IBAAS 2025
Technical Lecture Series

Lecture 6

Towards Defect-Free Manufacturing with Aluminum: Predictive Modelling using AM PravaH

27th June 2025
4 PM to 5 PM (IST)
10.30 AM to 11.30 AM (GMT)
Followed by Q & A

Speaker :
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PAANDUV APPLICATIONS, INDIA

Live Webinar

Free Registration

Monsoon season in India typically causes a **dip in Aluminium domestic scrap prices** and **elevates logistics costs**, tightening supply-side pressures.

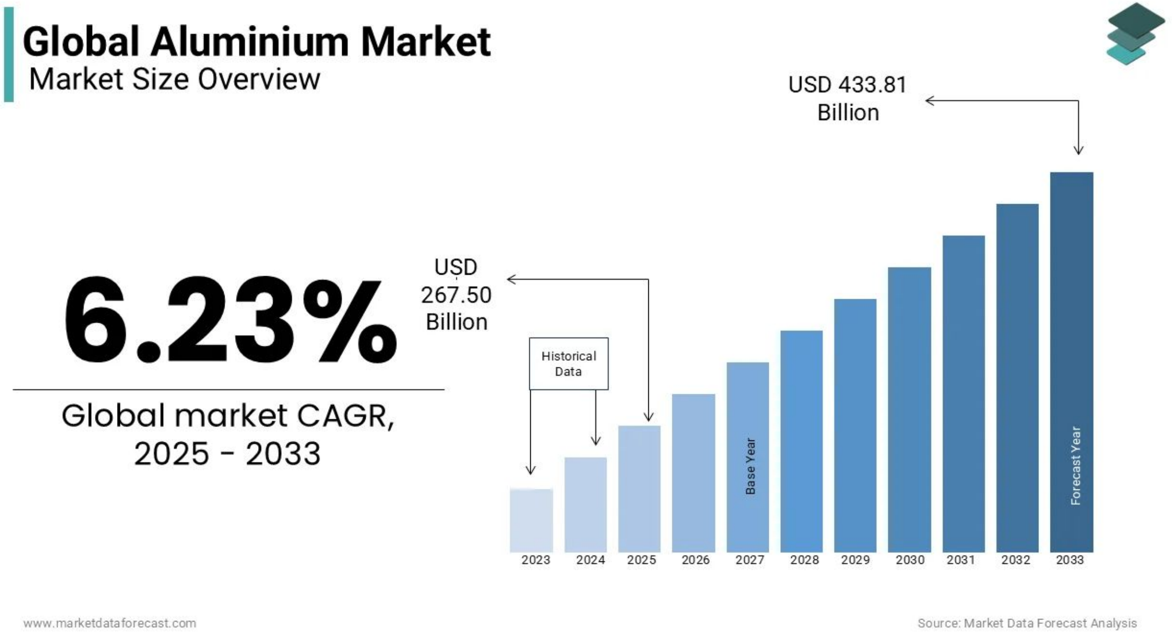
Aluminium market

Aluminium powder feedstock for AM reached about 658,900 tonnes in 2023, projected to grow to 767,500 tonnes by 2032—at a ~1.7 % CAGR

Aluminium alloy AM market (e.g., Al7xxx series) accounted for USD 22 million in 2020, projected to grow to ~USD 110 million by 2028, with CAGR ~26 %

Powder Bed Fusion (PBF) is the dominant production method, while Selective Laser Melting (SLM) held ~28.9 % market share in 2023

AlSi10Mg and other aluminium alloys are being optimized—some brands are introducing 30 % recycled-content aluminium powders

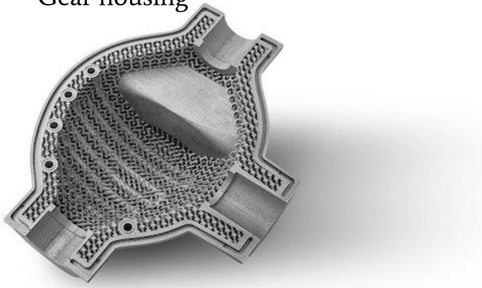


Additively manufactured Al parts

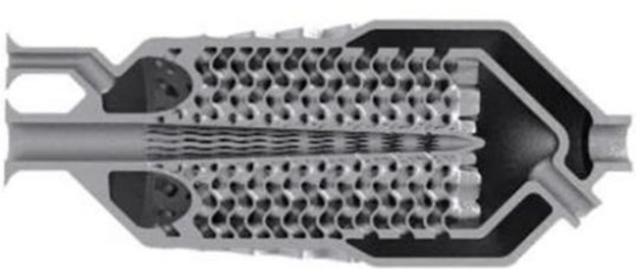
- High-performance material that offers interesting mechanical and chemical properties
- High strength-to-weight ratio and is weather resistant
- Less rigid than those made with steel
- Not a biocompatible metal, so it is not the ideal choice for use in the medical sector

Gear wheel

Gear housing



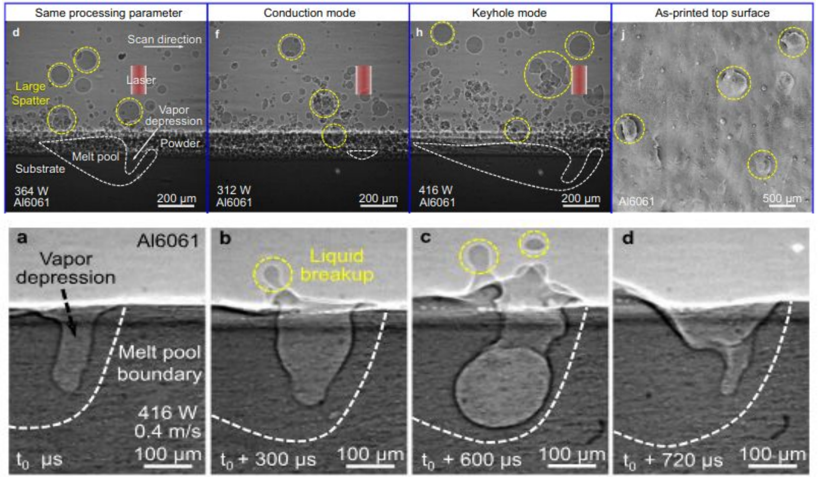
Heat exchangers of
aviation turbine engines



Alloy / Type	Composition / Standard Name	AM Processability	Processing Challenges	Typical Applications
Pure Aluminium	≥99.0% Al	❌ Poor	Low laser absorption, high reflectivity, rapid heat loss	R&D, electrical parts (rare), thermal components
AlSi10Mg	Al-10%Si-0.4%Mg	✅ Excellent (LPBF)	Porosity if parameters not tuned	Aerospace, automotive, housings, structures
AlSi12	Al-12%Si	✅ Excellent (LPBF)	Brittle if over-aged	Lightweight tooling, general parts
Al-Mg (e.g., 5083)	Al-4.5%Mg	⚠️ Moderate (DED > LPBF)	Hot cracking, large grain size	Marine, cryogenic tanks, automotive
Al-Cu (e.g., 2024)	Al-4.4%Cu	❌ Poor (Under R&D)	Severe hot cracking, poor weldability	Aircraft structures (R&D stage in AM)
Al-Zn-Mg (7075)	Al-5.6%Zn-2.5%Mg-1.6%Cu	❌ Poor (Emerging)	Hot cracking, oxidation	Aerospace, defense (not fully AM-suitable yet)
Al-Mg-Sc-Zr	Custom or Scalmalloy®	✅ Excellent (LPBF, DED)	High cost due to Scandium	Aerospace, high-performance structural parts
Nano-inoculated Al alloys	Al + TiB_2/Zr nanoparticles	✅ Promising (R&D)	Alloy design still in development	Crack-prone high-performance alloy processing

Current defects with additively manufactured Al

Al6061

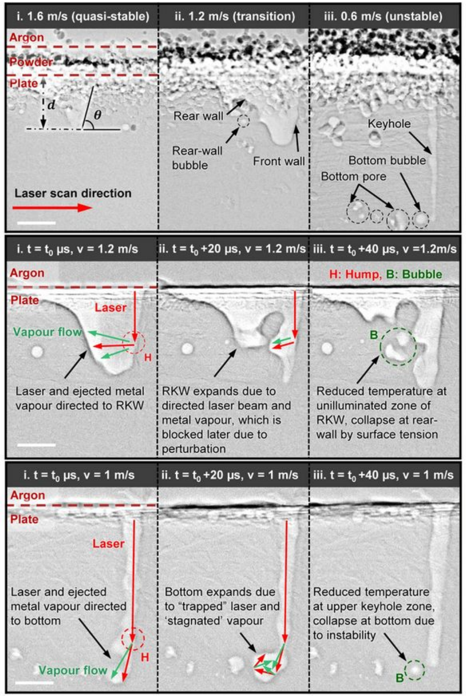


Qu, Minglei, et al. "Controlling process instability for defect lean metal additive manufacturing." *Nature communications* 13.1 (2022): 1079.

Huang, Yuze, et al. "Keyhole fluctuation and pore formation mechanisms during laser powder bed fusion additive manufacturing." *Nature communications* 13.1 (2022): 1170.

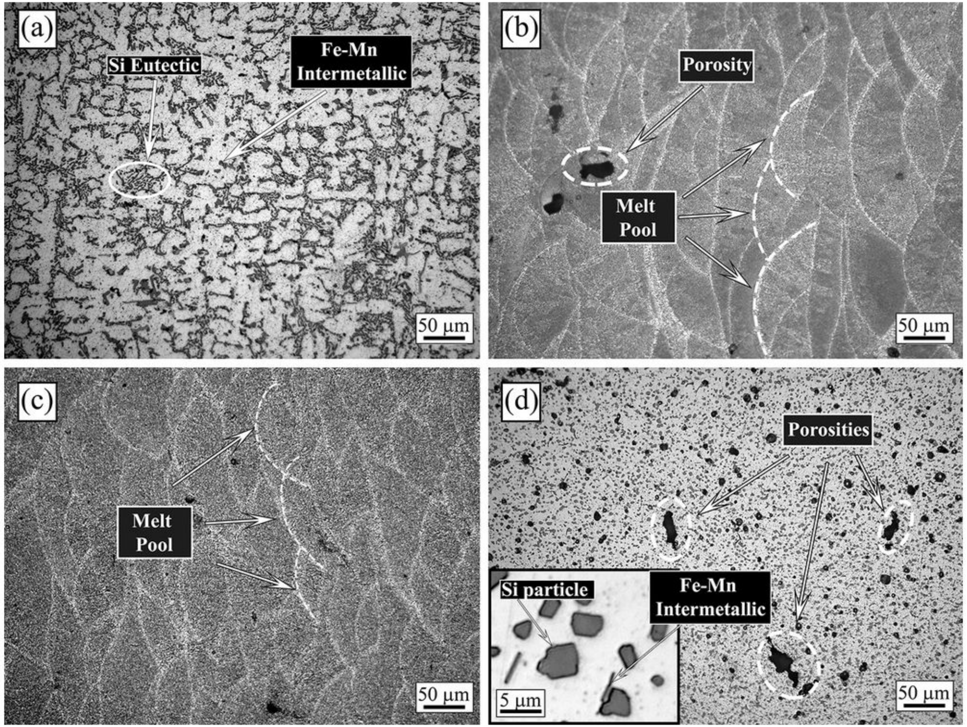
Al7A77

Pure Al



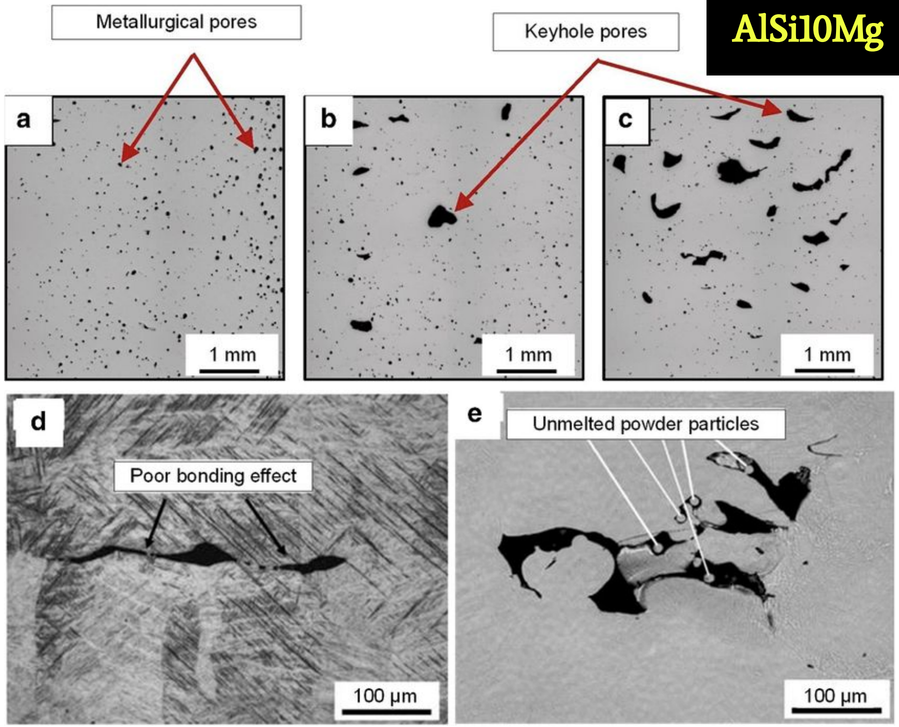
- Hump
- Bubbles
- Keyhole
- Spattering
- Liquid breakup
- Keyhole porosity
- Vapor depression
- Vapor plume ejection

Current defects with additively manufactured Al alloys



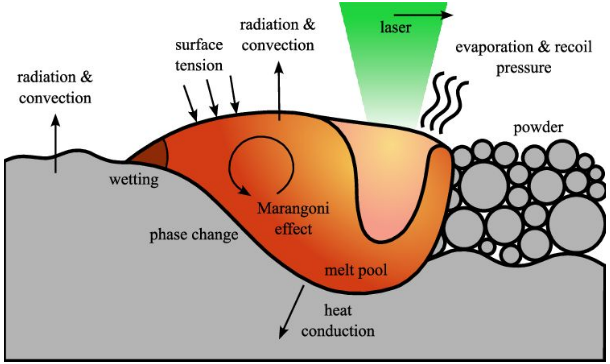
Pezzato, L., et al. "Influence of silicon morphology on direct current plasma electrolytic oxidation process in AlSi10Mg alloy produced with laser powder bed fusion." *Scientific Reports* 12.1 (2022): 14329.

AlSi10Mg



Afroz, Laboni, et al. "Fatigue behaviour of laser powder bed fusion (L-PBF) Ti–6Al–4V, Al–Si–Mg and stainless steels: a brief overview." *International Journal of Fracture* 235.1 (2022): 3-46.

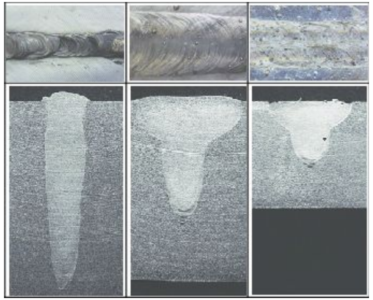
Experimentation to eliminate defects



Present aspirations of AM process engineer/researcher

To provide a sustainable technology
To prevent wastage
To achieve a heterogeneous fine grain microstructure
To produce a near net-shaped component

Melt pool geometry is associated with each of those aspects



- Optimizing process parameters
- Utilizing advanced monitoring techniques
- Employing machine learning for defect prediction and control

Shape and size of track relating to build rates
Interlayer adhesion (defects)
Powder-laser interaction
Temperature profile and gradients

Challenges in experimentation

1. Material-Related Challenges
2. Process Control and Reproducibility
3. Experimental Setup Constraints
4. Data Generation and Analysis
5. Defect Control and Characterization
6. Validation and Benchmarking
7. Iterative Nature of AM R&D

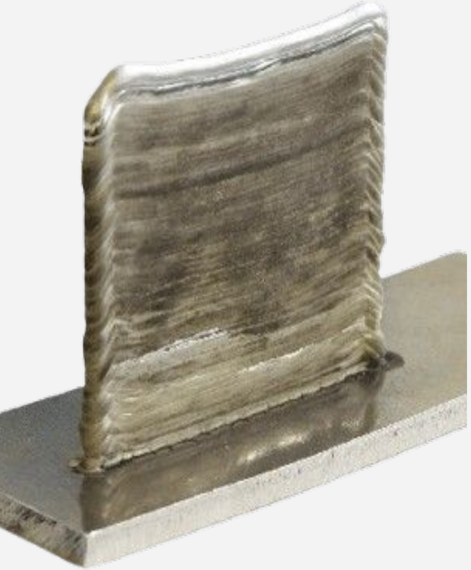
Cost

Resources

Cycle time

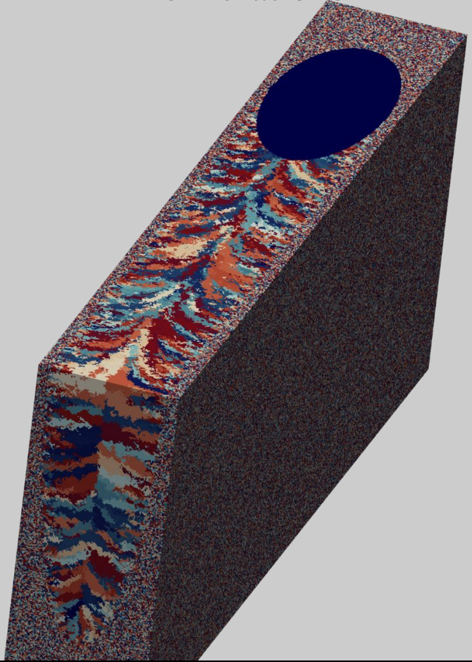
Multiscale simulations to eliminate defects

Real coupon

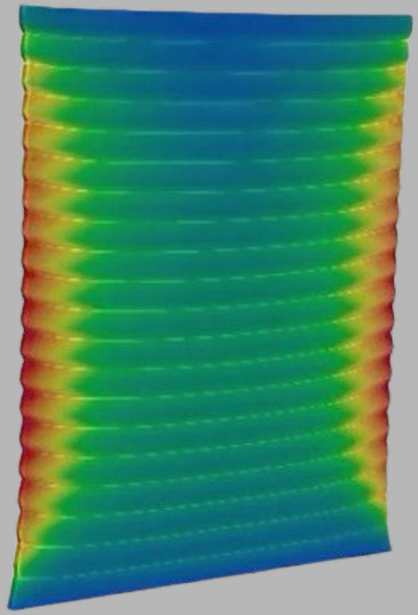


High-fidelity melt pool dynamics simulations

Microstructure growth simulations

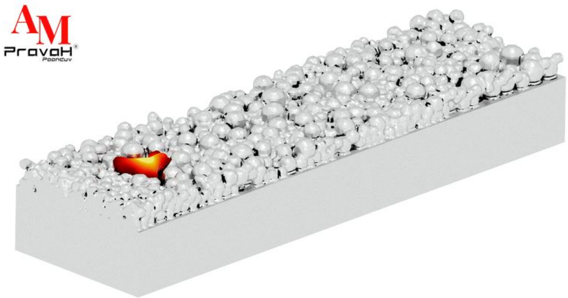


Stress and deformations simulations



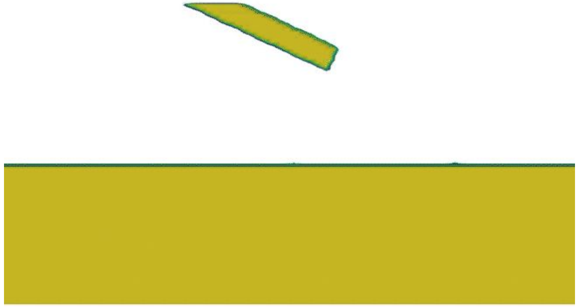
Predictive modeling using AM PravaH®

AM PravaH® Paanduv



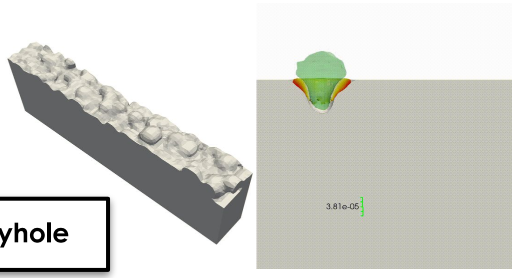
Laser powder bed fusion (L-PBF)

Wire-Laser direct energy deposition (W-LAM)

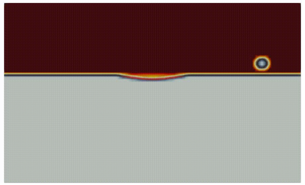


Wire-arc Additive Manufacturing (WAAM)

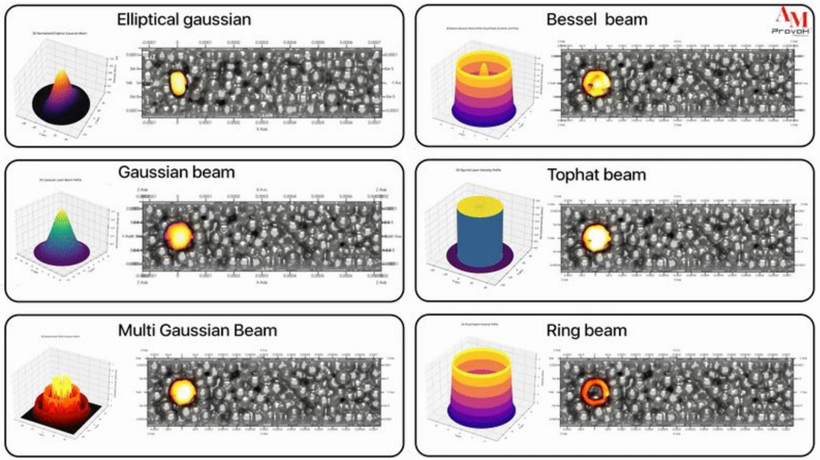
AM PravaH® general capabilities

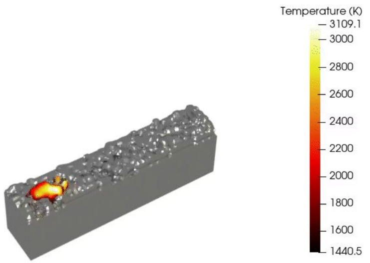


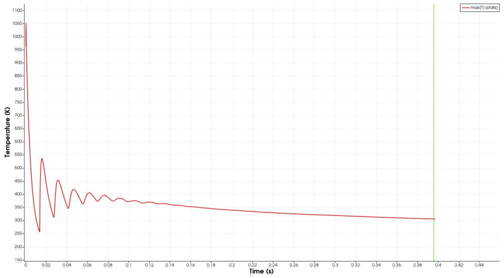
Keyhole

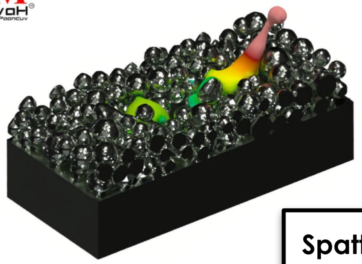


Gas induced porosity





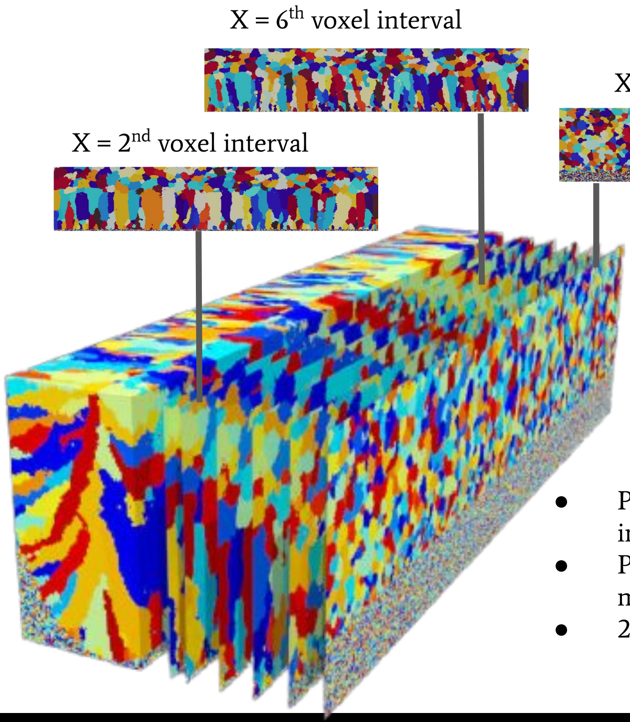


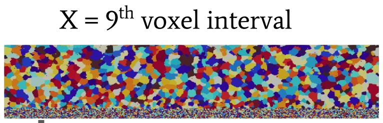


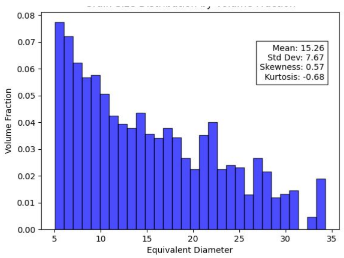
Spattering

AM PravaH® general capabilities

Microstructure evolution with KMC model and Rosenthal equation

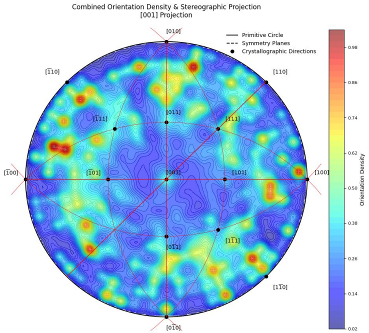


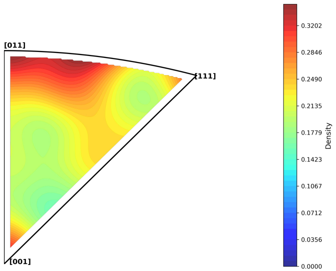




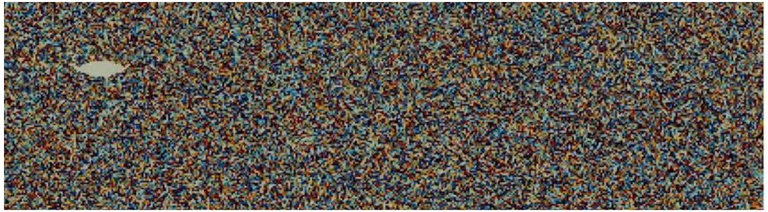
- Provides 3D-tomographic information
- Provides time frames for microstructure evolution
- 2D-sections of spatial variations

Crystallographic texture



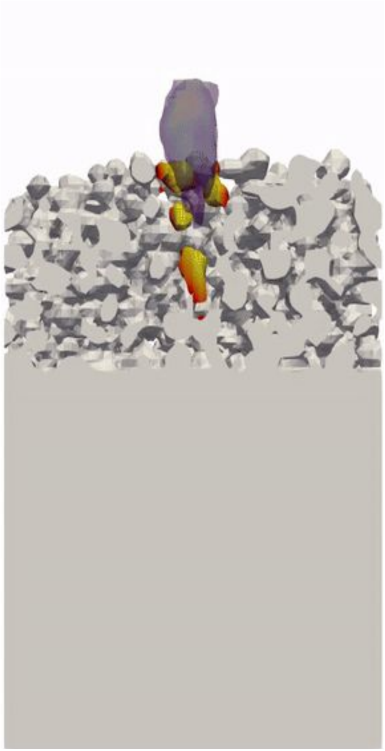


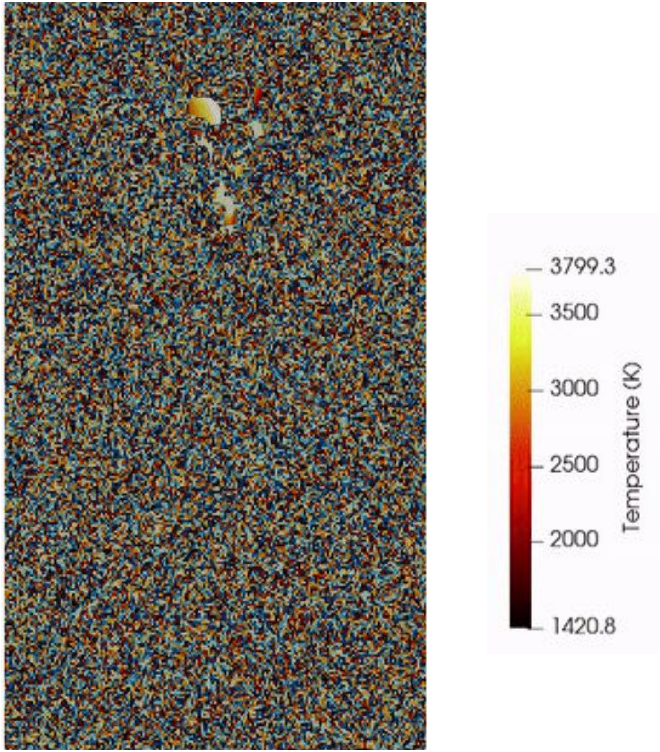
Microstructure evolution with temperature gradient from MP Dynamics



Coupling melt pool dynamics with microstructure

Modelling the physics for the melt pool evolution





High fidelity melt pool simulation

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Dynamic thermal and solidification fields

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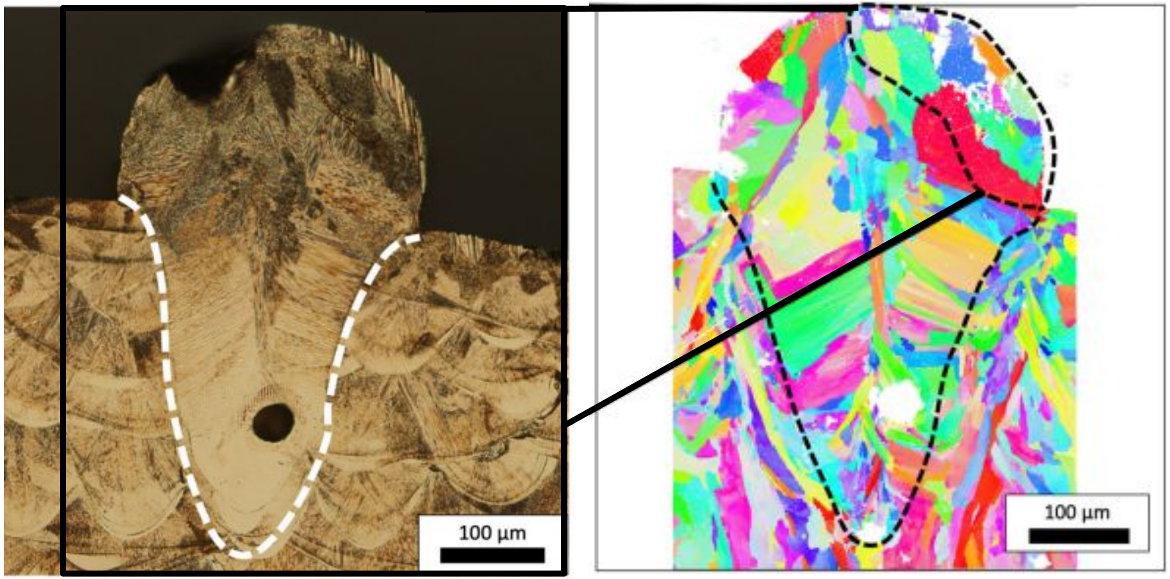
Monte Carlo nucleation and growth

↓

Microstructure evolution

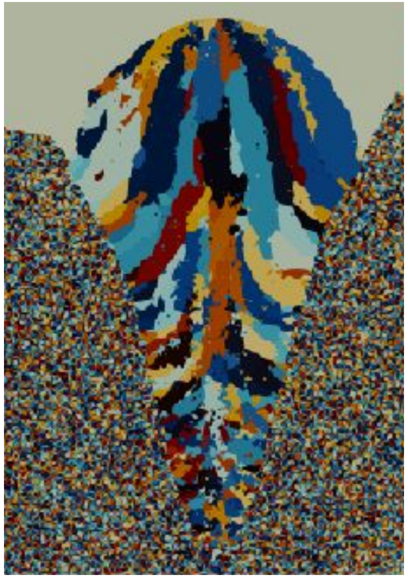
Coupling melt pool dynamics with microstructure

Experimentally obtained microstructure



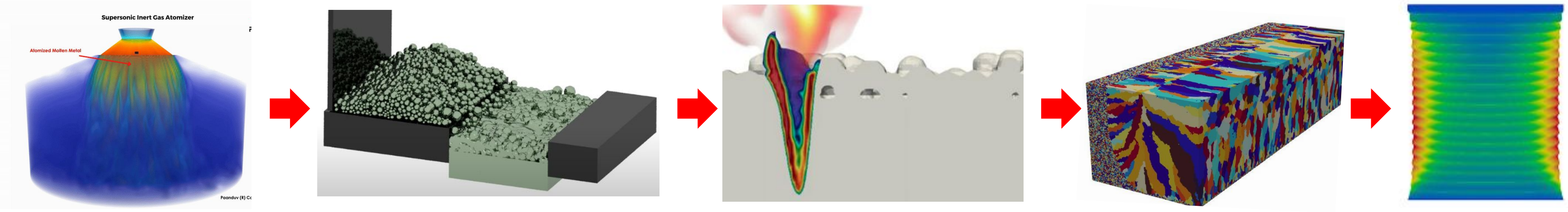
Process parameter: 200 W, 1600 µs

AM PravaH simulated microstructure



AM PravaH® World's first all-inclusive simulation software for AM industry

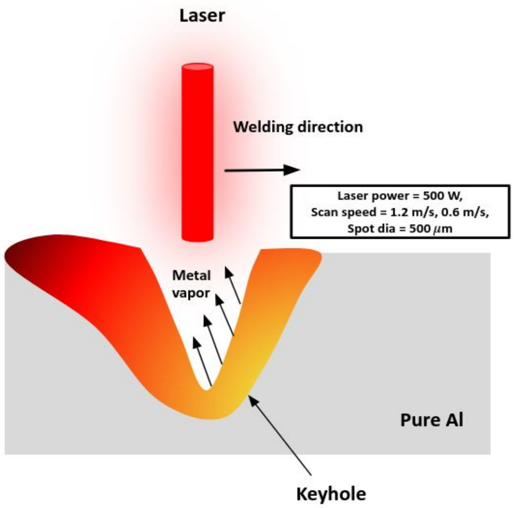
- End-to-end simulation solution for AM, Powder-to-part scale simulation
- Cut down the cost by ~67% in initial process optimizations, 20-30% saving on material costing, it can reduce the rate of failure to ~10%.
- Saves experimental trials and characterizations
- Emerging as a virtual twin for L-PBF and other AM processes



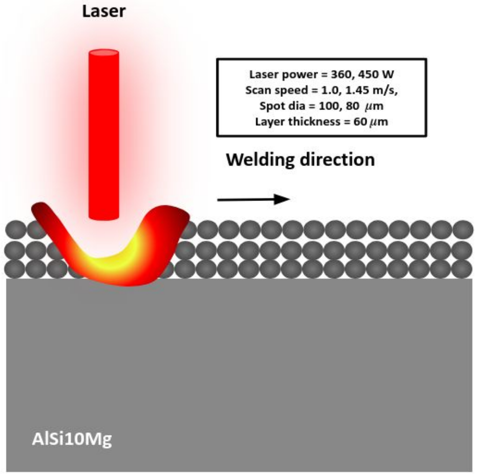
Modeling the Additive Manufacturing Chain: Powder Manufacturing to Part-Scale Mechanics

Case studies

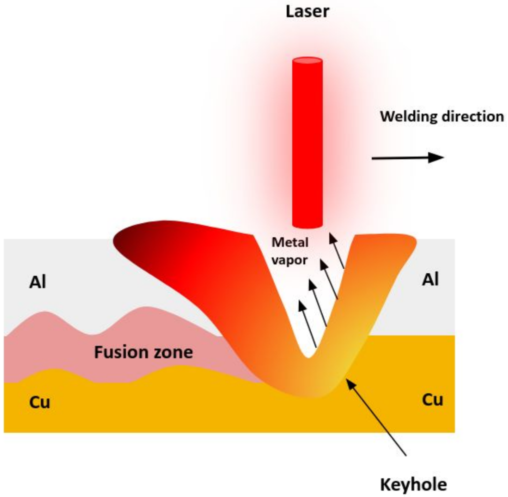
Case 1



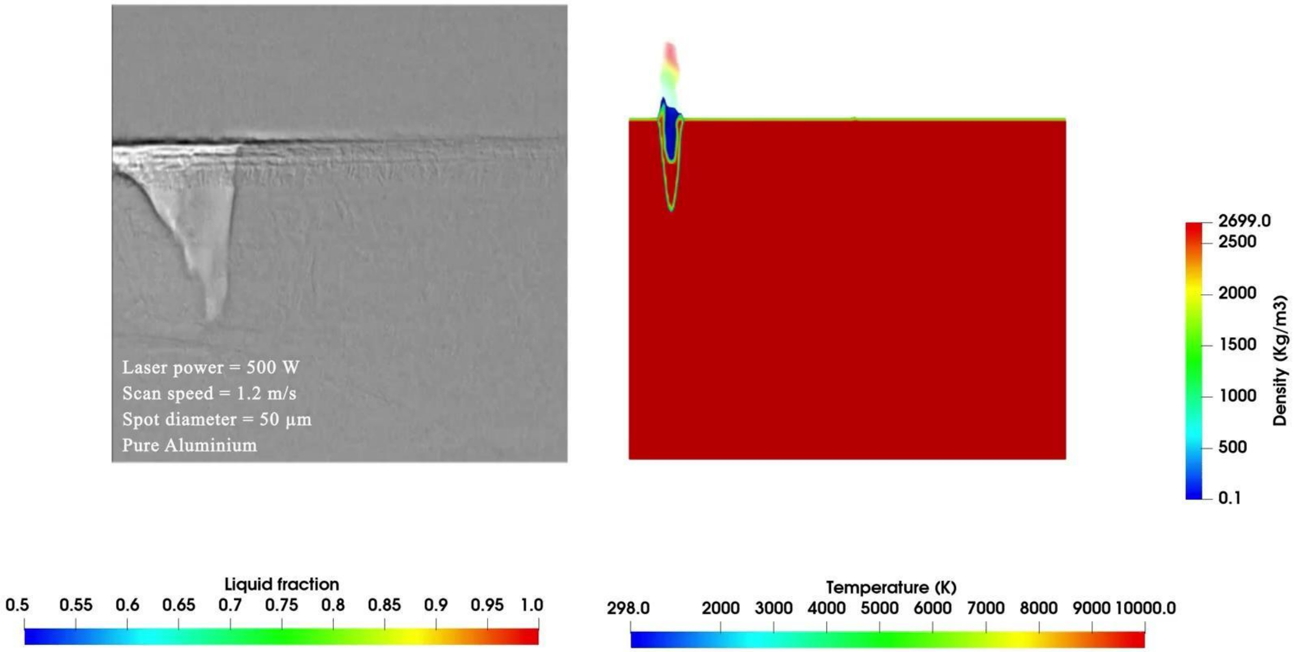
Case 2



Case 3



Case 1: 3D Printing of Aluminium plate using AM PravaH®



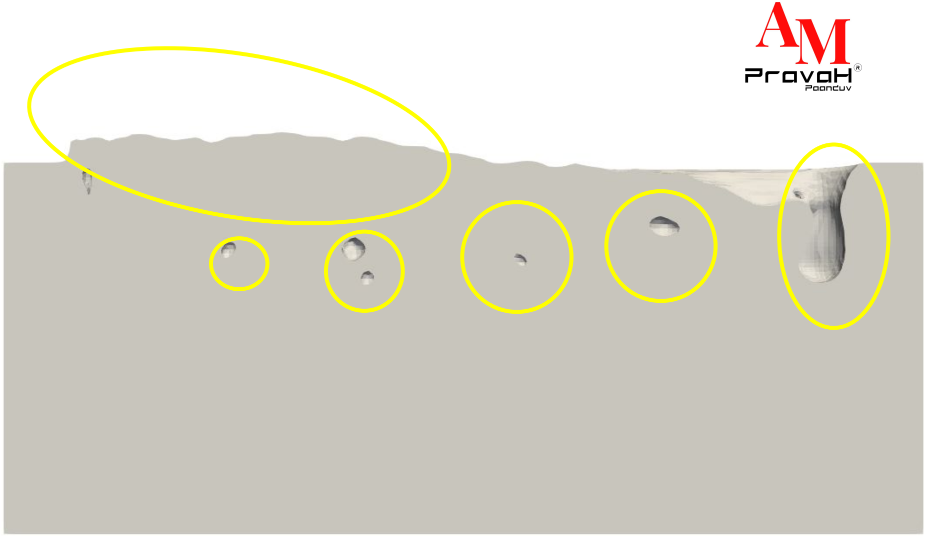
High energy density

Interplay for multiphysics

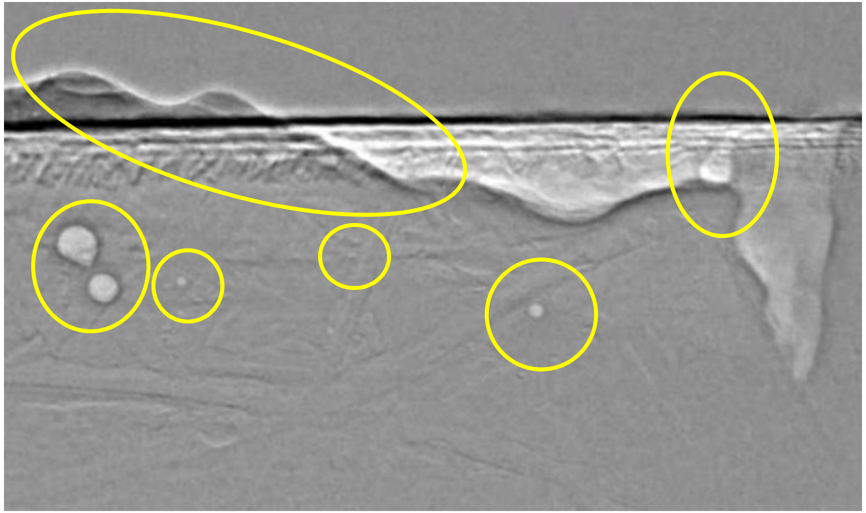
High-fidelity melt pool dynamics simulations vs

Time of the simulation (μs)	Front wall angles, experimental (Degree)	Front wall angles, AM PravaH simulated (Degree)
80 (μs)	85	85
180 (μs)		82
260 (μs)		81
Average keyhole depth	200 μm	

High-fidelity melt pool dynamics simulations vs experiments

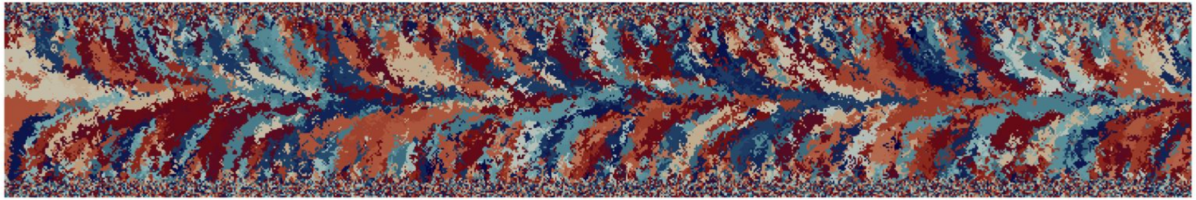


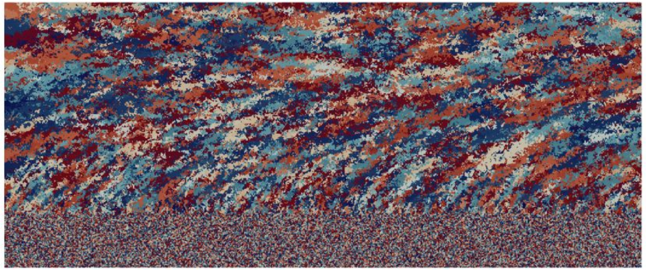
Simulation

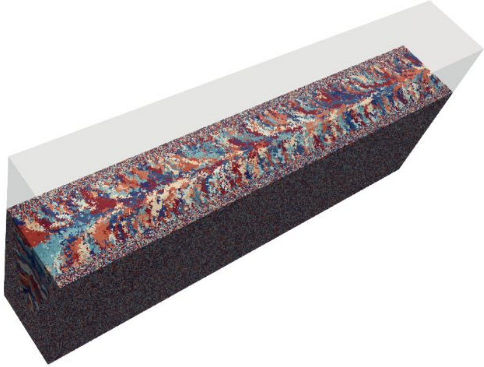


Experiment

Microstructure grain growth



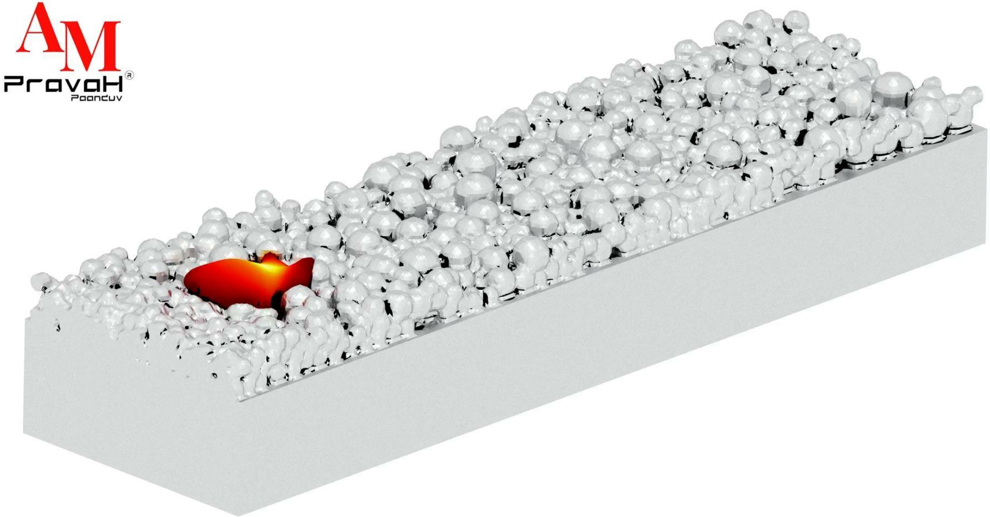




Case 2: 3D Printing of AlSi10Mg plate using AM PravaH®

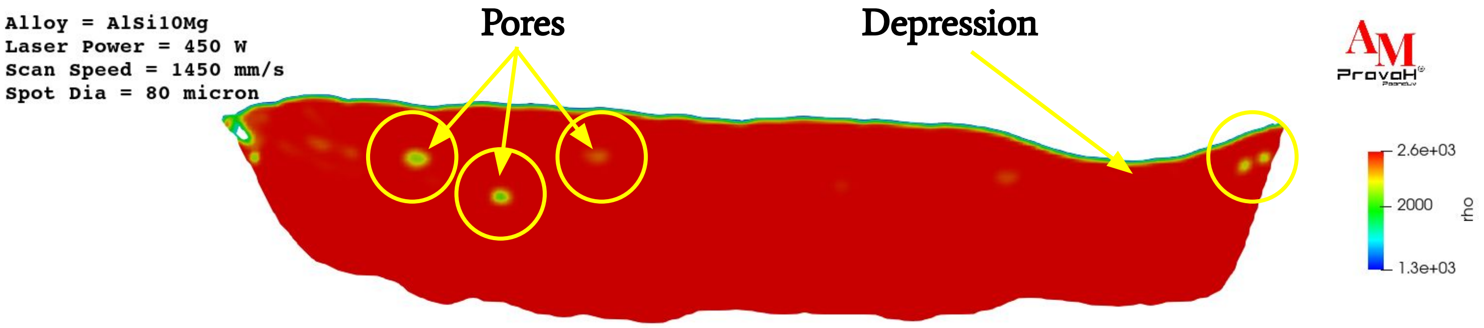
AlSi10Mg is significant in AM due to its:

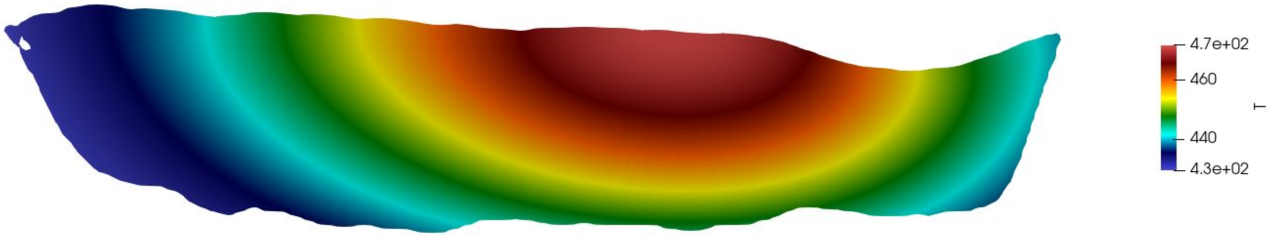
- High printability
- Balanced mechanical and thermal properties
- Lightweight design potential
- Compatibility with post-processing
- Strong industry track record
- Thermal and Corrosion Resistance
- Microstructure Tailoring



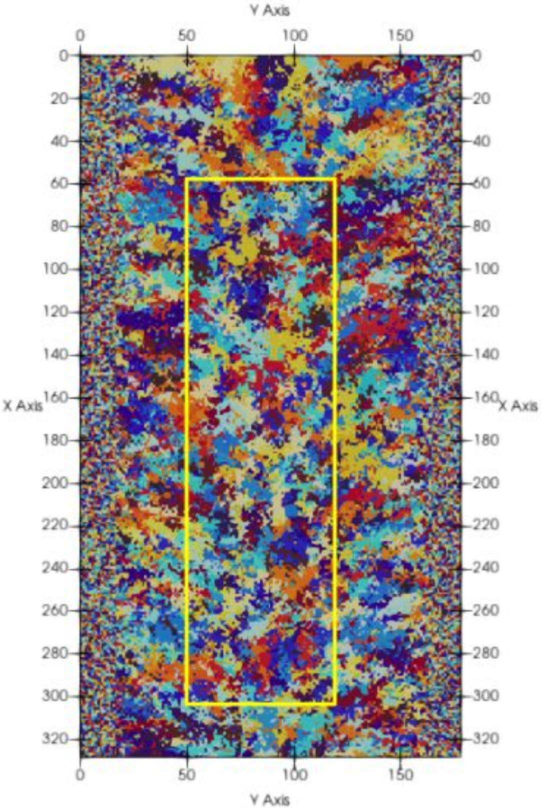
Power	Speed	Spot dia	Layer thickness	Width	Depth	**Exp. Width**	**Exp. Depth**	**Deviation in width**	**Deviation in Depth**
360	1000	100	60	240	200	**278±25**	**168±25**	**5 - 20 %**	**3 - 39 %**
450	1450	80	60	230	130	**230±25**	**100±28**	**< 1%**	**30 %**

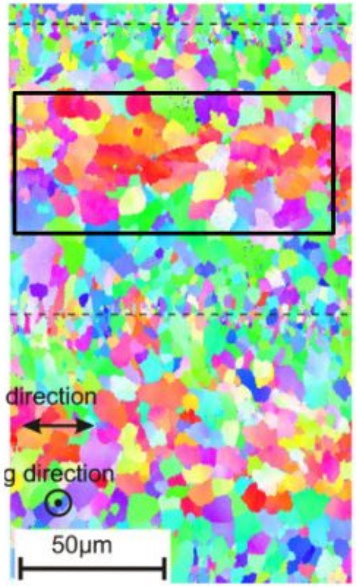
Melt pool defects

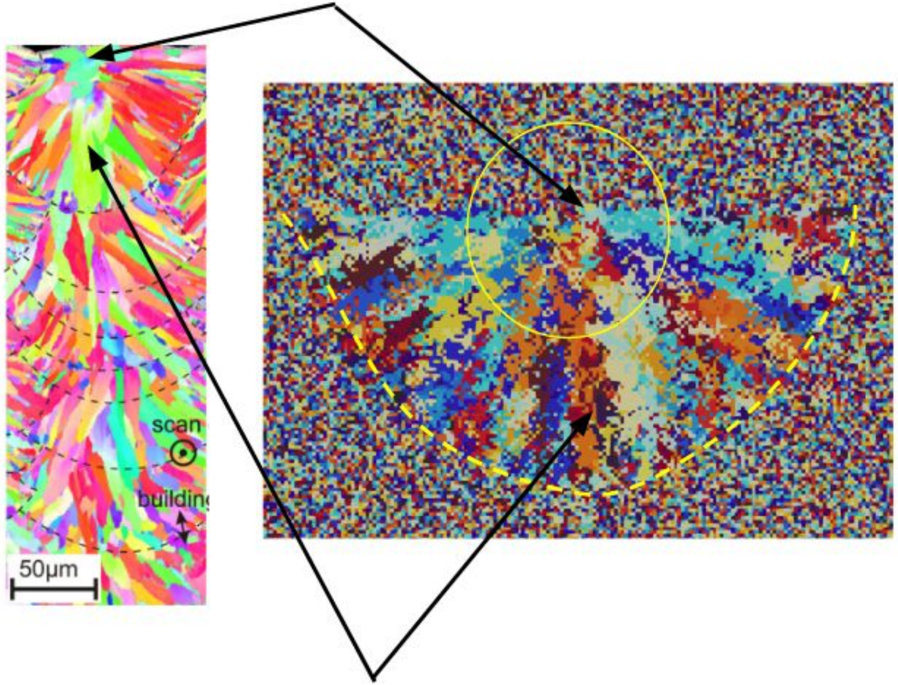




Structural defects







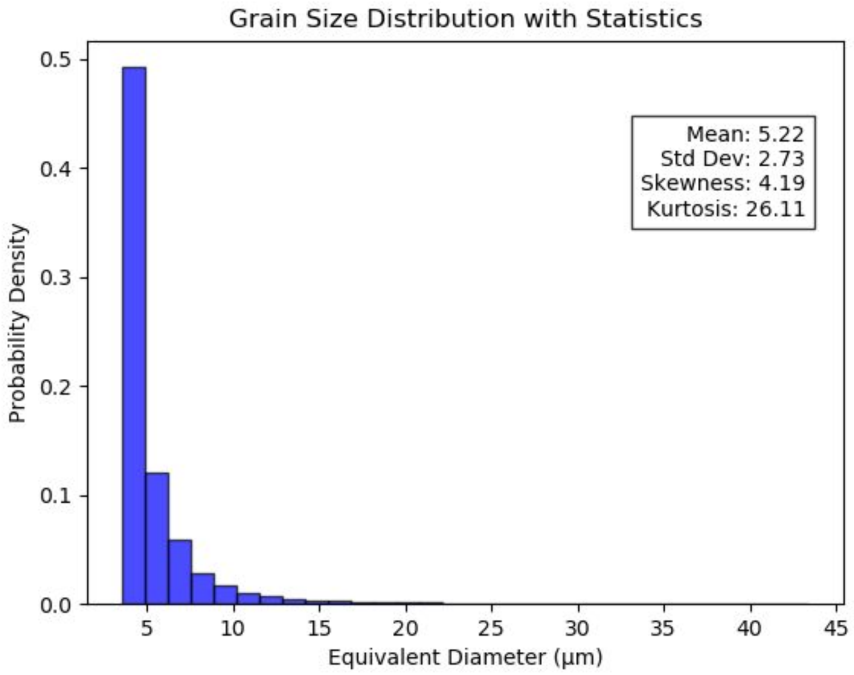
Acta Materialia 61 (2013) 1809–1819

Estimated structural property correlation

Strength mechanism

Hall-petch equation

$\sigma_y = \sigma_0 + k_y d^{-1/2}$



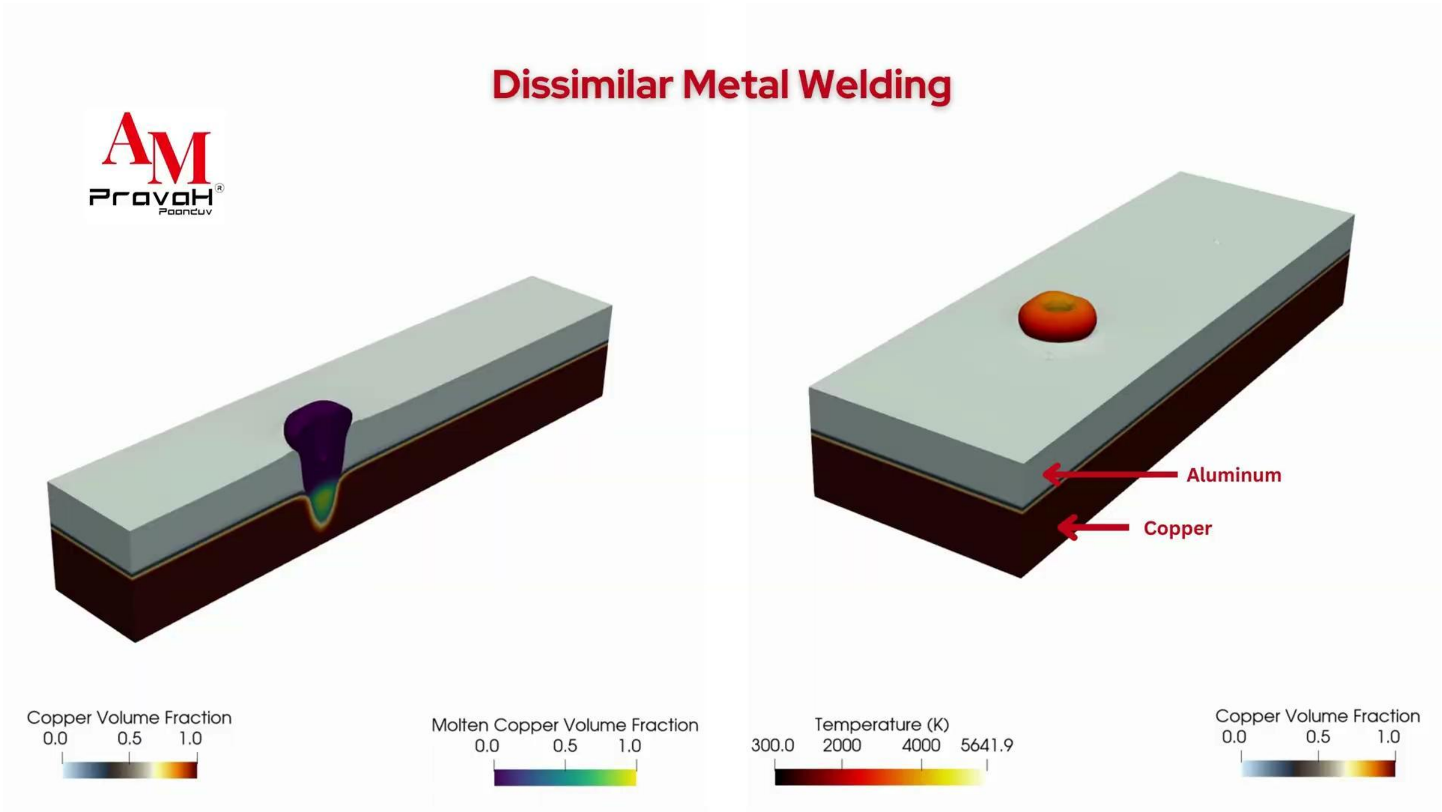
Case 3: Al-Cu Multimaterial welding

Battery systems : Joining copper and aluminum in battery tabs.

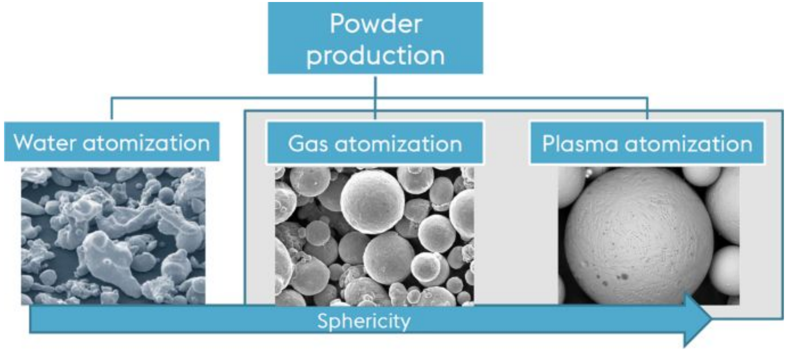
EVs and aerospace : Aluminum–carbon fiber composites.

Biomedical : Metal–ceramic interfaces for implants.

Additive Manufacturing : Multi-material 3D printed parts requiring integrated joining strategies

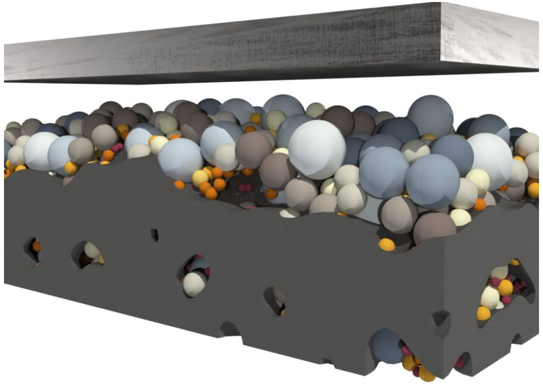


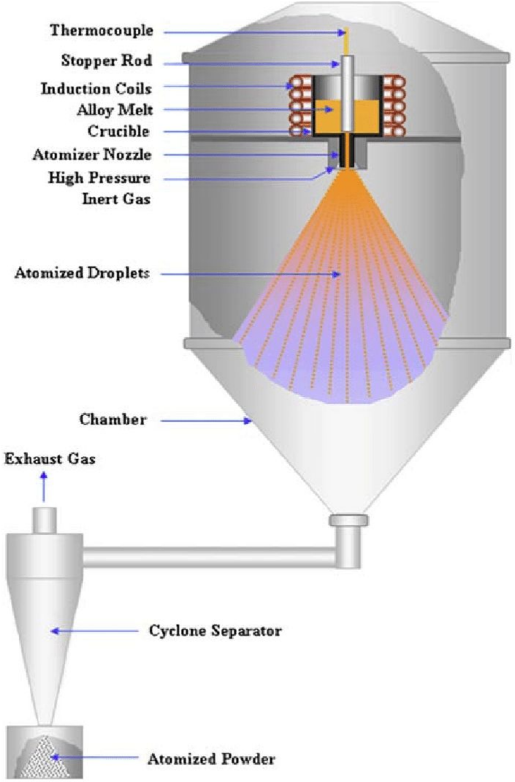
Aluminium powder feedstock for AM



The powder used in AM processes can be produced using various atomization processes such as water, gas or plasma.

Plasma atomization gives the highest grade spherical powder particles.





Inert gas atomization

1. Multiphase Flow (Gas–Liquid Interaction)

- Primary breakup: Molten metal jet is disrupted by high-velocity gas jets.
- Secondary breakup: Large ligaments or droplets further disintegrate into finer particles.

2. Compressible Gas Dynamics

- The inert gas is often injected at supersonic or subsonic speeds through nozzles.
- Shock waves, pressure drops, and turbulence must be captured (e.g., using compressible Navier–Stokes equations).

3. Surface Tension and Capillary Instabilities

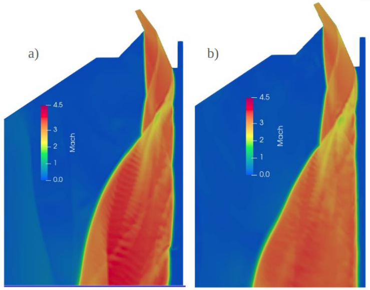
- Surface tension governs droplet formation and breakup thresholds.
- Captures Rayleigh–Plateau and Kelvin–Helmholtz instabilities during fragmentation.

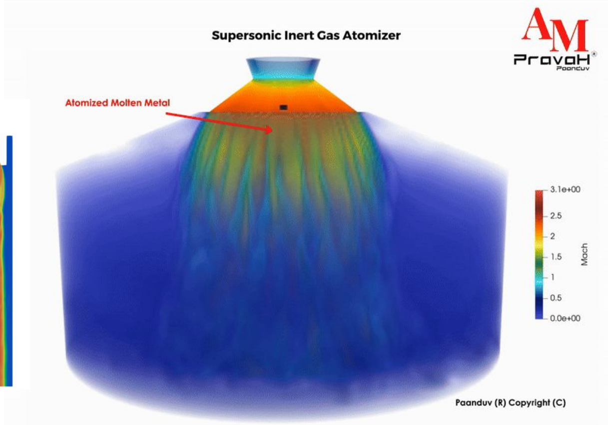
4. Thermal Effects and Heat Transfer

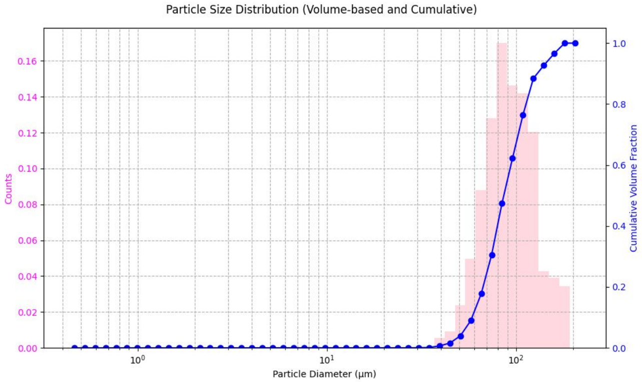
- Interaction of hot metal (~1400–1700°C) with cooler inert gas.
- Includes radiation, convection, and conduction.
- Cooling rate determines solidification behavior and particle sphericity.

5. Solidification Kinetics

- After fragmentation, droplets rapidly cool and solidify in-flight.
- Some models couple CFD with solidification kinetics to predict grain size, porosity, and morphology of powders.







About Paanduv®

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