C3TS report 3 – Heat treatments for AlSi10Mg and 316L

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So far there have been two materials in use which are acid proof steel AISI 316L and aluminum alloy AlSi10Mg. There have been made studies for stress relief heat treatments and without any heat treatments. Studies include:

- Hardness measurements
- Tensile tests

Used oven was Sarlin, with the characteristics to change temperature and time on steps. Also thermoelements were used to ensure the right temperature during the procedure. Hardness were tested by 1 kg weight and Vickers method was in use. Specimens were polished with 800 GRIT sandpaper.

Tensile tests were tested without extensometer which means that real tension is a bit different than graph shows. Speed of the test was 1mm/min up to 3 mm and after that 5mm/min. Tensile test bars were 3D-printed vertical position. For AISI 316L the printing parameters was 30 µm layer thickness. AlSi10Mg parameters was 50 µm layer thickness. There have been made also sandblasting for all specimens. In the fig.1 is shown tensile test bar.

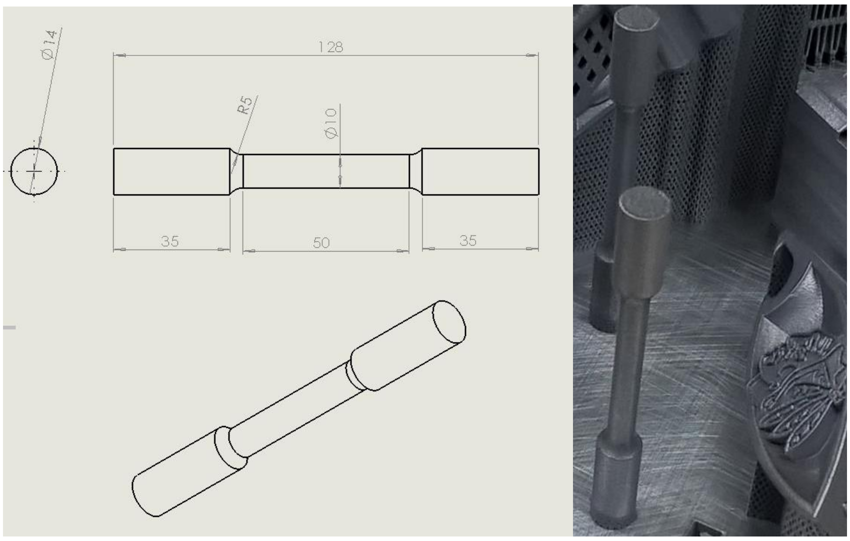

Fig.1 Tensile test bar and 3D-printing orientation

AISI 316L

Oven parameters for AISI 316L was 10 °C /min to 600 °C, 2 h holding time and cooling in air. Also argon atmosphere was in the oven to avoid parts to tarnish. Stress relief treatment is important to AISI 316L because there will be some inner stresses after 3D-printing.

Hardness tests (HV)

Without heat treatments the hardness were about 250 HV and heat treated part had about 230 HV. After heat treatments hardness lowers slightly.

Tensile tests

In fig.2 is shown graph of the tensile tests for AISI 316L.

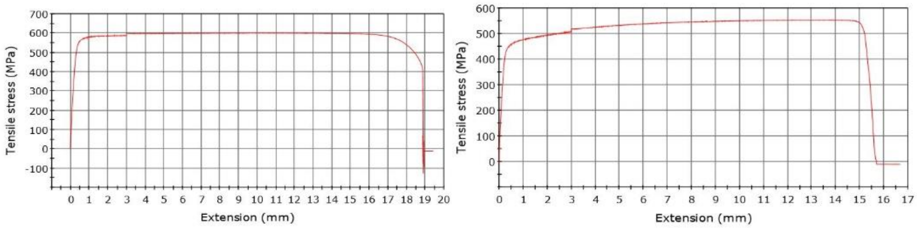

Fig. 2 Tensile tests for AISI 316L (without heat treatments on the left and heat treated on the right side)

Fig.2 shows that yield strength ($R_{p0.2}$) of the without heat treated part is about 550 MPa and 450 MPa for heat treated. Tensile stress is about 600 MPa and 550 MPa respectively. Break strain of the without heat treated specimen is about 16-17 mm.

There were some variation of the heat treated specimens and some of the specimens broke early. This caused that the specimens had to inspect more with microscope. Used microscope were Keyence VHX-2000. There came up really alarming errors. Part of powder has not melted properly during laser processing so this caused porous texture which was the reason for early broke for the specimen. Normal particle size for AISI 316L powder is 10-45 µm and measured grain in microscopic image is about 46 µm. (SLM Solutions material book). In the fig 3. is shown microscopic texture of the specimens. Fig.4. is shown 316L powder on a tape and there can be found microscopic images of powder particles.

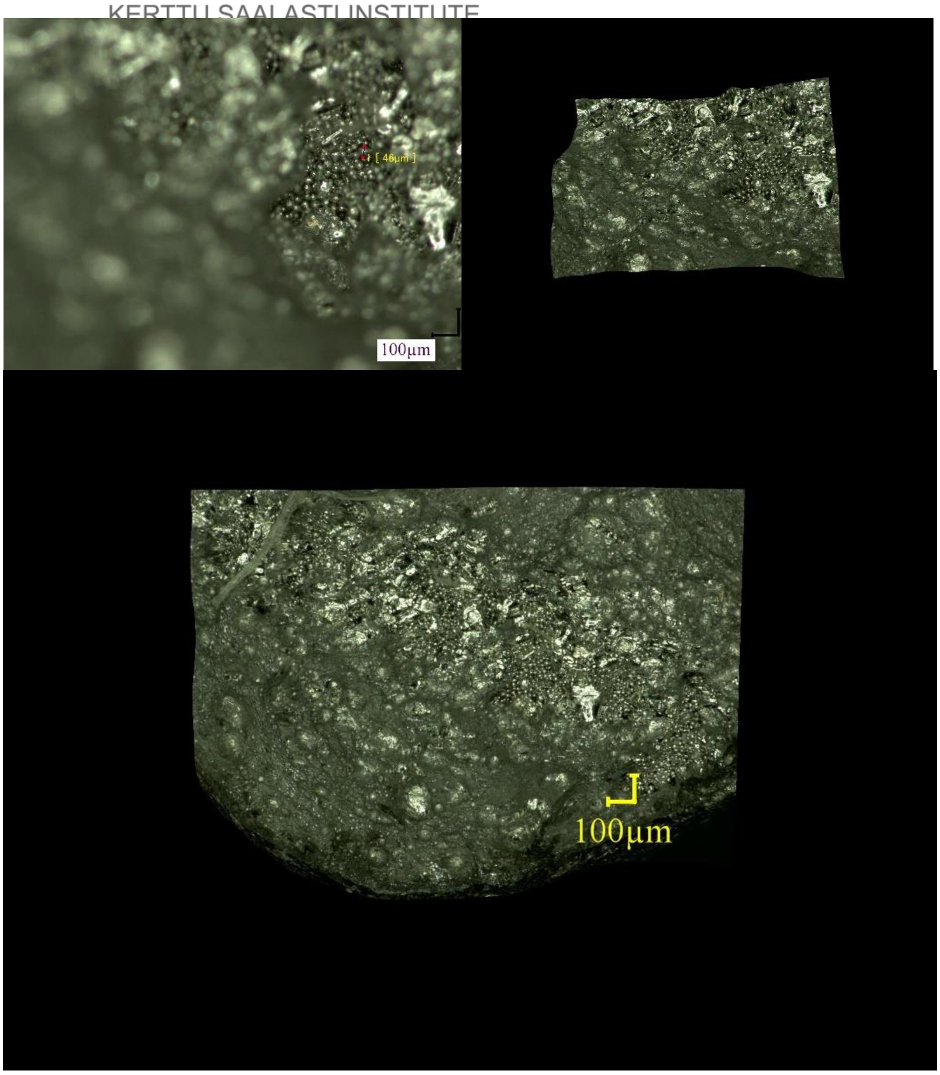

Fig. 3 Microscopic image of the tensile test bar (upper left closer image in fracture plane, upper right is 3D image in fracture plane and lowest is bigger area image)

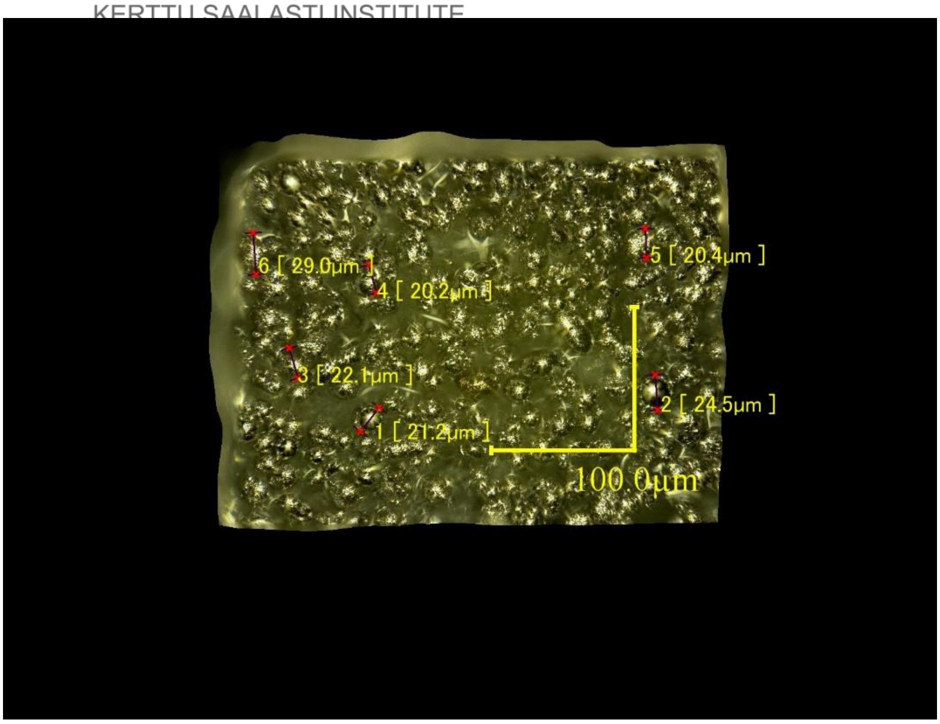

Fig.4 powder particles in microscopic image

In the fig.4 is shown 316L particles on a tape. Particle sizes is 20 µm to 30 µm. It is quite clear that the particle (46 µm) which is measured in fig. 3 is unmelted particle in laserprocessing.

One reason for bad quality of tensile test bars can be that recoater have damaged during the job and made unstable powder bed which have caused porous structure to specimen. Used recoater was made of silicone which is soft material and therefore easy to brake. Using other recoater materials (steel and ceramics) might help to overcome this issue. In the fig.5 is shown unstable powder bed and there can be seen how stripes across tensile test bars (marked with red circles in the pictures) causing porous structure.

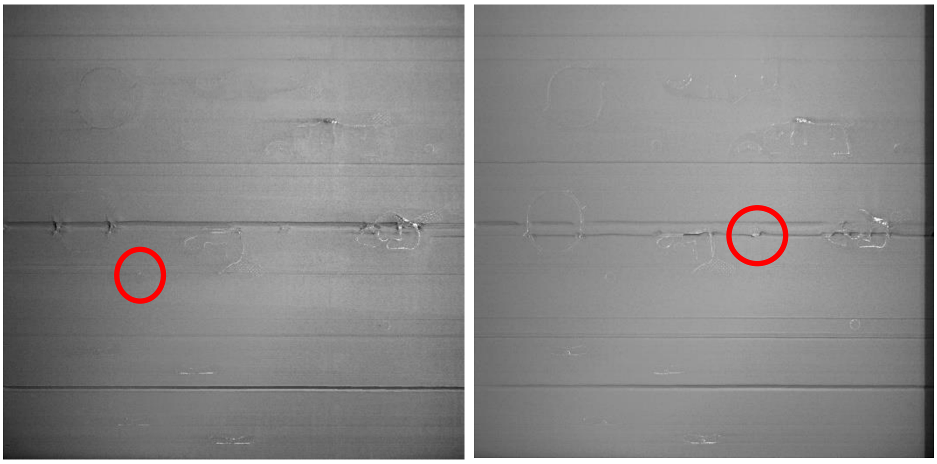

Fig.5 Unstable powder bed

Article 1 shows that there is difference in obtained results compared to this study. Hardness rises up from 245 HV to 271 HV in article 1 when heat-treatment is done and in this study it lowers about 20 HV. In hardness tests used weight was 0.5 kg and in this study it was 1 kg. Also tensile strength rises after heat-treatment from 620 MPa to 650 MPa and in this study it lowers from 600 MPa to 550 MPa. Yield strength lowers in article 1 from 500 MPa to 480 MPa and in this study it lowers from 550 MPa to 450 MPa.

Outokumpu makes same steel grade (1.4404, AISI 316L) in plates and in their handbook (article 2) is shown mechanical properties for hot rolled plate. Yield strength ($R_{p0.2}$) is 260 MPa and $R_{p1.0}$ is 300 MPa. Tensile strength is 570 MPa and break strain 55 %. Hardness is about 180 HV.

AlSi10Mg

Oven parameters for AlSi10Mg was 1 h ramp to 300 °C and 2 h holding time as well as cooling in air. Heat treatments was under argon atmosphere. Aluminum is only heat treated but not ageing treated.

Hardness tests (HV)

Without heat treatments the hardness were about 124 HV and heat treated parts had about 92 HV. This shows that the hardness of the parts will lower when heat treatment is done.

Tensile tests

In fig.6 is shown graph of tensile test.

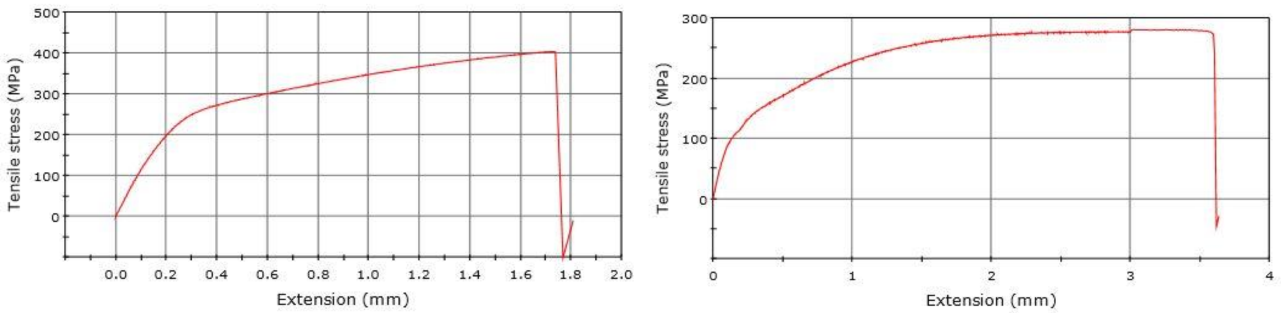

Fig.6 Tensile test graph for AlSi10Mg; without heat treatments on the left and on the right side is heat treated

Fig.6 shows that yield strength ($R_{p0.2}$) of the without heat treated specimen is about 250 MPa and 150 MPa for heat treated specimen. Tensile stress is 400 MPa without heat treated and 300 MPa for heat treated. Break strains are 1.6 mm and 3.5 mm respectively.

Same kind of results for material behavior (AlSi10Mg) after solution heat treatments is studied in article 3. There the heat have been 550 °C and 2 h holding time. The results are same kind:

- Tensile strength lowers to 168 MPa which is 434 MPa without any heat treatments
- Hardness also lowers when heat treatments are done (depending on how high is the heat). In hardness tests (in this study and article 3) used weight was 1 kg.
- Toughness remarkably increases from 5.3 % to 23.7 %.

In article 4 is inspected the mechanical properties for casted AlSi10Mg. For conventional cast and aged aluminum the ultimate tensile strength (UTS) is 300-317 MPa and hardness is 86 HV which is measured with 0.5 kg weight. With high pressure die casting the values are UTS 300-350 MPa and hardness 95-105 HV. Previous with aged condition values are UTS 330-365 MPa and hardness 130-133 HV. This means that aluminum AM parts are competitive in mechanical properties with casted ones.

Conclusions of heat treatments

- Mechanical properties lowers slightly after heat treatments for AISI 316L
    - Yield strength ($R_{p0.2}$) 550 MPa → 450 MPa
    - Tensile strength 600 MPa → 550 MPa
    - Toughness remains almost same
- Porous texture can be due to bad recoating
    - When structure is porous the mechanical properties lowers critically
        - especially toughness
    - More studies need to be done
- AISI 316L mostly needs stress relief treatments
- Mechanical properties for AlSi10Mg will lower after this specific heat treatment
    - Yield strength ($R_{p0.2}$) 250 MPa → 150 MPa
    - Tensile strength 400 MPa → 300 MPa
- Except the toughness will grow
    - Break strain 1.6 mm → 3.5 mm
- Difficult to verify the deformations due to inner stresses for aluminum

References

Article 1: M.L. Montero Sistiaga et.al, Effect of heat treatment of 316L stainless steel produced by selective laser melting (SLM); Conference paper (2016)

Article 2: Outokumpu Stainless Steel Handbook, 53/92, http://www.outokumpu.com/sitecollectiondocuments/outokumpu-stainless-steel-handbook.pdf

Article 3: Wei Li et.al, Effect of heat treatment on AlSi10Mg alloy fabricated by selective laser melting: Microstructure evolution, mechanical properties and fracture mechanism; Materials science & Engineering A 663, 116-125 (2016)

Article 4: K.Kempen et.al, Mechanical properties of AlSi10Mg produced by Selective Laser Melting; Physics Procedia 39, 439-446 (2012)