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AA7075-seoksen suorakerrostus

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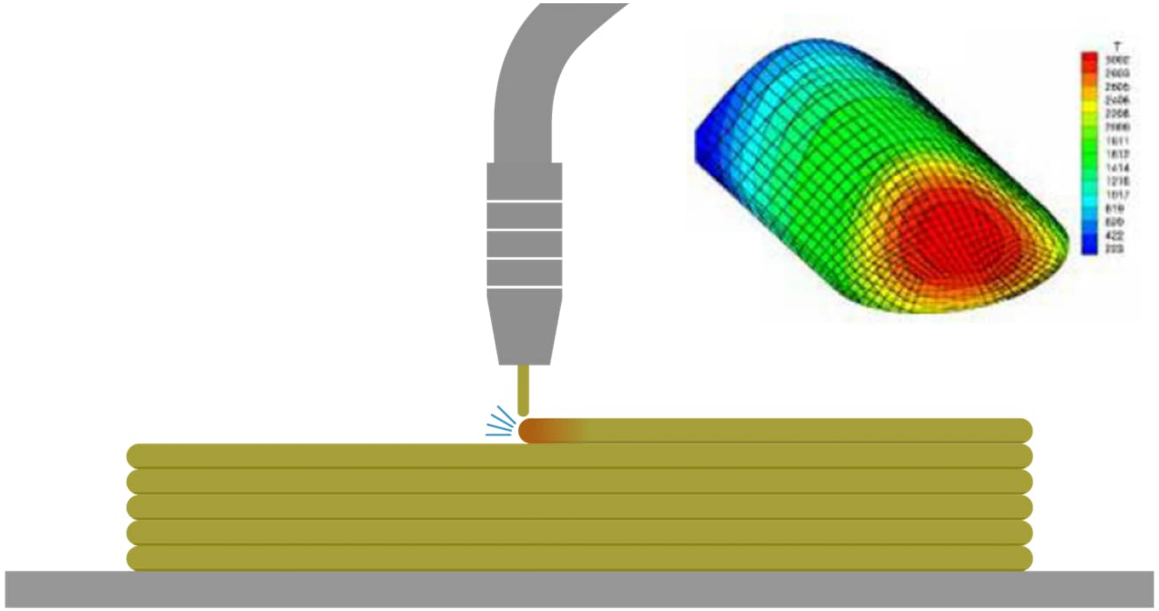
Outline

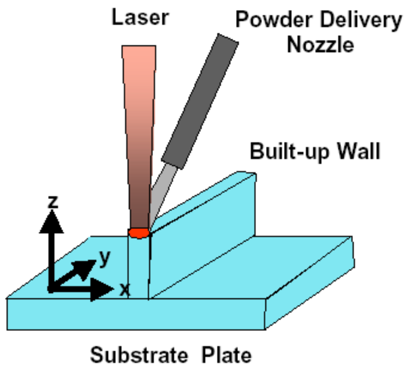
- Directed energy deposition (DED) = suorakerrostus
- DED methods
- Aluminium alloys for DED
- Aluminium DED applications
- AA7075:
  - Characteristics
  - Weldability
  - Nanofunctionalization
  - DED experiments with powder & wire
- Summary

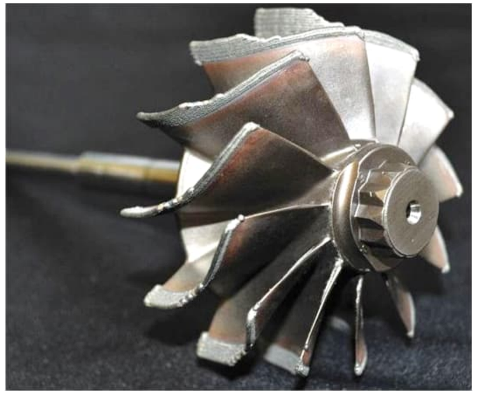


Directed energy deposition (DED) - Definition

- ISO/ASTM 52900:2016 ”Additive manufacturing – General principles – Terminology”
  - DED is AM process in which focused thermal energy (laser, EB, plasma or electric arc) is used to fuse materials by melting as they are being deposited
  - The build surface can be an existing part onto which material is added (repairing, remanufacturing, feature addition)







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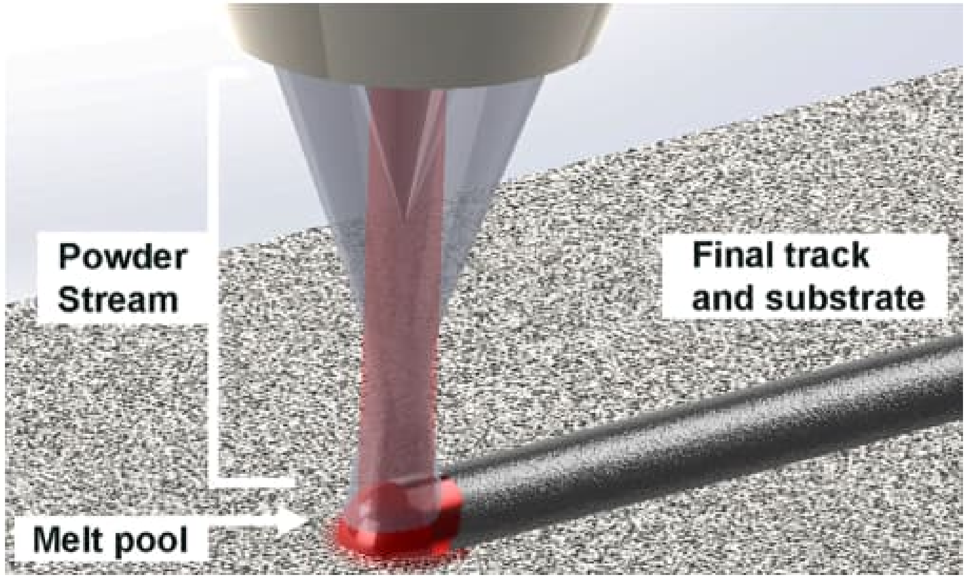
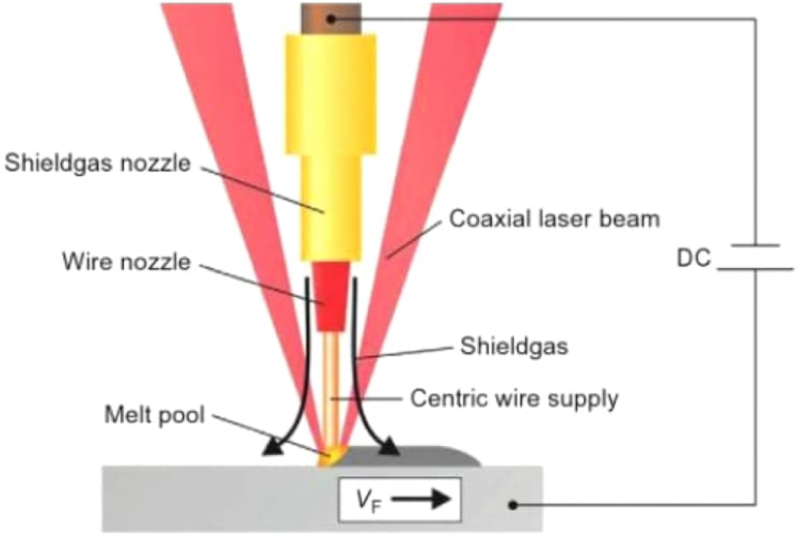
DED methods

BEAM



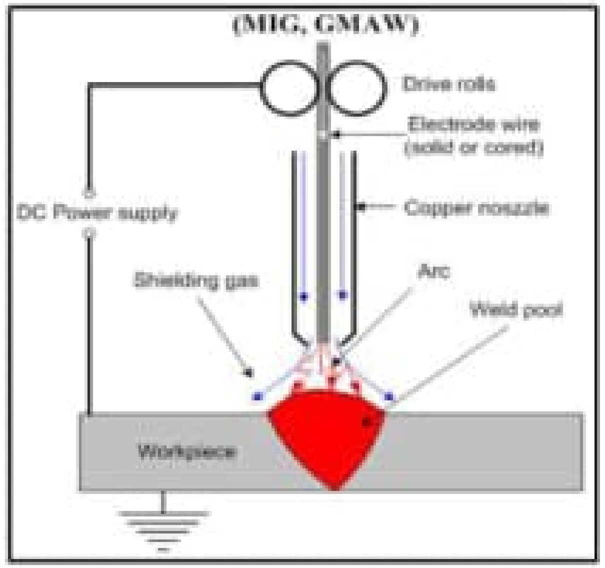
Coaxial powder laser method



Coaxial wire laser method

- Productivity moderate
- Material efficiency moderate (powder), high (wire)
- Heat input moderate
- Accuracy moderate

ARC (WAAM)



MIG/MAG short arc, CMT

- Productivity high
- Material efficiency high
- Heat input high
- Accuracy low

Others: friction stir welding, electron beam welding, cold spraying

Commercial DED devices

Laser powder

Laser wire

WAAM

Laser powder (additive + subtractive)

Laser powder + wire

EB wire

DED of aluminium alloys

DED	Feedstock/process	Aluminium alloy
Laser	Powder	2024, 4046, 4047, 6061, 7075
	Wire	2319, 5087, 7075
EB	Wire	2139
WAAM	MIG/MAG/CMT	1100, 205A, 2319, 4043, 4047, 4220, 4943, 5087, 5183, 5356, 5356 + B_4C, 6061, 7xxx, Al-Mg-Sc, AA + BN nanotubes
	TIG	2050, 2219, 2319, 4043, 5087, 5356, 7075
	Plasma	5356
FSW	Rod	6061, 7075, Recycled

Series	1xxx	2xxx	3xxx	4xxx	5xxx	6xxx	7xxx	8xxx
Alloying elements	---	Cu, Mg, Si	Mn, Mg	Si	Mg, Mn	Mg, Si	Zn, Mg, Cu	Li, Cu, Mg

Aluminium DED applications

Laser-DED powder: Al 6061-RAM2, Rocket engine nozzle (NASA, USA, 2023)

Arc-DED wire: Wing rib, material savings 500kg (Cranfield University, UK)

Laser-DED wire: Y branch pipe (Fraunhofer IWS)

Arc-DED wire: Stiffened Al panel (Stelia Aerospace, France)

Arc-DED wire: Bicycle frame (MX3D, the Netherlands)

FSW: Al 6061 (MELD 2020, USA)

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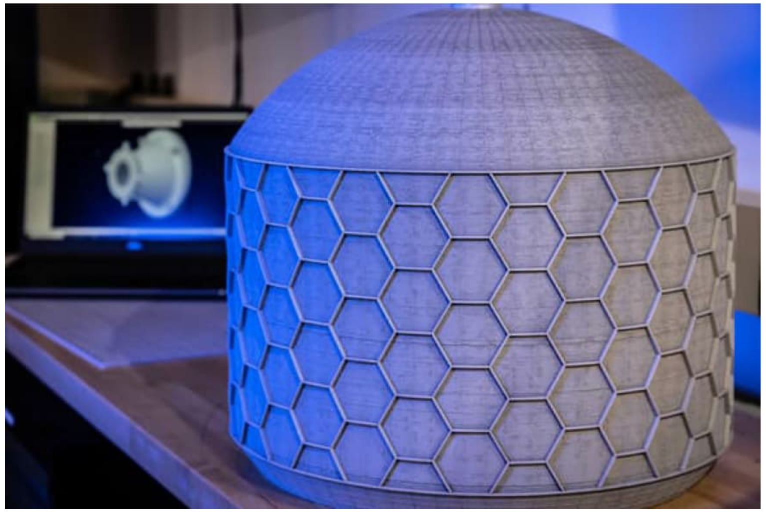
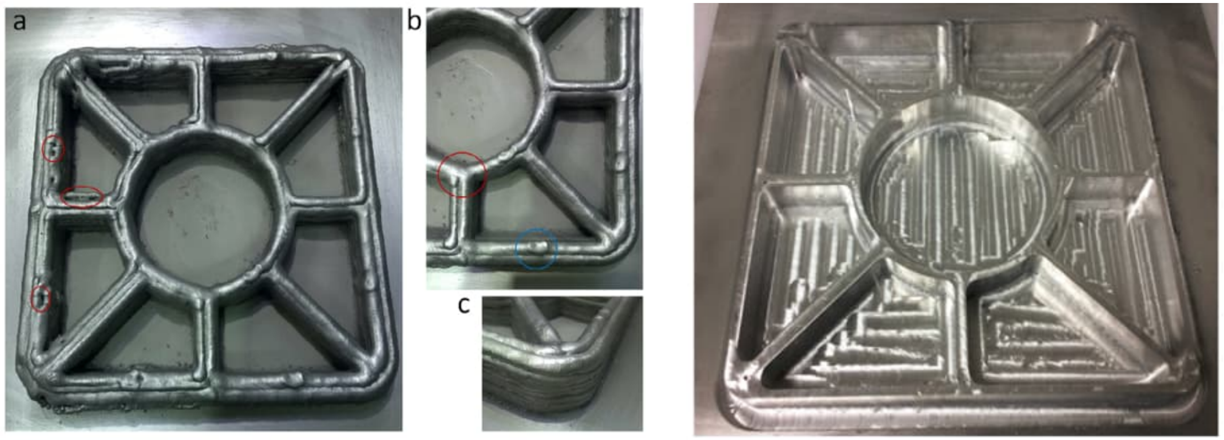
Aluminium DED applications



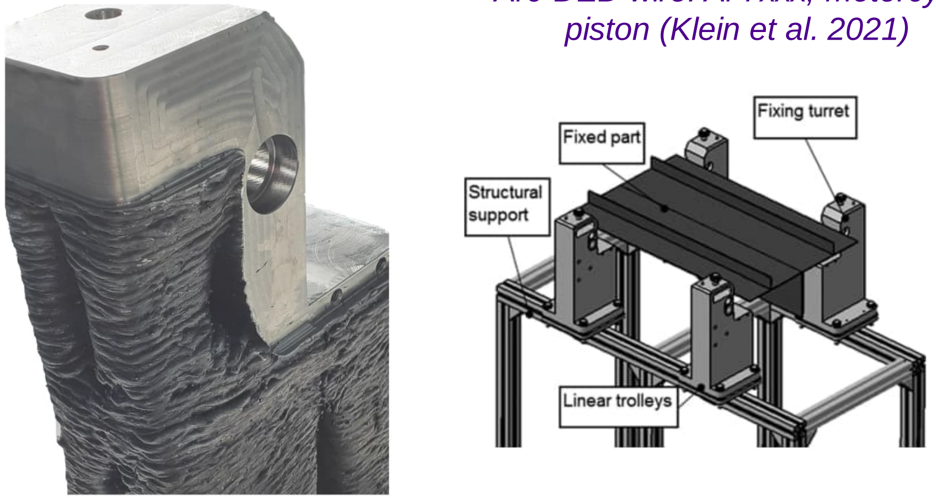
Laser-DED powder: Al 6061-RAM2, Vacuum jacket tank, (NASA, 2023, USA)

Arc-DED wire (TIG): Aluminum, (Wang et al. 2000, USA)

Arc-DED wire: Al 7xxx, motorcycle piston (Klein et al. 2021)



Arc-DED wire: Al (5%Mg, 5xxx) (Ding et al., 2016, Australia)



Arc-DED wire: Al 5356, fixing turret (Veiga et al. 2023)

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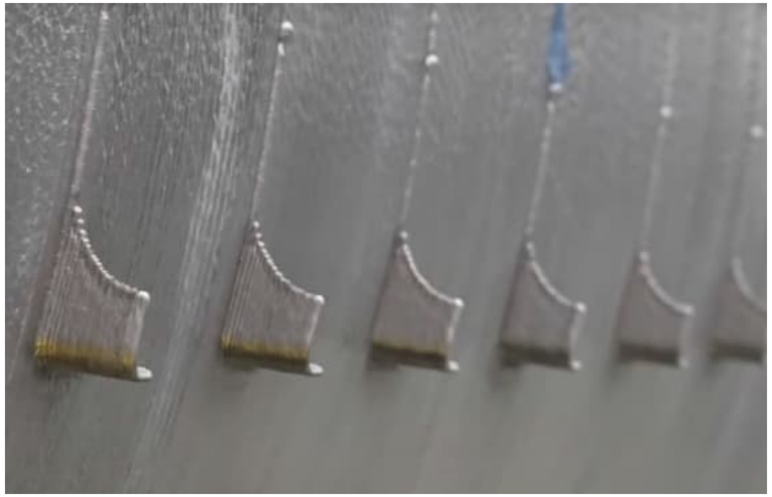
Aluminium DED applications

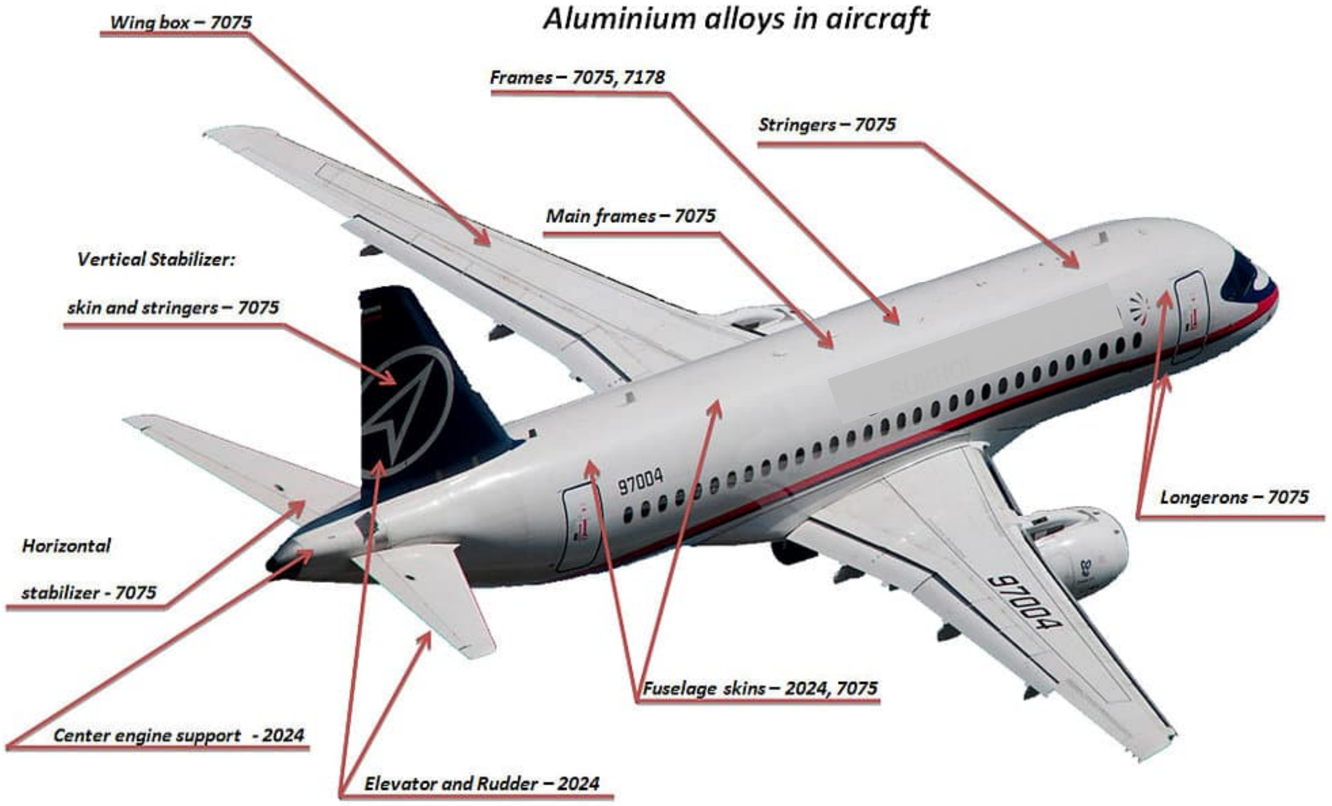


Arc-DED wire: Terran 1 rocket, high-strength aluminium (Relativity Space, USA), h = 33 m, 85% of mass 3D printed:

-> 10x faster production time
-> 100x fewer parts

AA7075 alloy

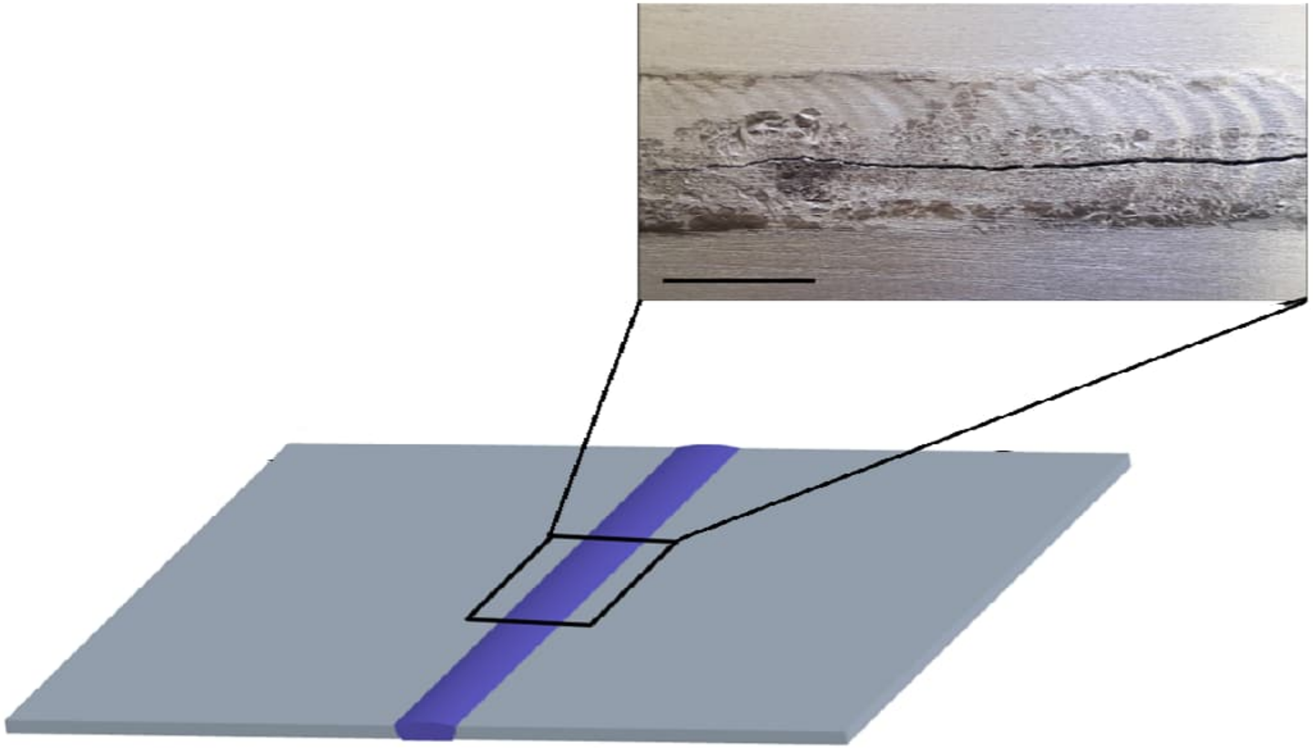
- Al-Zn-Mg alloy
- Widely used in aerospace and automotive applications
- Outstanding high strength-to-weight ratio
- Good corrosion resistance
- Heat-treatable
- Non-weldable



Meneses Fuentes et al. NOLAMP 2023

Weldability / Printability issues of AA7075

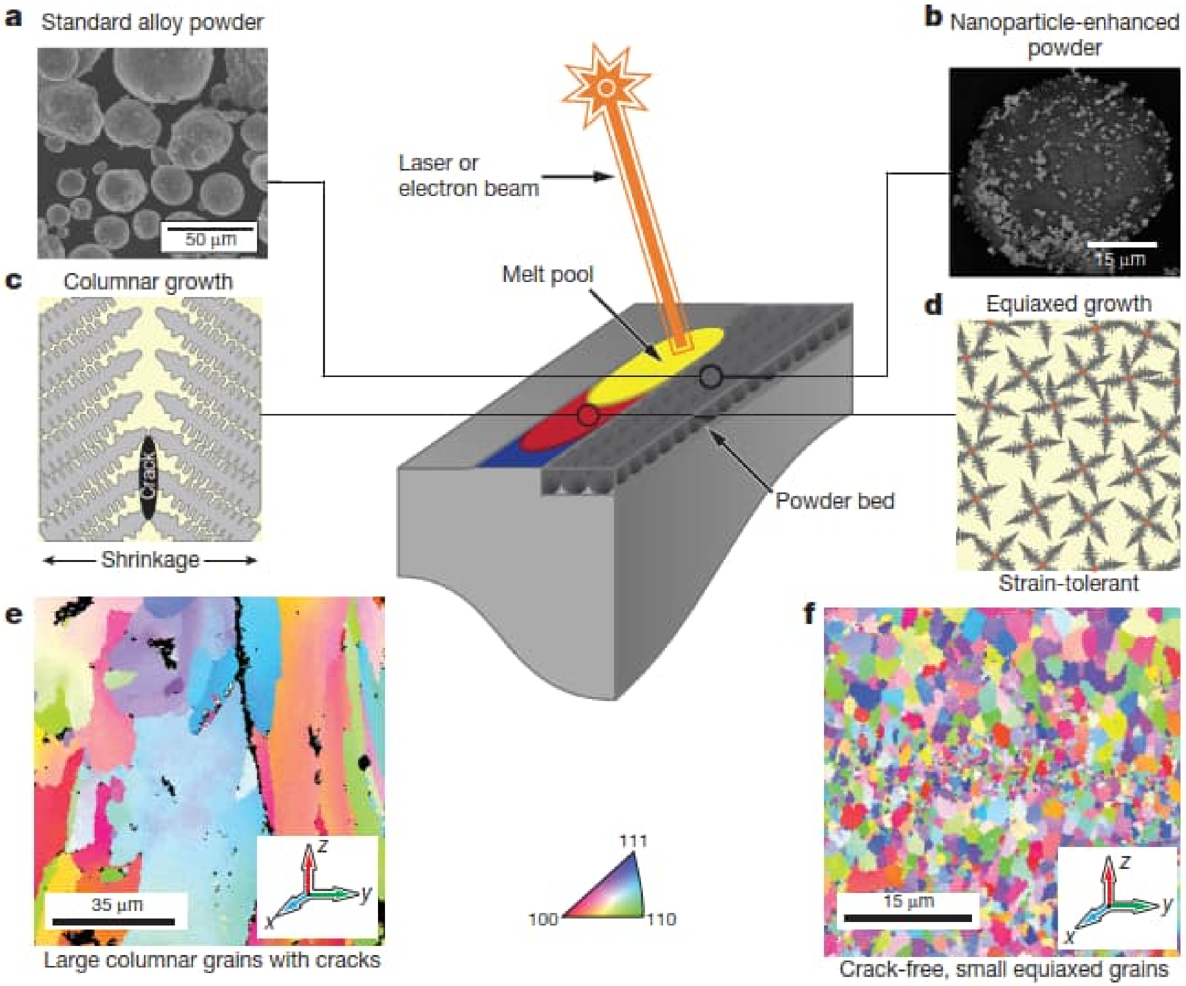
- Hot cracking
  - Large solidification range (~100°C)
  - Low melting point phases (Al_2CuMg, Zn)
- Porosity
  - Hydrogen solubility
  - Low boiling point of Zn and Mg
- Alumina foils



Sokoluk M, Cao C, Pan S, Li X. Nanoparticle-enabled phase control for arc welding of unweldable aluminum alloy 7075. Nature communications. 2019;10(1):98–98.

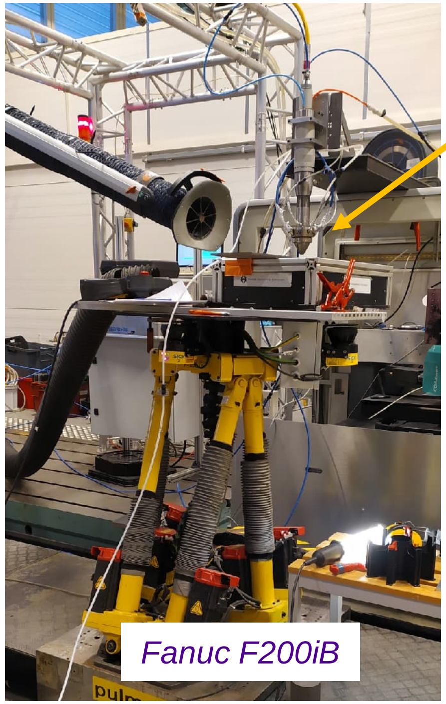
Nano-functionalization

- Use of nanoparticles (TiB_2, TiC, ZrH_2) to promote heterogenous nucleation and produce a refined equiaxed grain microstructure



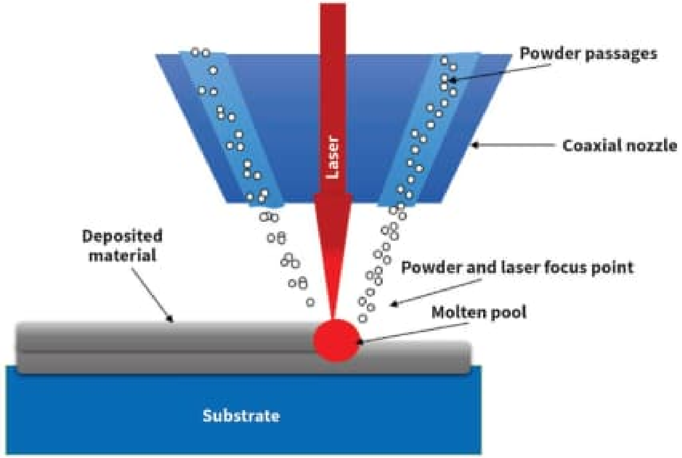
Martin JH et al. (2017), 3D printing of high-strength aluminium alloys, *Nature 549*, 365–369.

Coaxial powder laser method

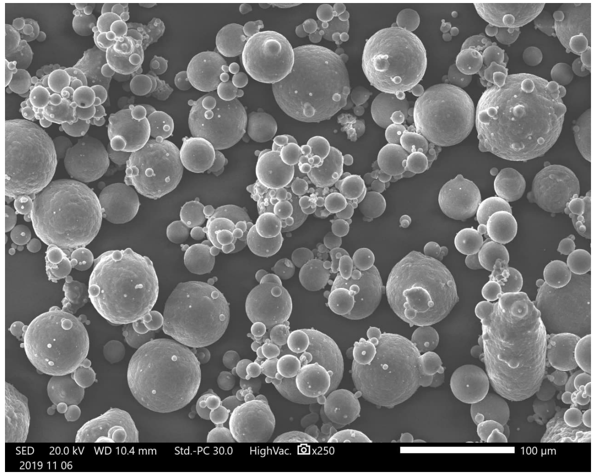


Fanuc F200iB

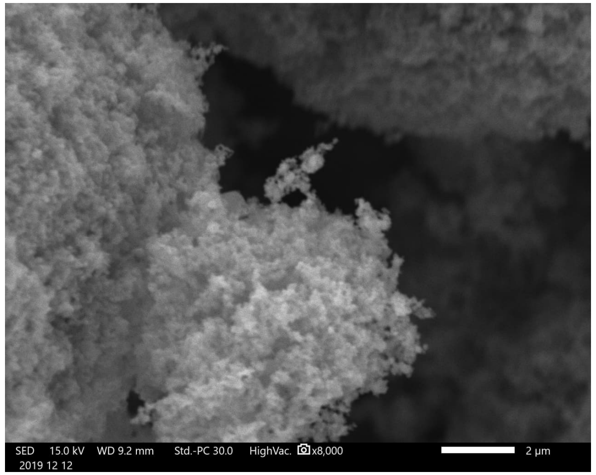
COAX 8



AA7075 (50-150µm)



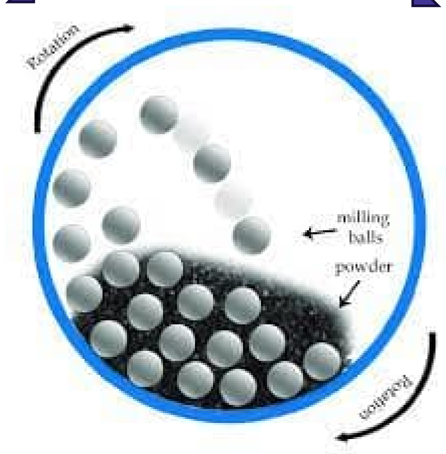
TiC (~50nm)



Fraunhofer IWS COAX 8

Coherent 3 kW

Parameter	Value
Power	1000 W
Spot ∅	2.5 mm
Travel speed (TS)	8.3–16.7 mm/s
Powder feed rate (PFR)	1.6–3.2 g/min



High-energy ball milling

Cobian Gonzalez et al. RIM 2022

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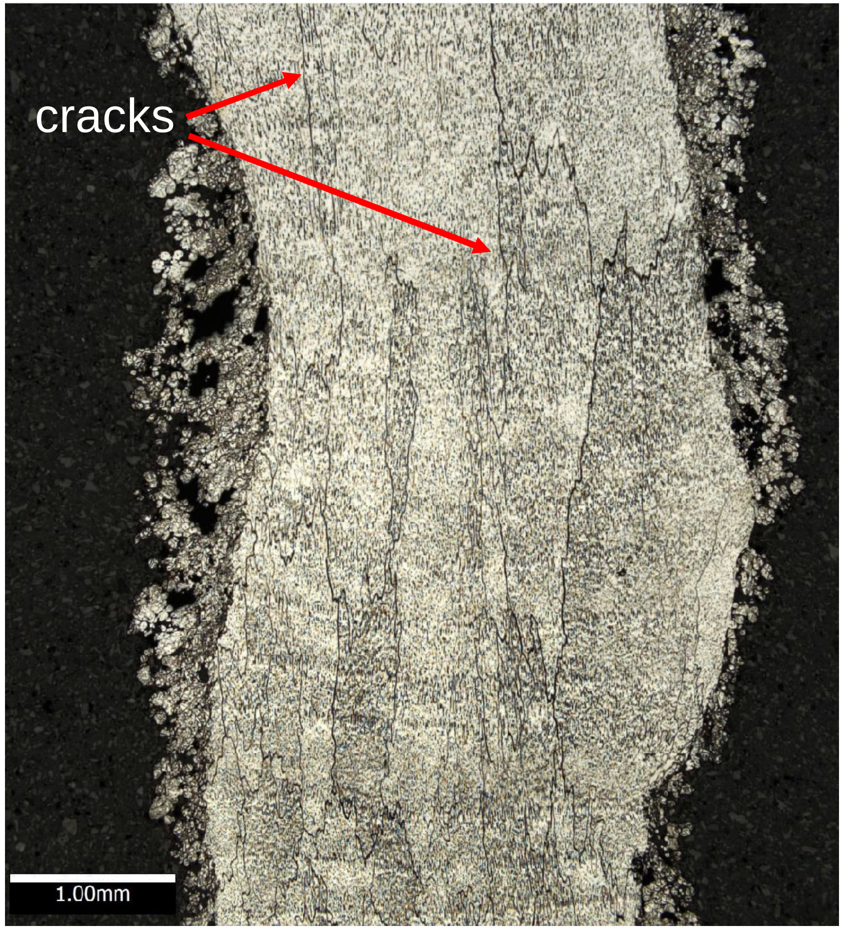
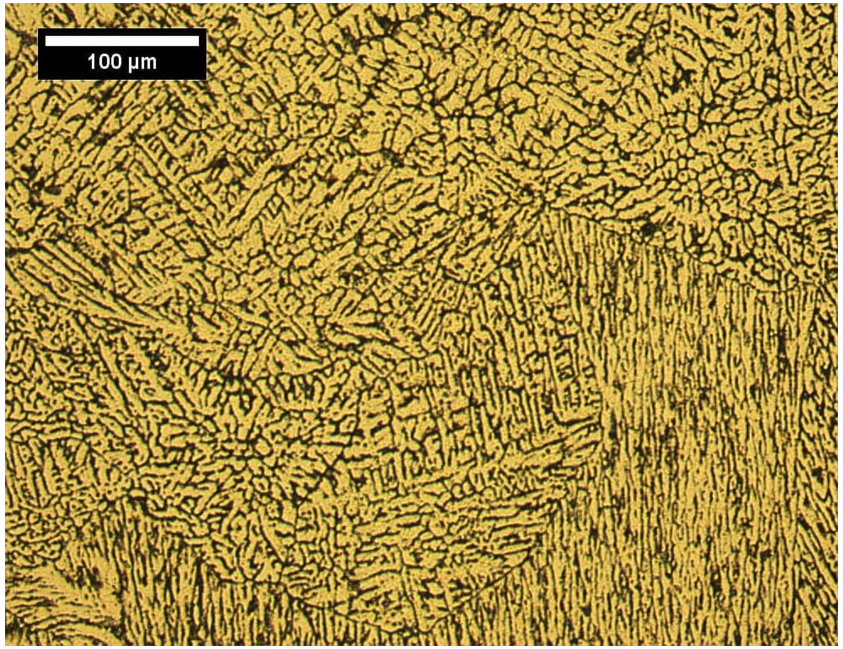
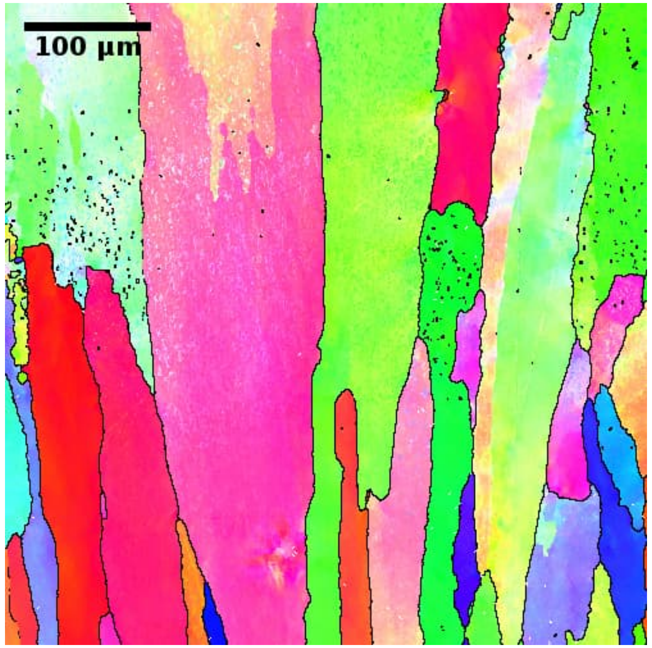
Coaxial powder laser method

Cobian Gonzalez et al. RIM 2022



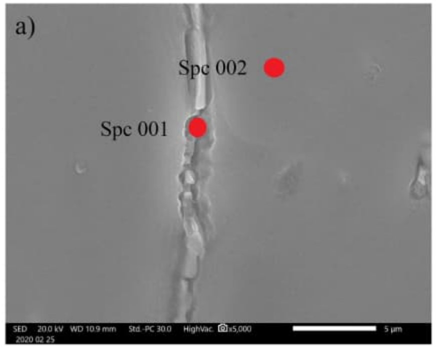
Liquation-cracked pore-free AA7075 deposit

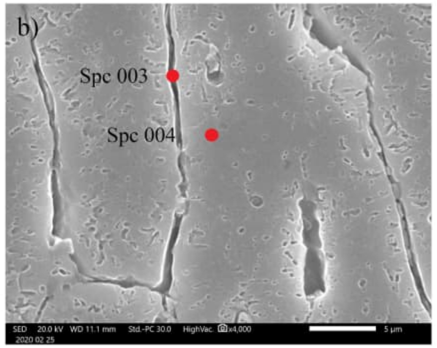




Columnar-dendritic sub-structure (OM, EBSD)

Large grains





EDS results in wt.%.

Location	Al	Cu	Zn
Spc 001	83.2 ± 0.6	10.4 ± 0.4	6.4 ± 0.4
Spc 002	95.9 ± 0.5	0.9 ± 0.1	3.2 ± 0.2
Spc 003	84.0 ± 0.7	10.4 ± 0.5	5.7 ± 0.4
Spc 004	96.8 ± 0.5	0.5 ± 0.1	2.8 ± 0.2

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Coaxial powder laser method

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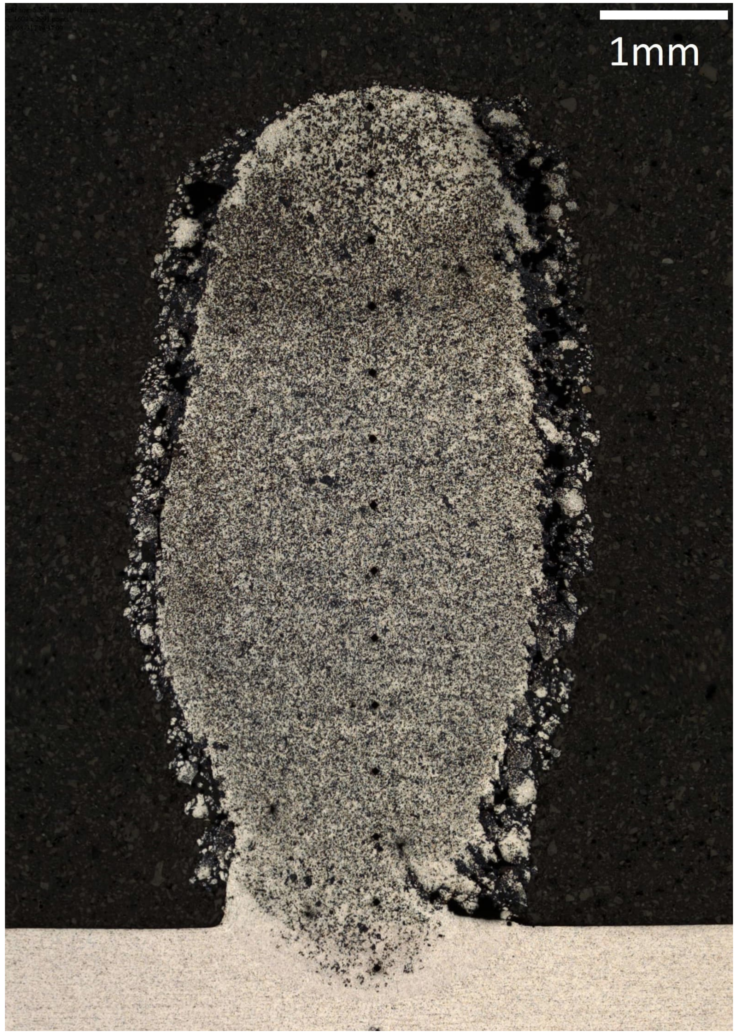
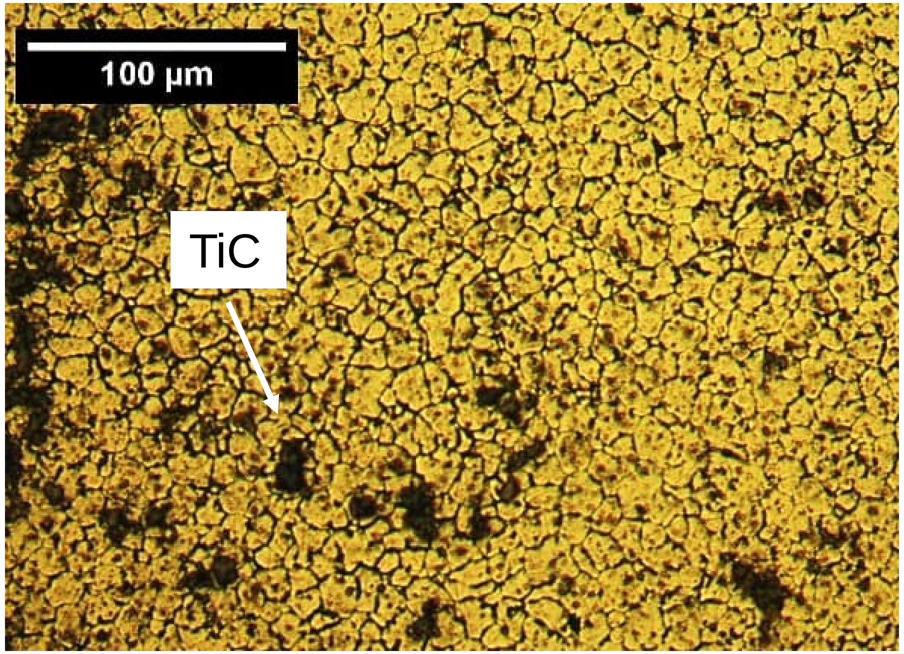
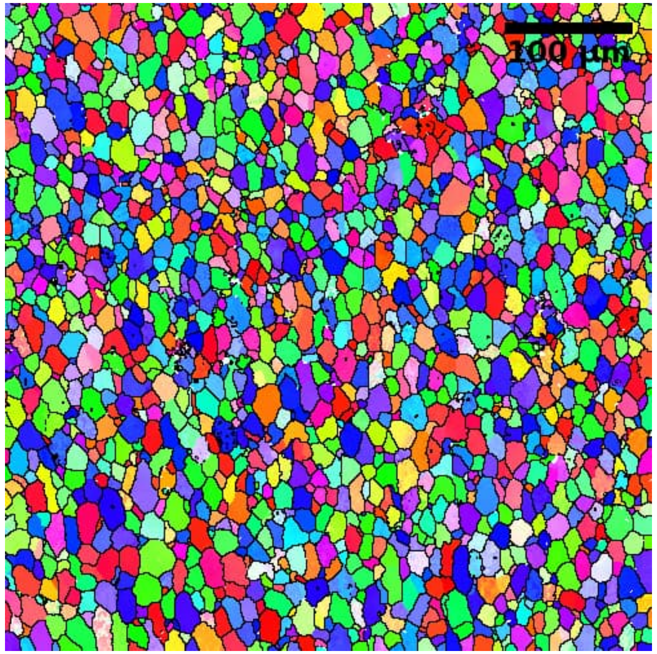


Crack- and pore-free AA7075-TiC deposit





Fine equiaxed grain structure (OM, EBSD) with clustered TiC

Grain size ~10µm

Deposit	Condition	Microhardness
AA7075-TiC	As-printed	90-100 $HV_{0.2}$
AA7075-TiC	T6	110-115 $HV_{0.2}$

AA7075-T6 wrought is 160-175HV

→ Poor response to T6 due to Zn evaporation during printing

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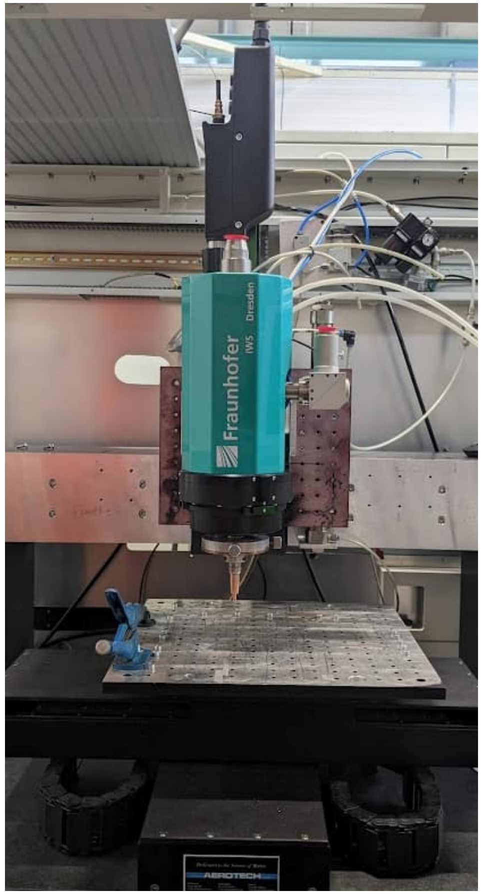
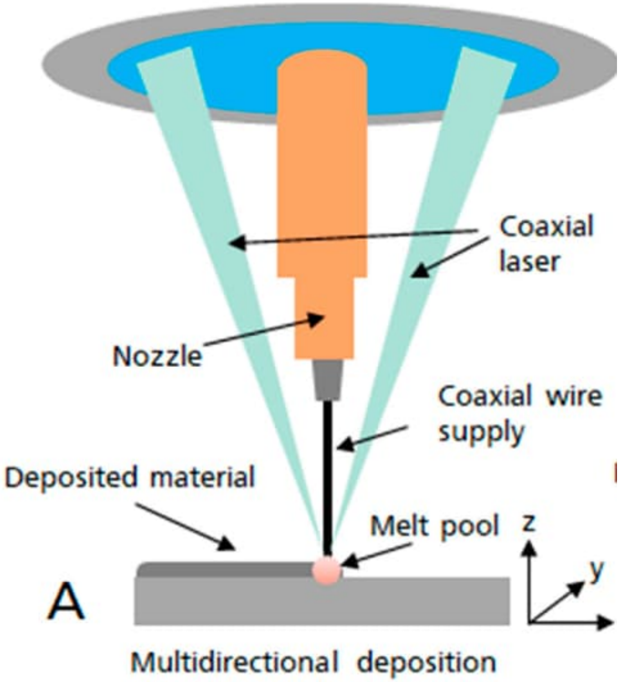
Coaxial wire laser method



Meneses Fuentes et al. NOLAMP 2023



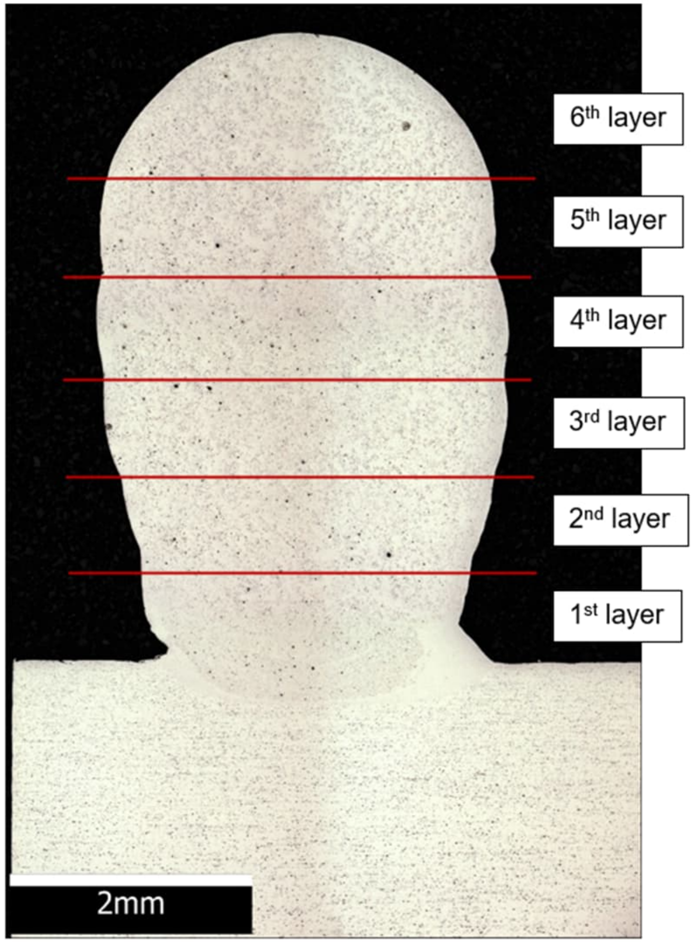
Stehmar C, Gipperich M, Kogel-Hollacher M, Velazquez Iturbide A, Schmitt RH. Inline Optical Coherence Tomography for Multidirectional Process Monitoring in a Coaxial LMD-w Process. Appl Sci. 2022 Mar 5;12(5):2701

Parameter	Value
Power	2700 W (for 1st and 2nd bead) and 2500 W (for the rest)
Traverse speed (TS)	15 mm/s
Wire feed rate (WFR)	2 m/min
Shielding gas flow (Ar)	12 l/min
Step size	1.1 mm
Interpass time	60 s
Wire diameter	1.2 mm
Bead length	70 mm

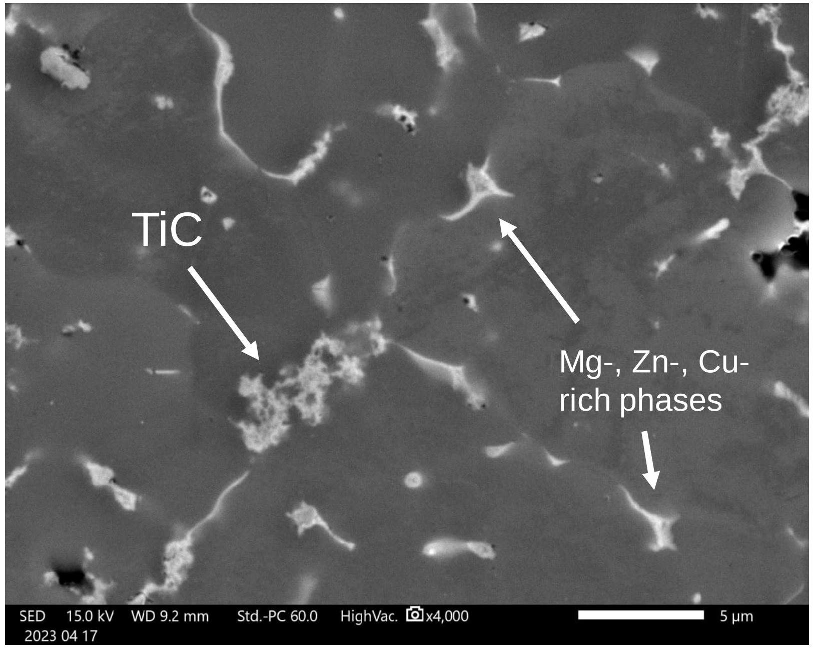
Ø1.2mm 7075NP wire (40-60nm TiC)

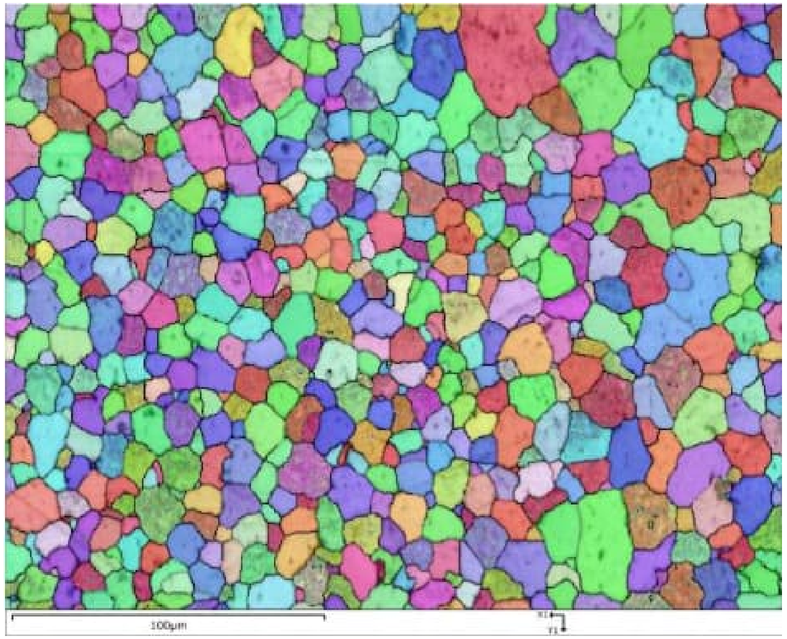
Coaxial wire laser method

Meneses Fuentes et al. NOLAMP 2023



Crack- and pore-free AA7075-TiC deposit





Fine equiaxed grain structure (SEM, EBSD) with only tiny TiC clusters

Grain size ~10µm

Deposit	Condition	Microhardness
AA7075-TiC	As-printed	~120 $HV_{0.2}$
AA7075-TiC	T6	~170 $HV_{0.2}$

AA7075-T6 wrought is 160-175HV

→ Good response to T6 due to overalloyed Zn content in the wire

Summary

- DED methods: 1) Laser, 2) WAAM, 3) EB and 4) FSW
- High productivity, cost efficient, no size limitations
- Also for repairing, reconditioning & remanufacturing
- Commercial DED devices available (also hybrid)
- Suits for wide range of aluminium alloys: 2xxx, 4xxx, 5xxx, 6xxx, and 7xxx-series
- Non-weldable grades can be 3D printed with nucleation enhancers
- TAU focuses on laser-DED and CMT-WAAM methods

Questions!