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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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.

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?
SiCOMaP
Internationalisation

Internship at

University of Manitoba
Heat affected zone cracking susceptibility of SLM-manufactured Alloy 718

Total crack length measurements

<table>
<thead>
<tr>
<th>Material condition</th>
<th>Specification</th>
</tr>
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<tbody>
<tr>
<td>As-built</td>
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<tr>
<td>Solution heat treatment (SHT)</td>
<td>954°C - 1hr</td>
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<tr>
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<td>982°C - 4.5min</td>
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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
Microstructure of SHT+AGE condition showing (1) delta phase, (2) MC-type carbide and (3) matrix with strengthening phases $\gamma'$ and $\gamma''$.

Solution heat treatment 954°C/ 1hr + Aging heat treatment 760°C/ 5hrs + 649°C/ 1
Delta phase pinning the grain boundary

NbC carbide, γ’ and γ’’

Δ-phase, γ’ and γ’’
Wrought

Mill-annealed at 982°C - 4.5min
Heat affected zone (HAZ) cracking susceptibility of SLM-manufactured Alloy 718

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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 occurred. 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.
Thanks for your attention
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