Slutseminarium Nationellt Rymdtekniskt Forskningsprogram
NRFP3

Selective laser melting of Alloy 718

Influence of heat treatments on heat affected zone cracking of selective laser melted and TIG-welded Alloy 718

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Swedish National Space Agency
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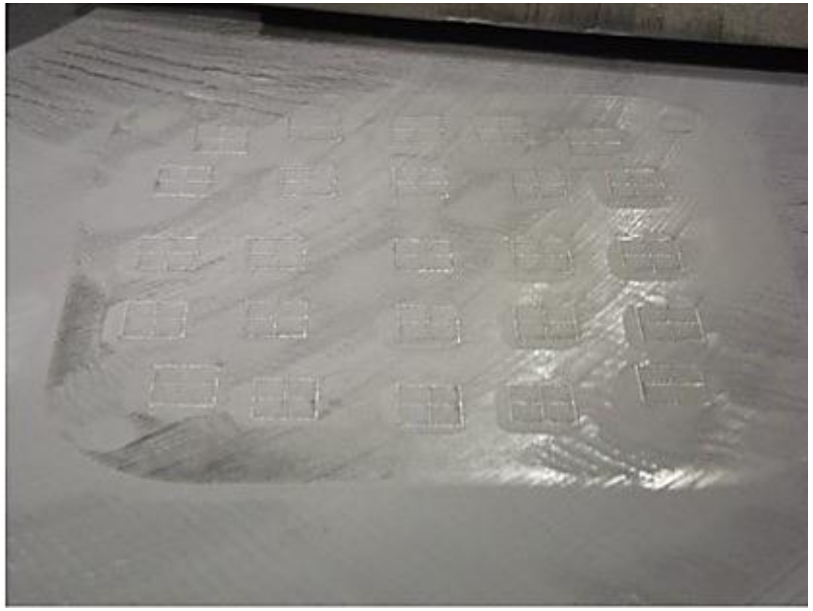
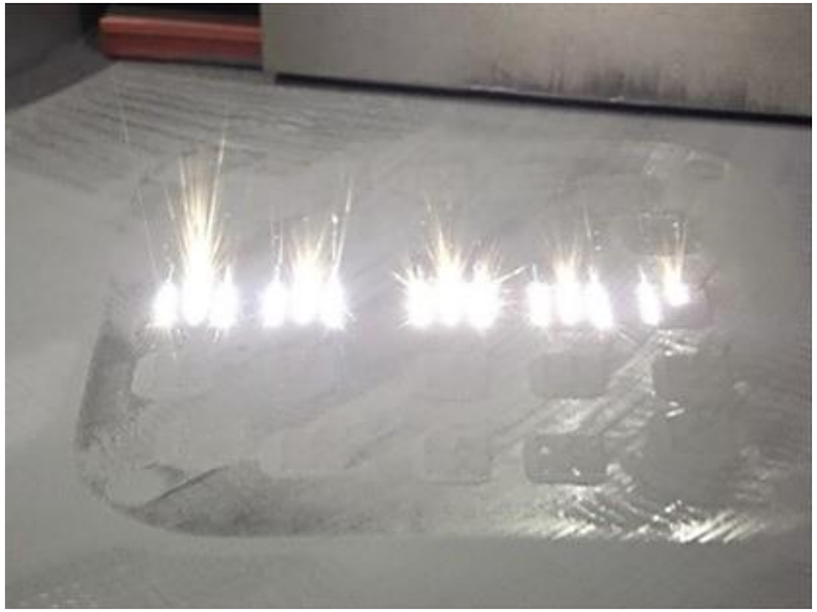
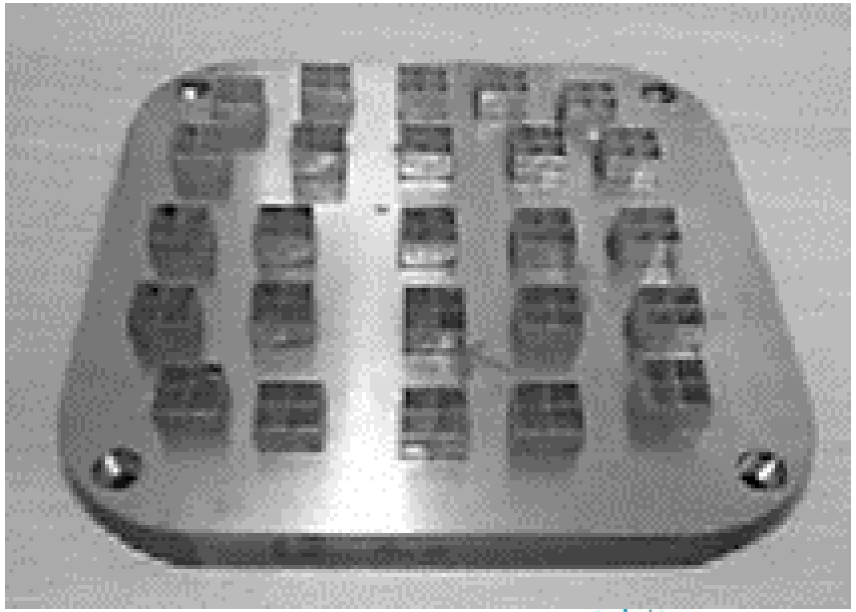
15 Nov 2018

Selective laser melting process

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



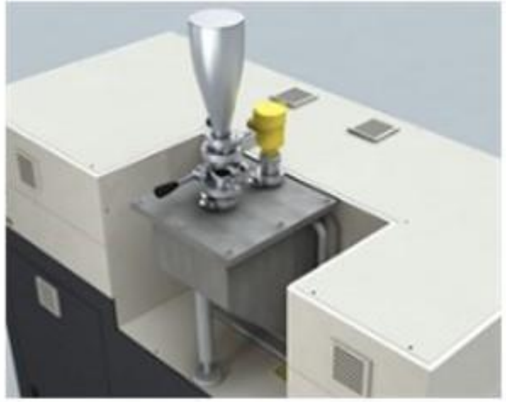




https://www.twi-global.com/capabilities/joining-technologies/additive-manufacturing//

Selective laser melting process

1. Loading powder

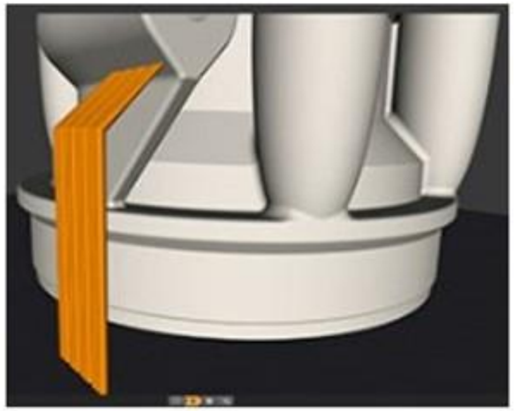


Loading metal powder before and during build.

2. Build plate loaded

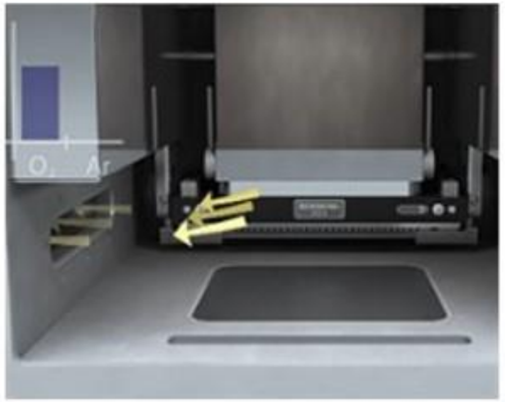
Build plate is loaded into the system chamber and secured.

3. Build preparation



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

4. Remove air



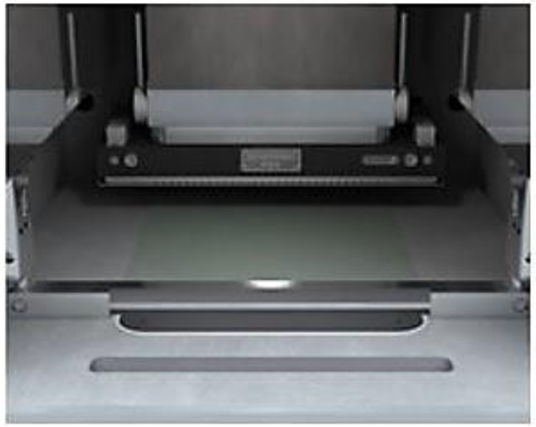
Build chamber is prepared with vacuum removal of air.

Selective laser melting process

5. Inert gas

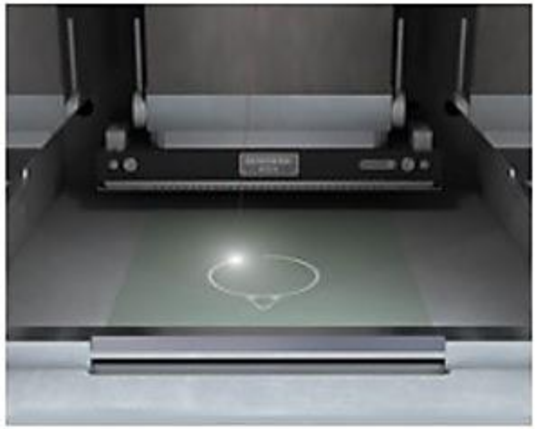
Chamber is filled with argon inert gas - class leading low gas consumption.

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.

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

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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

Research objectives

- To investigate the effect of process parameters on microstructure and defects, as well as to fundamentally understand how SLM-manufactured Alloy 718 behaves in welding.

  - What type of defects are of prime concern in SLM manufactured parts and how are they affected by specific process parameters?
  - What is the influence of post process heat treatments on SLM manufactured Alloy 718 microstructure?
  - What is the influence of pre-weld heat treatments on the susceptibility towards hot cracking in SLM manufactured Alloy 718?

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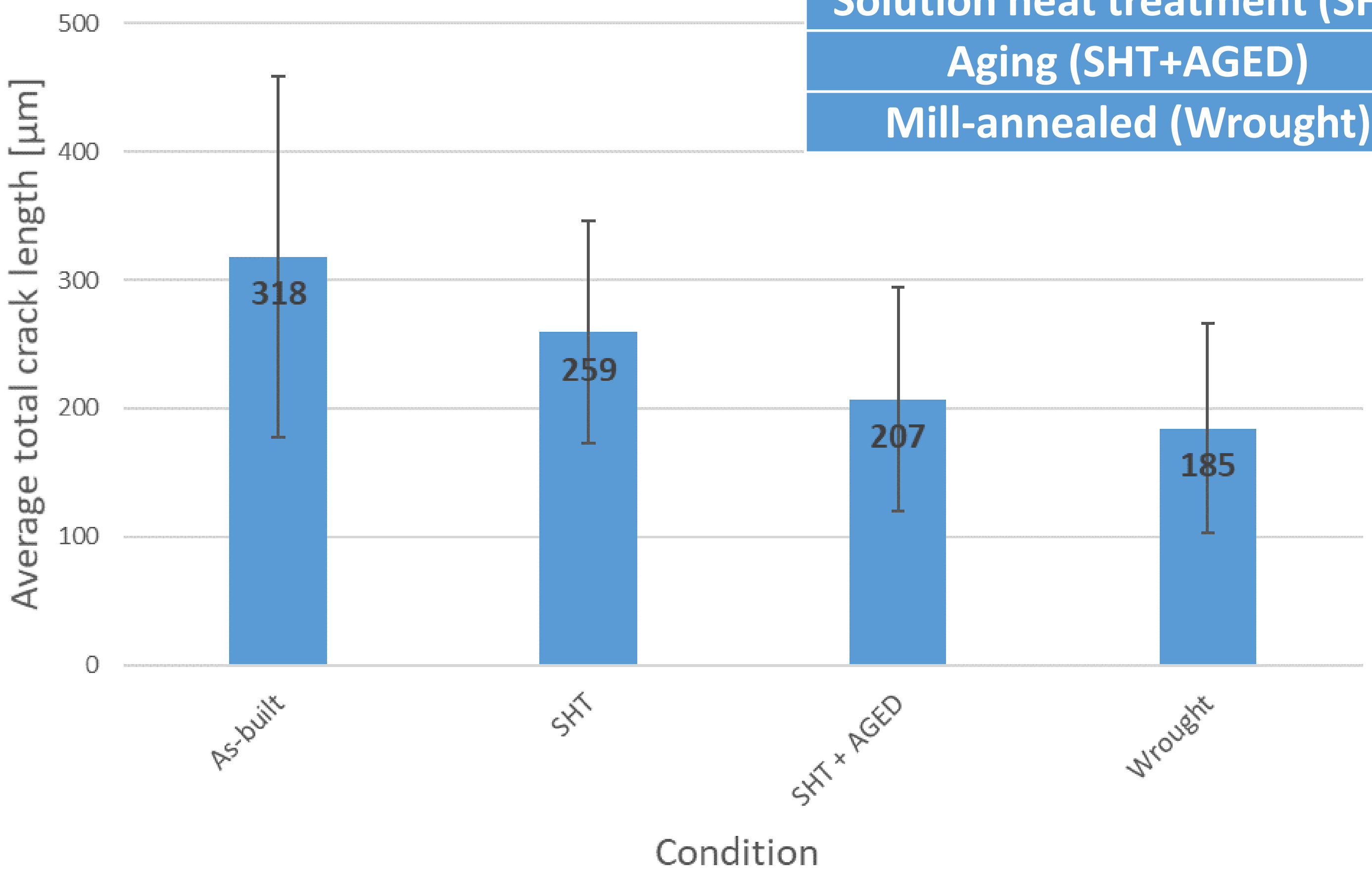
Heat affected zone cracking susceptibility of SLM-manufactured Alloy 718
Total crack length measurements

Material condition	Specification
As-built	SLM-manufactured and no heat treatment
Solution heat treatment (SHT)	954°C - 1hr
Aging (SHT+AGED)	760°C - 5hrs + 649°C - 1hr
Mill-annealed (Wrought)	982°C - 4.5min



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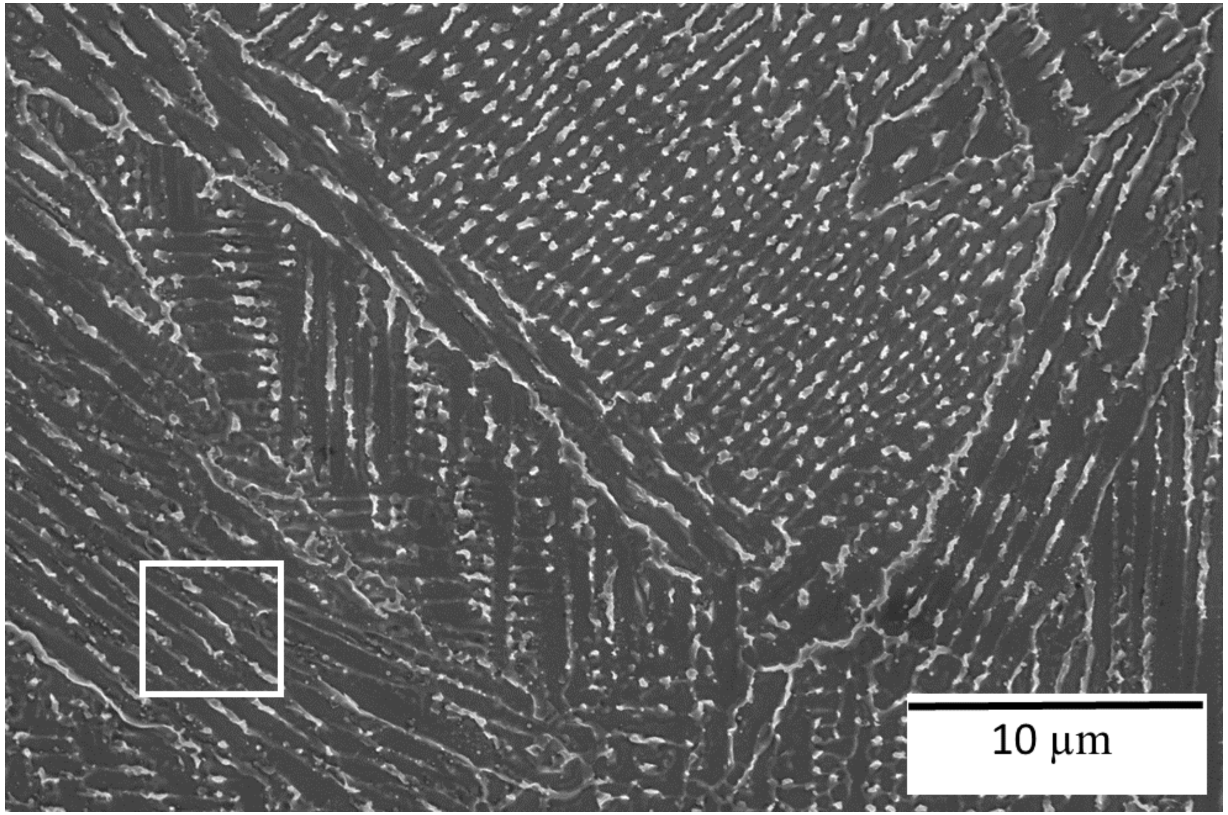
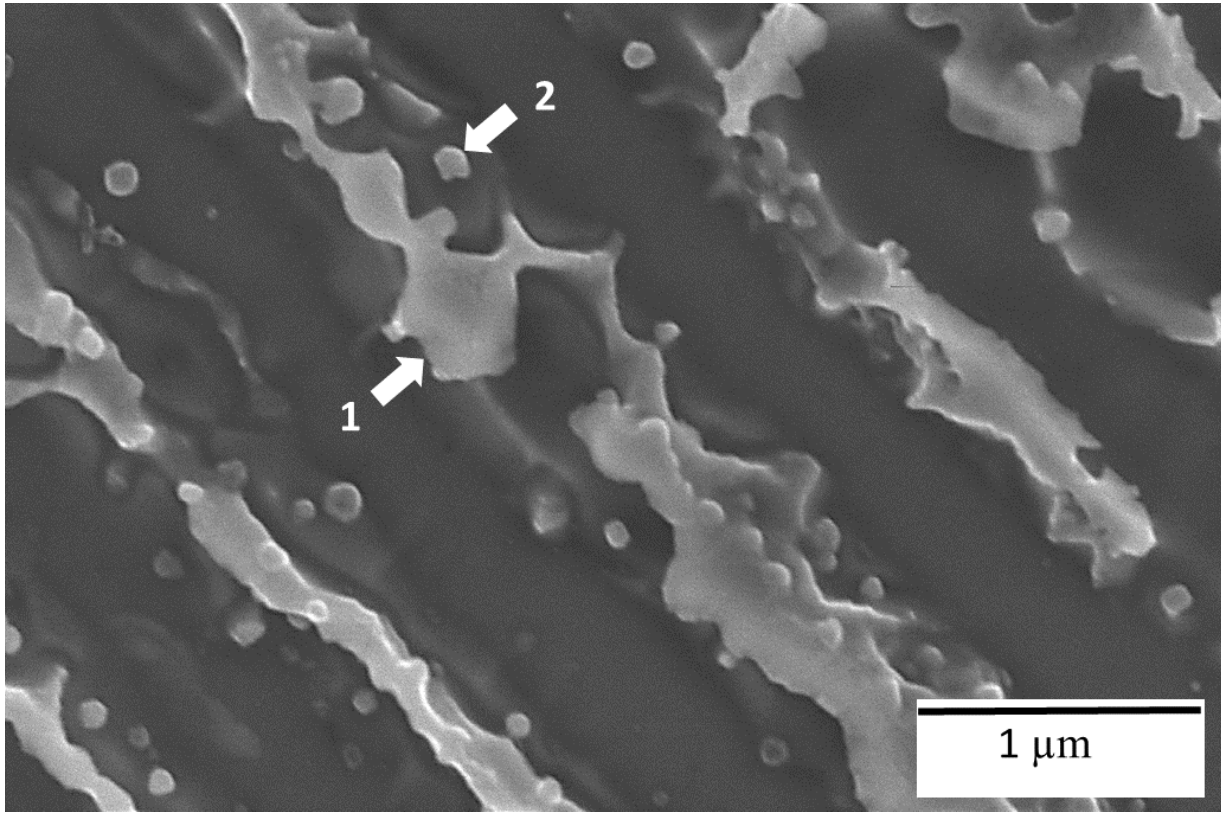
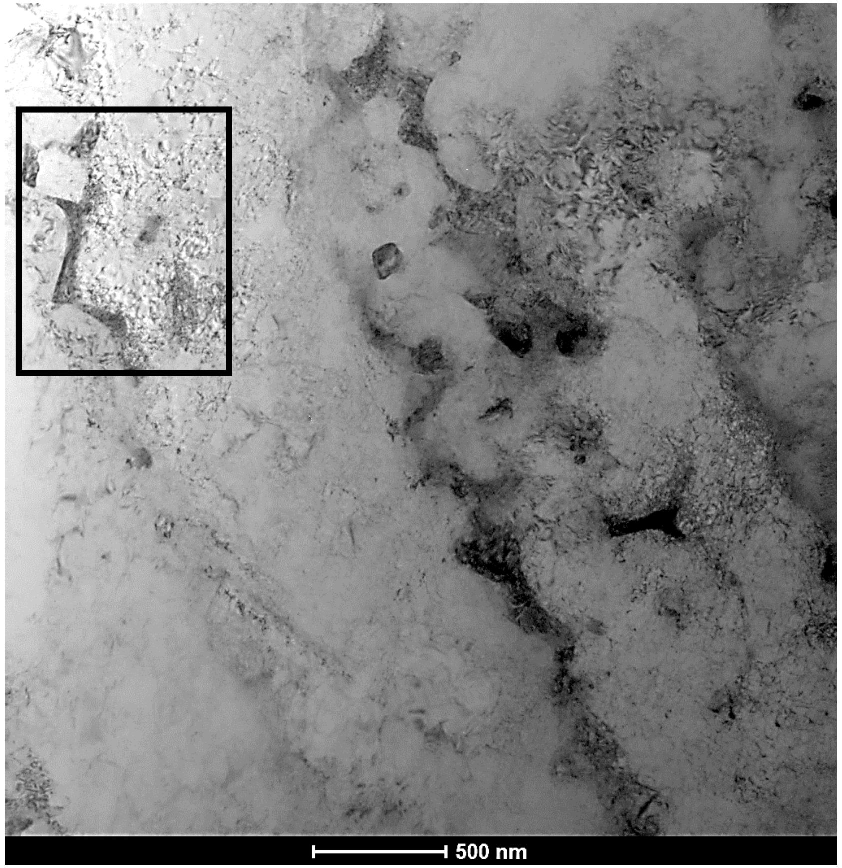
SLM As-built Alloy 718
Base metal

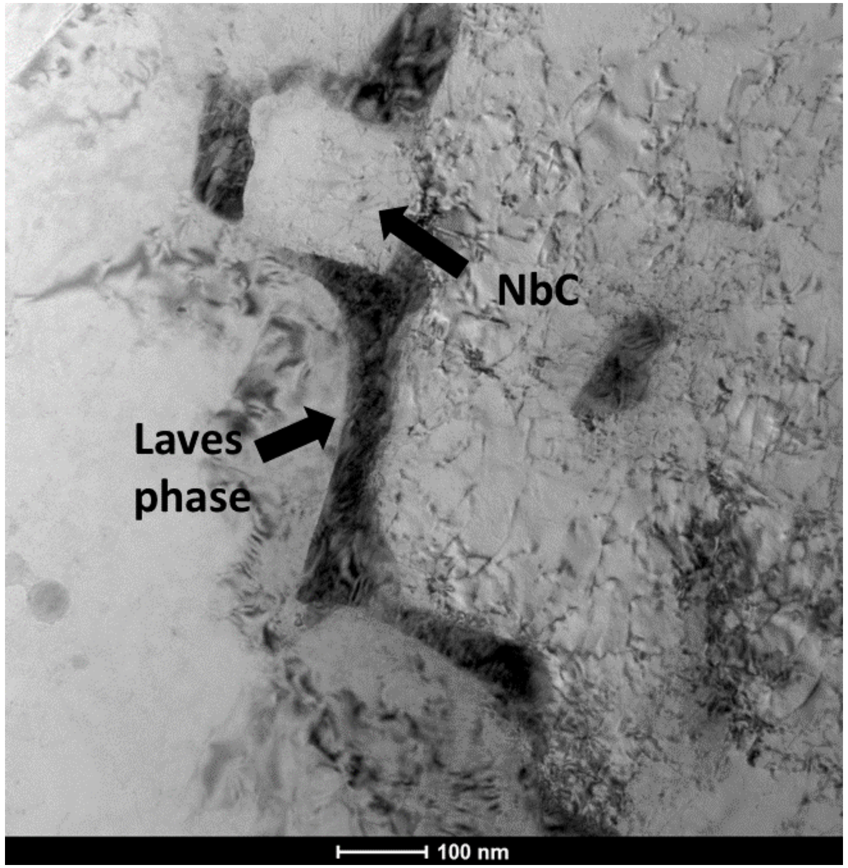




Interdendritic regions in as-built condition showing (1) Laves phase and (2) MC-type carbide

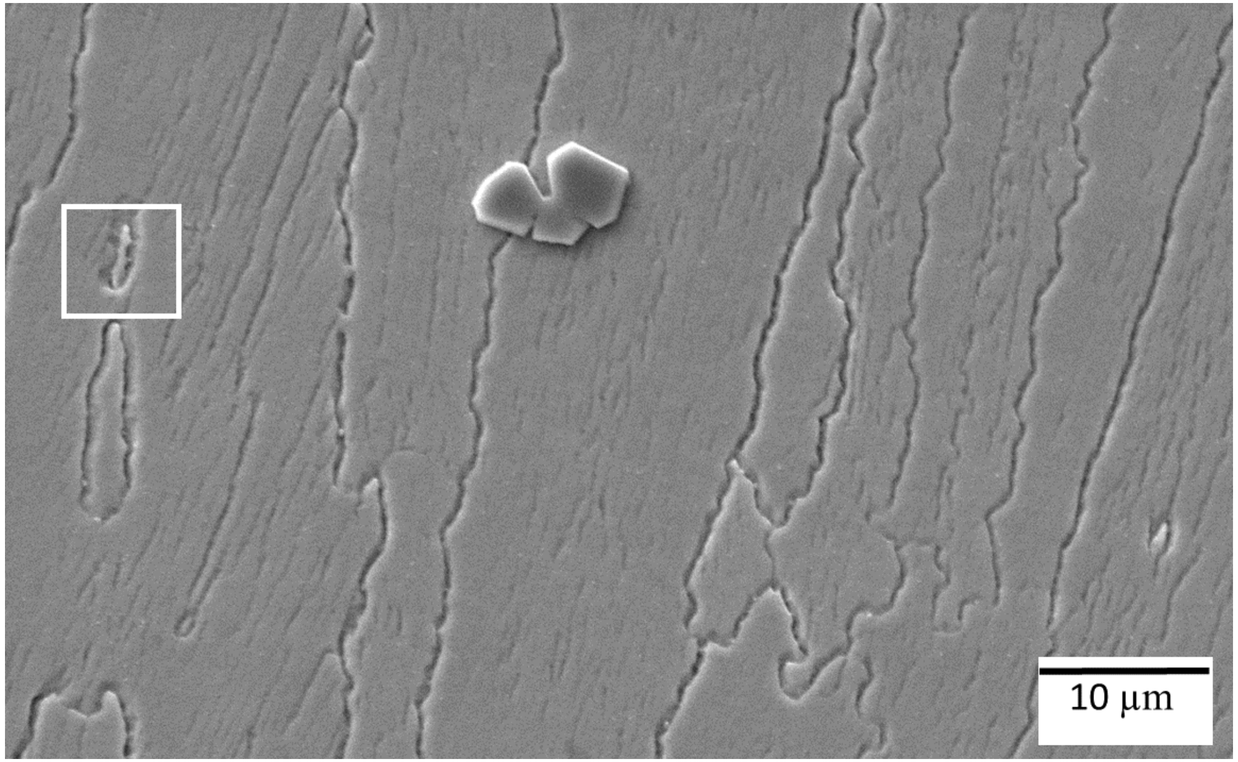
SLM As-built Alloy 718
Base metal

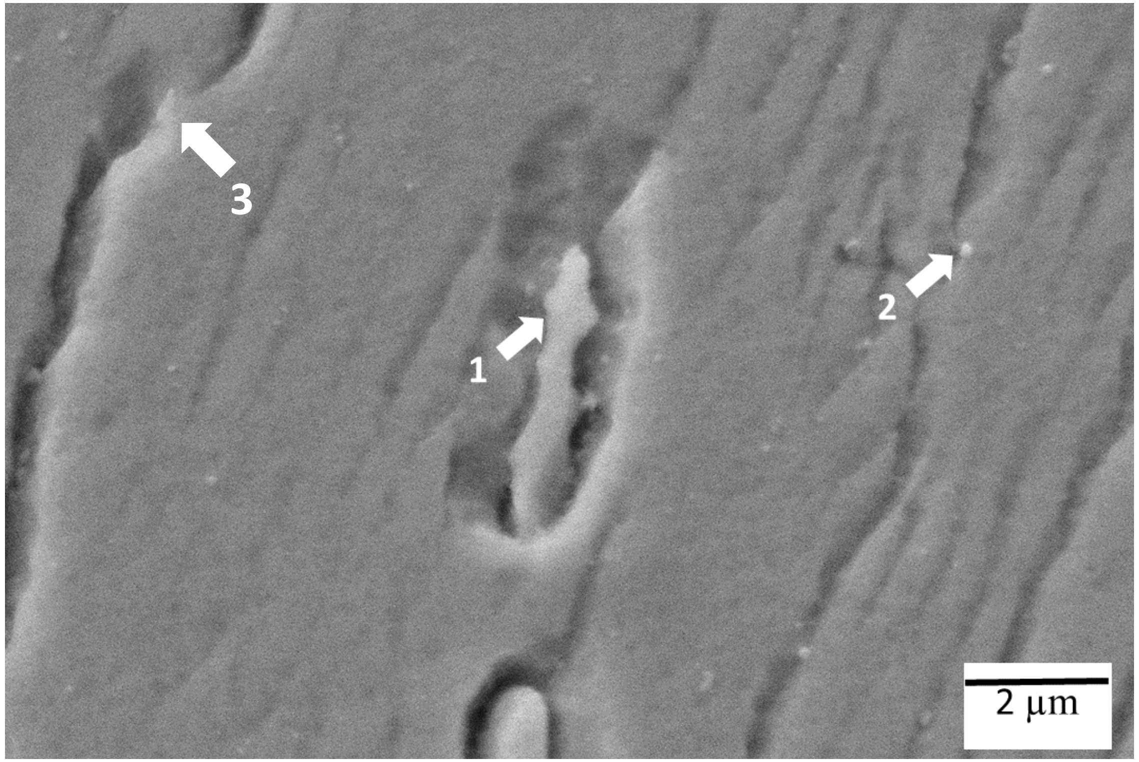




TEM bright field image of Laves phase and NbC carbide in interdendritic regions

SLM Solution heat treated
Base metal





(1) Remnants of Laves phase (2) MC-type carbide and (3) Delta phase in SHT condition

Solution heat treatment at 954°C - 1hr

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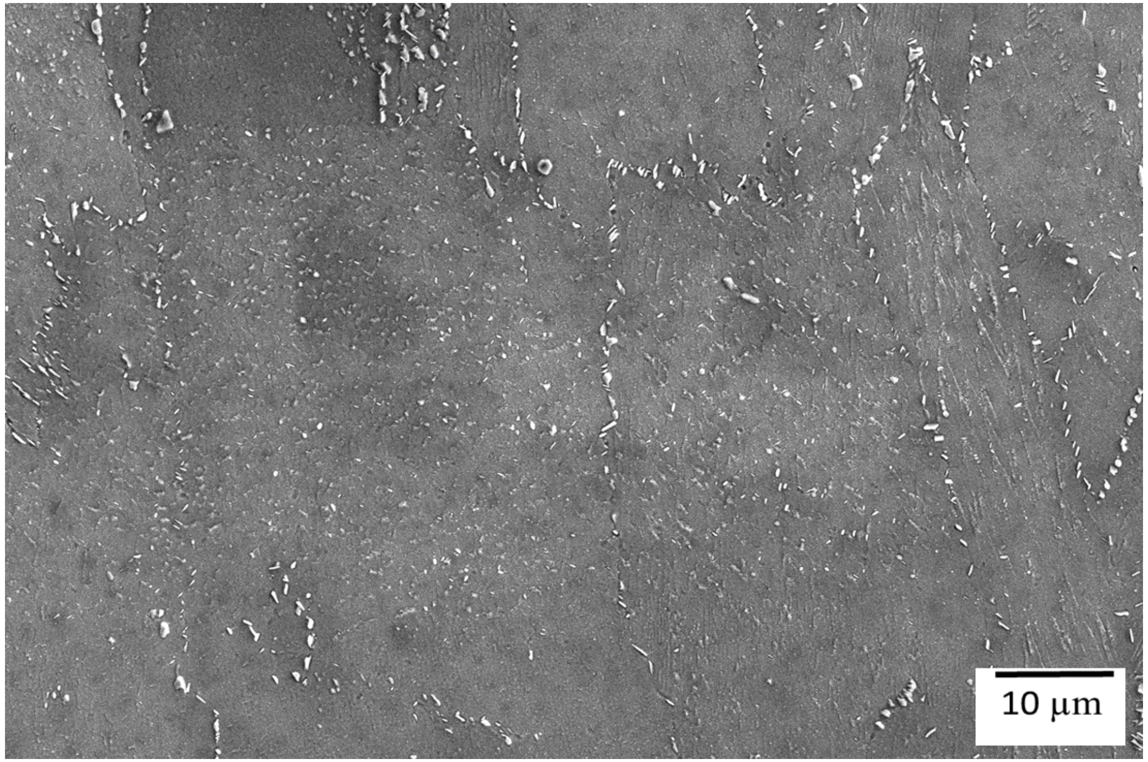
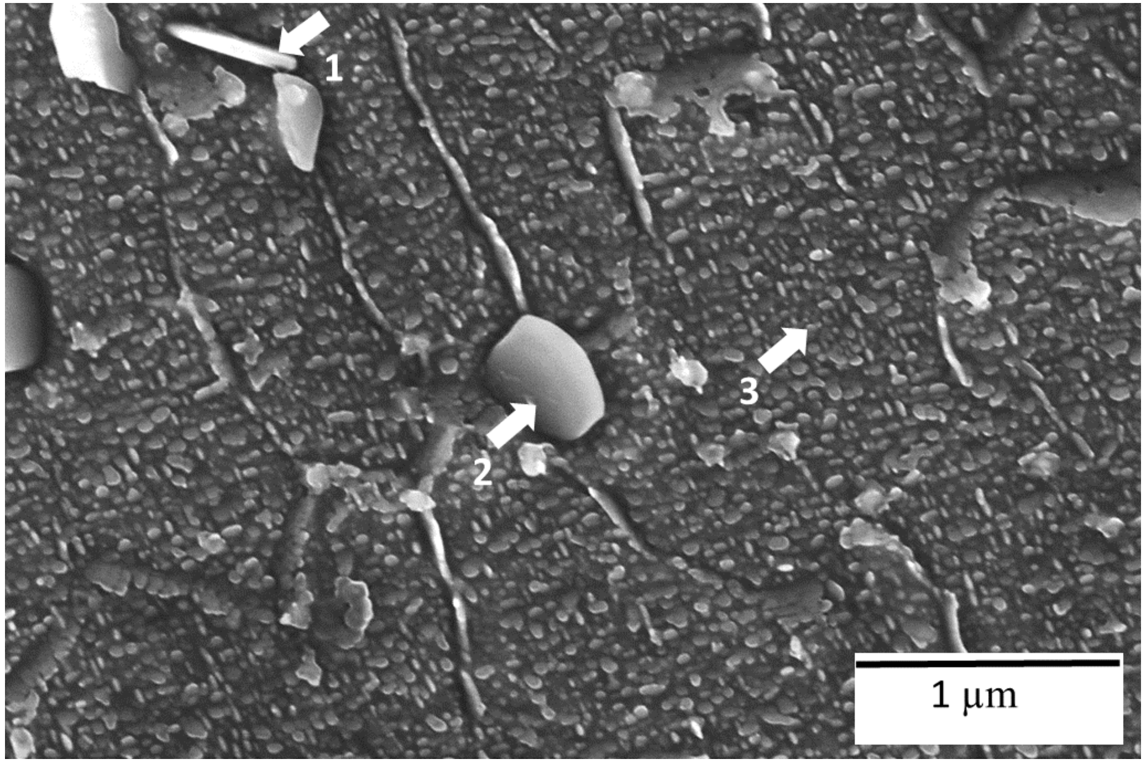
SLM Solution heat treated + Aged
Base metal

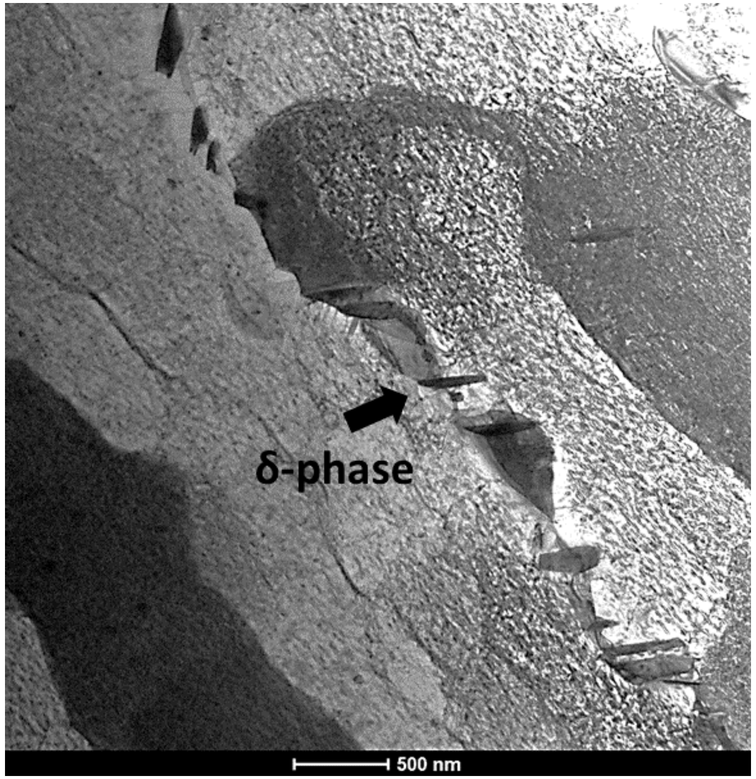




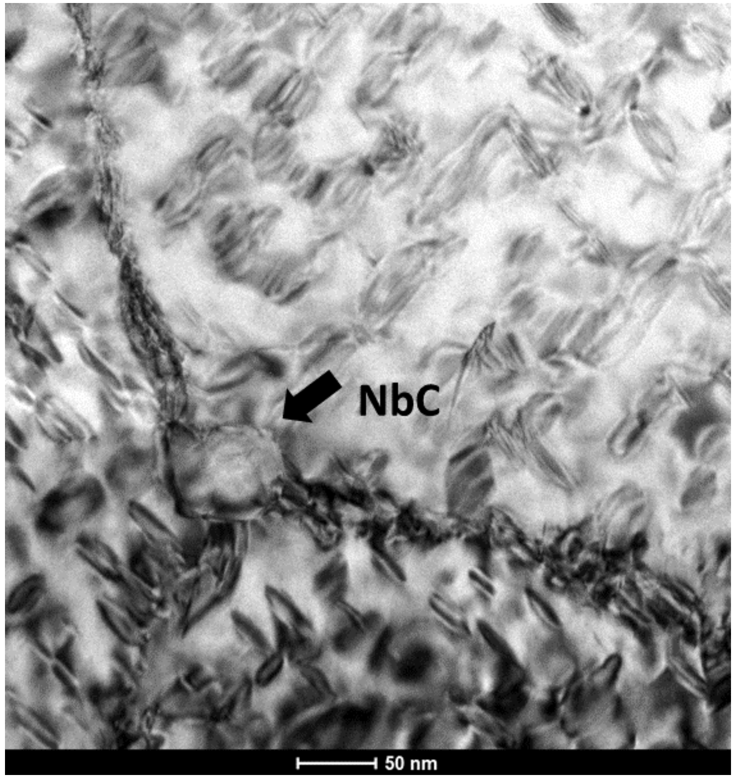
Microstructure of SHT+AGE condition showing (1) delta phase, (2) MC-type carbide and (3) matrix with strengthening phases γ’ and γ’’

Solution heat treatment 954°C/ 1hr + Aging heat treatment 760°C/ 5hrs + 649°C/ 1

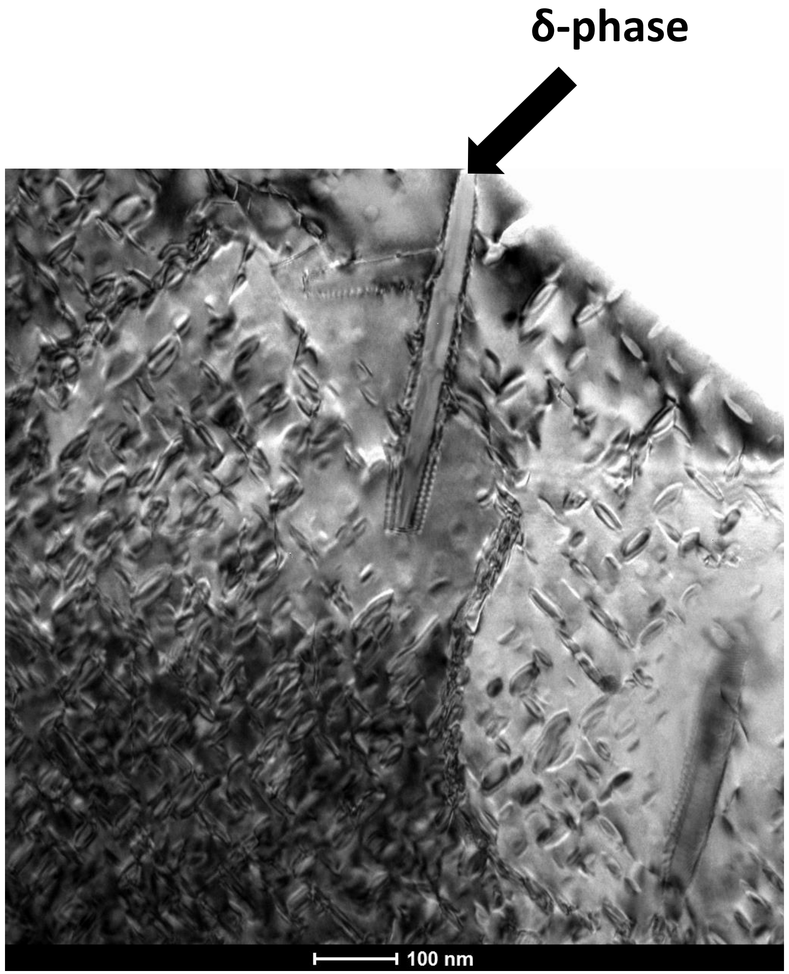
SLM Solution heat treated + Aged
Base metal



Delta phase pinning the grain boundary

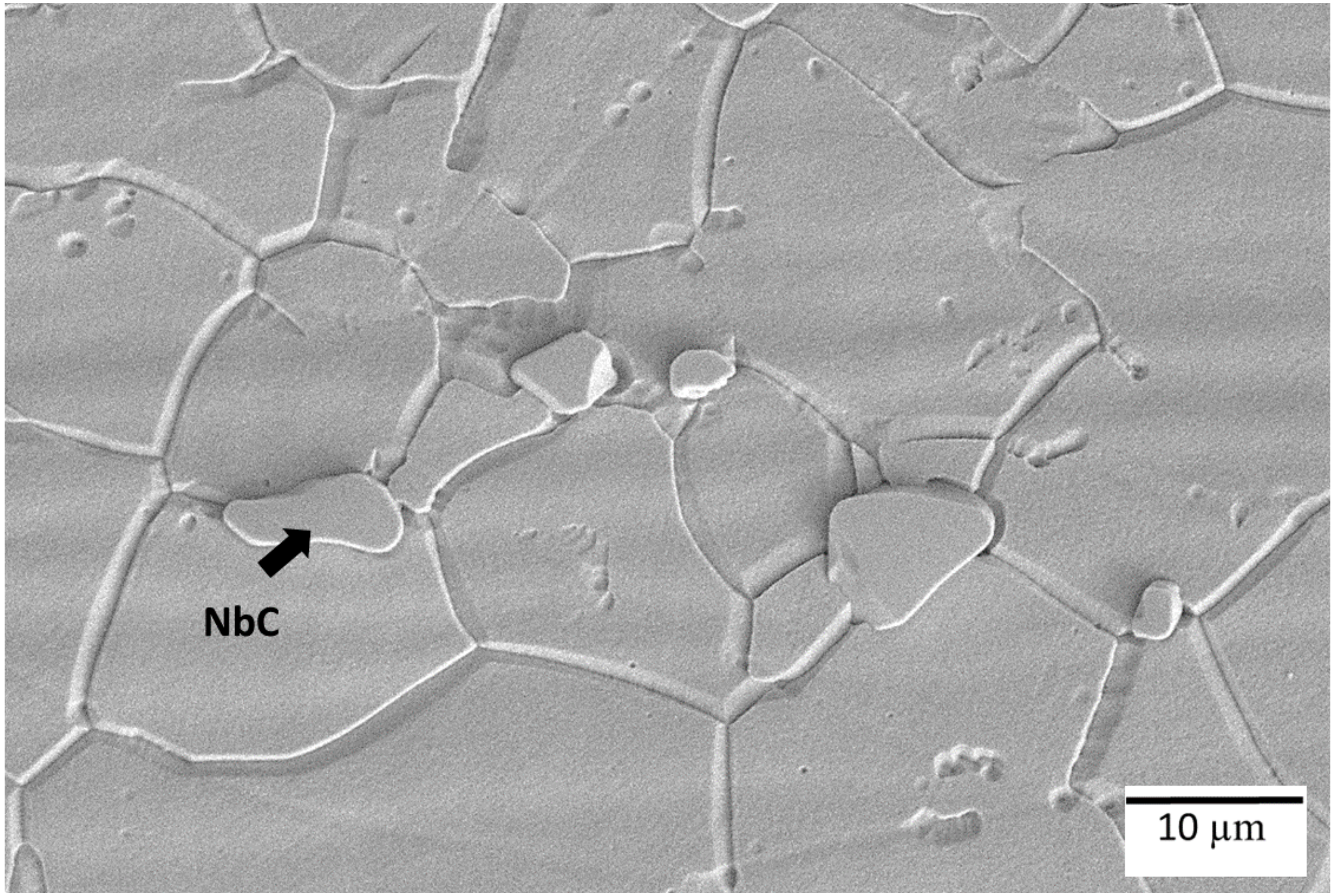


NbC carbide, γ' and γ''



Delta phase, γ' and γ''

Wrought



Mill-annealed at 982°C - 4.5min

Heat affected zone (HAZ) cracking susceptibility of SLM-manufactured Alloy 718

Total crack length measurements

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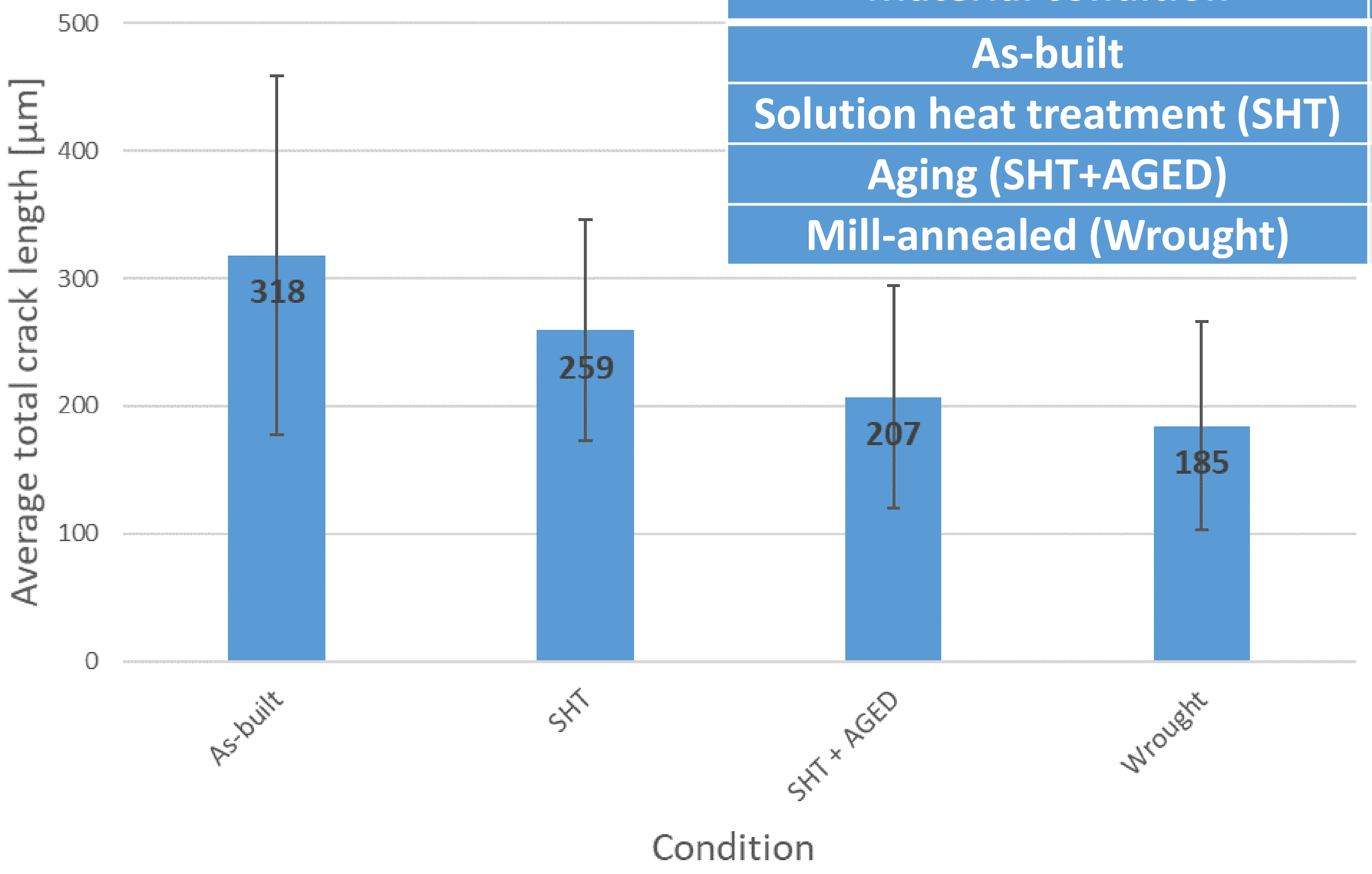

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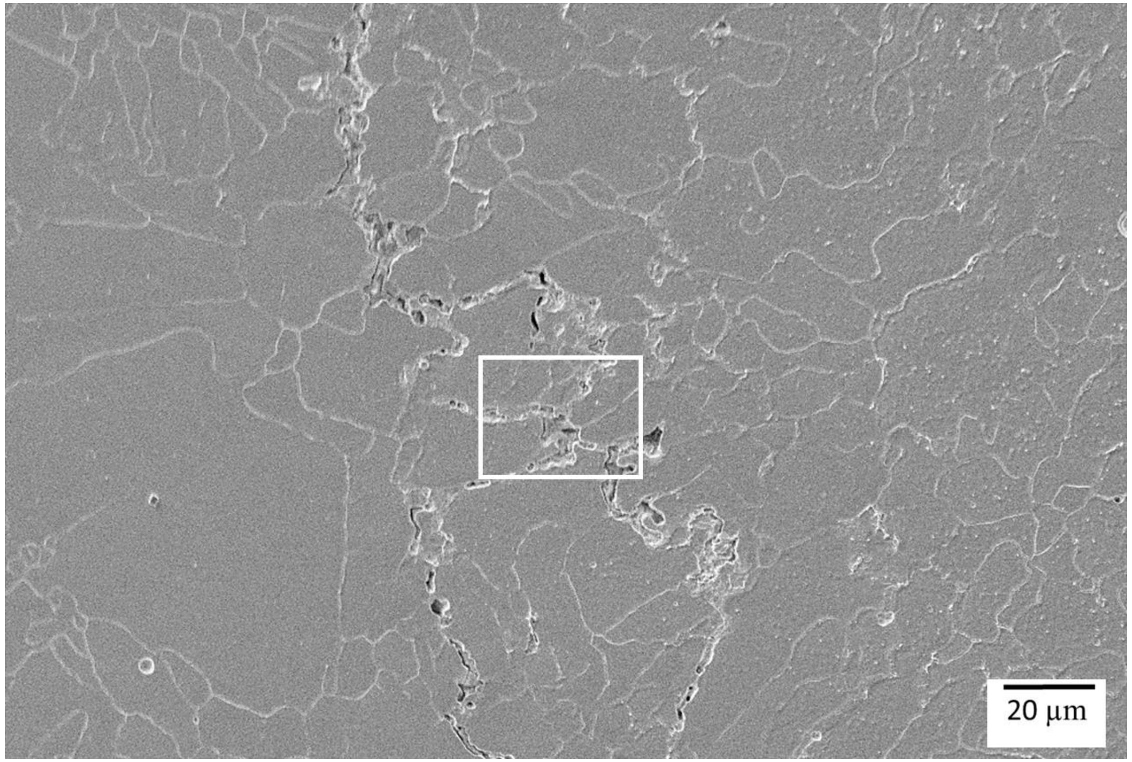
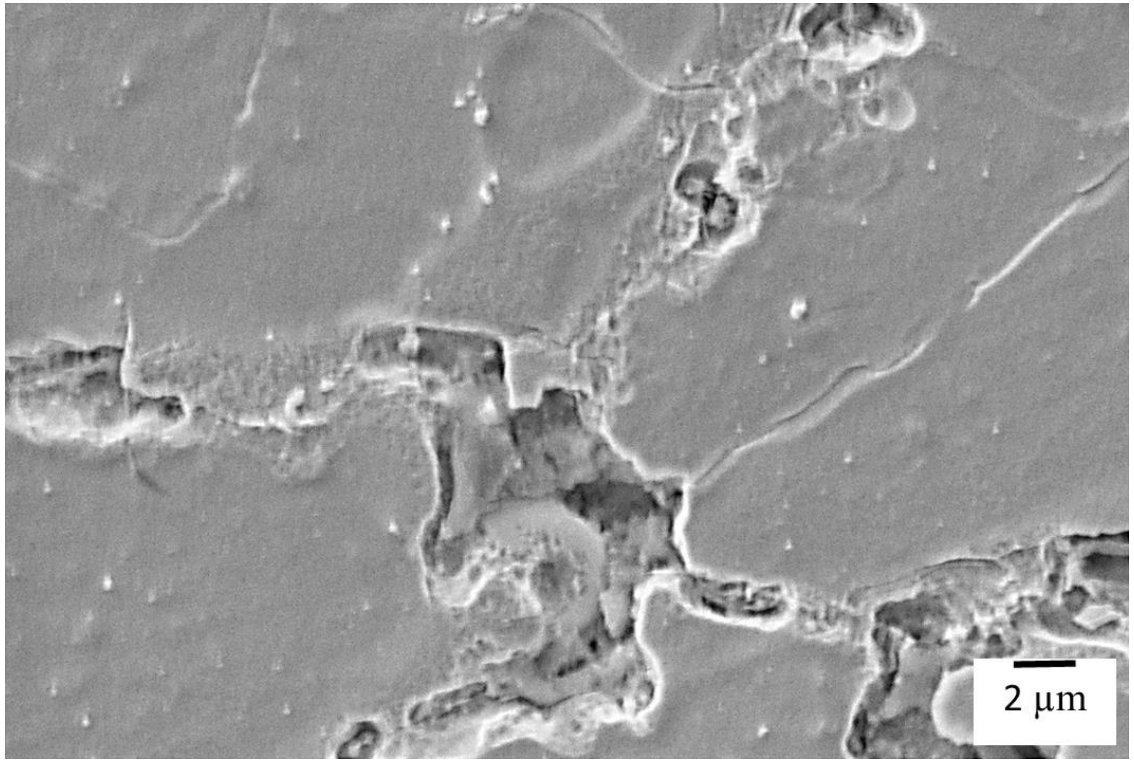
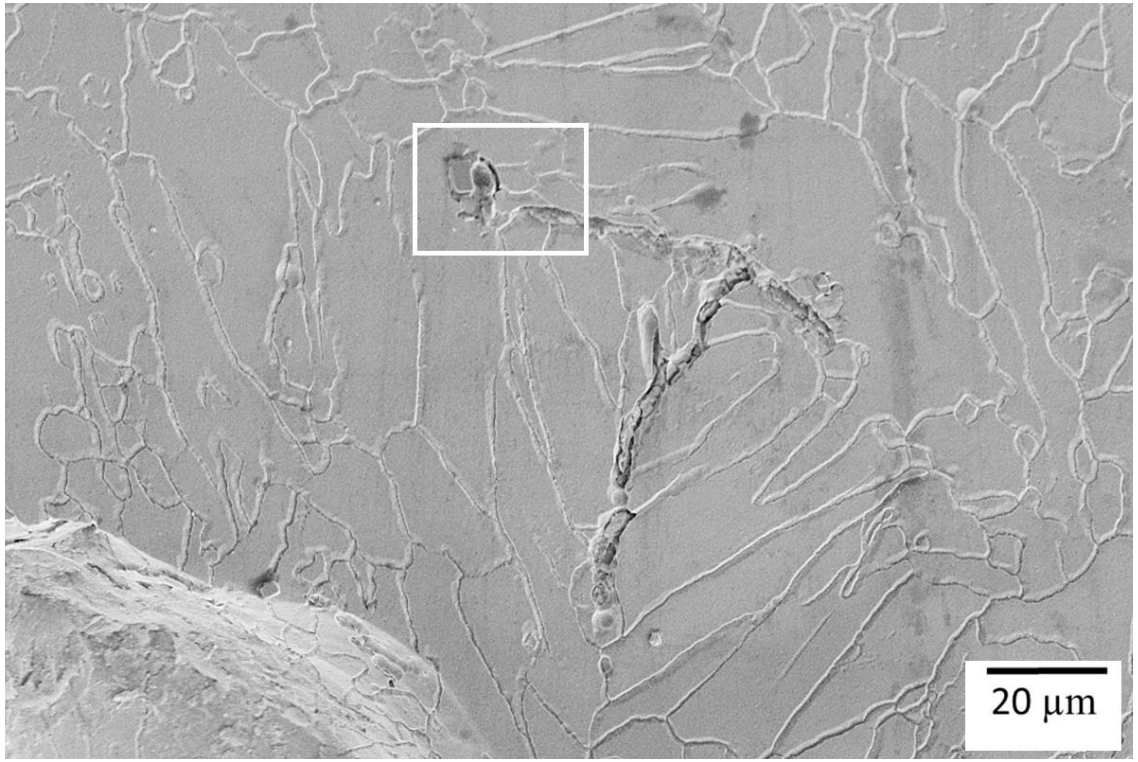
HAZ cracking in as-built condition

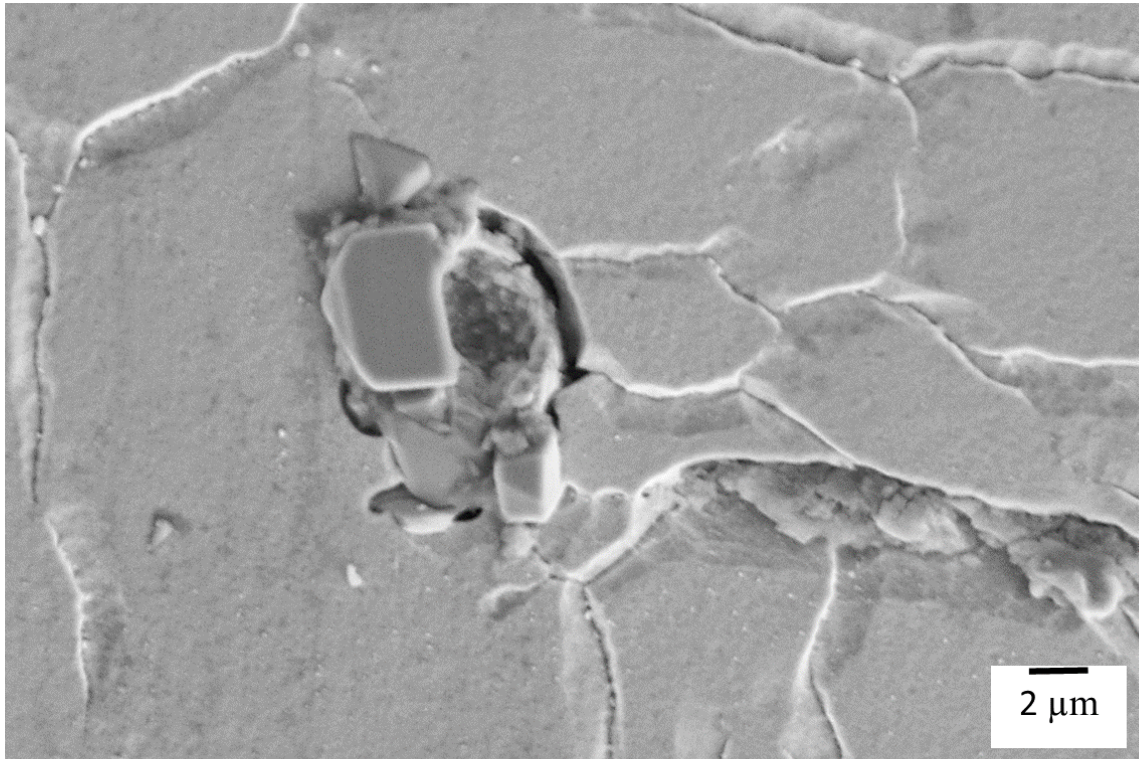




Cracking in as-built condition due to the liquation of Laves phase and carbide

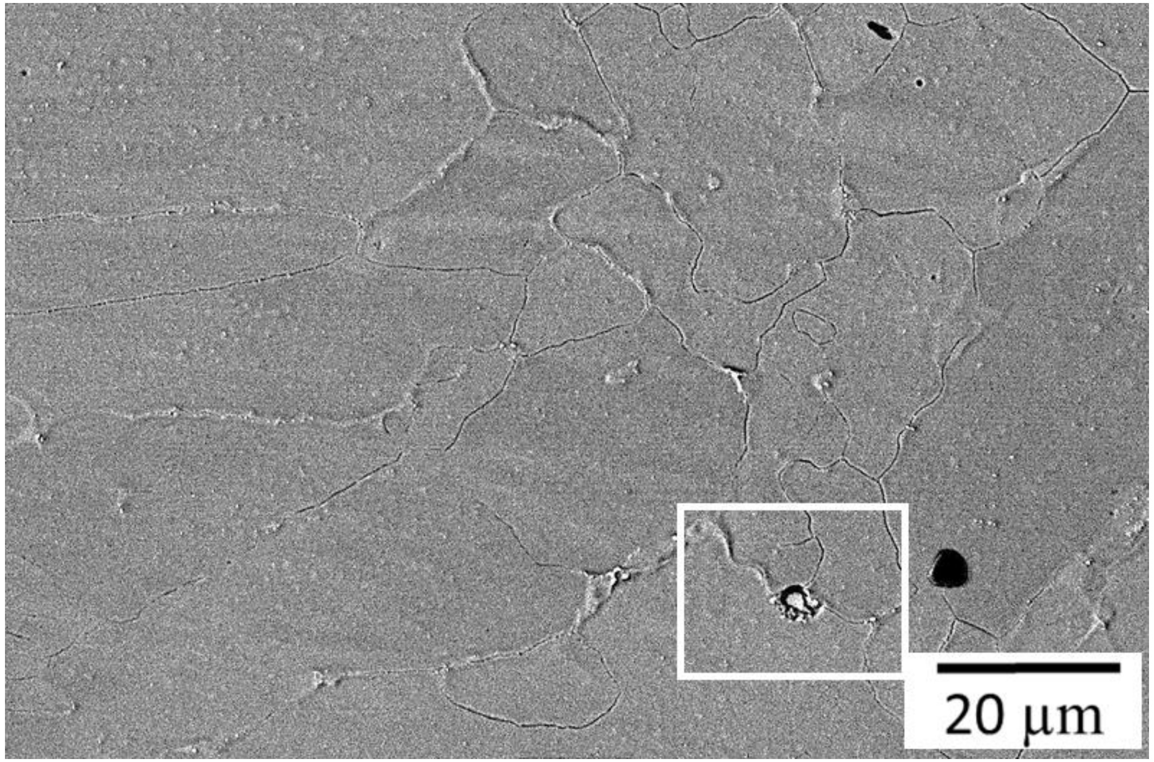
HAZ cracking in solution heat treated condition

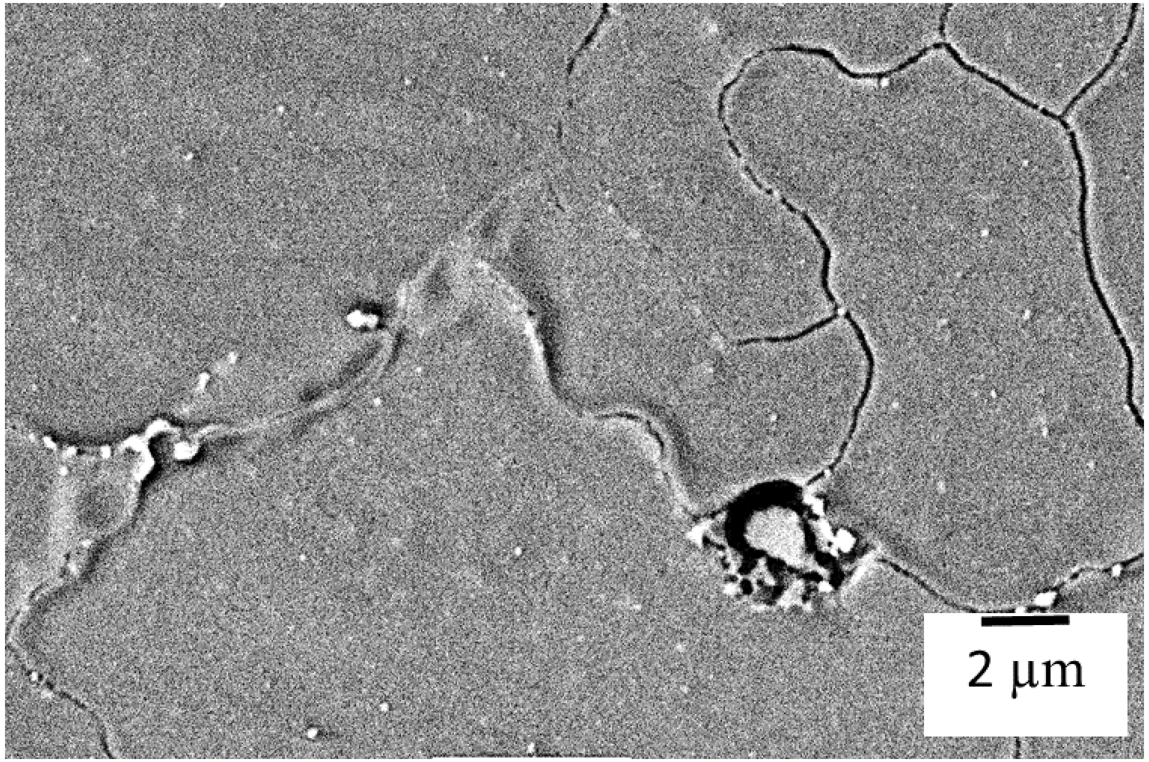




Liquation of carbide and Laves phase causing intergranular cracks in SHT condition

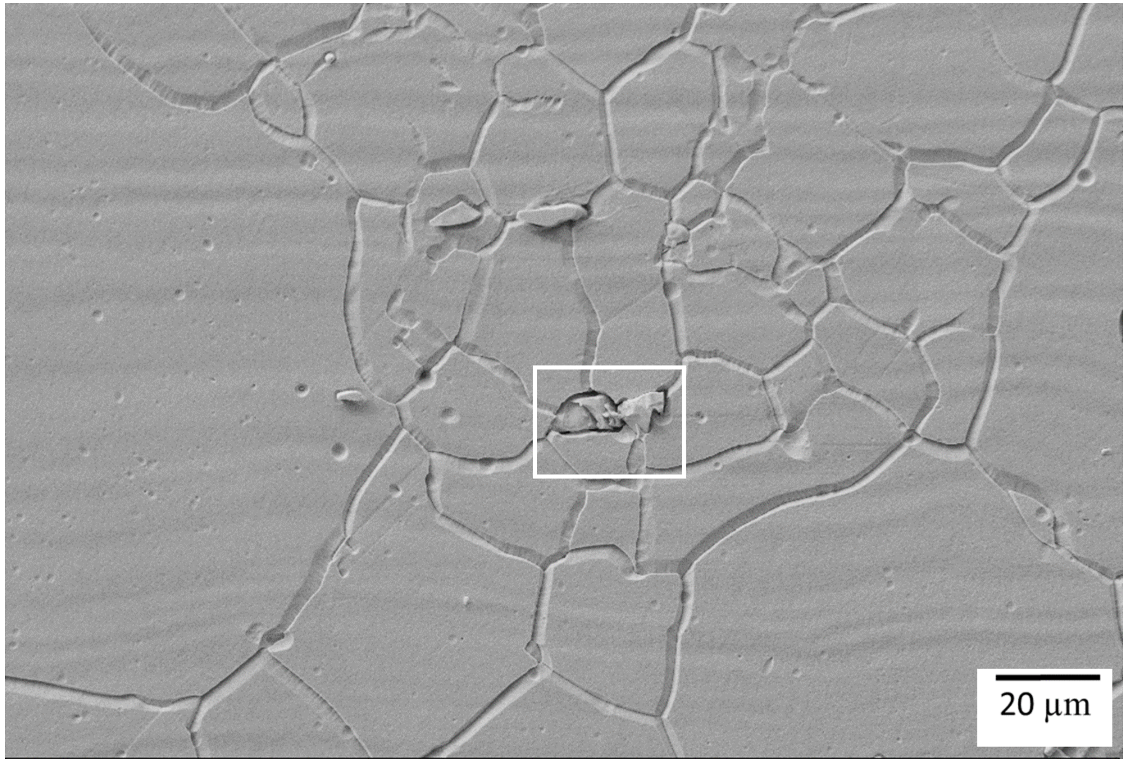
HAZ cracking in solution heat treated + aged condition

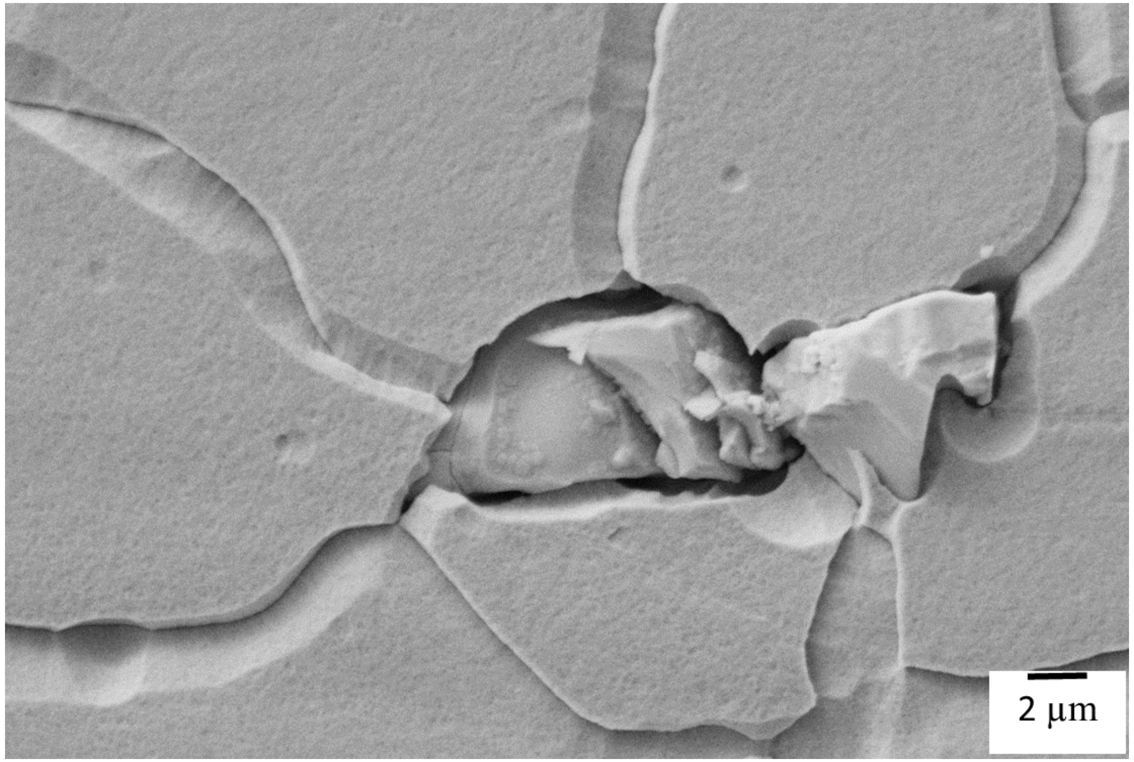




Liquation of carbides causing intergranular crack in HAZ of SHT+AGED condition

HAZ cracking in wrought Alloy 718





Liquation of carbides creating crack in HAZ of wrought Alloy 718

Conclusions

- **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 heat treatment**, most of the Laves phase was dissolved and precipitation of delta phase occured. The remnants of Laves phase along with NbC carbides were liquated and created cracks during welding process.

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

- After **SHT+AGED** heat treatment, the cracking susceptibility of SLM-manufactured Alloy 718 became almost similar to **wrought** Alloy 718.

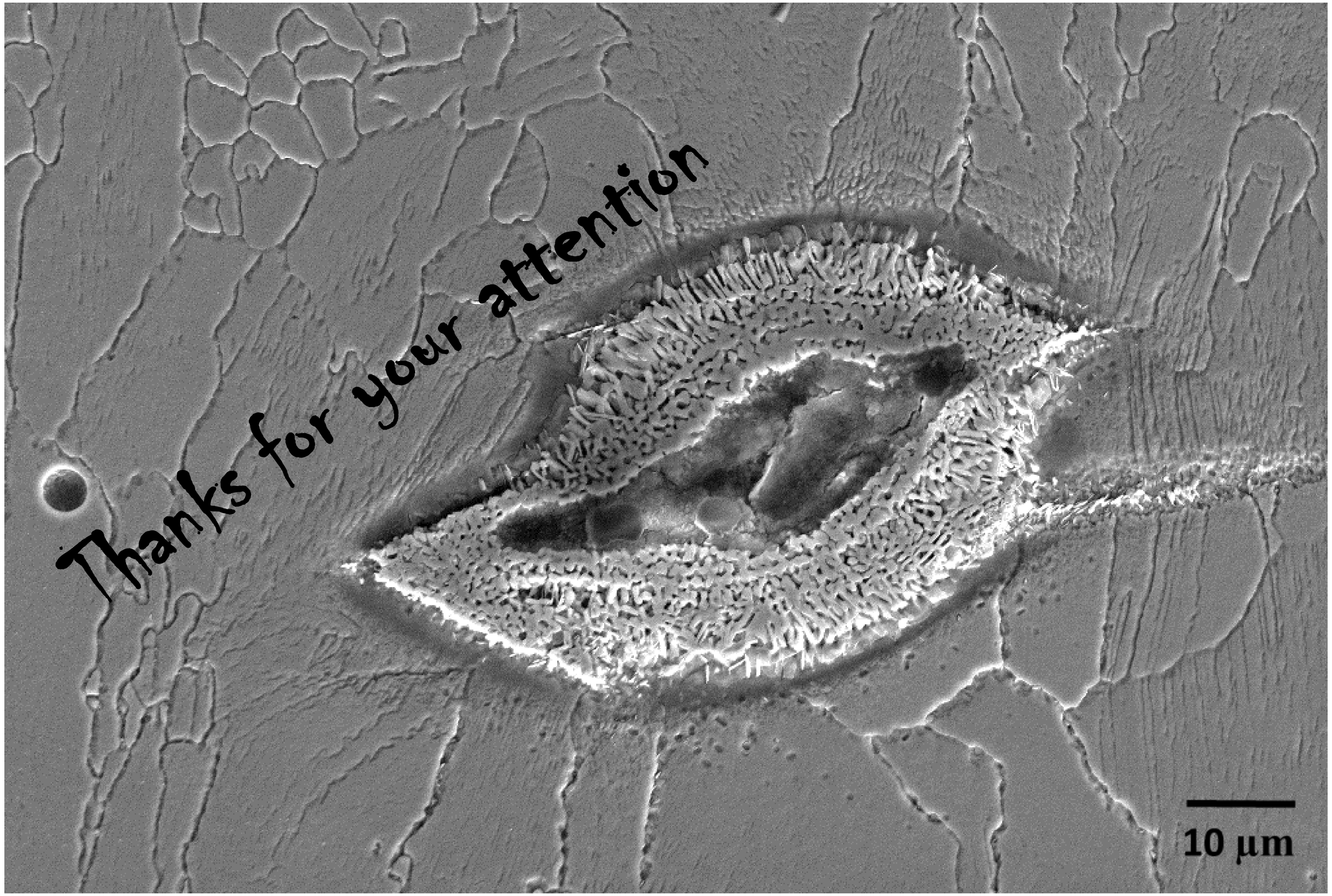
Plans for autumn 2018 and spring 2019

Article completed:
- Comparison: TIG-welded **as-built, SHT** and **SHT+Aged** SLM-A718 with **wrought** A718 samples.

Article under process:
- Comparison: TIG-welded **HIPed** SLM-A718 with **as-built** and **wrought** samples.

Ongoing experiment:
- Varestraint test: **As-built** compared with **HIPed** (Laser welding)

Experiment planned:
- Gleeble hot ductility test; comparing **as-built** with **HIPed** condition.



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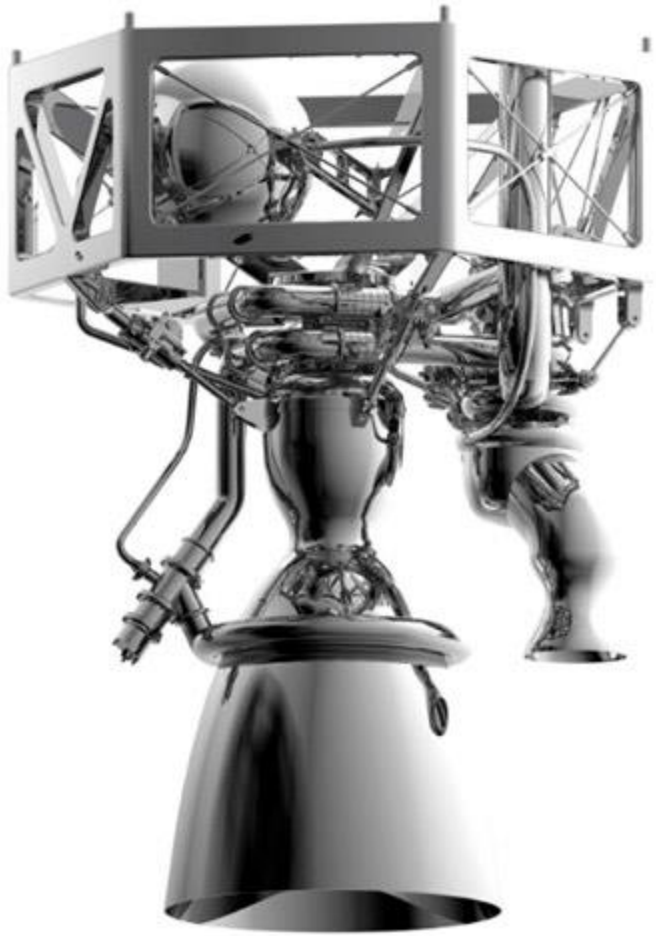
Example of the future application for Alloy 718 Laser Powder Bed at GKN



Prometheus, a low cost reusable rocket engine, using methane propellants

Prometheus casing prototype:
The Prometheus pump main casing is the biggest part produced with an M400 ALM machine

https://www.gknaerospace.com/en/newsroom/news-releases/2018/gkn-aerospace-wins-contract-from-arianegroup-for-ground-breaking-additively-manufactured-rocket-engine-turbines/