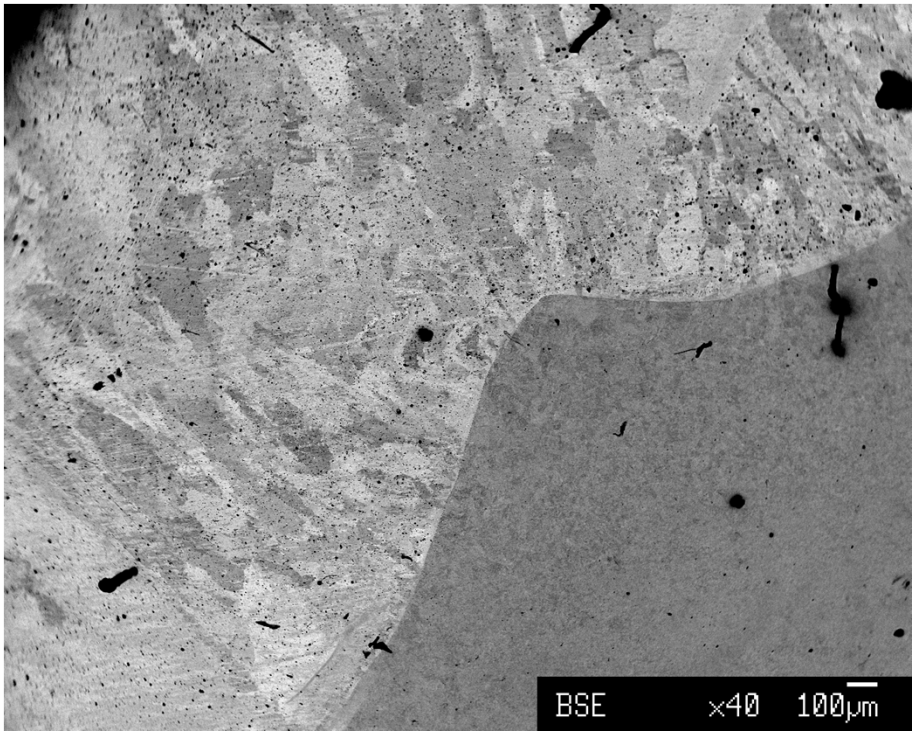


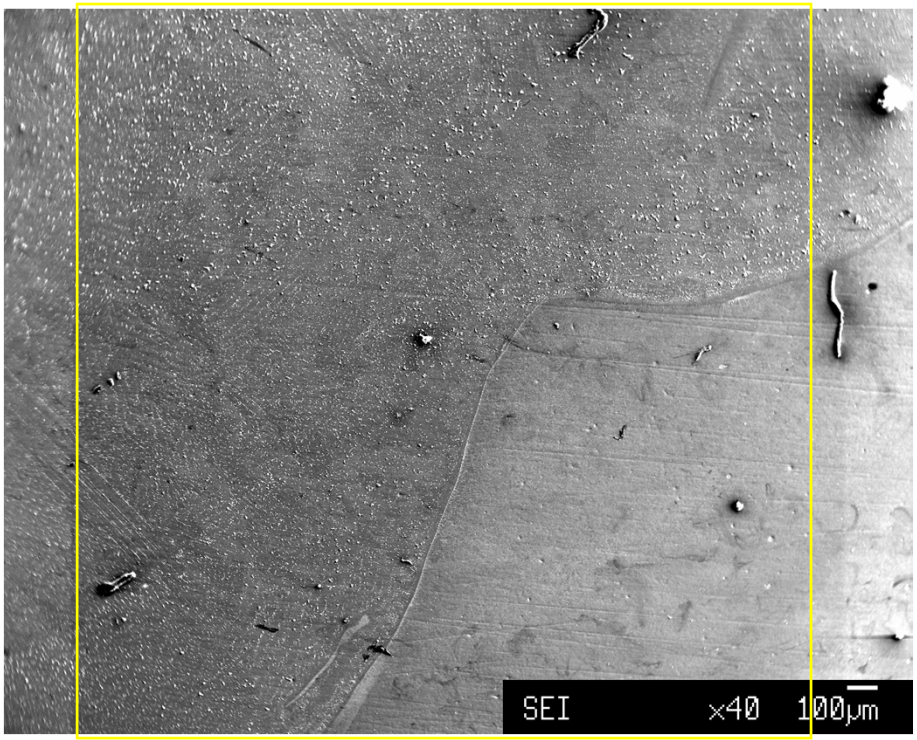
yellow box shows
approximate area mapped

J-Groove- Bottom area (crack)- Map



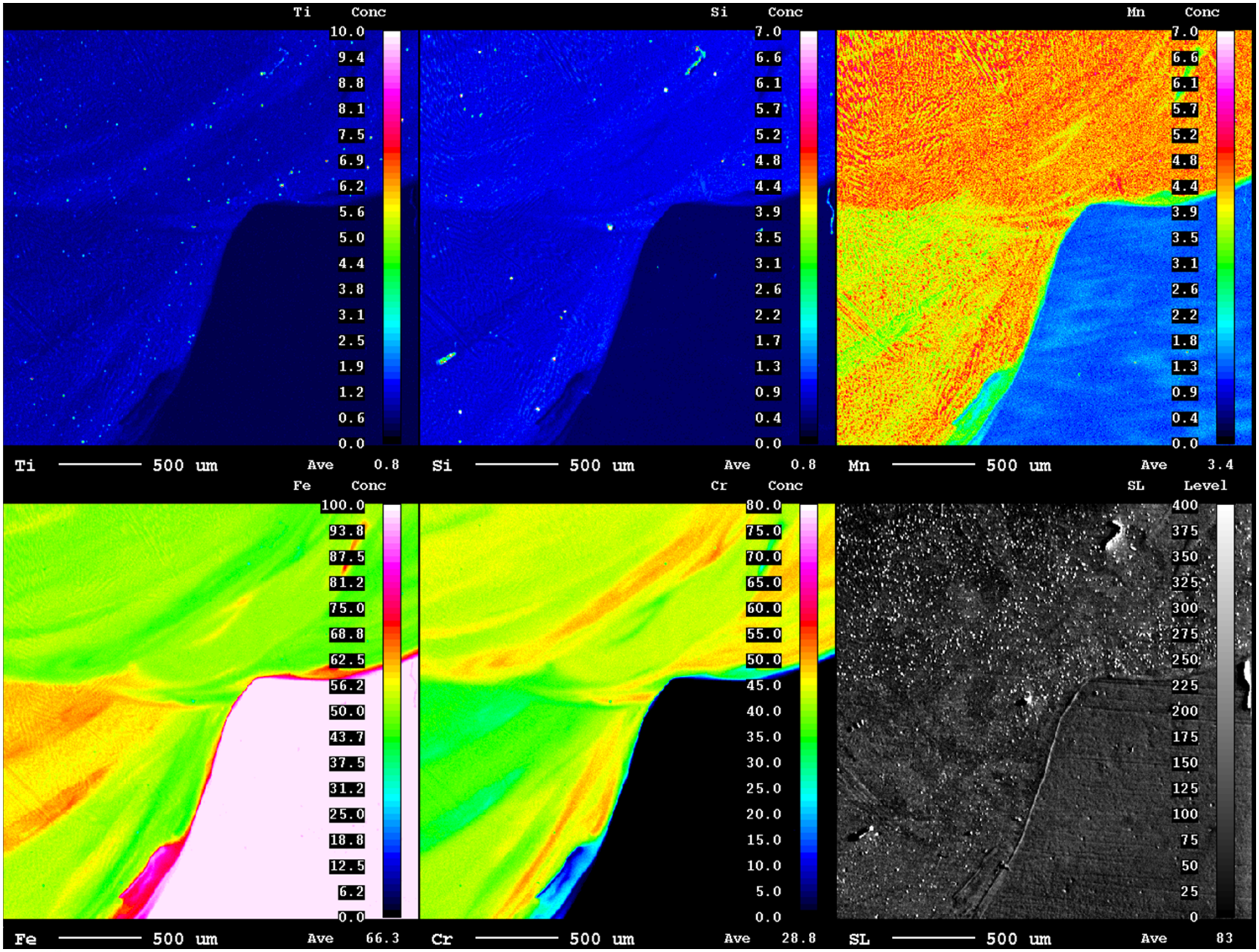
J-Groove- Weld Steel Join





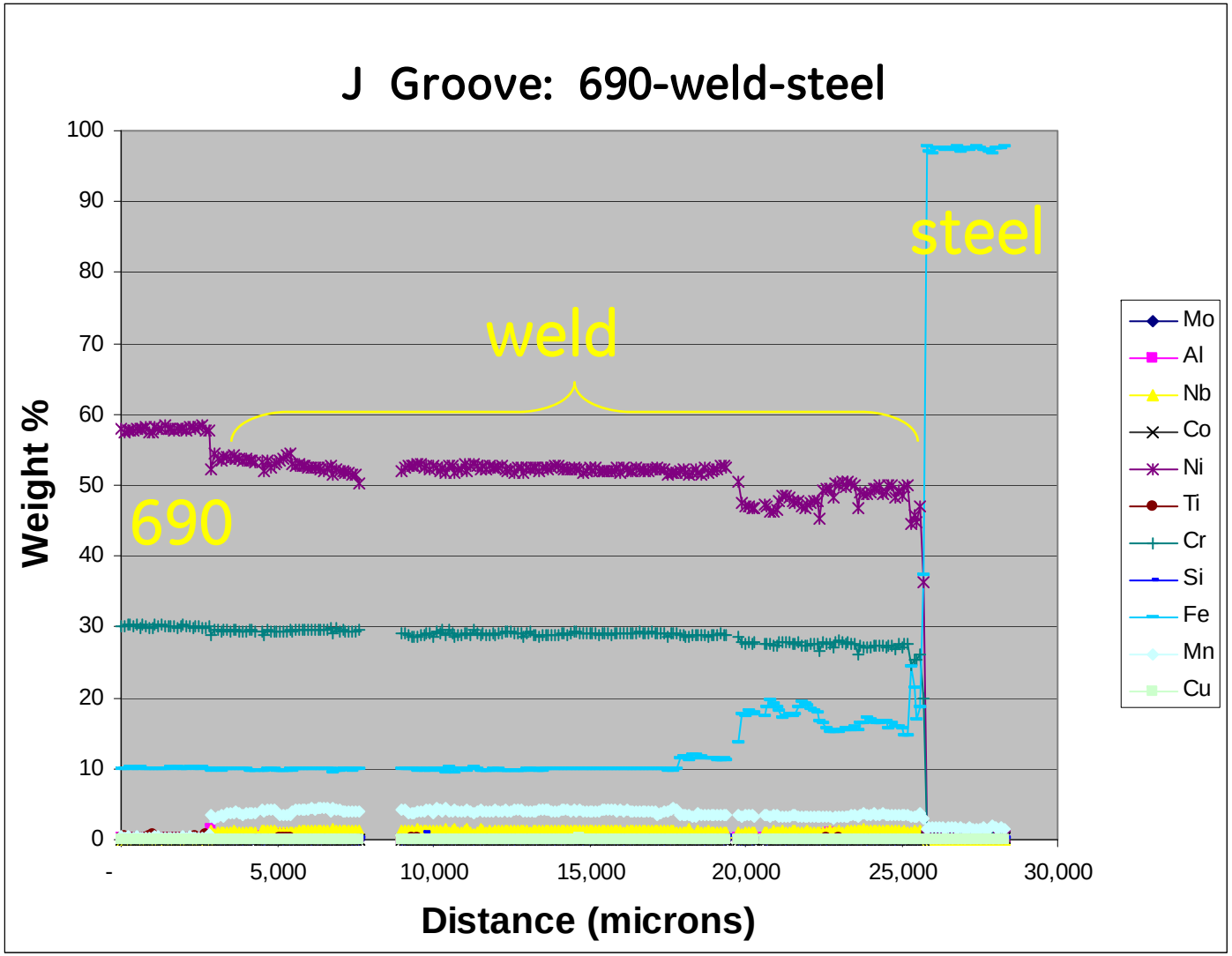
yellow box shows
approximate area mapped

J-Groove- Weld Steel Join- Map

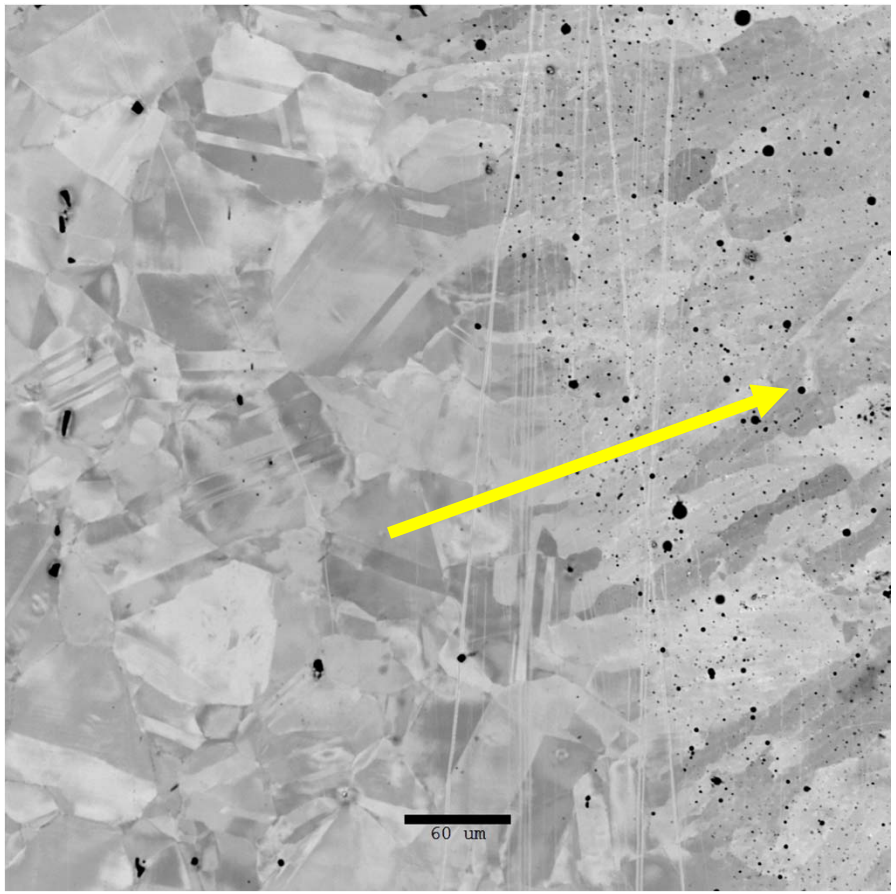


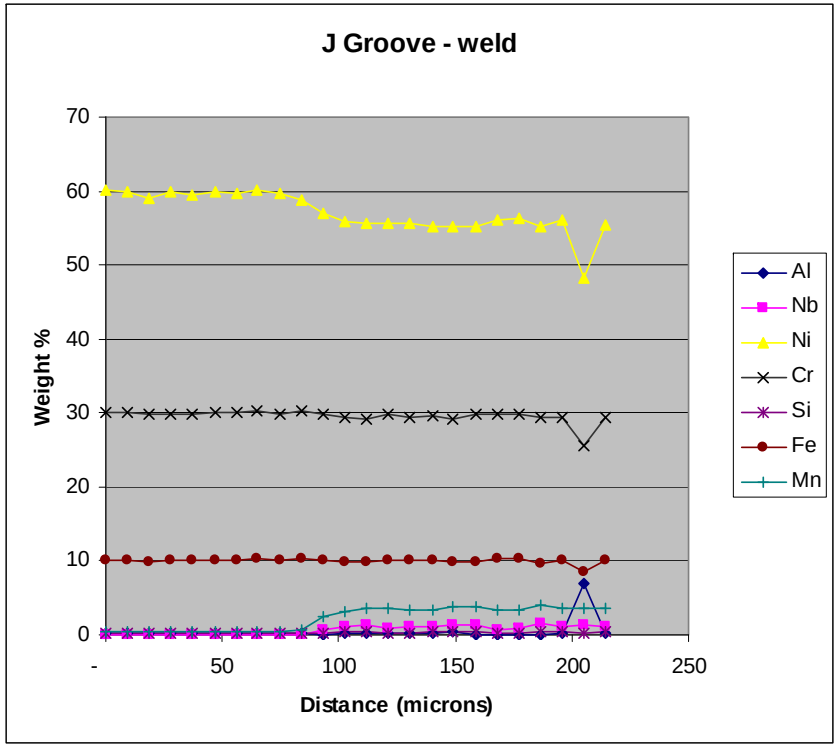
Linescan from 690, across weld into steel

(large gap where sample was cut)

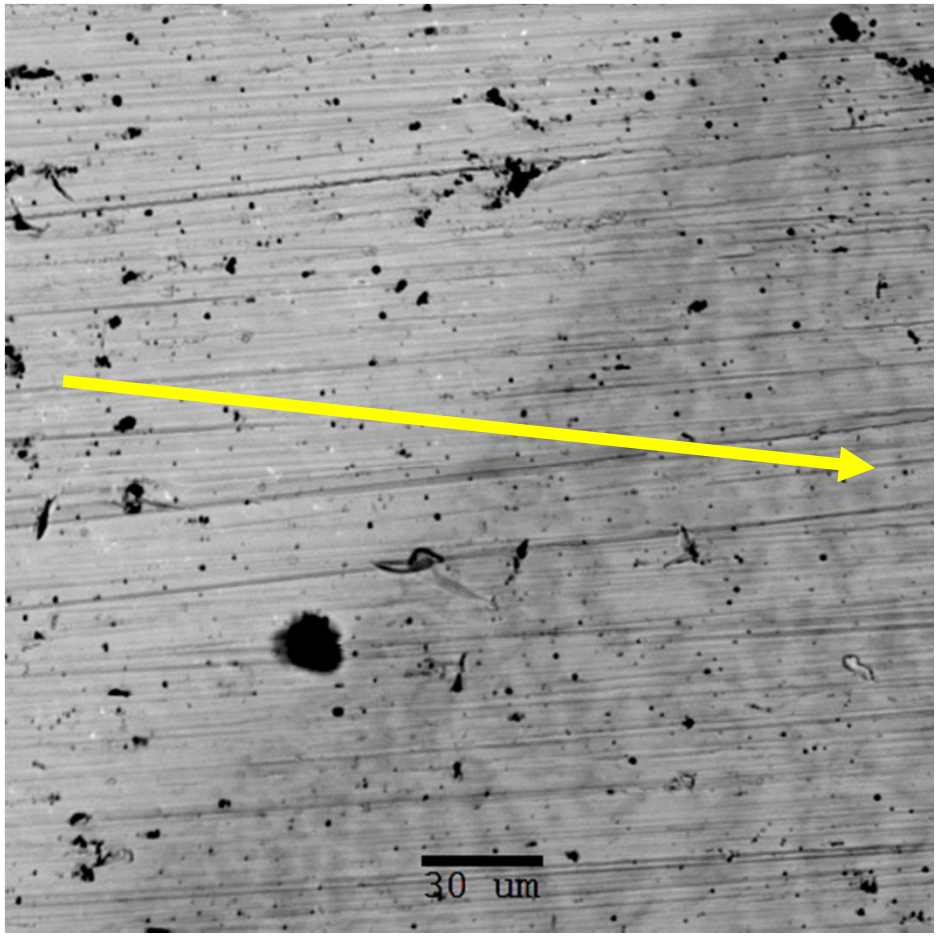


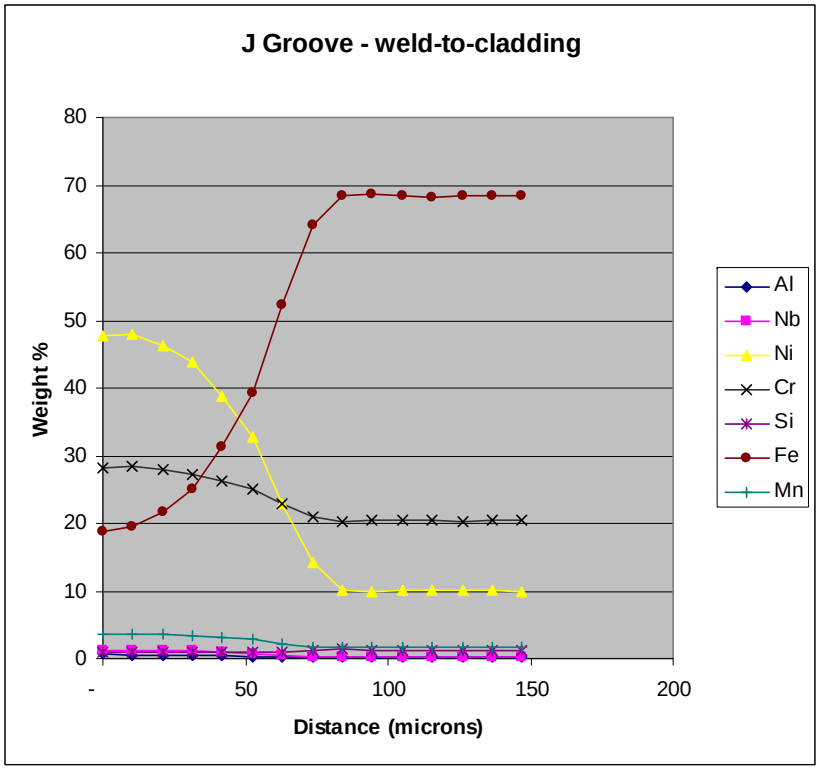
Detailed linescan from 690 into weld



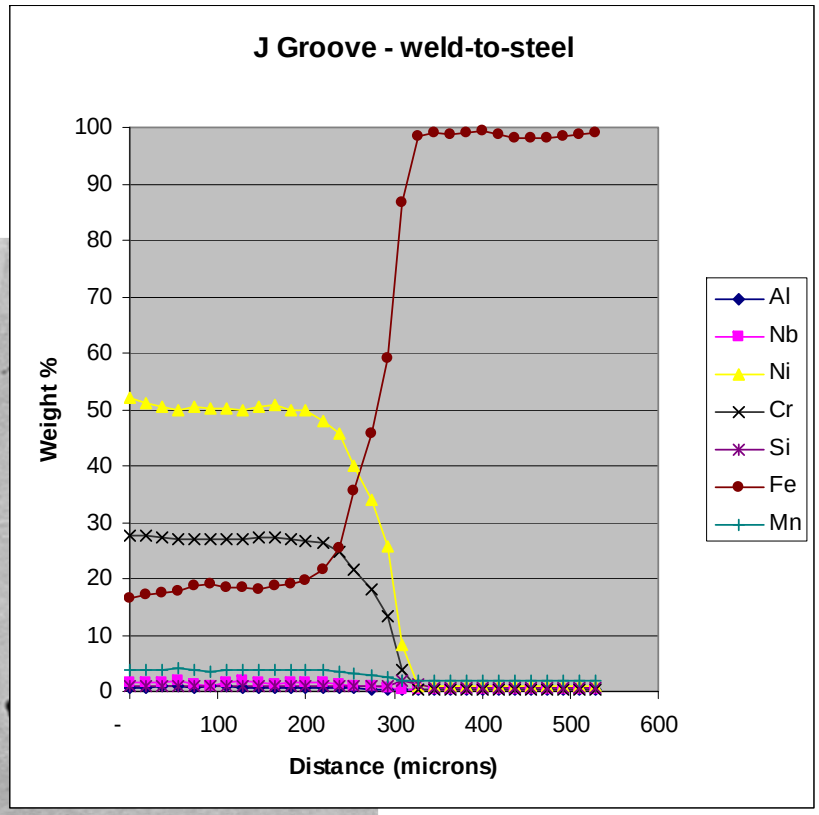


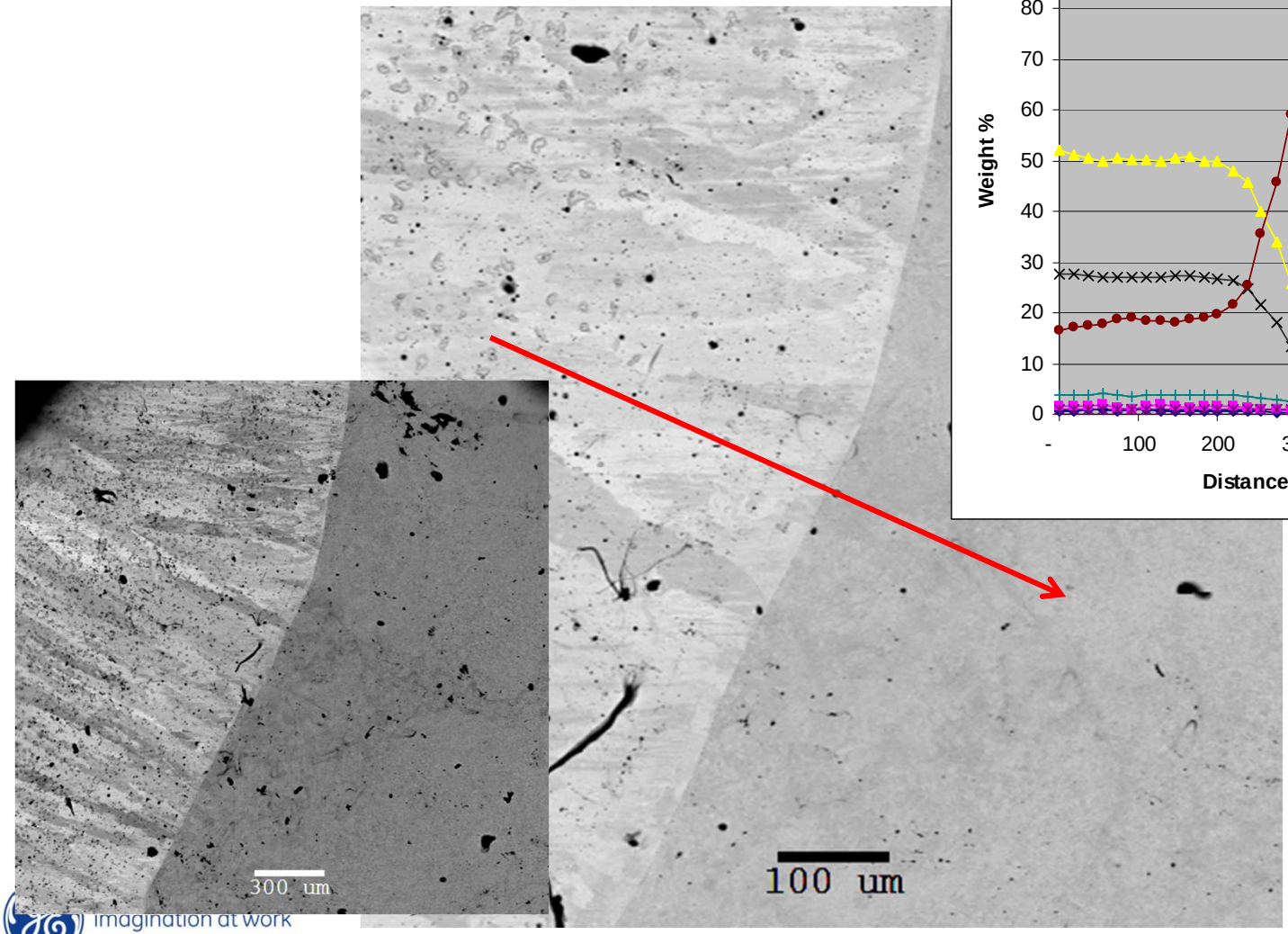
Detailed linescan from weld into cladding





Detailed linescan from weld into steel

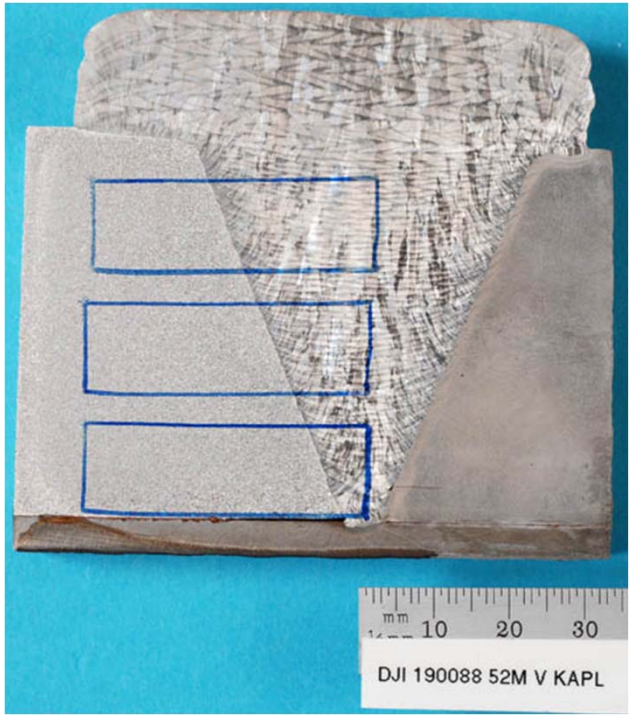




imagination at work

Comparison SS-CS V-Groove Weld with EN52M Filler Metal

DJI 190088 52M V-Groove Weld
Stainless Steel to 52M Interface



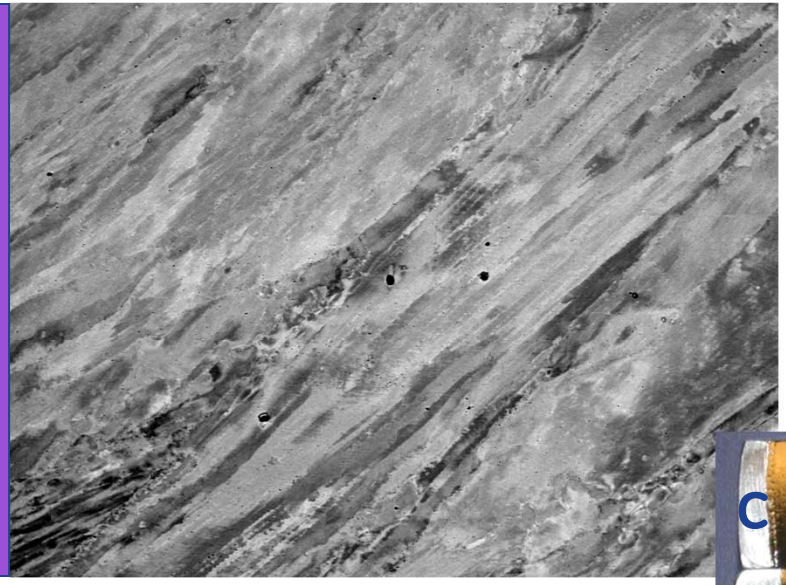
EBSD Strain Analysis

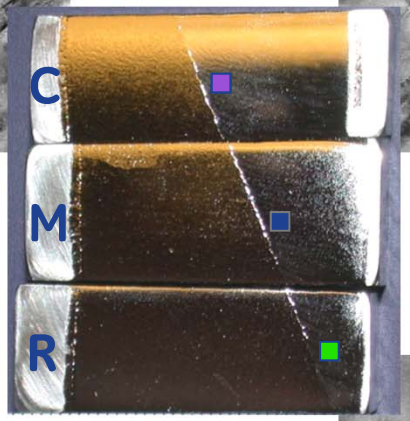
imagination at work

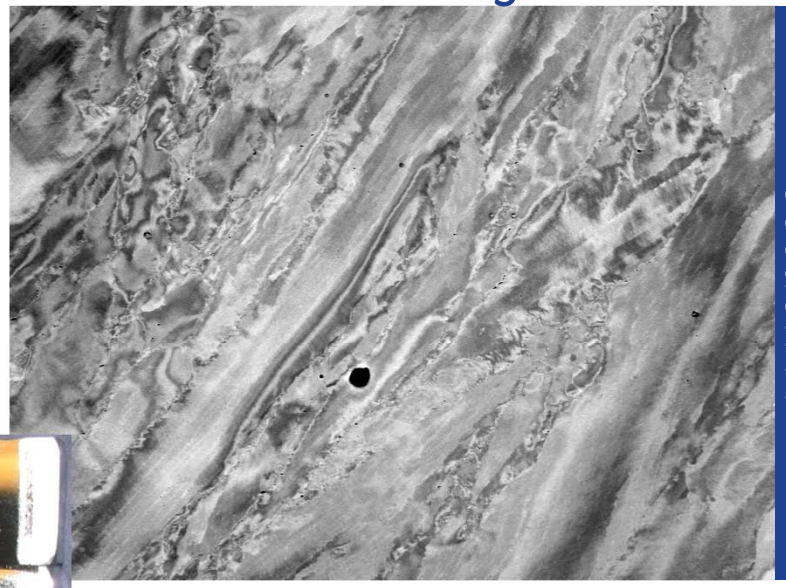
DJI 190088 52M V Plate: 2mm Before Interface

BSE Images: 100x

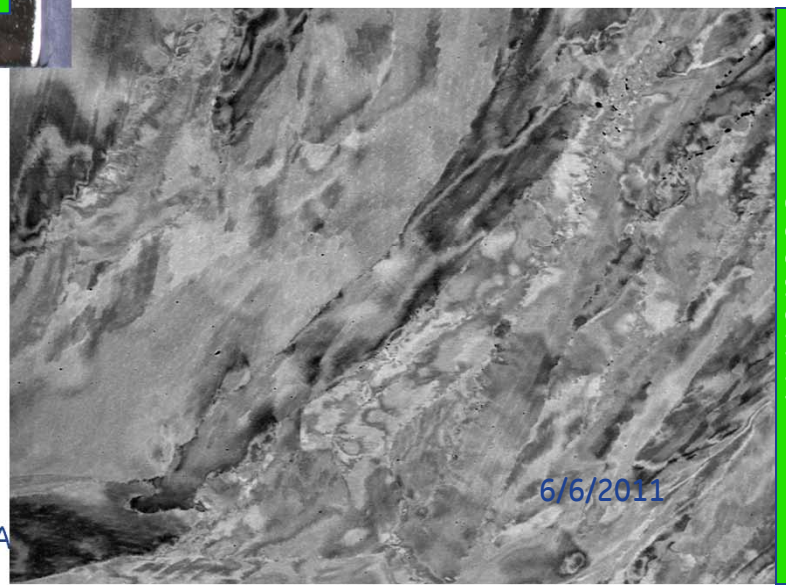
Section C







Section M

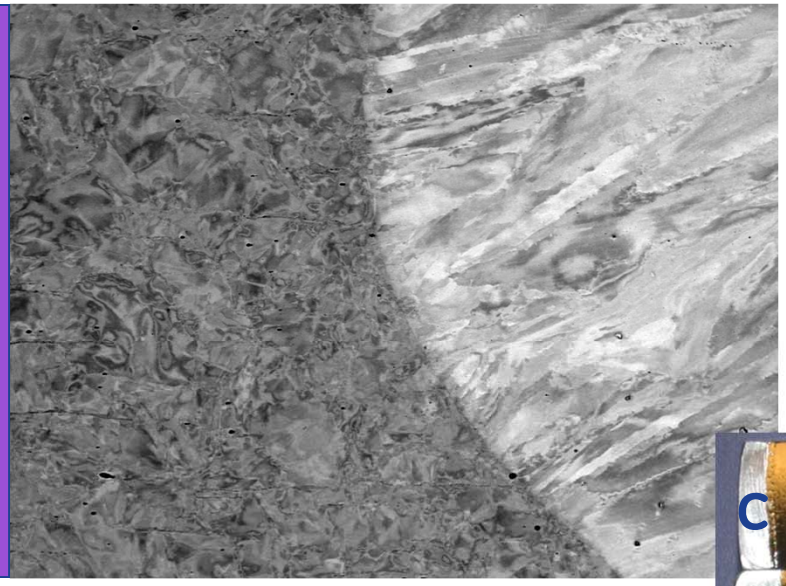


Section R

— 100 um

DJI 190088 52M V Plate: Stainless Steel to 52M Interface BSE Images: 100x

Section C



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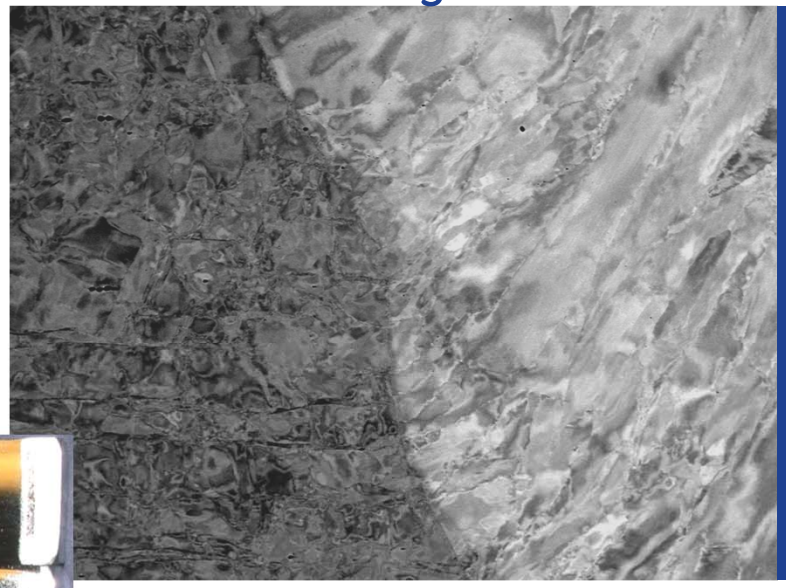
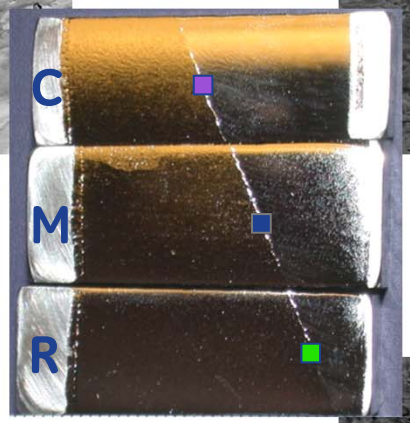
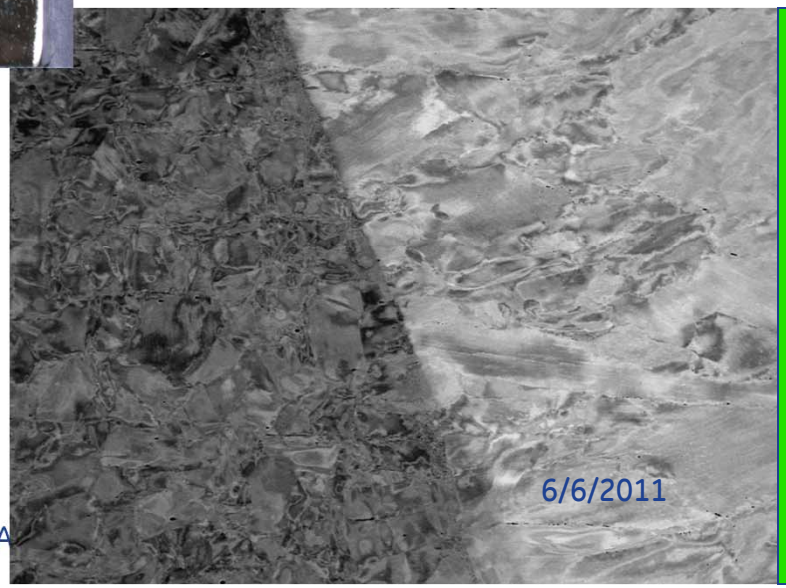




Sharp weld interface

Section R

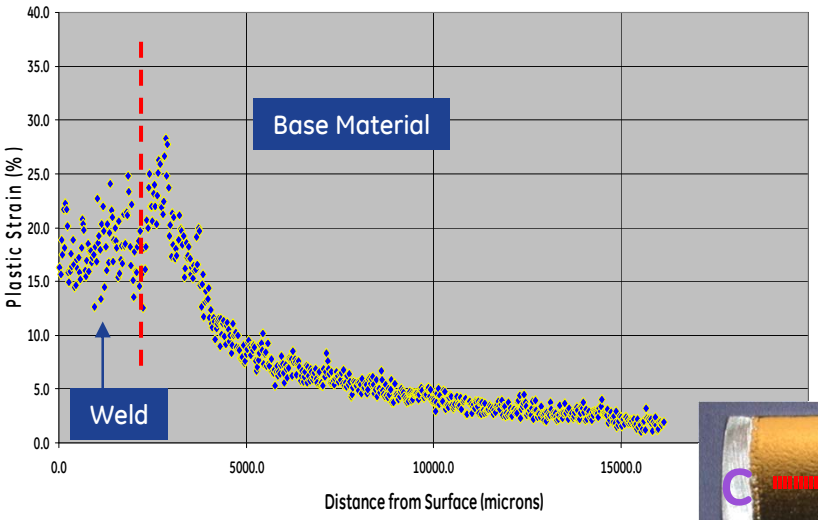


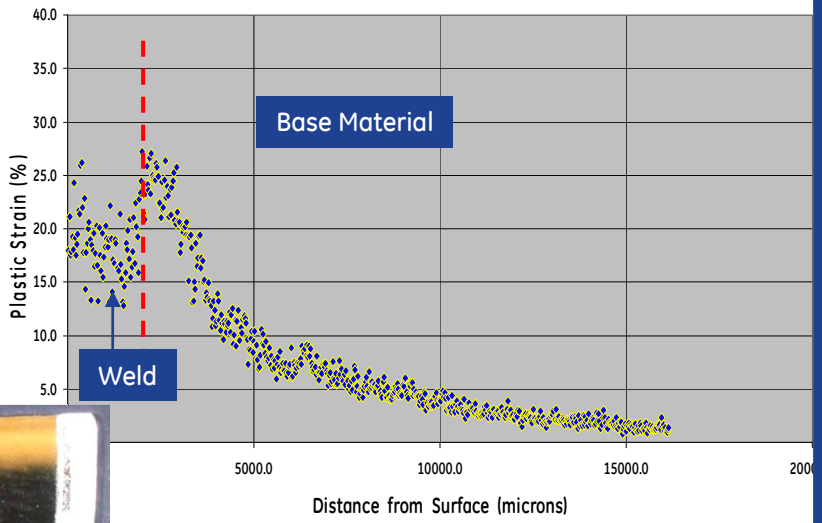
— 100 um

DJI 190088 52M V KAPL Plate

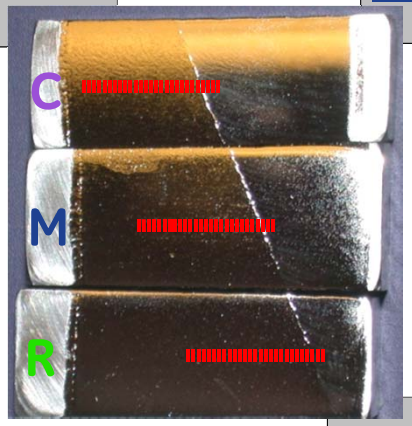
Distance vs. Plastic Strain

Section C

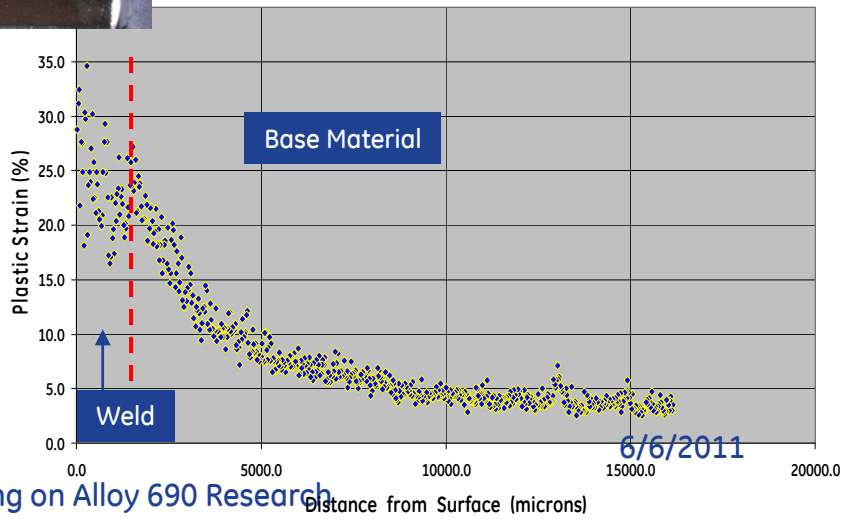




Section M



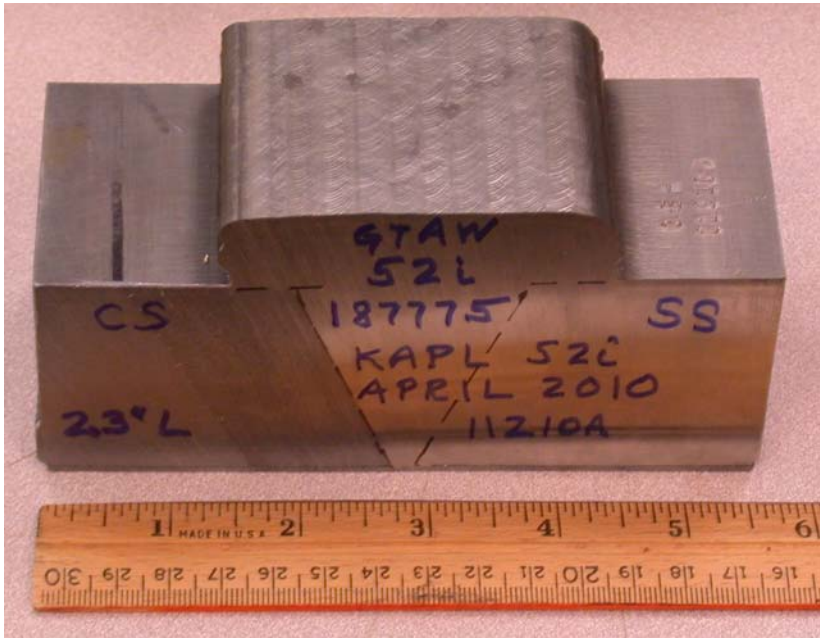
Sharp peak in plastic strain in SS at interface, above 25% plastic strain.



Section R

Conventional V-Groove Weld with EN52i Filler Metal Heat 187775

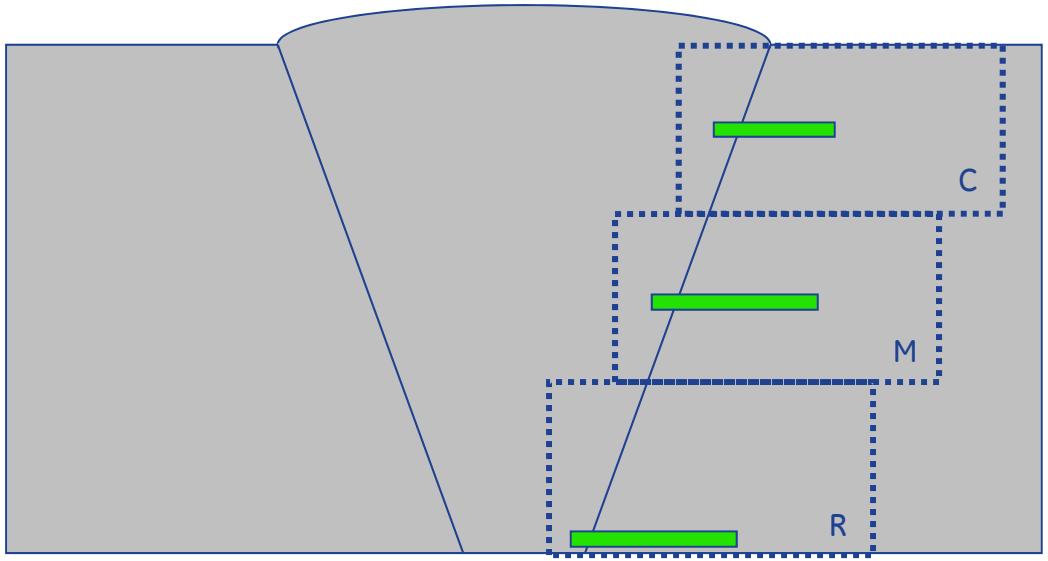
SS-CS Weld 52i 187775



SS-CS Weld 52i 187775

Residual Plastic Strain Analysis by EBSD

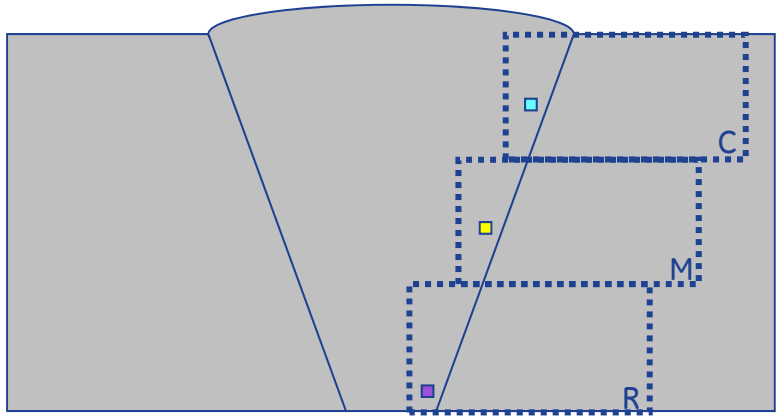
Images at Weld 52i/SS Interface

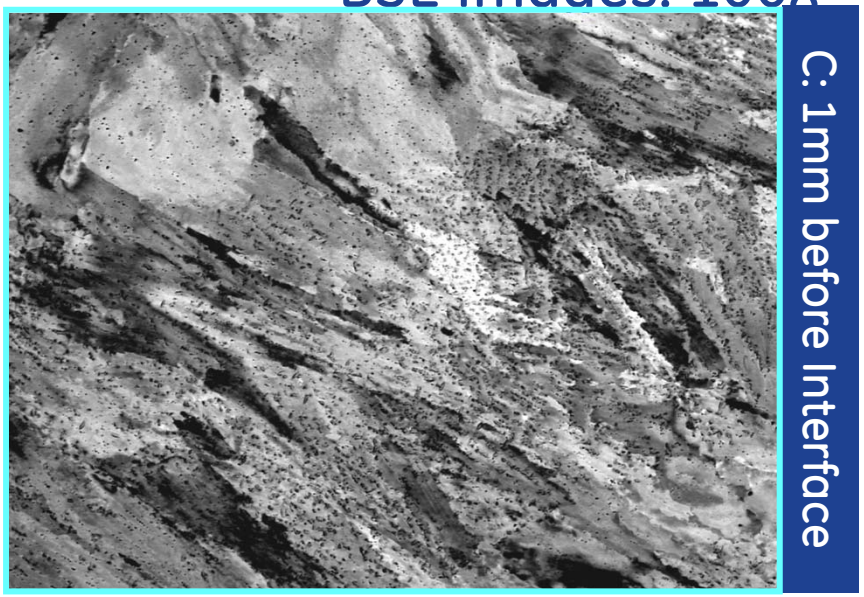


imagination at work

52i 187775 : 1mm before Interface

BSE Images: 100x

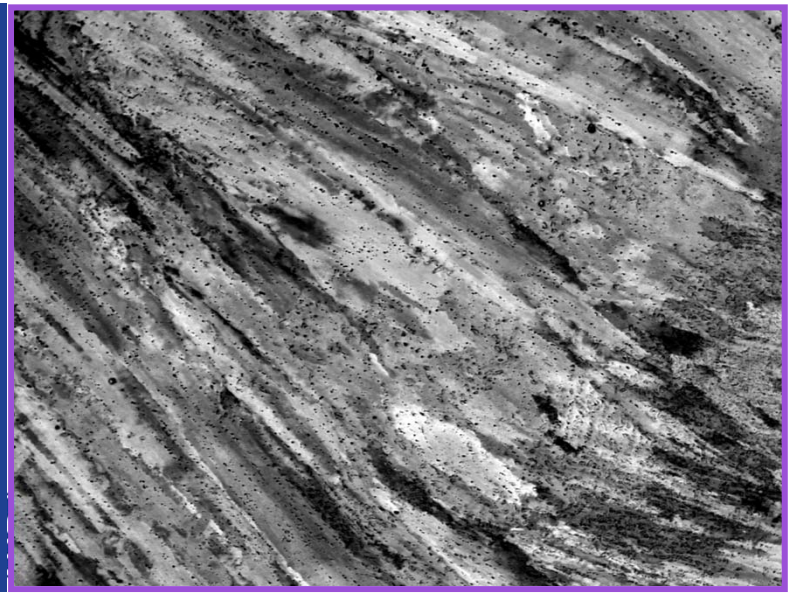


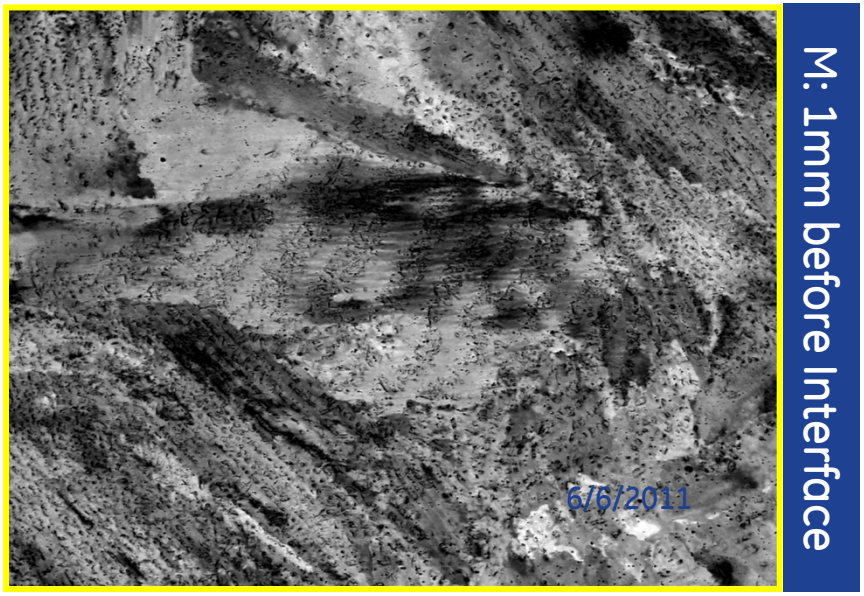


C: 1mm before Interface

— 100 um

R: 1mm before Interface

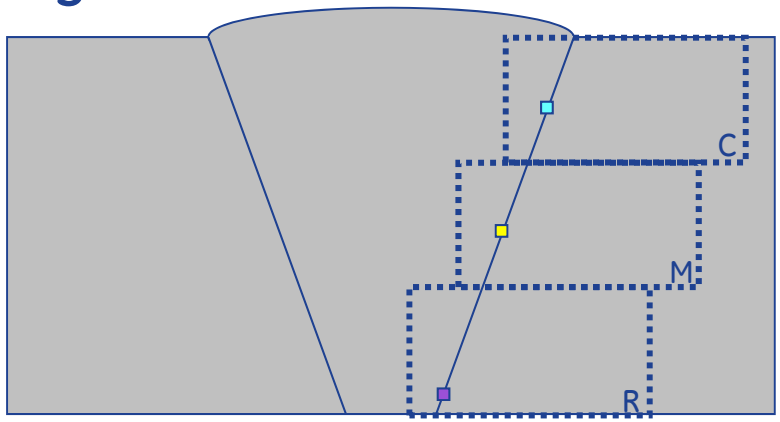




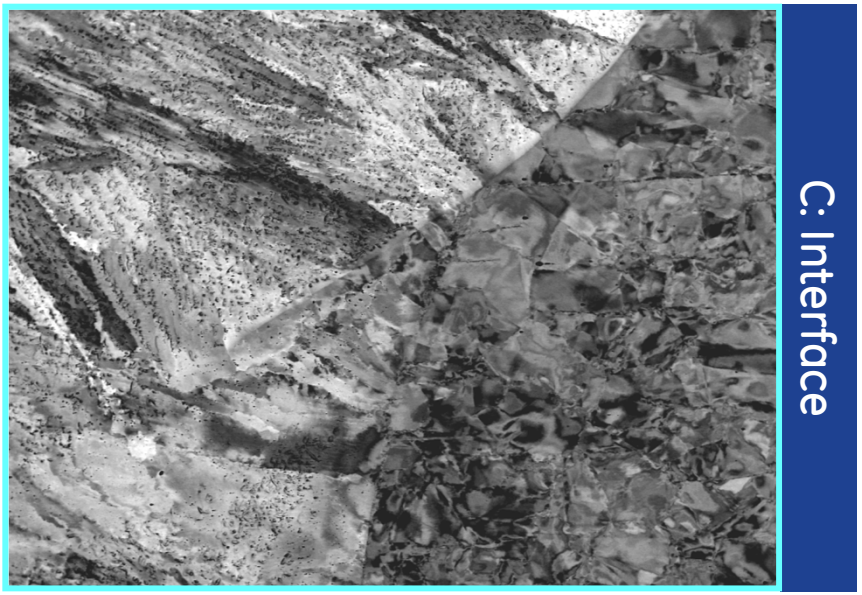
M: 1mm before Interface

KAPL 52i 187775 : Interface

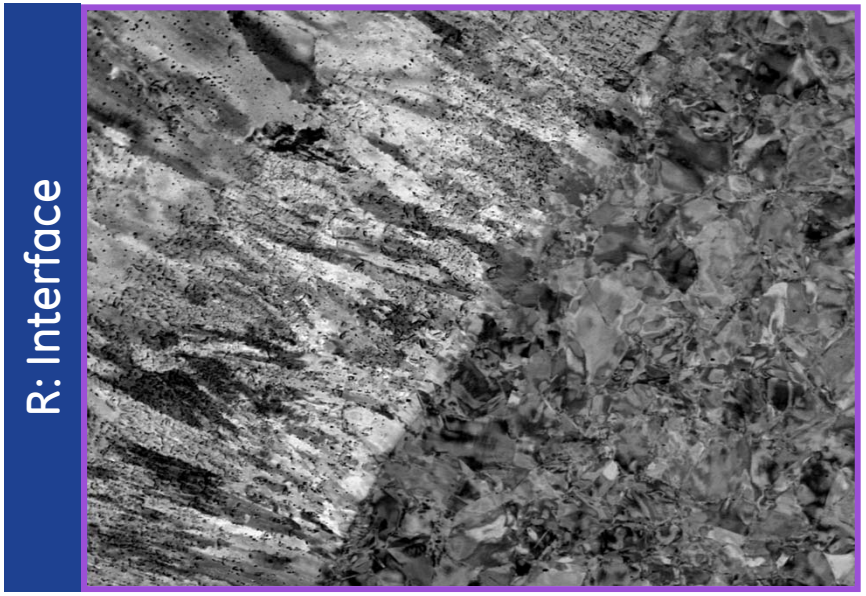
Images: 100x



BSE



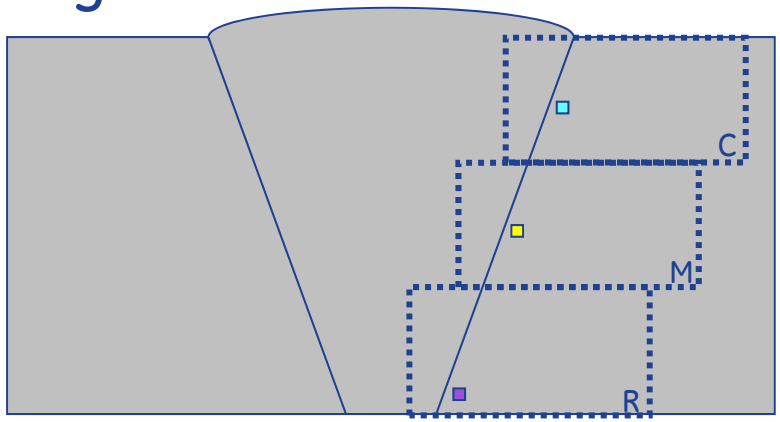
— 100 um

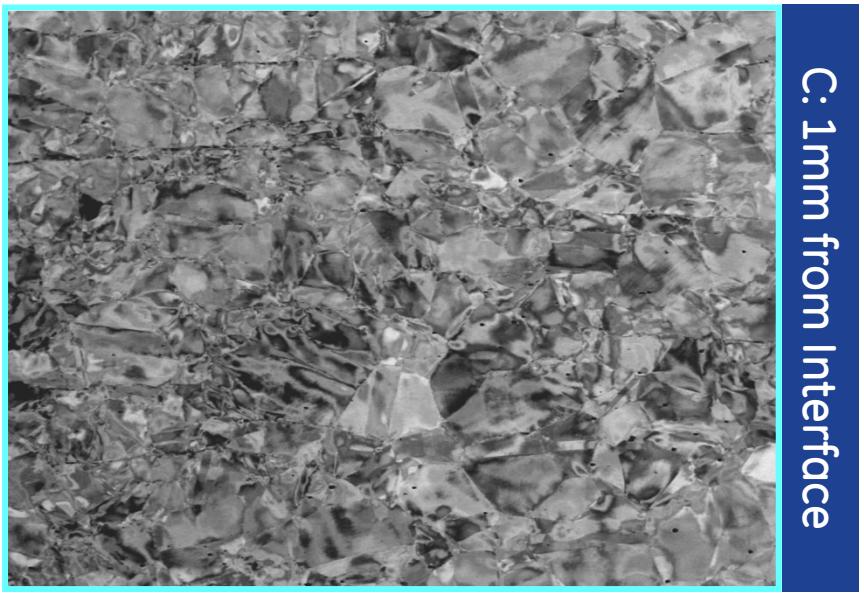


KAPL 52i 187775 : 1 mm from Interface

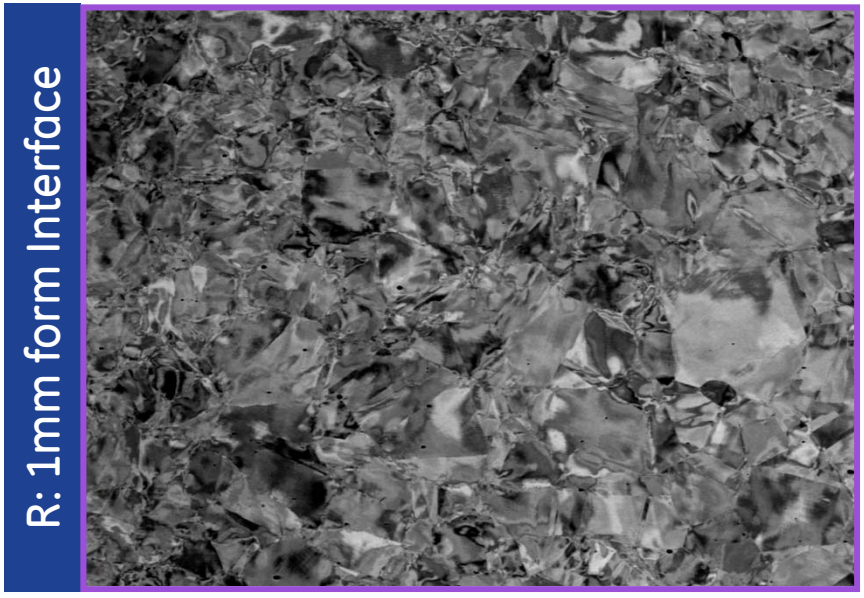
BSE

Images: 100x



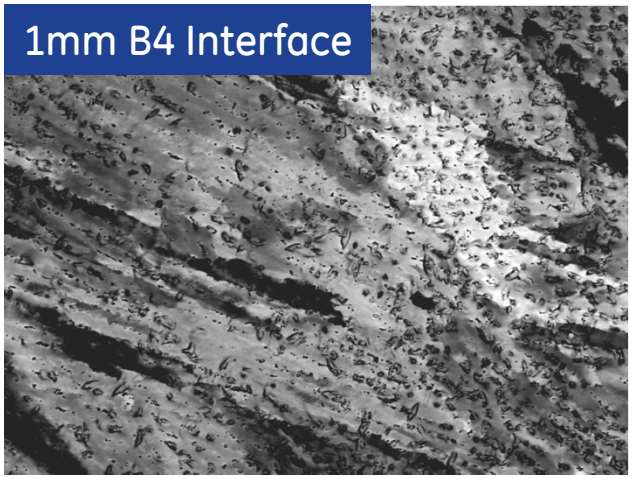


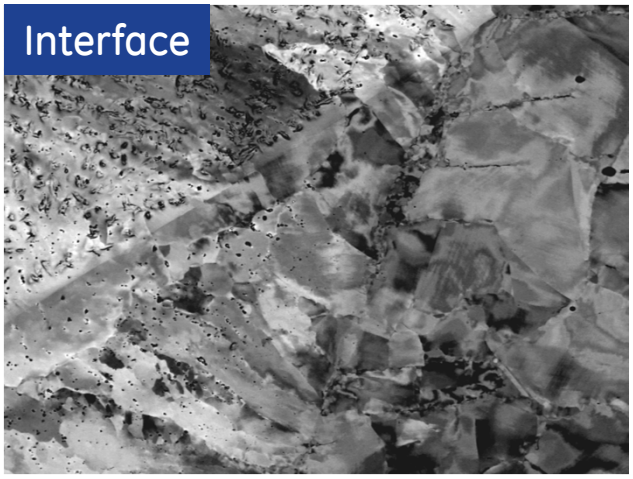
— 100 um

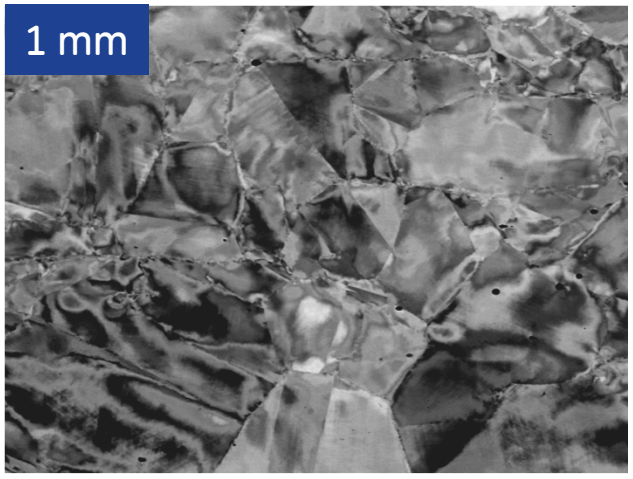


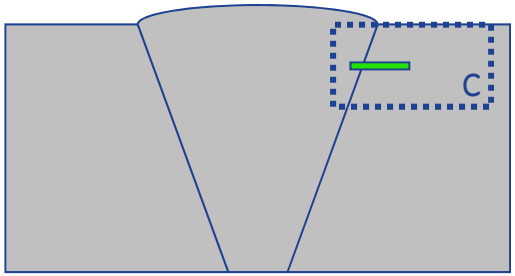
KAPL 52i 187775 : C Images

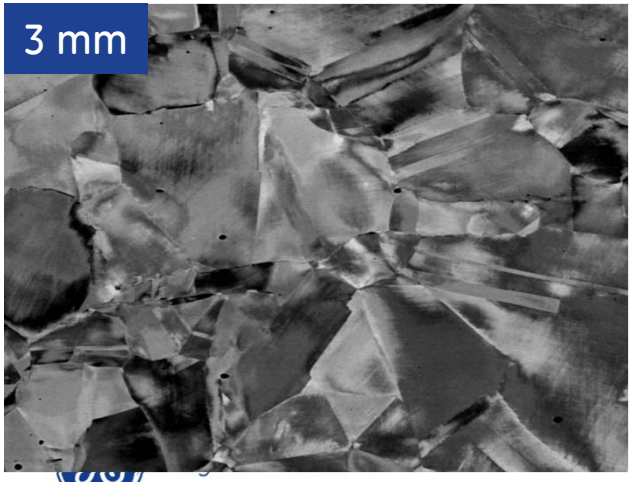
BSE Images: 250x

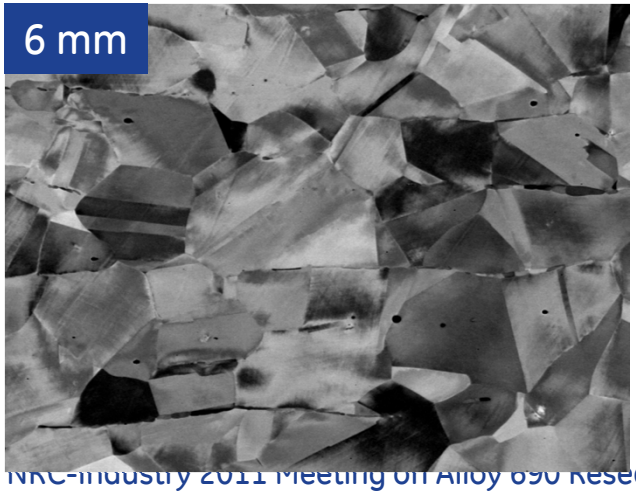


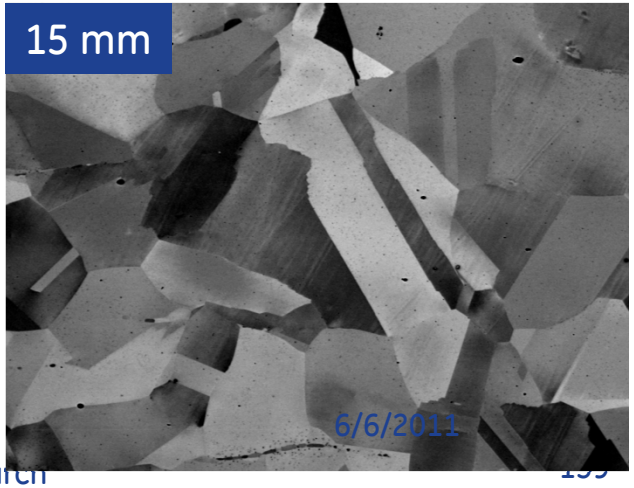






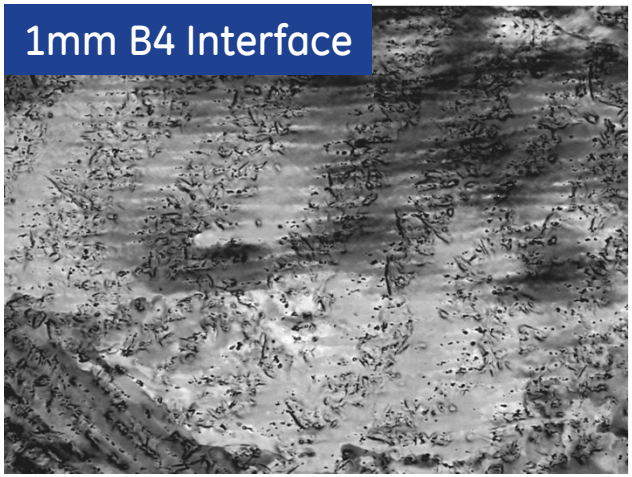


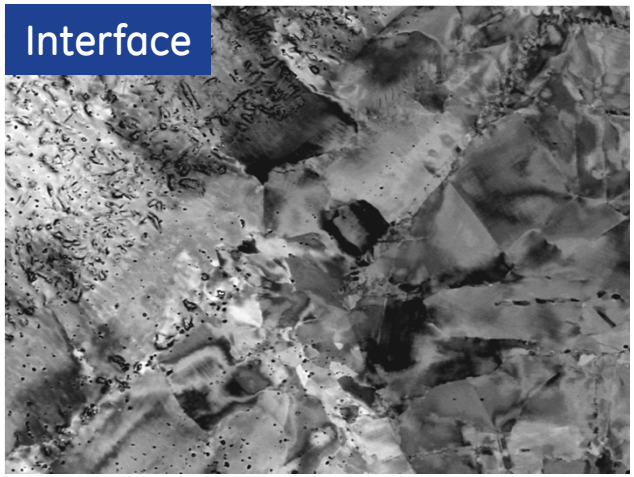


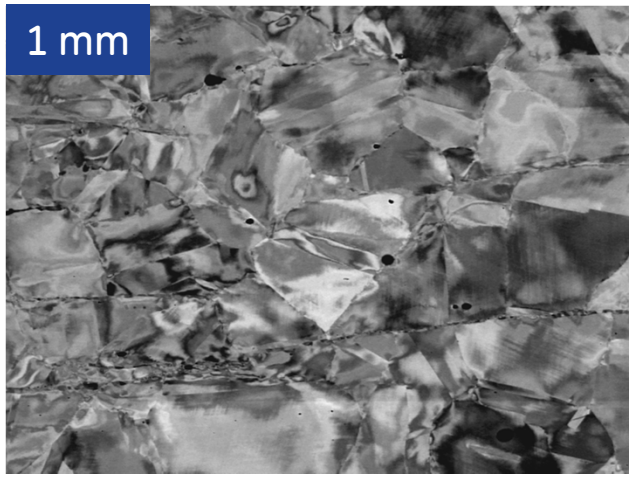


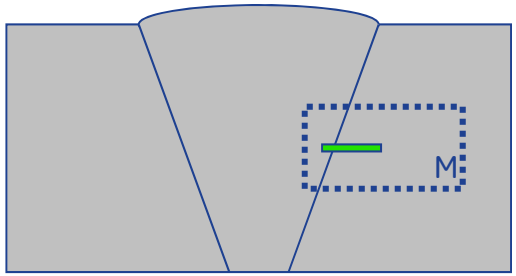
KAPL 52i 187775 : M Images

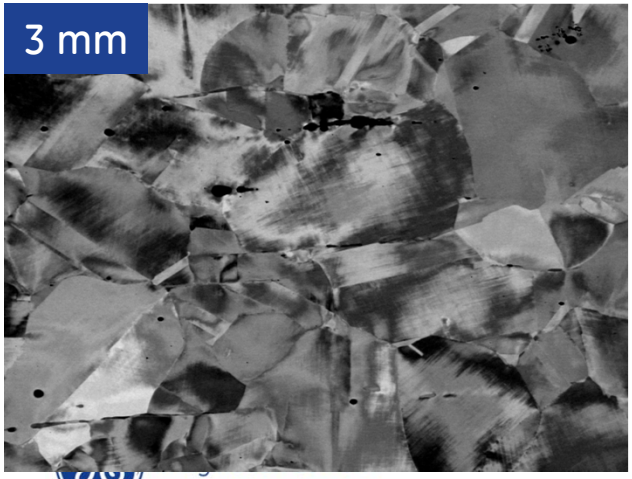
BSE Images: 250x

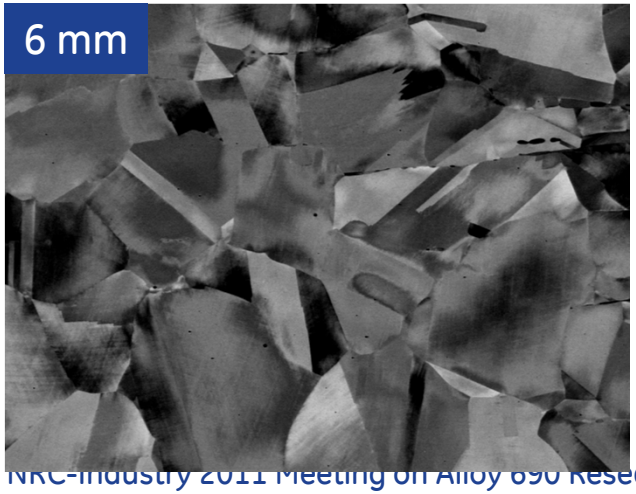


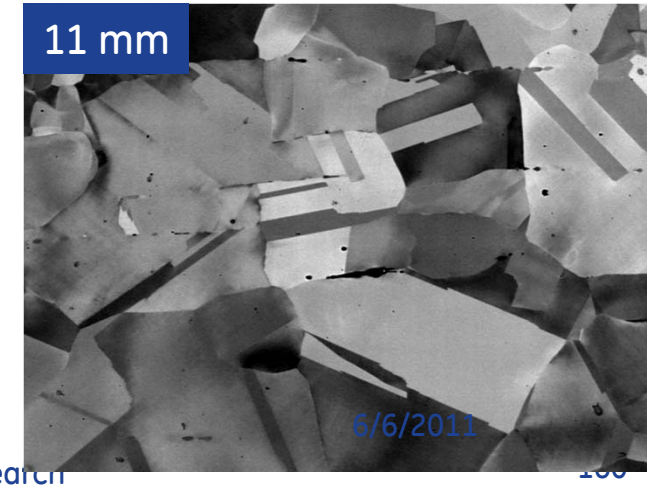






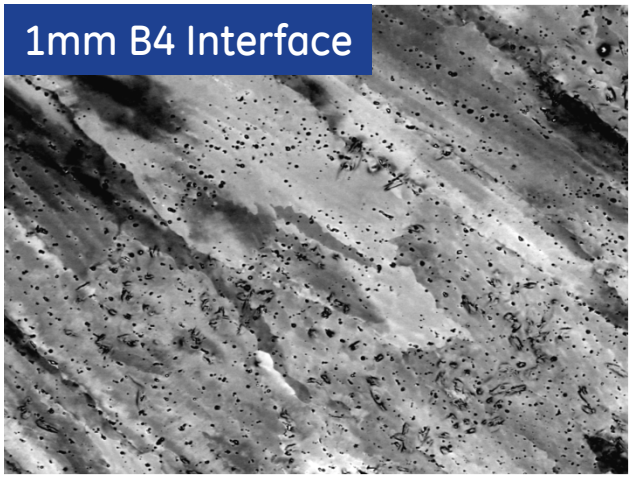


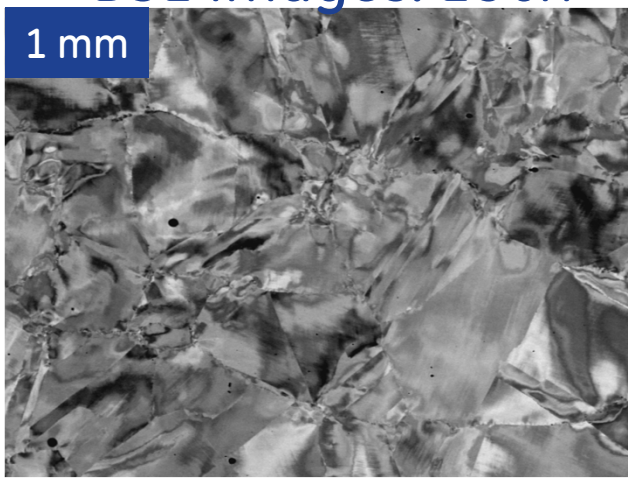


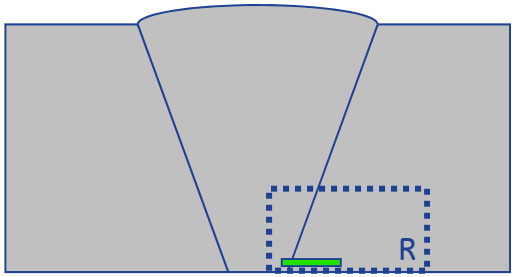


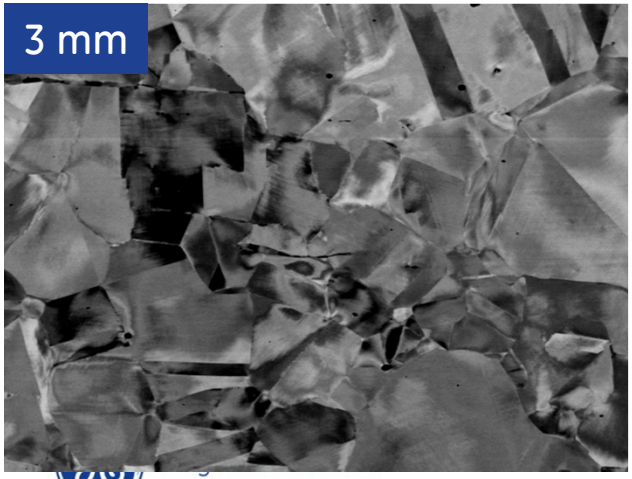
KAPL 52i 187775 : R Images

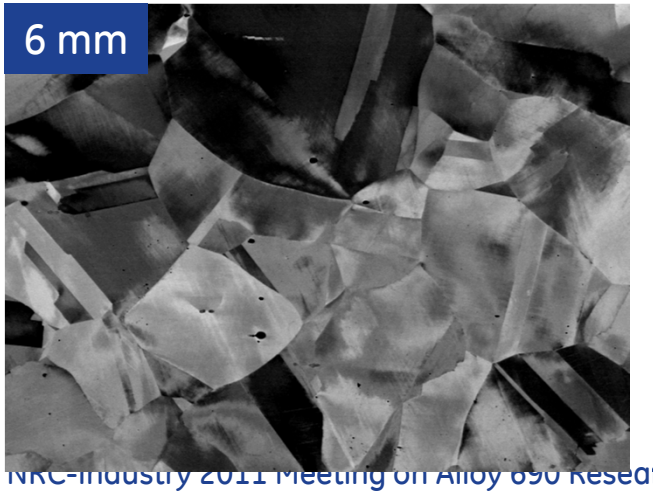
BSE Images: 250x

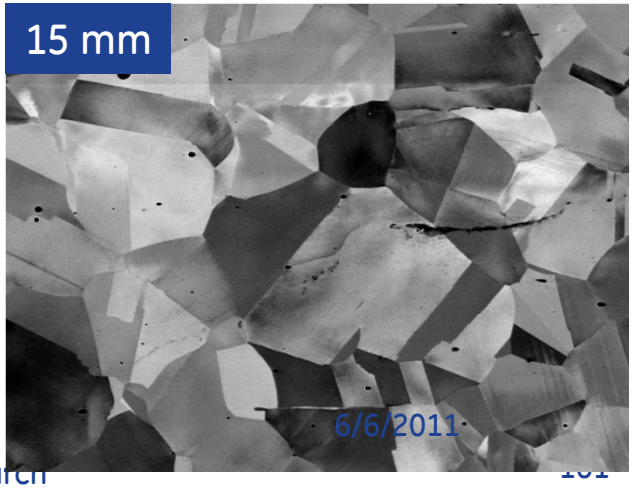




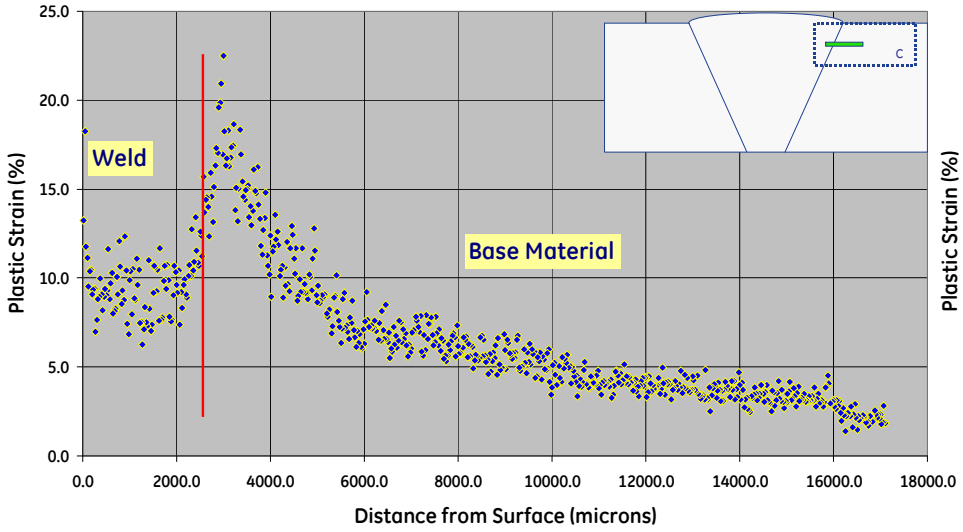


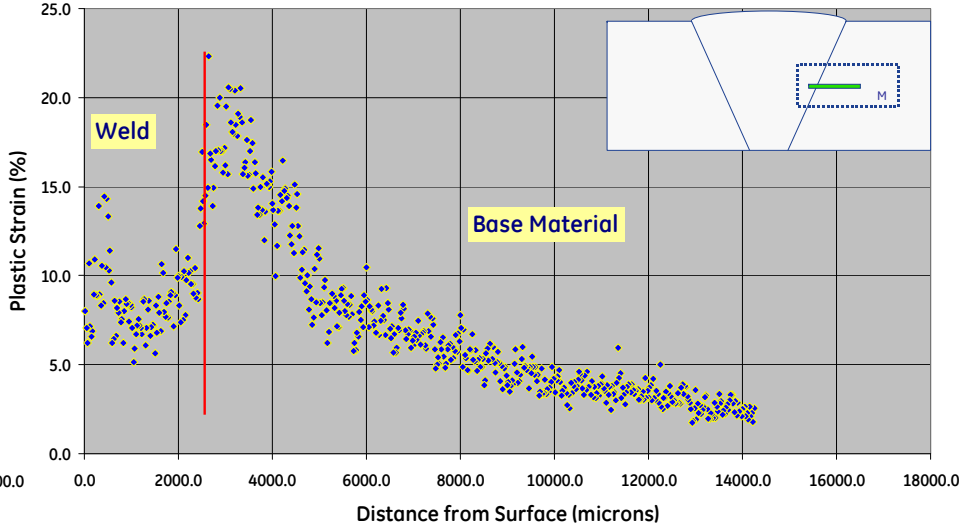


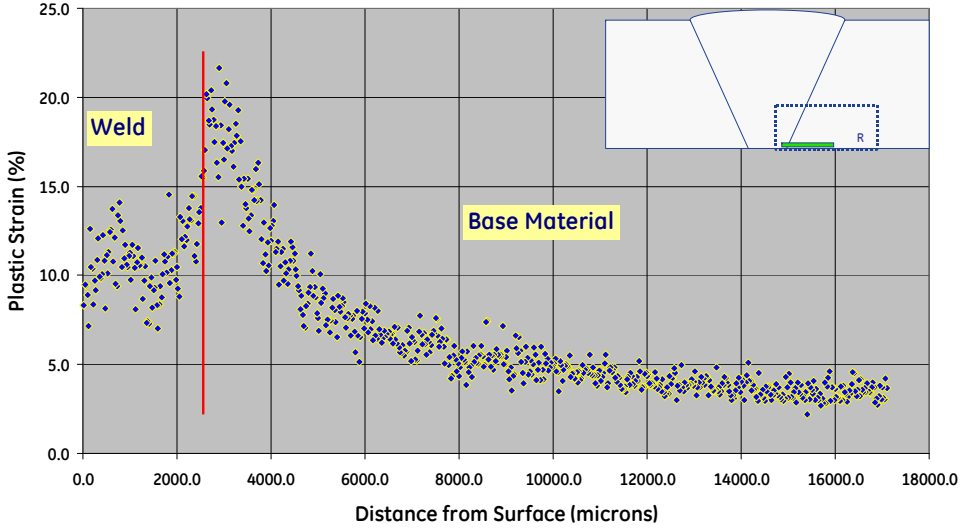




304 SS to EN52i Filler Metal Heat 187775 Distance vs. Plastic Strain







The location of the plastic strain peak in the stainless steel base metal is consistent

SUMMARY

- 690 – 52M weld interface appears to be more complex than seen in 52M – SS weld interfaces with the peak in residual plastic strain shifted to just inside the interface defined by the fine grained base metal.

- Peak in plastic strain in the 52M – 690 interfaces occurs just inside the interface defined y the fine grain 690 base metal.

- Prominent peak in residual plastic strain in coarse grain/epitaxial dendrite mix zone.

- Residual plastic strain in mix zone above 20% in some welds

- Other 52M-690 weld interfaces

  NX2579JK – peak at 12% strain in interface mixed structure zone
  MLTS-3-Cr – peak from 12 to 14% strain in interface mixed structure zone