AEROSPACE TECHNOLOGY CONGRESS 2019
SUSTAINABLE AEROSPACE INNOVATION IN A GLOBALISED WORLD
FT2019

Selective laser melting of Alloy 718

Heat affected zone cracking in different heat-treated conditions of selective laser melted Alloy 718 subjected to gas tungsten arc welding

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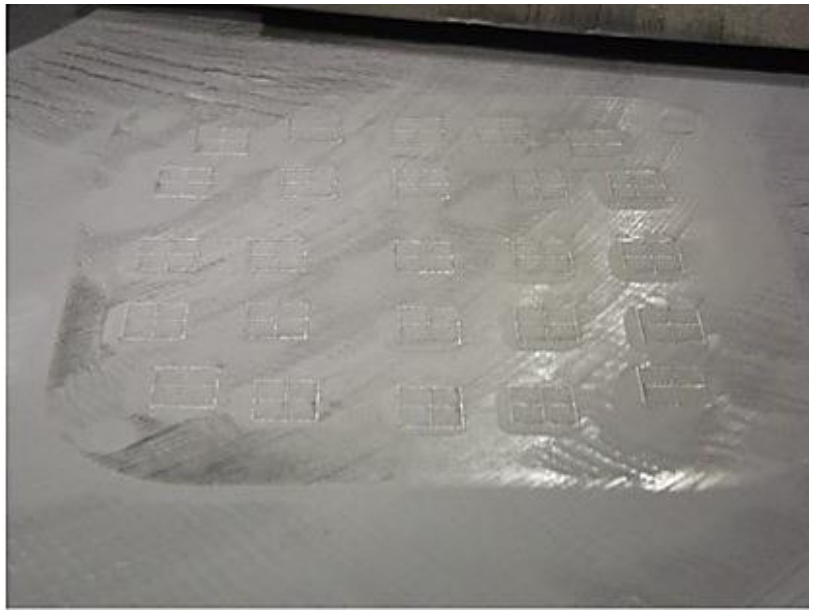
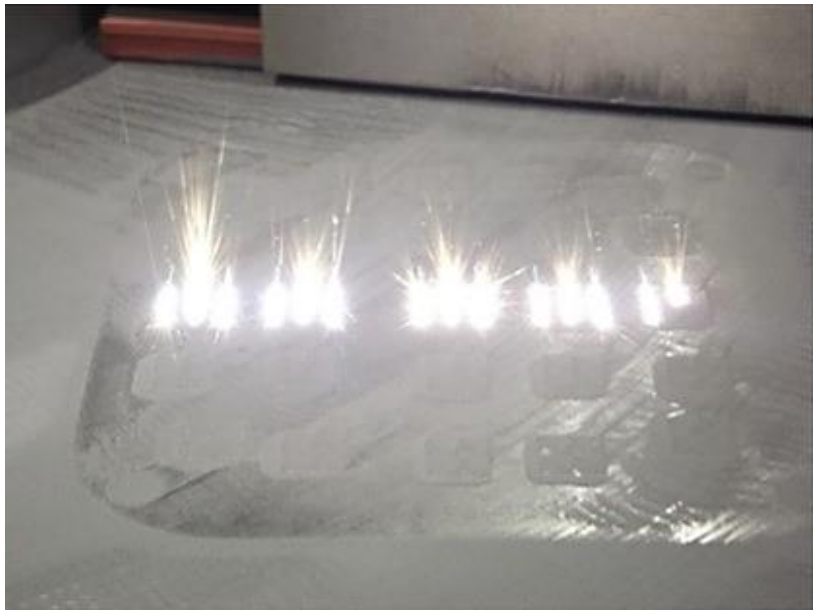
TWI

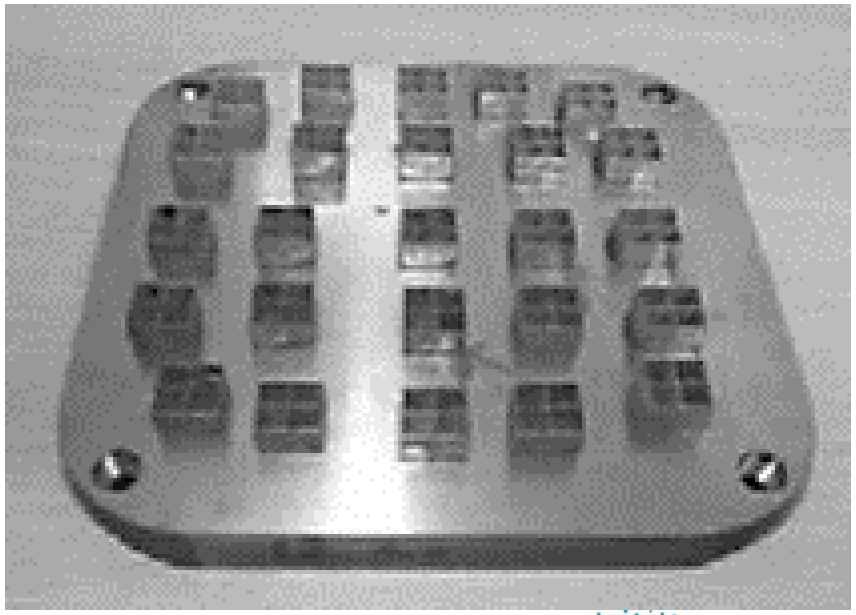
Oct 2019

Selective laser melting process

SLM/ DMLS/ Laser Cusing: Additive manufacturing powder-bed process:
3D CAD data > Laser beam > Fuse metal powders > 3D metal parts







https://www.twi-global.com/capabilities/joining-technologies/additive-manufacturing//

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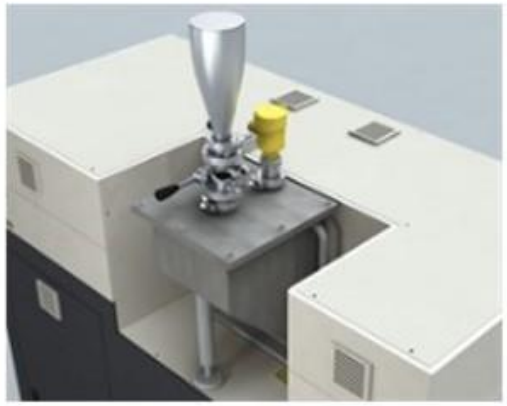
Selective laser melting (SLM) process

1. Loading powder

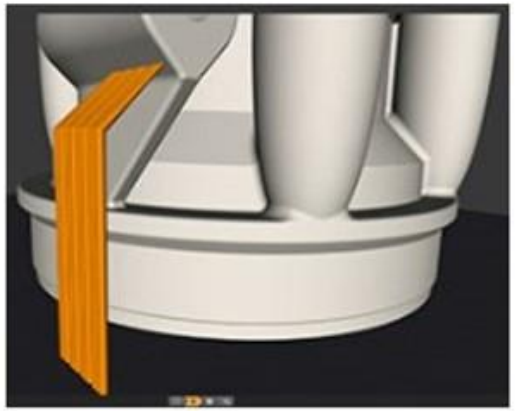


Loading metal powder before and during build.

2. Build plate loaded

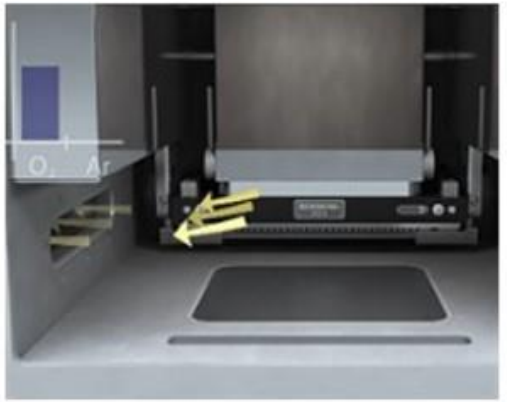
Build plate is loaded into the system chamber and secured.

3. Build preparation



Offline build preparation file is exported to the additive manufacturing system.

4. Remove air



Build chamber is prepared with vacuum removal of air.

[http://www.renishaw.com/en/our-technology—27362]

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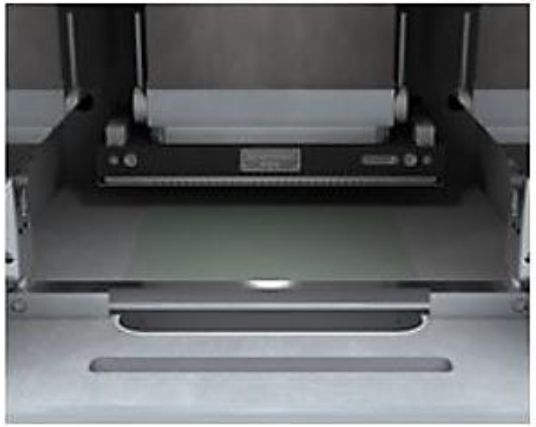
Selective laser melting (SLM) process

5. Inert gas

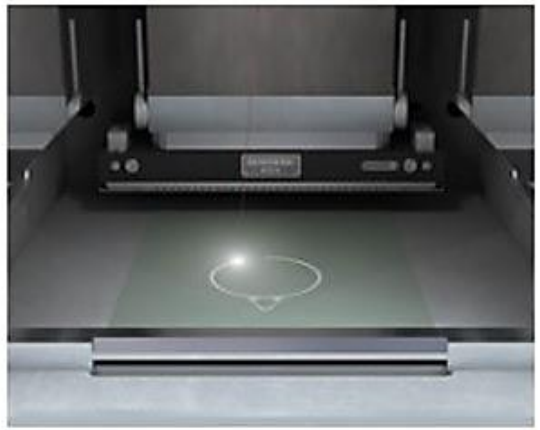
Chamber is filled with argon inert gas - class leading low gas consumption.

6. Powder delivery



Layer of metal powder is delivered.

7. Laser melting



Laser melting using a fibre laser.

8. Building in layers

Build plate moves down and next layer is built up.

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Alloy 718

Ni	Cr	Fe	Nb	Mo	Ti	Mn	C	Al	Co
Bal.	19	18	5	3	0.90	0.04	0.05	0.48	0.08
Si	N	Cu	B	Ca	Mg	P	S	Se	
0.04	0.02	0.02	<0.006 (ppm)	<0.010 (ppm)	<0.010 (ppm)	0.015 (ppm)	<0.010 (ppm)	<0.001 (ppm)	

Chemical composition, wt %

- Fe-Ni based superalloy
- Applications: Nuclear, aerospace, oil and gas industry
- Excellent creep properties, oxidation resistance and hot corrosion resistance
- FCC (g) gamma matrix
  - γ'' (Ni3Nb)
  - γ' [Ni3(Al, Ti)]
  - δ-phase (Ni3Nb)
  - Laves phase [(Ni, Fe, Cr)2(Nb, Mo, Ti)]
  - Metal carbides and nitrides: NbC, TiC, and TiN.

Sims CT, Stoloff NS, Hagel WC. Superalloys II: New York: Wiley-Inter science; Hoboken, NJ, USA, 1987
R. Reed. The Superalloys, Fundamentals and Applications. Cambridge, UK: Cambridge University Press. 2006.
Geddes et al. Superalloys: Alloying and Performance. Materials Park, OH: ASM International. 2010.

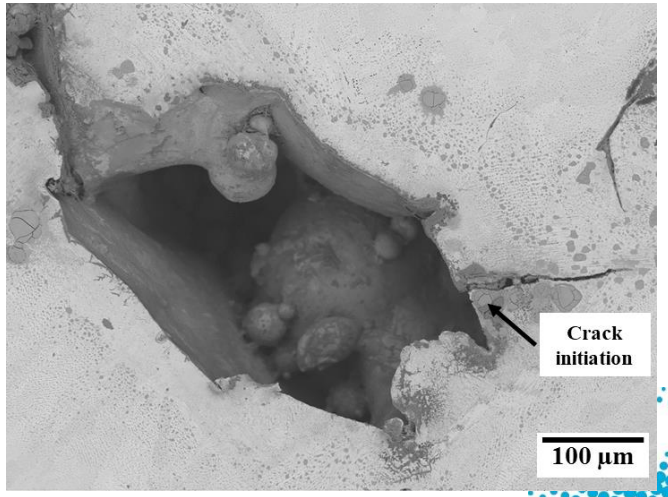
Possibilities and challenges with SLM

Possibilities

- Capability to produce complex geometries
- Low-volume fabrication of expensive components
- Individually customized products
- Minimum waste of material > unmelt powder can be sieved and reused

Challenges

- Quality and repeatability of SLM manufactured parts is not good enough
  - Porosities (gas porosity, shrinkage porosity)
  - Lack of fusion
  - Cracks
  - Residual stresses



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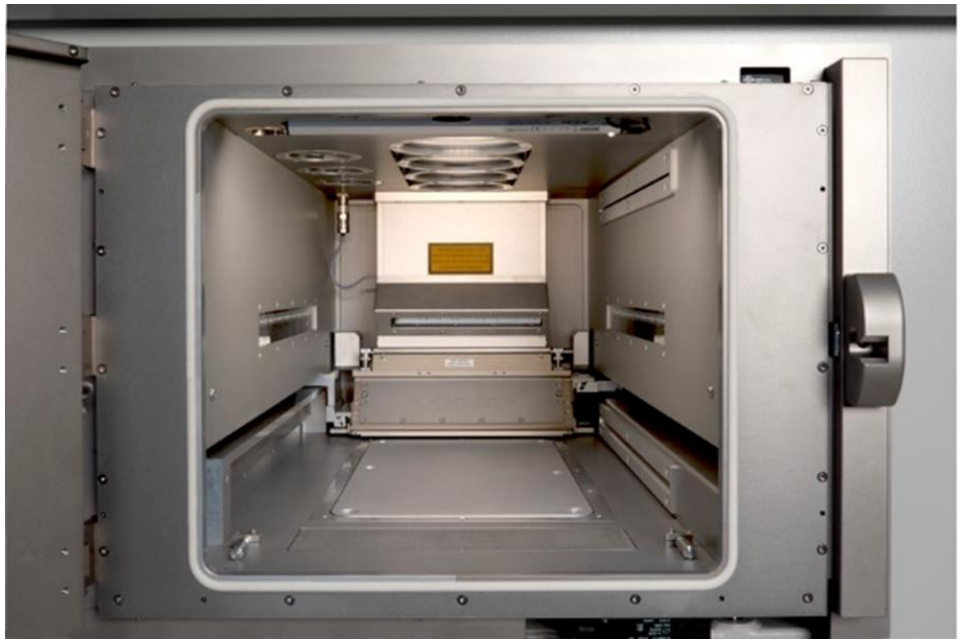
Weldability of SLM-manufactured Alloy 718

- Limited size of SLM manufactured parts due to the size of building chamber

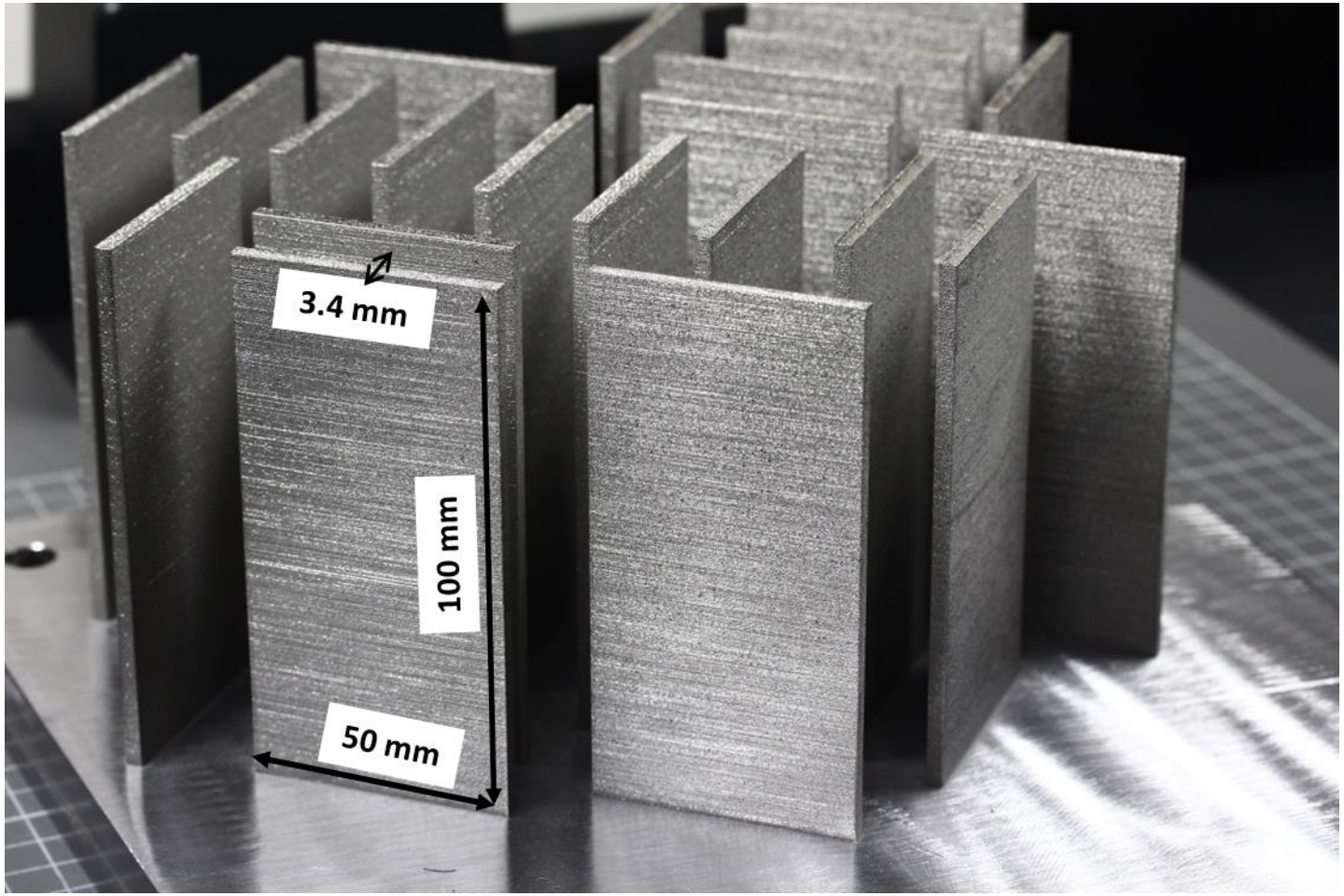


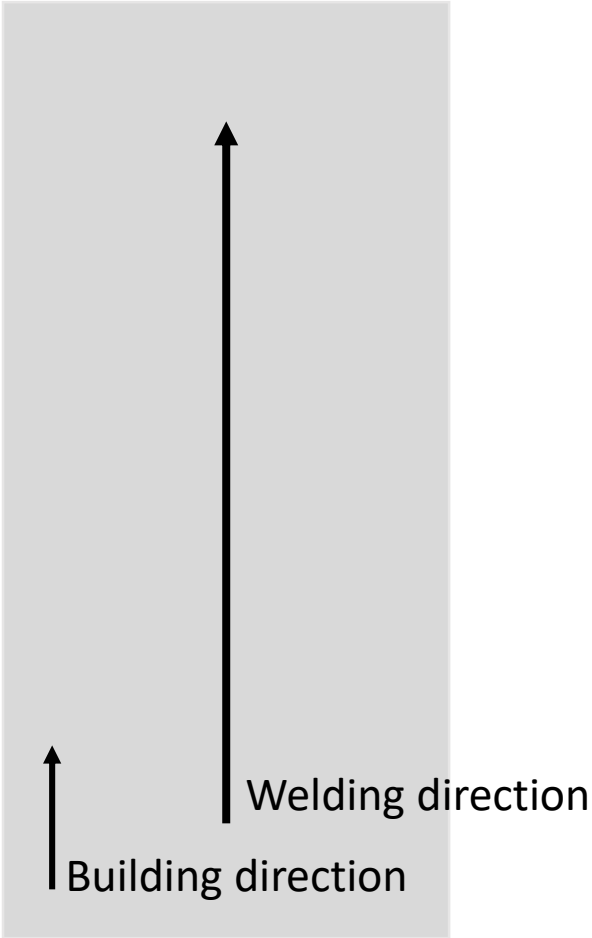
- Aim of the study:

Investigate the **SLM-manufactured Alloy 718** susceptibility towards hot cracking during **gas tungsten arc welding** in various **heat-treated conditions**.

Wrought Alloy 718 was used as the reference material.

Samples produced with SLM process

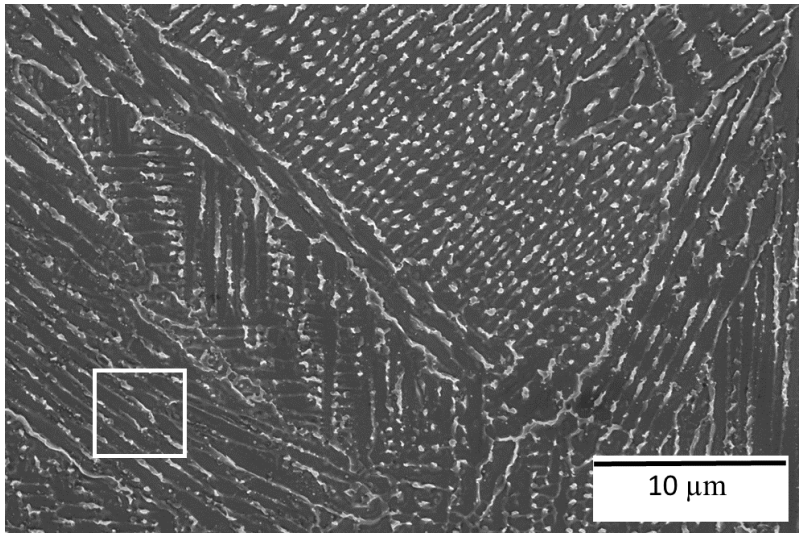


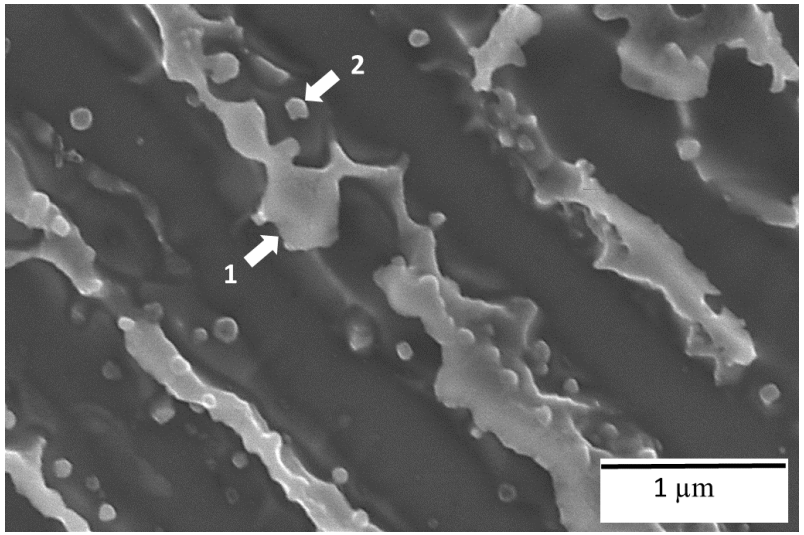


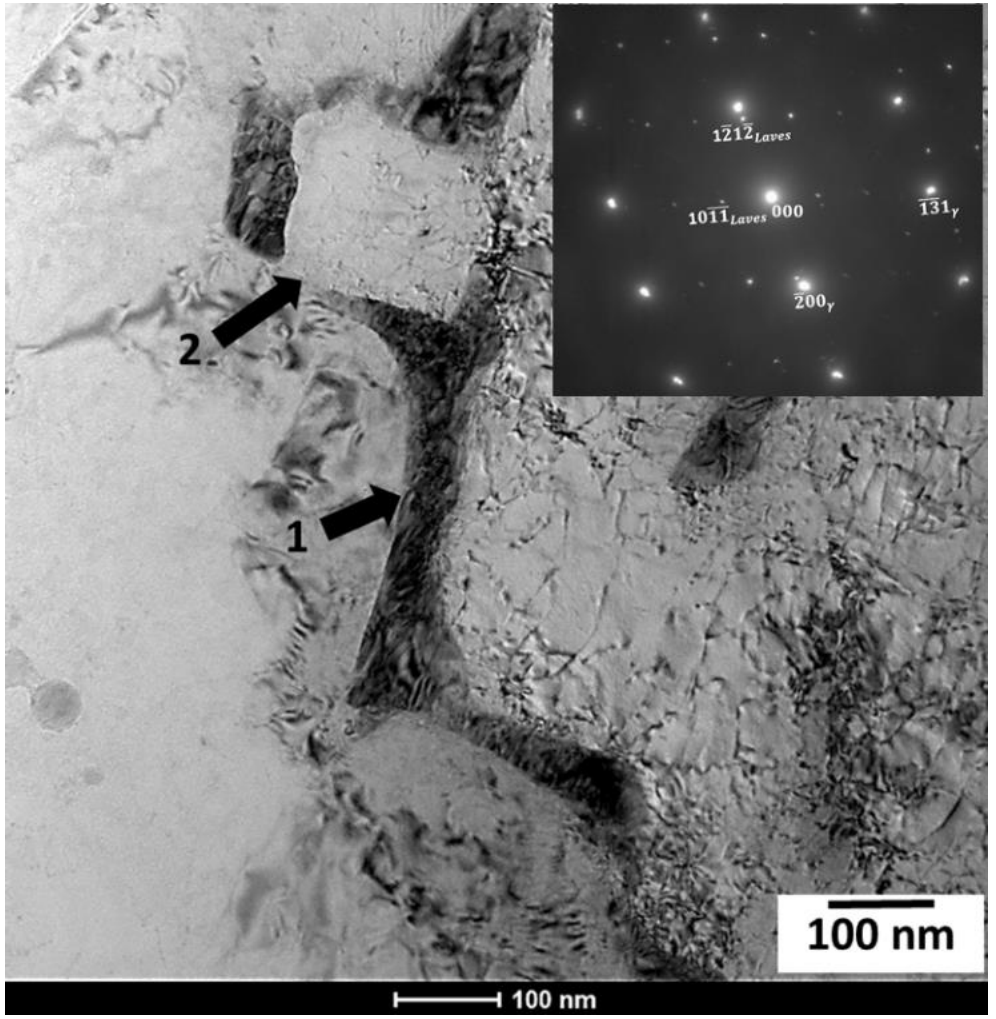
Heat treatments

Material condition	Specification
As-built	SLM-manufactured without any heat treatment
Solution + Aging (SHT+AGED)	954 °C for 1 h + 760°C - 5hrs + 649°C - 1hr
HIP	1160°C – 105 MPa – 4hr
Mill-annealed (Wrought)	982°C - 4.5min

SLM As-built Alloy 718

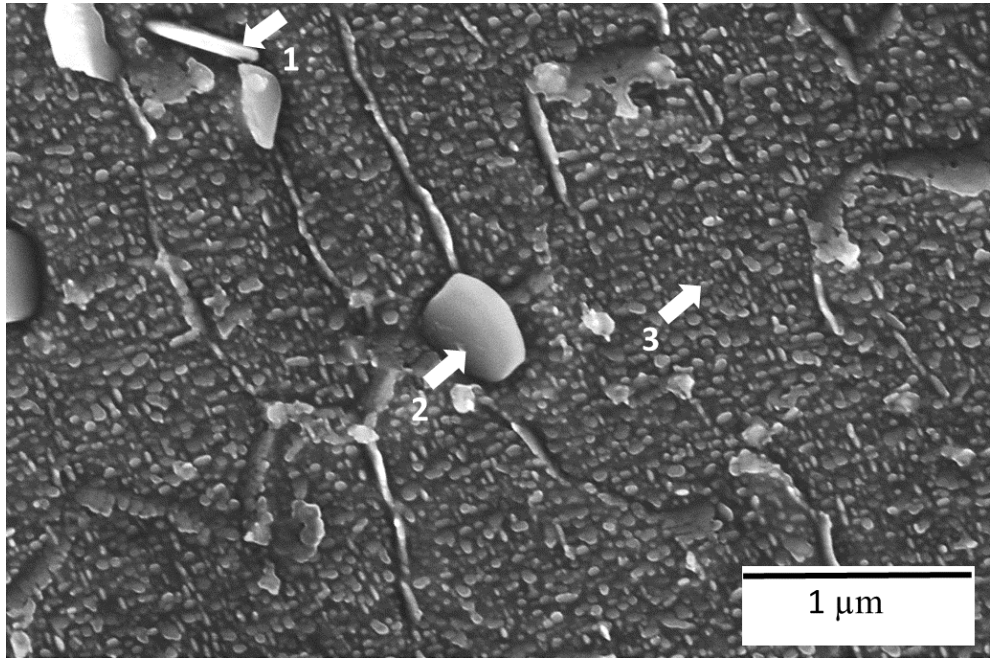


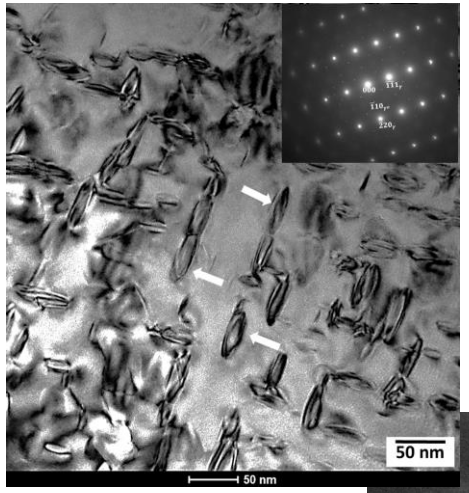


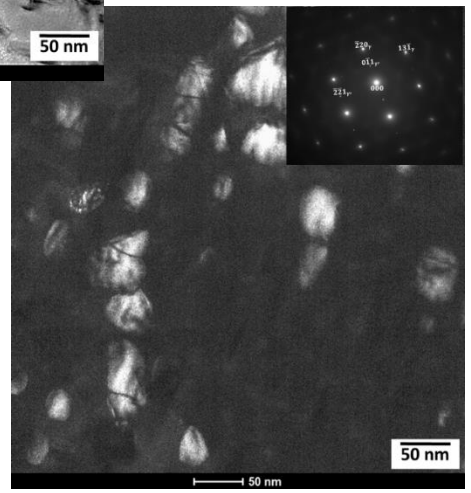


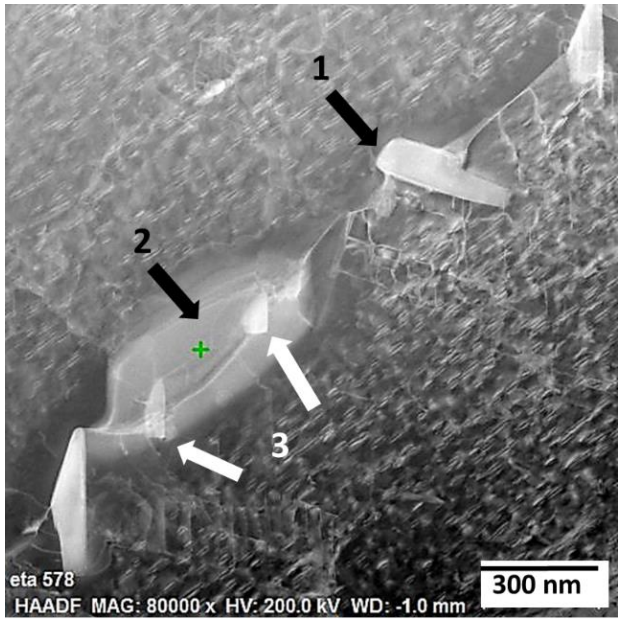
Interdendritic regions in as-built condition showing (1) Laves phase and (2) NbC carbide

Solution heat treated + Aged
954°C/ 1hr + 760°C/ 5hrs + 649°C/ 1hr





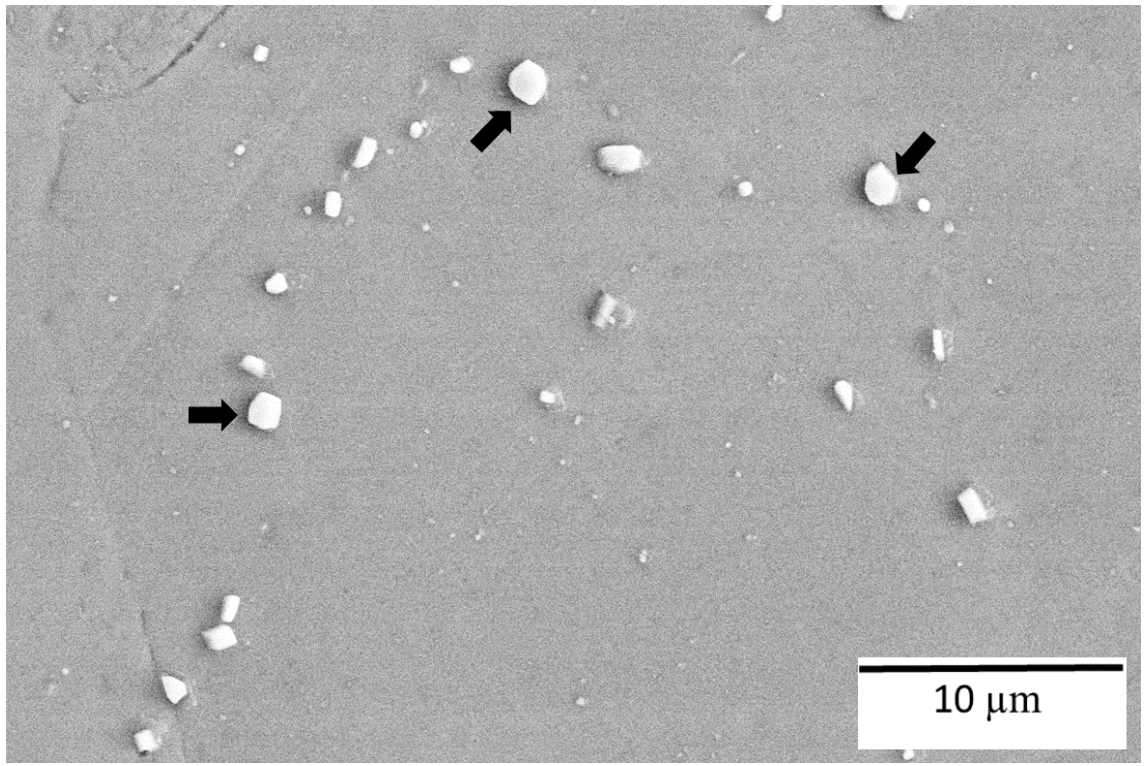




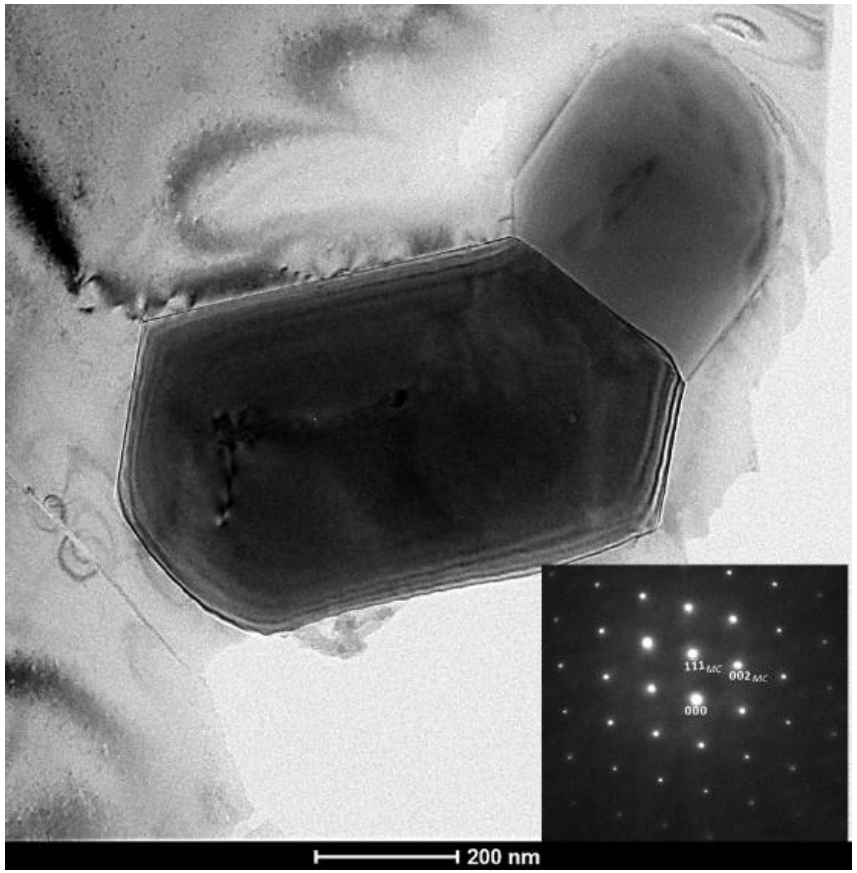
(1) δ-phase forming from the
(2) Laves phase

(1) Delta phase, (2) NbC carbide and (3) matrix with strengthening phases γ’ and γ’’

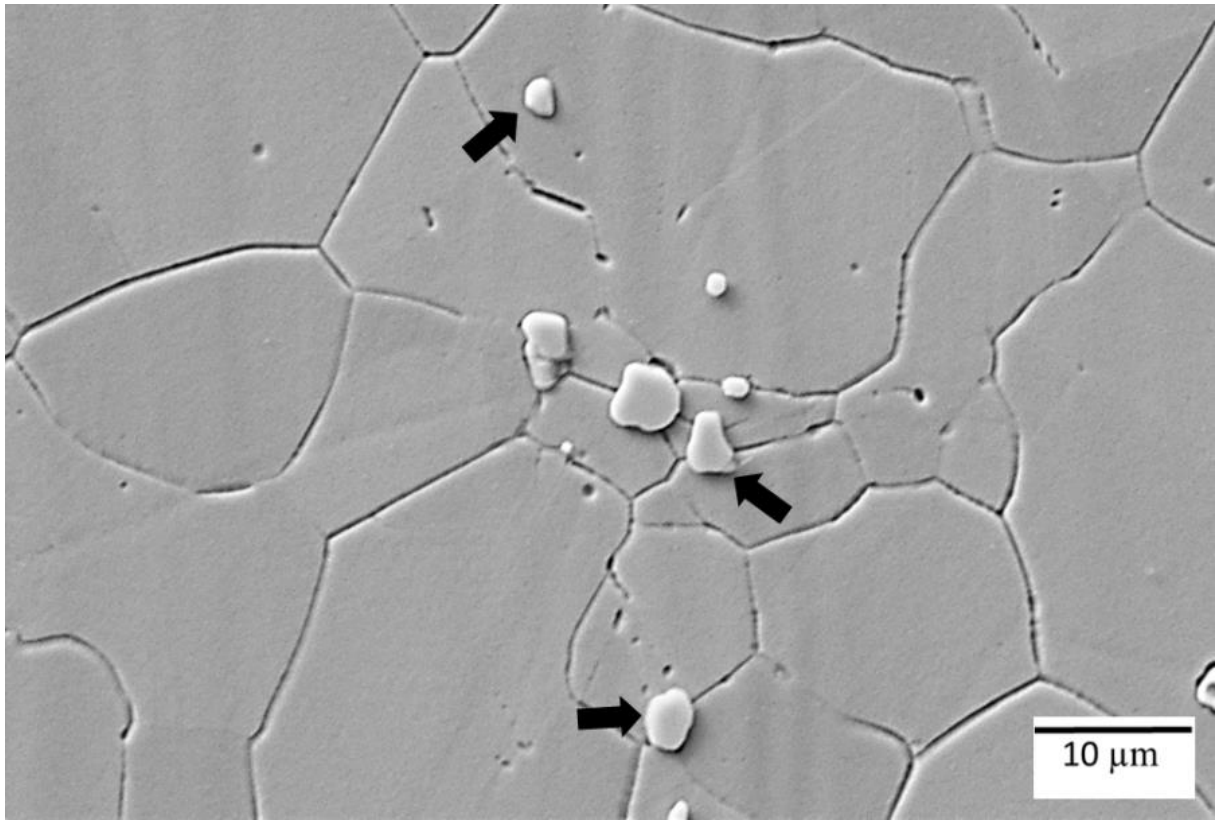
Hot isostatic pressed (HIP)
1160°C – 105 MPa – 4hr



NbC carbides in SLM HIP condition



Wrought
Mill-annealed at 982°C - 4.5min

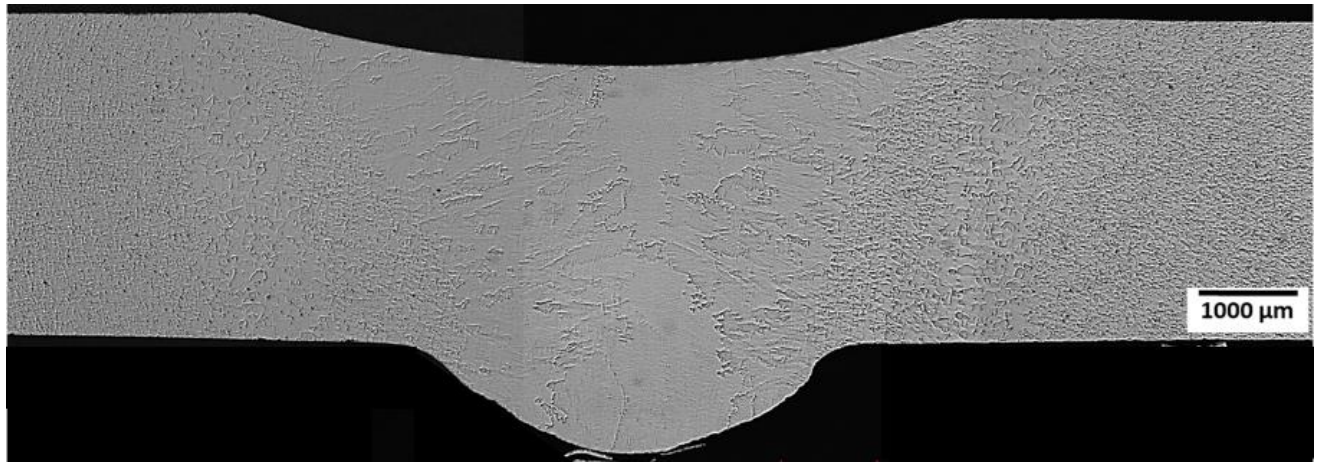


NbC carbides in wrought Alloy 718

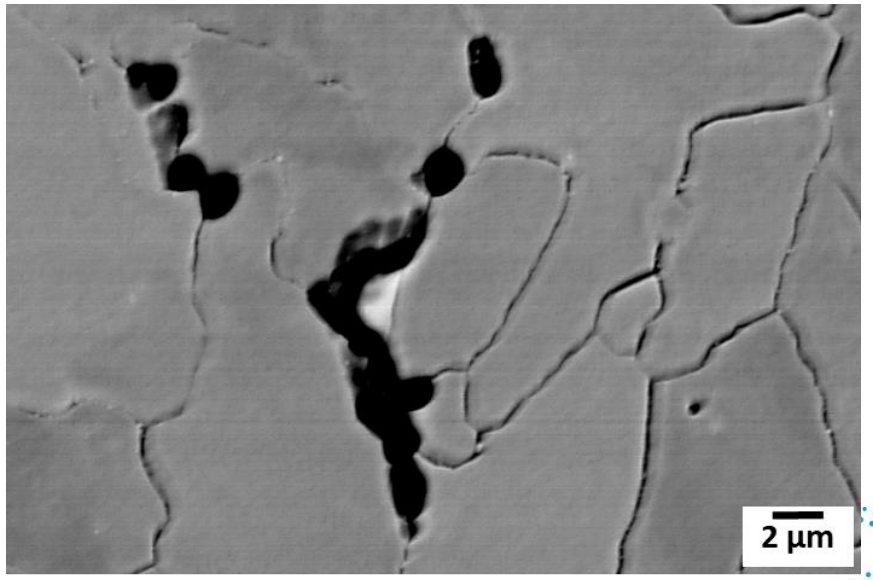
Welding parameters and examination

Welding process	Gas Tungsten Arc Welding
Sheilding gas	Argon
Welding current	70 A
Arc voltage	10 V
Welding speed	1 mm/s

Examination:
5 cross sections from each condition of the welded plates were excised for the measurements of total crack length.
Crack measurements were done by SEM examination.



Weld cross section



Crack examination by SEM

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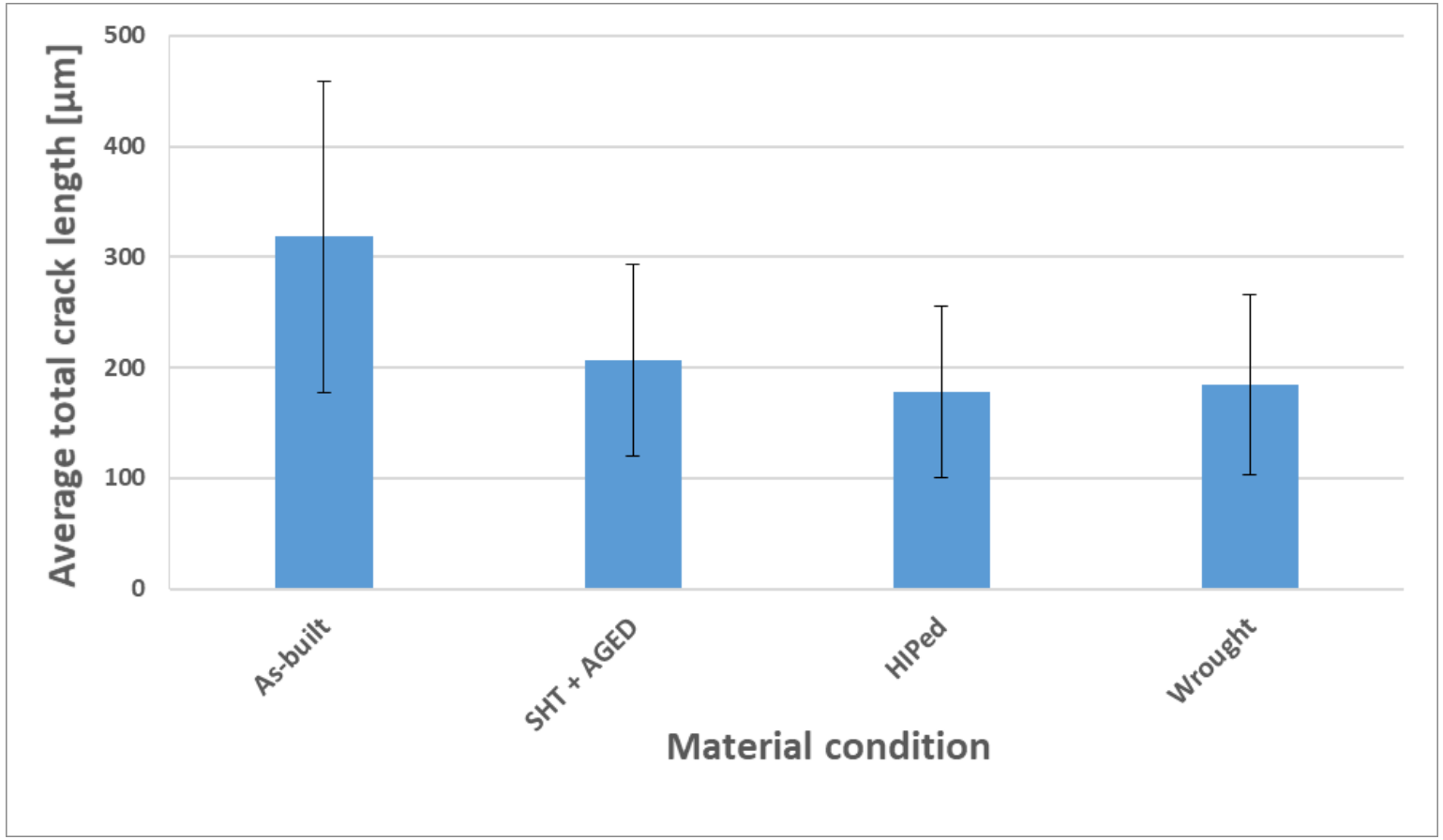
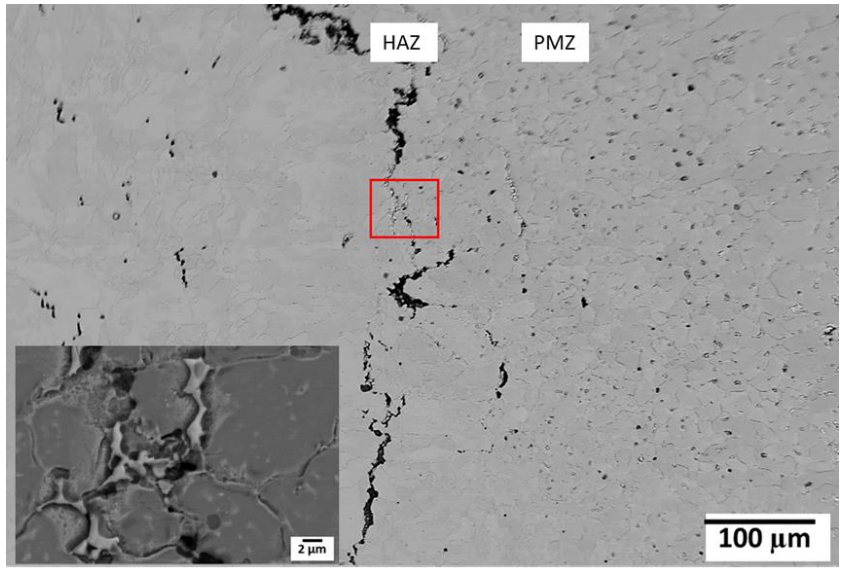
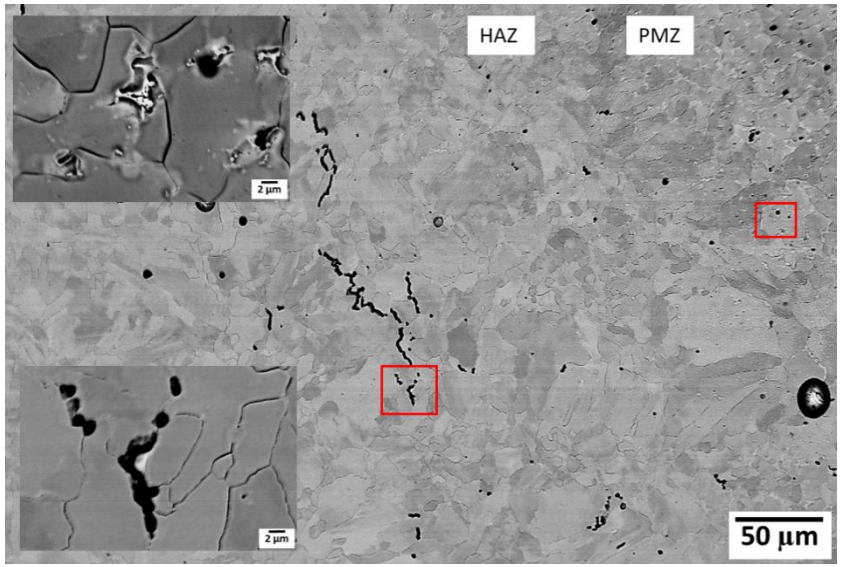
Heat affected zone cracking susceptibility of SLM-manufactured Alloy 718



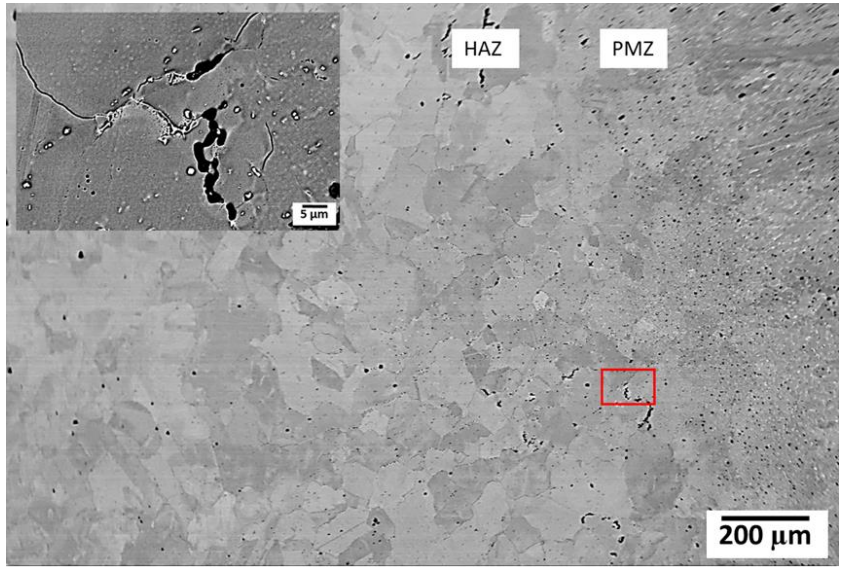
HAZ cracking in SLM-manufactured Alloy 718



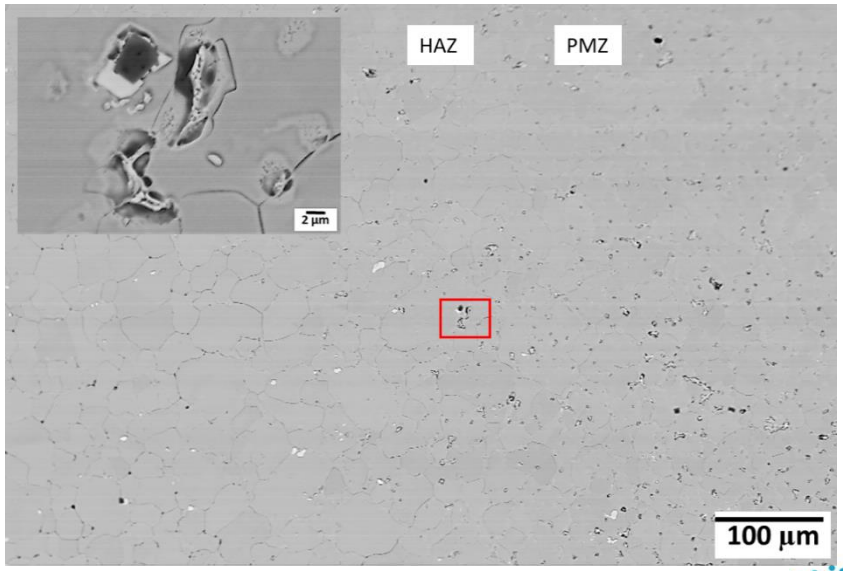
SLM As-built



SLM SHT+AGE

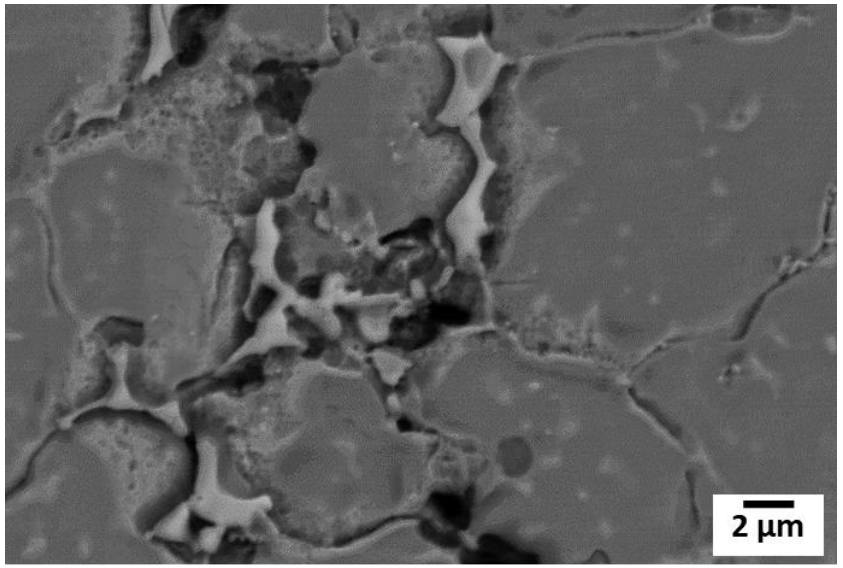


SLM HIPed

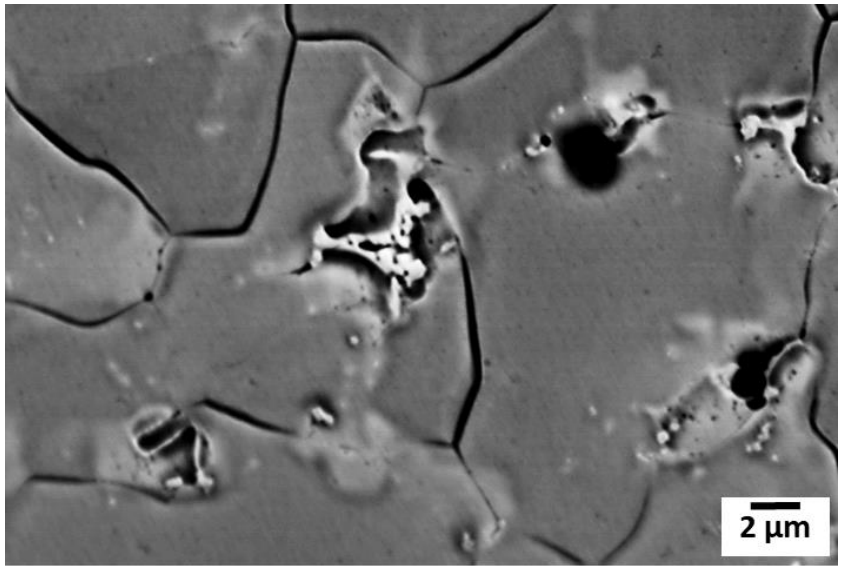


Wrought

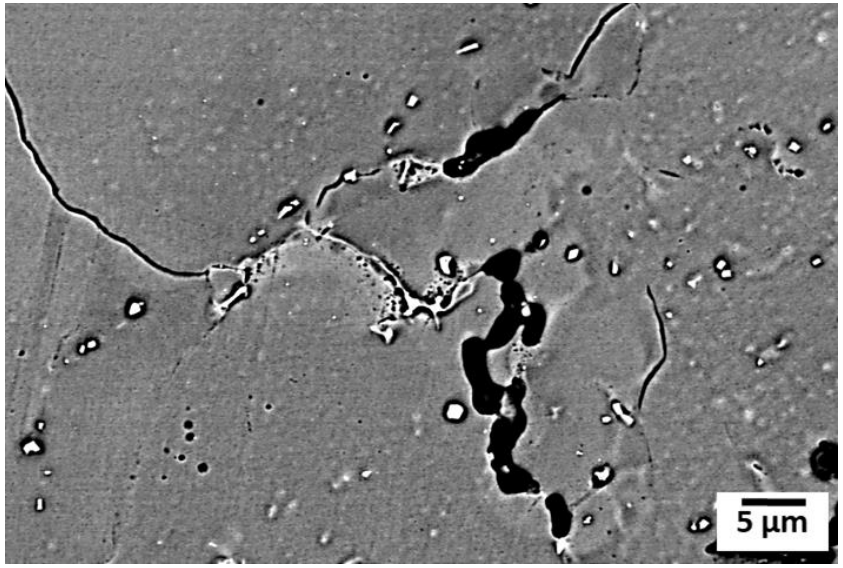
HAZ cracking in SLM-manufactured Alloy 718



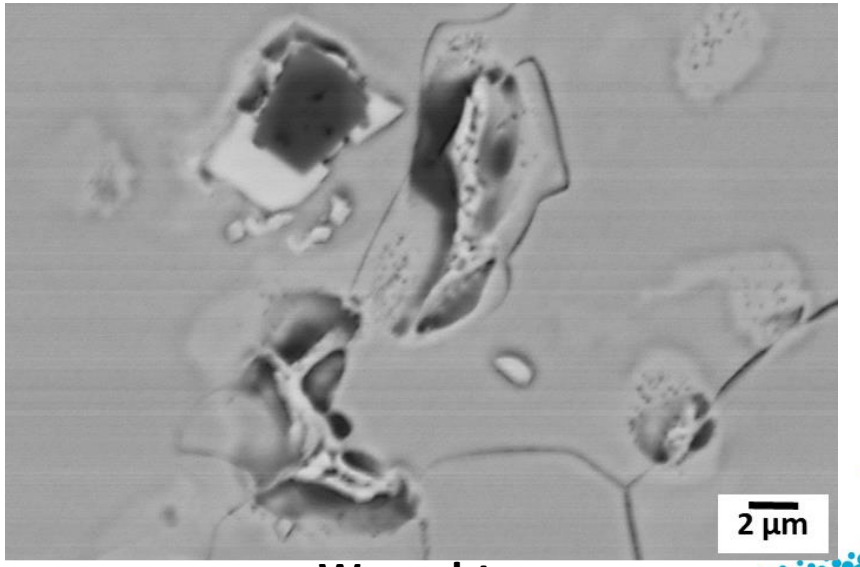
SLM As-built



SLM SHT+AGE



SLM HIPed



Wrought

Conclusions

- Total crack lengths in HAZ were **highest in the SLM as-built condition** and **lowest in the SLM hot isostatic pressed condition.**

- **As-built** Alloy 718 contained Laves phase and NbC carbides in interdendritic regions that caused the liquation of grain boundaries in HAZ during welding.

- After **solution + aging treatment**, the Laves phase was partially dissolved and extensive amount of delta phase was formed at grain boundaries.
    - Liquation of Laves phase and NbC carbides was the main cause of HAZ liquation cracking in this condition.

- After **hot isostatic pressing**, the cracking susceptibility of SLM-manufactured Alloy 718 became almost like **wrought** Alloy 718.
    - Constitutional liquation of NbC carbides was the main cause of HAZ liquation cracking in these condition.

Source: http://www.gkngroup.com/gknsweden/aerospace/produkter/Pages/rymd.aspx

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