Microstructure Stability During Creep of Friction Stir Welded AA2024-T3 Aluminum Alloy

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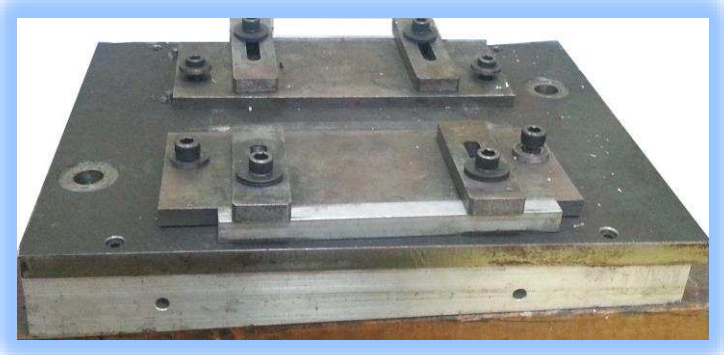
Outline

- The FSW process
- Experimental procedure
- Results (optical metallography, SEM, TEM, EDS)
- Discussion
- Conclusions

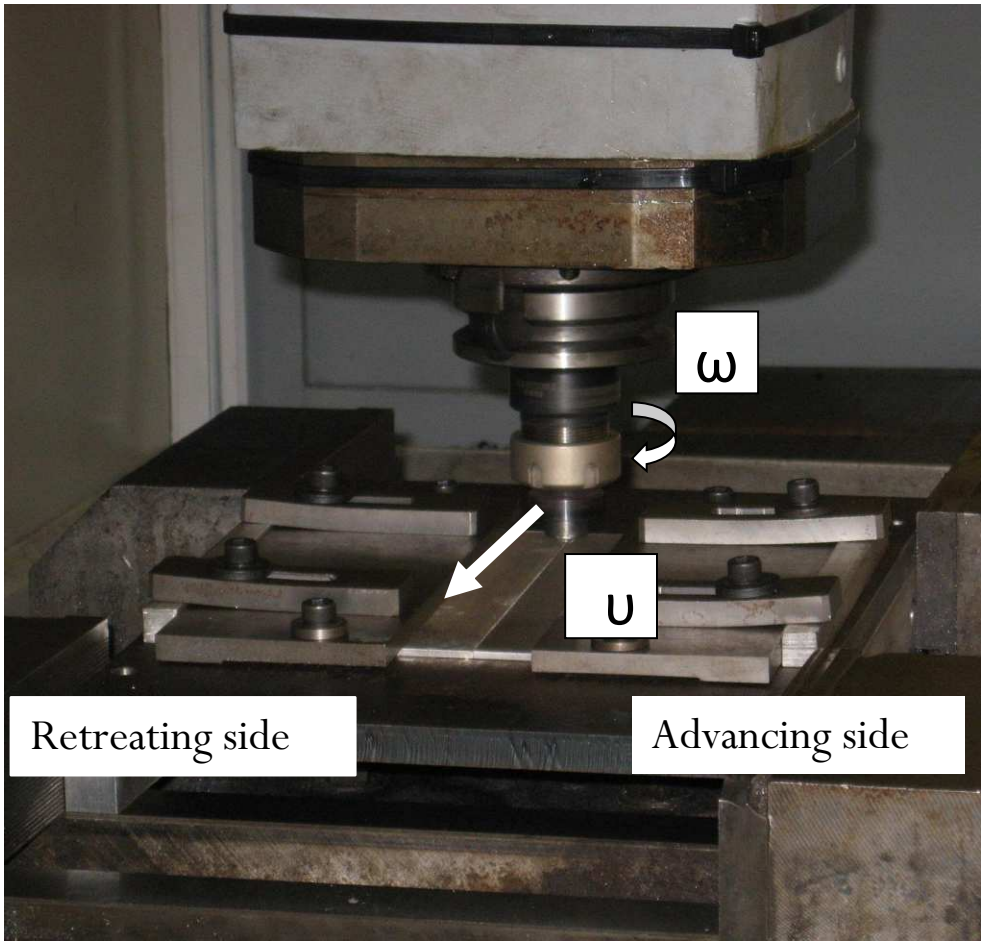
The advantages of FSW

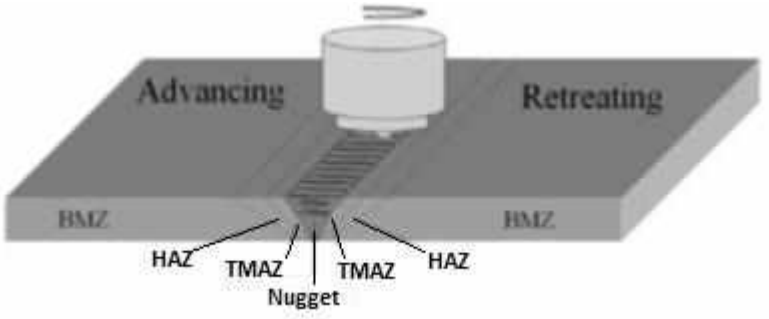
- No filler
- The welding tool lasts for ~1000m
- Minimum preparation
- About 20% heat input compared with TIG
- No fusion/solidification defects
- Dissimilar weldings, unweldable alloys, composites


hpm-30
sharnoa



The FSW process



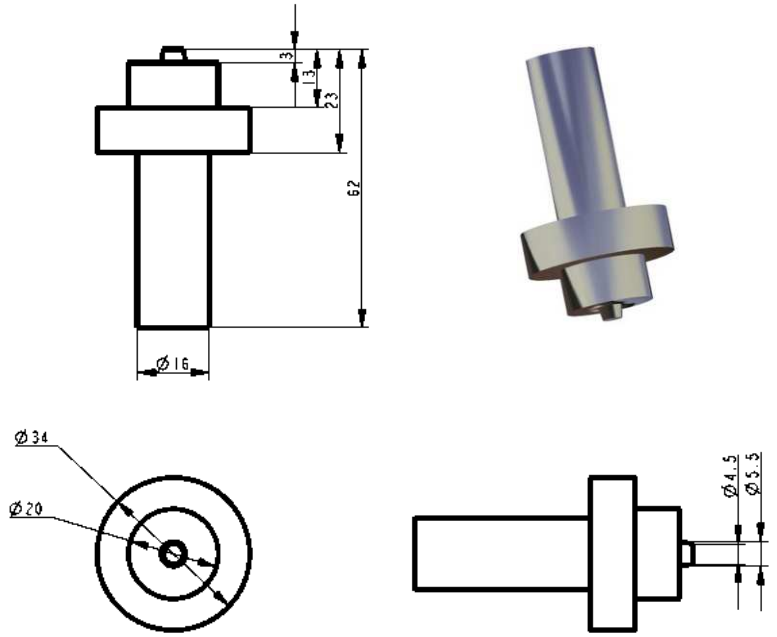


Experimental Procedure

- Material – 3.175mm thick 200x100mm plates of commercial AA2024-T3 alloy

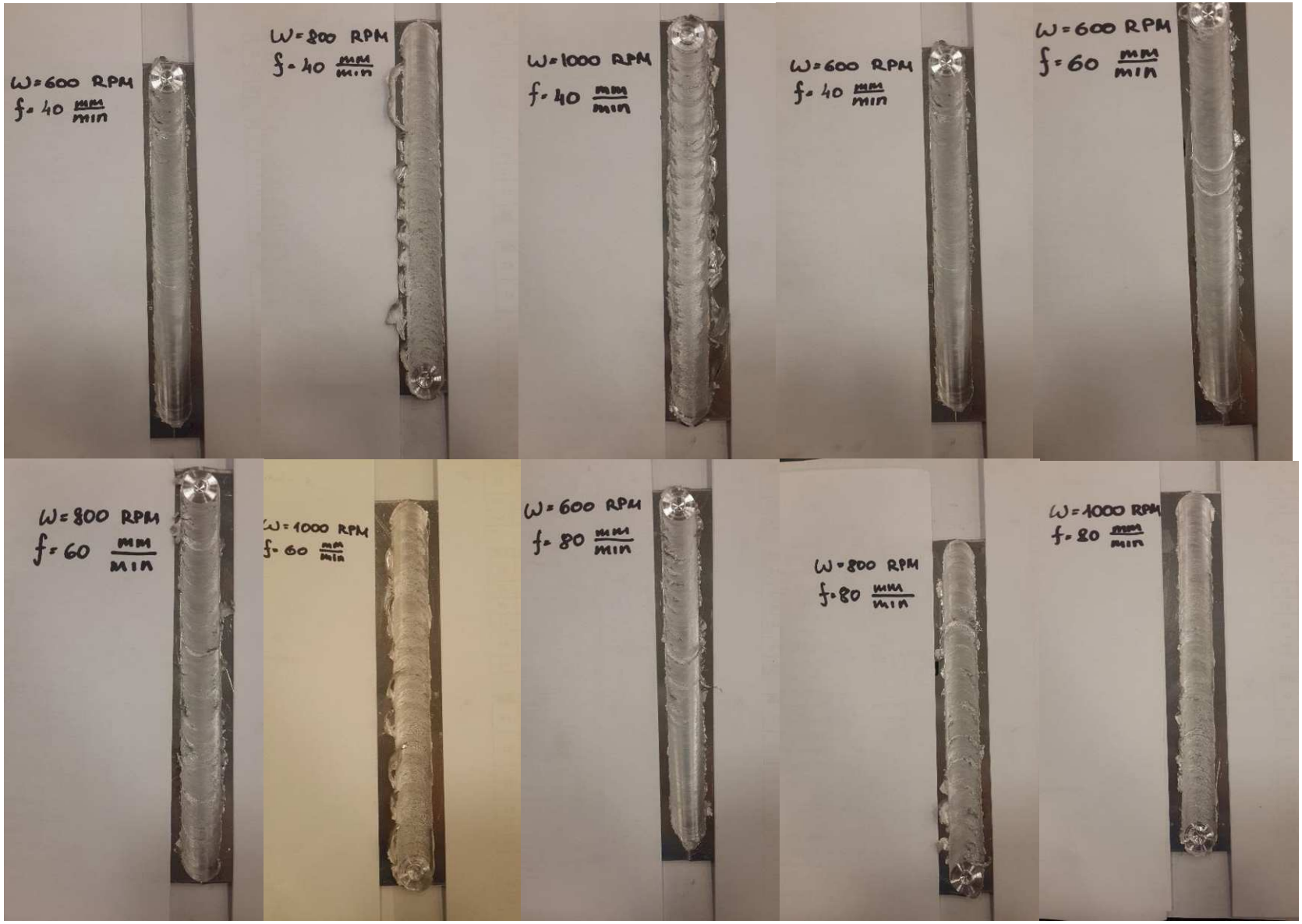
Element	Cu	Mg	Mn	Fe, Si	Ti	Zn	Al
Content (wt%)	3.8-4.9	1.2-1.8	0.3-0.9	Max 0.5	Max 0.15	Max 0.25	Bal.

- An H-13 welding tool



Assesment stage:

- Visual inspection
- Optical microscopy of X-sections
- Radiography


W=600 RPM
f=40 mm/min
W=800 RPM
f=40 mm/min
W=1000 RPM
f=40 mm/min
W=600 RPM
f=40 mm/min
W=600 RPM
f=60 mm/min
W=800 RPM
f=60 mm/min
W=1000 RPM
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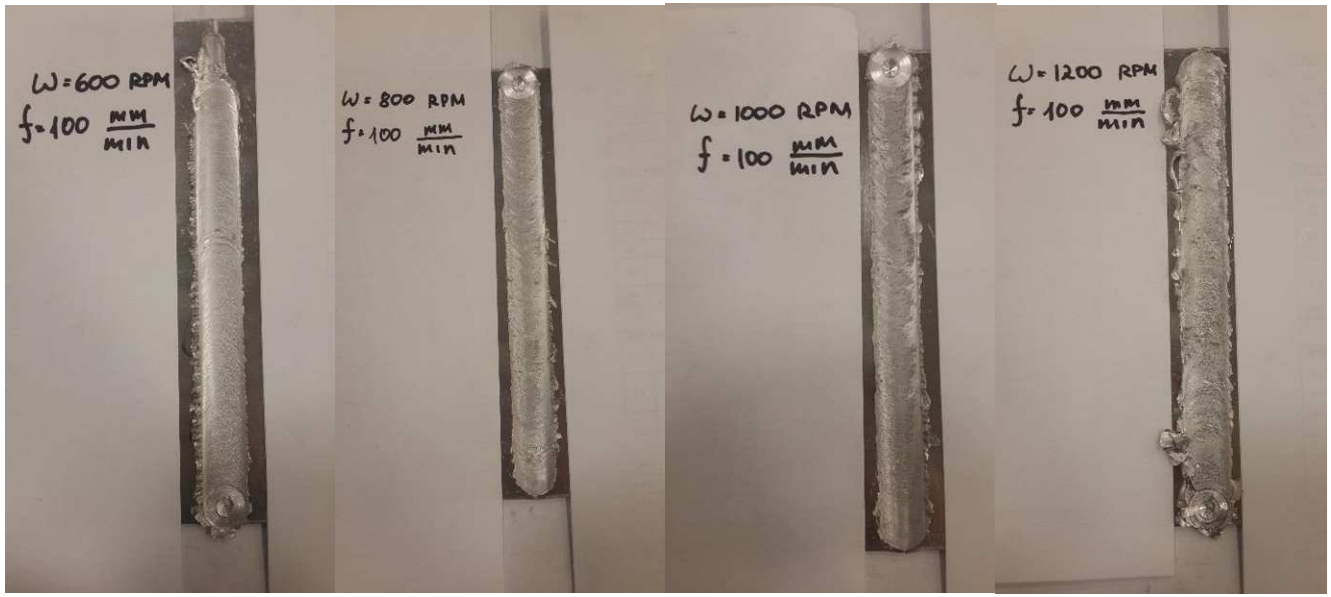
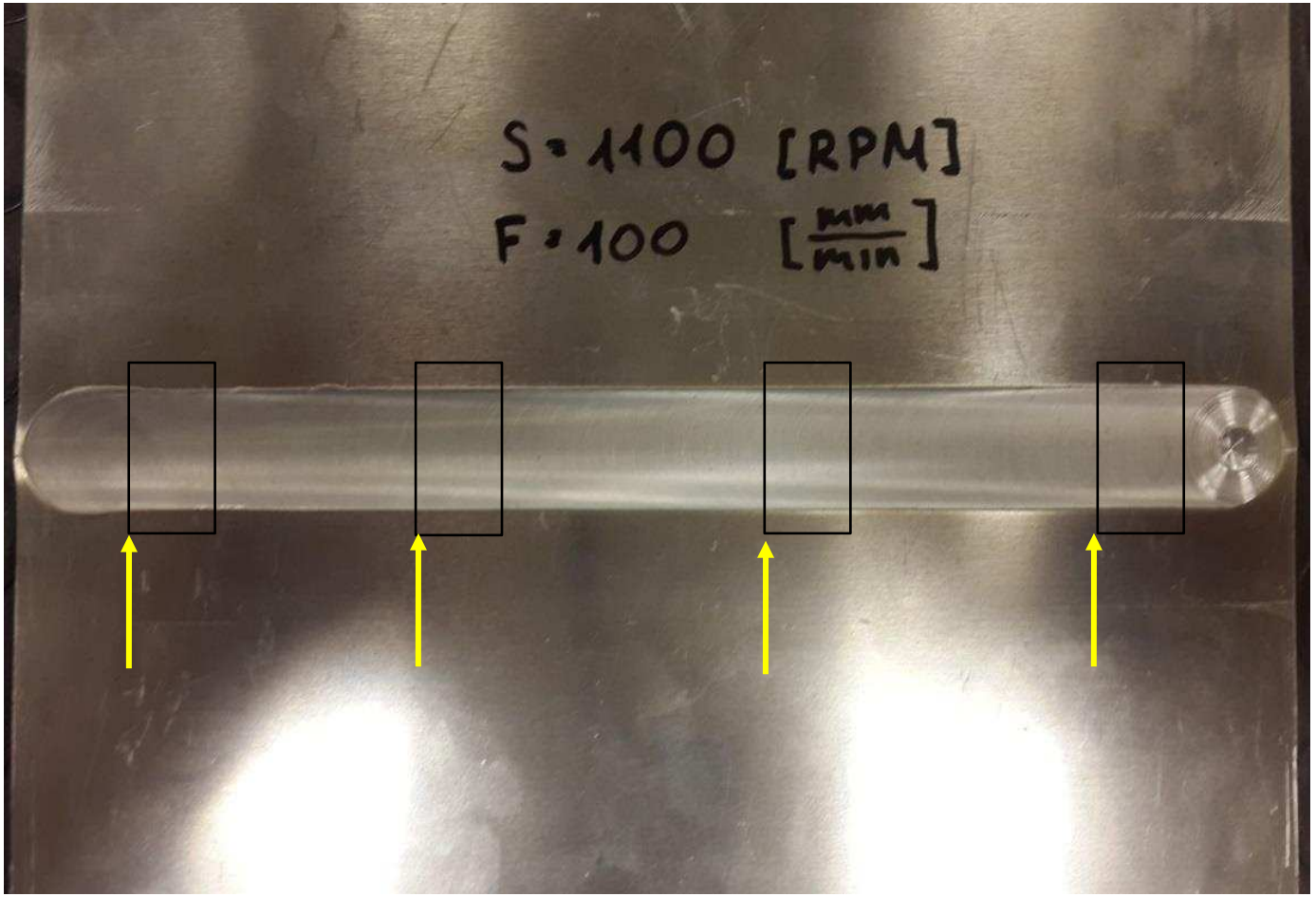
W=600 RPM
f=80 mm/min
W=800 RPM
f=80 mm/min
W=1000 RPM
f=80 mm/min


ω = 600 RPM
f = 100 mm/min
ω = 800 RPM
f = 100 mm/min
ω = 1000 RPM
f = 100 mm/min
ω = 1200 RPM
f = 100 mm/min


S = 1100 [RPM]
F = 100 [mm/min]

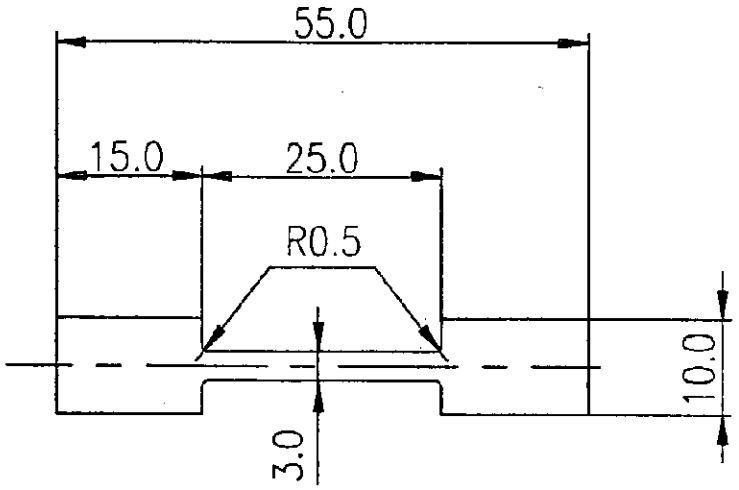
Selected welding parameters:

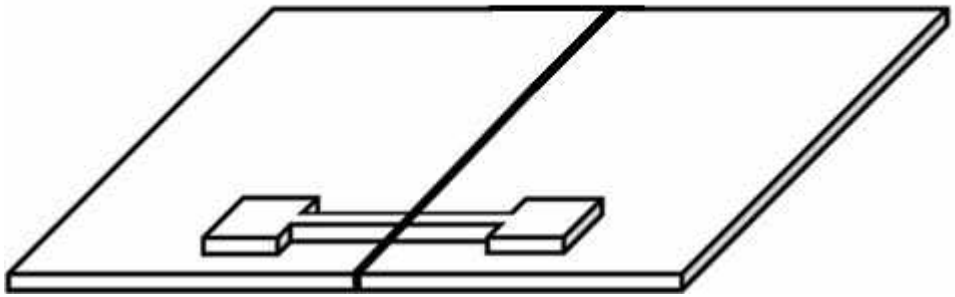
- Rotational speed of 800 rpm and a transverse speed of 80 mm/min

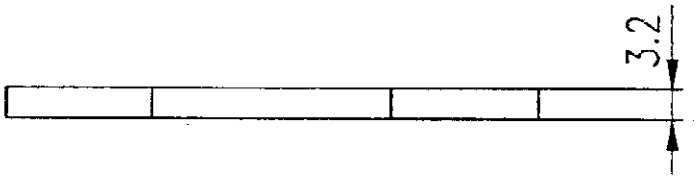
Study:

- Optical metallography
- SEM
- HRSEM
- Creep tests at 250^{0}C and at 315^{0}C
- TEM study
- Thermal stability of AA2024-T3 at 300^{0}C for up to 280 hours

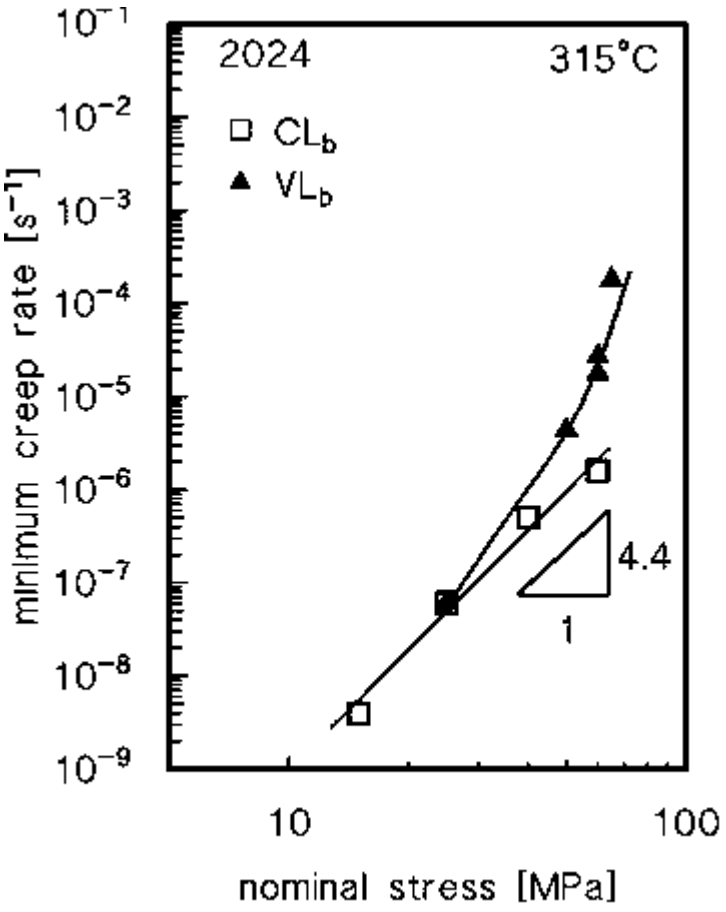

1
1

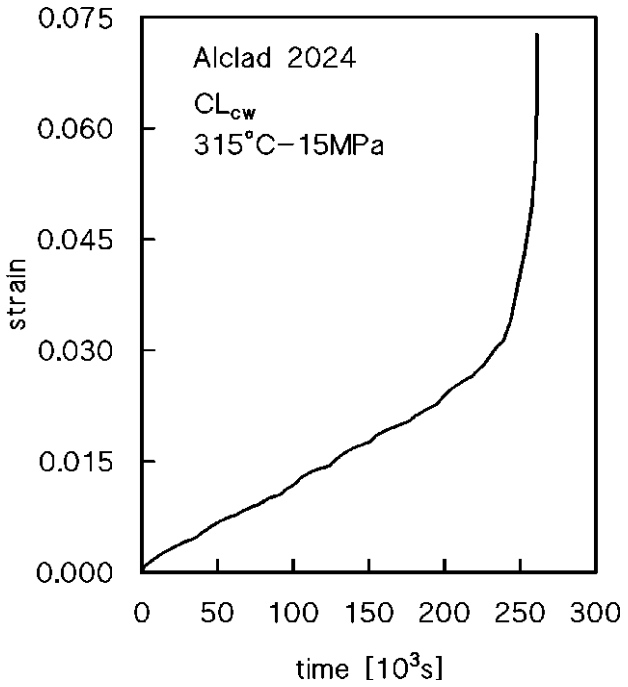

55.0
15.0
25.0
R0.5
10.0
3.0

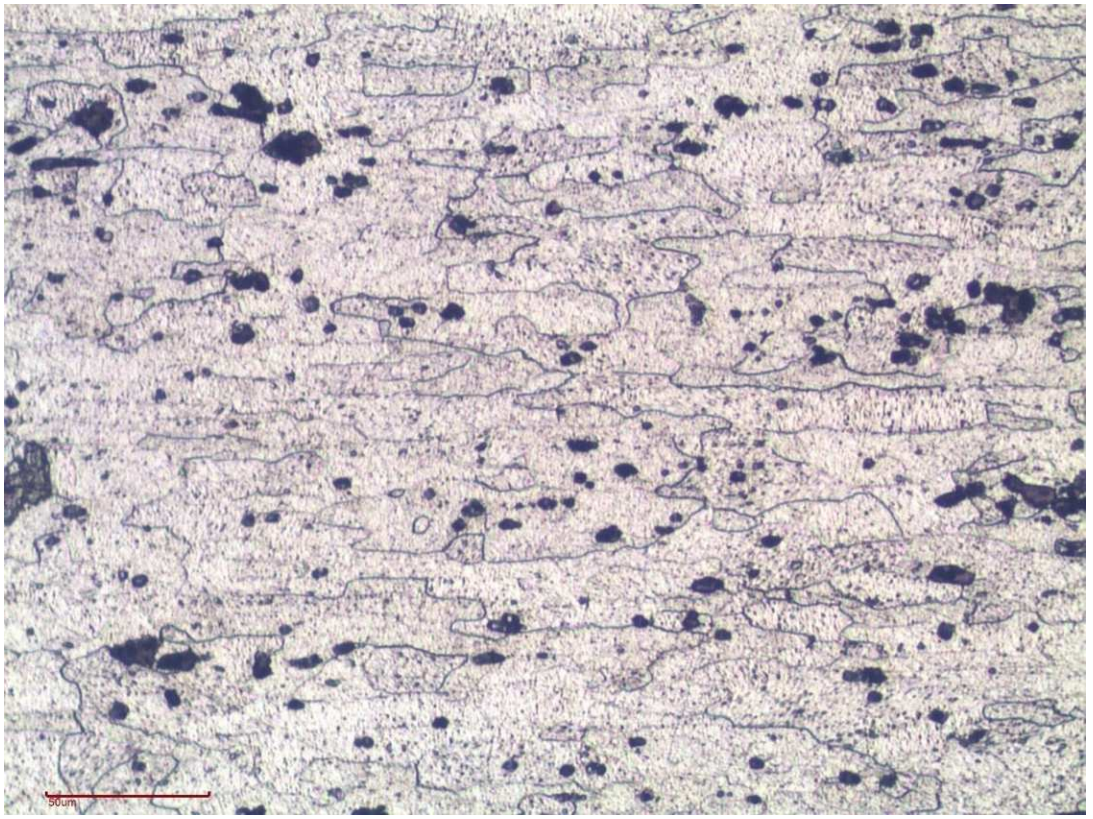



3.2

Results

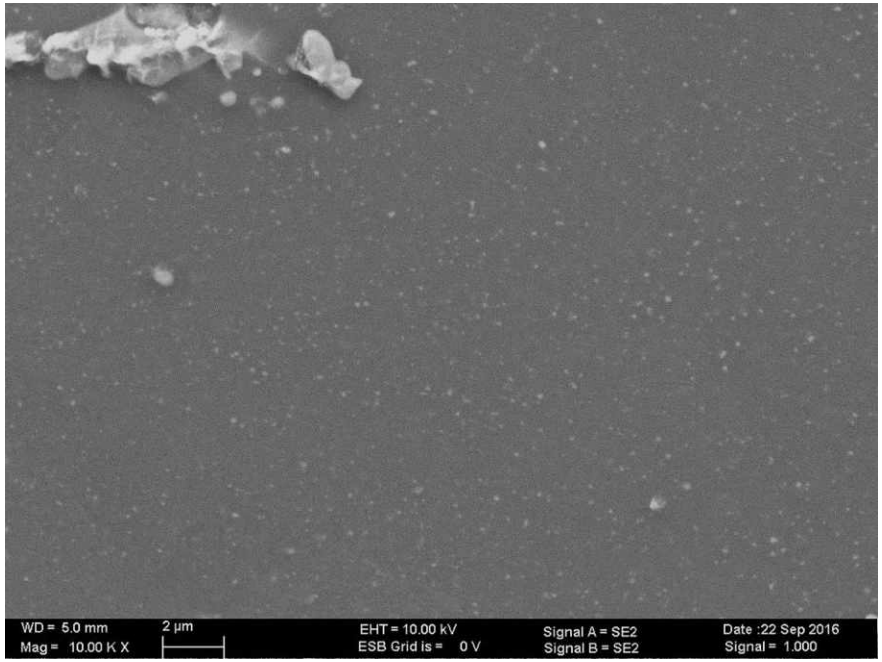

2024
315°C
CL$_b$
VL$_b$
4.4
1
minimum creep rate [s^{-1}]
nominal stress [MPa]
10
100

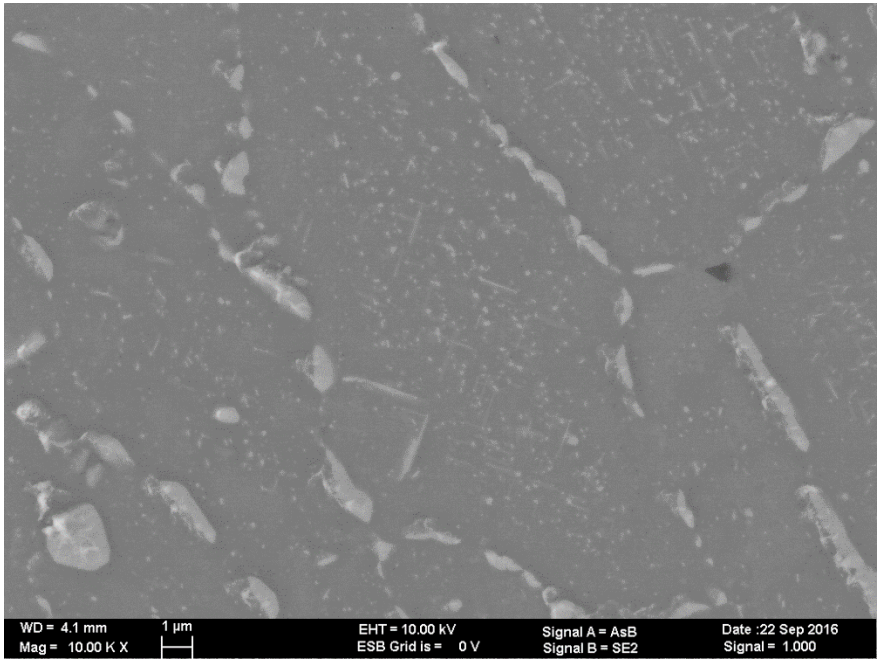

Alclad 2024
CL$_{cw}$
315°C–15MPa
strain
time [10^{3}s]
0.075
0.060
0.045
0.030
0.015
0.000
0
50
100
150
200
250
300



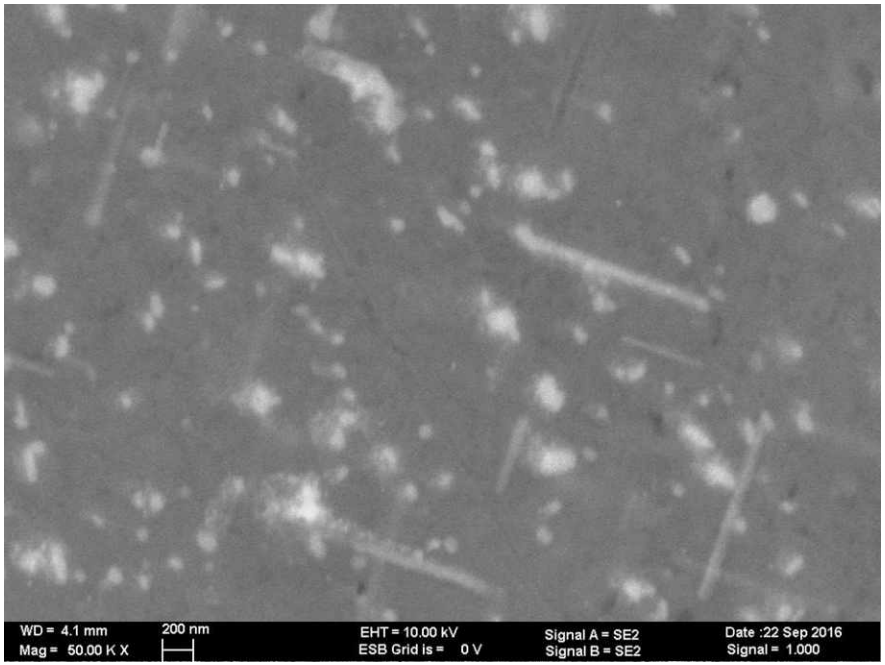
AA2024-T3 parent metal – optical metallography

Nugget – optical metallography



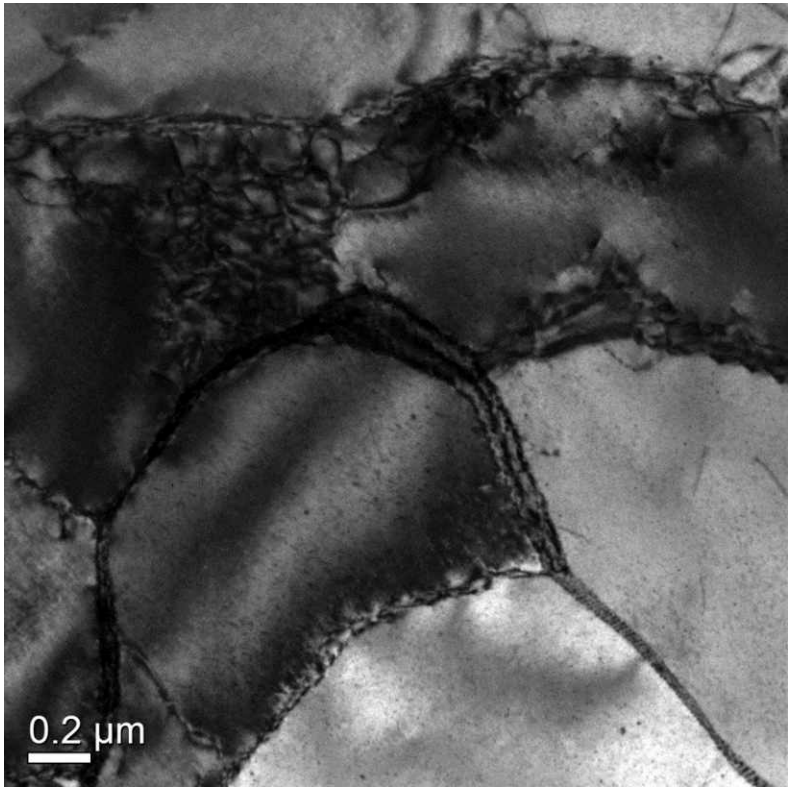


AA2024-T3 HRSEM images of raw material and after 170 hour long exposure to 315^0C

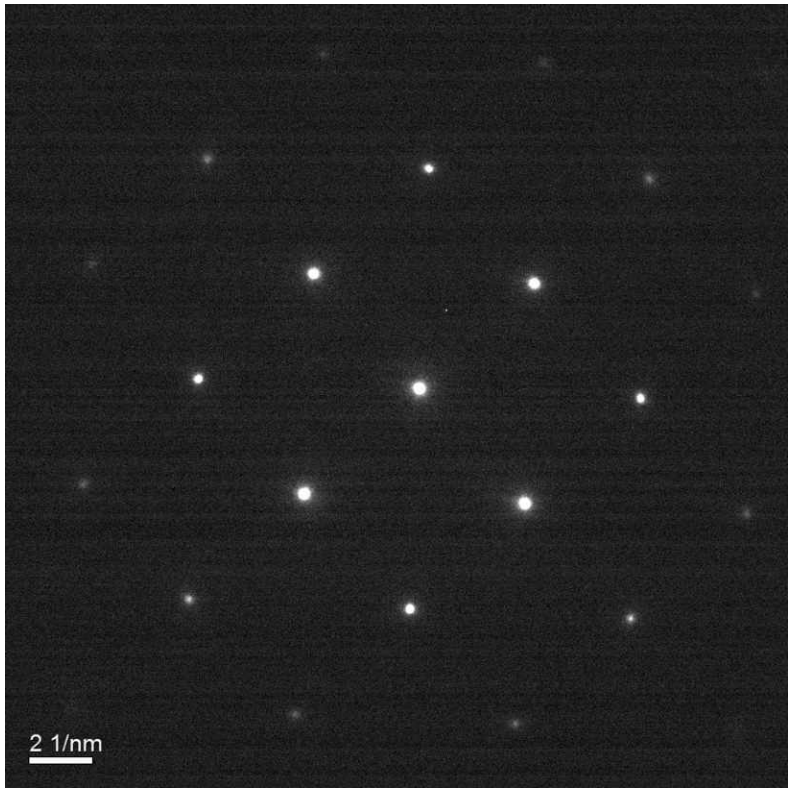


AA2024-T3 HRSEM image - 170 hour at 315^0C

Parent material

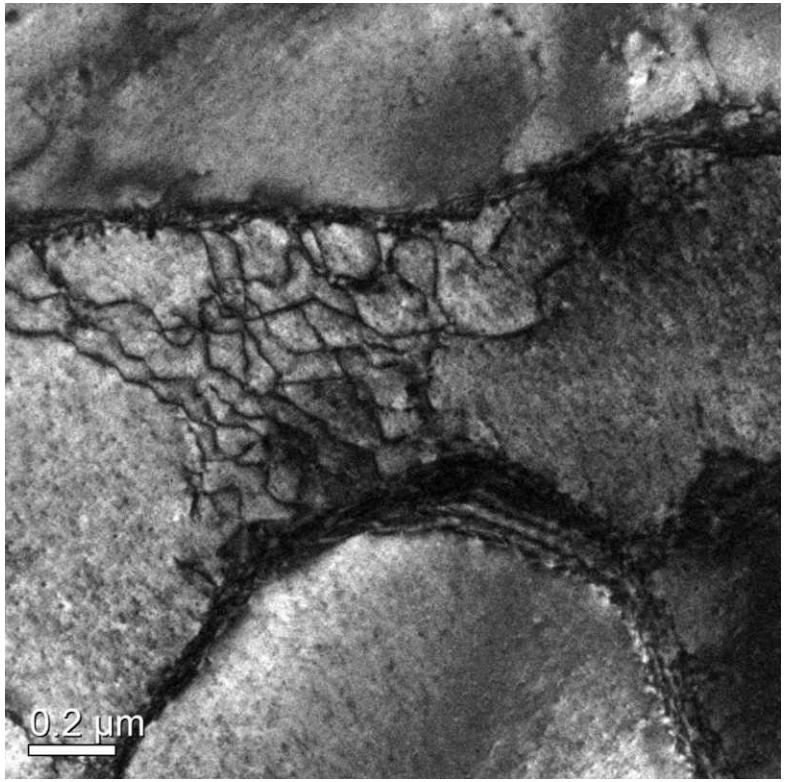


BF image



<001> z.a.

Parent material



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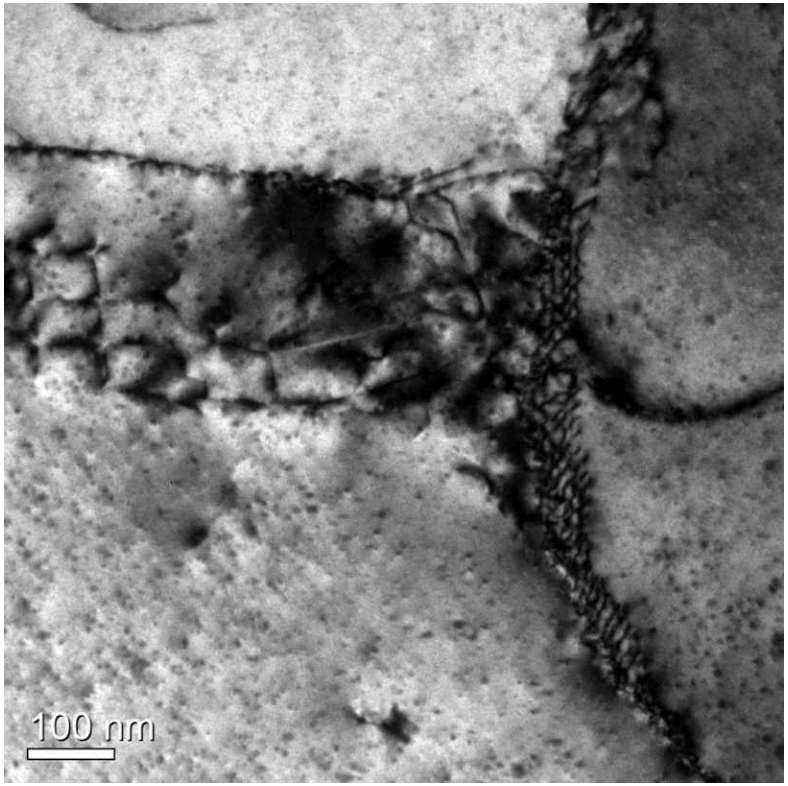
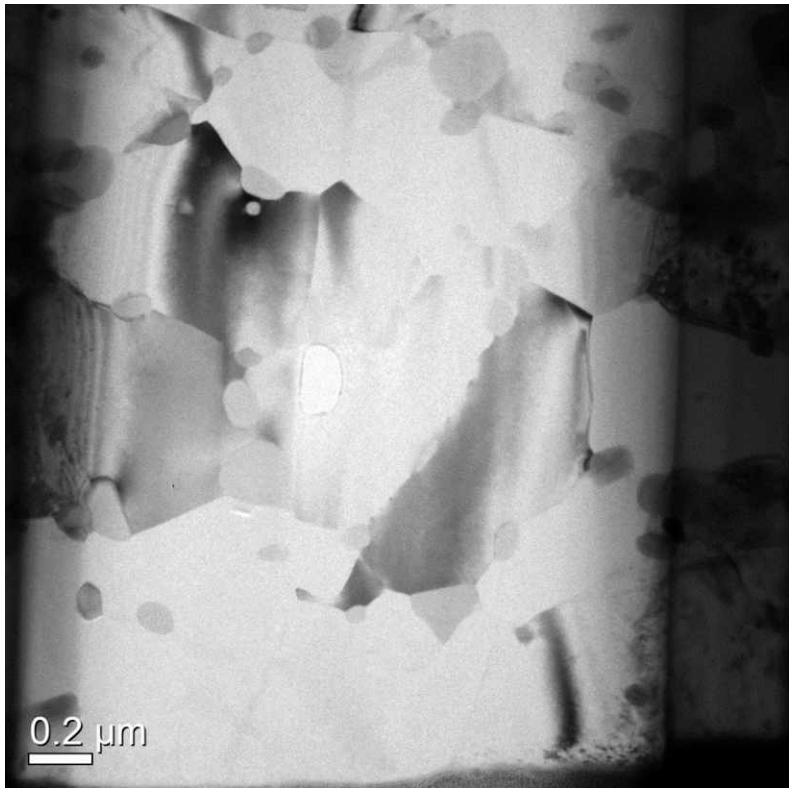


BF image

Crept parent material - 17 hours, 120MPa, 250^{0}C



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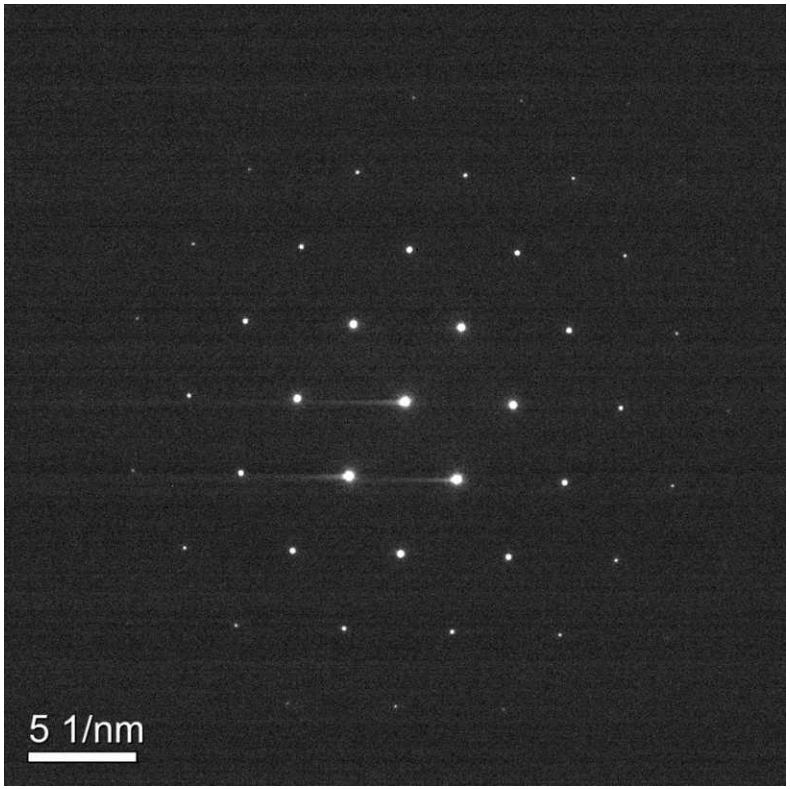

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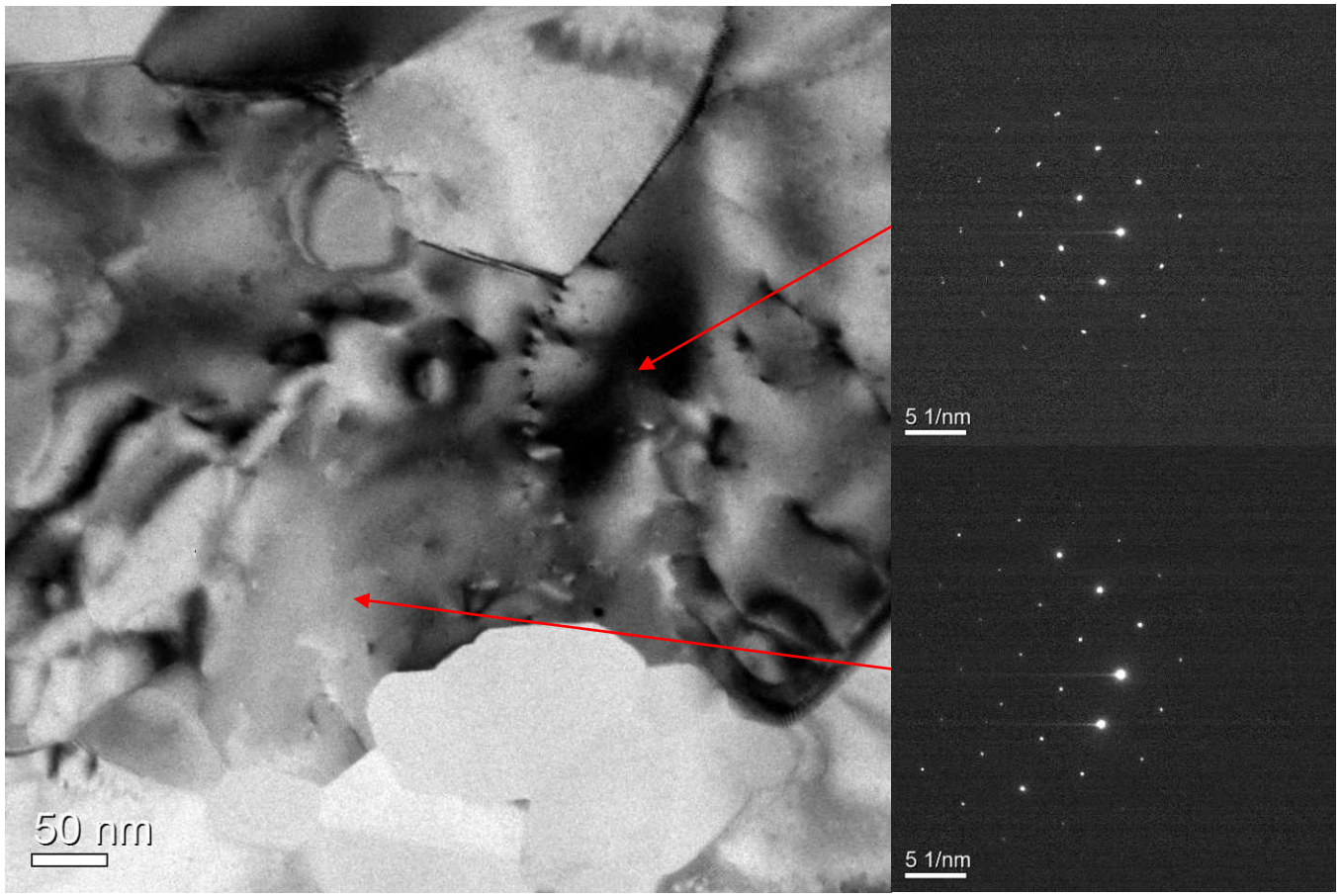
Crept parent material - 17 hours, 120MPa, 250^{0}C



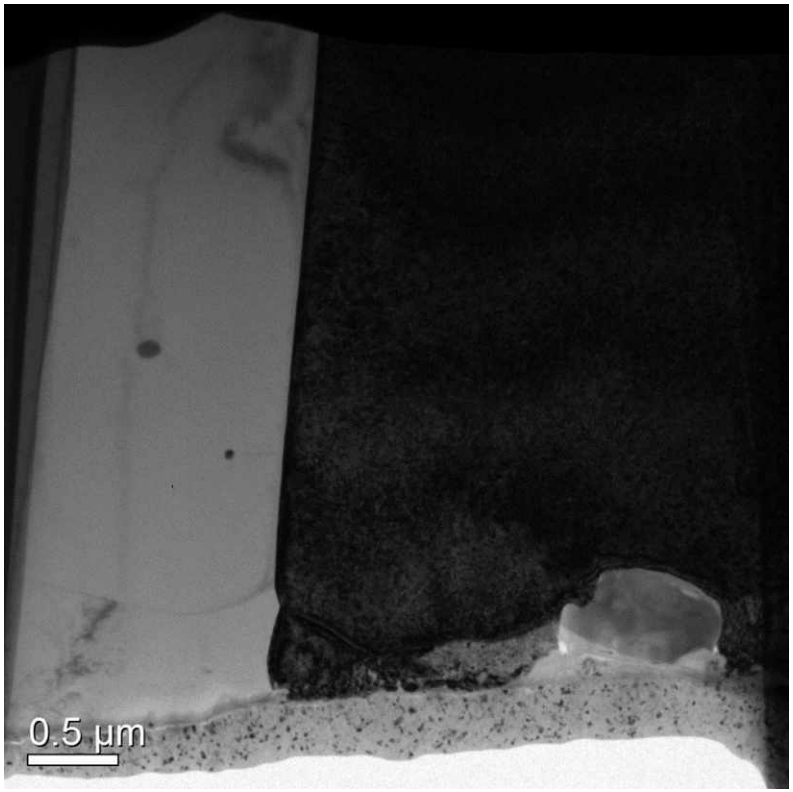
<011>

z.a.

<011>

z.a.

FSW – as welded



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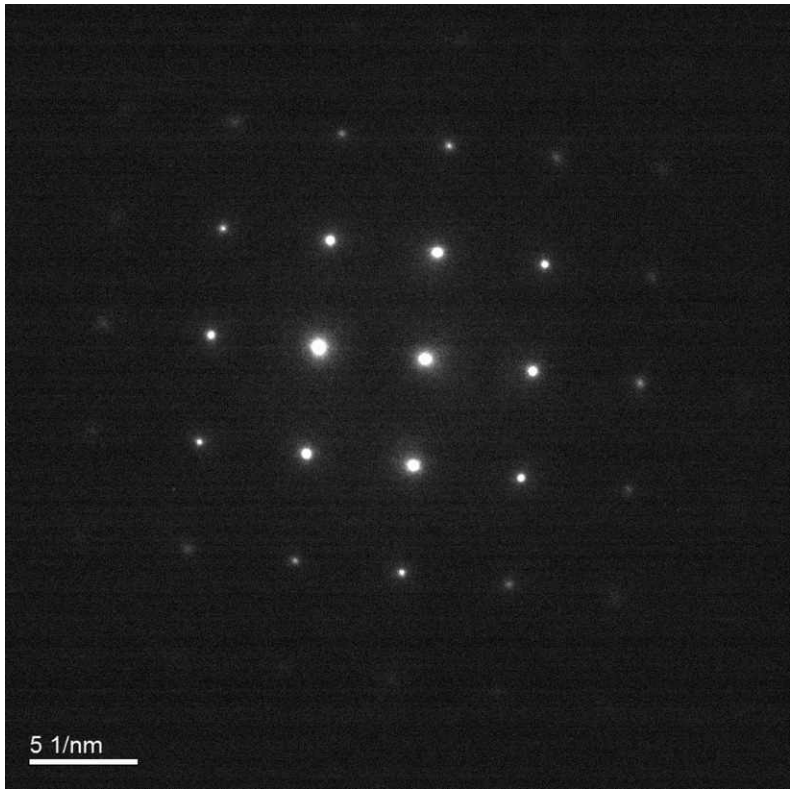

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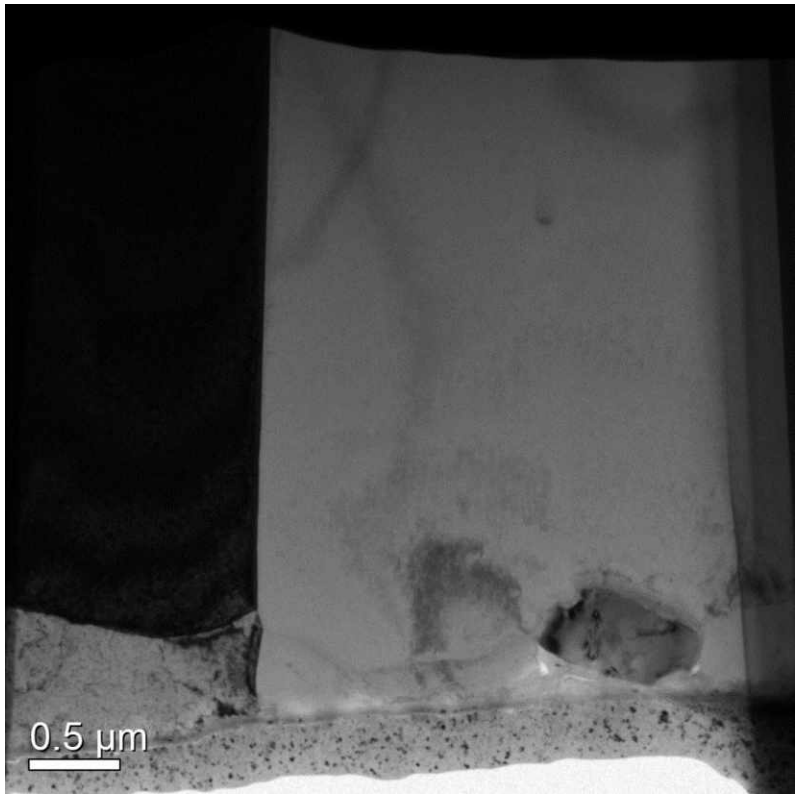
FSW – as welded



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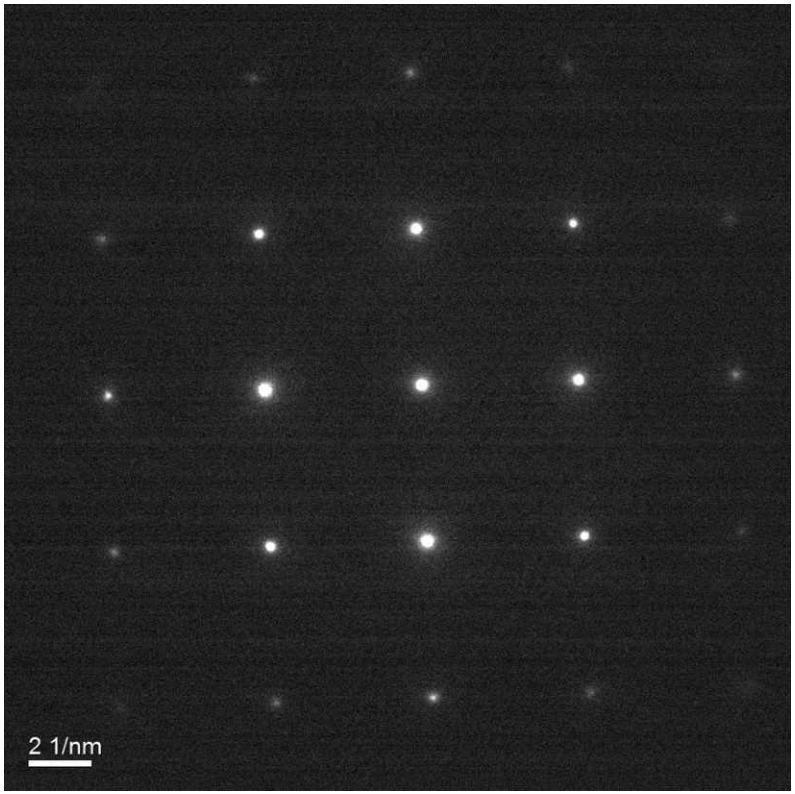

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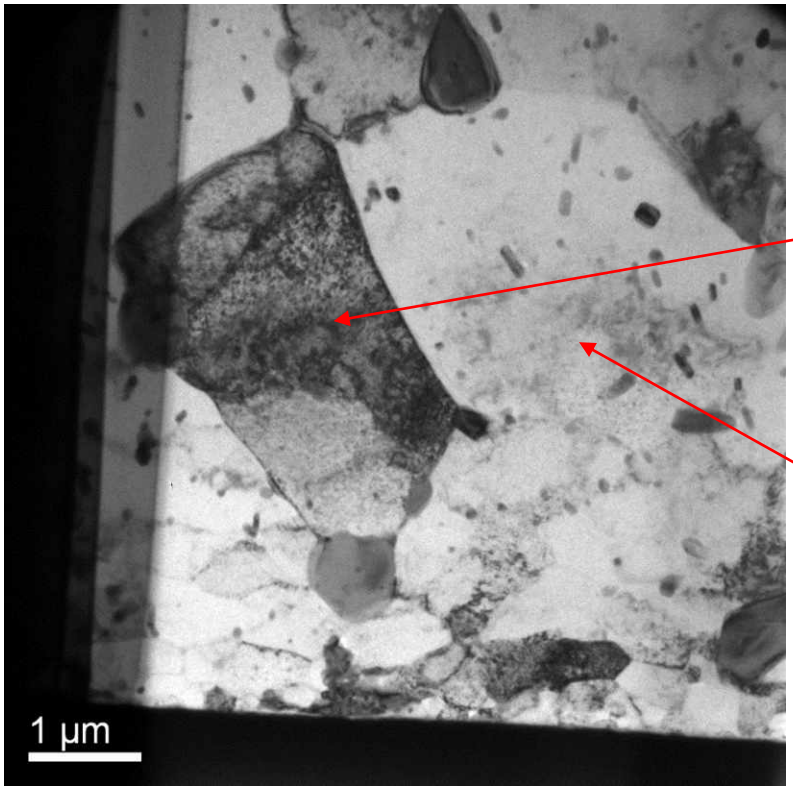
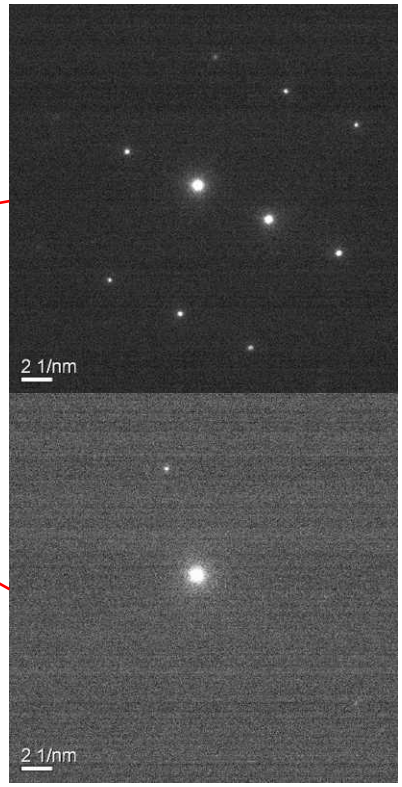
Crept FSW material - 139 hours, 10MPa, 315^{0}C



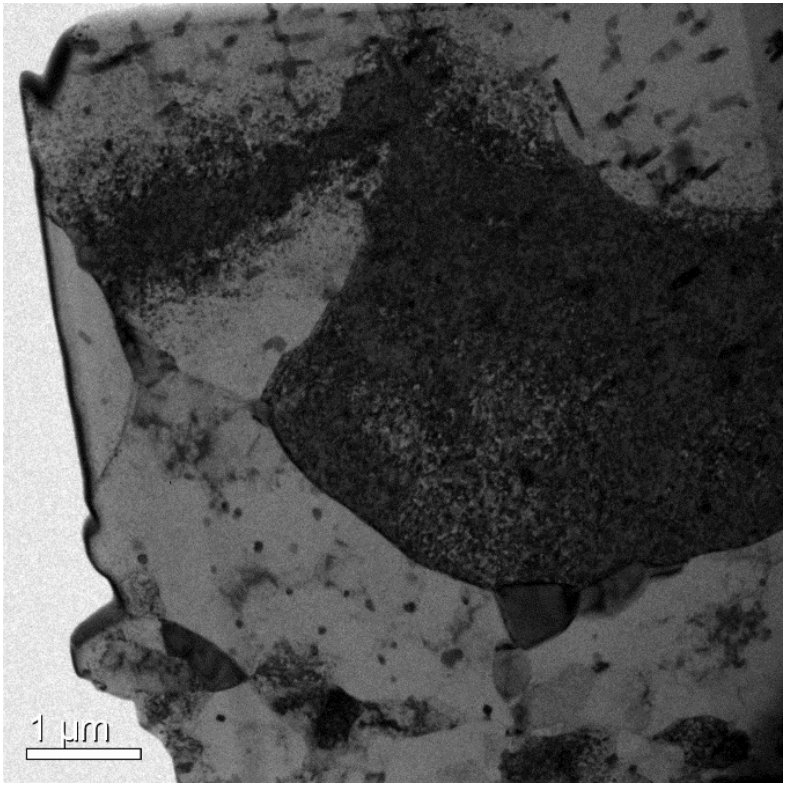


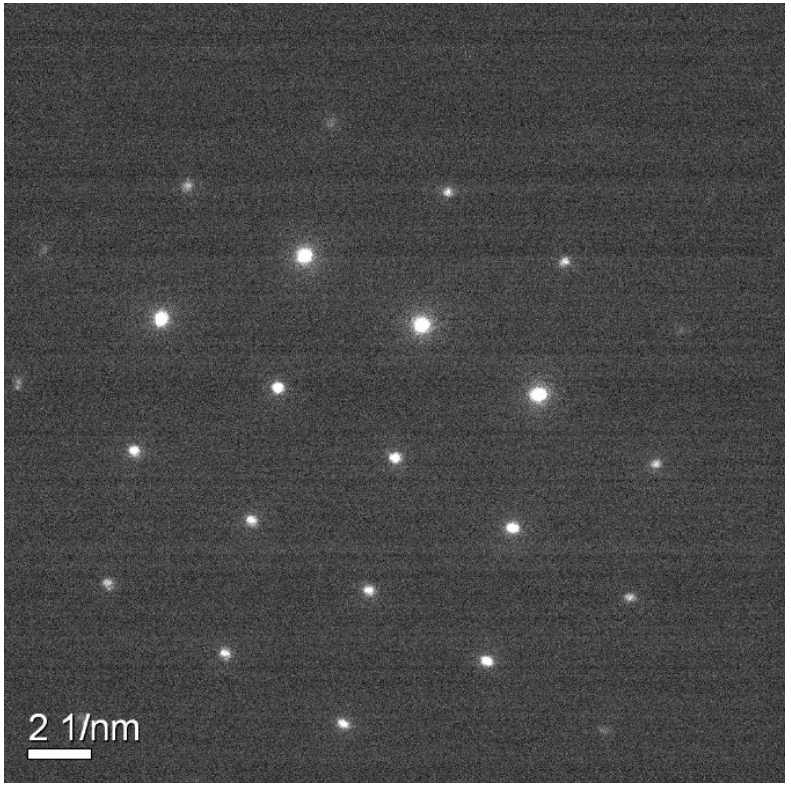
<013>

z.a.

BF image

Crept FSW material - 139 hours, 10MPa, 315^{0}C





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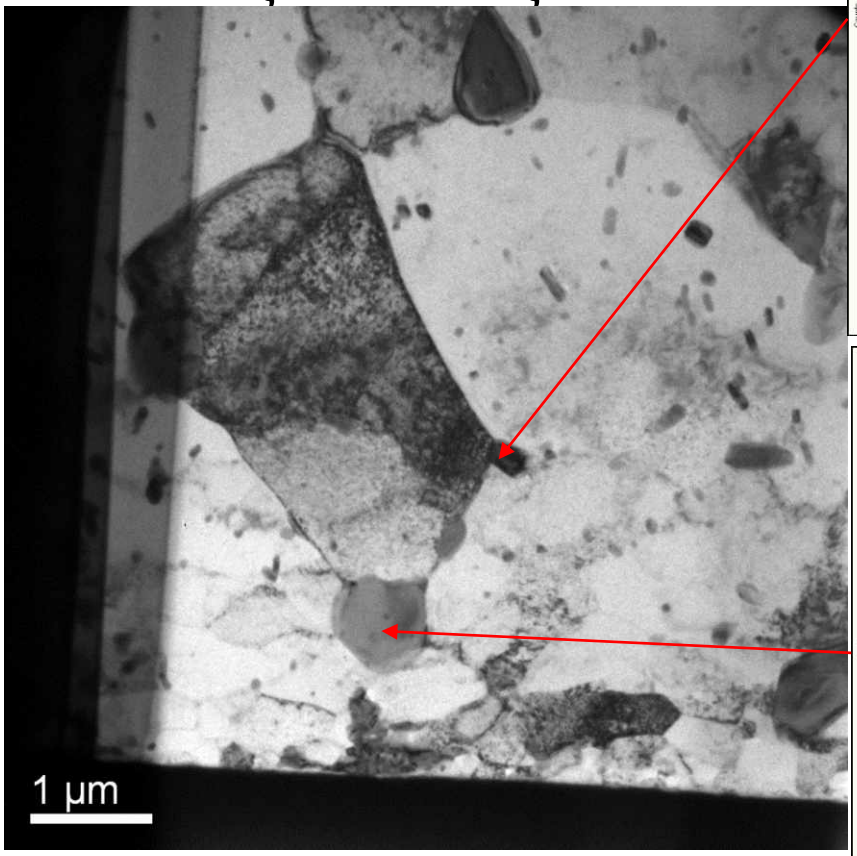
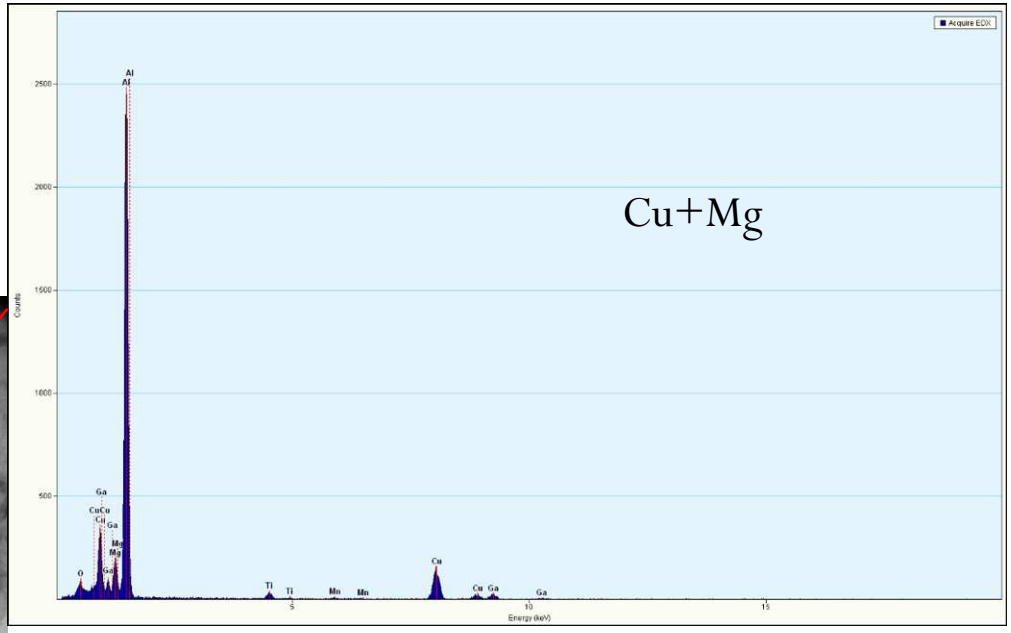
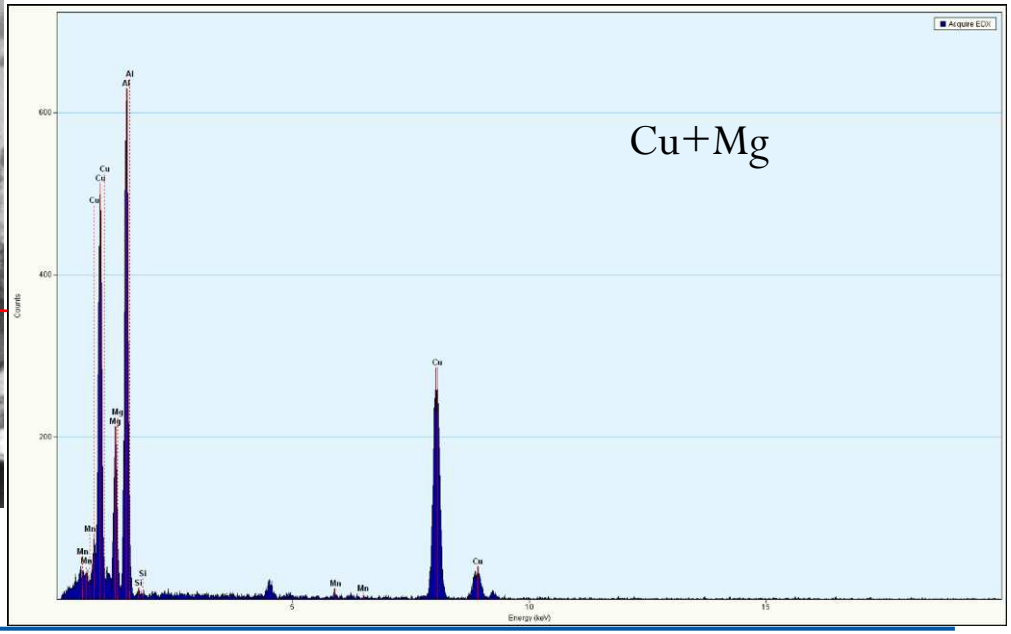
<011> z.a.

Precipitate analysis - crept FSW material 139hrs, 10MPa, 315^{0}C







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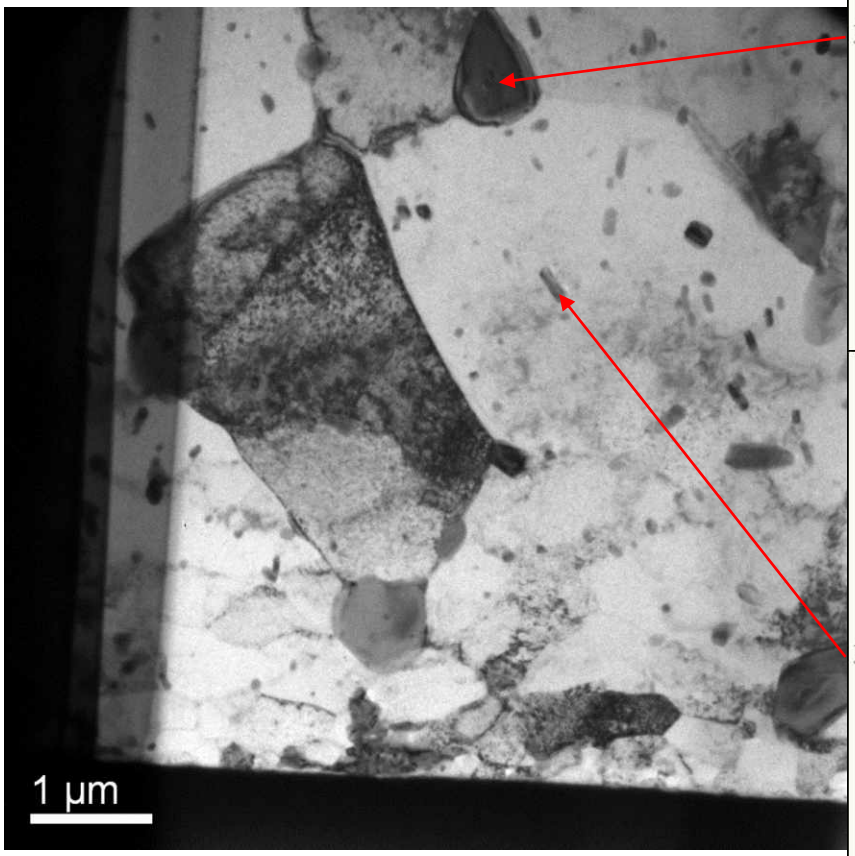
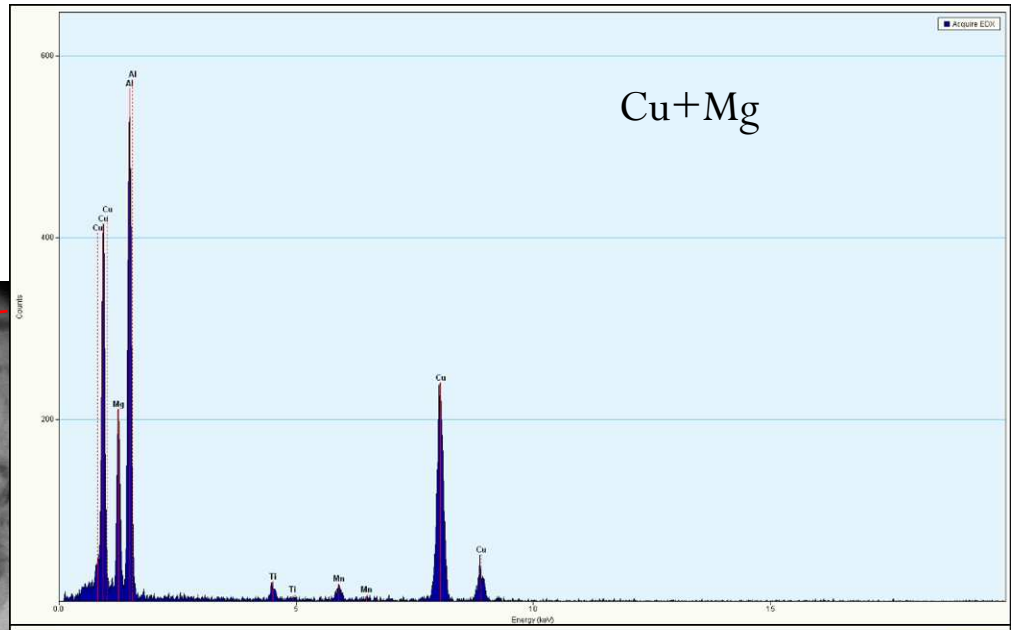
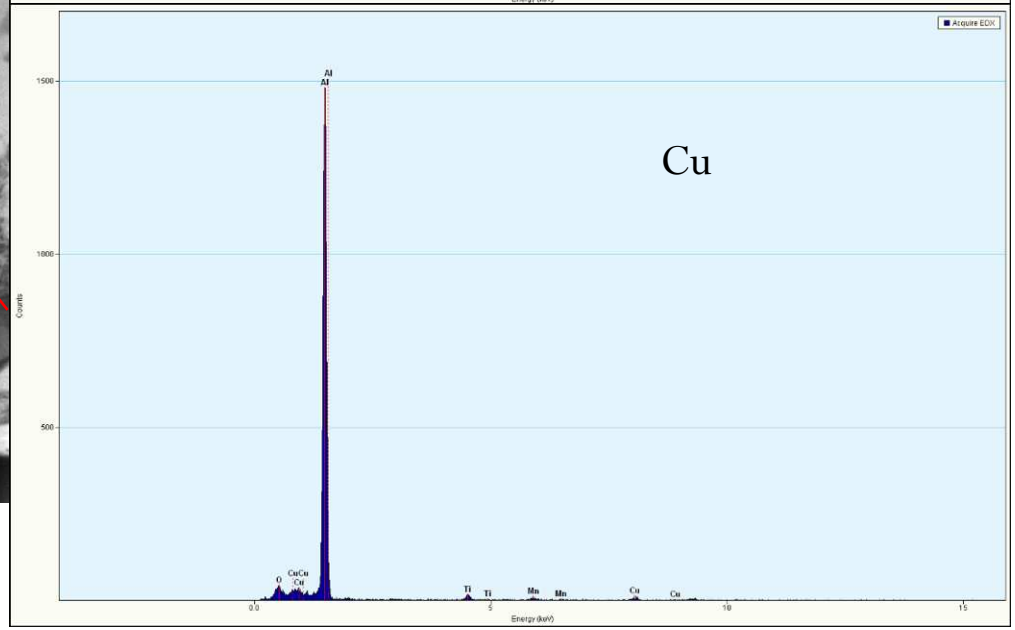
Crept FSW material
139hrs, 10MPa, 315^{0}C







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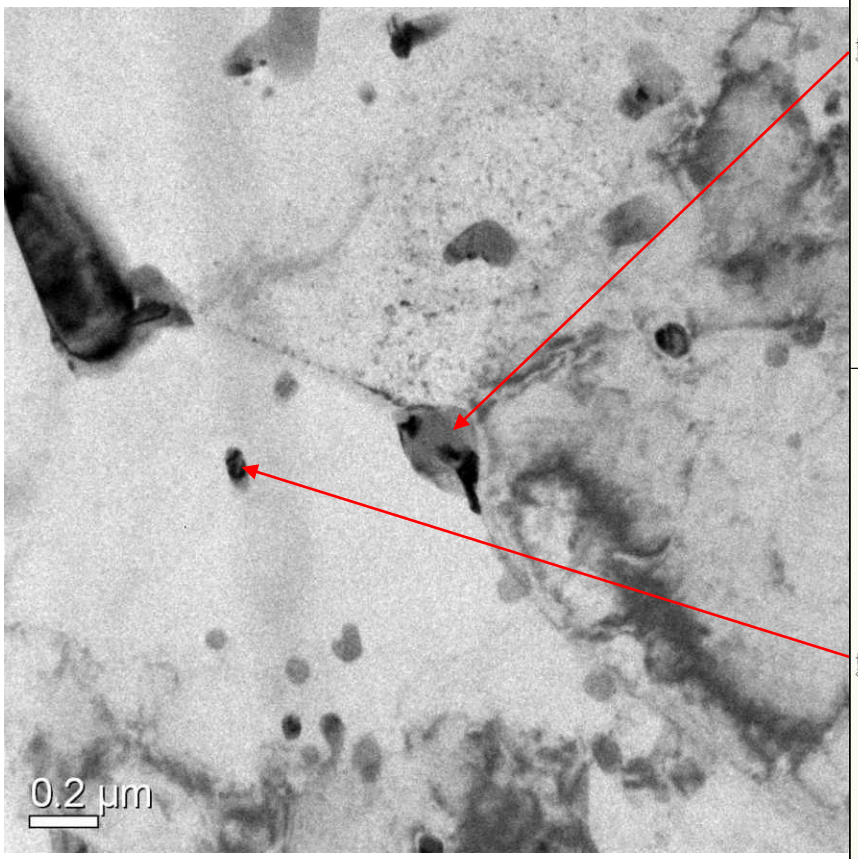
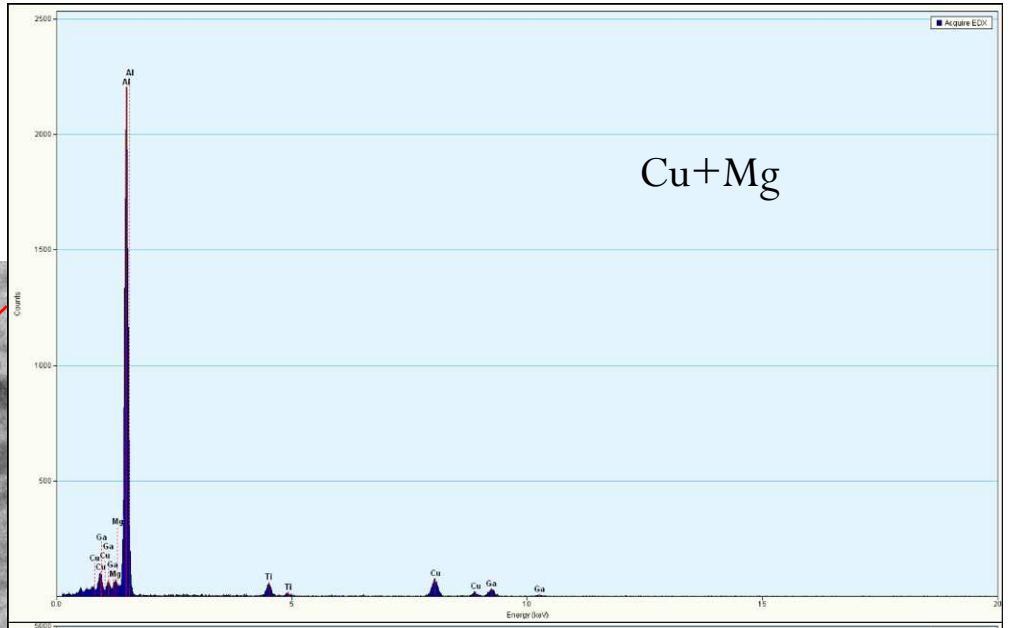
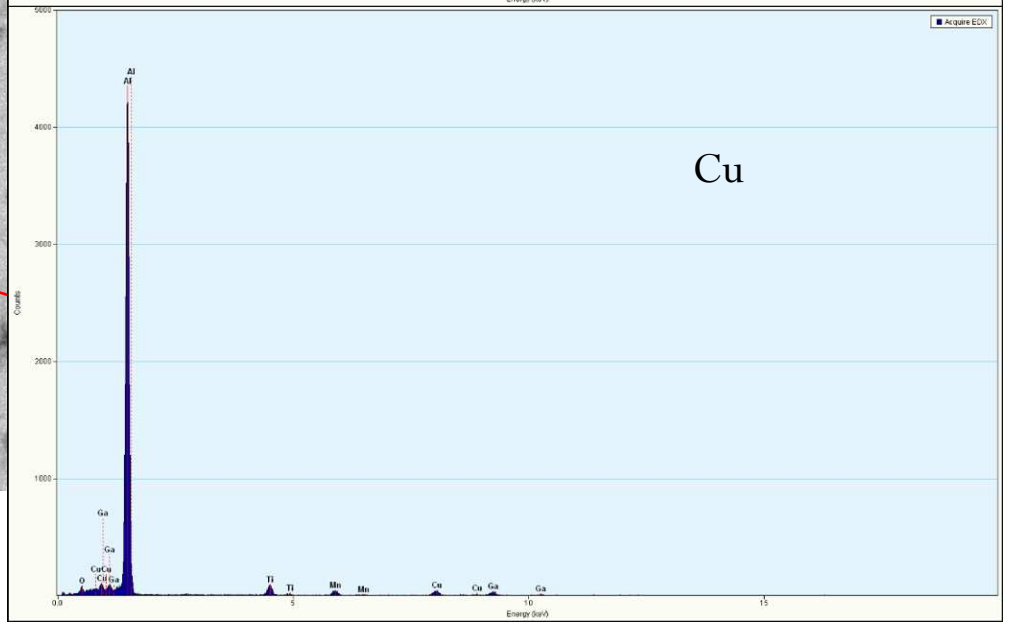
Crept FSW material
139hrs, 10MPa, 315^{0}C







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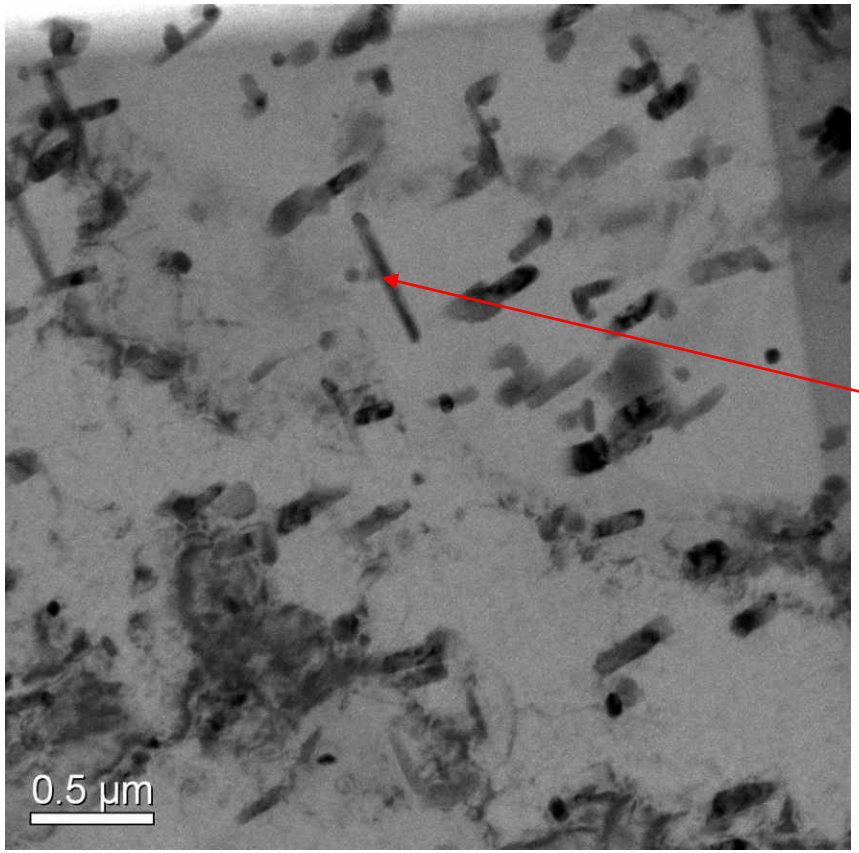
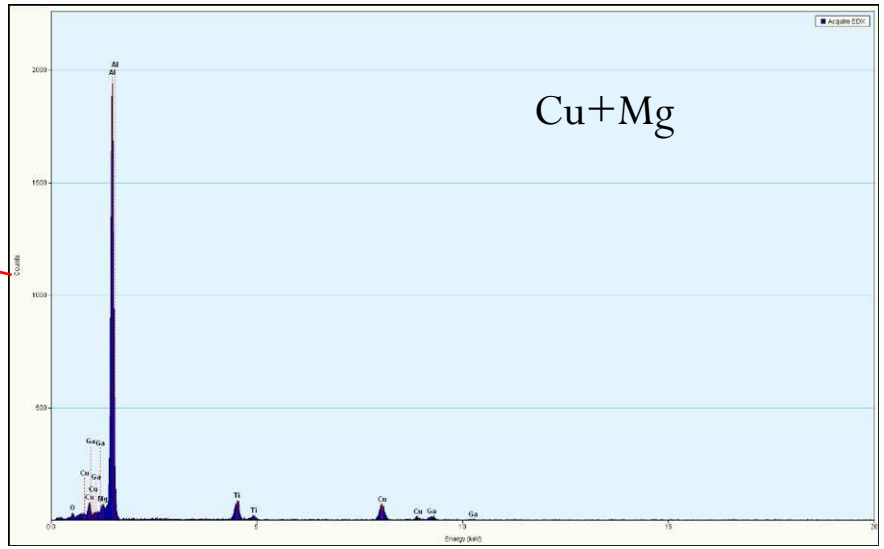
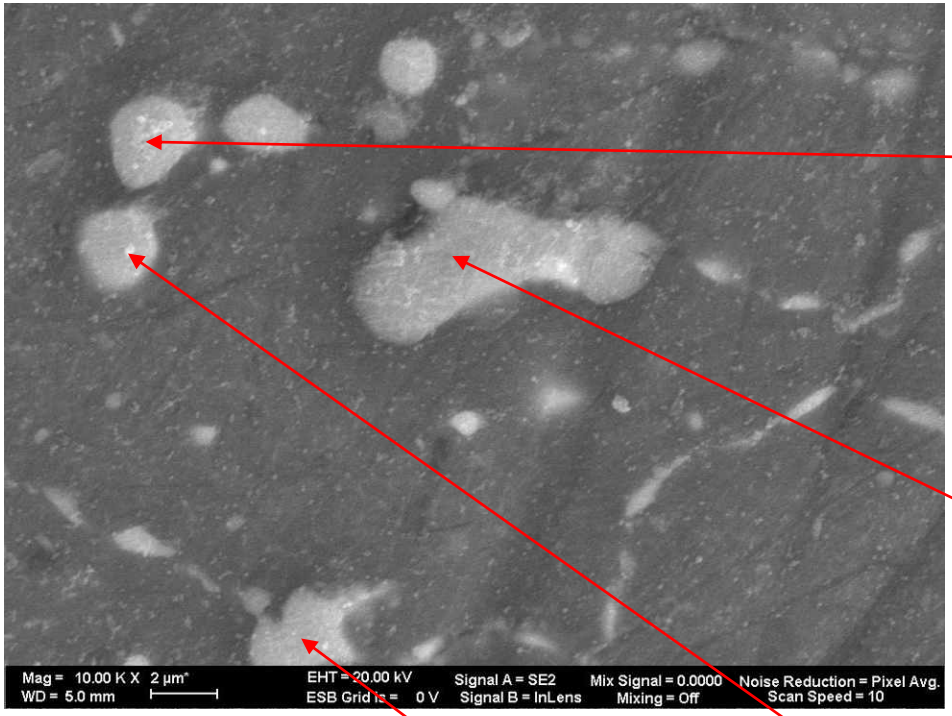
Crept FSW material

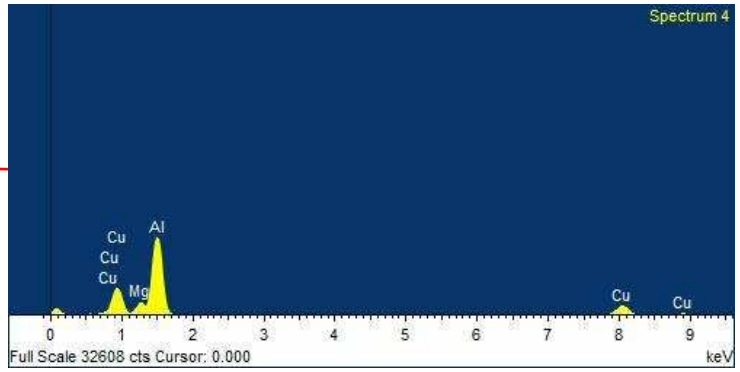
139hrs, 10MPa, 315^{0}C

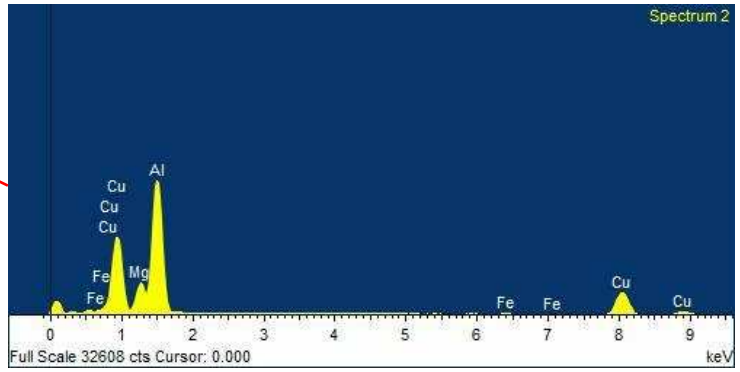


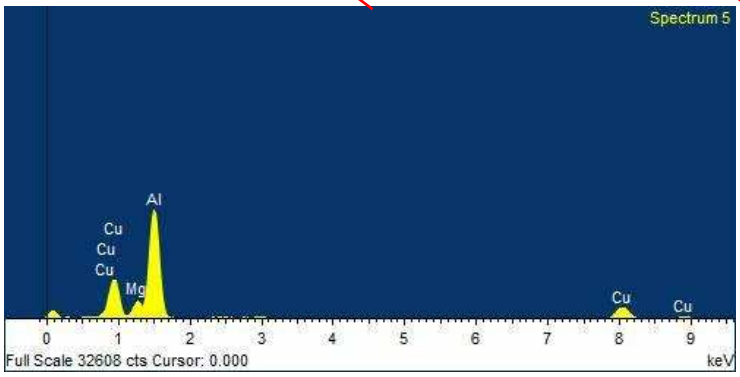


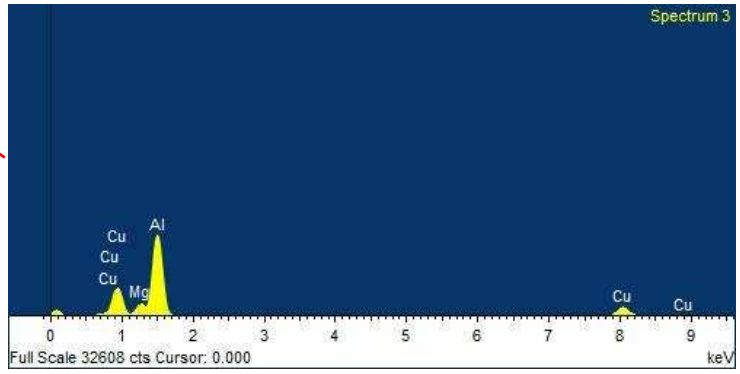
Aged 280hrs @ 300^{0}C











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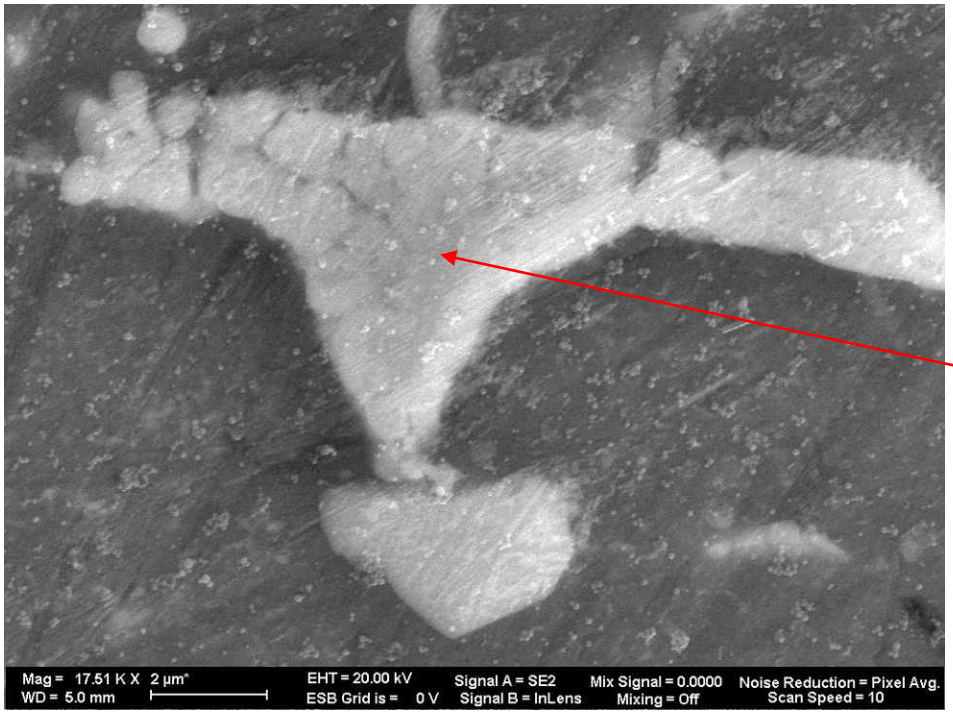
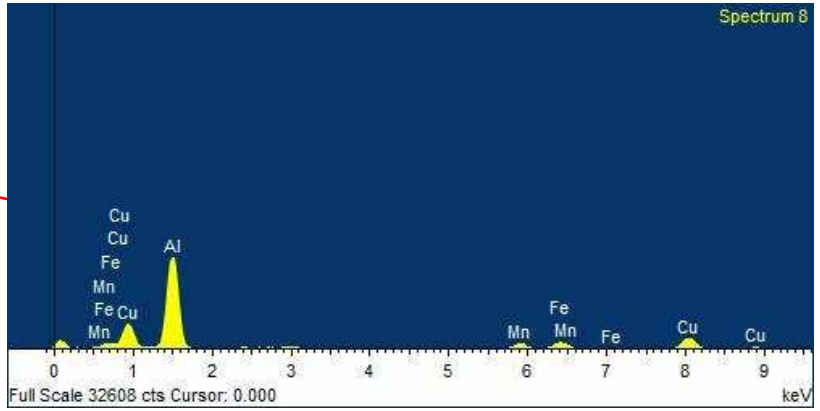
Aged 280hrs @ 300^{0}C





Discussion

- The stress exponent points at dislocation creep
- The dislocation density and networks observed at the parent AA2024-T3 metal as well as the dislocation free grains at the welded nugget point at DRX occurring due to heavy plastic deformation during FSW, this is in line with optical microscopy
- The appearance of ultrafine grains at the crept material can be related to DRX
- Subgrains do not disappear during creep of the parent material

- AA2024 was introduced in 1931 (Alcoa SPD-10-036), is there anything left to study about its microstructure?
- The answer is YES!
- T ($Al_{20}Cu_2Mn_3$) Wang and Starink, *Int. Mater. Rev.*, **50**, 193-215, (2005)

Phase	Crystal structure	Lattice parameter (Å)
$Al_{12}(Fe,Mn)3Si$	Im3	a = 12.6
Al_7Cu_2Fe	P4/mnc (tetragonal)	a = 6.32, c = 14.76
Mg_2Si (β)	Fm-3m	a = 6.34
Al_2Cu (θ)	I4/mcm (tetragonal)	a = 6.03, c = 4.86
AlFeMgSi	P6/mmm (hex)	a = 6.62, c = 14.63
$CuMgAl_2$ (S)	Cmcm	a = 3.93, b = 9.42, c = 7.16
Al (α)	Fm-3m	a = 4.01

Zhang et al., *Acta Mater.*, **111**, 385-398, (2016)

- The θ aging sequence:

$$\alpha(ssss) \rightarrow GP\ zones \rightarrow \theta''(Al_3Cu) \rightarrow \theta'(Al_2Cu) \rightarrow \theta(Al_2Cu)$$

- The S aging sequence:

$$\alpha(ssss) \rightarrow GPB\ zones \rightarrow S''(Al_2CuMg) \rightarrow S'(Al_2CuMg) \rightarrow S(Al_2CuMg)$$

- The chemical composition of the precipitates together with their morphology are in line with reports on S (Al_2CuMg) and θ (Al_2Cu) precipitates

Conclusions

- The AA2024-T3 alloy undergoes precipitation process during exposure to creep temperatures
- The material undergoes DRX during the FSW
- The parent metal undergoes DRX during creep, precipitation processes occur as well
- The friction stir welded material, which has already recrystallized during welding, undergoes the same processes so that ultra-fine grains are being created concurrently

- Other microstructural changes of the friction stir welded AA2024-T3 such as grain coarsening are still under investigation
- Complexity arising from the material being both friction stir welded and unstable

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