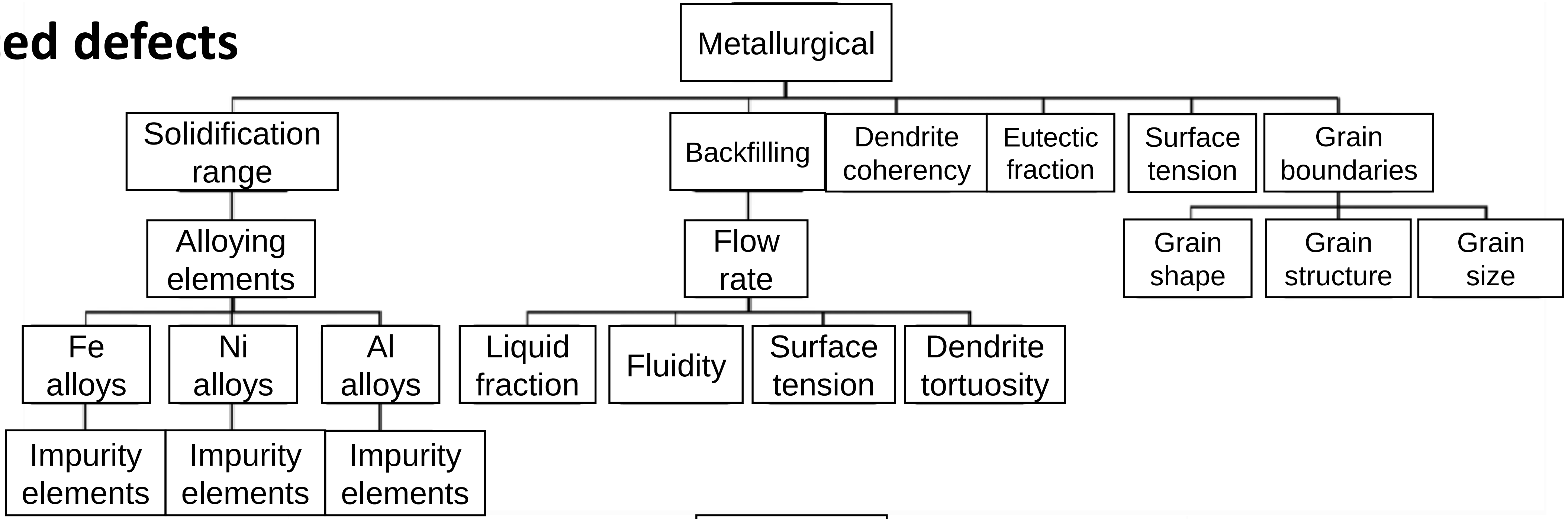
Additive manufacturing challenges and applications

Contents

Introduction

- Ti, Al, Fe, Ni-based systems
- Needed deep understanding of processing defects
- Need to relate to microstructural features

Process-induced defects



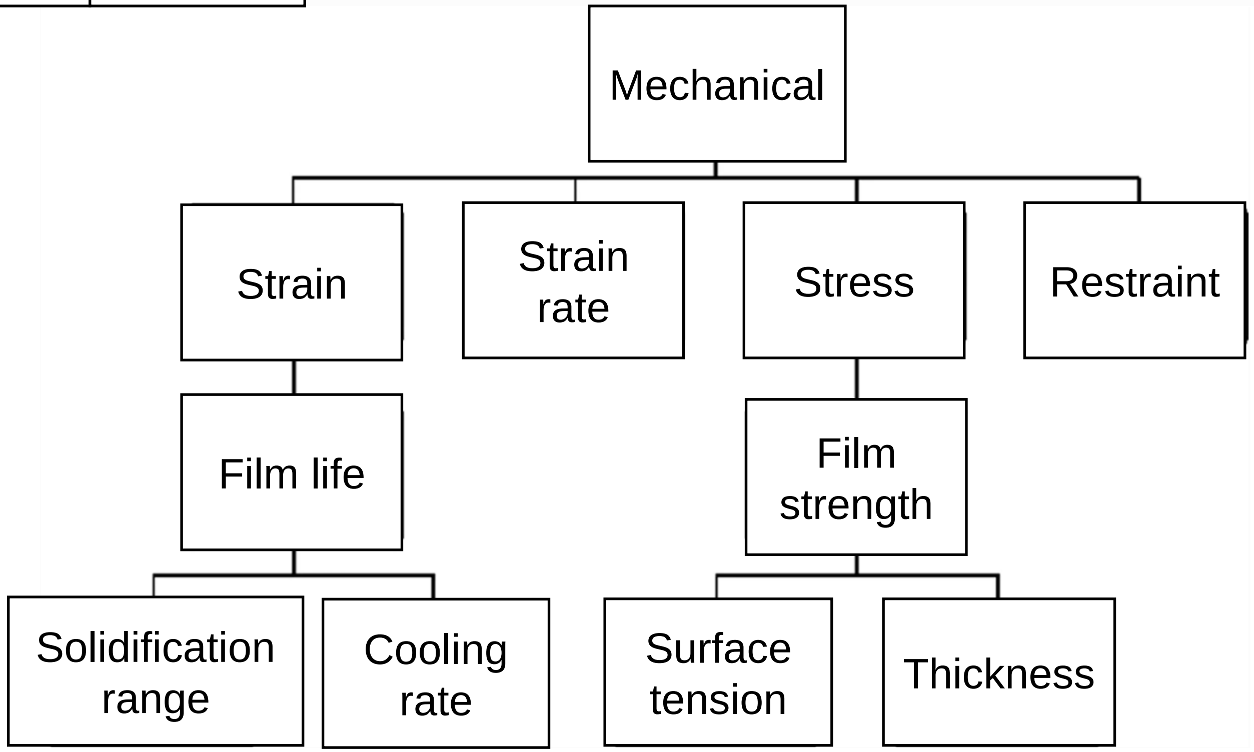


Fig. Factors contributing to the solidification cracking

Source: Brennan et al. 2020 [https://doi.org/10.1007/s11665-021-05919-6]

Process-induced defects – Hot cracking

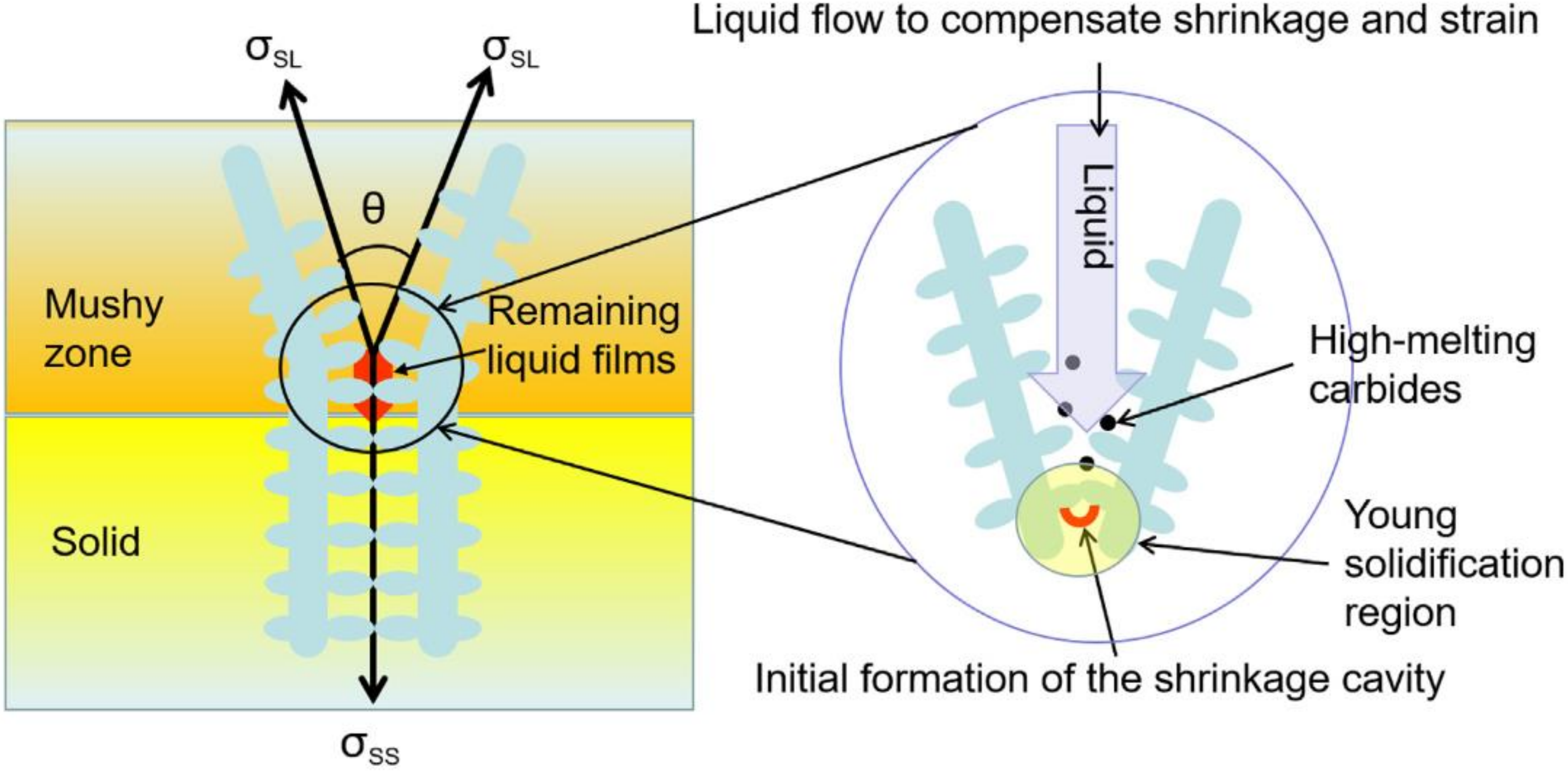


Fig. Schematic mechanism of hot cracking

σ_{SL}: solid-liquid interfacial stress,
σ_{SS}: grain boundary interfacial stress,
ϑ: is the misorientation angle.

Source: Zhou et al. 2018 [https://doi.org/10.1016/j.matdes.2018.10.042]

Process-induced defects – Hot cracking

Backfilling parameters:

- Dendrite tortuosity,
- Liquid fraction, fluidity,
- Surface tension

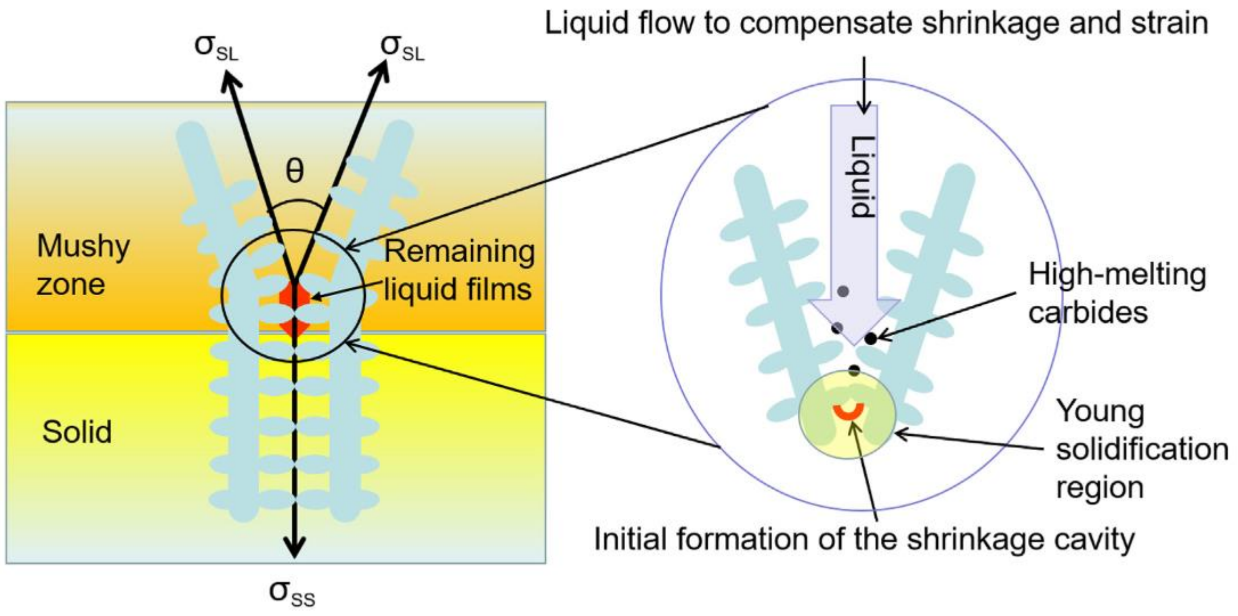


Fig. Schematic mechanism of hot cracking

➢ Cracking during solidification can occur in systems with intermediate wettability and backfilling values

Process-induced defects – Hot and liquation cracking

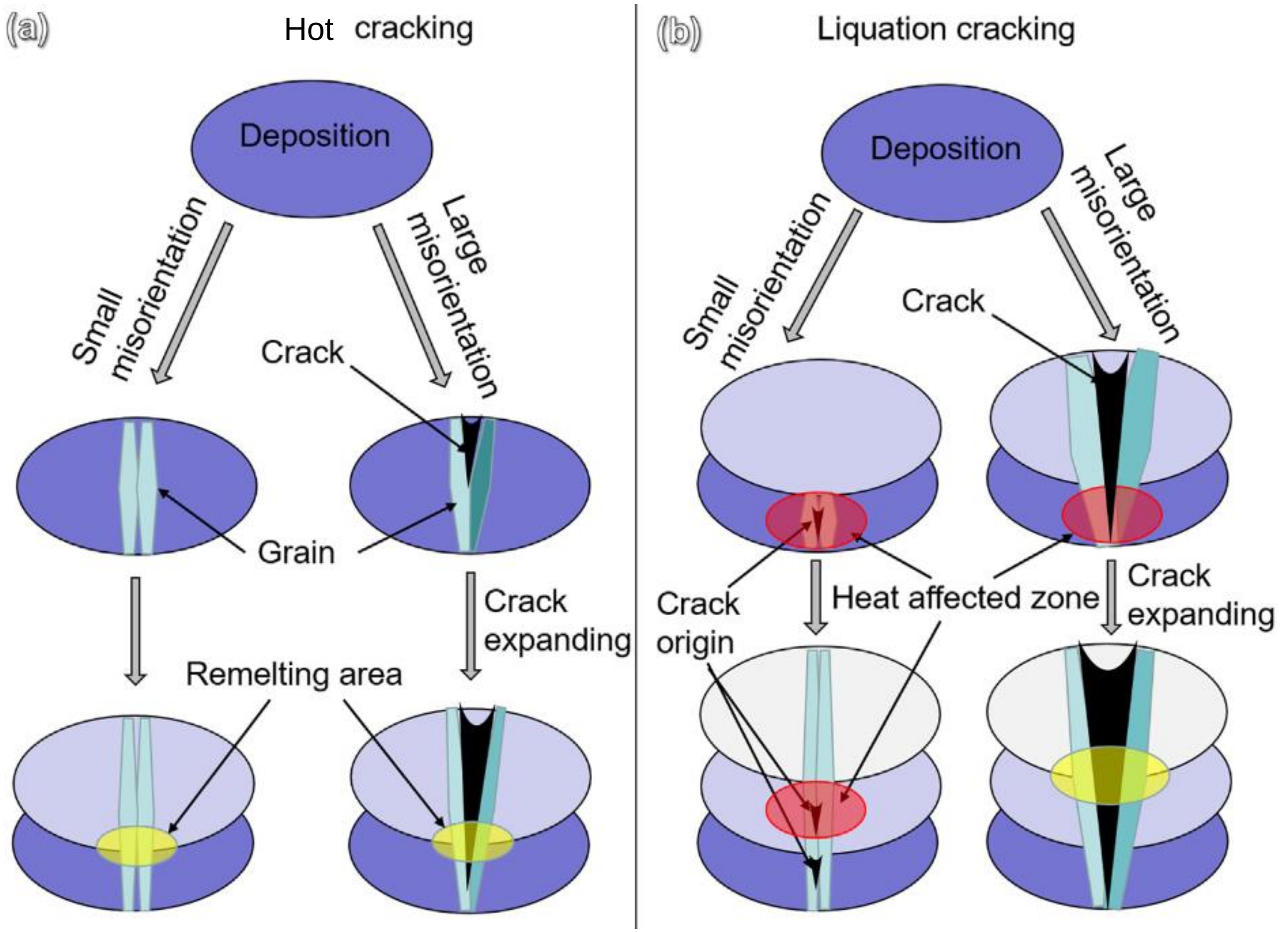


Fig. Representation of cracking expanding modes

Source: Zhou et al. 2018 [https://doi.org/10.1016/j.matdes.2018.10.042]

Process-induced defects – Hot and liquation cracking

Liquation cracking occurrence:

- Grain boundary angle
- Low melting point compounds
- Thermal stress causes liquid films to be torn apart
- Large residual stresses

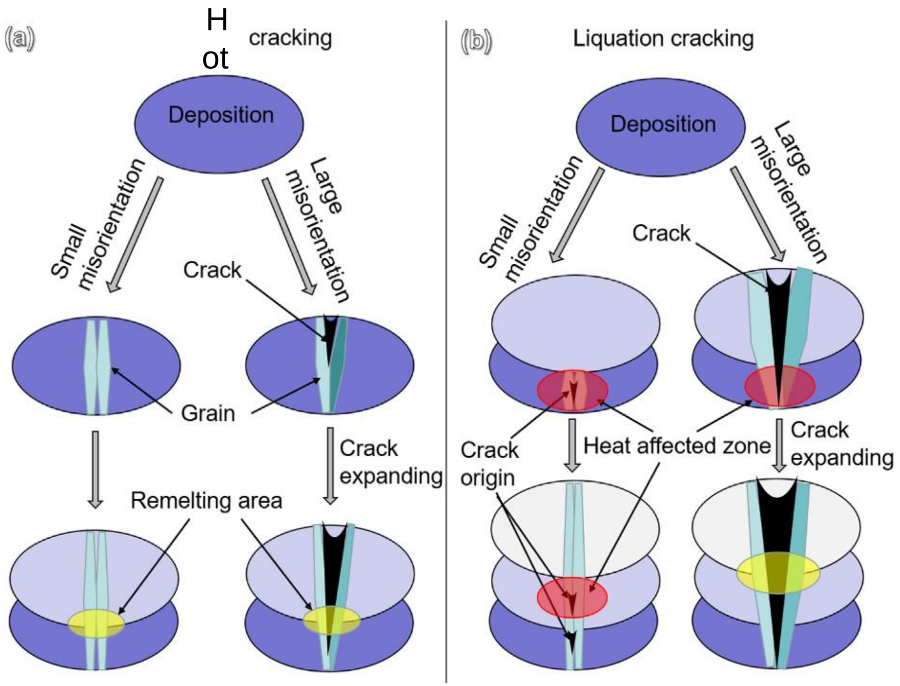


Fig. Representation of cracking expanding modes

Process-induced defects - modelling

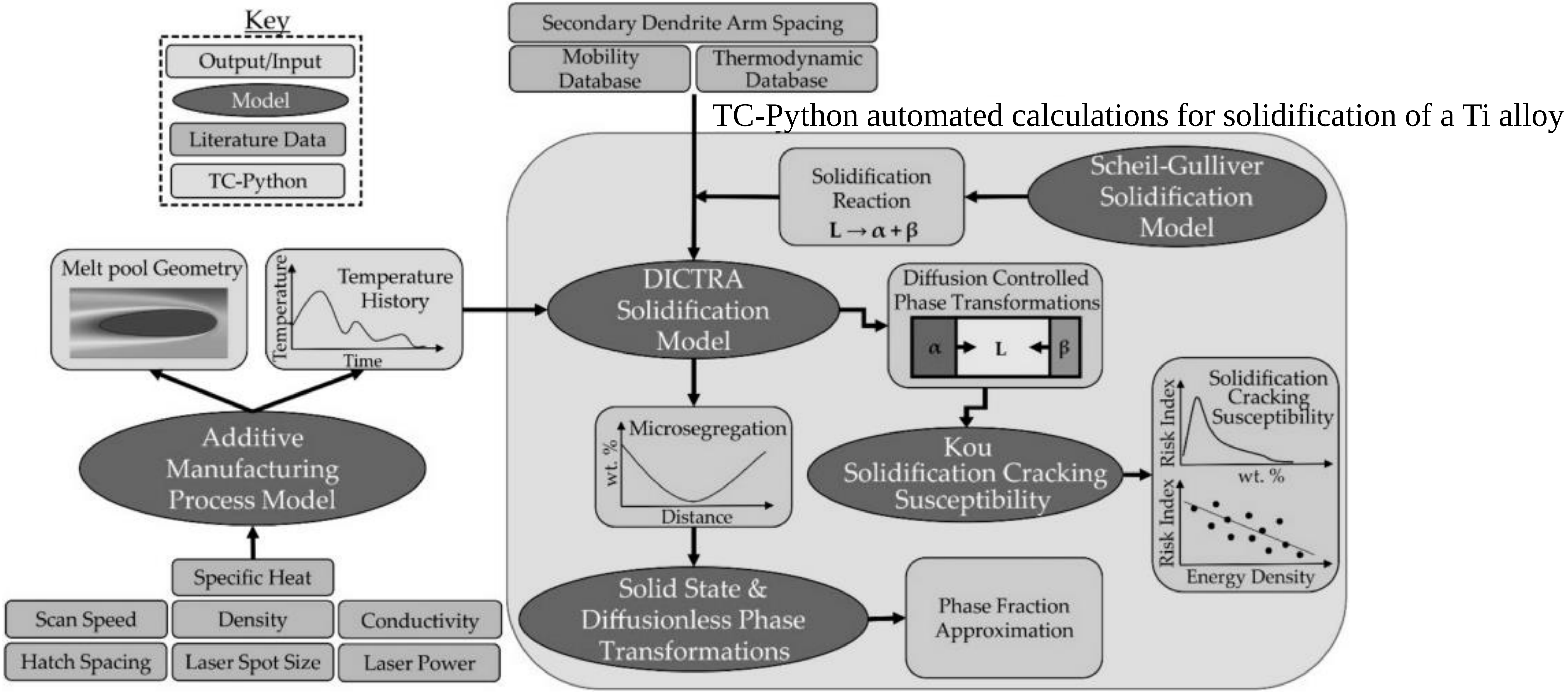
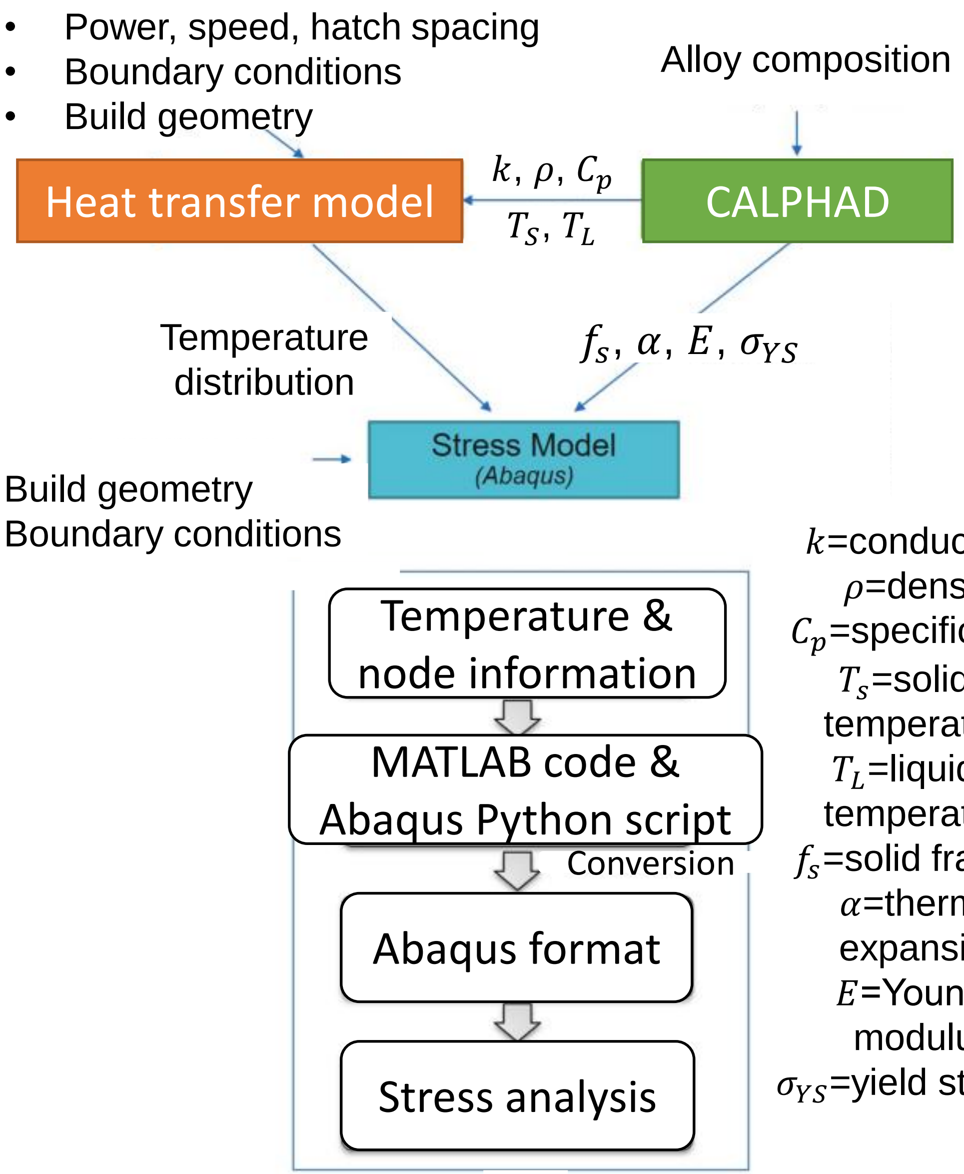


Fig. CALPHAD-based ICME framework to model solidification cracking susceptibility of an AMed Ti alloy

Source: Sargent et al. 2021 [https://doi.org/10.3390/met11040570]

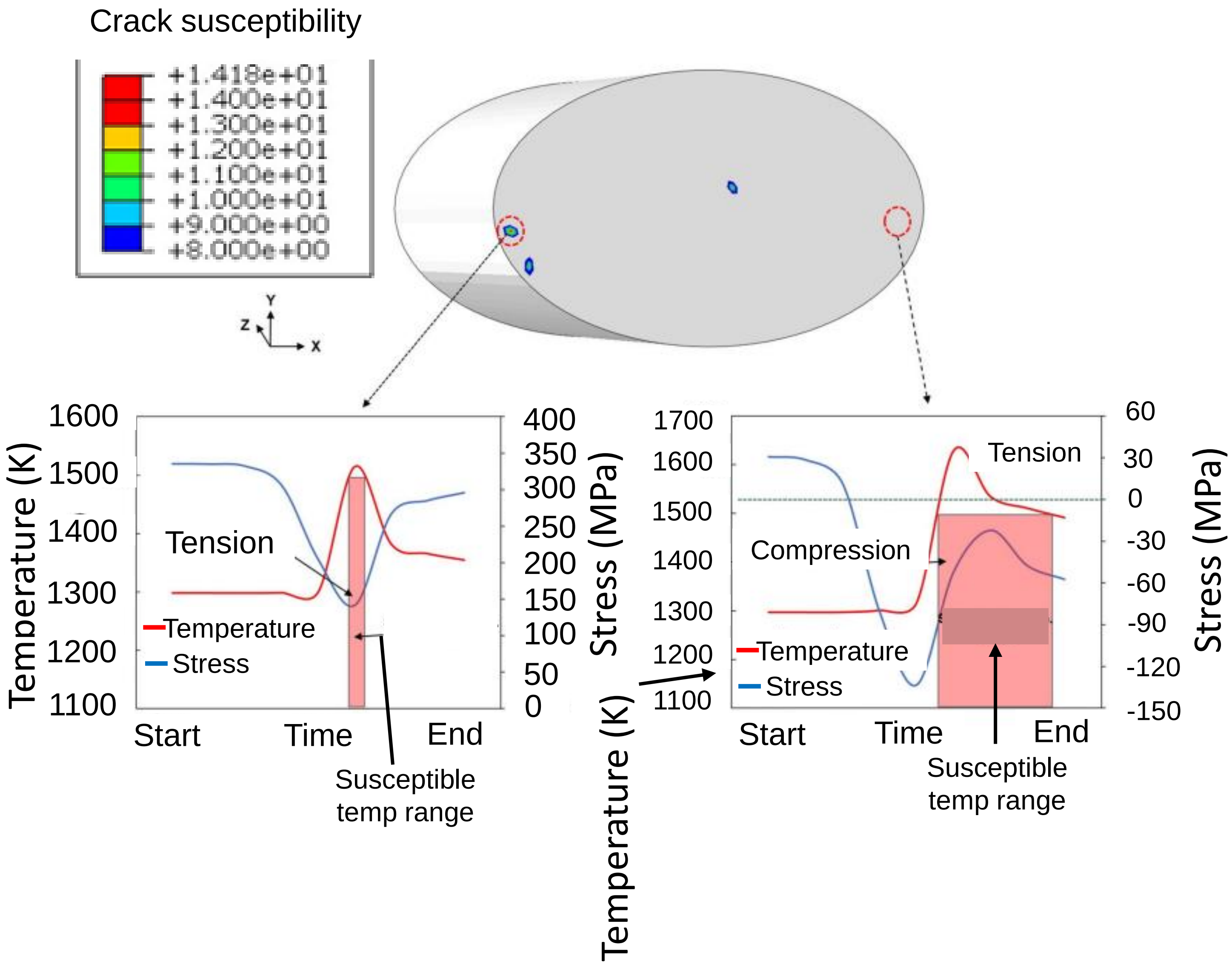
Process-induced defects

(a) flowchart of cracking analysis



k=conductivity
ρ=density
C_p=specific heat
T_s=solidus temperature
T_L=liquidus temperature
f_s=solid fraction
α=thermal expansion
E=Young's modulus
σ_{YS}=yield strength

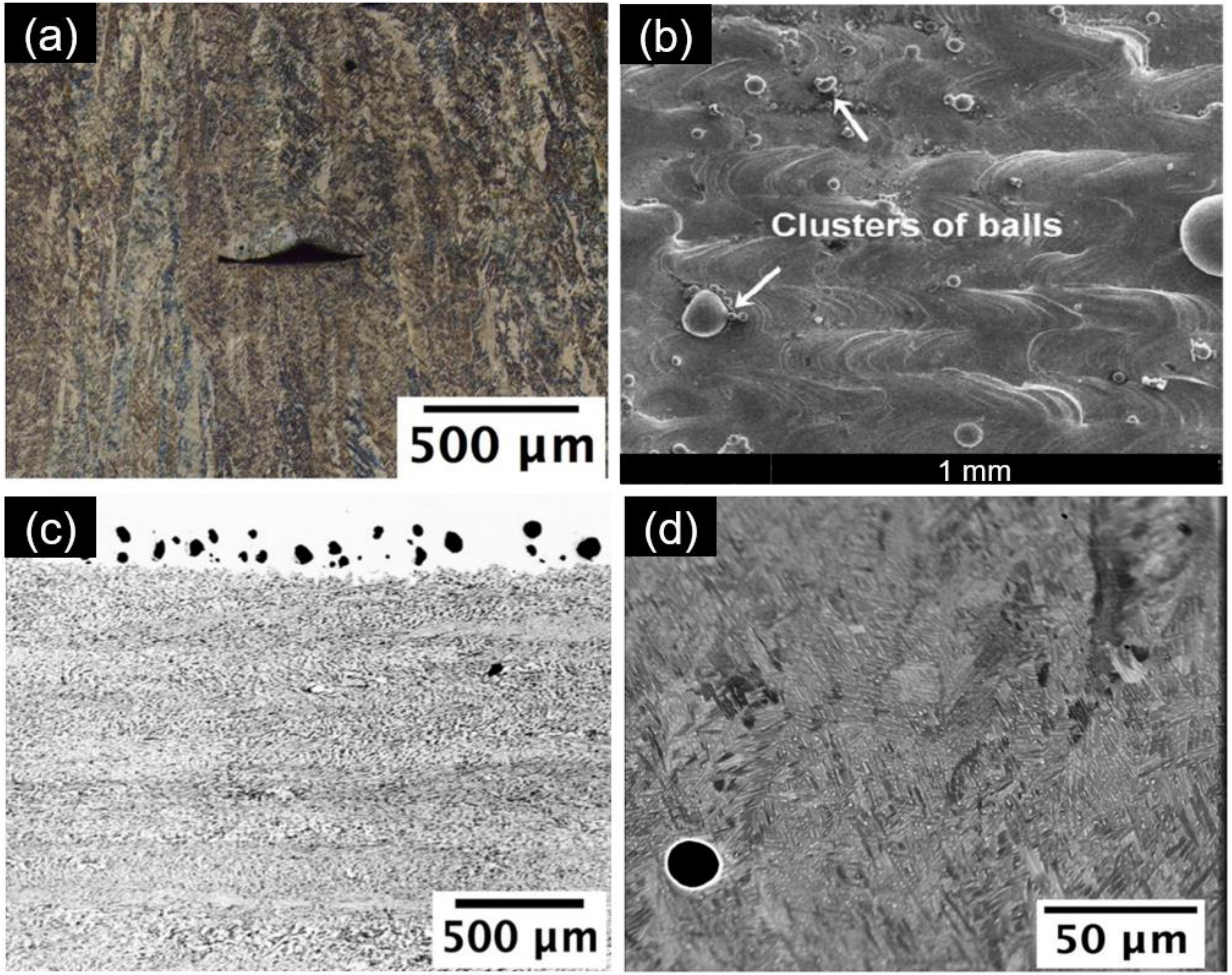
(b) Cracking susceptibility



Source: Lee et al. 2018 [https://doi.org/10.1007/s11661-018-4788-8]

Process-induced defects – porosity

Fig. Types of defects:
(a) cracks, (b) balling,
(c) lack of fusion, and
(d) porosity



Source(a),(c),(d) : Cunningham et al. 2016 [https://doi.org/10.1007/s11837-015-1802-0]
(b)Zhang et al. 2016 [https://doi.org/10.1179/1753555715Y.0000000076]

Process-induced defects – porosity

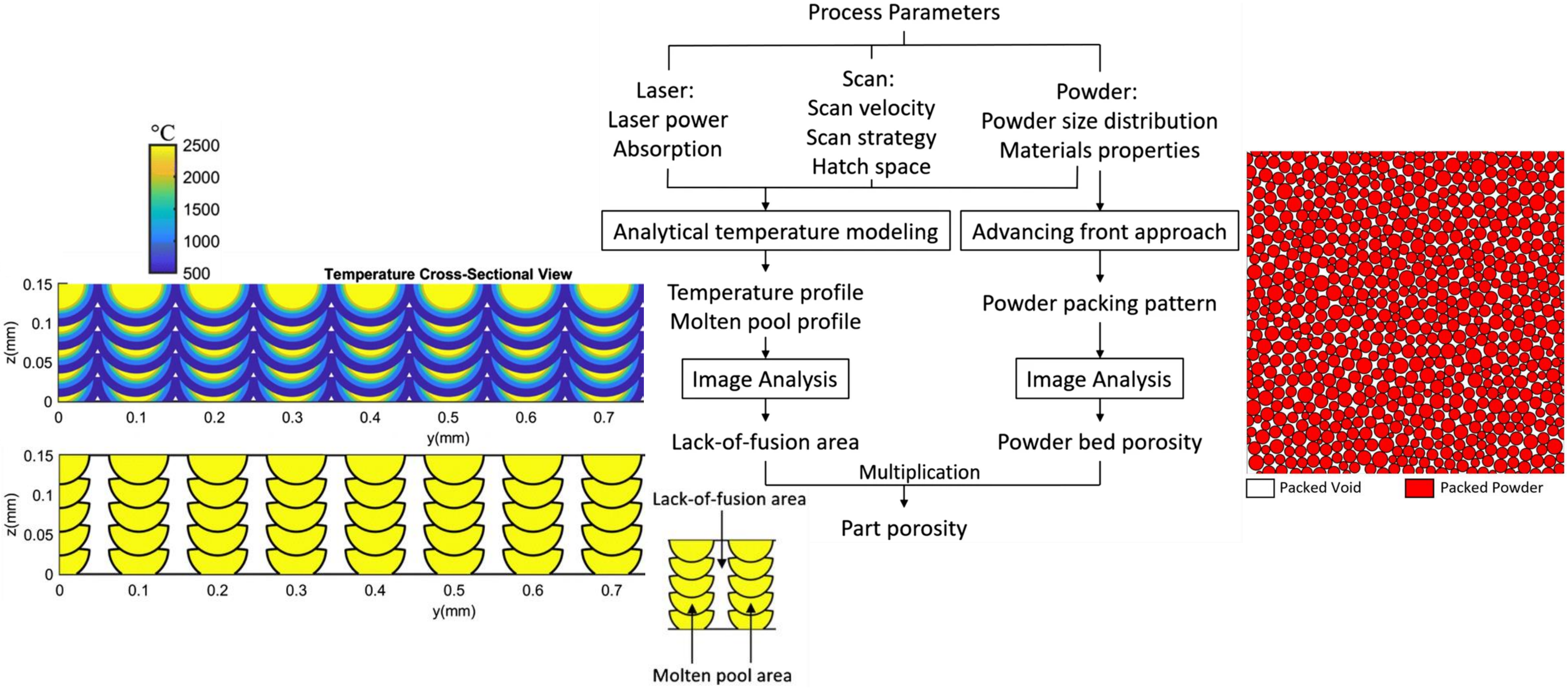


Fig. Schematics of an algorithm for modelling of porosity in AMed builds

Source: Ning et al. 2019 [https://doi.org/10.1007/s00339-019-3092-9]

Process-induced defects – porosity criteria

Lack of fusion $\left(\frac{h}{W}\right)^2 + \frac{t}{t+D_m} \leq 1.$ $\left(\frac{h}{W}\right)^2 + \left(\frac{t}{D_m}\right)^2 \leq 1,$

$$D_m/t > 1.5$$

h: hatch distance,
W: melt pool width,
t: layer thickness,
D_m : melt pool depth
L: melt pool length

Balling $L/W < 2.3,$

Lack of fusion
& key hole

$$E_D = \frac{P}{vht}.$$

$$H_n = \frac{AP}{h_s\sqrt{\pi v d D^3}},$$

Process-induced defects – roughness

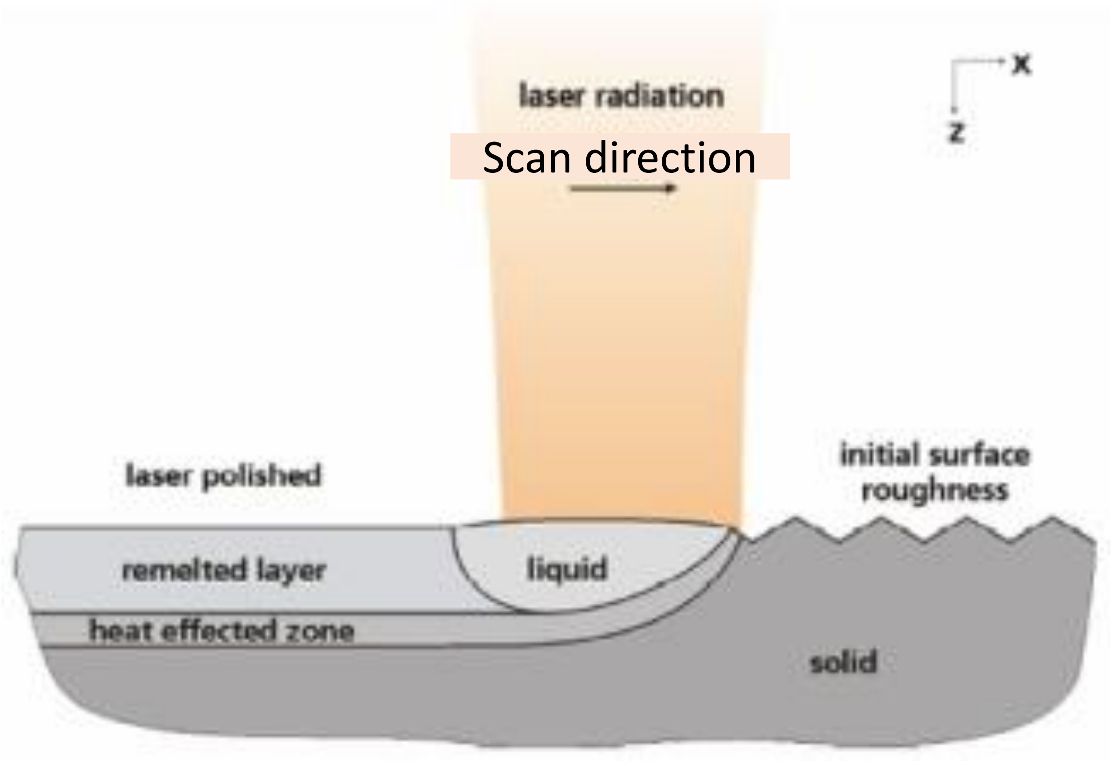


Fig. Influence of laser on roughness reduction

Source: Temmler et al. 2012 [https://doi.org/10.1117/12.906001]

Process-induced defects – residual stress

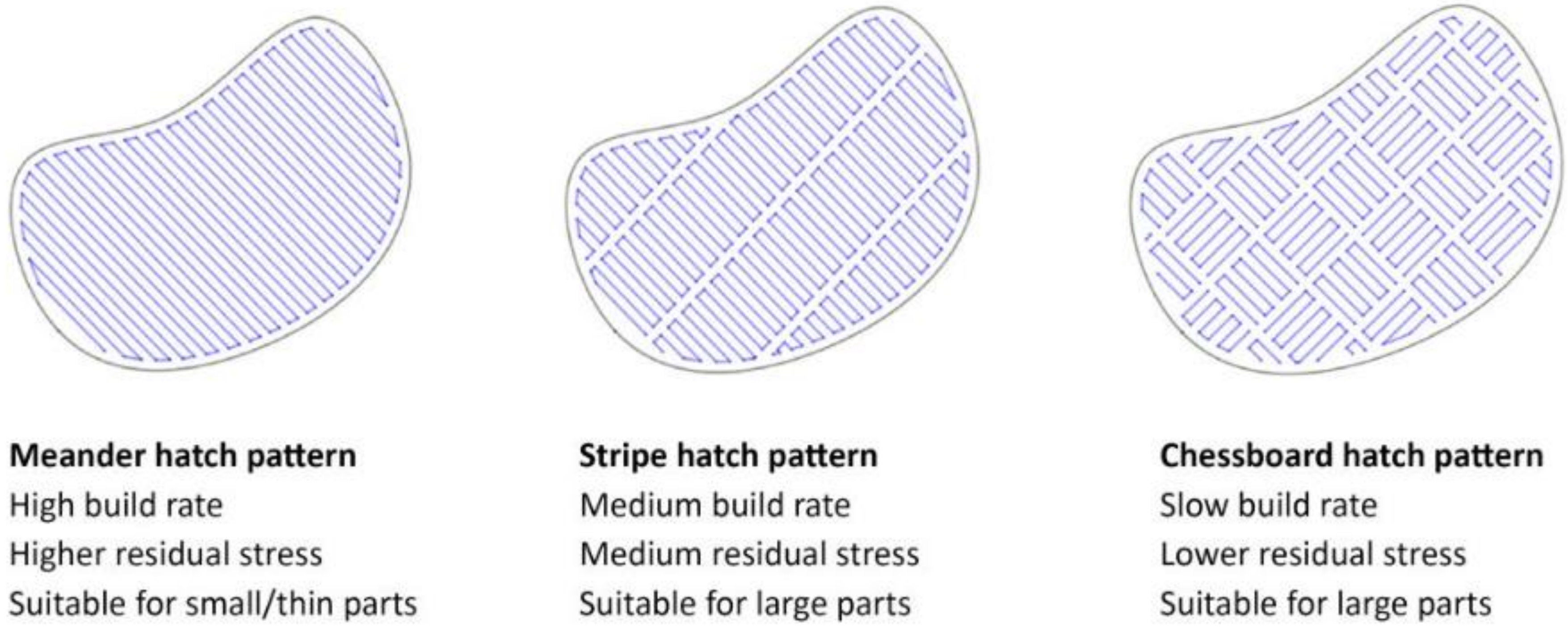


Fig. Selected hatch pattern examples that leads to various residual stress contents

Printability

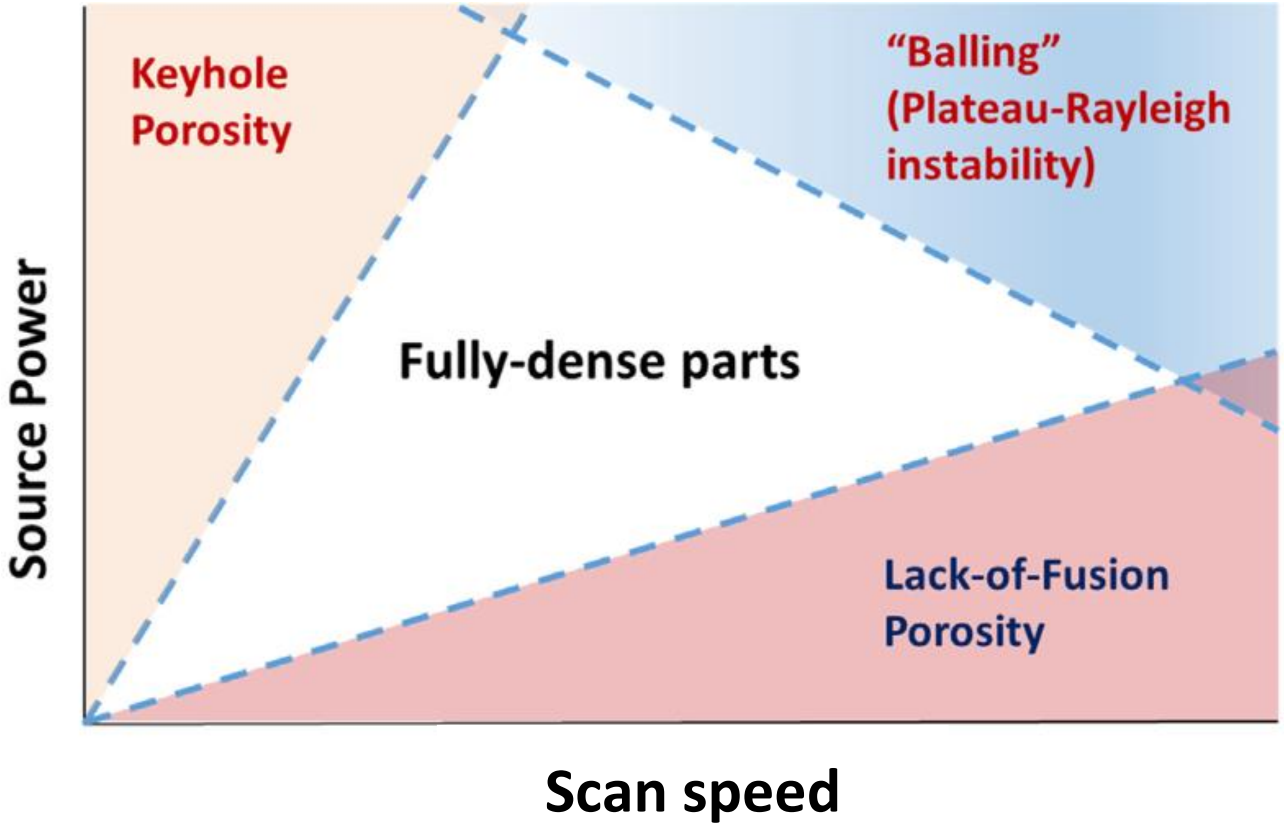


Fig. compromise among key processing parameters

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

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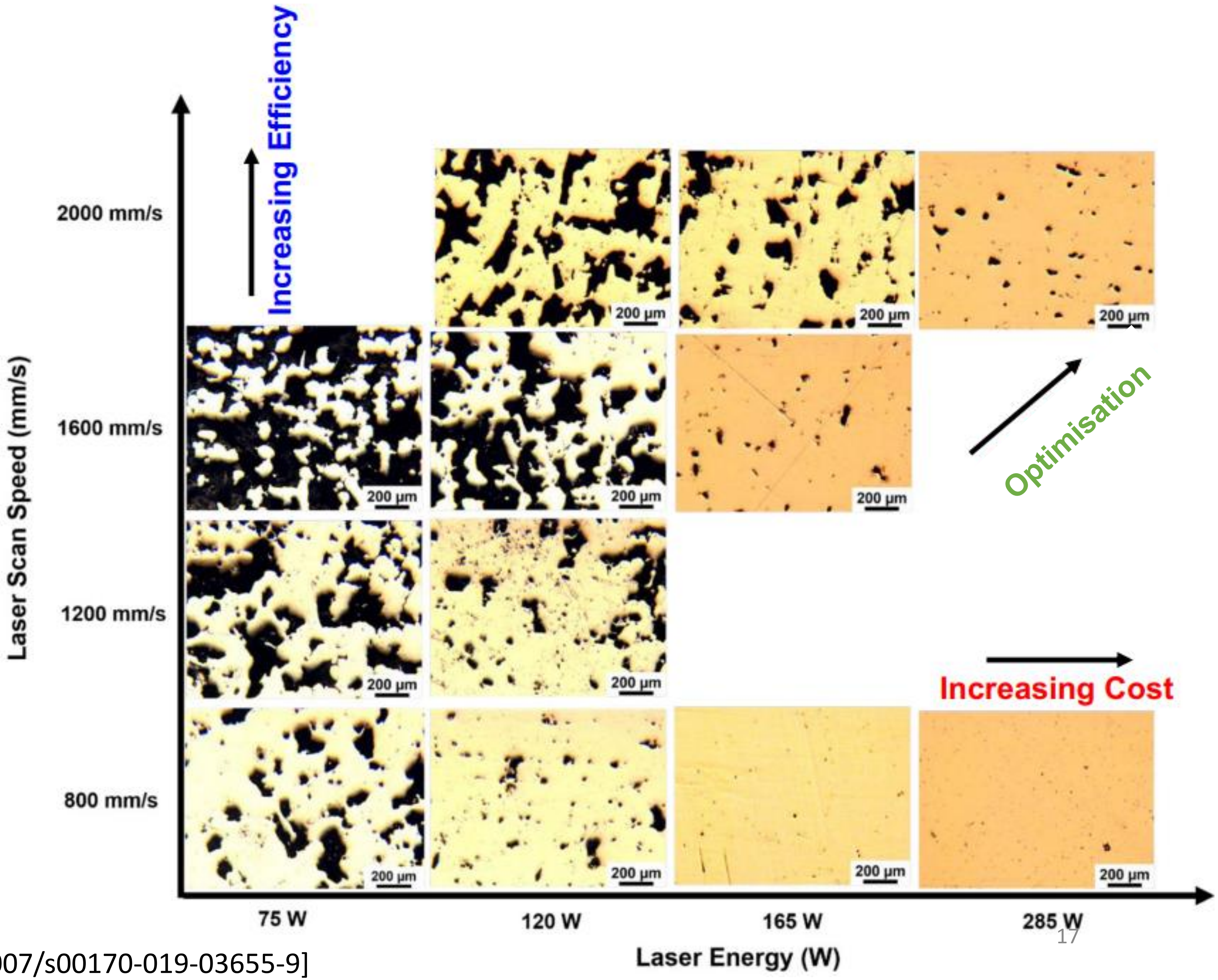

Fig. Influence of scan speed and Laser energy on defect formation

Source: Kumar et al. 2019 [https://doi.org/10.1007/s00170-019-03655-9]

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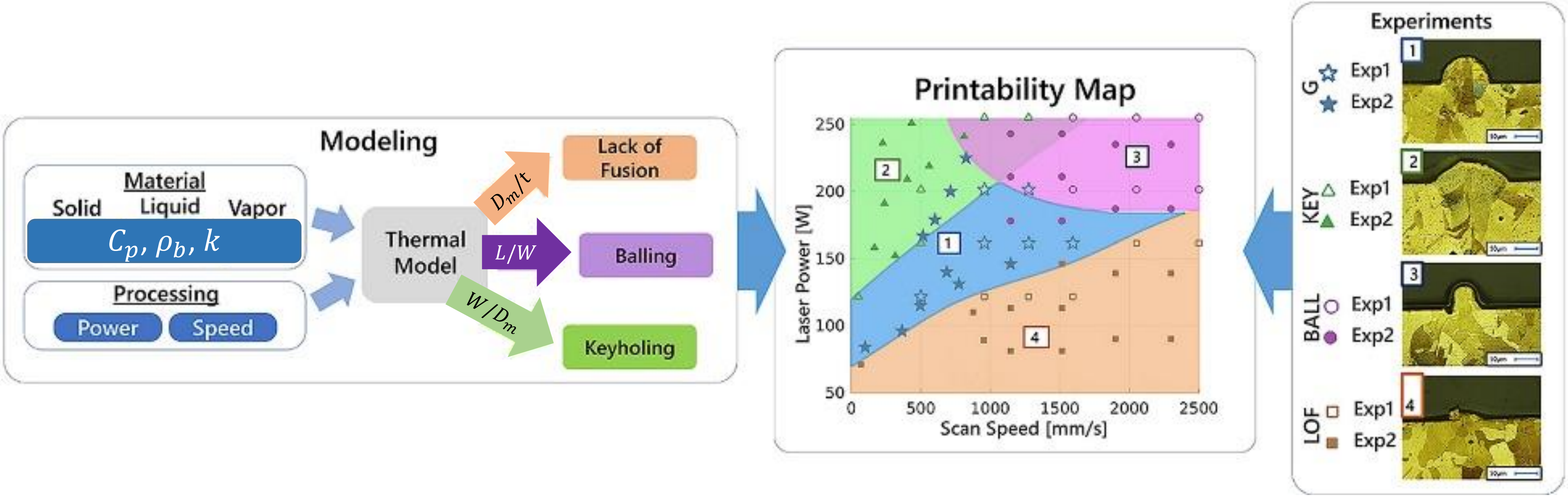

Fig. Inputs and outputs in for the computational modelling of a range of AM defects

Source: Johnson et al. 2019 [https://doi.org/10.1016/j.actamat.2019.07.005]

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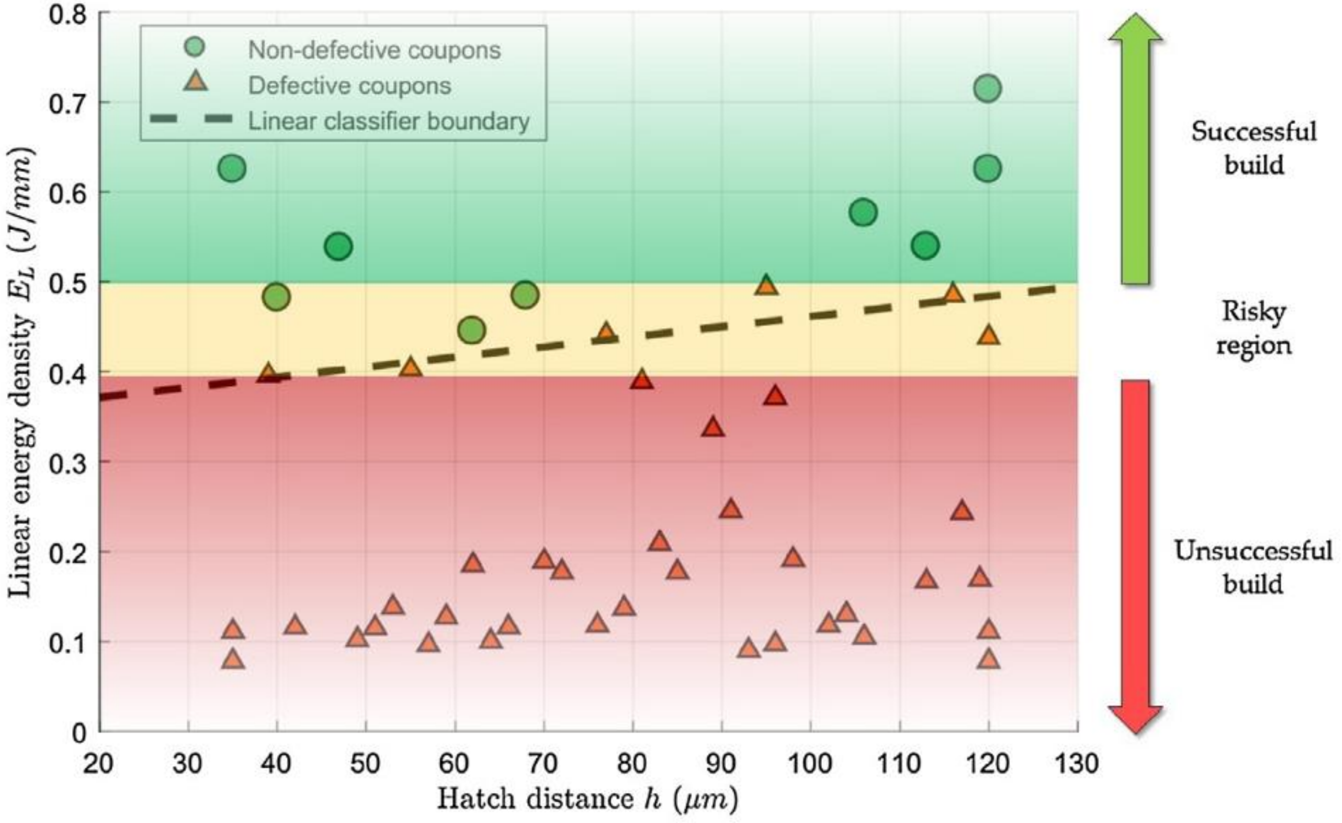


Fig. Influence of linear energy density and hatch distance on build qualtiy

Source: Mahmoudi et al. 2018 [https://doi.org/10.1016/j.jmapro.2018.08.037]

Current application of additively manufactured alloys

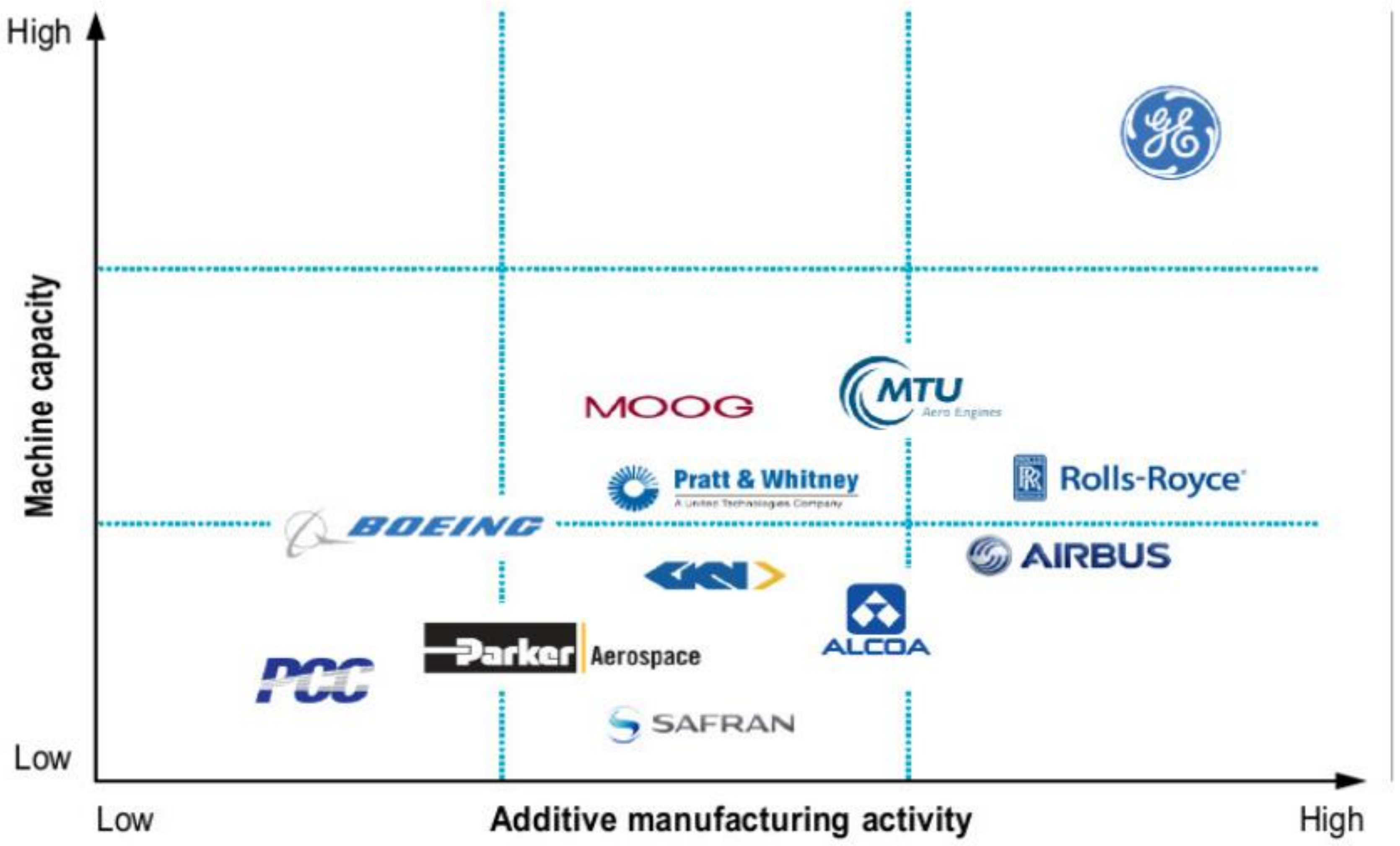
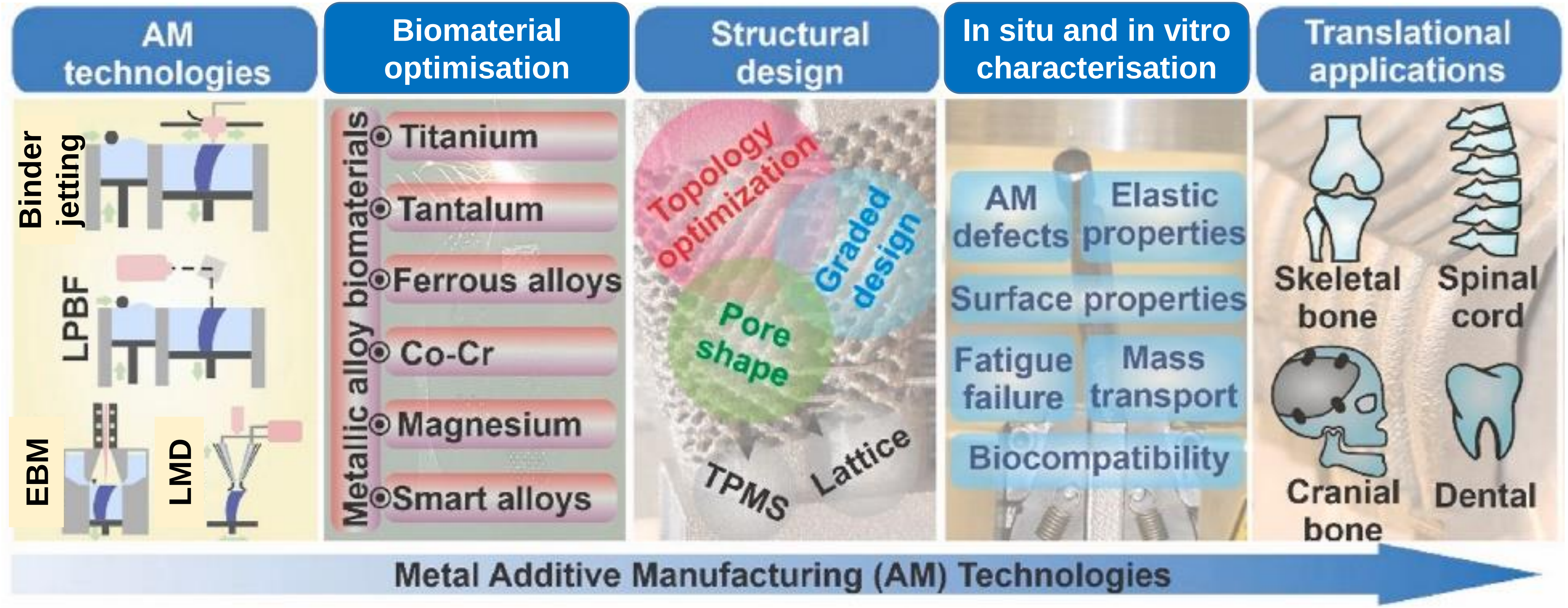


Fig. Capability of major companies on AM activity

Source: Yong et al. 2020 [http://dx.doi.org/10.3390/met10121576]

Current application of additively manufactured alloys



Source: Davoodi et al. 2022 [https://doi.org/10.1016/j.bioactmat.2021.12.027]

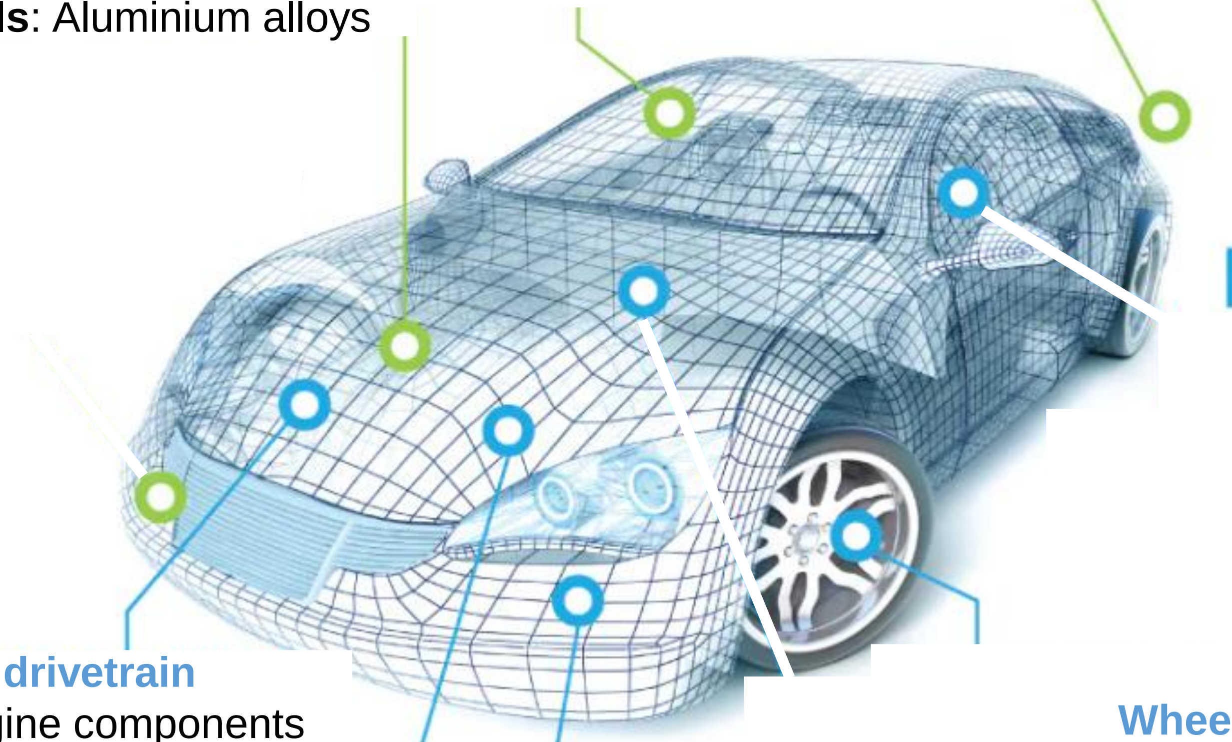
AM application to automotive

CURRENT

Fluid handling
Applications: Pumps, valves
AM technique: LPBF, EBM
Materials: Aluminium alloys

Manufacturing process
Applications: Prototyping, customised tooling, investment casting
AM technique: Binder jetting, LPBF
Materials: Hot work steels

Exhaust/emissions
Applications: Cooling vents
AM technique: LPBF
Materials: Aluminium alloys



FUTURE

Powertrain, drivetrain
Applications: Engine components
AM technique: LPBF, EBM
Materials: Aluminium, titanium alloys

Frame, body, doors
Applications: Body panels
AM technique: LPBF
Materials: Aluminium alloys

OEM components
Applications: Body-in-white
AM technique: LPBF, EBM
Materials: Aluminium alloys, steels

Wheels, suspension
Applications: Hubcaps, suspension springs
AM technique: Binder jetting, LPBF
Materials: Aluminium alloys

Source: Cotteleer et al. 2013 [http://d2mtr37y39tpbu.cloudfront.net/wpconter uploads/2014/03/DUP718-dditive-Manufacturing Overview MASTER1.pdf