



HAL
open science

Influence of process parameters on the final 316L stainless steel properties manufactured by selective laser melting (SLM)

A. Chniouel, F. Lomello, P. F. Giroux, P. Aubry, H. Maskrot

► **To cite this version:**

A. Chniouel, F. Lomello, P. F. Giroux, P. Aubry, H. Maskrot. Influence of process parameters on the final 316L stainless steel properties manufactured by selective laser melting (SLM). Euromat2017, Sep 2017, Thessalonique, Greece. cea-02417316

HAL Id: cea-02417316

<https://cea.hal.science/cea-02417316v1>

Submitted on 18 Dec 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

INFLUENCE OF PROCESS PARAMETERS ON THE FINAL 316L STAINLESS STEEL PROPERTIES MANUFACTURED BY SELECTIVE LASER MELTING (SLM)

A. CHNIOUEL^{a*}, Dr F. LOMELLO^a,
Dr P.F. GIROUX^b, Dr P. AUBRY^a,
Dr H. MASKROT^a

^aDEN – Service d'Etudes Analytiques et de Réactivité des Surfaces (SEARS), CEA, Université Paris-Saclay, F-91191, Gif sur Yvette, France.

^bDEN – Service de Recherches Métallurgiques Appliquées (SRMA), CEA, Université Paris-Saclay, F-91191, Gif sur Yvette, France

*Corresponding author *E-mail adress*: aziz.chniouel@cea.fr

Additive Manufacturing: growing technology in the industrial world for different sectors: aeronautics – automotive – medicine.

- ❖ **Nuclear industry?** Exploring by DOE (U.S.A) since 2012 for different materials: IN600, IN718, IN800, 316L SS, ODS steels.
- ❖ **Benefits:**
 - Complex manufacturing of geometrical parts for nuclear applications.
 - Components manufacturing which are impossible to process by others traditional processes (cast, forge, rolling,...).
 - Processing steps reduction depending on parts complexity (i.e. GE-SAFRAN Leap-X fuel injector).
 - Waste reduction: powder recyclability.
 - **Rapid prototyping.**
- ❖ **Question:** Is additive manufacturing adapted for producing nuclear components? (GEN IV – Sodium Fast Cooled Reactor).
 - Material: 316L SS.
 - Mechanical, corrosion and irradiation properties ?
 - **Understand relation between process and microstructure.**



Raw material properties: 316 SS powder

Experimental details

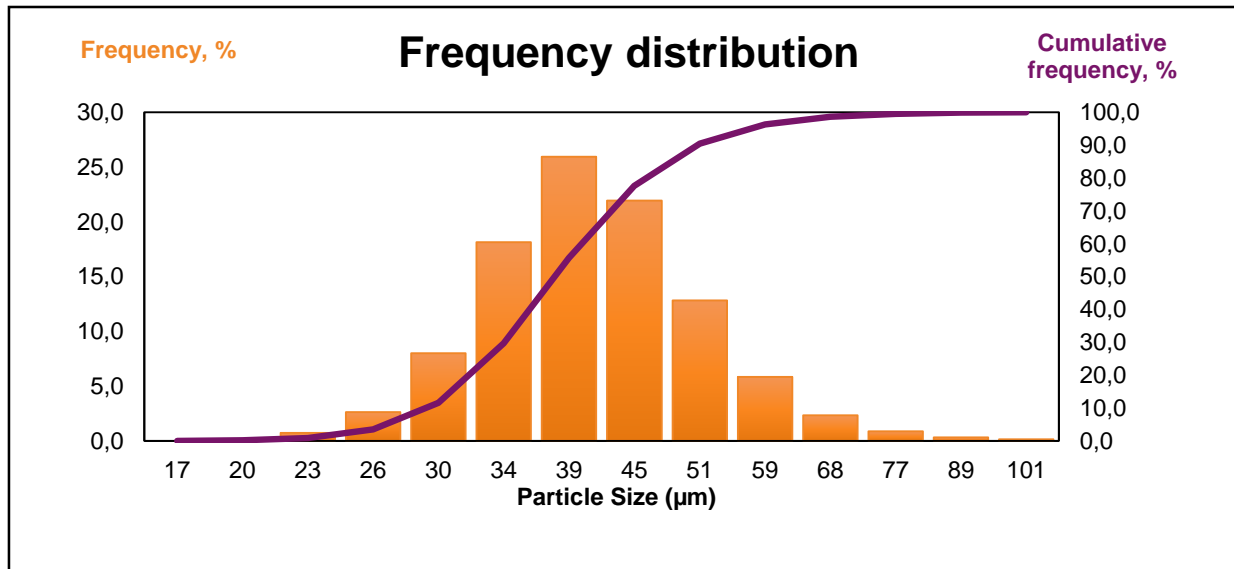
Influence of the processes parameters on the samples properties

❑ Chemical composition

	Majority elements by ICP-OES (% wt) (uncertainly related of 3%)					Minority elements (%wt) By GDOES and LECO (uncertainly related of 5%)				
	Cr	Ni	Mn	Si	Mo	C	N	O	S	P
Standard RCC-MRx	16,5-18,50	10-13	2 max	1 max	2-2,5	300 max	1100 max	-	150 max	300 max
316L SS powder	17,35	11,45	1,06	0,51	2,07	230	982	1876	130	305

- Chemical composition in good agreement with RCC-MRx Code → French Nuclear Standard for Experimental Reactors

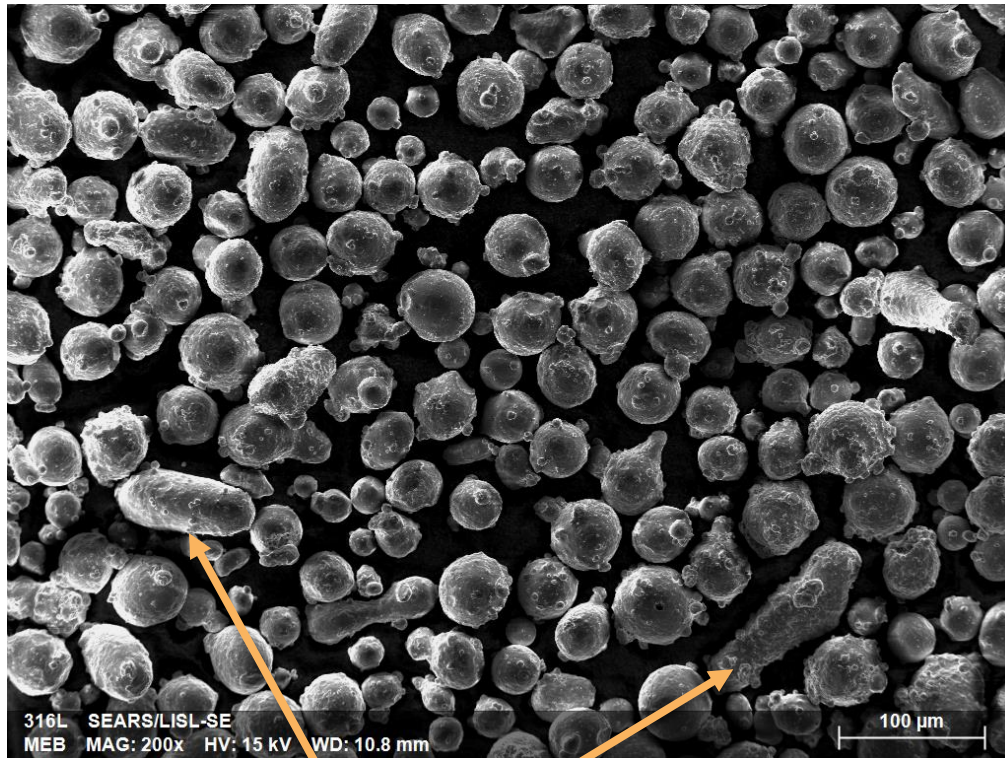
❑ Particles size



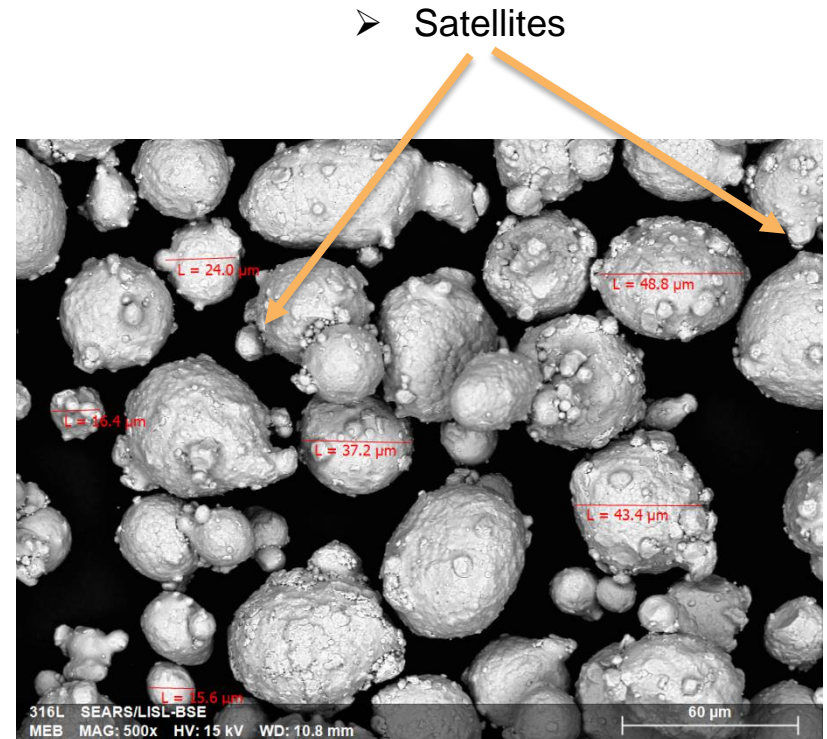
D₁₀	29 µm
D₅₀	38 µm
D₉₀	51 µm

❑ Morphology

- Argon atomized powder.
- Typical heterogeneous shapes.



➤ Rod-like particles



Raw material properties: 316 SS
powder

Experimental details

Influence of the processes parameters
on the samples properties



SLM 280^{HL}

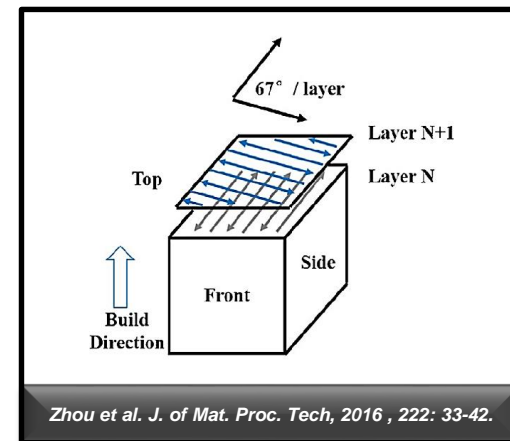
- Selective laser melting
- Power max: 400 W
- Ytterbium doped laser fiber.
- Laser's spot size: 75 µm

❖ Fixed process parameters:

- Power: 175W
- Layer thickness, $e=30\ \mu\text{m}$
- Scan speed, $v=700\ \text{mm/s}$
- Hatching distance, HD: $100\ \mu\text{m}$

$$E = \frac{P}{e \cdot v \cdot HD} = 84\ \text{J/mm}^3$$

- Argon gas atmosphere.
- Scan Strategy:
incrementation of 67° between each layer

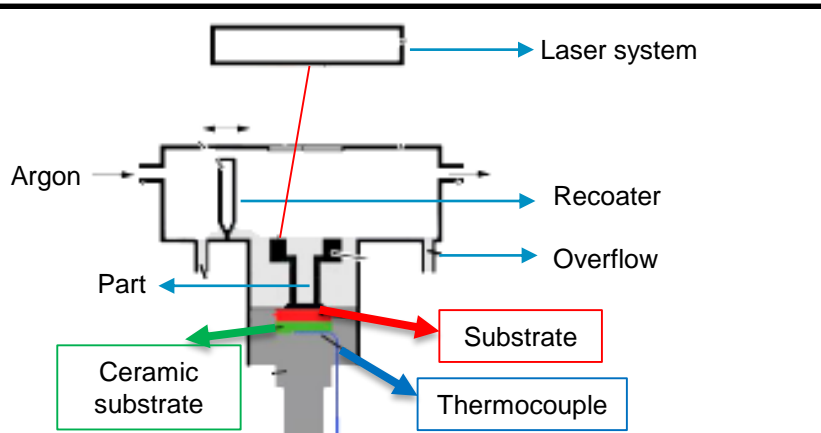


Zhou et al. J. of Mat. Proc. Tech, 2016 , 222: 33-42.

❖ Variable process parameter:

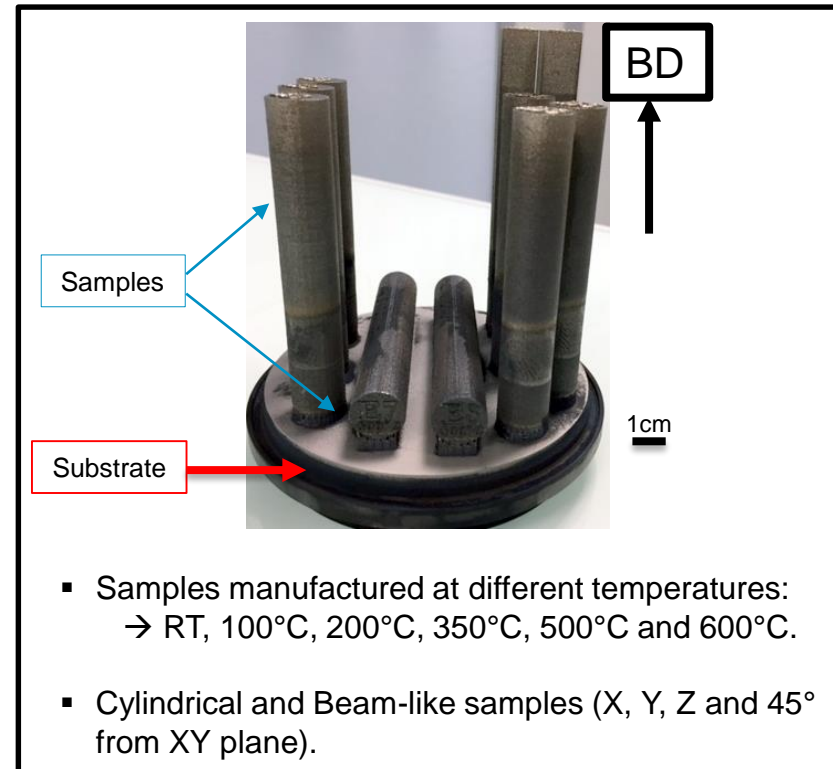
- Heating Platform

$$RT=25^\circ\text{C} < T < 600^\circ\text{C}$$



Flow diagram

- Build envelope size: $\varnothing=100$ mm and height 100 mm.
- Aim: reduce thermal stresses and formation of cracks in the parts.



- Samples manufactured at different temperatures:
→ RT, 100°C, 200°C, 350°C, 500°C and 600°C.
- Cylindrical and Beam-like samples (X, Y, Z and 45° from XY plane).

Aim of In situ heat:

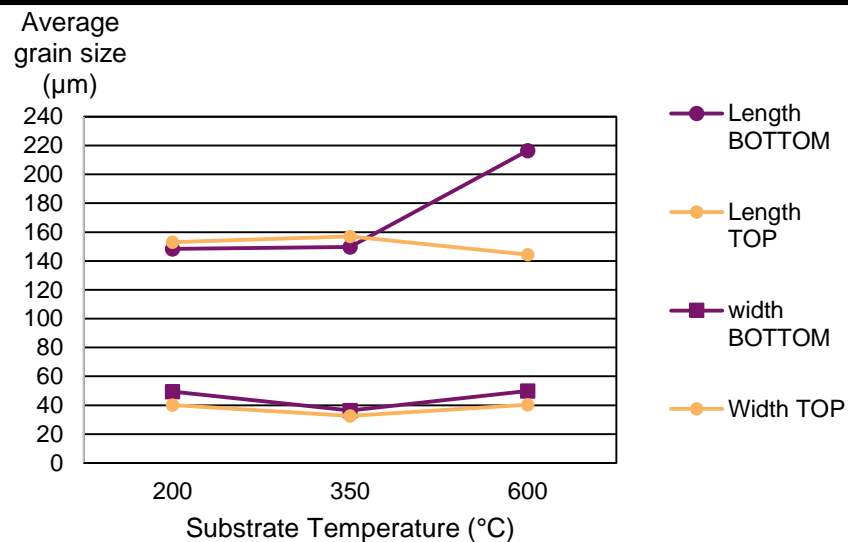
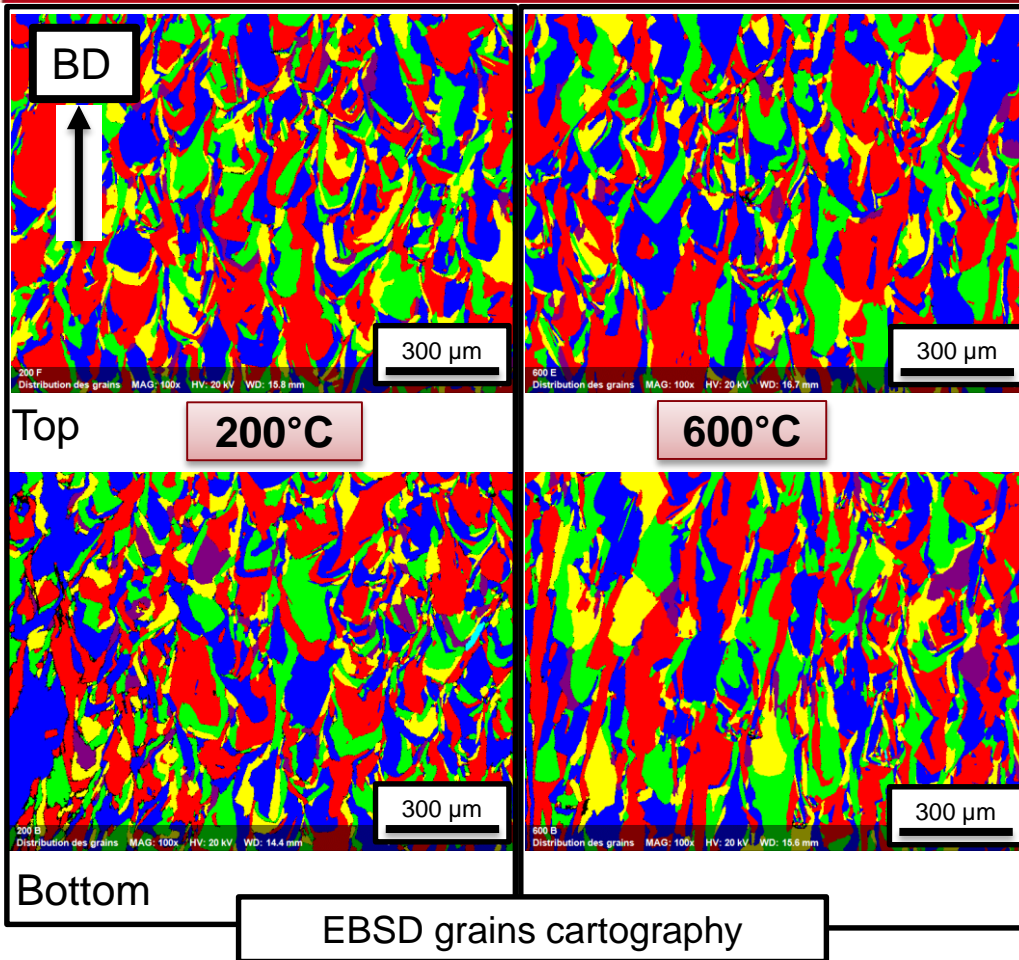
- Decrease internal thermal stresses.
- Grain sizes modification.
- **“In situ” heat treatment in order to reduce post process steps.**

Experimental details

Raw material properties: 316 SS
powder

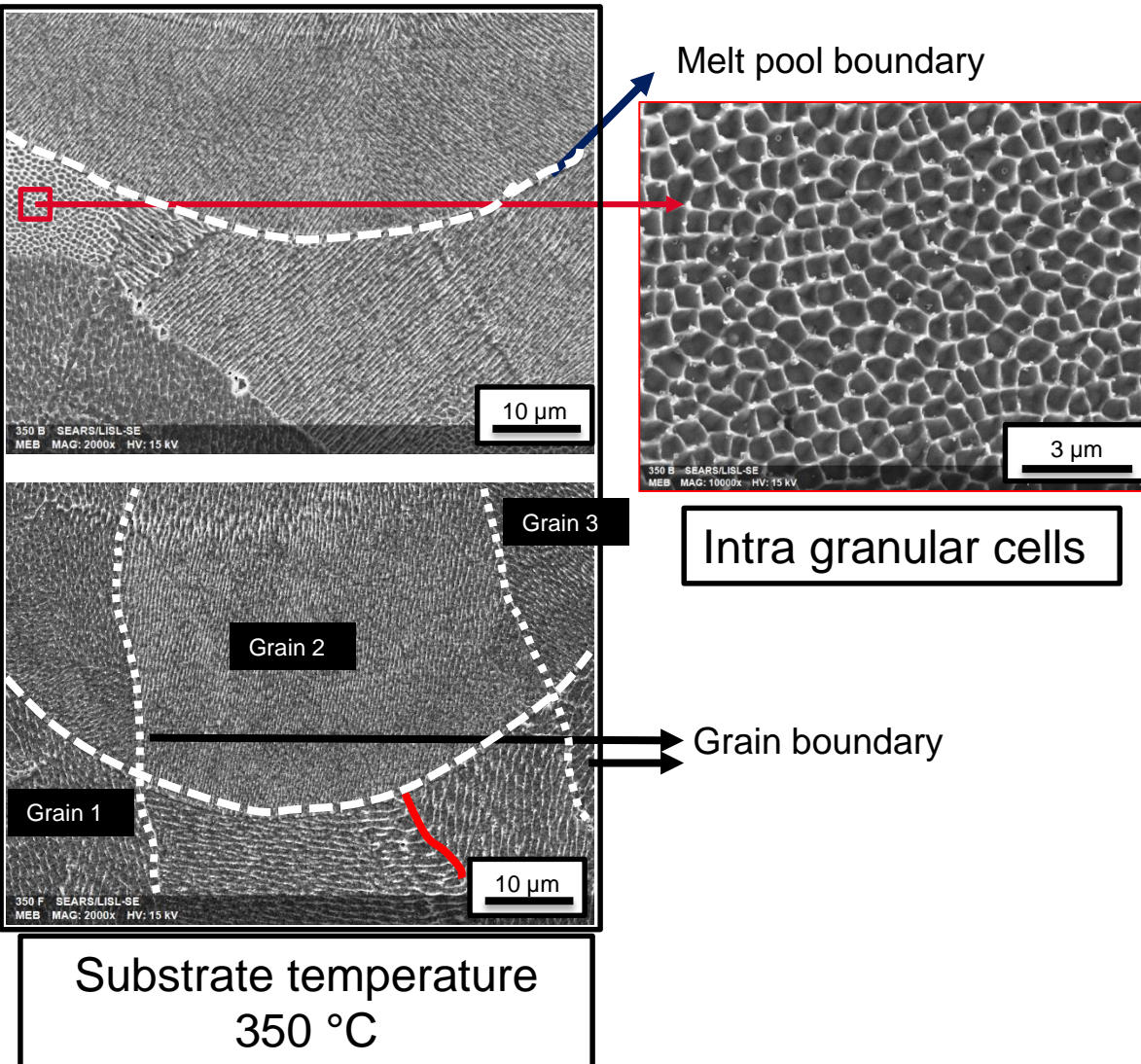
Influence of processes parameters on
the samples properties

Micro scale: Grains



- Columnar grains along B.D.: length around 4 times width.
- Grains grow across layers (30 μm).
- Grains are more **elongated at 600°C on the BOTTOM** (L=220 μm)
→ Grains size influenced by the substrate temperature (Temperature higher at the bottom).
- No influence of temperature on grains width.

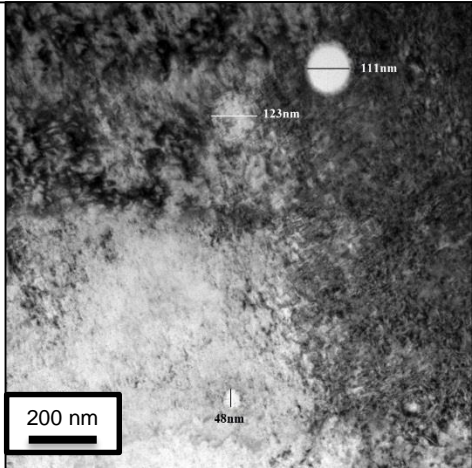
Micro scale: Grains



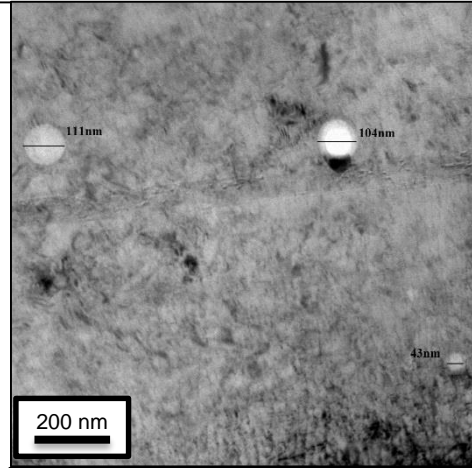
- No significant influence of the substrate temperature on the cells size:
- intra granular cells size between 0.6 and 1 μm .
- High cooling rate (10^3 - 10^6 K/s) - *Casati and al. Journal of Materials Science and Technology*, 2016, 32: 738-744
- Inside a same grain: (grain 2) Direction of growth of S/L interface can vary from one melt pool to another - *Mertens and al., Materials Science*, 2011, 783-786, 898-903

Nano scale: Precipitates

- ❑ Analyse at the middle of the sample height (4.5 cm).
- ❑ No influence of the substrate temperature on:
 - Structure: amorphous.
 - Shape: spherical.
 - Size: diameter ranging 10 to 170 nm.
 - Composition: O, Si, Mn.
 - Trace of S, Mo and Al in some precipitates.

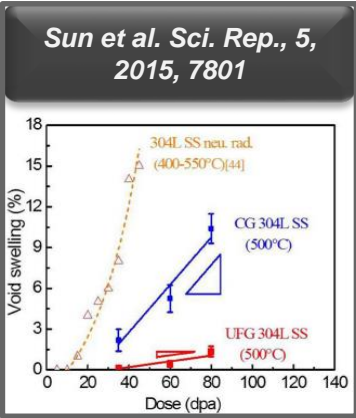
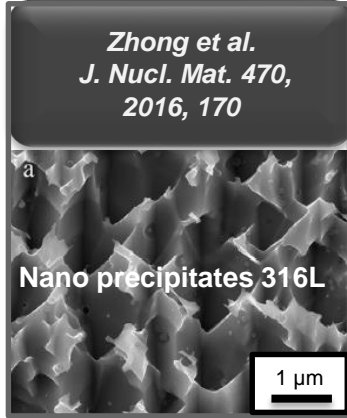


STEM BF
Substrate Temperature 350°C



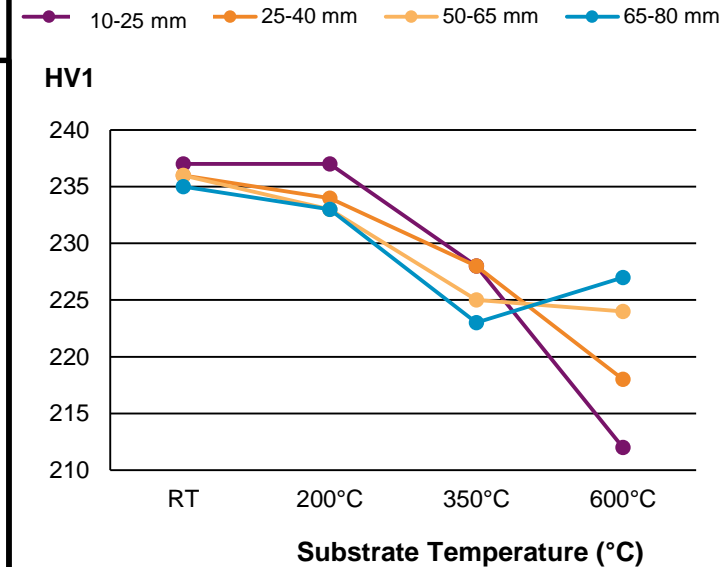
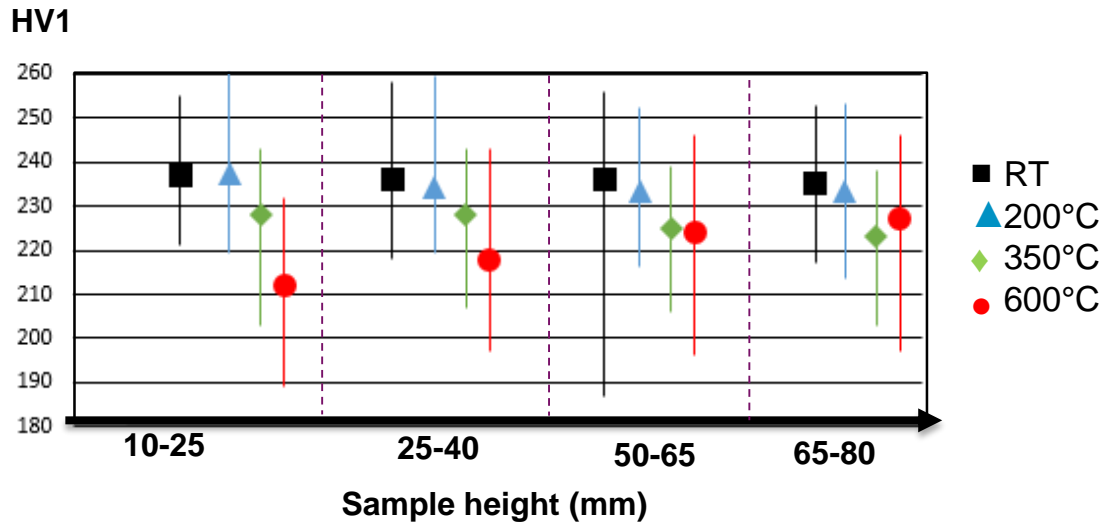
STEM BF
Substrate Temperature 600°C

- ❑ Nano oxides formation in situ during the build process → improve mechanical properties - *K. Saeidi Ph. D. Thesis (2016)*.
- ❑ Precipitates size and density are highly influenced by the oxygen content in the build chamber - *Zhou et al. Mater. Sci. Eng., 2017, 167*.
- ❑ Nano precipitates can improve swelling resistance under neutron irradiation - *Sun et al., Sci. Rep., 2015, 5, 7801*.



Micro Hardness

Microhardness along **building direction**, Z direction.



→ No influence of the height on microhardness for RT, 200°C and 350°C.

→ At **600°C**, microhardness increases linearly according to sample height.

- Grains more columnar (Hall Petch effect)
- Internal stresses relieved on the **BOTTOM**
- **Thermal gradient.**

→ Microhardness decreases as a function of temperature.

→ Same trend observed after heat treatment - *Herliansyah and al., Proceedings, 2015.*

Zhong et al. J. Nucl. Mat. 470 (2016) 170.

Micro-hardness measured on the side (top and bottom in building direction) and cross-section surface (HV1) of as-built sample, cf. discussion in the text.

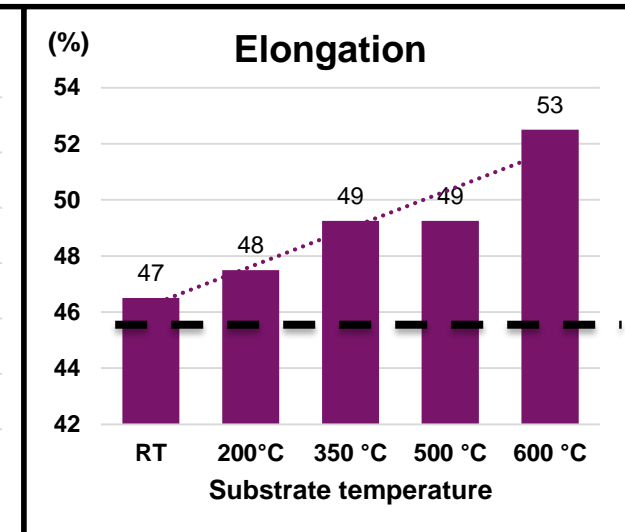
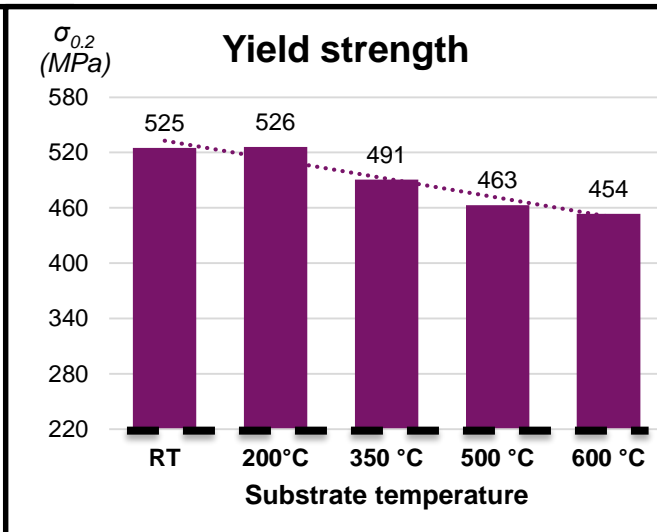
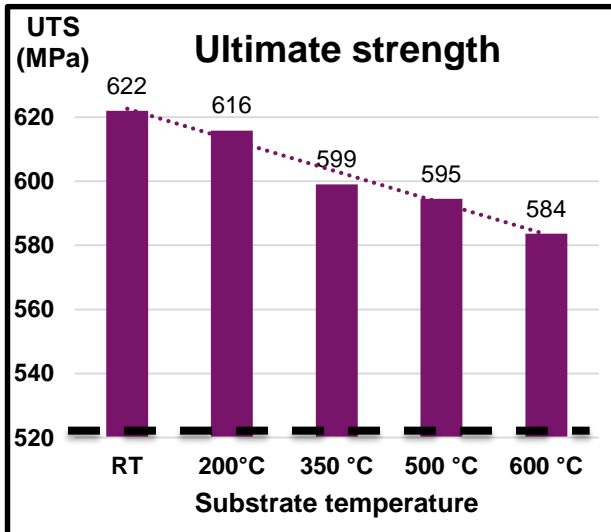
Bottom of side surface	Top of side surface	Cross-section	HIPed(Hv0.3) [26]
239 ± 5	219 ± 5	228 ± 4	~220

→ Same values reported by *Zhong*:

Tensile test
Samples manufactured along B.D.
Influence of the substrate temperature

- Samples machined according the ISO 6892-1 standard.
- Test at room temperature.

— Forged 316LSS, RCC-MRx France nuclear Standard



- Strength and Yield strength decrease linearly as a function of temperature.
- Similar trend followed by the microhardness.

- Elongation increases linearly as a function of temperature.

➤ Same trend observed after heat treatment:

Dislocation / Internal stresses relieved ?



Grains are more columnar along building direction when temperature increases.

- Mechanical properties respect the minimum requirement of the nuclear standard.

❑ Microstructure:

- ❖ Columnar grains along the Z-direction with intra granular cells (around 0.6 to 1 μm).
- ❖ **Grains length** influenced by substrate temperature especially at **600°C** on the **bottom** of sample.

❑ Mechanical properties:

- ❖ Same trend observed after heat treatment.
- ❖ **Mechanical properties respect the minimum requirement of the nuclear standard.**

❑ Perspectives:

- ❖ Measurement of the internal stresses.
- ❖ Mechanical properties as a function of **build direction** at high substrate temperature.
- ❖ Post-processing heat treatments and hot isostatic pressing.

Thank
you for
your
attention.