Willkommen
Welcome
Bienvenue

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Materials Science and Technology

Laser additive manufacturing of a tailored 2xxx Al-Cu-Mg alloy

AMTC Conference – 12th-14th October, 2021

P. Hoffmann, M. Schuster

AM equipment at Empa

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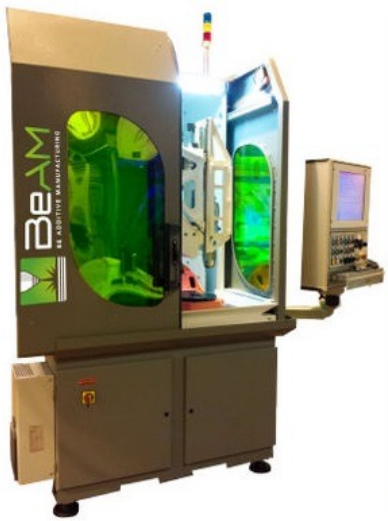
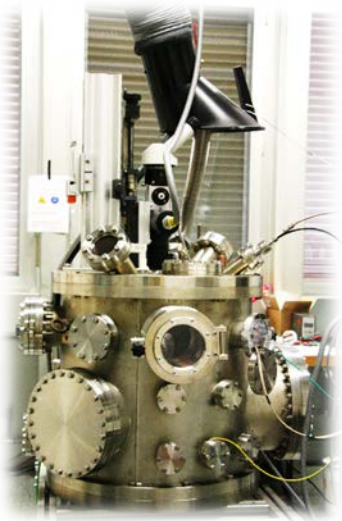


Beam Mobile1.0
MP + NP DED

800 µm



Home-built DMD NIR, 532nm

10 µm

Sisma MySint 100

55 µm

Concept Laser M2

95 µm

AddUp FormUp350

70 µm

Monitoring of 3-D metal printing

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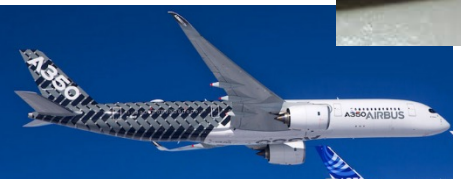
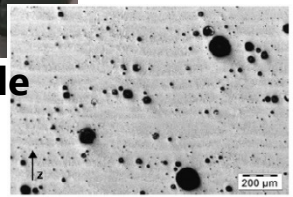
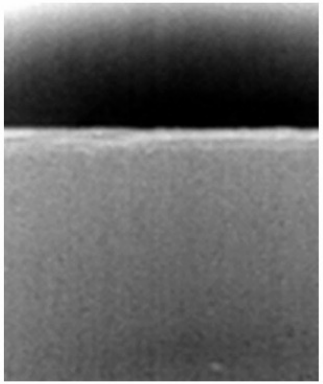
Bad sample

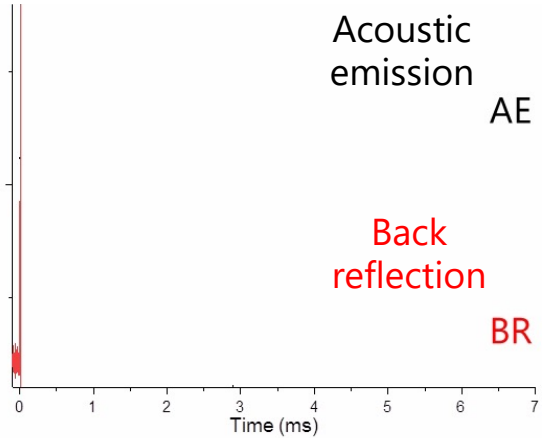


Good sample



Invisible defects





High speed X-ray imaging of a 10 ms laser pulse

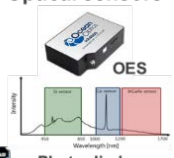
Acoustics

Piezo

Optical Fibre

High speed imaging

Optical sensors



Sensors

Machine learning / Artificial intelligence

Human intelligence

Real-time monitoring & control

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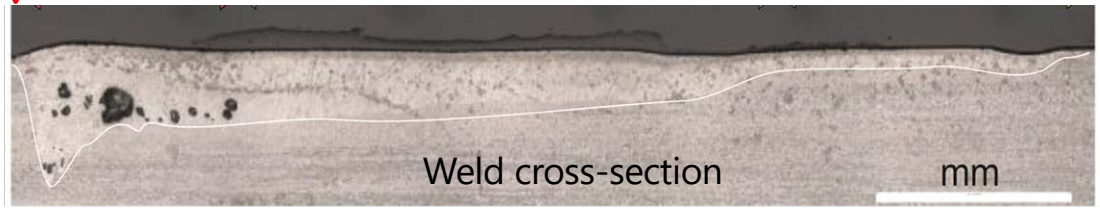
Laser beam

Real-time process monitoring

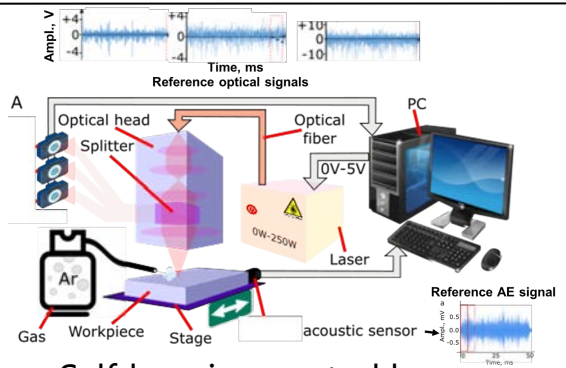


Bad process (1) | Good process | Bad process (2)

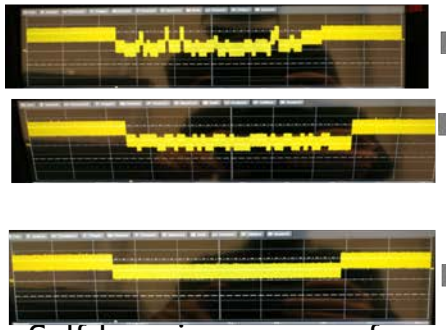
Quality classification

Classifications
- Accuracy **> 90%**
- Distance = **25 µm**
- Time:
  - Today **70 ms**
  - Tomorrow **1 µs**
  - Planned **100 ns**

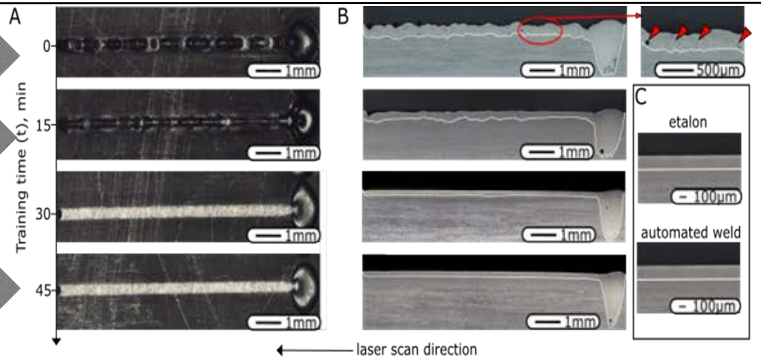
Shevchik S.A., Le-Quang T., Vakili-Farahani F., Neige F., Meylan B., Zanoli S., and Wasmer K., IEEE Access, Vol. 7, Issue 1, pp: 93108 - 93122, 2019



Self-learning control loop



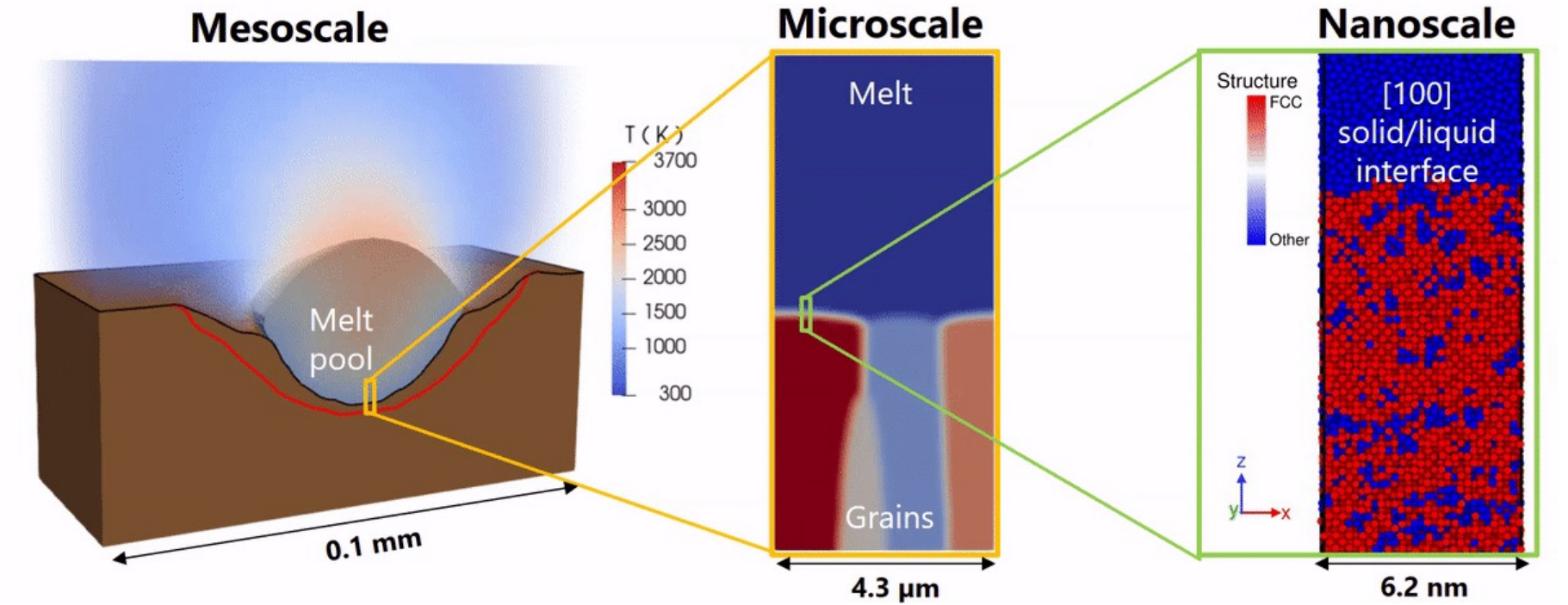
Self-learning process for defect free laser welding



Comparision self-learning control and etalon

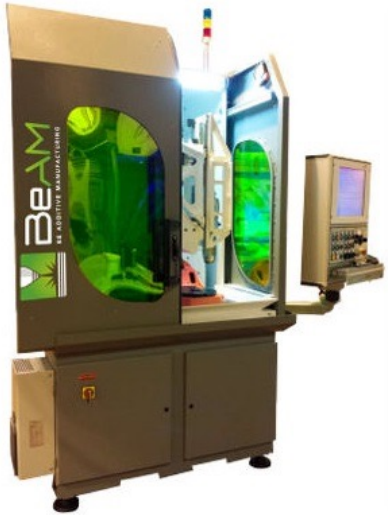
Masinelli G., Le-Quang T., Zanoli S., Wasmer K., and Shevchik S.A., IEEE Access, 2020

Multiscale microstructure modeling

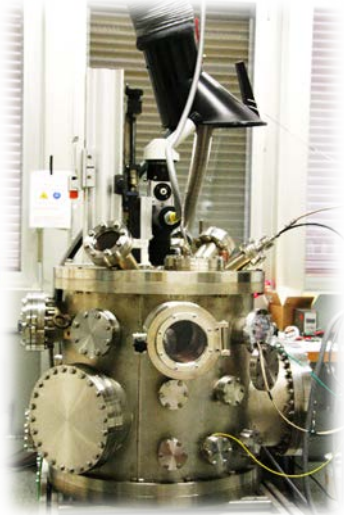


Multiscale modeling of solidification microstructure in copper after laser melting

AM equipment at Empa



Beam Mobile1.0



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AM equipment at Empa

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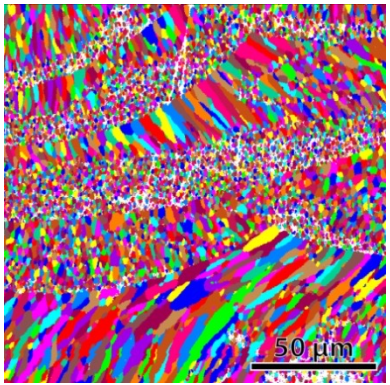
Al_{2xxx} cross section EBSD

Upper part, second laser scan

Cooling rate
~10^6 K/s



Cooling rate
~10^4 K/s

Sisma MySint 100

55 µm

The alternative – new powder alloy !

- **Pros**
- Printable with any metal fusion printer
- Large printing process window
- Printing at high built-up rates
-
- **(Con)**
- Heat treatment

AM of 2xxx series Al-Cu alloys

Applications and challenges

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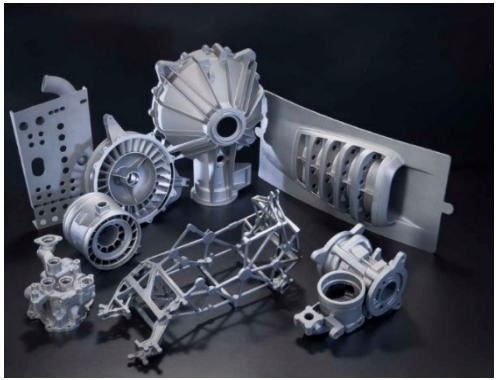
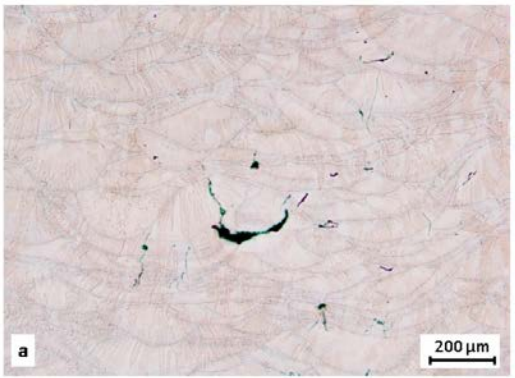
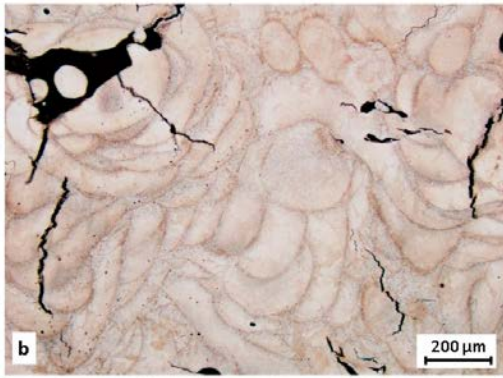


AM





D. Koutny et al., *Influence of Scanning Strategies on Processing of Aluminum Alloy EN AW 2618 Using Selective Laser Melting*, Materials. 11 (2018) 298.

2xxx series Al-Cu alloys are…

- **Heat-treatable**
- Show **excellent mechanical properties**
- **Widely used** in aerospace, defense, automotive
  (Pistons, impellors etc.)

BUT:

- **Non-weldable**
- Show **extensive cracking during AM**, even for optimized processing conditions
- **Heat-treatment** for AM parts often **not successful**
- **No commercial AlCu alloy** for AM available

Processing 2xxx series alloys by AM is challenging. Improvements in the composition are required.
How can the alloy composition be tailored to AM?

Development of model alloy

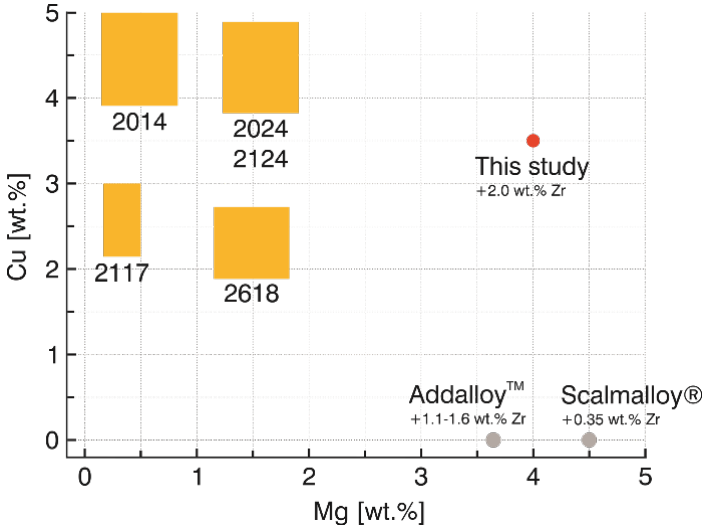
Alloying and Heat-Treatment Strategy

A, Alloying strategy

- … **Simple model alloy system**
- … Reduced to main precipitate-forming elements Al-Cu-Mg-Zr
- … Solving the cracking issue
- … Add 2 wt.% **Zr**
  - *1. Equiaxed grains*
  - *2. Precipitation hardening*
- … Increase **Mg** content
  - *Compensate Mg evaporation*

Wt.-%	Al	Cu	Mg	Zr
Target	Rem.	2.40	**4.00**	**2.00**

- **Composition of typical 2xxx series** alloys, two commercial AM alloys and this study



Combining findings of 5xxx alloys (Addalloy™, Scalmalloy®) to 2xxx alloys to mitigate cracking.
What about the heat-treatment?

Development of model alloy

Alloying and Heat-Treatment Strategy

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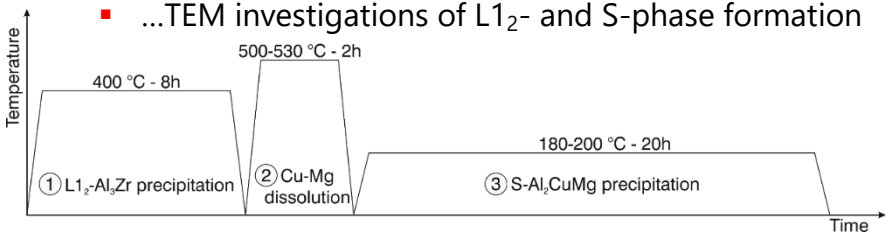
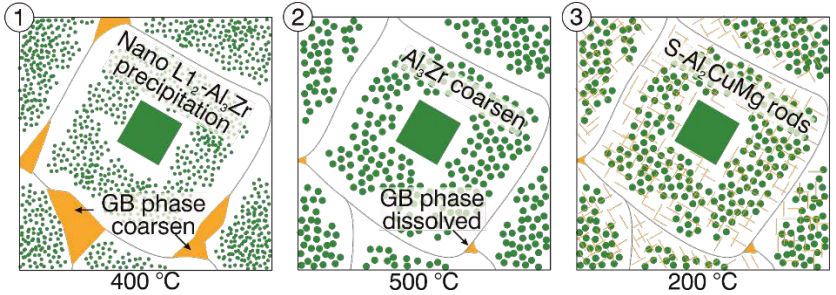
As-built

Wt.-%	Al	Cu	Mg	Zr
Target	Rem.	2.40	**4.00**	**2.00**

B, Heat treatment strategy

- … **Examination of precipitate formation by**
  - …Thermodynamic simulations using Thermo-Calc®
  - …TEM investigations of $L1_2$- and S-phase formation

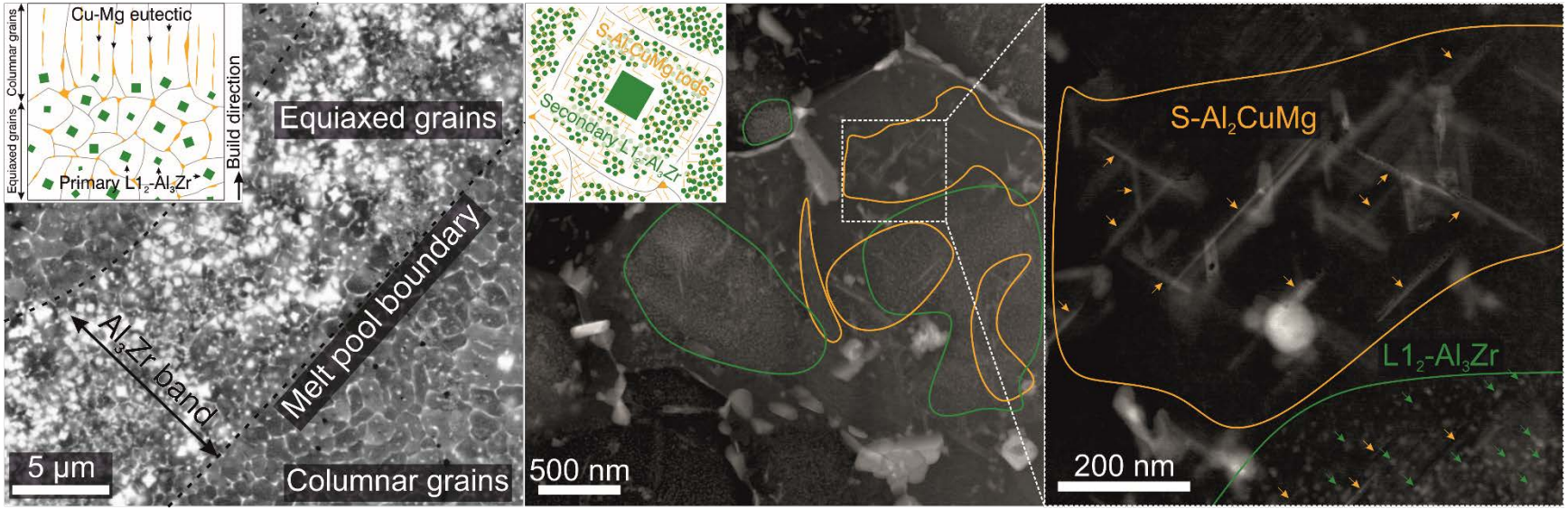




Simplified composition, still forming crucial precipitates ($L1_2$, S) responsible for strengthening.
Is it processible? Do the predicted phases form? How about mechanical properties?

LPBF of tailored alloy

As-built and Heat-Treated Microstructure



As-built

- Highly dense
- No cracks
- Fine grained, equiaxed microstructure

Three-step heat treated

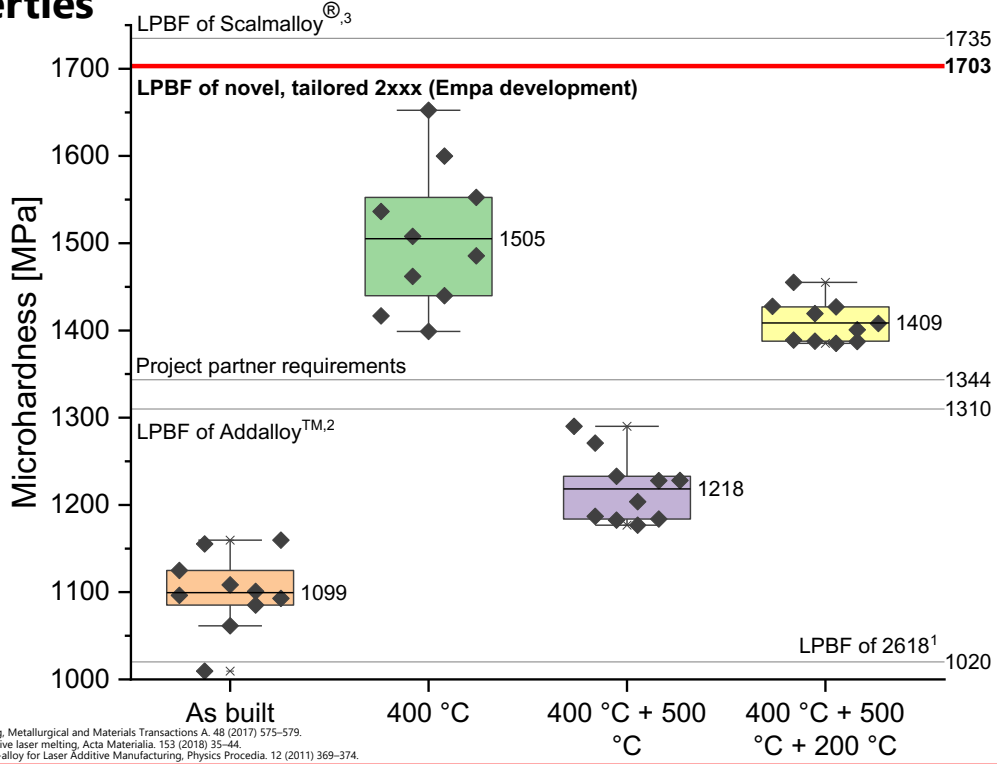
- Precipitation strengthening by nm-sized $L1_2$/S-phase
- High microhardness, young's modulus and yield strength

Schuster et al., Precipitation in a 2xxx series Al-Cu-Mg-Zr alloy fabricated by laser powder bed fusion, Materials & Design. 211 (2021) 110131.

The alloy shows a **highly dense (>99.5%), crack free** and **extremely fine-grained** microstructure. For the first time, the crucial **nm S- and $L1_2$-phases** could be proven for **AM of a 2xxx alloy**.

LPBF of tailored alloy

Mechanical Properties



1: Casati et al., Aging Behavior of High-Strength Al Alloy 2618 Produced by Selective Laser Melting, Metallurgical and Materials Transactions A. 48 (2017) 575–579.
2: Croteau et al., Microstructure and mechanical properties of Al-Mg-Zr alloys processed by selective laser melting, Acta Materialia. 153 (2018) 35–44.
3: K. Schmidtke et al., Process and Mechanical Properties: Applicability of a Scandium modified Al-alloy for Laser Additive Manufacturing, Physics Procedia. 12 (2011) 369–374.

The simple model alloy shows **excellent mechanical properties** as compared to other alloys.
Strong strengthening effect by **grain refinement** and **precipitation hardening.**

Conclusions and Outlook

Summary and what comes next?

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Summary

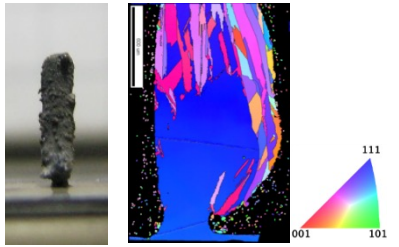
- **AlCuMgZr can be processed by additive manufacturing (LPBF)**
- Preliminary DMD tests were successful and showed promising microstructures and hardnesses
- **High relative density** and **very few defects**
- Successful confirmation of expected phases by TEM
- As-built part shows the anticipated chemical composition
- **Mechanical properties** of project partner fulfilled, **exceeding** properties of **comparable LPBFed alloys**

Outlook

- Experimental evaluation of **DMD processability, heat-treatability and mechanical performance**
- **Tests for laser weldability**
- **Apply knowledge to other 2xxx series alloys** – Development of novel or modification of established, widespread alloys to laser-based AM
- **Commercialization** of advanced 2xxx alloy compositions

Thank you

Si pillars on wafer



M. Le Dantec, et al. Proc. Int. Conf. Add. Manu. in Products and Applications (2018)