Laser powder bed fusion and heat treatments of tool steels

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  - Search terms LPBF, tool steel, heat treatment
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- VTT Near future actions
  - High throughput vision

Literature survey
Alloys

- Very common alloy to investigate is H13
- Incremental studies begin with an existing alloy, do changes to composition and report results
- Narvan2021: *Laser powder bed fusion of functionally graded bi-materials: Role of VC on functionalizing AISI H13 tool steel*
  - *Composite powder manufactured with ball milling*
- Improved wear resistance and effect on laser absorption

M. Narvan, A. Ghasemi, E. Fereiduni et al.

Source:Narvan2021

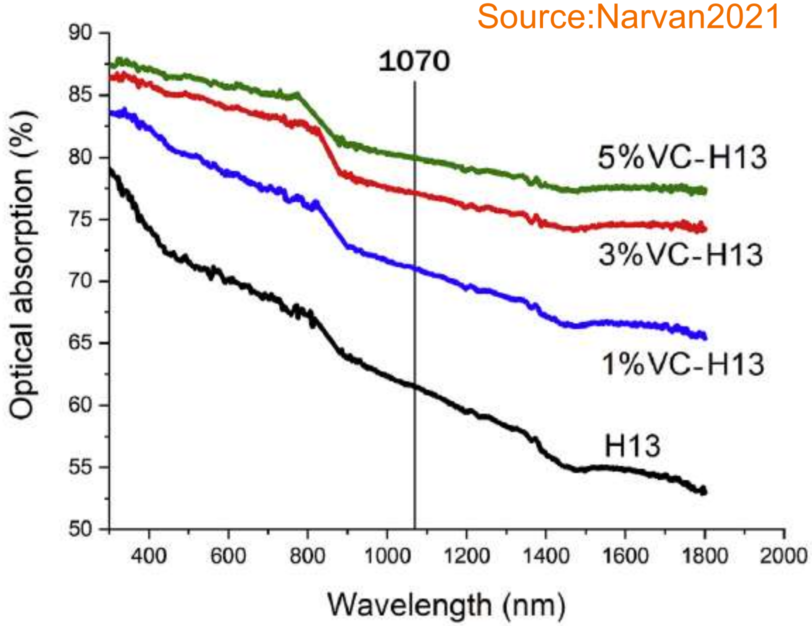


Fig. 6. The optical absorption versus the wavelength for monolithic H13 and composite powders containing 1, 3, and 5 wt% VC. 1070 nm line indicates the wavelength of the laser in the LPBF machine used in this study.

Literature survey
Alloys

He21, HSS M2

Element (Wt. Pct)	W	Cr	Mo	Mn	V	Ni	Si	C	Fe
	6.0	4.0	4.7	0.3	1.83	0.25	0.3	0.86	bal.

Saewe21

Chemical Elements [wt.-%]	C	W	Mo	V	Co	Cr	Si	Fe
HS6-5-3-8 (1.3294)	1.23-1.33	5.9-6.7	4.7-5.3	2.7-3.2	8.0-8.8	3.8-4.5	< 0.7	Balanced

Platl22_2

Fe	C	Si	Mn	Ni	Cr	W	Mo	V	Co
Bal.	0.85	0.53	0.36	0.19	4.25	2.46	2.72	2.01	4.35

Tian22, L-40 tool steel developed for LPBF

C	Cr	Ni	Mo	Cu	Nb	N	Fe
0.15	11.2	2.01	1.77	0.75	0.05	0.059	Bal.

Sinico22, M789 maraging steel

Cr	Mo	Ni	Ti	Al
12.20	1.00	10.00	1.00	0.60

Tian21, Uddeholm/Voestalpine Heatvar

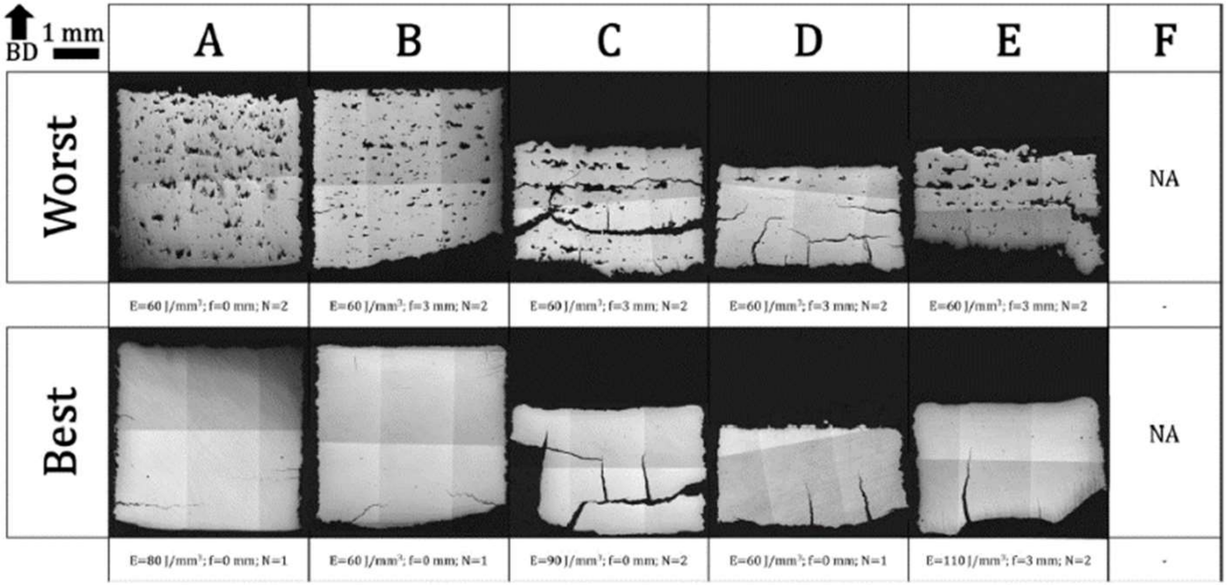
Elements	C	Cr	Ni	Mo	Co	S	P	Fe
Nominal	0.03	5.00	2.00	8.00	12.00	<0.002	<0.002	balance
ICP	0.03	5.19	2.06	7.78	11.70	0.001	0.001	balance

Bergmueller22, PM HSS S390 Microclean

Elements	Fe	C	W	Mo	V	Co	Cr	Ni	Mn	Si	S	P	O
wt%	bal.	1.64	10.09	2.28	5.12	8.32	4.91	0.20	0.26	0.30	0.018	0.018	0.0041

Literature survey
Alloys

- Good illustration on what happens when compositional effects cannot be overcome by process parameters



Designation and nominal chemical compositions of the tool steels alloys in wt%. Letters denote the alloy type.

Alloy	Designation	C	Si	Mn	P	S	Cr	Mo	Ni	V	W	Cu	Co	N	O	Fe
A	Fe25Co15Mo	0.01	–	–	–	–	–	15	–	–	–	–	25	–	–	Bal.
B	HS3–3-2–5	0.85	0.53	0.36	0.019	0.011	4.25	2.72	0.19	2.01	2.46	0.1	4.35	0.04	0.004	Bal.
C	HS6–5-3–8	1.28	0.6	0.29	0.019	0.016	4.04	4.91	0.21	2.97	6.12	0.12	8.19	0.047	0.005	Bal.
D	HS6–5-4	1.31	0.58	0.29	0.020	0.013	4.07	4.94	0.2	3	6.13	0.13	0.24	0.054	0.003	Bal.
E	HS6–5-3C	1.34	0.56	0.29	0.023	0.017	3.99	4.92	0.16	3.95	5.43	0.11	0.28	0.061	0.008	Bal.
F	HS10-2–5-8	1.62	0.31	0.25	0.021	0.013	4.86	1.87	0.26	4.7	10.23	0.12	7.82	0.058	0.004	Bal.

Source: Galbusera22: *Processability and cracking behaviour of novel high-alloyed tool steels processed by Laser Powder Bed Fusion*

Literature survey
Process

- When adjusting laser parameters are not enough, **elevated platform pre-heat** is used

Chemical compositions of tool steels reported in the literature. Each content in the composition is expressed in wt.%.

Refs.	Alloy	Processability	C	Si	Mn	Cr	Mo	V	Co	W	Fe
Buls and Humbeeck, 2014; Liu et al. (2011)	M2 HSS	Severe cracking Crack free with BP[1] at 473 K	0.9	0.35	0.38	3.97	4.89	1.82	–	6.15	Bal.
Saewe et al. (2020)	HS6–5-8–3	Severe cracking Crack free with BP at 773 K	1.31	0.5	0.3	4.0	4.7	2.9	8.5	6.4	Bal.
Saewe et al. (2019, 2018)	AISI M50	Severe cracking Crack free with BP at 773 K	0.83	0.2	0.25	4.0	4.3	1.05	–	–	Bal.
Yan et al. (2017)	AISI H13	Lower residual stresses with BP	0.41	1.12	0.41	5.20	1.23	1.10	–	–	Bal.
Beal et al. (2008)	AISI H13	Porosity Cracking	0.32–0.42	0.85–1.15	0.4	4.75–5.25	1.25–1.75	0.9–1.1	–	–	Bal.
Mertens et al. (2016)	AISI H13	Crack free and lower residual stresses with BP at 573 K	0.32–0.4	1.0	–	5.13–5.25	1.33–1.4	1.0	–	–	Bal.
Krell et al. (2018)	AISI H13	Cracking Crack free with BP at 573 K	0.39	1.0	0.3	4.9	1.2	1.0	–	–	Bal.
Narvan et al. (2019)	AISI H13	Cracking Crack free with BP at 573 K	0.39	1.08	0.40	5.27	1.34	0.97	–	–	Bal.
Sander et al. (2016)	Fe85Cr4Mo8V2C1	Crack – free with BP at 773 K	1	–	–	4	8	2	–	–	Bal.
Sander et al. (2017a, b)	Fe85Cr4Mo8V1C1	Crack – free with BP at 773 K	1	–	–	4	8	1	–	–	Bal.
Sander et al. (2017a)	FeCr4Mo1V1W8C1	Crack – free with BP at 773 K	1	–	–	4	1	1	–	8	Bal.
Platl et al. (2020a)	–	Severe cracking Porosity	0.85	0.53	0.36	4.25	2.72	2.01	4.35	2.46	Bal.

[1] Baseplate Preheating (BP).

Source: Galbusera22: *Processability and cracking behaviour of novel high-alloyed tool steels processed by Laser Powder Bed Fusion*

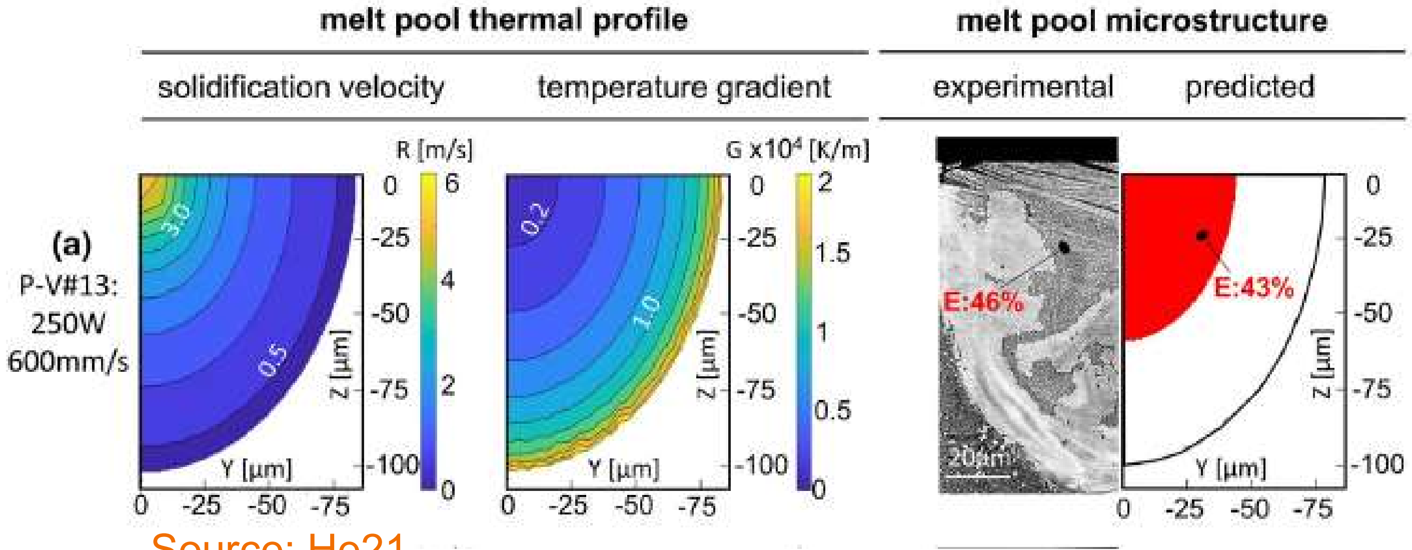
Literature survey
Process

- Sinico et al. studied large layer thickness (120um) process of M789 tool steel for improved productivity
  - High relative density (99,6%) was achieved, but poor surface roughness due to thick layers
  - Was mitigated by using hybrid printing with 60um thickness on the surface and 120um internally

- Increasing layer thickness can promote hot cracking but may be helpful in controlling **residual stresses** due to slower cooling and softer thermal gradient

Literature survey
Process

- He21: The Columnar-to-Equiaxed Transition in Melt Pools During Laser Powder Bed Fusion of M2 Steel
  - Microstructure prediction with FEM and Thermo-calc simulations and validation with corresponding process parameters



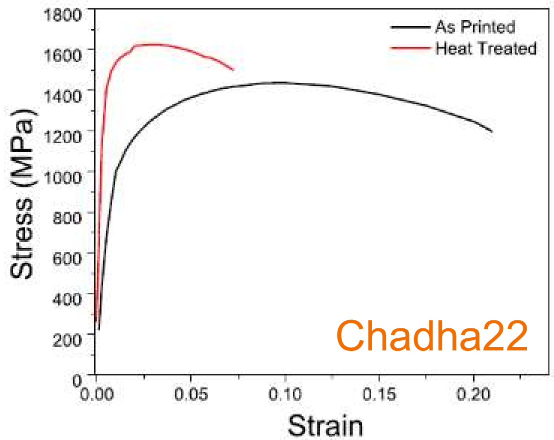
Source: He21

Literature survey
Heat treatments

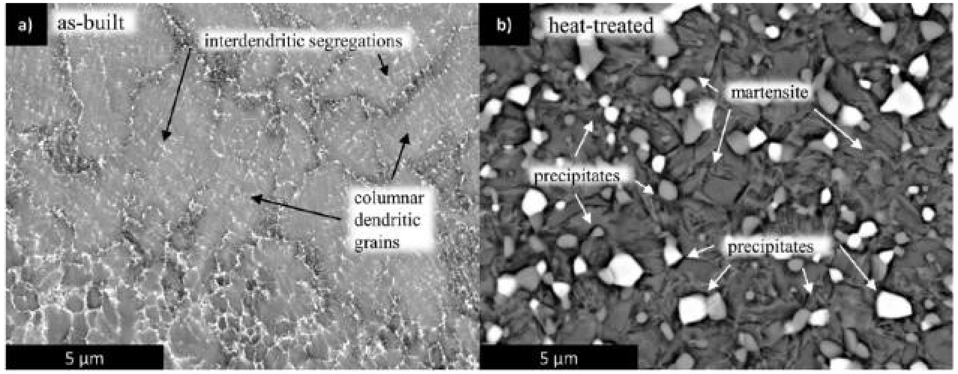
- Residual stress relieving
  - Can be employed in-situ with high enough platform pre-heat
- Solution annealing + aging common for maraging steels
  - Solution annealing also for increased corrosion resistance [Haghdadi21]
  - Common materials 17-4PH, 15-5PH, M300 Maraging steel.
- Direct aging (no solution annealing after printing)
- Tempering
  - Residual austenite removal
  - Carbide precipitation of tool steels [Haghdadi21]

Literature survey
Heat treatments

- Chadha22:
  - Austenite fraction of 1,8% in as manufactured state
  - After heat treatment 2h@1030ºC → 3h@593ºC → 2nd 3h@580ºC → 3h@550ºC austenite fraction was 0,08%
- Bergmueller22:
  - Crack free processing due to in-situ heat treatment, build platform at 800ºC
  - Austenitizing at 1150ºC, oil quenching, tempering at 2h@570ºC, air cool



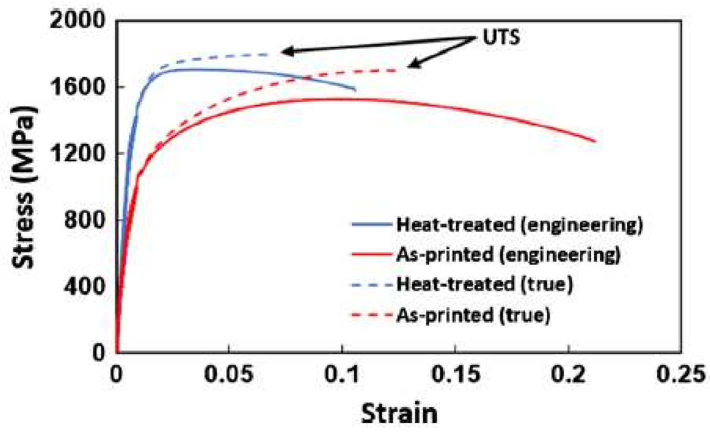
Chadha22

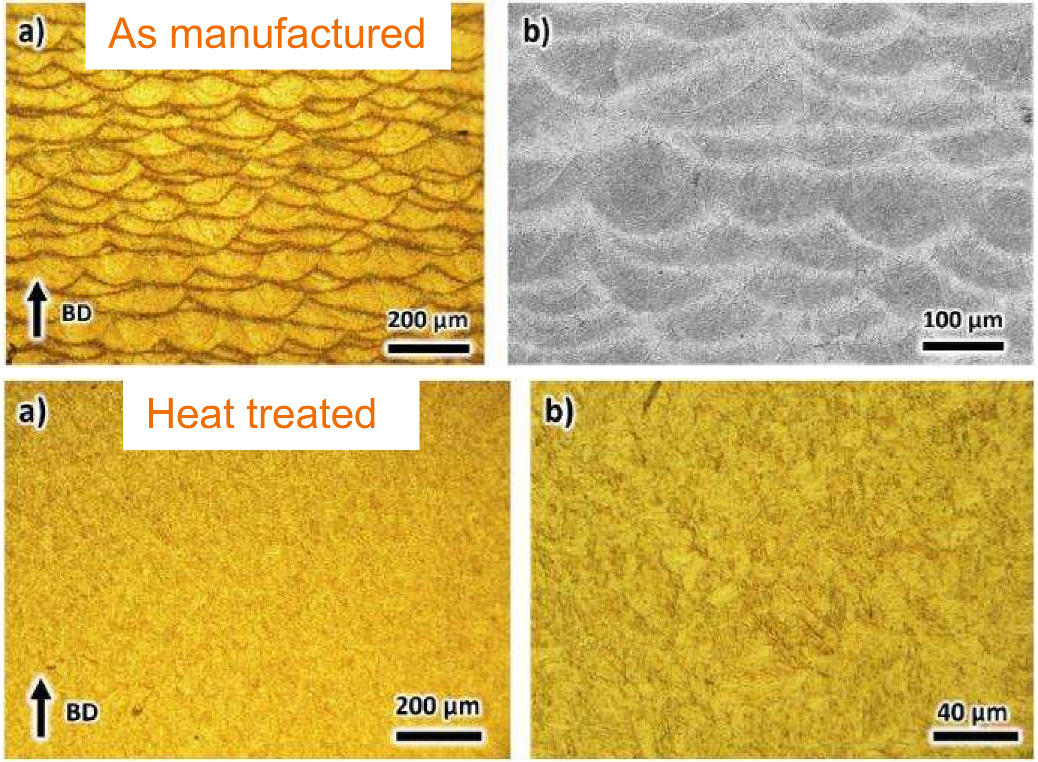


Bergmueller22

Literature survey
Heat treatments

- Tian22: Deformation-Induced Strengthening Mechanism in a Newly Designed L-40 Tool Steel Manufactured by Laser Powder Bed Fusion
  - Submicron dendritic structure with 14% residual austenite in as manufactured state
  - After heat treatment mainly martensitic with 1,5% residual austenite

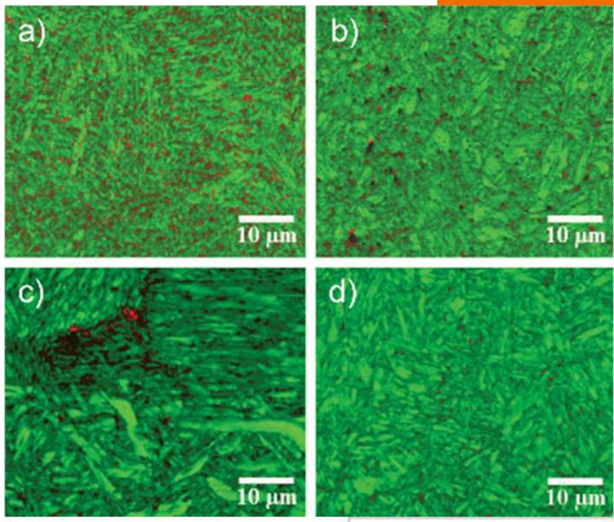


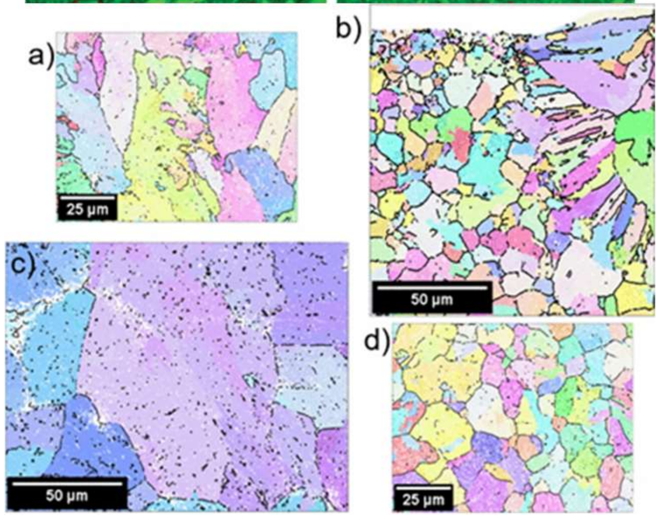


Source: Tian22

VTT Activities
Single track scanning

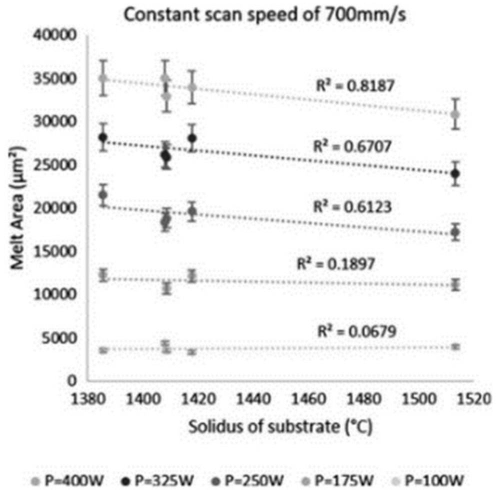
- Antikainen, Reijonen, Lagerbom et al.: Single-Track Laser Scanning as a Method for Evaluating Printability: The Effect of Substrate Heat Treatment on Melt Pool Geometry and Cracking in Medium Carbon Tool Steel
- LPBF H13 had much more residual austenite than conventionally quenched samples
- Primary austenite size much larger in LPBF (a) than in conventional (b,d) material

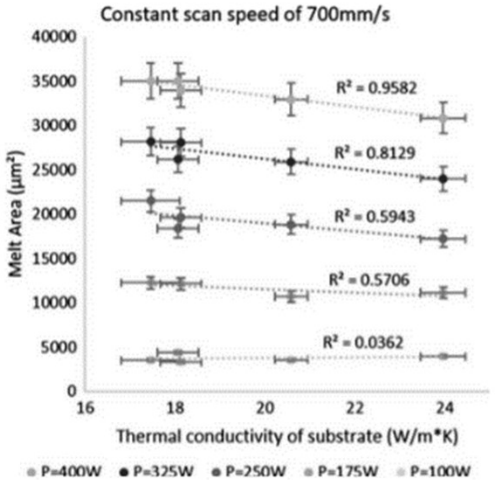


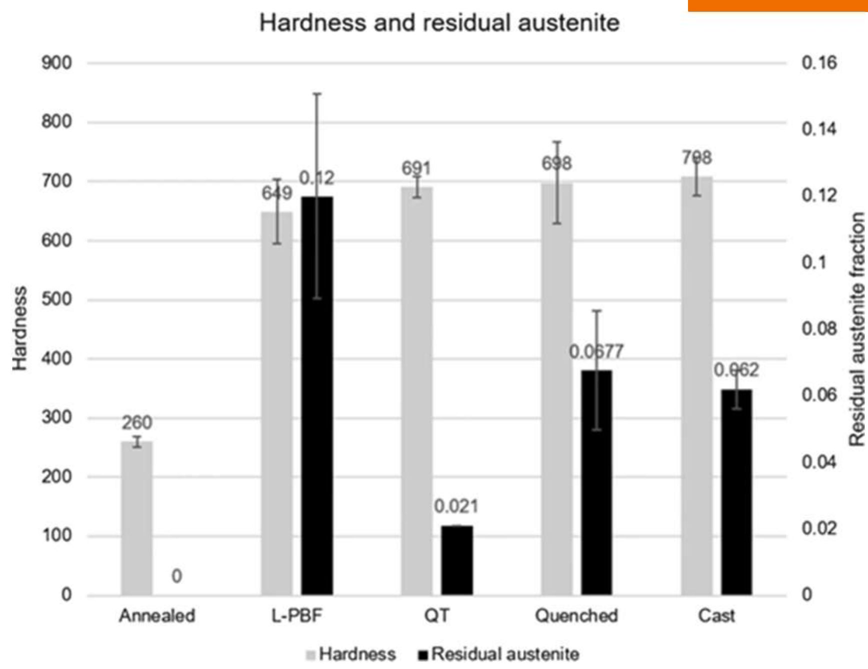


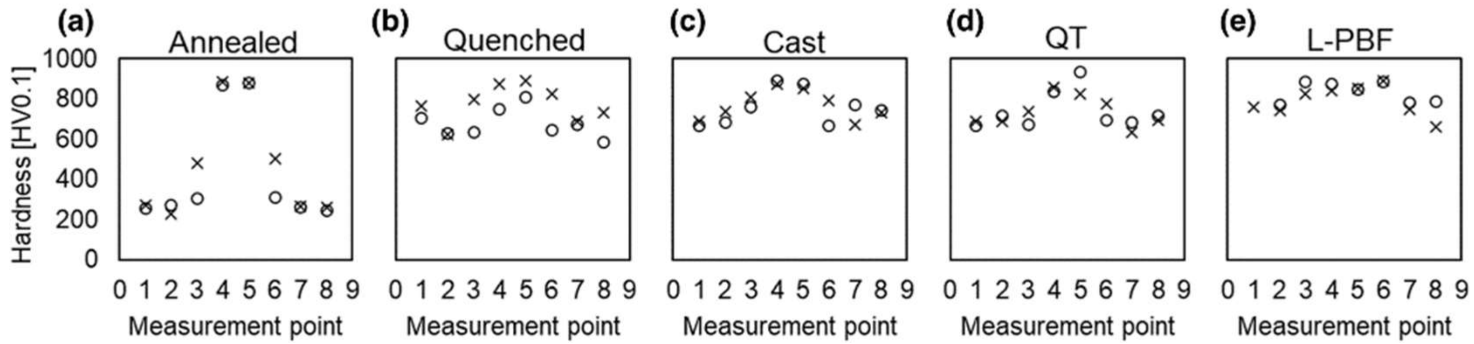
a) LPBF, b) oil quenched, c) copper mold cast, d) oil quenched and tempered once

VTT Activities
Single track scanning





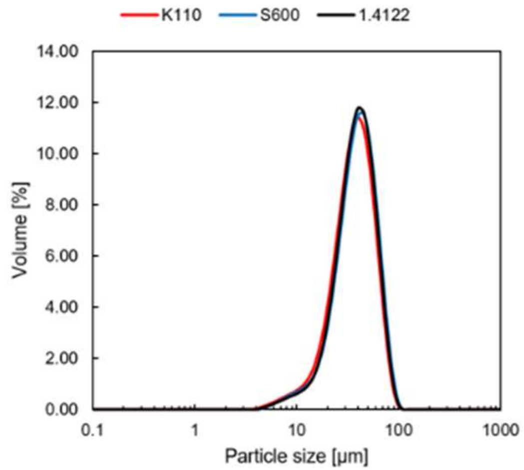




Source: Antikainen et al. 2022

VTT Activities
LPBF of tool steels

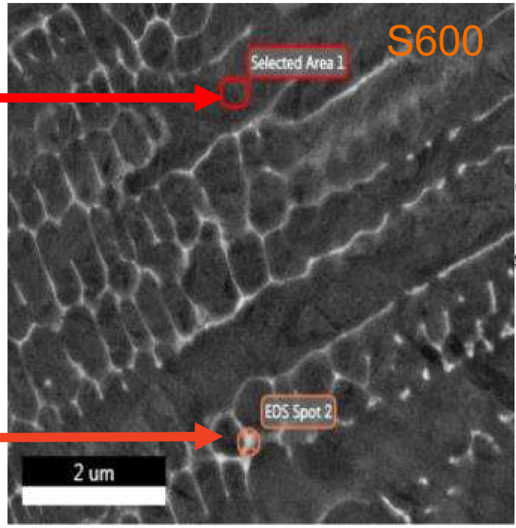
- Conference paper by Reijonen, Antikainen, Lagerbom et al.
- Printing of in-house atomized tool steels with high pre-heating of 350-380ºC

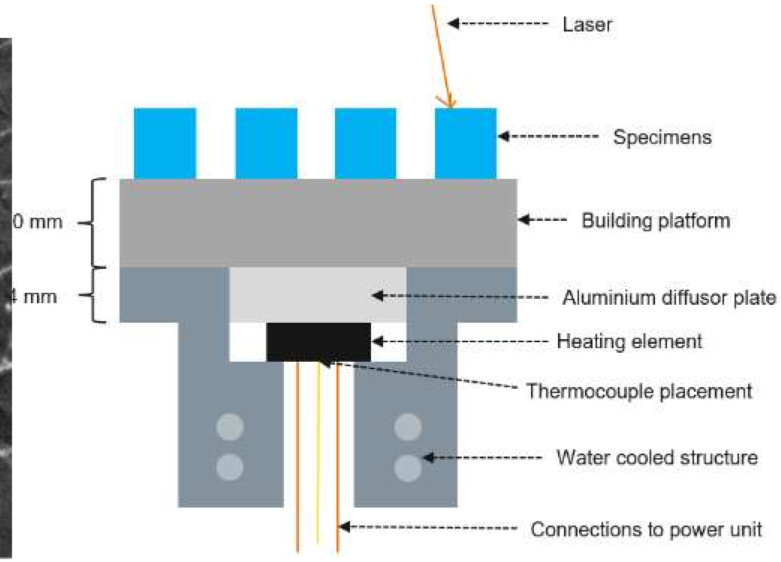


Element	K110	S600	1.4122
C	1.55	0.90	0.38
Si	0.25	-	0.40
Mn	0.35	-	0.65
Cr	11.50	4.10	16.00
Mo	0.70	5.00	1.00
Ni	-	-	0.80
V	1.00	1.80	-
W	-	6.20	-
Fe	bal.	bal.	bal.

Element	Weight %	Atomic %
C K	0.58	2.73
W M	4.44	1.37
MoL	2.93	1.73
V K	1.67	1.86
CrK	4.02	4.39
FeK	86.37	87.90

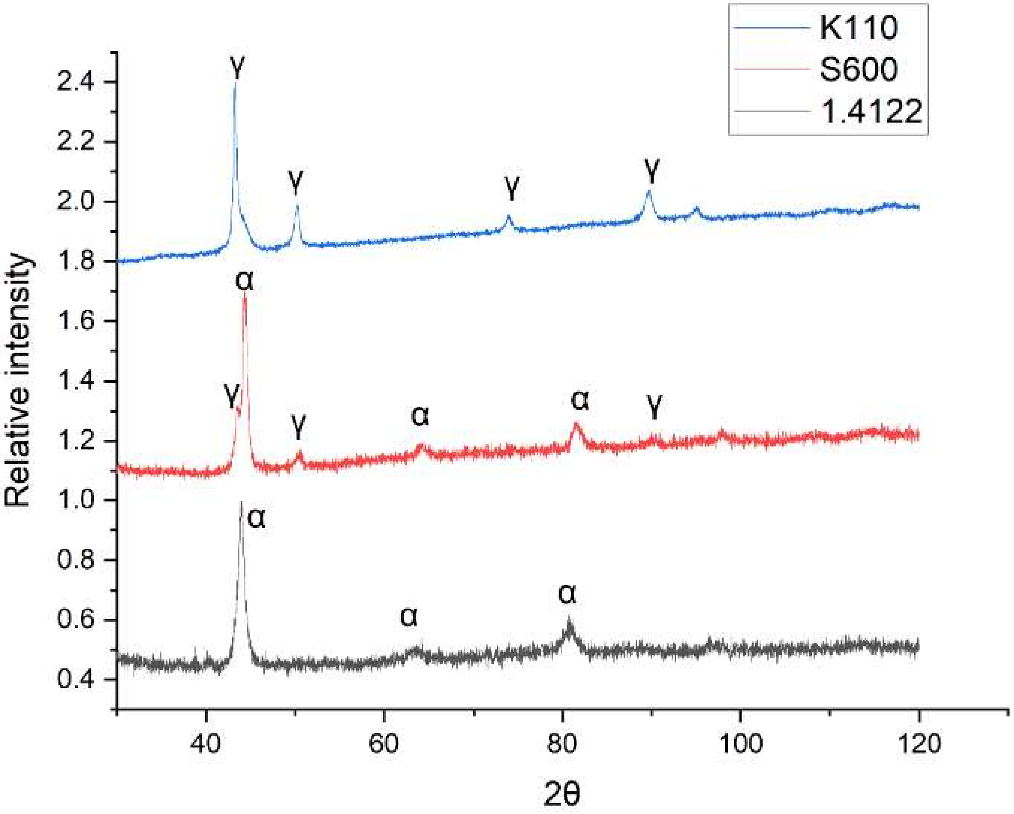
Element	Weight %	Atomic %
C K	2.78	12.73
W M	8.85	2.65
MoL	7.92	4.54
V K	5.40	5.83
CrK	5.68	6.00
FeK	69.37	68.26





VTT Activities
LPBF of tool steels

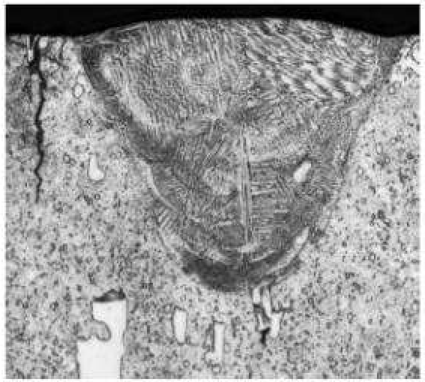
- Conference paper by Reijonen, Antikainen, Lagerbom et al.
- 1.4122 is ferritic/martensitic
- S600 Ferritic/martensitic with notable residual austenite
- K110 almost entirely austenite



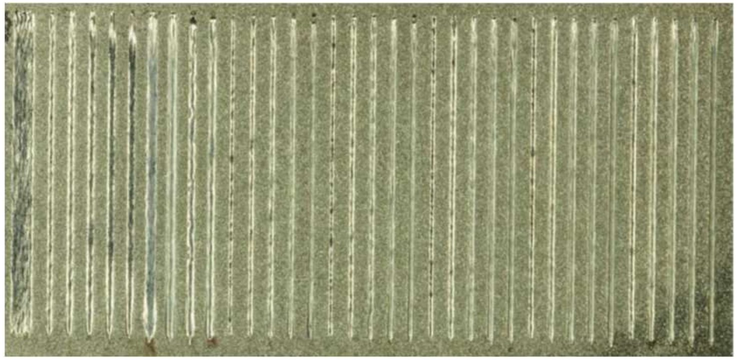
VTT Activities
LPBF of high carbon cold work tool steel

- Unpublished work by Antikainen, Reijonen, Lagerbom
- LPBF of high carbon tool steel D2/K110
- Preliminary tests with single track scanning
- Melt pools OK, cracking only in HAZ
  - Printable?

C	Si	Mn	Cr	Mo	V
1,55	0,25	0,35	11,50	0,70	1,00

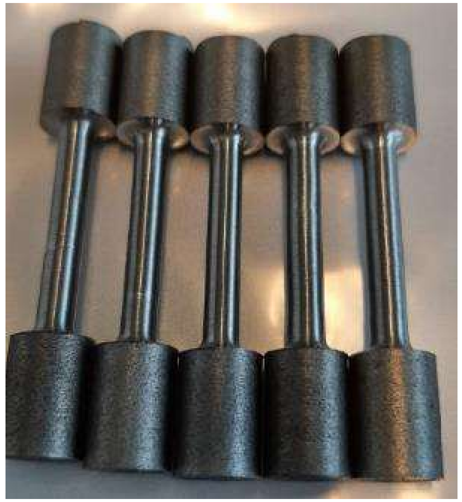


EBSD image of a single laser scan (left) and optical image of a microstructure (right) of D2 tool steel with a crack in the heat-affected zone.



VTT Activities
LPBF of high carbon cold work tool steel

- Unpublished work by Antikainen, Reijonen, Lagerbom
- Successfully printed tensile test bars with platform preheating
  - Demo extrusion nozzle
  - An article about heat treatments and mechanical properties to be published this year
- Best Yield strenght >1400MPa
- Best Ultimate tensile strength >1800MPa



VTT Near Future Actions

- Printability, properties and performance based on chemical composition
- High throughput experimental research
  - Sample preparation
    - Arc melting
    - Insstek Multi-material DED
  - Printability estimation and parameter space estimation
    - Single track scanning
    - High Temperature XRD
  - Mechanical properties
    - Tensile testing
  - Heat treatments
    - DSC
    - High Temperature XRD

Within few workdays

References

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