AMPOWER INSIGHTS

Metal Additive Manufacturing with **sinter-based** technologies

A deep dive
into the emerging
AM technologies

INSIGHTS GAINED:

- State of the art of sinter-based AM technologies
- Impact of new technologies on established AM technologies
- Potential new business cases
- Material properties and design guidelines

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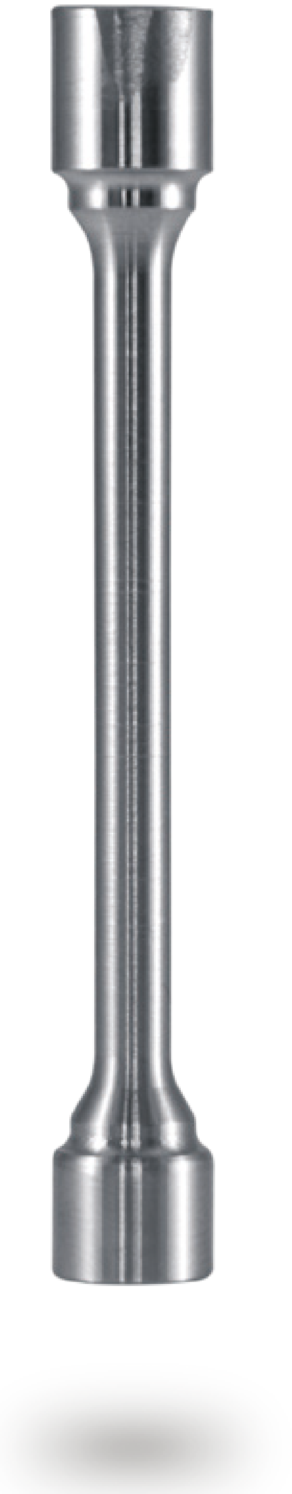


Insights gained

State of the art of sinter-based AM technologies
Impact of new technologies on established AM technologies
Potential new business cases
Material properties and design guidelines

Management summary

Starting out mainly as a prototyping technology Additive Manufacturing (AM) gained tremendous momentum for use in industrial applications over the last 5 years. For highly demanding functional parts, laser beam powder bed fusion (LB-PBF) became the most dominant AM technology. In the past two years, binder jetting technology (BJT) and fused deposition modeling (FDM) of metal components raised end user expectations to enable new applications by massively reducing cost. This claim has been fueled lately by large US companies such as HP, Desktop Metal and Markforged.

In this study, Ampower presents an objective and independent view on the current capabilities of sinter-based AM technologies compared with LB-PBF and metal injection molding (MIM). By analyzing over 50 specimens from 9 different system suppliers, Ampower is revealing the characteristics of the different technologies.

The cost analysis confirms expectations of cost savings through use of sinter-based technologies. Today, cost reductions of over 40 % can be achieved in comparison to LB-PBF and are expected to increase up to 60 % within the next 2 years. However, prerequisite for those savings are a high packing density and large volume production. While metal FDM offers flexibility and low pricing for small quantities, BJT is targeting high production volumes leading to further cost savings.

In comparison to LB-PBF, analysis of material characteristics reveals lower performance of both sinter-based AM technologies when it comes to density and mechanical properties. For highly loaded metal applications, it is thus unlikely that end users will adapt either BJT or FDM technology in the near future.

The study closes with a deep dive into the design potentials and limitations. The greatest challenge of sinter-based AM technologies is the debindering and sintering process. To control these necessary process steps, a profound knowledge of sintering is required. Implementing sinter-based AM technologies will present new challenges to early adopters. Especially the investment in infrastructure and knowledge about the sintering processing should not be underestimated. For automotive and machine industry, binder jetting technology and metal fused deposition modeling offer great future potential. They will cover the gap between casting and LB-PBF regarding cost and productivity. When it comes to highly loaded applications, however, EB- & LB-PBF will remain the reference AM technologies for now.

Download this study at www.am-power.de/insights

This Insight is an excerpt of a comprehensive study which was conducted in co-operation with Alliance MIM SA, C. ILLIES & CO. Handelsgesellschaft mbH, Citim GmbH, Deutsche Bahn AG, Dr.-Ing. h.c. F. Porsche Aktiengesellschaft, Lufthansa Technik AG, SLM Solutions Group AG and YXLON International GmbH.

Content

About Ampower

Ampower is the leading consultancy in the field of industrial Additive Manufacturing. Ampower advises their clients on strategic decisions by developing and analyzing market scenarios as well as compiling technology studies. On operational level, Ampower supports the introduction of Additive Manufacturing by their targeted training program as well as identification and development of components suitable for production. Further services include the setup of quality management and support in qualification of internal and external machine capacity. The company is based in Hamburg, Germany.

Introduction

Additive Manufacturing metal technologies – an overview

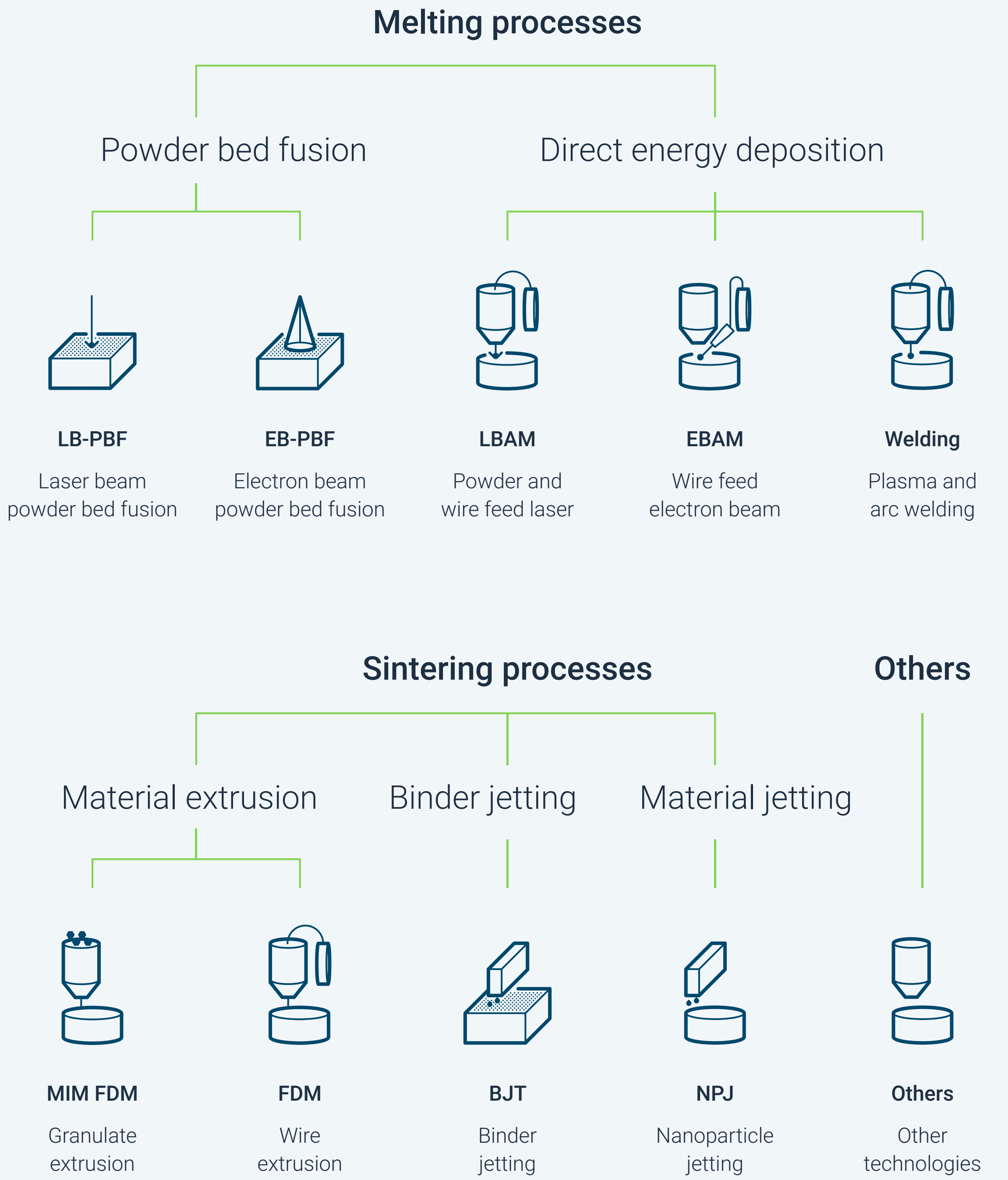
For industrial-grade metal applications, laser beam powder bed fusion is currently the most dominant Additive Manufacturing technology. With the appearance of sinter-based AM technologies this dominance, however, might be about to change.

Additive Manufacturing (AM) can look back on a history of over 30 years. Starting out mainly as a prototyping technology it gained tremendous momentum for use in industrial applications over the last 5 years. As of today, there are at least 11 major metal Additive Manufacturing technologies competing for applications in the industrial environment. Every technology has its specific advantages and limitations regarding part design, mechanical properties and costs.

This leads to a more and more complex decision when it comes to the choice of technology for a given application. The following technology map represents an approach of classifying the different metal AM technologies while taking the ISO/ASTM 52900 standard into account. Most of the processes can be classified into melting or sinter-based technologies.

While sintering always comes with a binder component and a two-step manufacturing process, melting technologies use powder or wire to directly produce the part. Classification of the melting technologies can be accomplished by distinction of the material depositioning method (direct or powder bed) and by energy source. Sinter-based AM processes require a sintering step and therefore have heat as the main energy source in common. They are also classified by the material depositioning method and further distinguished by the type of feedstock.

Metal Additive Manufacturing Technologies



Download the complete technology map with more details and supplier overview at:
am-power.de/en/insights/metal-additive-manufacturing

Geographic distribution of AM system providers

The early development of laser beam powder bed fusion of metals was mainly driven by German universities and several pioneering companies. It took more than a decade of continuous improvement until industrial maturity was achieved.

In contrast, sinter-based AM technologies are currently pushed heavily by US based large companies and start-ups with major funding from an industry full of expectations. Except for Evo-Tech and AIM3D, there are few major players of sinter-based technologies located in Europe.

Study overview

For this in-depth study, Ampower analyzes sinter-based AM technologies in comparison to laser beam powder bed fusion (LB-PBF) and metal injection molding (MIM). For this purpose, test specimens from nine different suppliers were acquired and examined. Besides density cubes and tensile bars, an automotive component as test geometry was investigated as well. By the time of publication, not all system manufacturers were capable to deliver full set of requested specimens. The results of the study represent the current and actual capabilities of binder jetting and metal FDM technology.

Working principle of sinter-based Additive Manufacturing

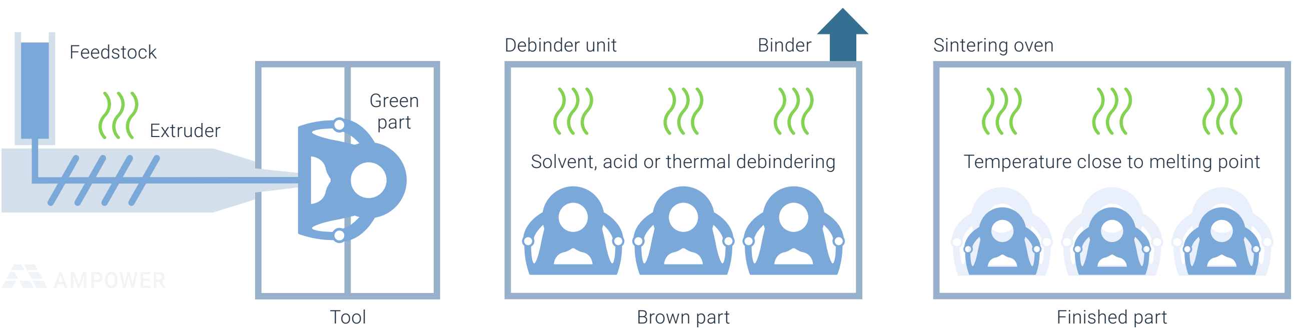
Conventional sintering technologies are established in today's manufacturing environments and have a far longer history in industrial applications than Additive Manufacturing.

Dating back to the early 1920s, the first ceramic injection molding processes were described using ceramic powder and polymer binder. In the 1950s, use of metal powders was investigated. The cost, however, was high and the process more complex in comparison to competing casting technologies. By 1970, high part complexity and growing experience in the sintering process justified the use of the more expensive MIM technology over casting. Development of new binder materials and debindering techniques enabled stable processes leading to high density and good material properties of metal parts. Today, the global market of metal injection molding is valued at over €2 billion with compound annual growth rate between 10 and 20 %. The MIM applications are dominated by complex components for medical instruments, jewelry, defense industry and electronic devices. Part sizes typically vary between 5 to 50 mm.

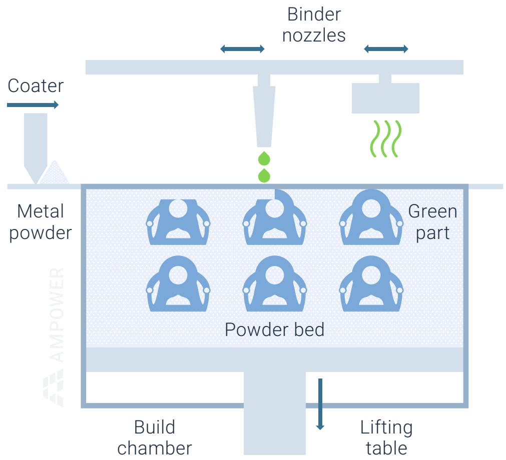
1 Molding of green part

2 Debindering

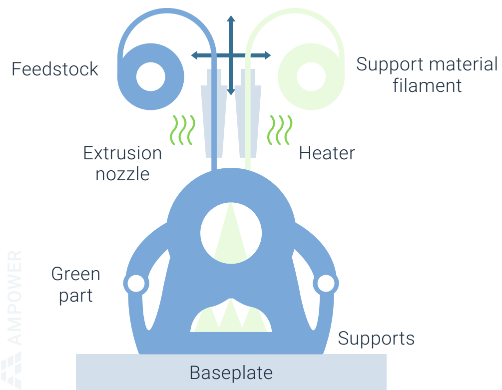
3 Sintering



The MIM process is based on three steps: molding, debindering and sintering. The new AM technologies share the second and third step with MIM. The forming of the green part, however, utilizes the layer wise manufacturing principle of Additive Manufacturing. Nevertheless, the actual material depositioning method to create the green part vary greatly from company to company.

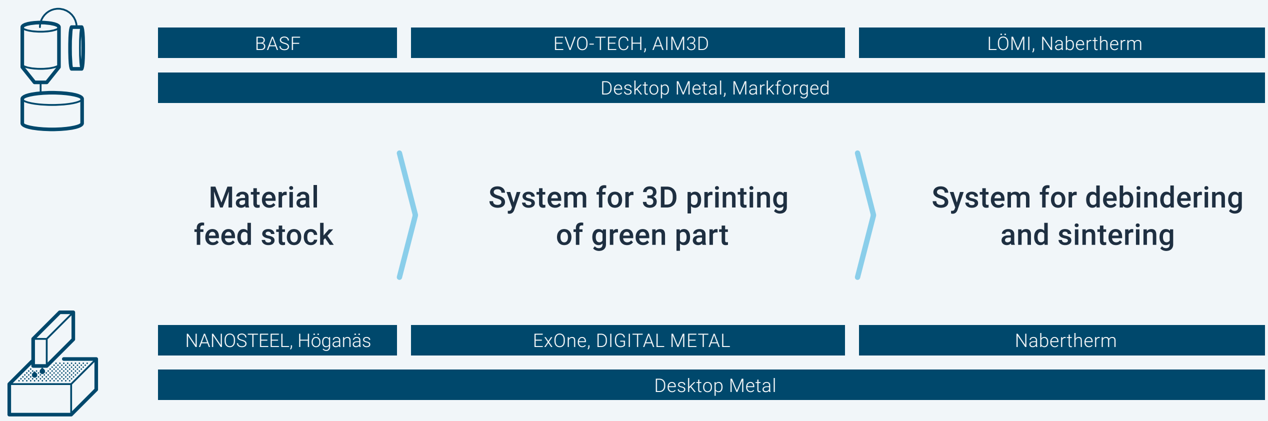


Binder jetting technology goes back to a MIT development which originally focused on sand casting forms. Since then, ExOne developed the first metal process based on binder jetting technology. Digital Metal followed with their own system. Desktop Metal and Hewlett Packard are expected to release similar systems until 2020. The technology principle is still based on the original MIT patents which refer to a powder bed of sand or metal powder on which binder is locally applied. This fluid binder solidifies by applying heat. A slightly different approach is described by 3DEO. Here the binder is applied on the full powder bed area followed by a milling process of the hardened layer with multiple machining spindles to create the contour of the part in each layer.



Metal FDM uses wire, MIM feedstock or rods as the base material. The raw material stock is a premixed compound of metal powder and polymer binder. While the machine principle is very similar to polymer FDM systems, the key difference lies in the printing head. The extrusion nozzle has specific characteristics for applying the metal feedstock. With Markforged, Desktop Metal, EVO-Tech and AIM 3D, four major suppliers are currently offering Metal FDM printing systems.

The business models vary as each company covers different aspects of the vertical value chain. While Markforged and Desktop Metal offer proprietary material and debindering/sintering solutions alongside their 3D printing system, EVO-Tech, AIM 3D, ExOne and Digital Metal use feedstock that is readily available on the market from established suppliers such as BASF. Furthermore, they use common sintering process equipment which is offered by oven manufacturers such as Nabertherm.



Process chain & cost

Process chain and debindering background

Sinter-based metal AM technologies require a debindering process before the final process step of sintering can occur. The process chain of BJT and metal FDM share certain 3D printing process steps in the forming stage with LB-PBF. In the blank production, process steps from metal injection molding are adapted.

A Thermal debindering

Thermal decomposition of binder system. Often practiced in one system together with sintering process.

+ Low cost
+ Combination with sintering

- Low speed, usually over 24h debindering time
- Limited to small wall thicknesses
- Delicate parts require careful handling due to missing 2nd binder

B Thermal catalytic debindering

POM based binder removal in gaseous acid environment, i.e. highly concentrated nitric or oxalic acid temperature of approximately 120°C.

+ Very fast and reliable process
+ Complete removal also in thick walls
+ Good shape retention

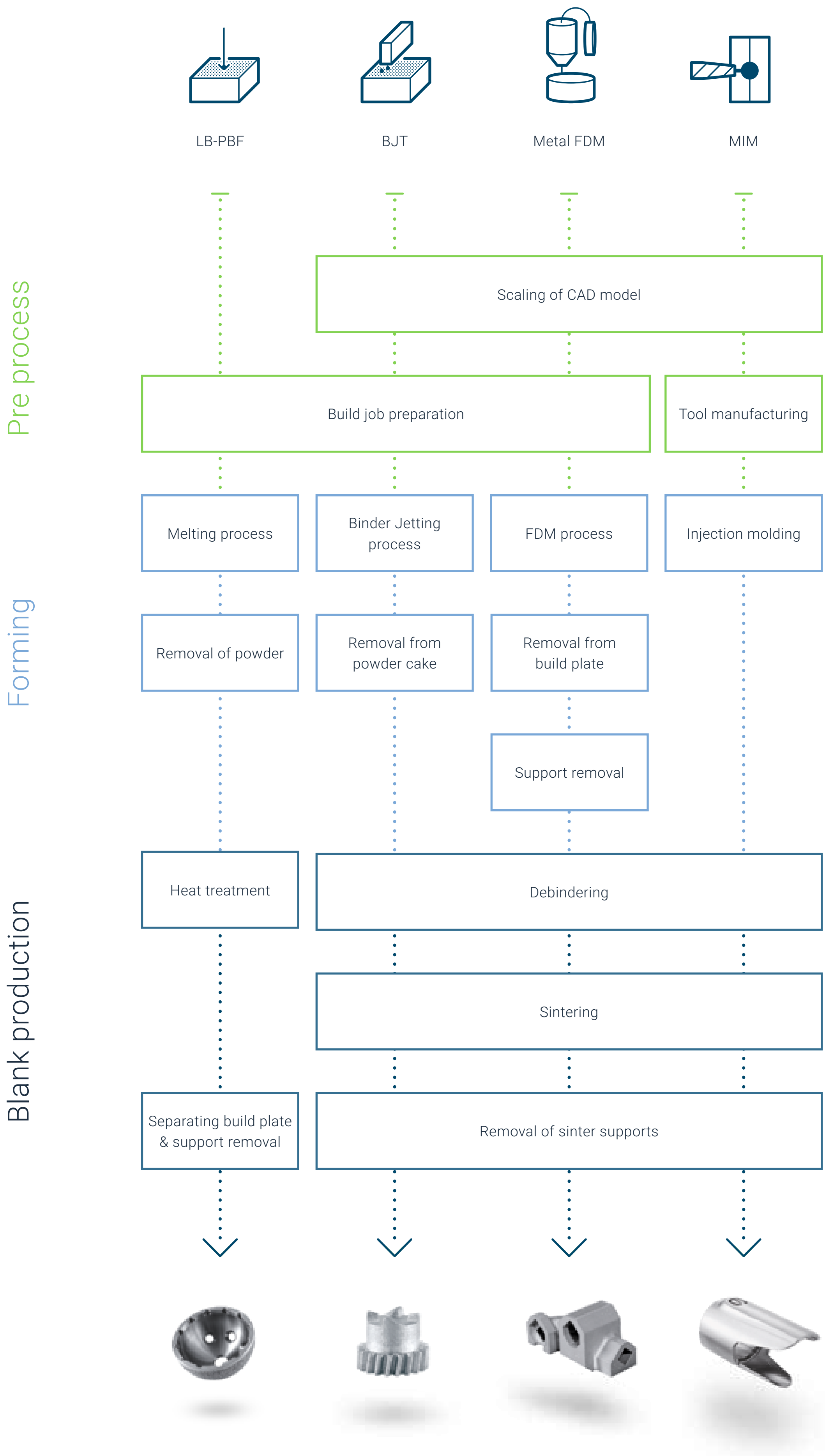
- High cost
- Expensive infrastructure
- Handling of acids

C Solvent debindering

Water or organic based solvent e.g. acetone or heptane.

+ Low cost
+ Environmental advantages

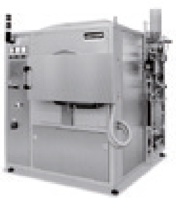
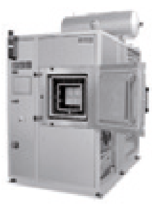
- Low speed
- Handling of hazardous liquids if not water based


LB-PBF
BJT
Metal FDM
MIM
Pre process
Scaling of CAD model
Build job preparation
Tool manufacturing
Forming
Melting process
Binder Jetting process
FDM process
Injection molding
Removal of powder
Removal from powder cake
Removal from build plate
Support removal
Blank production
Heat treatment
Debindering
Sintering
Separating build plate & support removal
Removal of sinter supports

Infrastructure & consumables

Investments in metal FDM systems are significantly less compared to BJT systems. System costs for debindering and sintering largely depend on the chosen process and are independent from the AM system technology to produce the green part. The values given in this overview are an exemplary impression of the infrastructure and consumables required for sinter-based Additive Manufacturing.

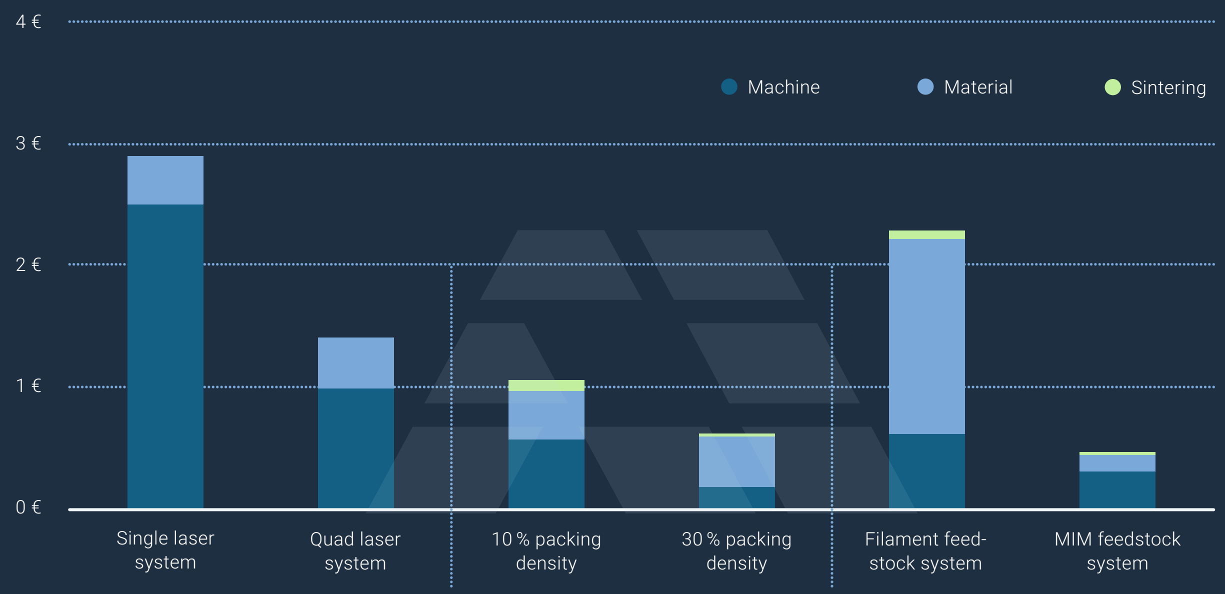
Technology	**Machine hourly rate** incl. consumables, excl. feedstock	Build envelope	Consumables
Metal FDM  Exemplary system Desktop Metal Studio	3-5 €/h	250 - 300 x 200 - 250 x 200 - 250 mm^3	Feedstock Electricity Compressed air
Binder jetting  Exemplary system Digital Metal DM P2500	35-50 €/h	170 - 400 x 150 - 250 x 60 - 250 mm^3	Metal powder Liquid binder Electricity
LB-PBF  Exemplary system SLM Solutions SLM 500 HL	35-50 €/h	250-500 x 250-280 x 200-380 mm^3	Metal powder Electricity Protective gas

Technology	Machine hourly rate incl. consumables, excl. feedstock	Build envelope	Cycle time	Consumables
Catalytic debindering  Exemplary system retort furnace Nabertherm NRA 40/02 CD	18-22 €/h	300 x 450 x 300 mm^3	10 h	Nitric acid Electricity Nitrogen Propane Compressed air
Solvent debindering  Exemplary system debindering Loemi EDA-30	0,5-1 €/h	380 x 200 x 216 mm^3	4 h	Solvent Electricity
Thermal debindering  Exemplary system retort furnace Nabertherm NRA 50/09 H_2	11-15 €/h	325 x 475 x 325 mm^3	16 h	Hydrogen Electricity Nitrogen Propane Compressed air
Sintering under hydrogen  Exemplary system retort furnace Nabertherm VHT 40/16-MO H_2	20-25 €/h	250 x 430 x 250 mm^3	16 h	Hydrogen Electricity Nitrogen Propane Compressed air

Cost as the game changer

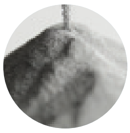
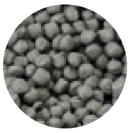
Compared to traditional high-volume manufacturing technologies, LB-PBF is generally associated with high machine and material cost at low production speed. Thus, not every part that is technologically feasible is reasonable from a business perspective. Sinter-based metal AM technologies promise to change this and lower the cost for metal parts for higher production volumes.

Average cost per cm³

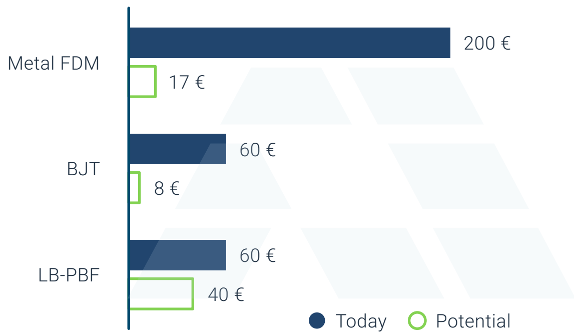


Material

The cost for stainless steel powder suitable for LB-PBF ranges between 40 to 80 €/kg. Similar to LB-PBF, current binder jetting technologies use spherical powder particles. However, BJT start-ups like Desktop Metal claim to work with classical MIM powder. This could tap into significant material cost saving of up to 90 %: MIM powder of alloy 316L has a price range of only 6 to 12 €/kg. For metal FDM, the feedstock consists of wire, granulate or rods made of metal powder and polymer binder compound with significant spread in feedstock cost. While granulates are based on classic MIM granulate and range between 15-18 €/kg for alloy 316L, filaments such as the BASF Ultrafuse 316LX are priced at 200 €/kg. However, similar metal filaments from alternative suppliers are available for 100 €/kg.

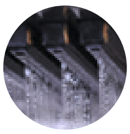




FEEDSTOCK COST PER KG FOR 316L

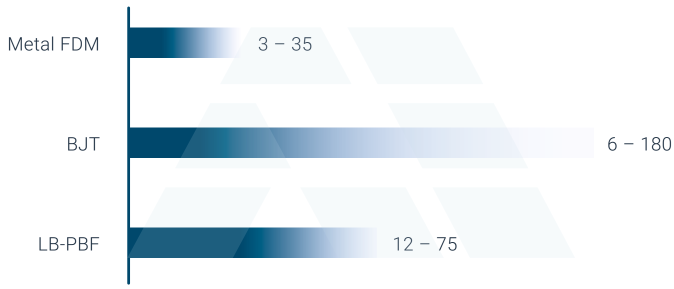


Productivity

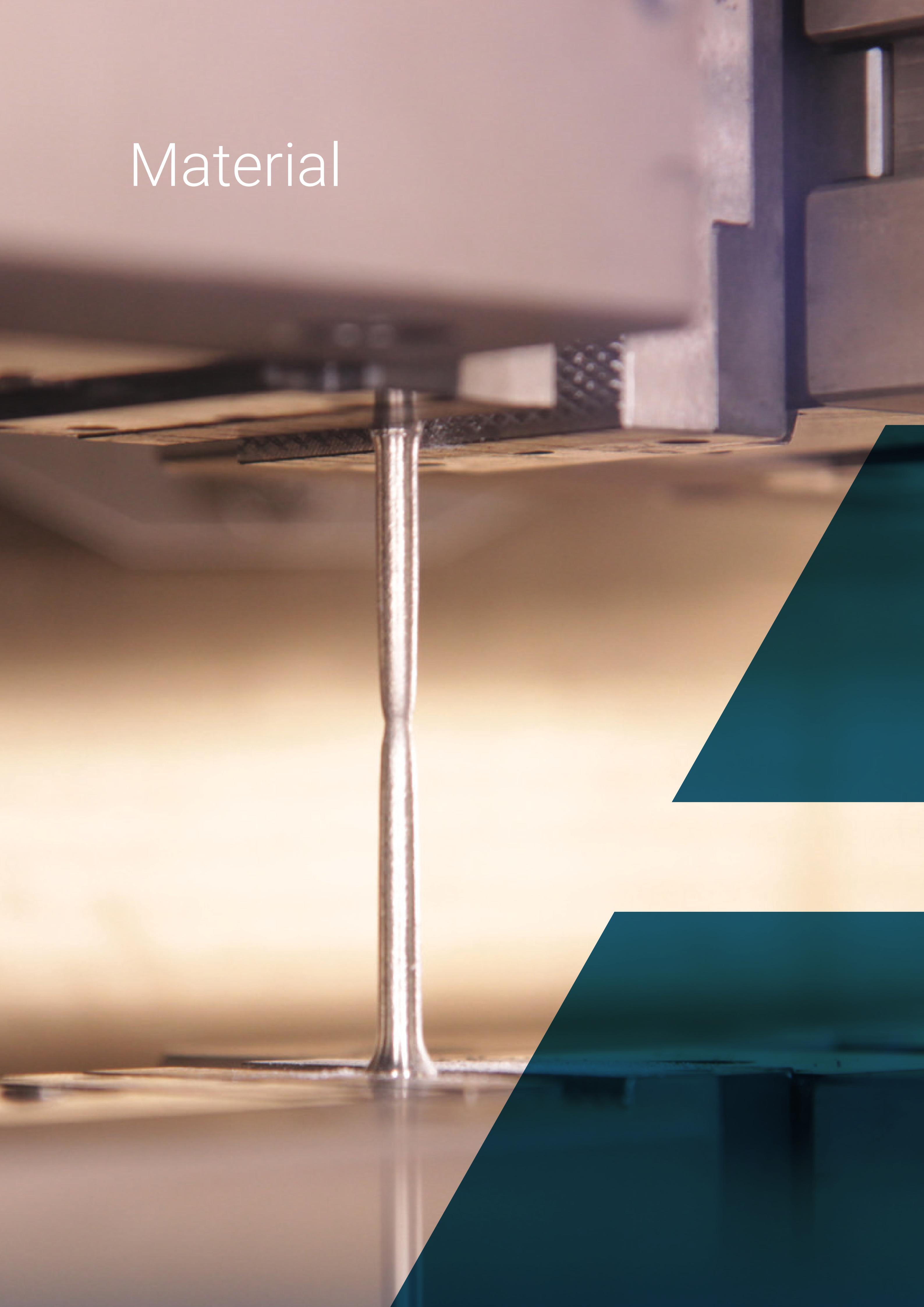
Analysis shows that LB-PBF production speed mainly depends on the number of lasers working parallel in the build chamber. For metal FDM the layer thickness is the key factor to increase the build volume per time. By increasing this parameter, the production rate increases but also leads to a strong reduction of resolution and surface quality. As mentioned above, the cost for feedstock also vary depending on the system. Production speed in binder jetting is calculated from the total build job time and the packing density. The packing density reflects the sum of all part volumes referred to the complete build envelope. Packing density is typically 10 % for mixed build jobs with different parts and 30 % for optimized stackable parts in a large volume production. Build job times are between 20-40 hours. Considering advertised improvements of the technology within the next years the build envelope will increase while the total build job time reduces to 10 hours due to single pass jetting.



CURRENT PRODUCTION SPEED IN CM³/H



Material



Material range – enabling applications

Material availability and performance is a key enabling factor for new AM applications. As of now, primarily stainless steel alloys 17-4PH and 316L are available for BJT and metal FDM technologies.

At the moment only LB-PBF offers a wide range of metal materials with alloys based on aluminum, titanium, nickel, steel and precious me als as well as other materials in development such as magnesium. In theory, every weldable material can be processed by LB-PBF. A multitude of available publications on mechanical properties of all these alloys leads to confidence of engineers in the expected characteristics and ultimately a higher acceptance of the LB-PBF over lesser researched technologies.

In principle, all known sinter metals can be used for sinter-based AM technologies. Especially copper and carbide materials pose interesting future applications, since they have certain limitations in LB-PBF. On the other hand, aluminum alloys will remain challenging due to general difficulties of sintering aluminum.

	LB-PBF	BJT	Metal FDM	MIM
Stainless steel	●	●	●	●
Tool steel	●	○	○	●
Super alloy	●	○	○	●
Titanium	●	●	○	●
Aluminum	●	◌	◌	◌
Copper/Bronce	○	○	●	●
Carbide	○	○	●	●

● Available ○ Under development ◌ Inherently difficult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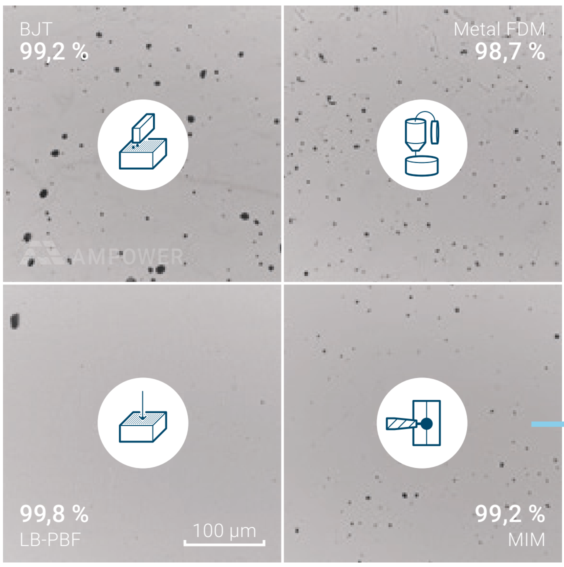
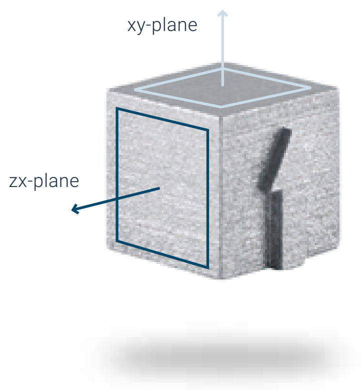
Material properties – density

For this study stainless steel alloys 316L and 17-4PH were examined to determine the material characteristics. These alloys are commonly available for the processes LB-PBF, MIM, metal FDM and BJT and therefore enable the best comparability. The obtained results are based on over 50 specimens from nine different system suppliers.

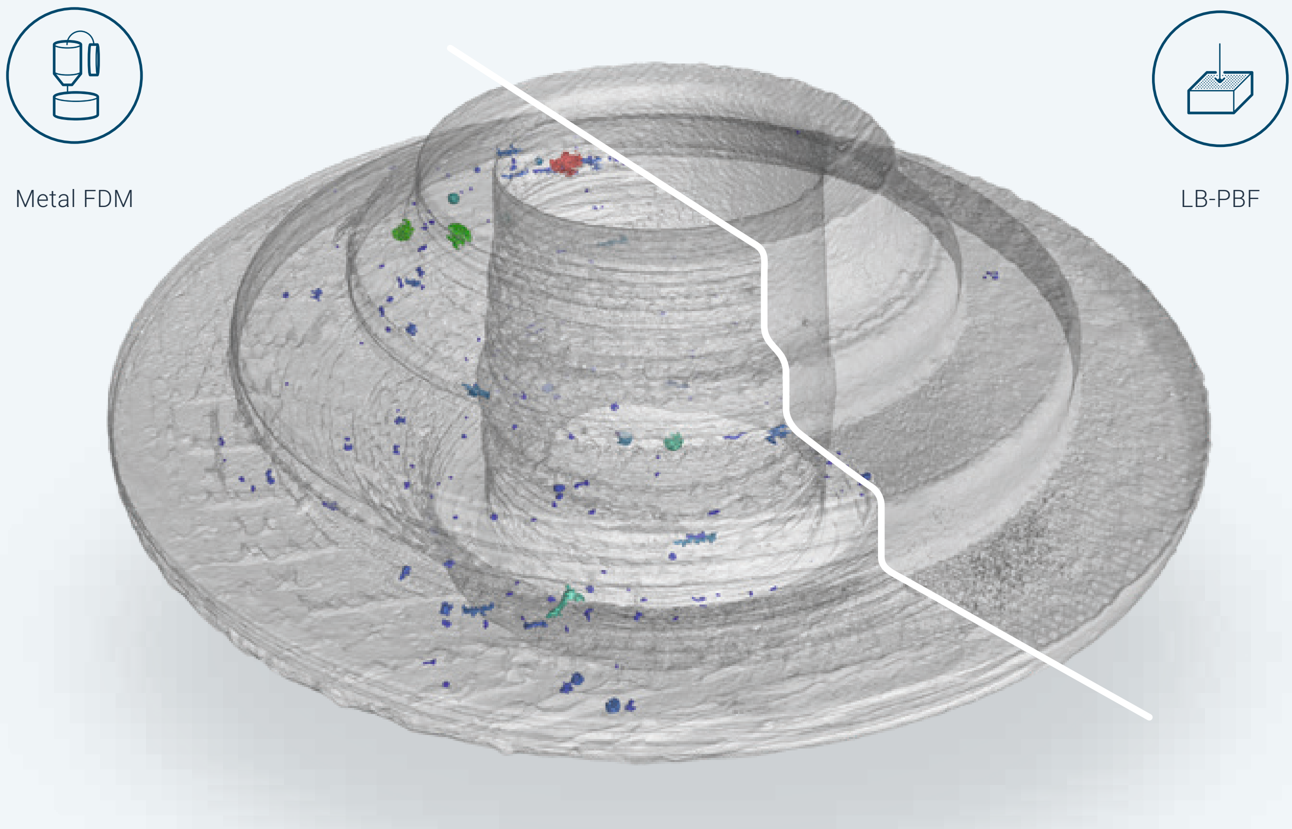
A high material density is paramount for good mechanical properties such as tensile strength and fatigue behavior. Also, with design restrictions in mind, a certain density is required for all components which carry fluids or gases. Low density leads to undesired large wall thicknesses to achieve impermeableness of the part.

For the porosity analysis, cross sections of each technology were analyzed by light microscopy. The density was calculated from three representative images each in the xy- and zx-plane. The aggregated results include micrographs from several BJT and metal FDM system manufacturers as well as MIM and LB-PBF specimen. The technologies show significant differences in pore size, shape and distribution. For the sinter-based technologies most dominant cause of this are the different debindering and sintering strategies and not the specific 3D printing mechanism.





Typical density values of MIM parts range between 95 to 97 %. The examined MIM specimen exhibits exemplary high quality with density of above 99 %.



Non-destructive material evaluation

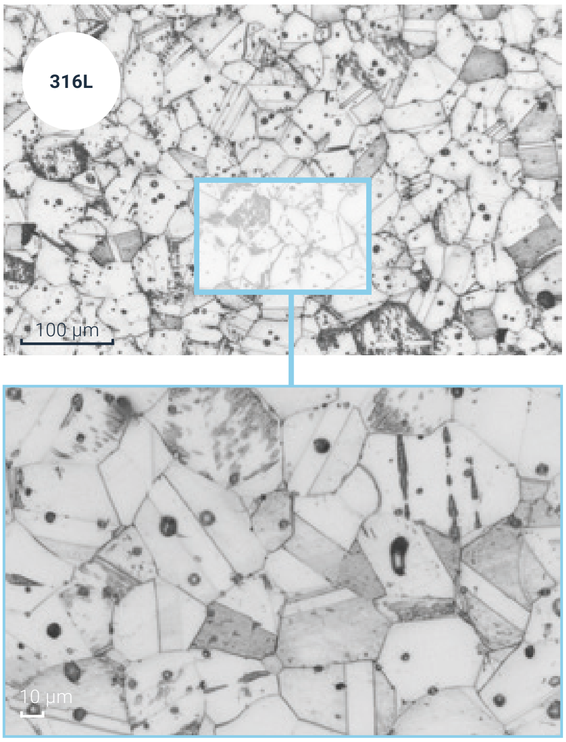
Computer tomography (CT) scans can be used to assess part quality. For validity of porosity analysis, the quality and resolution of the CT image has to be taken into account. Pores below the resolution may not be detected by the scan. The quantification of porosity is based on a threshold value that maps the gray scale value to solid material or voids. This value significantly influences the measurement result.

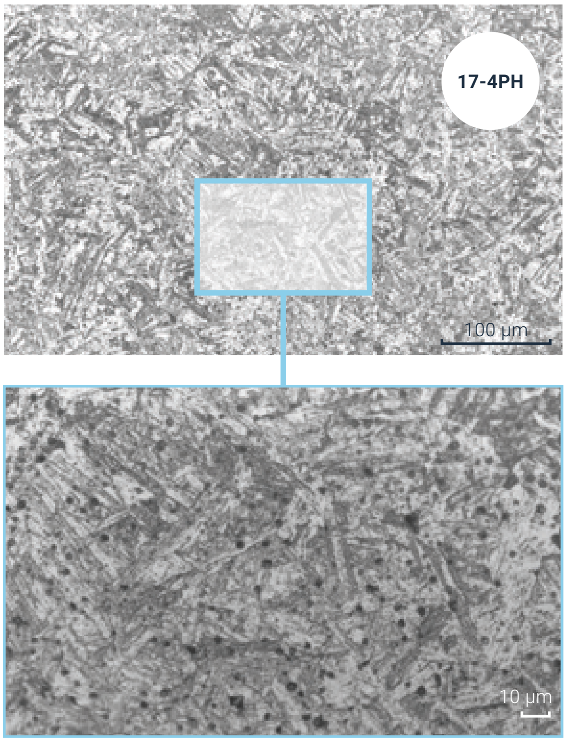
The comparison of computer tomography images of BJT, metal FDM and LB-PBF with same scan parameters reveals a higher pore distribution as well as larger defects in the BJT and metal FDM parts. This correlates with the results from the micrograph analysis.

- System: YXLON FF35 CT Metrology
- Resolution: 15 µm voxel edge
- Scan parameter: Voltage of 220 kV and tube current of 112 µA

Material properties – microstructure

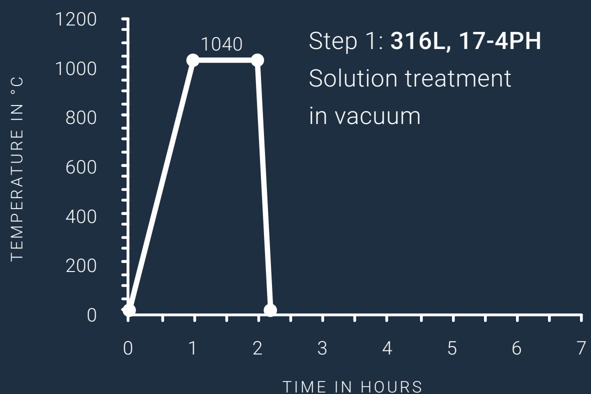
To minimize the influence of sintering temperature and other process inherent factors on the mechanical properties and to increase the comparability, all tensile specimens were post heat treated in identical cycles. All specimens were solution treated at 1040°C for one hour in vacuum. Specimens from alloy 17-4PH were additionally hardened to H1025 at 550°C for four hours in atmosphere.

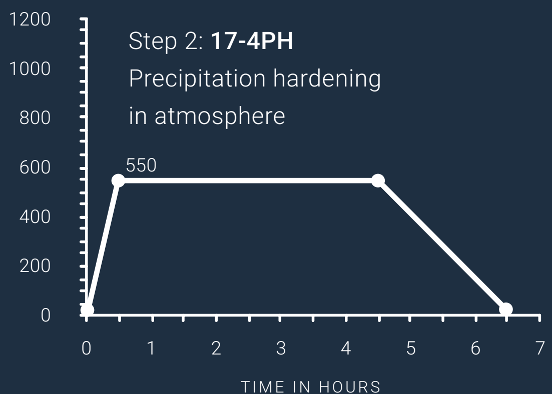




Specimens from alloy 316L show a twinned austenitic microstructure typical for sintered parts. The grain size varies between 50 to 100 µm. The 17-4PH specimens have a martensitic microstructure with some retained austenite. For both alloys, specimens from certain suppliers reveal delta ferrite precipitation which forms at higher sintering temperatures.

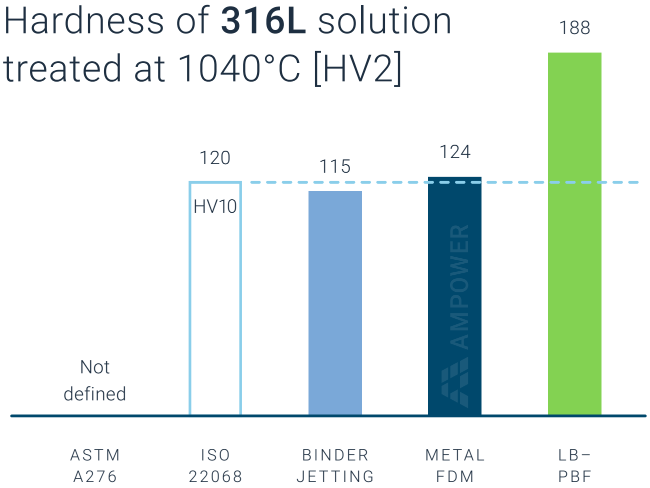
Heat treatment





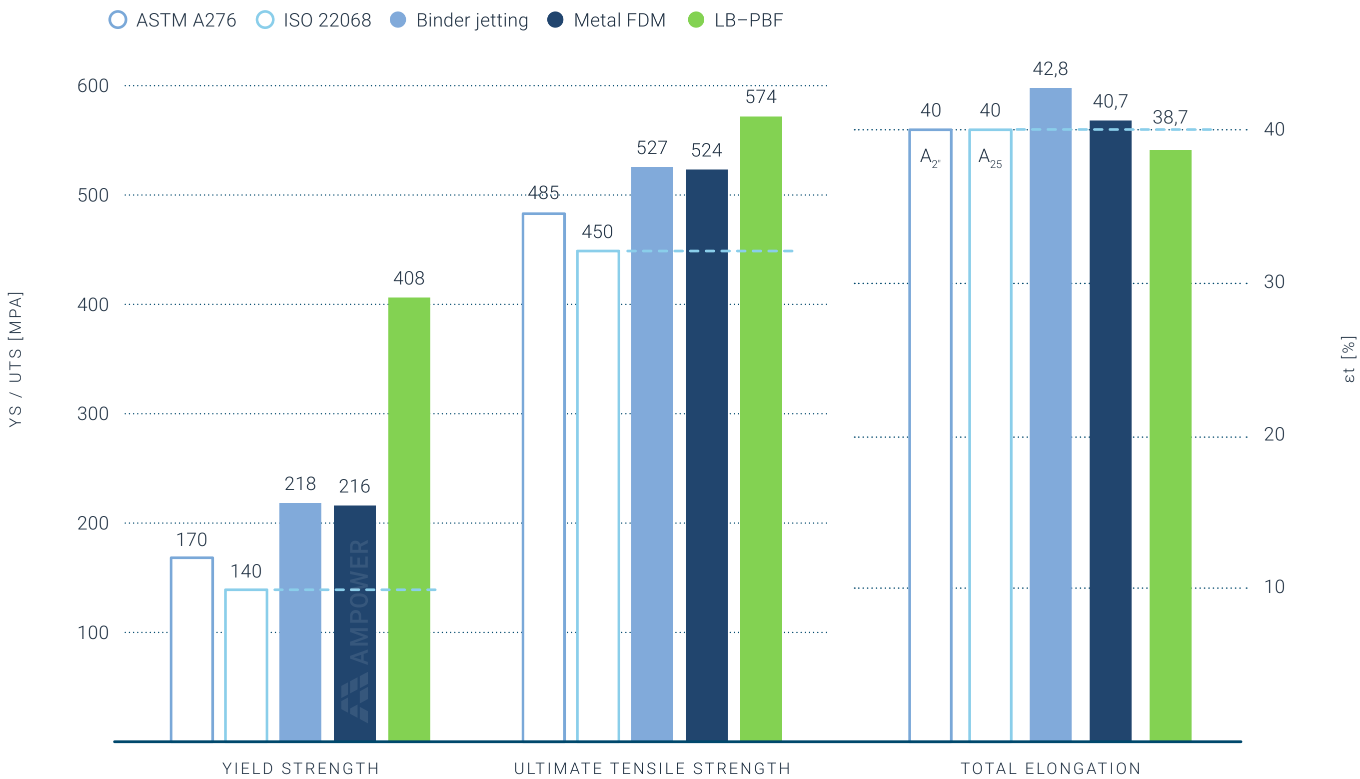
Material properties – tensile strength and hardness

Hardness of **316L** solution treated at 1040°C [HV2]



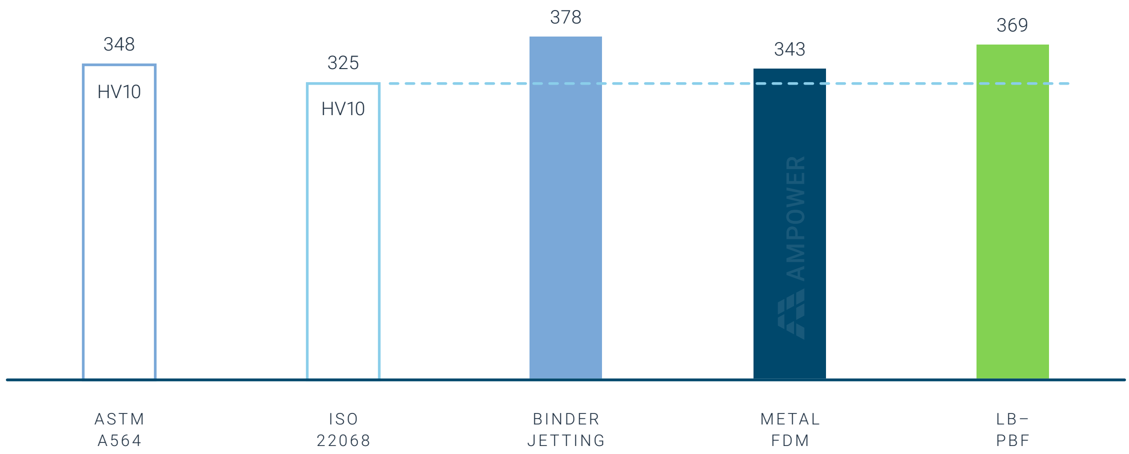
Sinter-based AM technologies achieve hardness close to the defined requirement for MIM alloys according to ISO 22068. Decrease in hardness below the value described in the standard might be attributed to the additional solution treatment and/or accumulation of porosity.

Tensile properties of **316L** solution treated at 1040°C

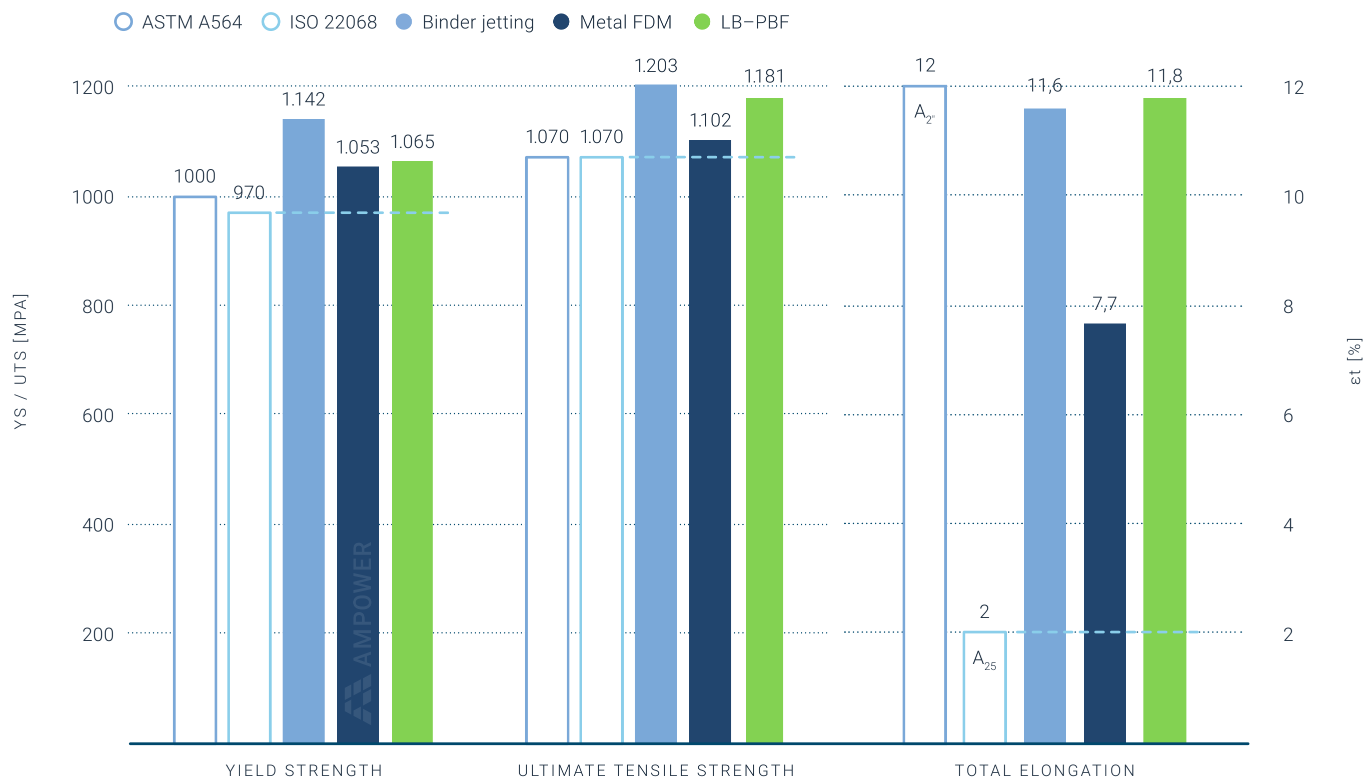


The sinter-based AM technologies excel the required tensile properties defined for conventional and metal injection molded 316L according to ASTM A276 and ISO 22068, respectively. Typical for LB-PBF, the material shows a long linear-elastic behavior resulting in extremely high yield strength. Due to the much finer microstructure in LB-PBF the elongation is slightly lower compared to sinter-based AM technologies.

Hardness of **17-4PH** hardened to H1025 [HV2]

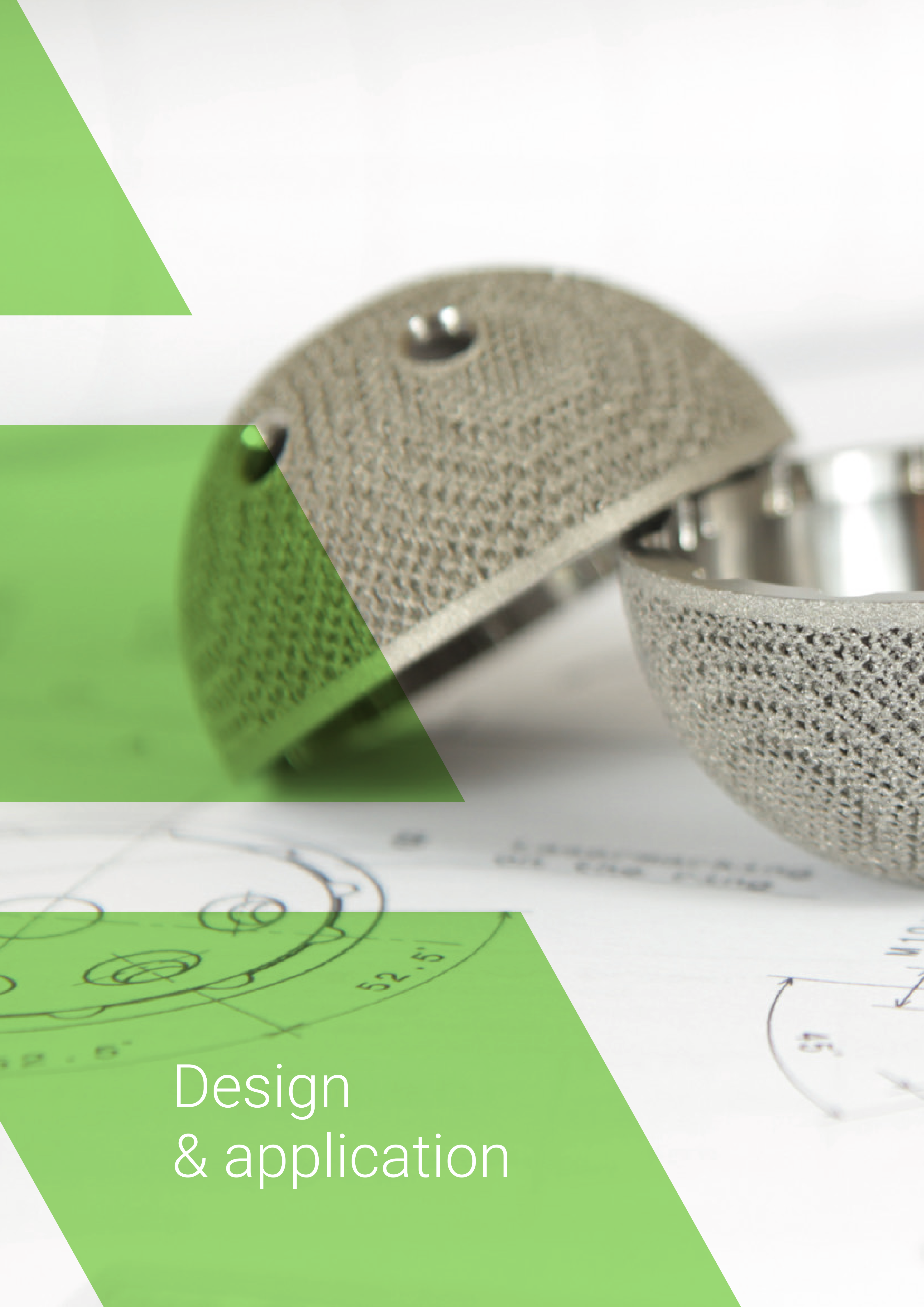


Tensile properties of **17-4PH** hardened to H1025



In precipitation hardened H1025 condition the strength of all AM technologies comply with the conventional and MIM material. The elongation values surpass the standard for MIM material by far. This is mostly due to the high density of 99 % of the tested specimens compared to average densities of 95 – 97 % for sintered alloys.

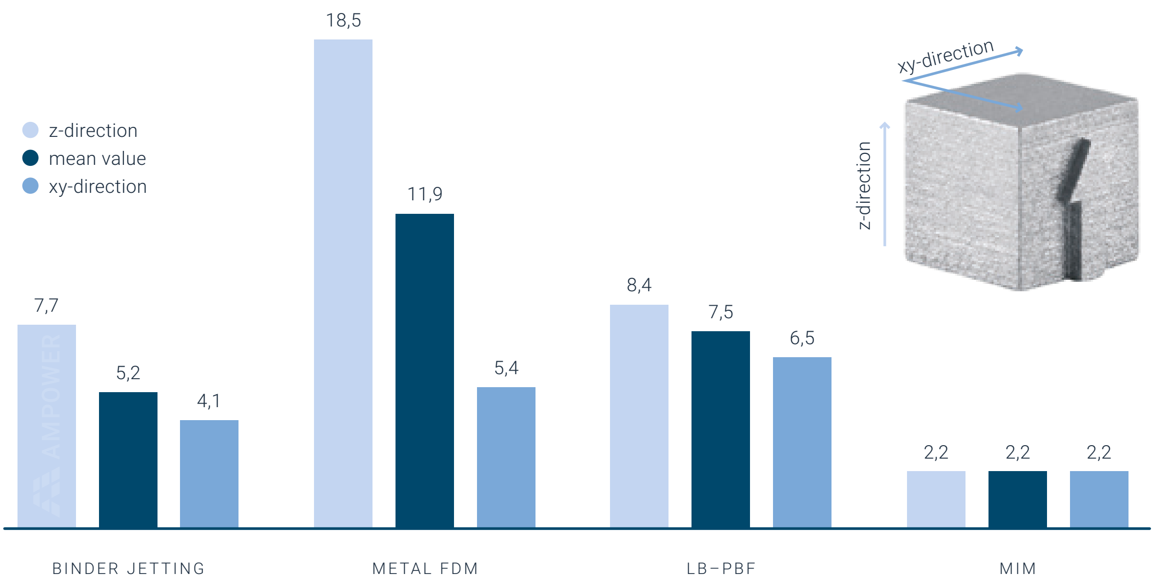
Design & application



Surface quality and dimensional accuracy

Surface quality and dimensional accuracy are important further factors in metal Additive Manufacturing. For a variety of applications, high accuracy and low surface roughness in as build condition may render additional mechanical post processing unnecessary. In this regard LB-PBF surface is often compared to casting quality.

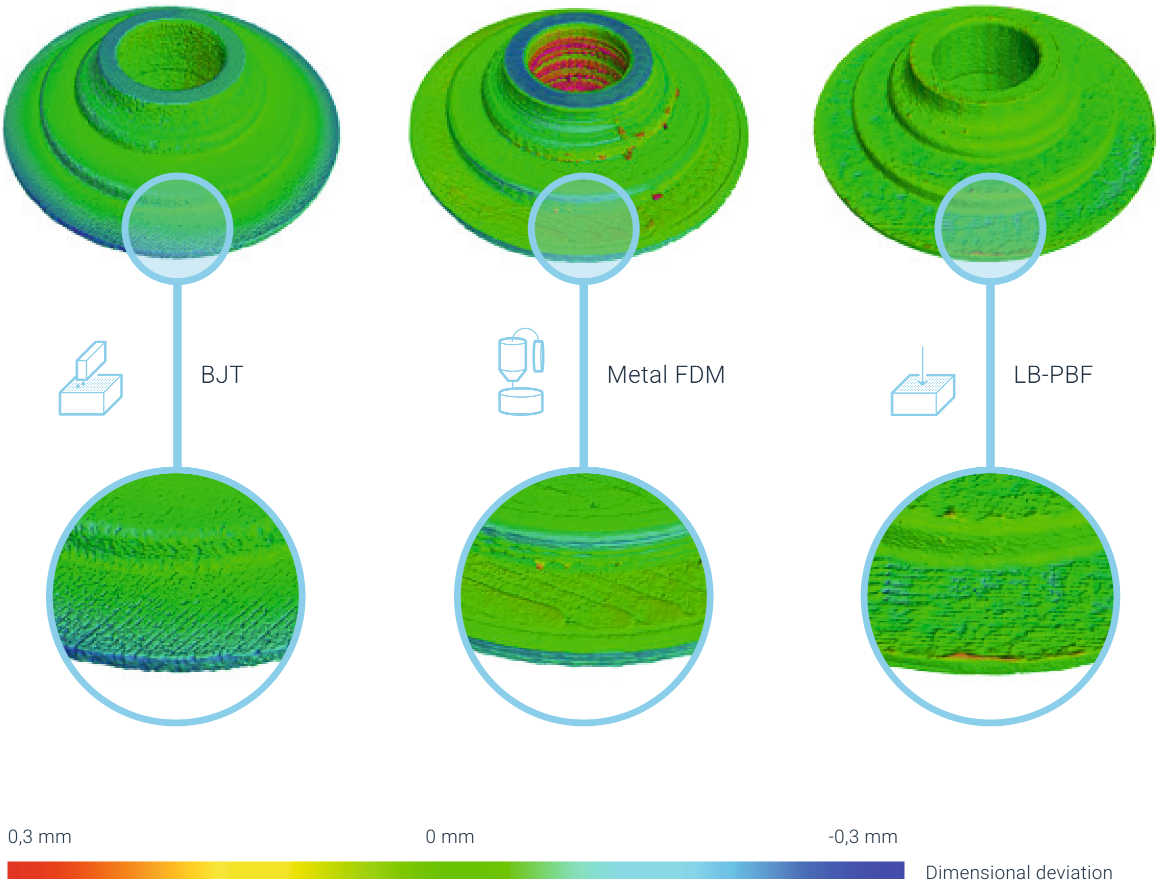
Arithmetic average roughness R_a as build in µm



To evaluate the surface quality the arithmetic average surface roughness in as build state is measured by tactile scanning. The values are obtained by measuring the specimens’ surfaces in the zx- and xy-plane. The mean value of both measurements are required for a meaningful technology comparison. Certainly, especially for metal FDM, the surface roughness depends significantly on the build direction.

While functional surfaces of AM parts are typically post processed, freeform surfaces can be kept as build or are simply sand blasted to obtain a sufficient roughness. Looking at MIM, the as build quality usually fulfills requirements for functional surfaces. The surface roughness as well as the repeatability of dimensional accuracy allows to manufacture highly precise parts without mechanical post processes.

If functional surfaces cannot be achieved by the molding process, it is common to process the parts in the green state. Milling operations are significantly easier before the part is sintered. The same holds for sinter-based AM parts. It is recommended to apply post processing during green part state, if sinter-induced distortions can be controlled.



Dimensional accuracy

Using high-resolution computer tomography, the dimensional accuracy of sinter-based AM technologies is evaluated using a demonstration part from the automotive industry. For comparison, LB-PBF specimens are examined, too.

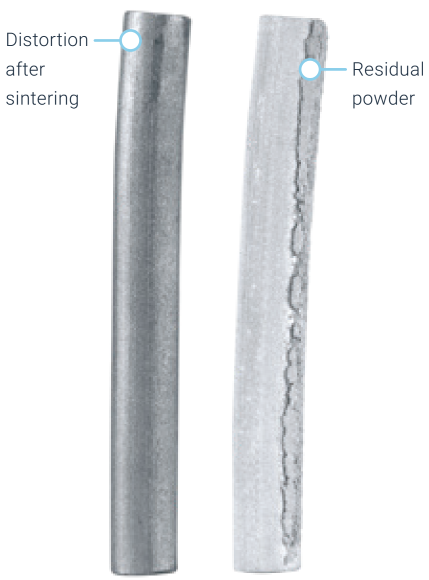
The results of sinter-based AM parts show distortion around the outer ring which are most likely caused during the sinter process. Excess and missing material on the flange influence the dimensional accuracy negatively. This is especially prevalent for the metal FDM part.

The high-resolution CT scan allows the depiction of the characteristic surface structure of the different AM processes. For all technologies, the specific vectors of material addition during the 3D printing process are clearly visible on the surface.

Design – potentials & limitations

Additive Manufacturing offers excellent design possibilities. However, process-induced residual stresses and the need for support structures restrict the freedom of design in metal AM technologies such as LB-PBF. Sinter-based AM technologies also have design limitations mainly due to the debindering and sintering process.

Regarding size, MIM parts are characterized by rather small component dimensions of typically less than 50 mm. This limitation is due to the debindering and sintering process. The debindering limits the maximum material thickness to 5 to 10 mm. Exceeding this value increases the debindering time exponentially or makes complete debindering even impossible. Furthermore, sintering requires temperatures just below the material melting point which may cause deformation of large masses. During the cooling phase after the sintering, the part shrinks and requires gliding surfaces.
All these MIM restrictions apply to sinter-based metal AM technologies as well. With difficult prediction of deformations during sintering, the major Additive Manufacturing advantage of small batch sizes is negated. Developing a sinter process for complex parts requires several test loops to control the distortion. This limits sinter-based AM technologies to either simple part geometries or try and error loops for complex parts.
Binder jetting technology needs no supports during the 3D printing process. Yet, the sintering process may require additional supports to prevent deformation of the part. To avoid such additional supports altogether, a ceramic mold can be used during sintering to hold the component in place and restrict deformation. Of course, this requires high production volumes to amortize the ceramic mold.



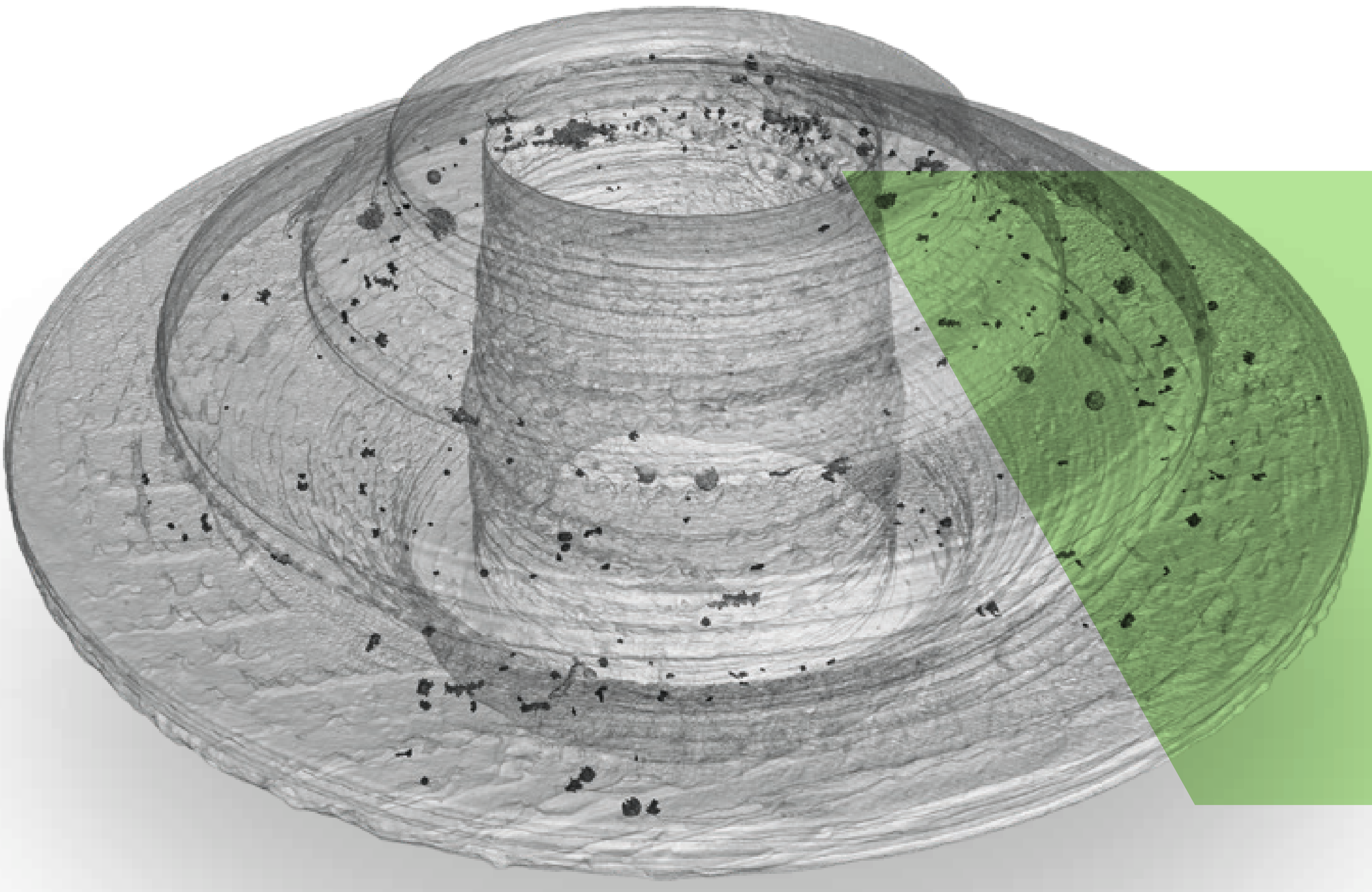
BINDER JETTING

METAL FDM

Design guidelines

	BJT	METAL FDM	LB–PBF
5-50 mm part size suited	●	●	●
50-500 mm part size suited	○	◑	◕
0,5-2 mm thickness suited	●	◑	◕
3-10 mm thickness suited	◕	◕	●
10-50 mm thickness suited	○	○	◕
Thickness jump possible	◑	◑	◕
Hollow body printable	◕	●	◕
Lattice structures possible	◕	◔	●
Support free design	●	◑	◔
Surface quality	●	◔	◕
Part shrinkage under control	◕	◕	●
Part distortion under control	◔	◔	◑
First time right potential	◑	◑	◕

High ● ◕ ◑ ◔ ○ Low

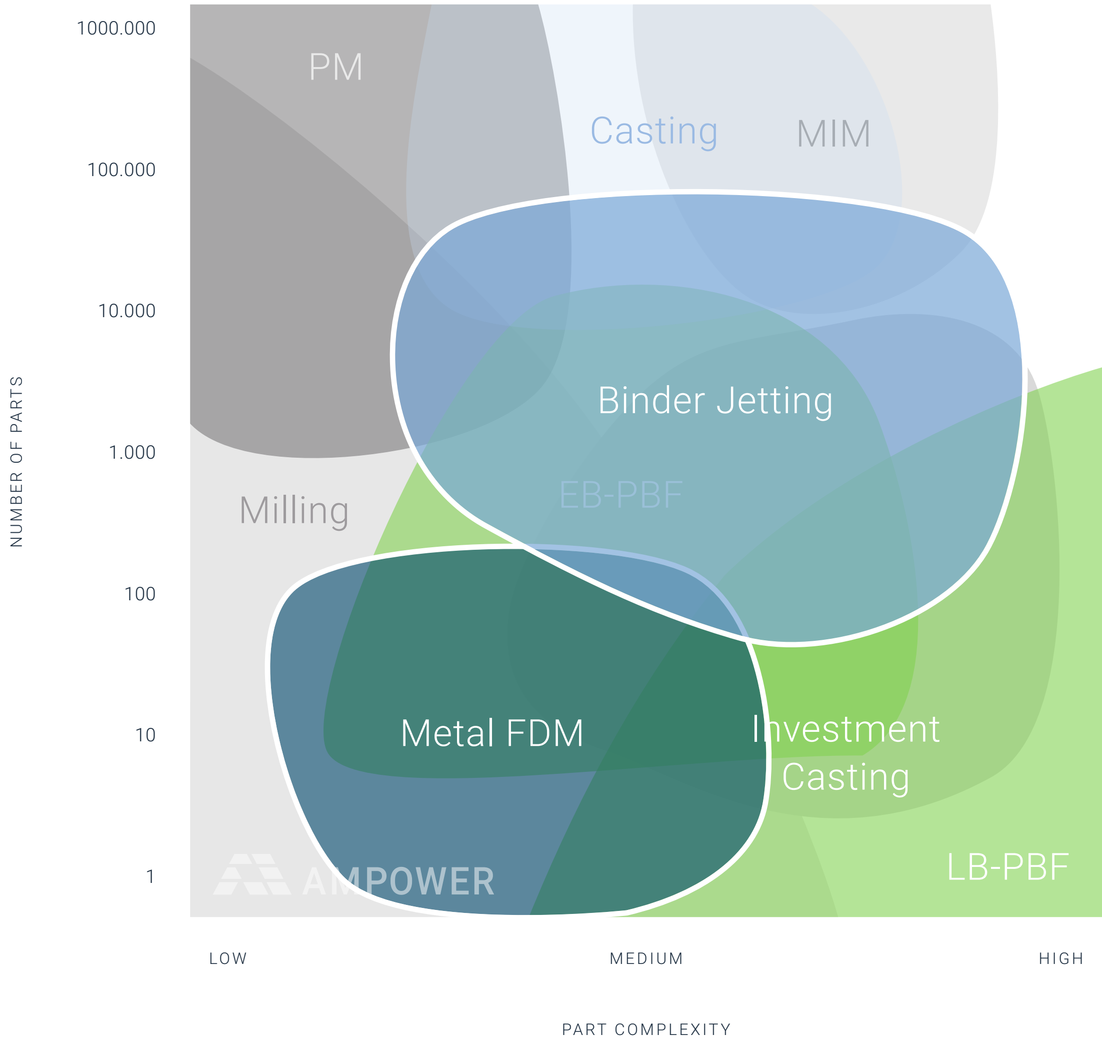


Impact analysis

Metal 3D Printing – disruption will continue

Component manufacturers now have more variety than ever when it comes to choosing the right technology for their application. However, this variety also challenges engineers to develop knowledge in several different technologies.

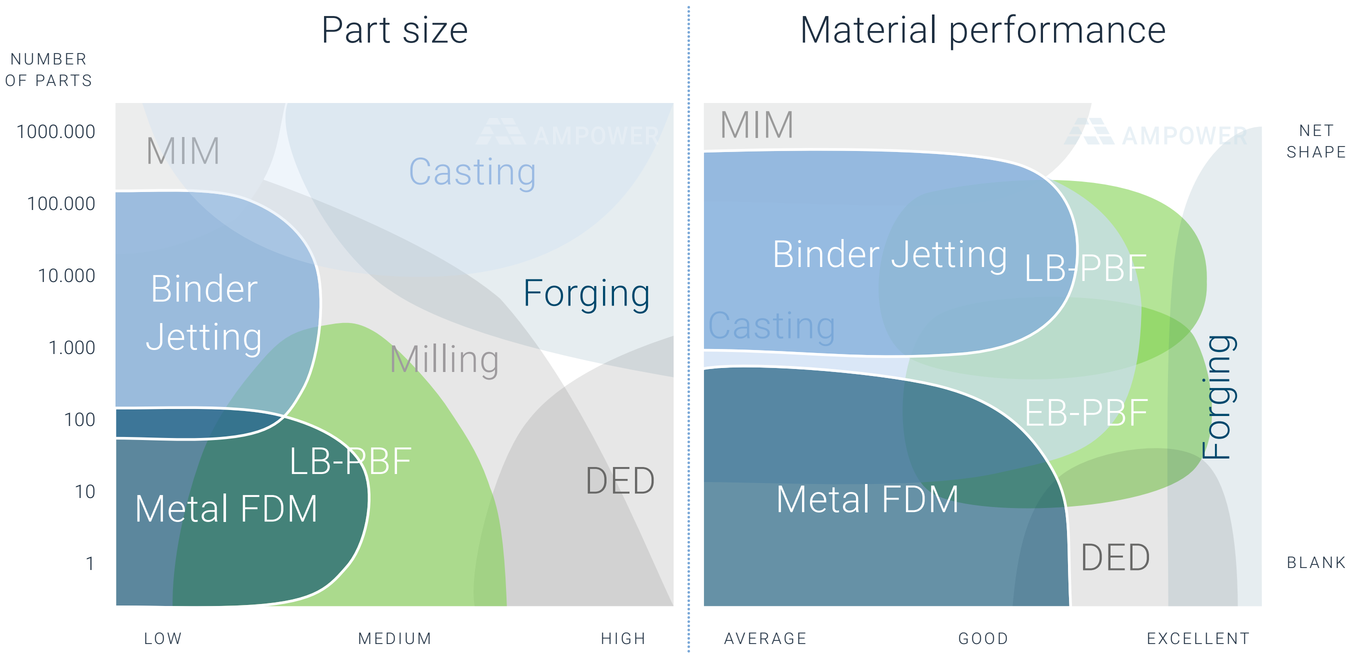
Technology impact in terms of production volume and part complexity



Impact of sinter-based AM technologies on medium to complex part geometries

Due to the debindering and sintering process challenges of large parts, binder jetting technology and metal FDM will most likely be used to manufacture small to medium-small components. Metal FDM will cover low production volumes due to its flexibility. Binder jetting technology, on the other hand, will close the gap to very high-volume production technologies such as MIM and will become a cost efficient alternative.

To have a broader view the metal AM technology of direct energy deposition (DED) is taken into account. For large parts, DED will be used for production volumes up to the point where tool amortization justifies forging and casting.

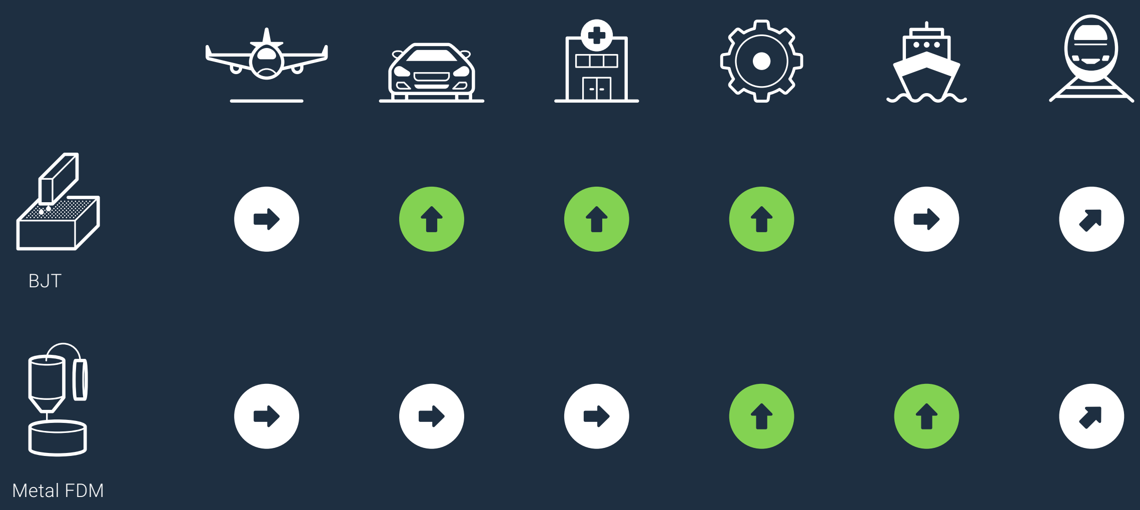


The material characteristics of forging still remain unchallenged by Additive Manufacturing technologies. However with some DED processes and LB-PBF advances, the quality is sufficient for numerous applications of highly loaded parts.
Currently, insufficient printing process control of metal FDM leads to material voids and subsequently the technology struggles to achieve high material properties. Combined with limited accuracy and high surface roughness, favorable applications will be jigs & tools, prototypes and small batch productions. Binder jetting technology achieves material characteristics identical to MIM, but the high accuracy and surface roughness of MIM still remains unchallenged.

Application drives technology

Binder jetting seems to be the AM technology the automotive industry has waited for. Numerous investments from major OEM in binder jetting start-ups support this. Metal FDM will enable small companies and job shops to enter the metal 3D printing market by low investment cost and high flexibility.

Industry Impact



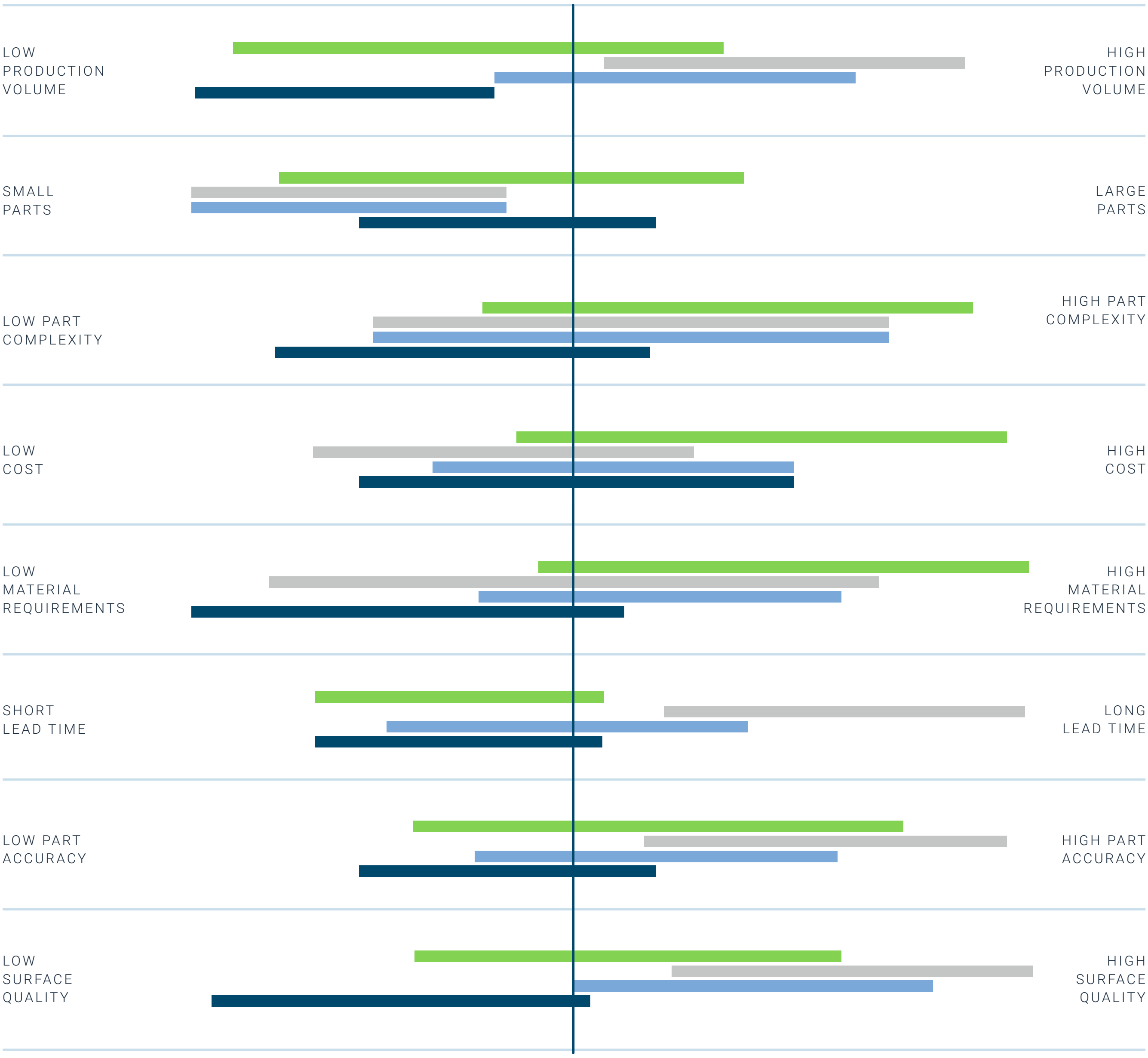
At Ampower we expect the main impact for binder jetting technology in environments of high batch numbers such as the automotive industry. Metal FDM technology will enable applications in the machine industry, especially when it comes to low production volumes, prototypes or jigs & tools. Due to the high requirements on material properties, we predict it to be unlikely that aviation and implant manufacturers will adapt sinter-based technology for highly loaded parts.

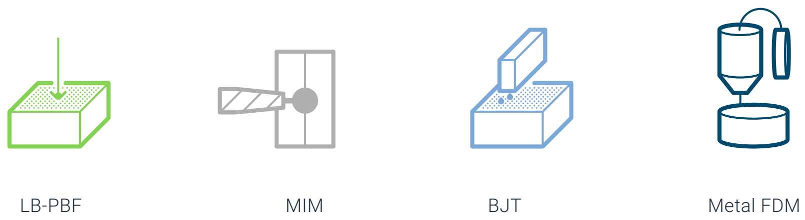
Ampower Insights Vol. 4

Learn more about the quality management in Additive Manufacturing. Ampower Insights Vol. 4 will present standards and best practices to achieve manufacturing excellence with Additive Manufacturing. Learn more:

www.am-power.de/insights

Technology identification map





About the authors

Dr.-Ing. Maximilian Munsch

Since 2007, Maximilian Munsch is a professional user of Additive Manufacturing. After finishing his dissertation on reduction of residual stresses in metal Additive Manufacturing in 2012, he acquired extensive hands-on experience with metal powder bed based Laser and Electron Beam Melting processes in industry. His focus is on the full Additive Manufacturing process chain required for industrial production. Max has successfully planned, implemented and qualified multiple Additive Manufacturing productions for regulated applications.

Matthias Schmidt-Lehr

Matthias Schmidt-Lehr successfully managed countless projects in Additive Manufacturing with focus on part screening, business case development, AM design optimization and production in both metal and plastic materials. With a history in the consulting business, he is committed to customer satisfaction, project management and controlling. In his former positions Matthias gathered experience in business development, customer relationship management, as well as marketing and sales.

Dr.-Ing. Eric Wycisk

Eric Wycisk can look back on 10 years in Additive Manufacturing with a focus on metal, especially titanium alloys. In his former affiliation, he was team leader and Key Account Manager for aviation applications and light weight design. He managed multiple projects concerning topology optimization and light weight design, process development and optimization as well as industrial implementation of Additive Manufacturing. The research in Eric's dissertation focuses on fatigue properties of laser beam melted Ti-6Al-4V.

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Missed out on our previous Issues?

Vol.1: Additive Manufacturing – Make or Buy
Additive Manufacturing became a game changer in many industries. Especially for SMEs, however, high part costs are still the main restriction for further wide-spread adoption of this production technology.
Ampower Insights Vol. 1 gives a detailed calculation of production costs and introduces the ratio of cost per unit of volume for an easy comparison of technologies and materials.

Vol.2: Additive Manufacturing of Automotive Components
Medical and Aerospace companies count among the early adaptors of metal Additive Manufacturing. The usually highly innovative automotive industry, however, so far struggles with the high manufacturing cost of Additive Manufacturing. An exception are high performance cars with low production volumes and demand for customization.
In the second issue **Ampower Insights** provides a deep dive into the manufacturing route of high performance automotive components.

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