Introduction to Powder based AM

Contents

Introduction

AM: layer by layer fabrication of components using digital data inputs

Benefits:
End-use parts
Design flexibility
Mass customization
Reduced wastage and lead times

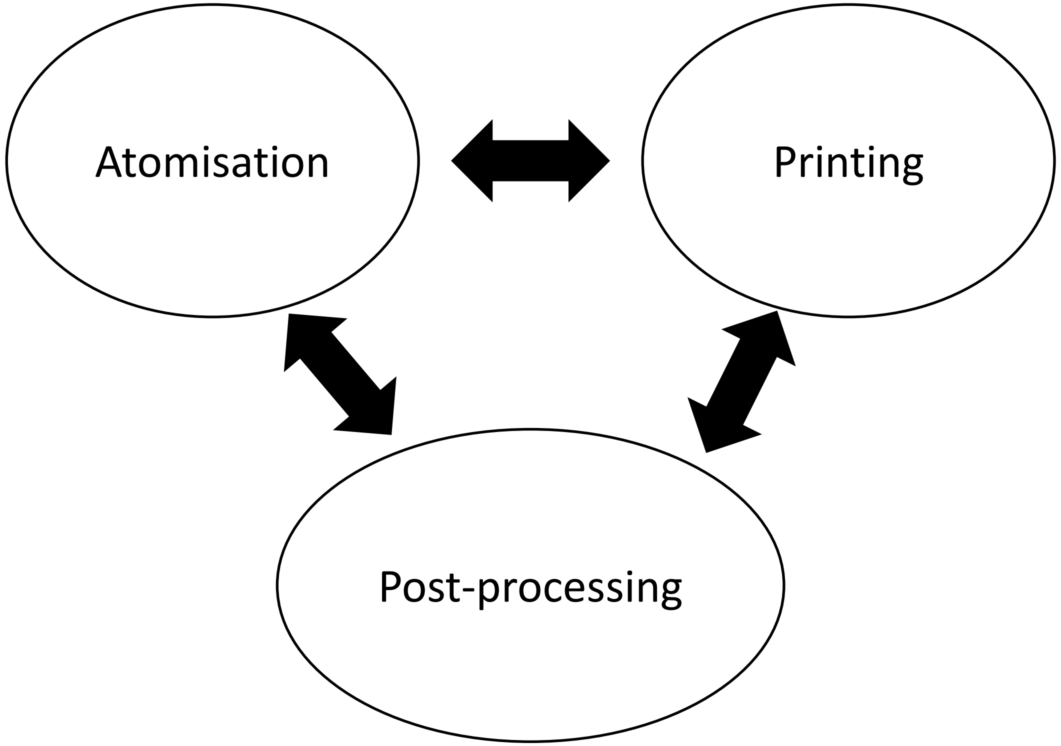


Fig. Schematic process of powder based additive manufacturing

Introduction

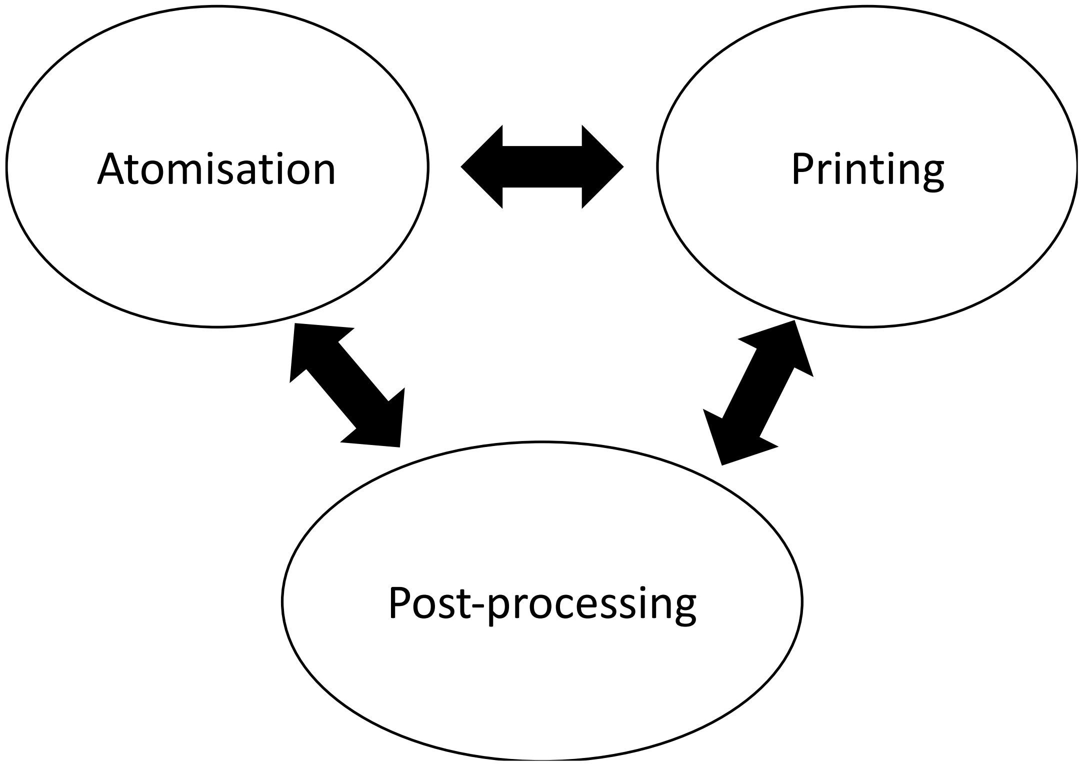


Fig. Schematic additive manufacturing cycle

- All metallurgical products need production and processing
- Conventional wrought processing includes casting – rolling, forging – treatment
- Alloy design, in all cases, required detailed understanding of all steps
- Design for component performance needs tailoring of microstructures

Laser Powder Bed Fusion (LPBF)

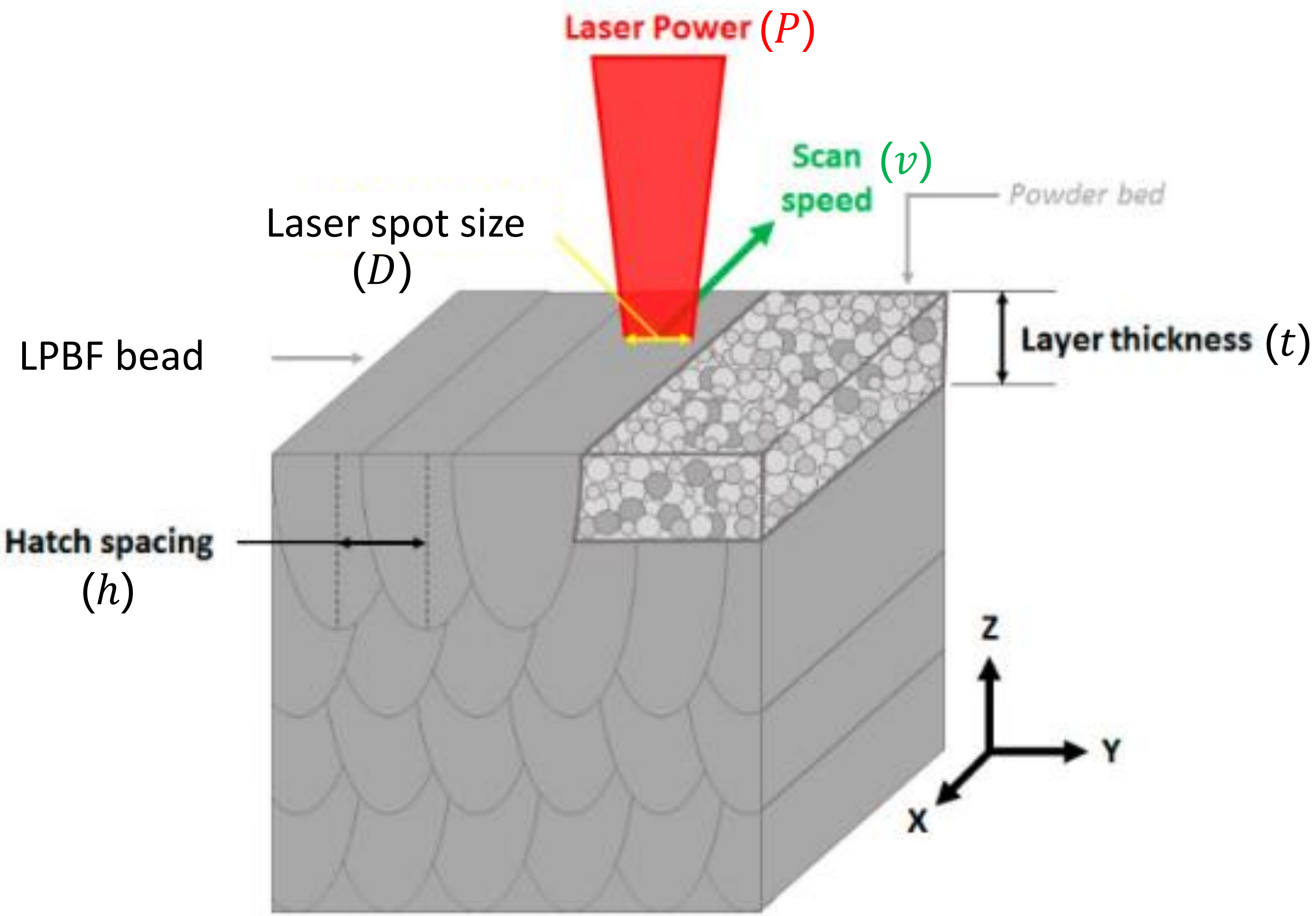


Fig. Schematic illustration of Laser Powder Bed Fusion parameters

Source: Terris et al. 2021 [https://doi.org/10.3390/met11040619]

Laser Powder Bed Fusion (LPBF)

- LPBF perceived as the most successful technique to be adopted by industry

- Small size powders, typically in the range between 15 – 45 µm were identified as suitable starting feedstock

- Recent efforts have reduced the particle size and layer thickness to under 10 µm -- micro-LPBF, and is expected to evolve and find applications in cell biology, biomedical sciences, and clinical diagnostics

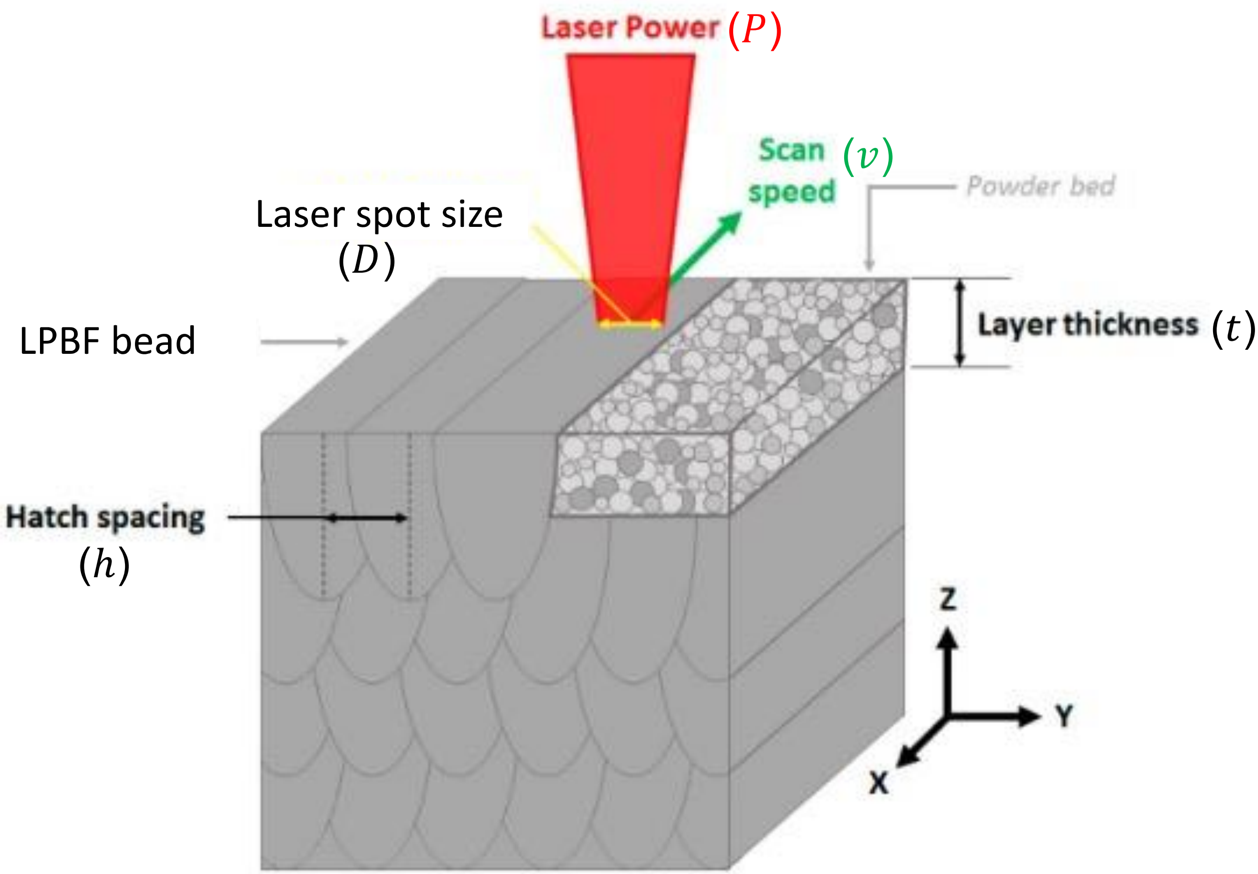


Fig. Schematic illustration of Laser Powder Bed Fusion parameters

Laser Powder Bed Fusion (LPBF)

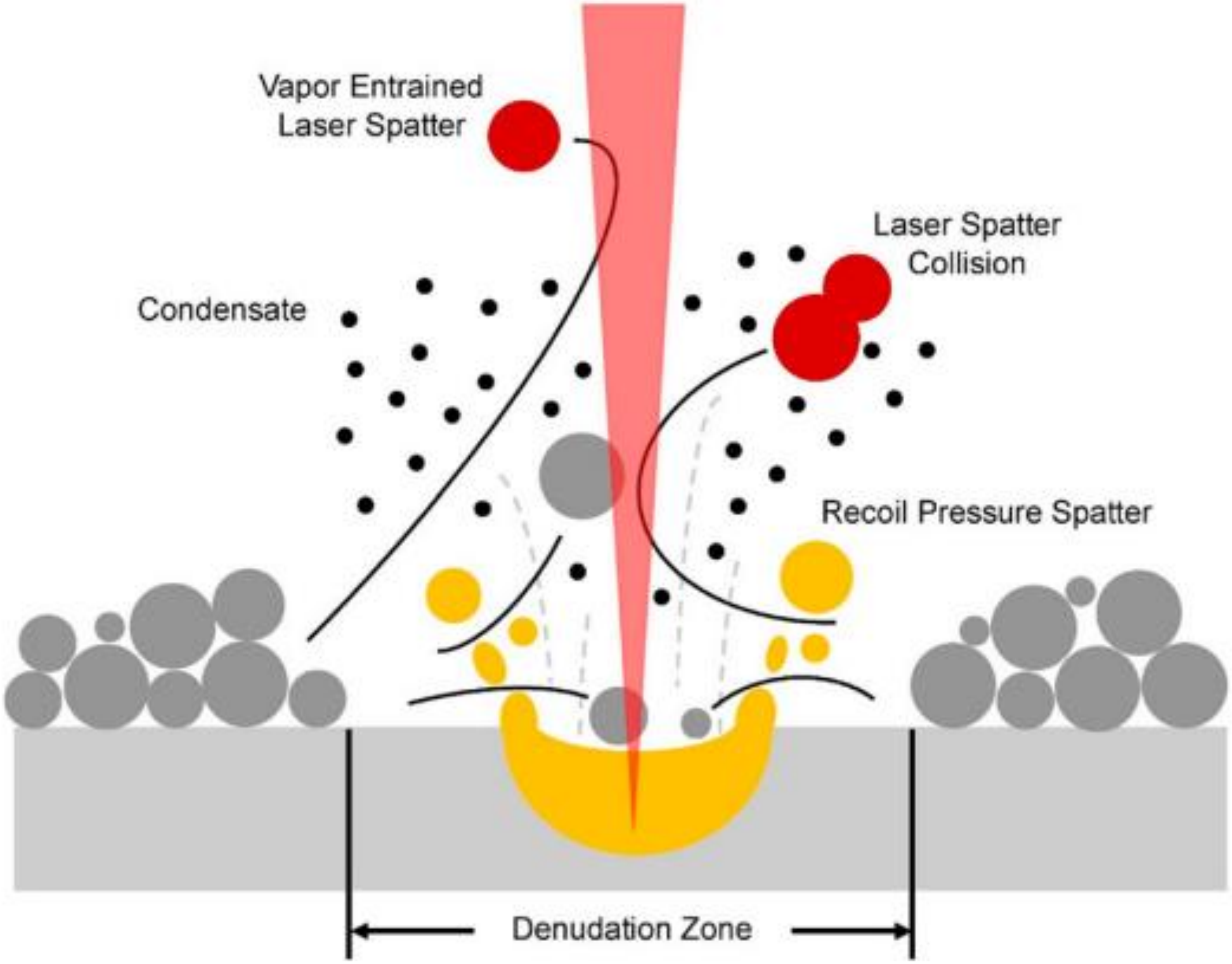


Fig. Laser spatter and condensate formation during LPBF

Source: Sutton et al. 2020 [https://doi.org/10.1016/j.addma.2019.100981]

Laser Powder Bed Fusion (LPBF)

There are two types of ejecta inherent to LPBF:

1. **Condensate:** Vapourised material while the laser interacts with the powder bed, which is a submicron powder formed as the vapour cloud above the melt pool is rapidly quenched in the chamber atmosphere

2. **Laser spatter:** Ejection of small metal droplets or particles from the laser-material interaction zone is referred to as spattering

Causes/mechanisms of spattering

- high recoil pressure
- vapour-driven particle entrainment via an induced gas flow

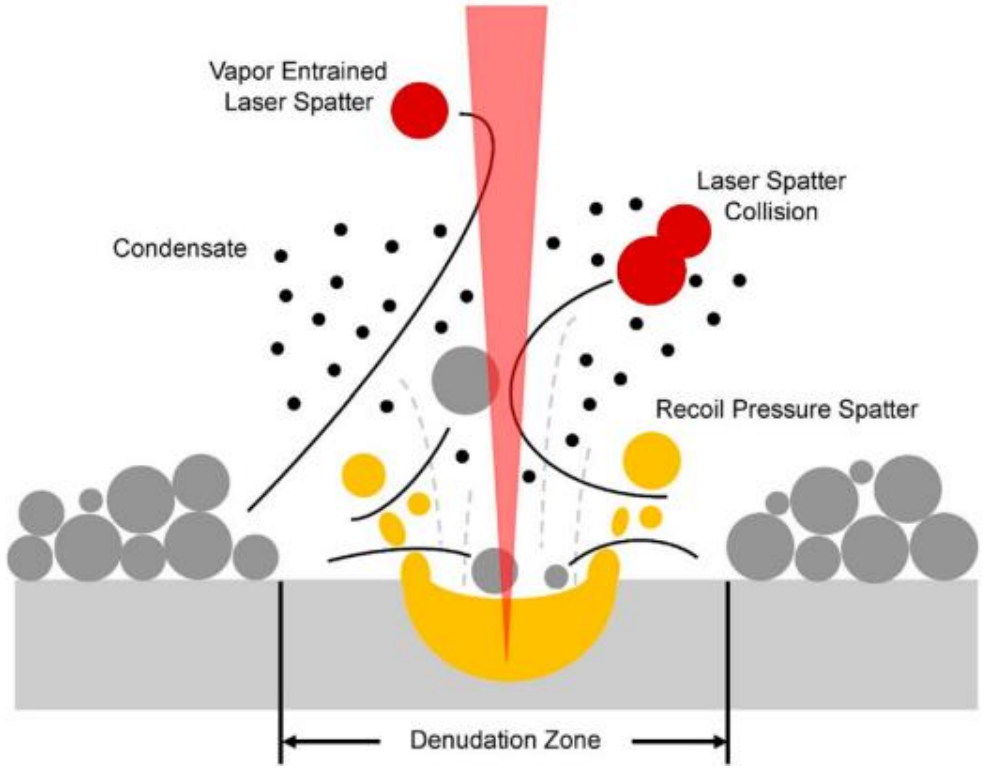
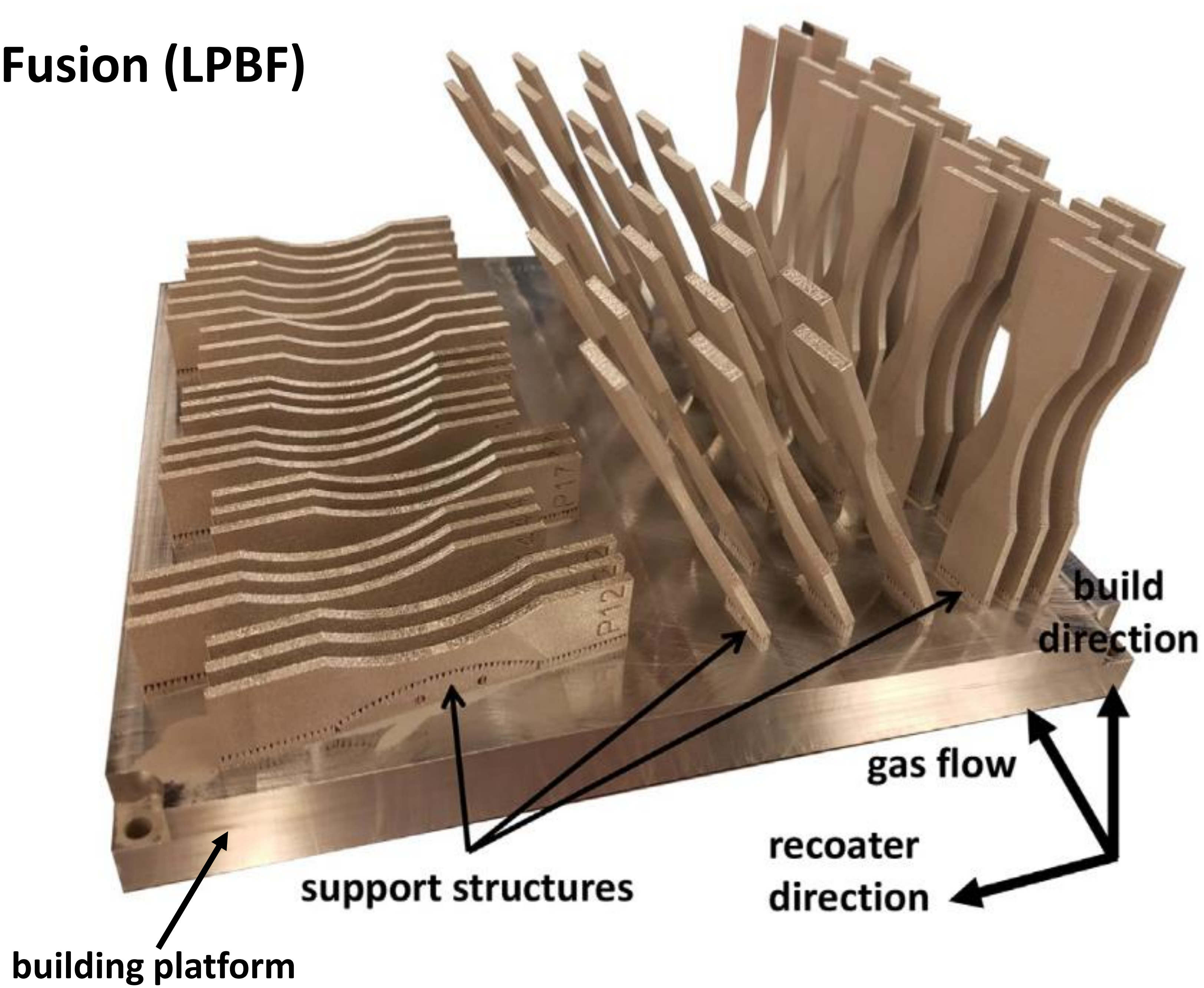


Fig. Laser spatter and condensate formation during LPBF

Laser Powder Bed Fusion (LPBF)

Fig. LPBF built specimens on a build plateform



Source: Watring et al. 2019 [https://doi.org/10.1016/j.msea.2019.06.003]

Laser Powder Bed Fusion (LPBF)

- ❖ Secure the part to the building platform,
- ❖ Conduct excess heat away from the part to prevent overheating, and
- ❖ Prevent warping/unexpected deflections due to residual stresses induced by the localised laser energy

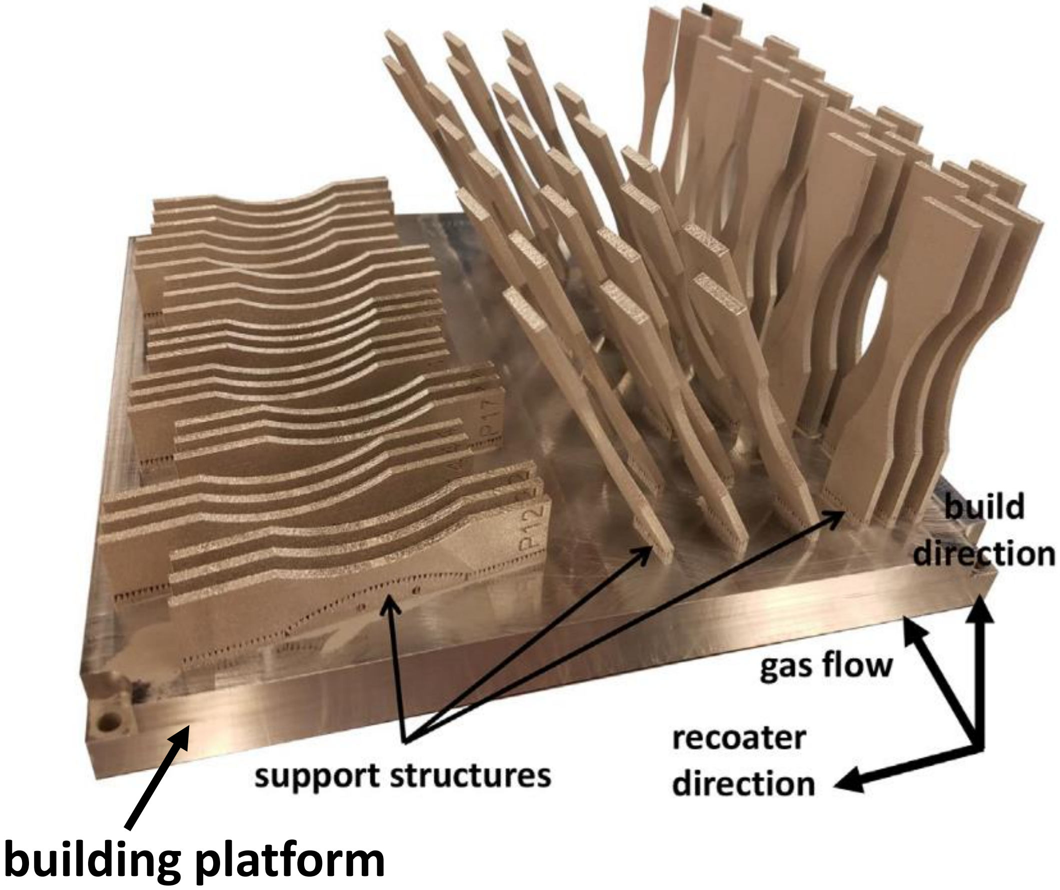


Fig. LPBF built specimens on a build plate

Laser Metal Deposition (LMD)

- The thickness of the layers is typically 250 µm to 500 µm
- Cooling rates are in the range of 1000 to 5000 K/s

- The laser scan speed, powder feed rate, and scan strategy are the most important process parameters in this method that must be optimised

- The process is typically performed within a controlled chamber with reduced oxygen levels (a fully inert chamber when reactive metals such as titanium alloys are fabricated)

- It is also possible to use a shielding gas to prevent contamination during LMD

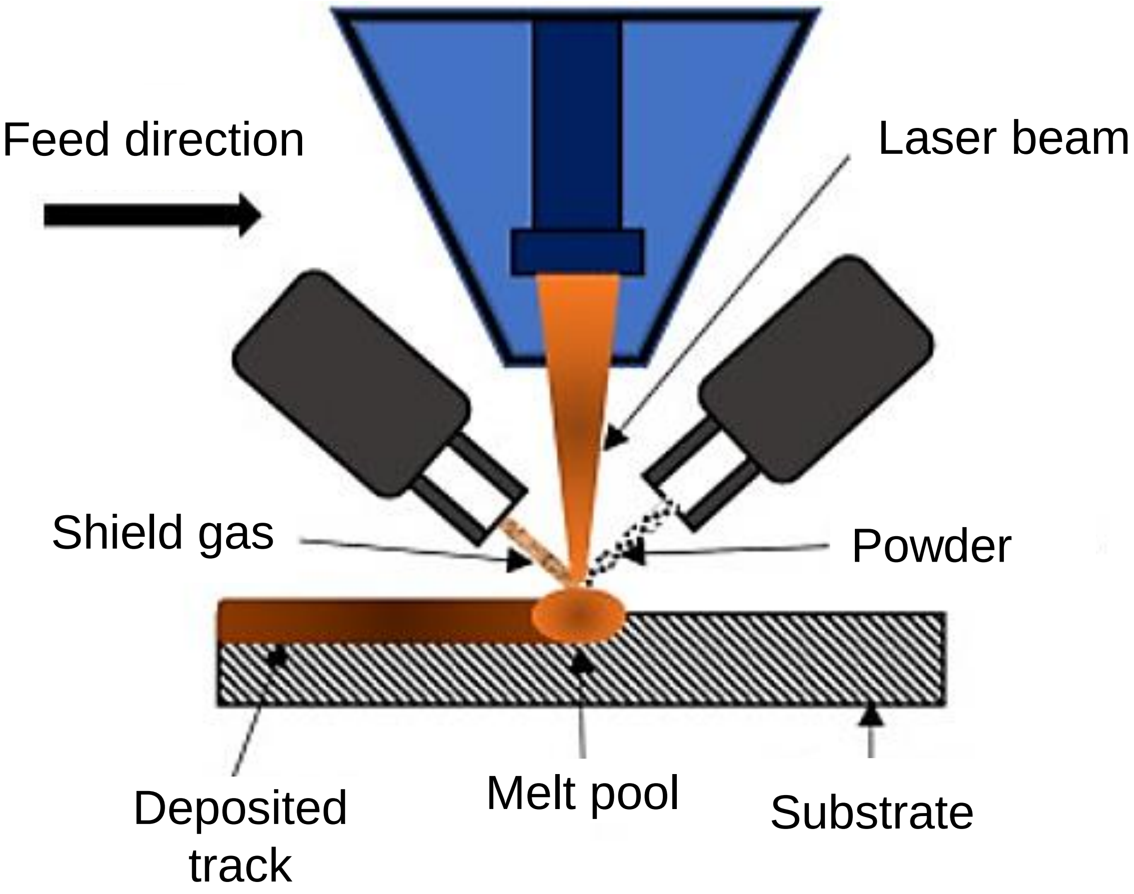


Fig. Schematic Laser Metal Deposition (LMD) process

Source: Nugroho 2021 [https://doi.org/10.1016/B978-0-12-820512-9.00013-7]

Laser Metal Deposition (LMD)

- Ability to produce functionally graded materials (FGM)

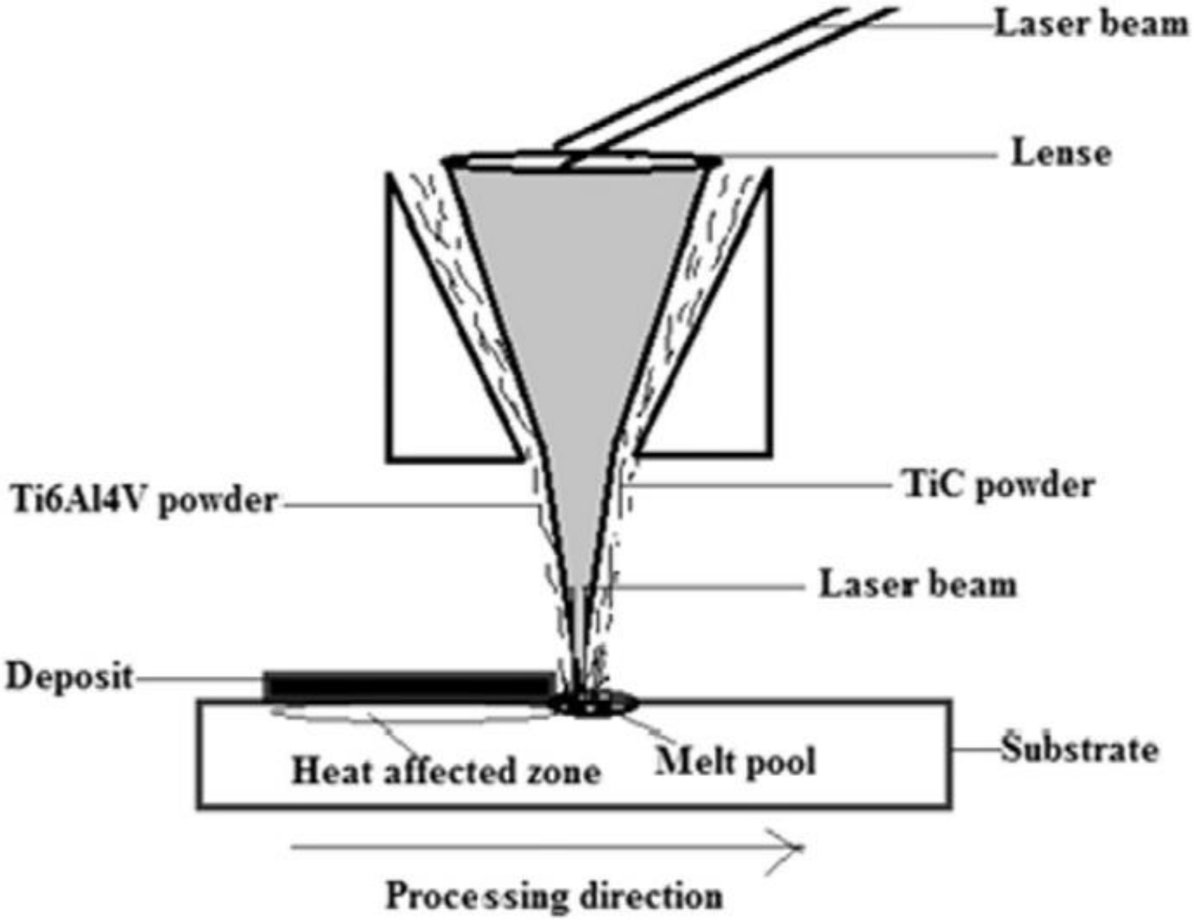


Fig. Schematic Laser Metal Deposition (LMD) process for FGM

Source: Mahmood & Akinlabi 2015 [http://dx.doi.org/10.1016/j.matdes.2015.06.135]

Laser Metal Deposition (LMD)

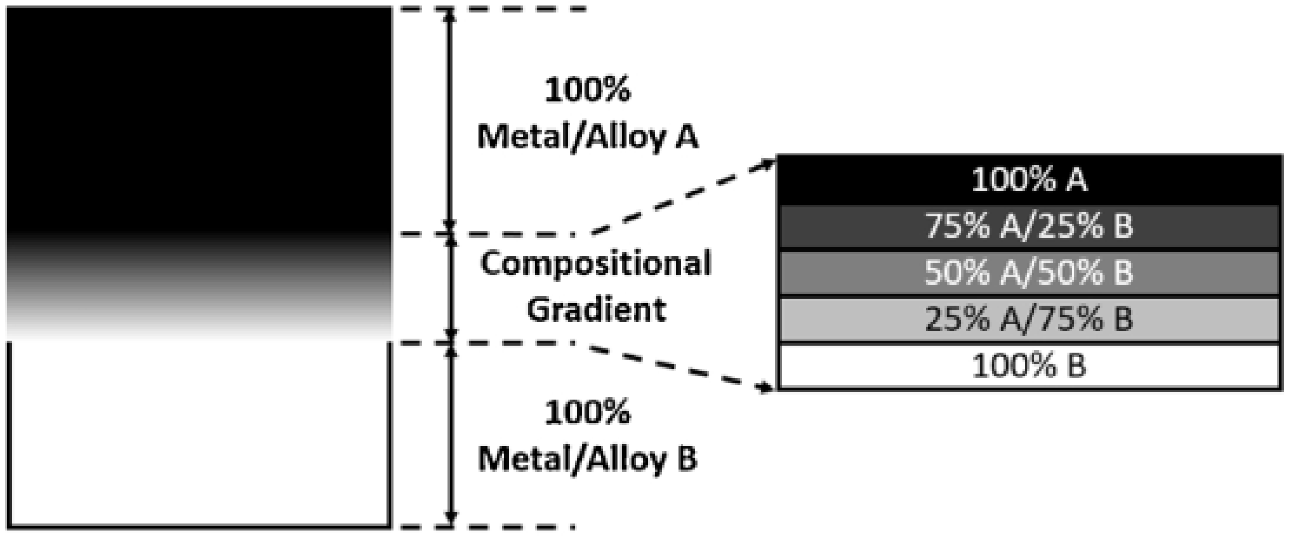


Fig. Schematic illustration of FGM comprising metal/alloy A, and metal/alloy B.

Source: Yan et al. 2020 [https://doi.org/10.1016/j.addma.2019.100901]

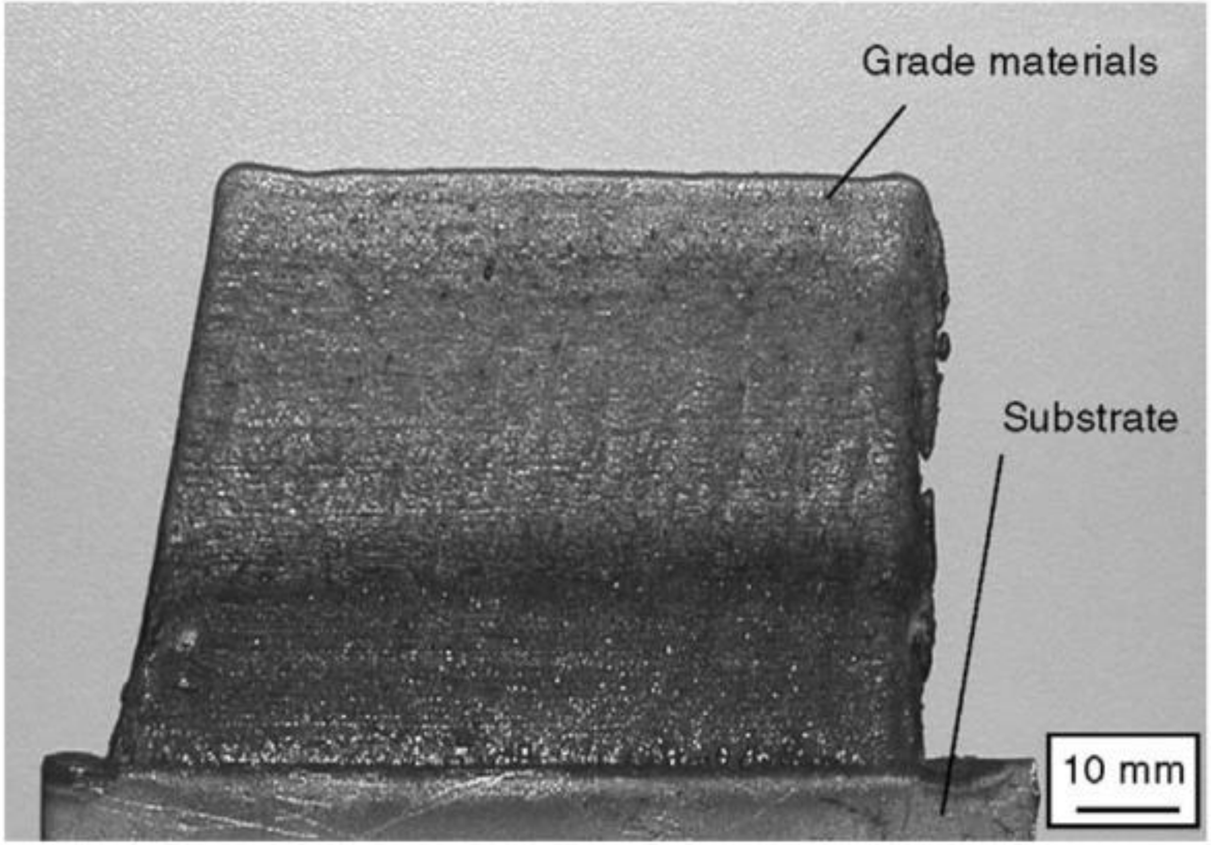
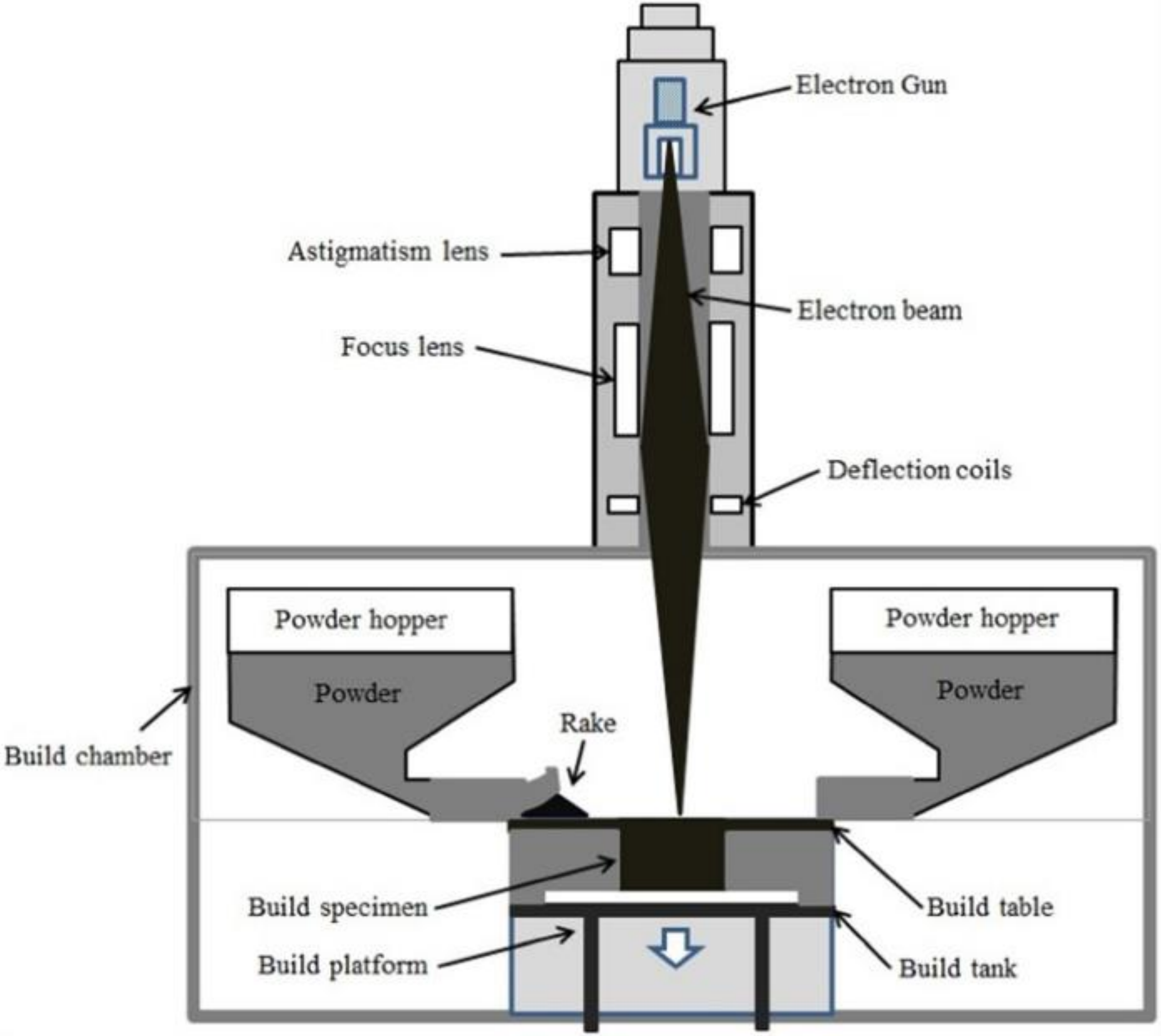


Fig. LMD build SS316L/Rene88DT FGM on SS316L substrate

Source: Lin et al. 2005 [https://doi.org/10.1016/j.msea.2004.08.072]

Electron beam melting (EBM)

Fig. Schematic principle of Electron Beam Melting (EBM)



Source: Ameen et al. 2019 [https://doi.org/10.1007/s00170-019-04007-3]

Electron beam melting (EBM)

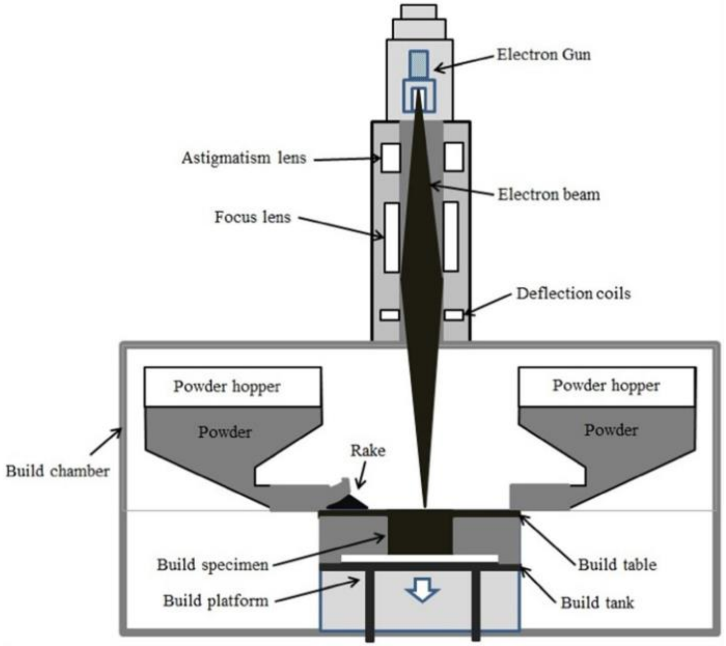


Fig. Schematic principle of Electron Beam Melting (EBM)

Advantages

- ➢ More powerful than a laser, result in faster printing speeds,
- ➢ High density (over 99%) due to preheating and high temperatures developing during printing.
- ➢ EBM produces much less waste compared to LPBF and LMD; most of the unused powder can be recycled for future use.

Limitations

- ❑ EBM parts have typically lower levels of accuracy than LPBF parts because LPBF machines use finer powders and thinner layers. Moreover, the diameter of an electron beam cannot be reduced beyond a certain limit.
- ❑ Limited range of materials; this is due to the process requires high-quality powder, which must undergo extensive prior testing; limited to electrically conductive materials.
- ❑ the cost of materials, combined with the cost of EBM machines (they are more expensive than LPBF and LMD machines), makes this technology an expensive option that is only suitable for crucial industrial applications.

Electron beam melting (EBM)

Potentials:

- Porous builds
- Metamaterials

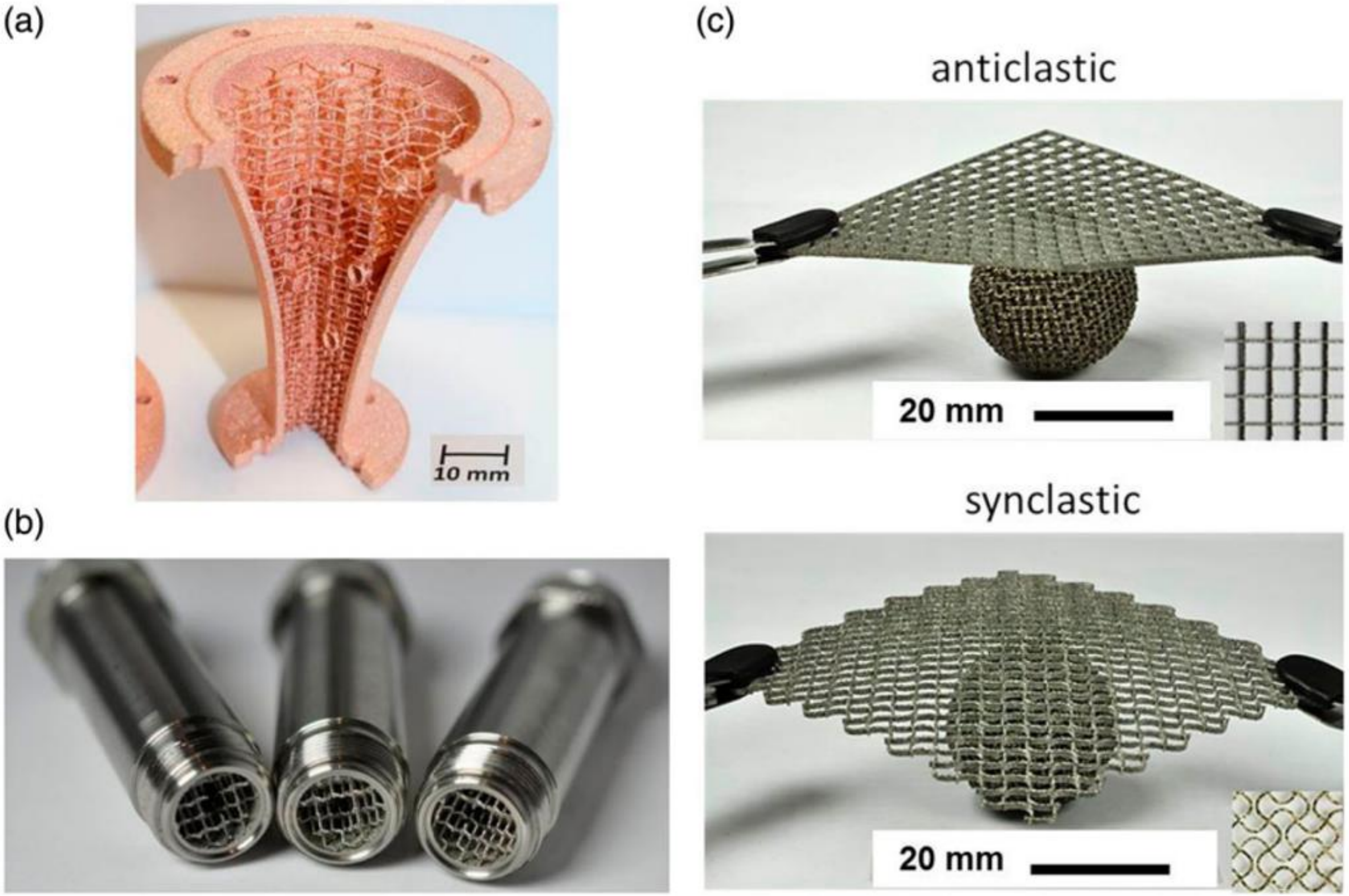


Fig. Cellular structures and materials: (a) pure copper component with a cellular core, (b) SS reactor for hydrogen release from perhydro-N-ethylcarbazole, and (c) Ti–6Al–4V lattice structure (anticlastic) versus auxetic structure (synclastic)

Source: Korner 2016
[https://www.tandfonline.com/action/showCitFormats?doi=10.1080/09506608.2016.1176289]

Binder Jetting

- Printing in layers, metallic powder
 and polymer binder
- Functionally graded structures
- Green part then cured

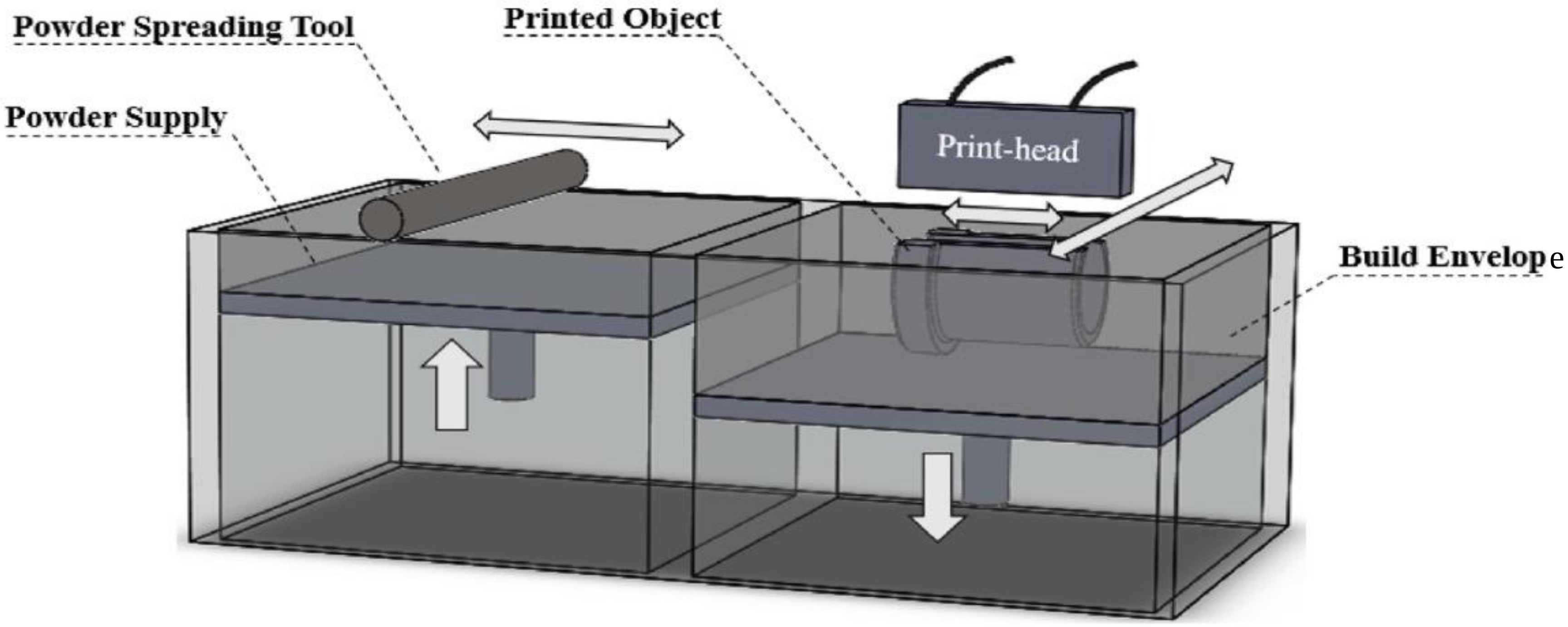


Fig. A schematic binder jetting system

Source: Ziaee and Crane2019
[https://doi.org/10.1016/j.addma.2019.05.031]

Key Processing Parameters

(a)

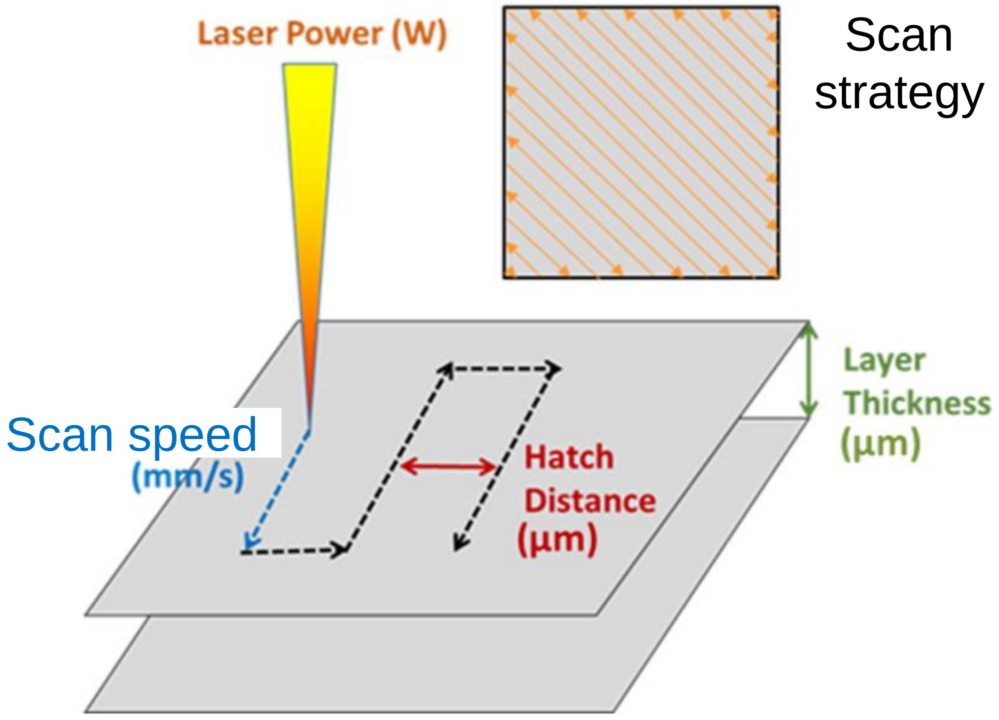


Fig. Common LPBF process parameters

Source: Oliveira et al. 2020 [https://doi.org/10.1016/j.matdes.2020.108762]

(b)

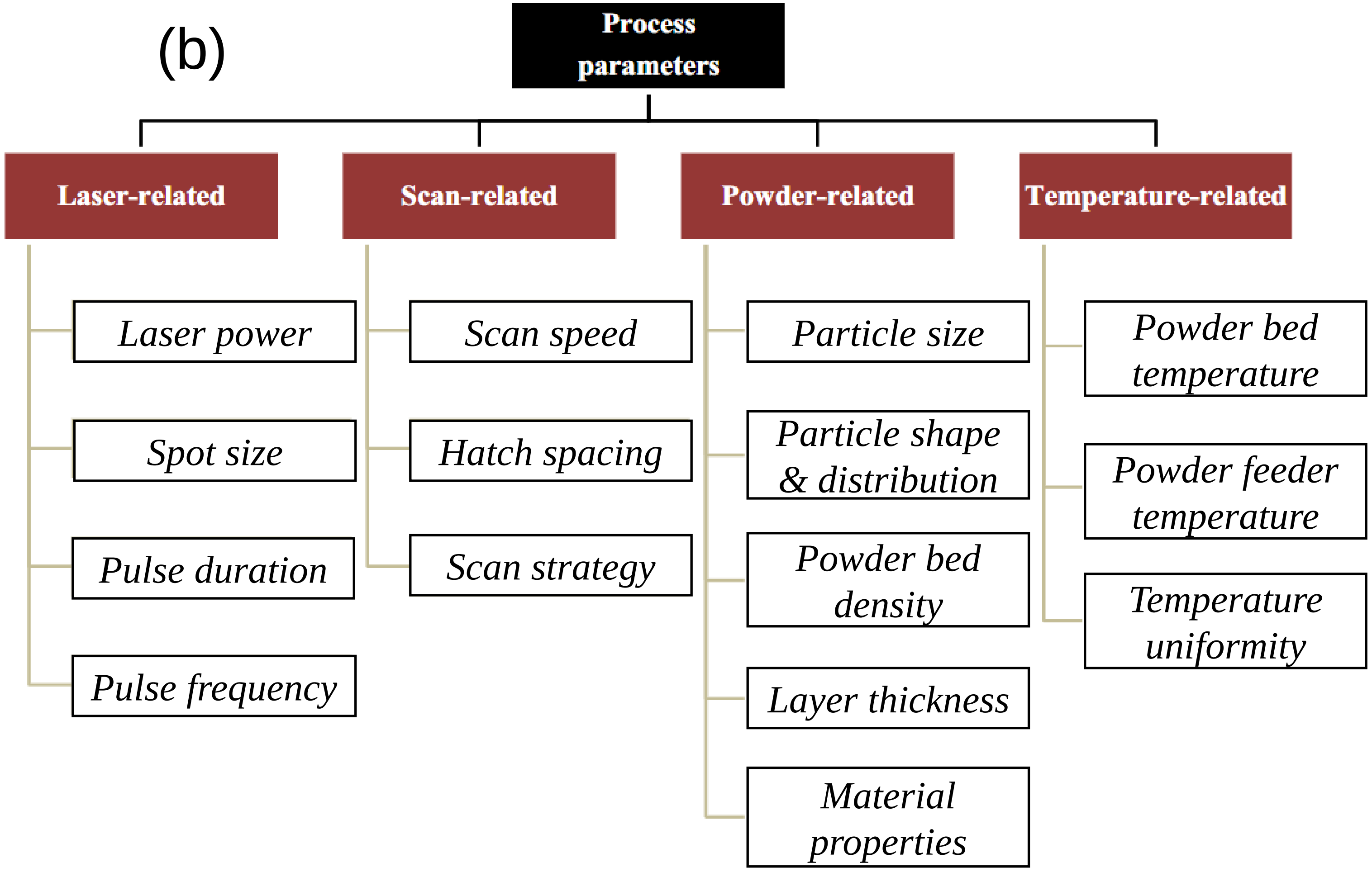


Fig. Classification of LPBF process parameters

Adapted from: Aboulkhair et al. 2014 [http://dx.doi.org/10.1016/j.addma.2014.08.001]

Key Processing Parameters

(a)

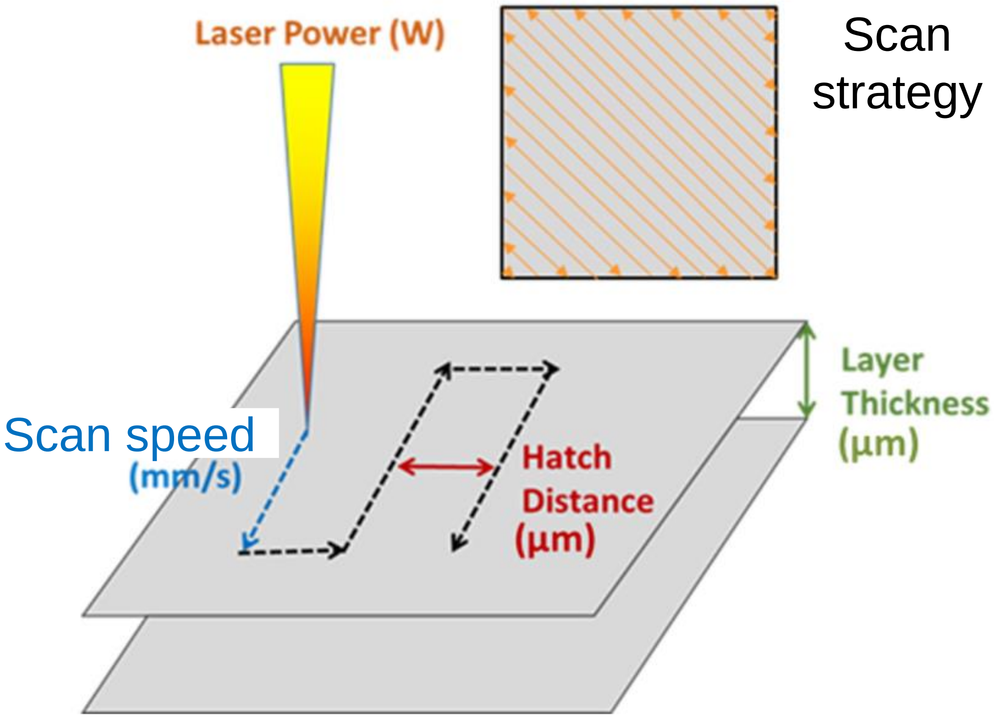


Fig. Common process parameters

Energy density, $E_d = \frac{P}{vht}$.

Normalised enthalpy, $\frac{\Delta H}{h_s} = \frac{AP}{h_s\sqrt{vdD^3}}$,

- h_s is the enthalpy at the melting temperature,
- A is the absorptivity,
- d is the thermal diffusivity

Key Processing Parameters

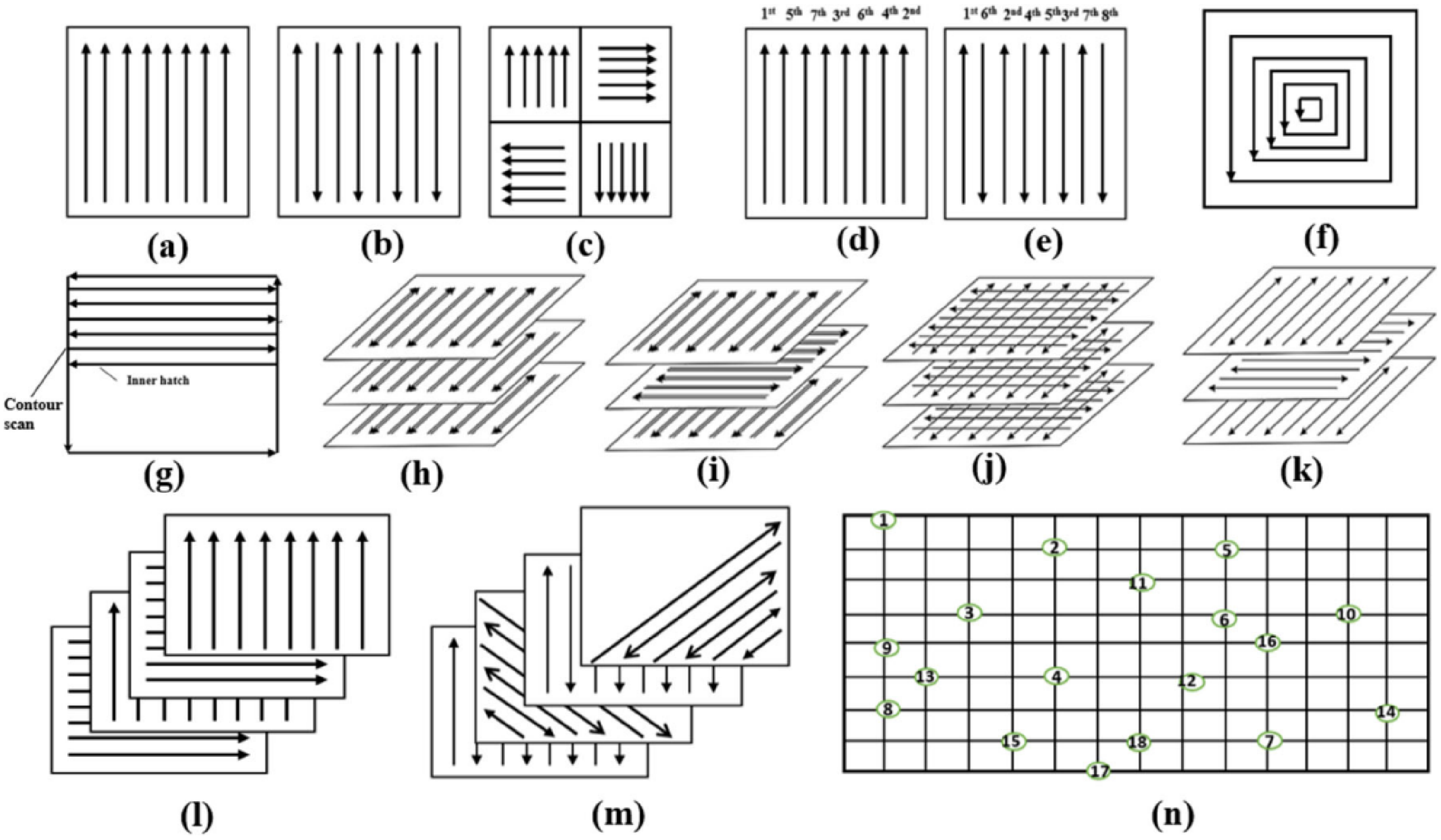


Fig. Schematic illustration of various kinds of scanning strategies

Source: Jia et al. 2021 [https://doi.org/10.1007/s00170-021-06810-3]

Key Processing Parameters

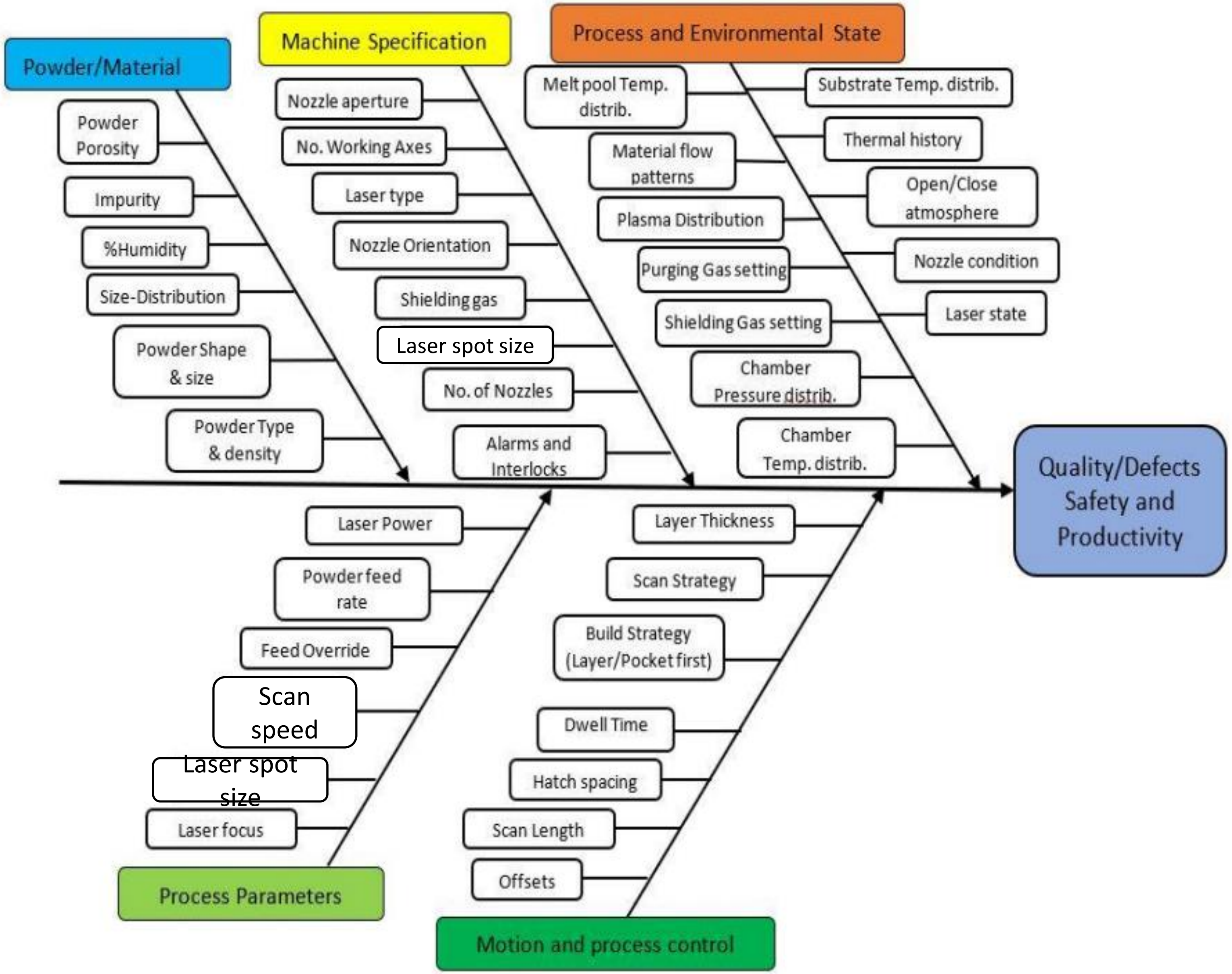


Fig. Process/material parameters in LMD process

Source: Liu et al. 2021 [https://doi.org/10.1016/j.promfg.2021.06.093]

Key Processing Parameters

Table 1.1: Comparison of key processing parameters in LPBF, LMD, and EBM.

Parameter	LPBF	LMD	EBM
Beam power or current	60 – 400 W	100 – 1000 W	5 – 20 mA
Scan speed (m/s)	Limited	Limited	Fast
Powder size (μm)	10 - 45	10 - 45	45 - 106
Minimum spot size (μm)	35	80	140
Layer thickness (μm)	20 – 60	30 – 300	50 – 200
Chamber atmosphere	Argon or nitrogen	Argon	Vacuum
Chamber temperature ($^\circ$C)	up to 200	25	up to 1000
Pre-heating method	Infra-red heaters	–	Electron beam
Surface finish	Excellent to moderate	Excellent to moderate	Poor
Residual stress	Yes	Yes	No

Key Processing Parameters- Binder Jetting

Printing process:

- green strength (the strength in the as-built state),
- microstructure, and
- subsequent properties of the components produced by binder jetting.

Binder properties

- jettability and wetting behaviour,
- viscosity and volatility of the binder;
- and printing-related parameters such as layer thickness, binder saturation, frequency of cleaning, as well as curing time and temperature

The layer thickness for binder jetting varies between 15 – 300 µm.

- The chosen layer thickness depends on the particle distribution size;
- layer thickness must not be less than the maximum particle size.

Powder spreading speed is determined by

- recoat speed (the speed at which the print head traverses while dispensing powder onto the bed),
- oscillator speed (the frequency at which dispensing mechanism oscillates),
- roller speed (the rotational speed of the roller, if used),
- and roller traverse speed (the speed at which the roller moves across the bed as it rotates).