Corrosion (and also wear-) resistant Fe-base materials for AM

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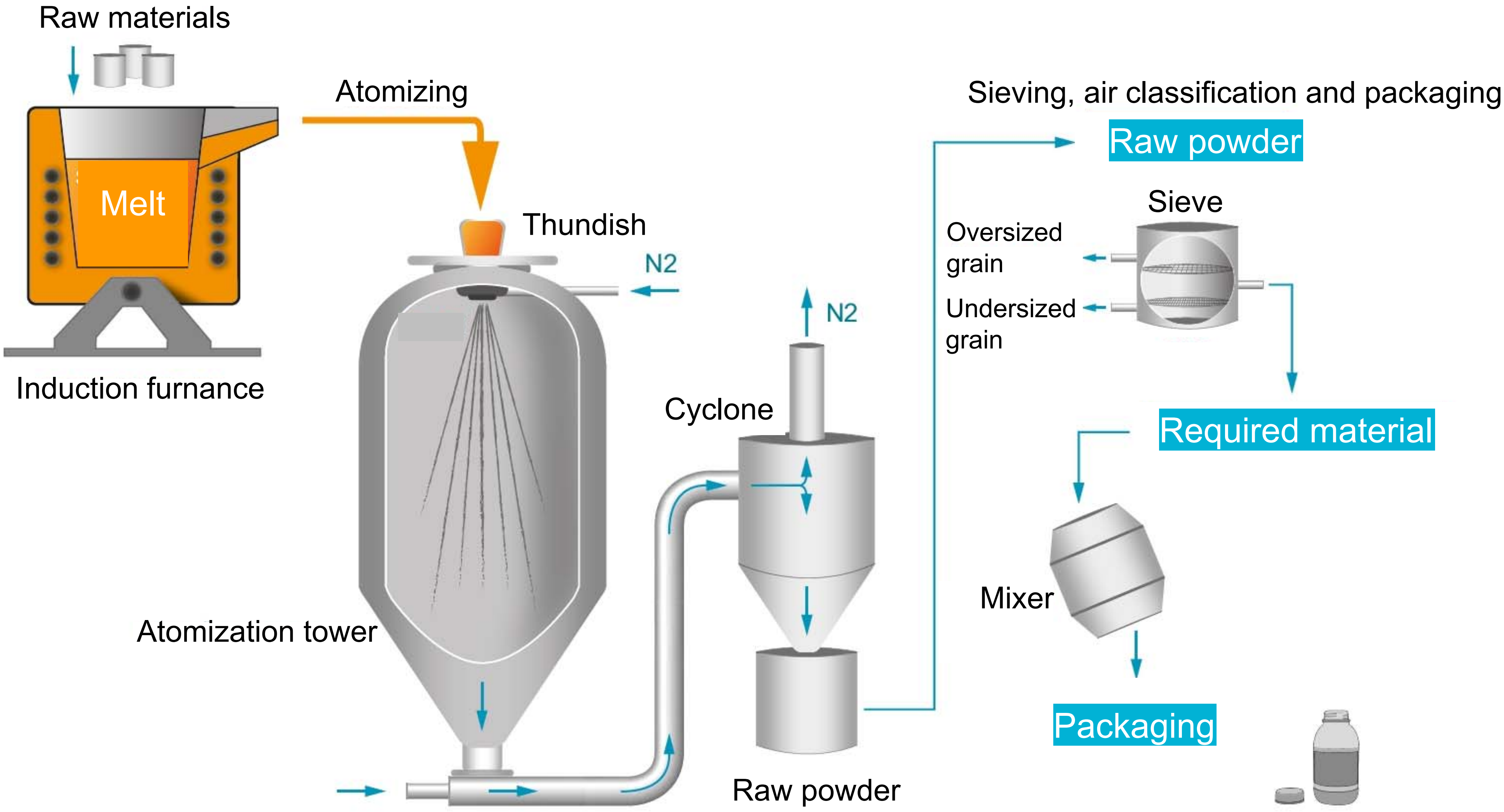
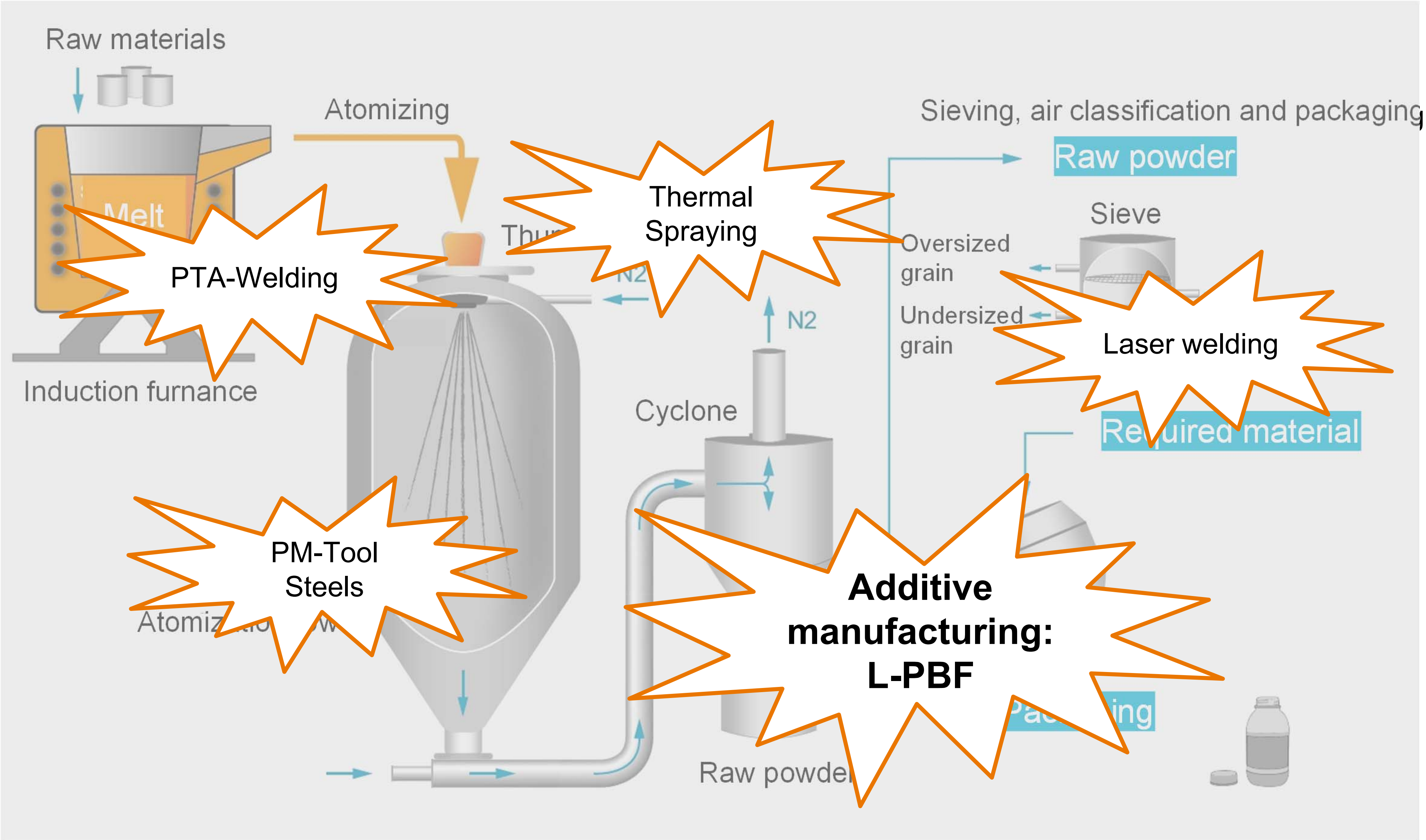
Introduction

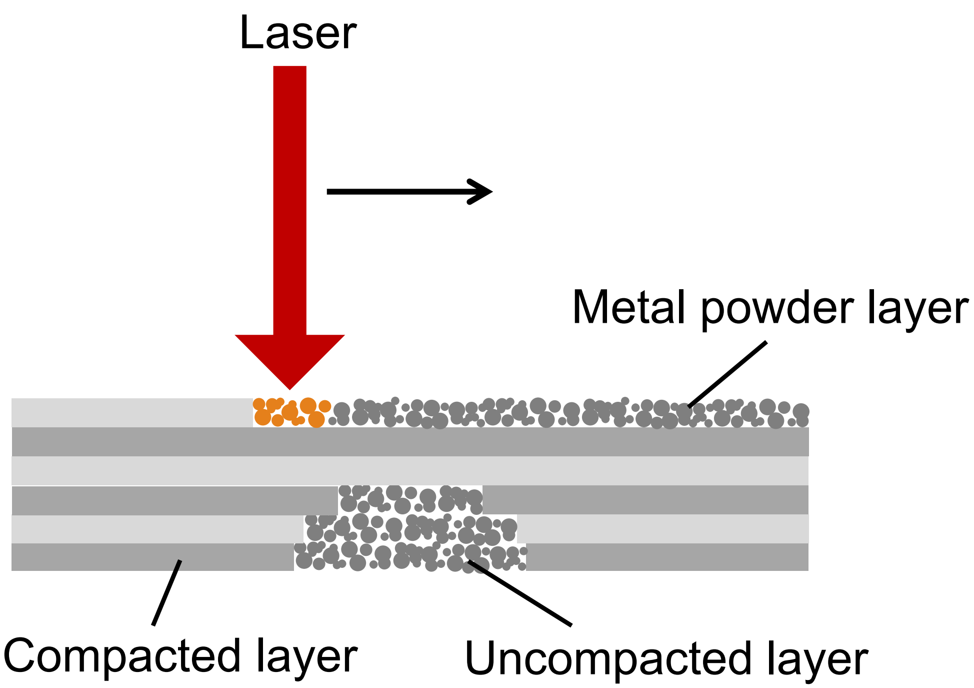
Metal powder production: Gas-atomization



Metal powder production: Gas-atomization

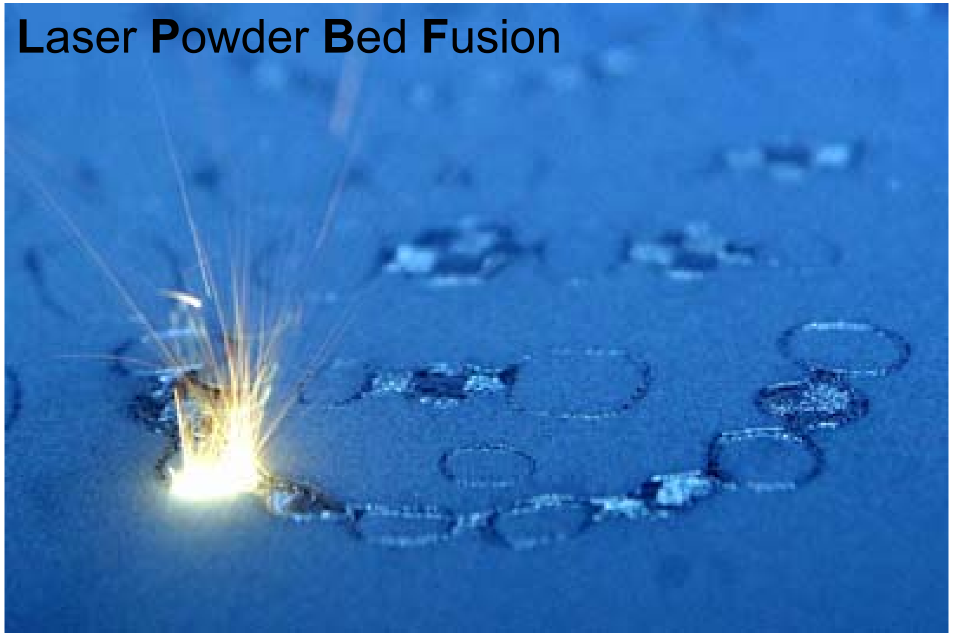


Additive Manufacturing: Process description LPBF



1) A thin powder layer is applied
2) A laser locally melts the powder
3) The building platform is lowered
4) A new layer of powder is applied

➔ **Repeat until the part is finished**
➔ **The part is build up "layer by layer"**



[3D printing of dental restorations, Metal powder report No.2, p. 32-33, 2013]

Additive manufacturing with wear-resistant materials

Material	C	Si	Mn	Cr	Mo	V
1.2343	0.37	1.0	0.5	5.5	1.3	0.4
1.2344	0.40	1.0	0.5	5.3	1.3	1.0

Properties	Fields of application	Potential for AM
➢ Martensitic tool steel ➢ High hardness and strength (also at elevated temperatures) ➢ Good wear resistance ➢ Hardness after heat treatment: approx. 52 HRC	➢ Die casting molds ➢ Injection molds ➢ Die inserts	➢ The materials are well known and investigated ➢ There are a lot of possible applications ➢ AM offers the possibility for more complex tools

***However,** is it possible to carry over this material to AM?*

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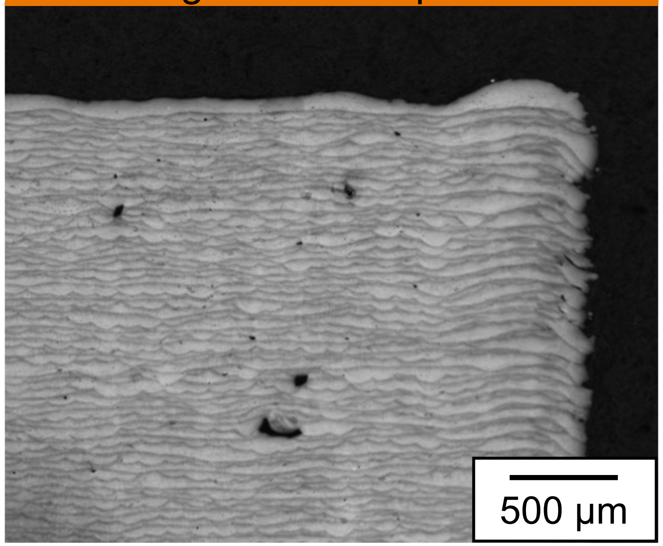
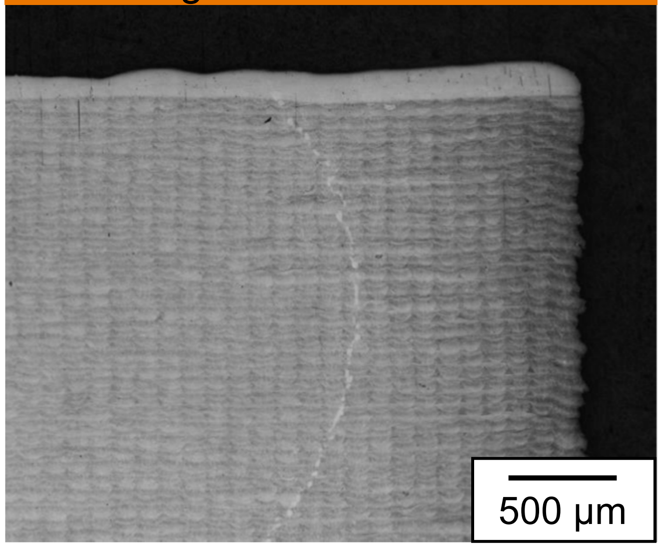
Additive manufacturing with wear-resistant materials

- Powder: 1.2344, 20 – 53 µm
- Identical processing parameters ➔ Volume energy E ≈ 67 J/mm^3
  - Laser power: 200 W
  - Scan velocity: 1.000 mm/s
  - Hatch distance: 100 µm
  - Layer thickness: 40 µm
- Preheating temperatures: Room temperature, 200°C, 400°C

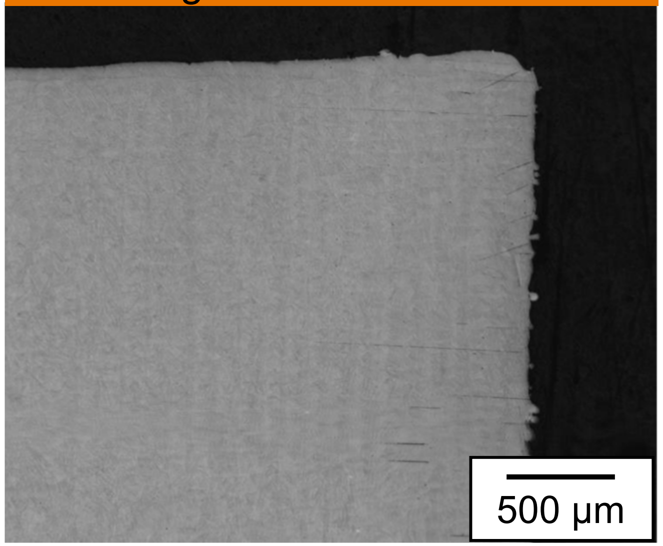
Preheating: Room temperature



Preheating: 200°C



Preheating: 400°C



***Yes, it is. But**, you have to deal with a small processing window → “cracks or pores”.*

02

Material development for AM

Example 1: Corrosion resistant austenite

Main alloy design of typical stainless austenitic steels

C
< 0.1 wt.-%
- Prevents the precipitation of chromium carbides

N
< 0.2 wt.-%
- Prevents the precipitation of chromium nitrides

Ni
10 – 14 wt.-%
- Stabilization of austenite

Cr
16 – 20 wt.-%
- Corrosion resistance

Mo
1 – 3 wt.-%
- Corrosion resistance

Properties of typical stainless austenitic steel (e.g. 1.4404/316L):
- Good corrosion resistance
- Low hardness and strength
- High toughness
- Good processing with L-PBF

Main alloy design of high strength stainless austenitic steels

C
0.1 – 0.6 wt.-%
- ➢ Strength
- ➢ Stabilization of austenite

N
0.1 – 0.6 wt.-%
- ➢ Strength
- ➢ Stabilization of austenite

Mn
16 – 23 wt.-%
- ➢ Stabilization of austenite

Cr
16 – 20 wt.-%
- ➢ Corrosion resistance

Mo
1 – 3 wt.-%
- ➢ Corrosion resistance

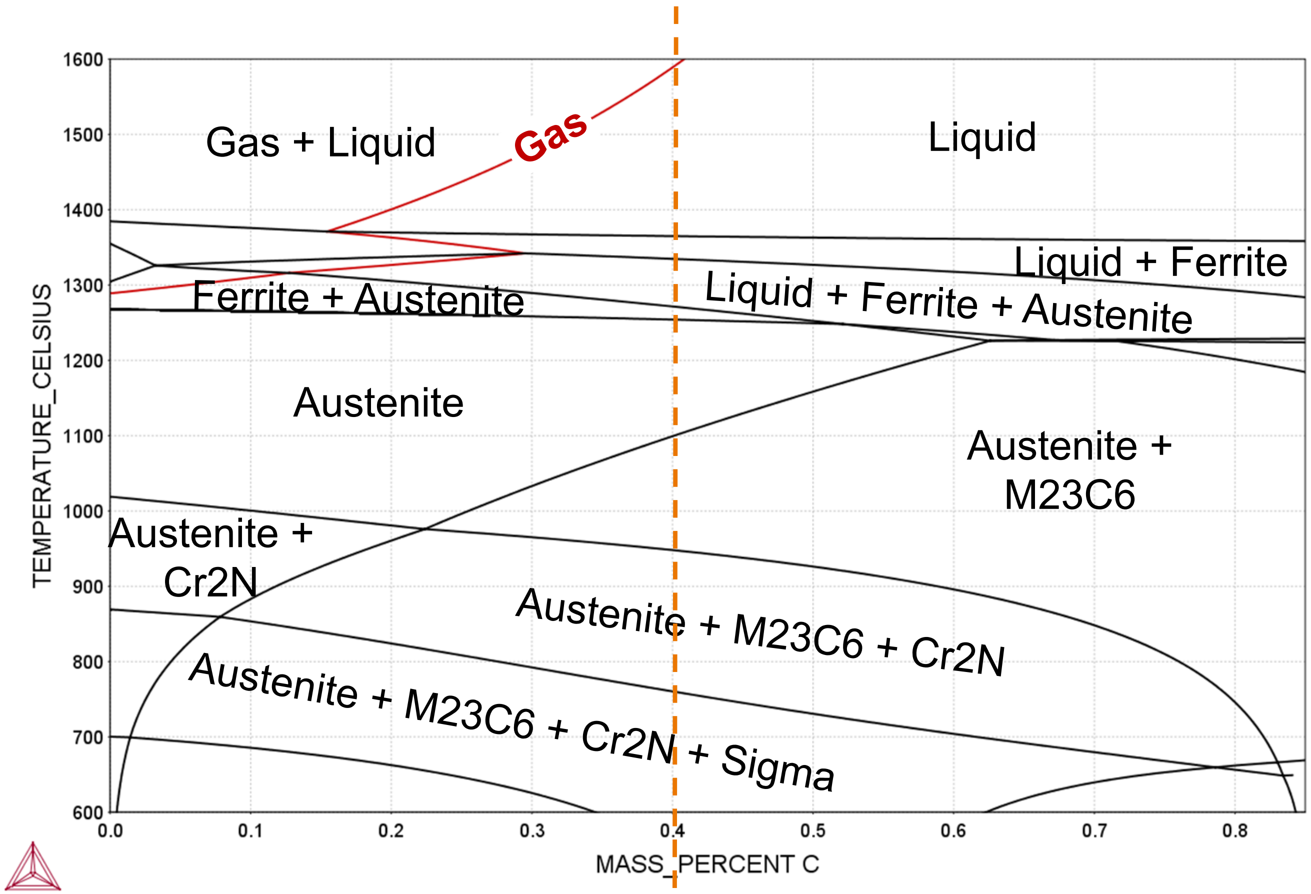
Benefits of high strength stainless austenitic steels compared to typical stainless austenitic steels (e.g. 1.4404/316L):

- ➢ Higher hardness and strength (however, reduced toughness)
- ➢ Comparable corrosion resistance
- ➢ Free from nickel → important for „Health & Safety“ during processing

Thermo-Calc (TCFe9-data base, nominal composition)

Material	C	N	Ni	Mn	Cr	Mo
Printdur HSA*	0.4	0.6	< 0.1	21.0	18.0	2.0

*HSA = **H**igh **S**trength **A**ustenite



Comparison: Printdur 4404 und Printdur HSA

Material	C	N	Ni	Mn	Cr	Mo
Printdur 4404*	0.02	0.08	12.7	0.81	17.2	2.1
Printdur HSA*	0.39	0.62	0.02	21.2	18.1	2.2

*OES-Analysis; Fe = base element, values given in wt.-%

Powder properties of Printdur HSA:

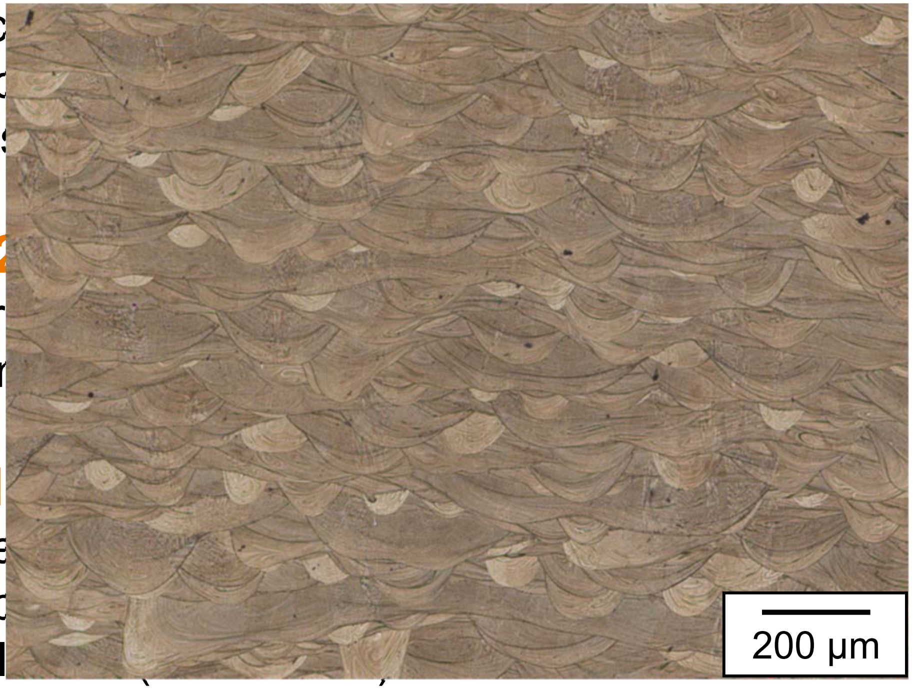
- Partic
- Bulk d
- Flow s

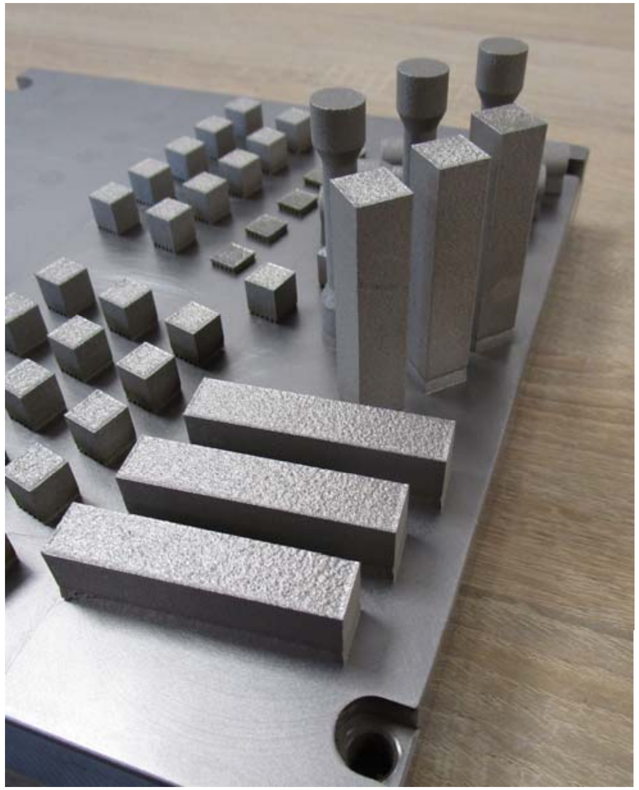
EOS M2

- Layer
- Printi

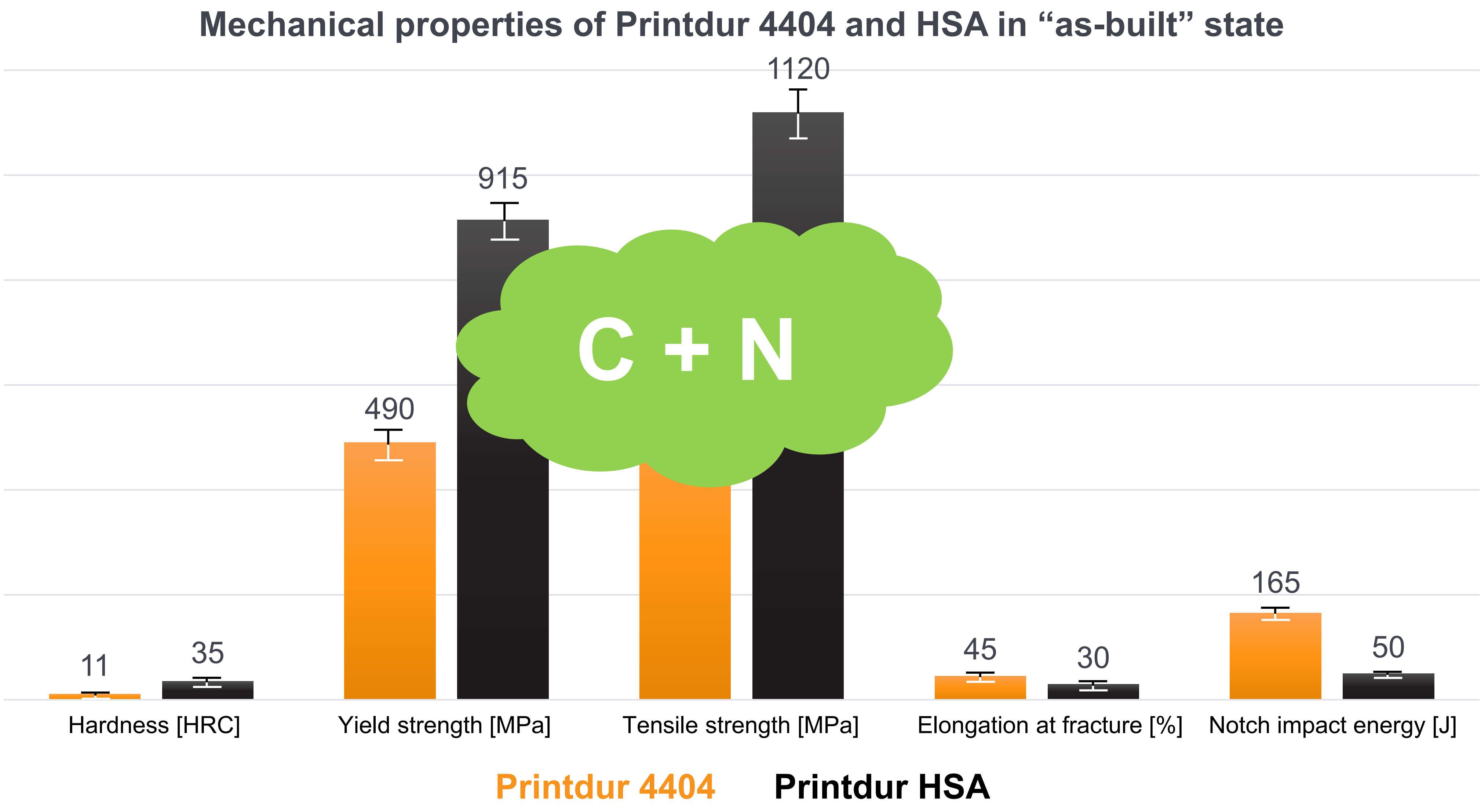
Printed

- „Cube
- Charp
- Tensil ( )





Mechanical properties



Corrosion properties: ASTM G150

Material	C	N	Ni	Mn	Cr	Mo	PREN
Printdur 4404	0.02	0.08	12.7	0.81	17.2	2.1	**25.5**
Printdur HSA	0.39	0.62	0.02	21.2	18.1	2.2	**35.3**

- The Pitting Resistance Equivalent Number (PREN) describes the resistance against pitting corrosion

- PREN = %Cr + 3,3 x Mo + 16 x %N

- Current-potential-curves according to ASTM G150
- Room temperature and 3.56% NaCl
- Breakdown potential = 100 µA/cm^2

Corrosion properties: ASTM G150

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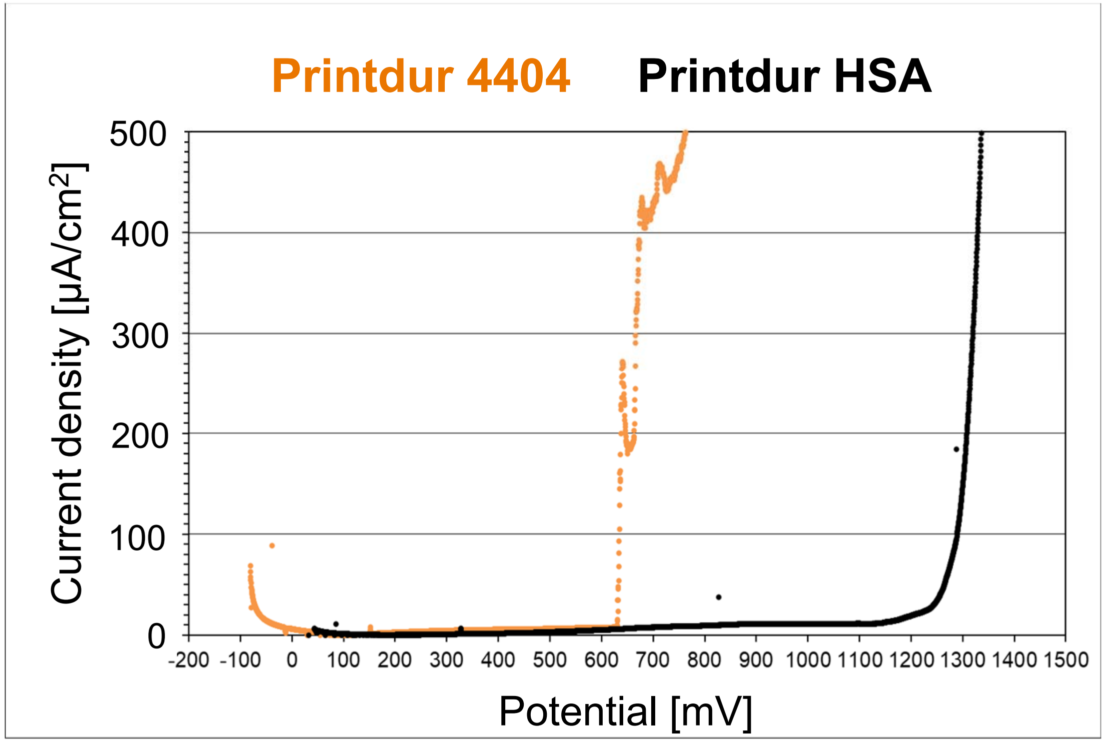
- The Pitting Resistance Equivalent Number (PREN) describes the resistance against pitting corrosion
- PREN = %Cr + 3,3 x Mo + 16 x %N
- N is only useful as it is dissolved within the metal matrix, otherwise it causes precipitations which reduces the corrosion resistance
- The fast cooling speed within the printing process inhibits the precipitation of carbides and nitrides



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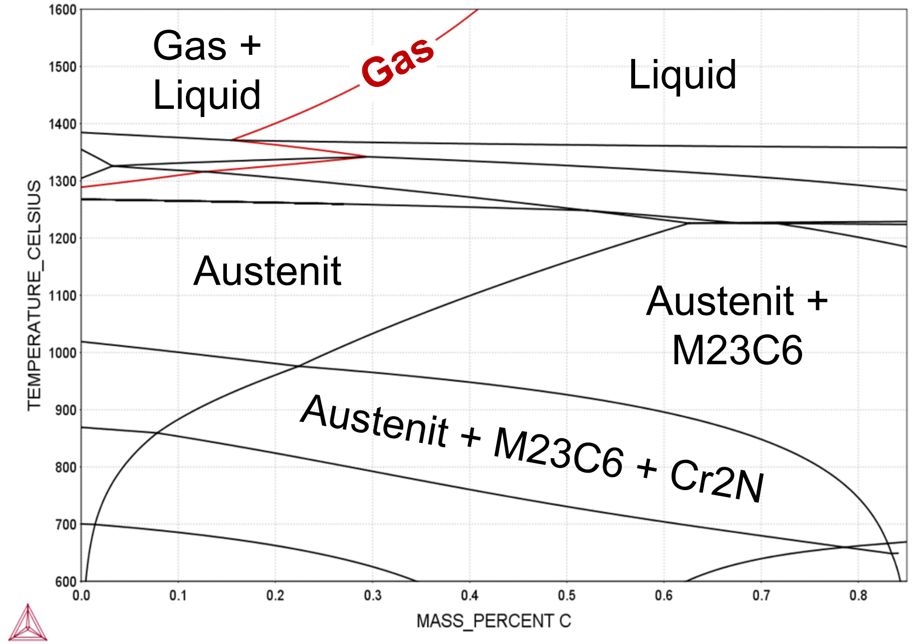

- **Consideration of the characteristics of the LPBF-process during development**

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02

Material development for AM

Example 2: Corrosion resistant martensite

Typical L-PBF materials for tooling

- For L-PBF we need a good processability = weldability
- But, materials with low carbon content don't provide a sufficient wear resistant

Grade / Norm	Chemical composition [mass-%]							
	C	Si	Mn	Cr	Mo	Ni	Co	Cu
Printdur Powderfort (~1.2709)	< 0.02	0.5	0.5	-	5.0	18.0	13.5	-
Printdur 2343 (1.2343)	0.37	1.0	0.5	5.5	1.3	-	-	-
Printdur 2344 (1.2344)	0.40	1.0	0.5	5.3	1.3	-	-	-

- The 1.2709 is a standard tooling materials for AM
  - Maximum hardness of approx. 55 HRC, no carbides
  - Alloyed with Ni and Co → "Health & Safety"

- H11 and H13 are very complex to process

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Printdur HCT: Corrosion resistant tool steel

Material	C + N	Mn	Cr	Mo
Printdur HCT*	0,41	3,1	13,2	1,1

*OES-Analysis; Fe = base element, values given in wt.-%

Powder properties of Printdur HSA:

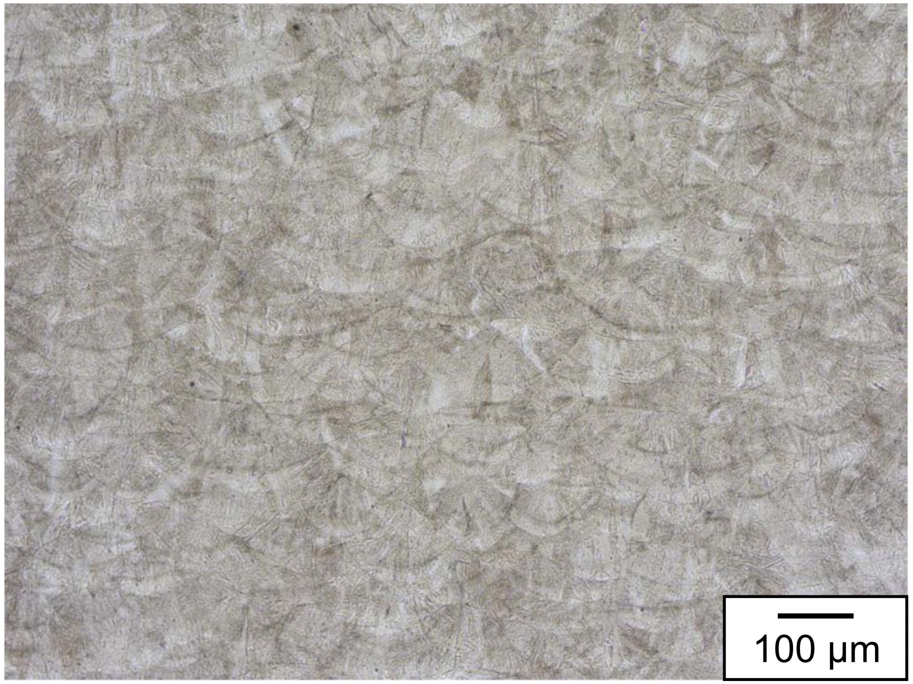
- Particle size distribution: 10 – 53 µm
- Bulk density: 4.3 g/cm^3
- Flow speed: 15.5 s/50g

EOS M290:

- Laser power: 180 W
- Scan velocity: 692 mm/s
- Hatch distance: 100 µm
- Layer thickness: 40 µm
- Preheating temperature: 150°C

Printed samples:

- „Cubes“ → Microstructure and density
- Compression test, Charpy V-notch test



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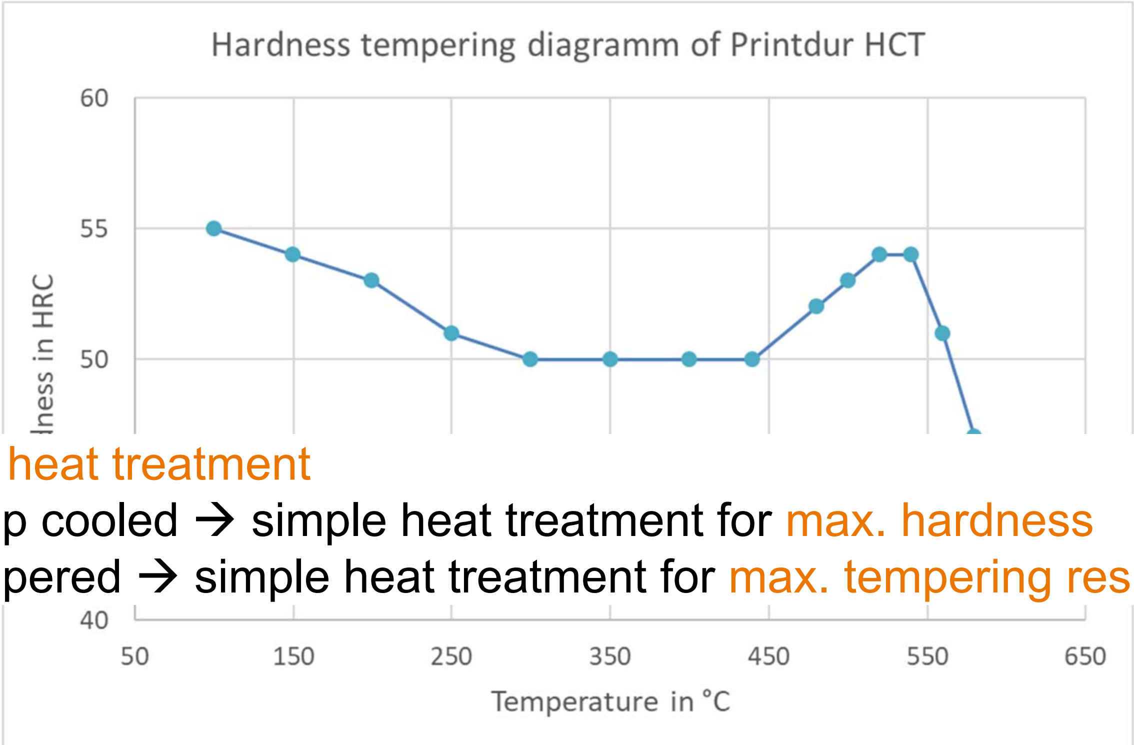
Mechanical properties

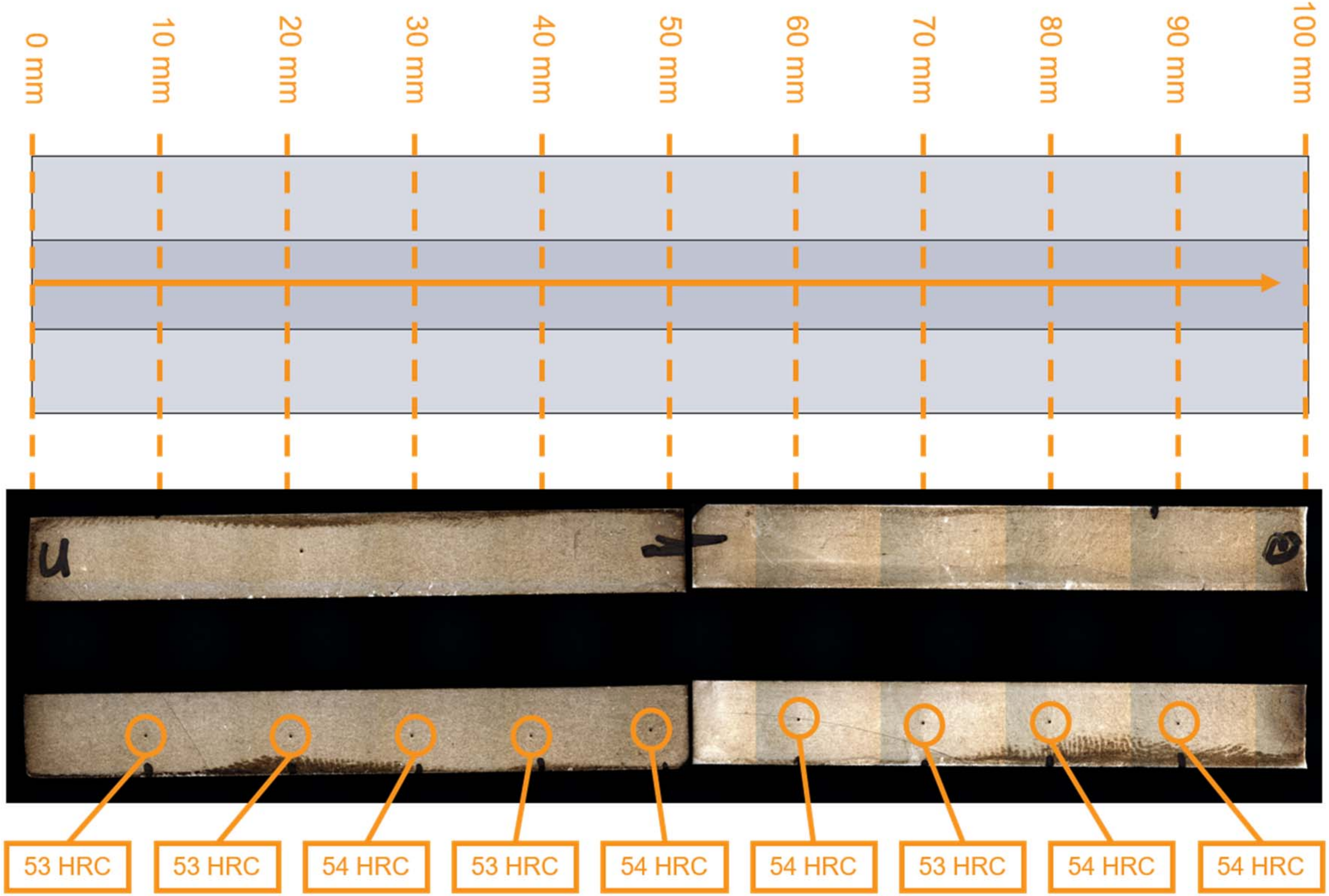
Heat treatment	Hardness in HRC	Offset yield strength in MPa	Notch impact energy in J
As-printed	53 ± 1	2130 ± 40	5 ± 1
As-printed + deed cooled	57 ± 1	2270 ± 45	5 ± 1
As-printed + tempered*	54 ± 1	1440 ± 32	10 ± 2

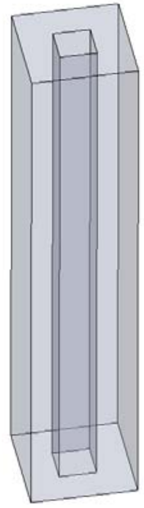
*Secondary peak hardness: 540°C, 90 min



- ➢ As-printed → no heat treatment
- ➢ As-printed + deep cooled → simple heat treatment for max. hardness
- ➢ As-printed + tempered → simple heat treatment for max. tempering resistance

Hardness profile





03

Conclusion

Conclusion

Printdur HSA in comparison to 316L:

- Tailored chemical composition for additive manufacturing
    - Similar processing parameters
    - Increased hardness and strength, reduced toughness
    - Improved corrosion resistance
    - No Nickel → **„Health & Safety“**

Printdur HCT:

- Tailored chemical composition for additive manufacturing
    - Corrosion resistant martensite
    - Hardness of approx. 53 HRC in the as-printed condition
    - Increase in hardness is possible be help of an easy heat treatment
    - No Ni and Co (in comparison to 1.2709) → **„Health & Safety“**

Vielen Dank für Ihre Aufmerksamkeit!

Together.
For a future that matters.