AMPOWER INSIGHTS

Additive Manufacturing of **Automotive Components**

A detailed view on the Additive Manufacturing process chain of automotive components

INSIGHTS GAINED:

- Feasibility of automotive applications
- Cost of serial production
- State of the art process chain
- Evaluation of quality

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Insights gained

Feasibility of automotive applications
Cost of serial production
State of the art process chain
Evaluation of quality

Management summary

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 this second issue **Ampower Insights** provides a deep dive into the manufacturing route of high performance automotive components. Considering both Laser Beam Melting (LBM) and Electron Beam Melting (EBM), the study evaluates the manufacturing feasibility of a tail pipe blend along the whole process chain from data preparation to surface finishing.

The thin double walled structure of the tail pipe blend presents a challenge for the EBM technology. An x-ray tomography reveals large powder remains in part areas with limited access to blasting tools. The following hot isostatic pressing results in solidification of the powder remains and renders it impossible to remove.

The study analyzes the effect of process inherent distortion along the manufacturing route. X-ray tomography is used to reveal large part deformation after hot isostatic pressing if placed incorrectly. The results show that correct placement and orientation of the part during the process reduces such distortions.

To finish the part both surface vibration grinding and micro machining are applied. As expected, the as build rough EBM surface proves to be challenging for both processes resulting in R_a values of around 3,6 µm. Using equal finishing operations on the LBM part yields a polished surface with R_a values below 0,1 µm.

The second **Ampower Insights** closes with an evaluation of the cost structure and lead time of the process chain including pre- and post-processing. The LBM technology proves to be more cost efficient, if multi laser systems are employed. The thin walled structure leads to lower effective build rates on the EBM machine. It turns out that the fast lead time of around 25 days is a game changing benefit of additively manufactured automotive parts such as the reviewed tail pipe blend compared to traditional tool-bound production.

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

Content

About Ampower

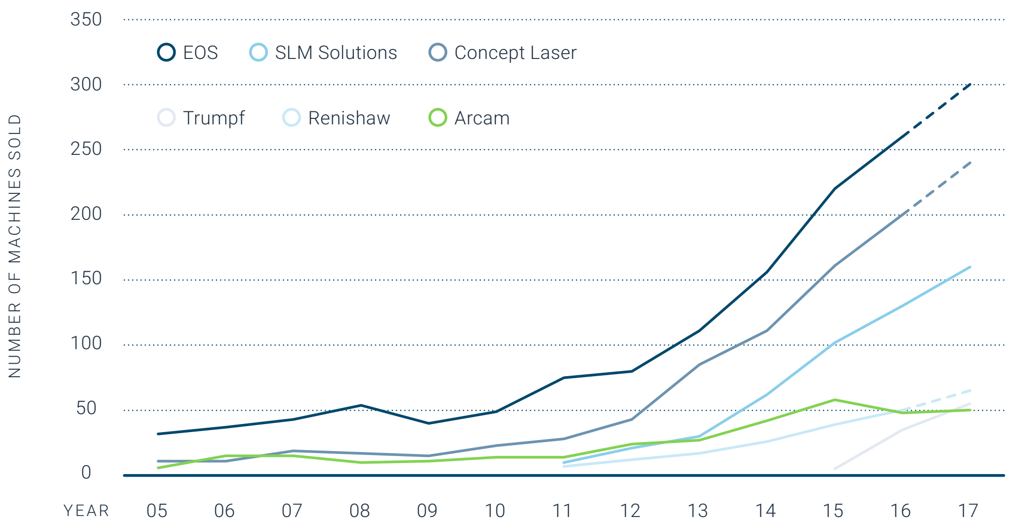
Consultancy Ampower specializes in industrial Additive Manufacturing. The company was founded by technology experts Dr. Maximilian Munsch, Matthias Schmidt-Lehr and Dr. Eric Wycisk.
Ampower advises their clients on the introduction of Additive Manufacturing and supports the setup and optimization of the whole value chain from R&D to production as well as procurement and management. This is achieved by a specialized training program, the identification and development of Additive Manufacturing applications, as well as an implementation and qualification methodology for internal and external machine capacity. The company is based in Hamburg, Germany.

Introduction

Competing Additive Manufacturing powder bed technologies

With metal Additive Manufacturing, two competing powder bed fusion technologies have been brought to industrialization in the past years. While typically Electron Beam Melting (EBM) is offering high productivity, Laser Beam Melting (LBM) offers higher resolution and geometrical freedom. However, LBM is closing in on productivity with multi laser systems.

Market shares of metal powder bed fusion systems

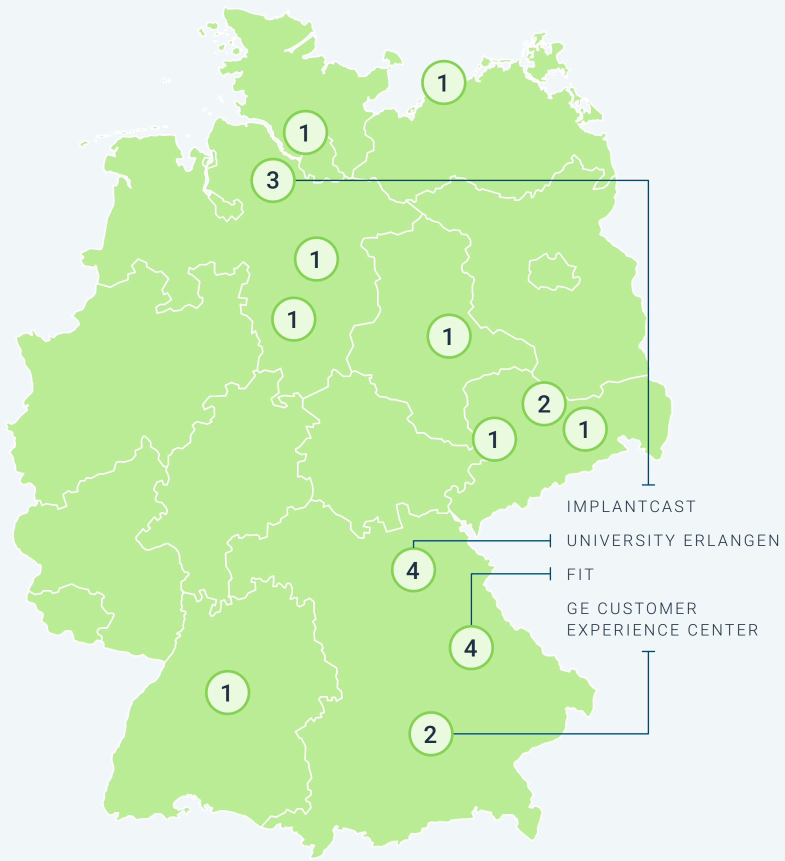


SOURCE: WOHLERS ASSOCIATES 2005 – 2015 AMPOWER 2016 – 2017

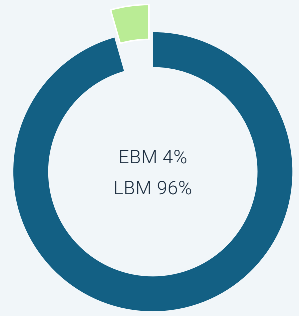
Even though there are several technologies referred to as Additive Manufacturing, powder bed fusion processes have the largest impact to traditional industries. They offer the highest degree of freedom of design and flexibility as well as excellent material properties.
When analyzing the maturity of powder bed fusion systems, it is worth taking machine sales into account.

The sales volume indicates if a specialized technology has turned into mainstream production technology. Between the years 2010 and 2012 machine sales have accelerated introducing a steeper incline that remains today. It implies the adoption of powder bed fusion technologies in serial production processes and the demand for industrial manufacturing set-ups with multiple machines.

EBM machines installed in Germany



Powder bed fusion technology market shares in Germany



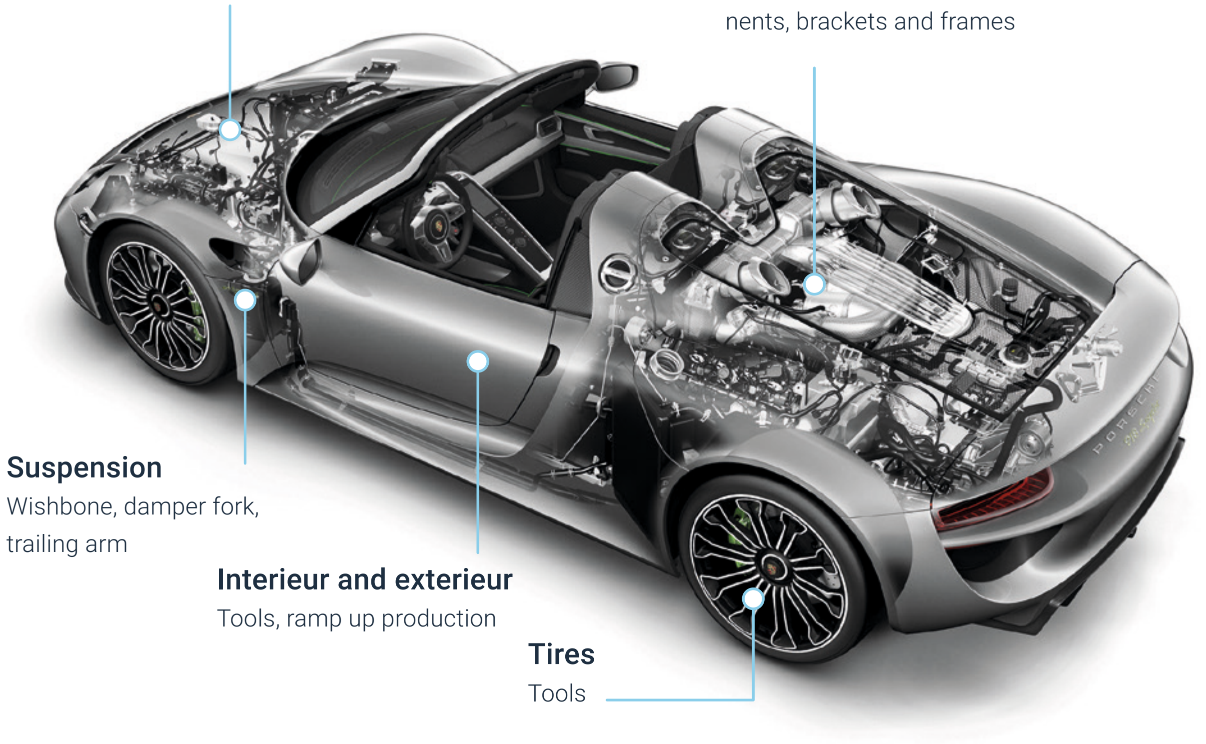
Currently LBM systems dominate the market due to their high range of possible applications and several machine suppliers. Up to now the number of EBM machines installed in Germany is only a fraction of the number of LBM machines.

Automotive application

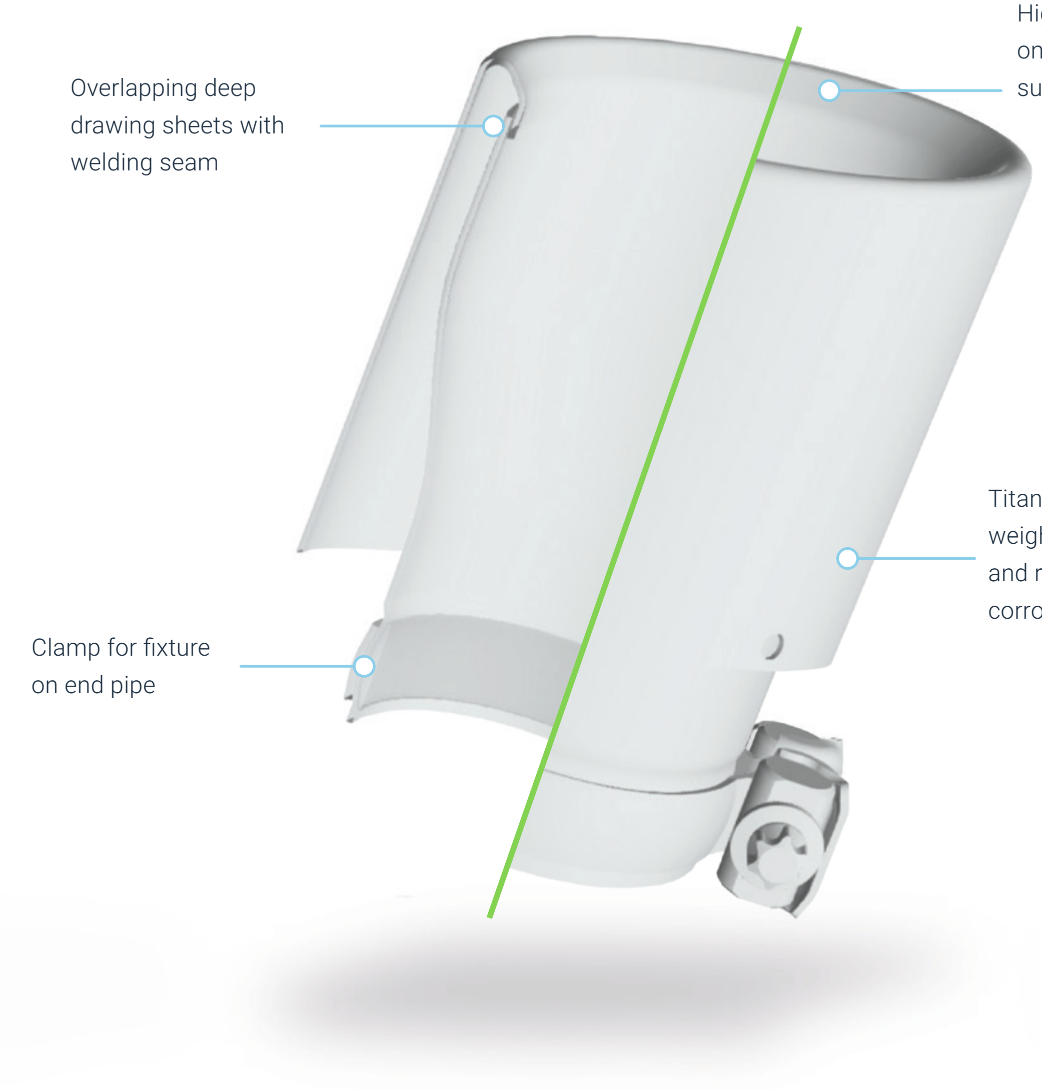
The study compares the Additive Manufacturing of a high-end automotive application – a tail pipe blend from a sports car – with LBM and EBM technology. It will examine the complete process chain including their respective quality assurance steps. The study shows that the requirements on surface quality and material properties challenge both technologies and their corresponding post processes.

Automotive applications for powder bed fusion

Identifying automotive powder bed fusion applications becomes challenging when taking the industries high demand regarding cost, quality and time into account. Because of the cost per volume of Additive Manufacturing parts, currently only high priced, low volume vehicles are targeted for application screening.



In large scale automotive production, cost per part dominates the final decision on whether they will be manufactured additively.
Manufacturers of high performance sports cars with limited quantities up to approximately 5.000 units per year will be early adopters of Additive Manufacturing. We expect the largest potential in automotive applications in the power- and drivetrain as well as the suspension system.

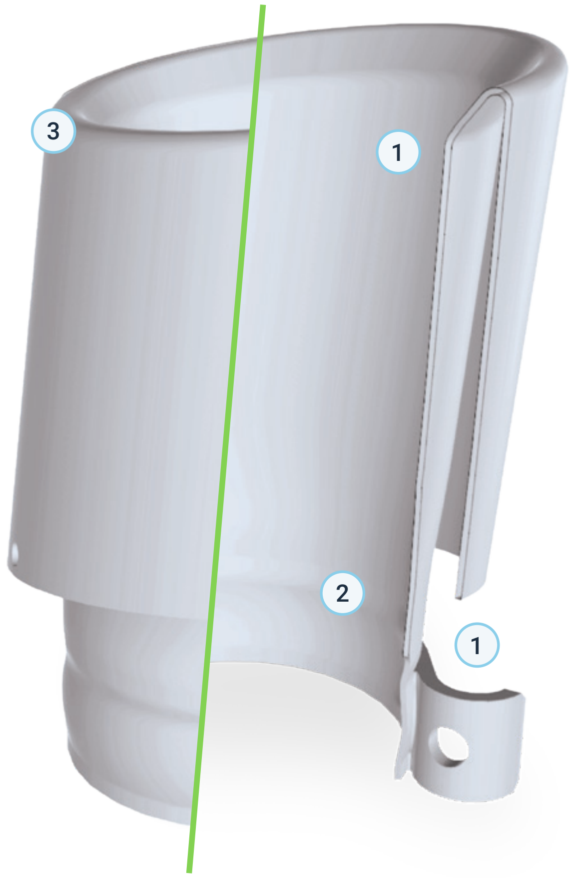


For this study the powder bed fusion process chain of a titanium tail pipe blend of a Porsche GT2 RS is investigated. Tail pipe blends are the visible part of the engine exhaust system. Optical requirements are high since the component reflects the engine's performance to the customer's eye. Conventionally, those blends are manufactured from stainless steel or titanium alloys. Two metal sheets formed by deep drawing are joined by a welding seam. Requirements for the mechanical properties are driven by vibration and corrosion which put high stress on the welding seam. Additionally tail pipes are subject to major design iterations. This leads to remanufacturing of deep drawing tools with high cost and typical lead times of over 12 months.

Material and design

Advantages of redesign

Additive Manufacturing rarely makes sense without uncovering the potential of redesign. The redesign has to consider the parts at hand as well as surrounding components, functions and assembly steps.



1 Integrated manufacturing of shells and fixture

2 Optimized structure of inner shell

3 Identical outer shell and optics. Potential for individualization

Advantages at a glance

- Short time to market due to tool-free manufacturing
- Increase of quality due to homogenous material properties
- Reduction of number of parts
- Potential for customized design

Manufacturing route

Data preparation
Data preparation includes orientation of the part on the machine platform and generation of support structures. For serial applications, this is done only once during qualification of the production process.

Build job
In serial applications the production is run under tightly controlled and qualified process parameters and environment. Manual machine preparation and cleaning processes hinder the adoption of powder bed fusion systems in today's automated production set-ups.

Unpacking
The unpacking process involves the removal of powder from the build chamber and part cavities as well as the powder recycling process. Close monitoring of powder condition over every production and recycling cycle is essential for a qualified serial production.

Heat treatment
Heat treatment eliminates process inherent residual stresses before removing the part from the base plate and therefore ensuring dimensional accuracy. For EBM parts, a heat treatment is optional due to low residual stresses from the manufacturing process. Additionally, heat treatment can be used to alter material characteristics to a desired value.

Support removal
Before support removal LBM parts have to be removed from the base plate typically by sawing or wire eroding. The support removal process is predominantly manual work. New automation concepts for the removal process are currently in development and mainly feasible for high volume throughput.

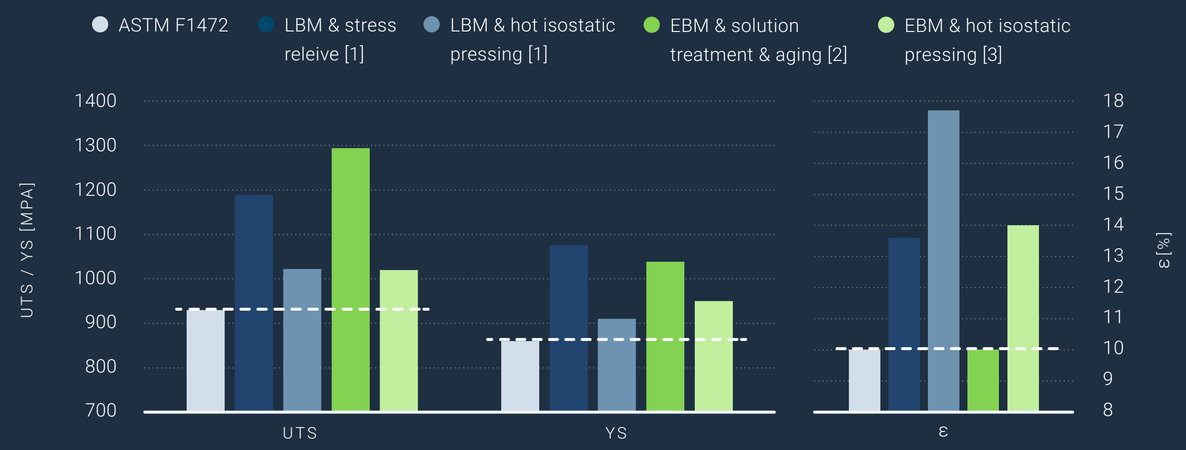
Hot isostatic pressing
Hot isostatic pressing (HIP) is a necessary step, if pores within the part affect material properties negatively especially under fatigue loading. Additionally, untreated porosity may also be visible after polishing on the part surface.

Vibration grinding
The surface quality of metal Additive Manufacturing parts is known to be rough due to adherent powder particles and welding seams on the surface. For complex surface geometries, vibration grinding offers a low-cost method to remove burrs and improve the surface quality significantly. The process is easy to scale to a serial production throughput.

Polishing
The complex free-form surface geometries of Additive Manufacturing parts benefit tool-less processes such as plasma- and electro-polishing. The study evaluates the innovative Micro Machining Process (MMP).

Material properties

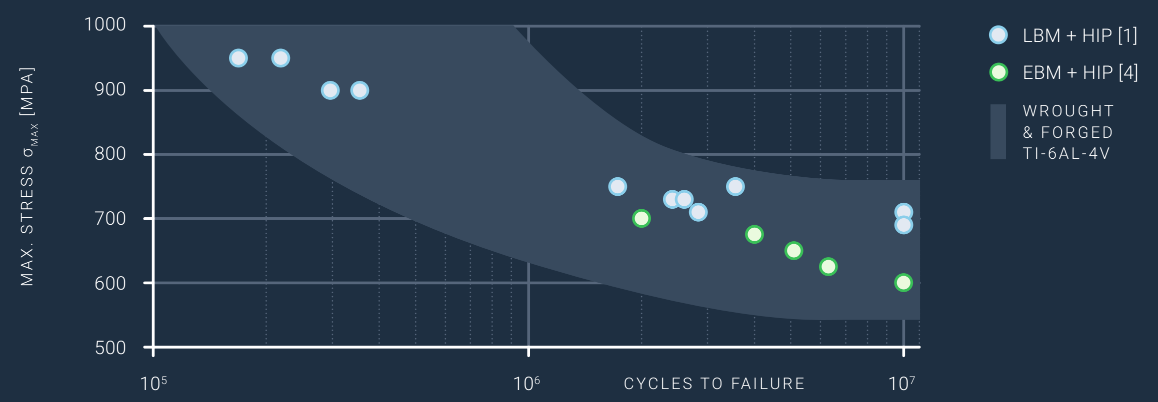
Mechanical properties of powder bed fusion Ti-6Al-4V



High cooling rates and very thin weld beads result in a fine to ultra-fine microstructure in powder bed fusion technologies. Depending on thermal condition and history during the manufacturing process, Ti-6Al-4V develops a very fine lamellar microstructure of α', α or α+β phase.

Additional post heat treatment can be used to alter the properties of the final part. Testing results show that additively manufactured Ti-6Al-4V alloy meets the mechanical requirements of all common standards for cast, wrought and forged material.

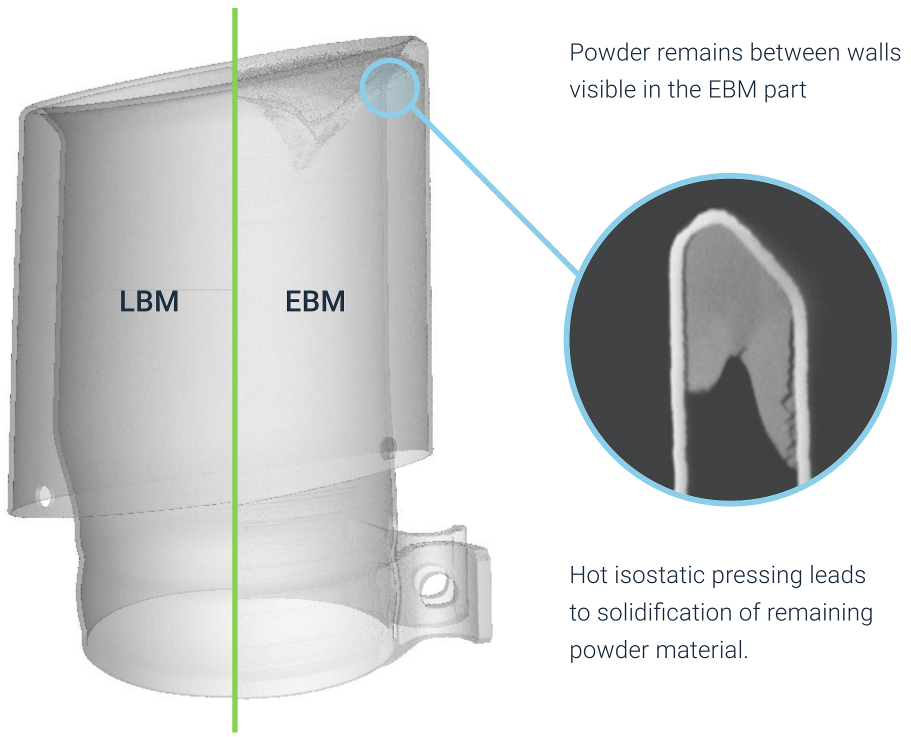
Fatigue properties of Ti-6Al-4V at R = 0,1



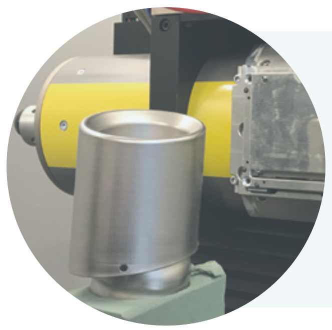
Dynamic driving forces and vibration require good fatigue properties in automotive applications. Using hot isostatic pressing to densify the material after production ensures that the low cycle fatigue as well as the fatigue limit at 10^7 cycles of additive manufactured Ti-6Al-4V compares to wrought and even forged material. However, high efforts to polish the complex free-form surfaces of Additive Manufactured parts have to be undertaken to ensure this excellent fatigue performance.

X-ray tomography

X-ray tomography analysis can reveal information that is not possible or difficult to be detected otherwise. With high resolution scans internal defects below 100 µm in size can be detected. For serial production only low to medium resolution scans are cost-efficient and are used for quality and dimensional accuracy inspection.

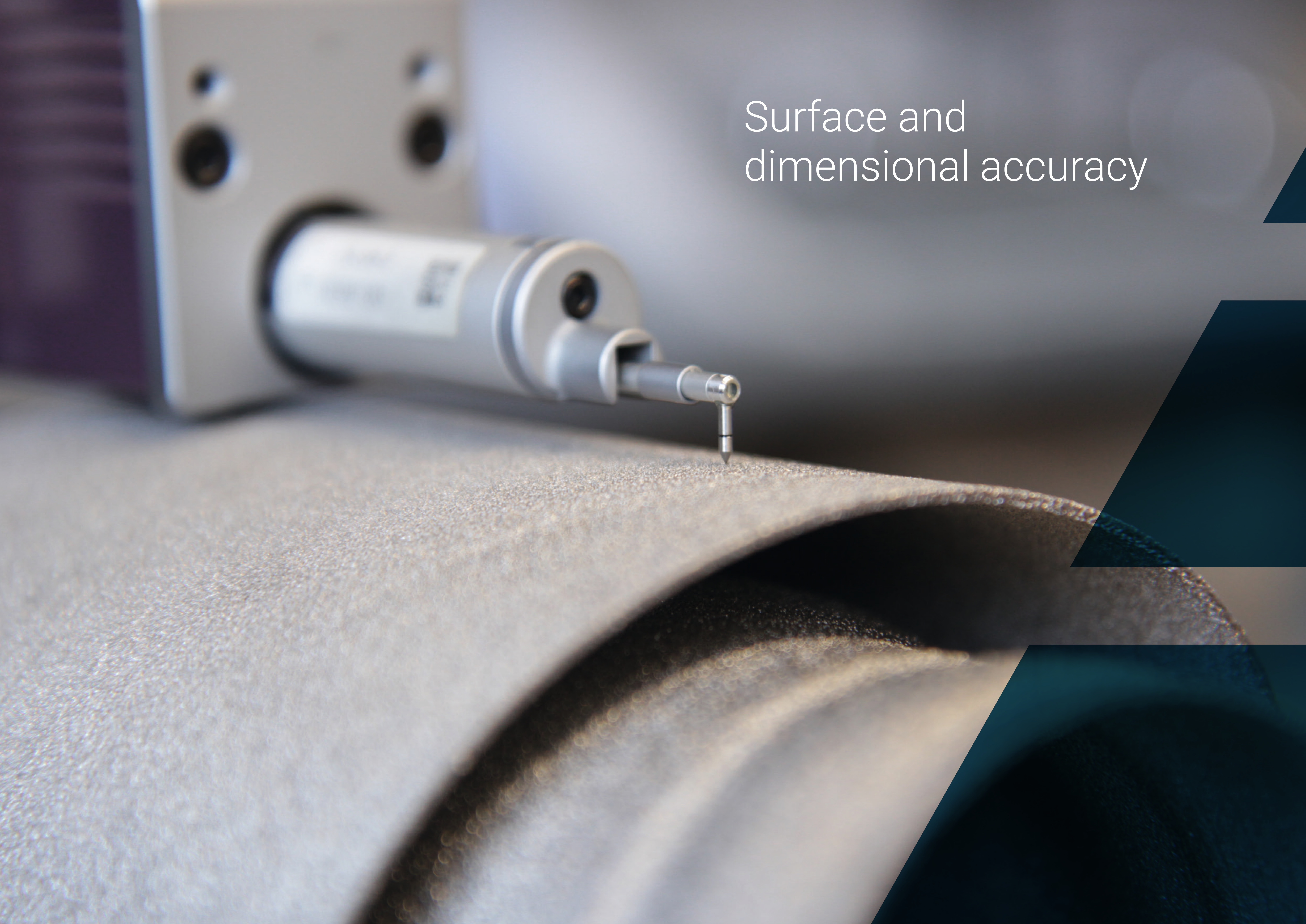


The x-ray scan of the tail pipe blend reveals powder remains between the walls of the EBM part. The preheating of the powder during the EBM process to several hundred degrees causes the powder particles to expand and adhere to each other to form a powder cake. Removal of parts requires mechanical work to loosen the particles. A common method is to use a blasting process. For such processes to work successfully, hollow structures require suitable access for the blasting nozzle.



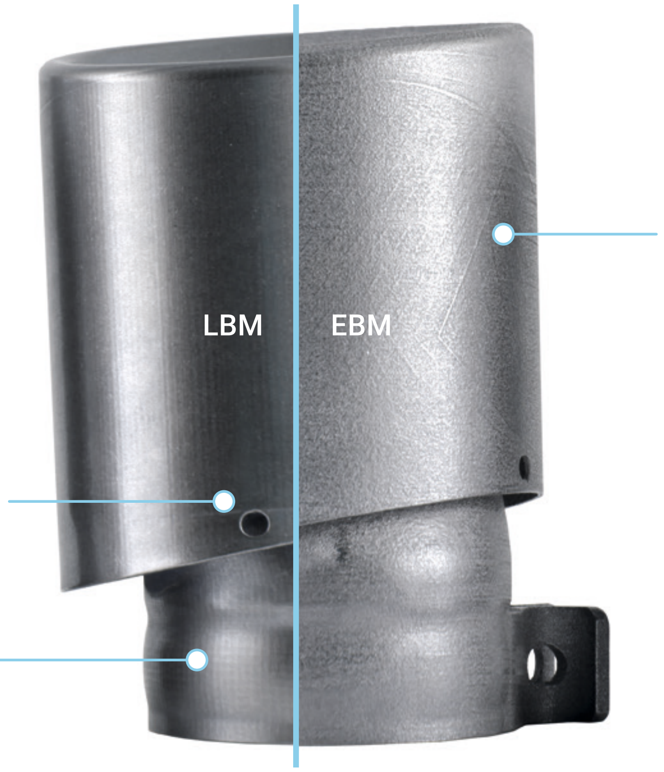
- System: YXLON Y.CT Modular
- Resolution: 60 µm voxel edge
- Scan parameter: Voltage of 250 kV and tube current of 2,4 mA
- Scan method: Circular Scan with vertical stitching
- Scan duration: Approx. 28 min per part

Surface and dimensional accuracy



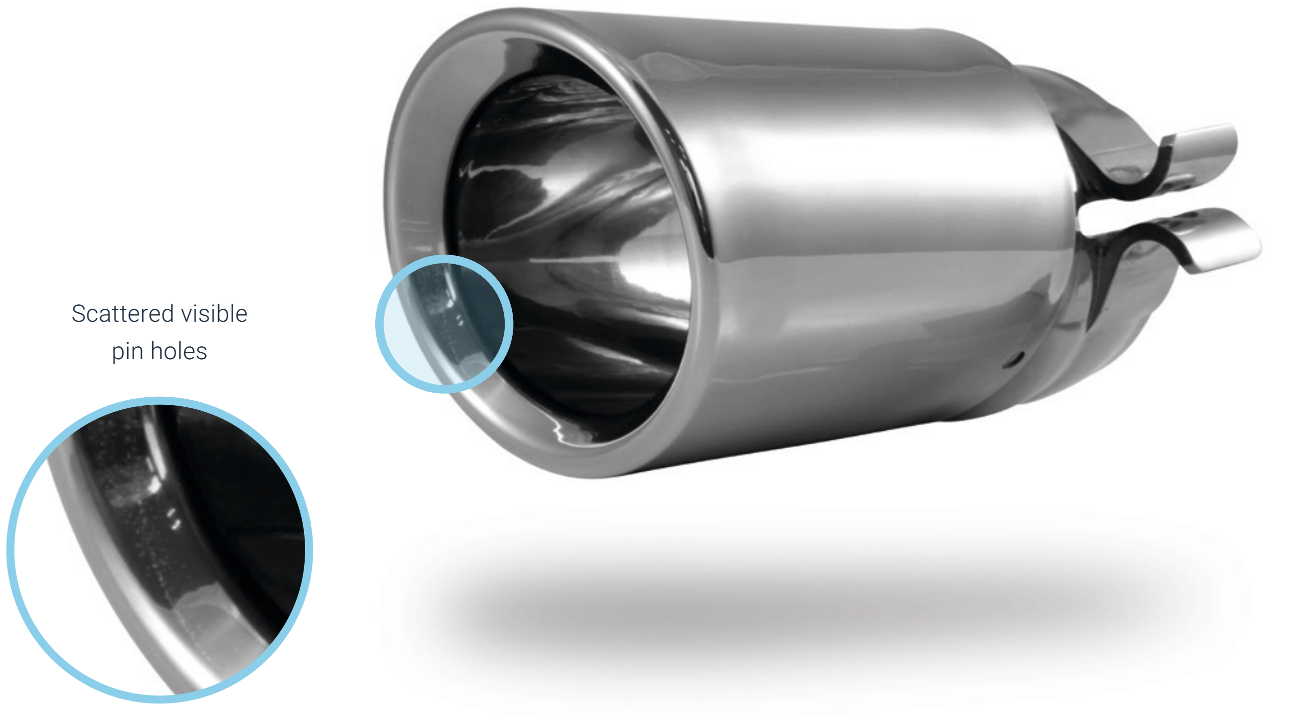
Vibration grinding and polishing

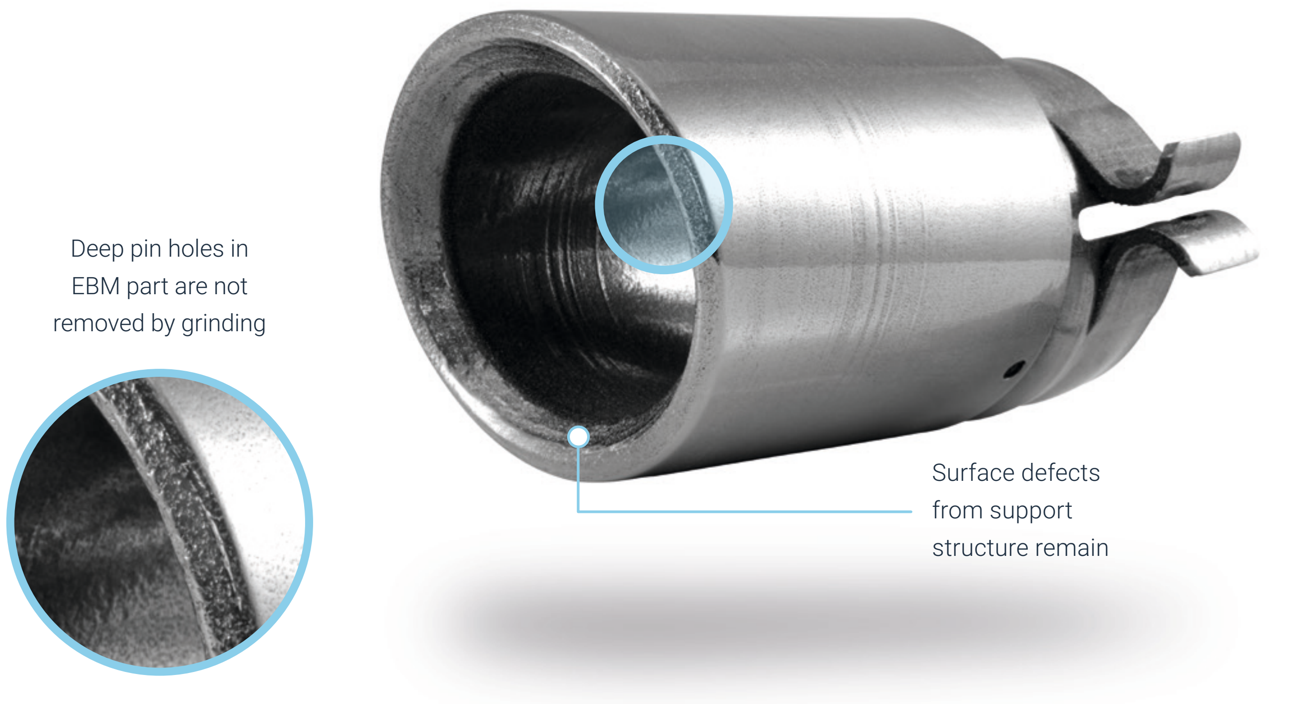
In general, Additive Manufacturing parts with functional or optical surfaces require post processing to meet surface quality demands. For the tail pipe blend two subsequent surface treatments are examined.



Grinding significantly improves the surface quality of the tail pipe blend. However, in both LBM and EBM parts large macroscopic defects remain visible on the surface. For serial production further design reviews and control of production are necessary to avoid such defects.

- Ceramic abrasive tool triangle 10 mm x 10 mm and water
- 10 h in tub vibrator



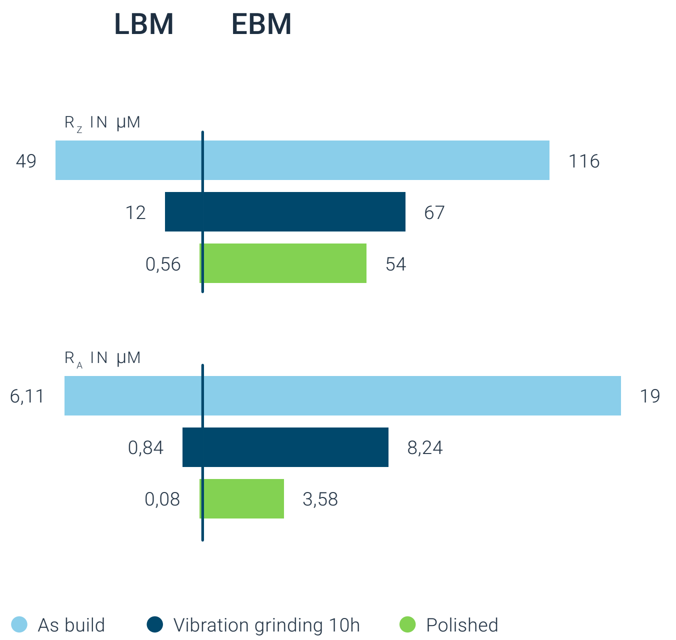


Surface roughness

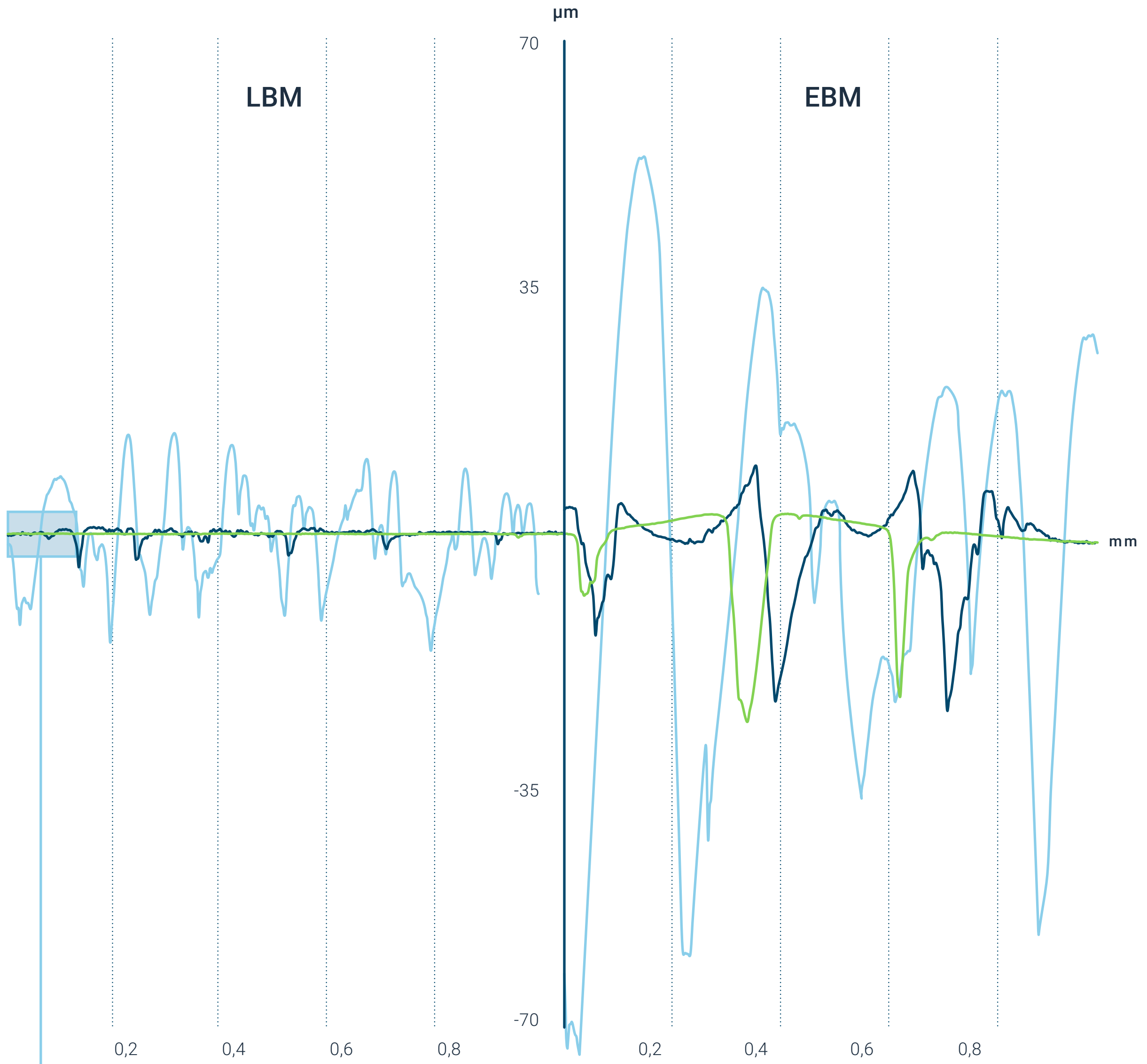
LBM has clear advantages in surface quality of as build parts compared to EBM. The post processing results show that this quality gap remains after grinding and polishing.

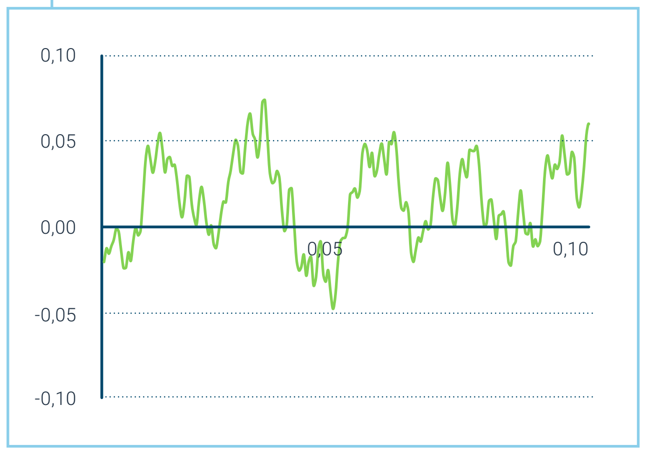
Both technologies show high surface roughness in as build condition. While LBM surface roughness is a result of adherent powder particles and welding seam overlaps, the EBM tail pipe shows additional macroscopic surface defects from electromagnetic field disturbances.

Such macroscopic defects cannot be removed with the examined grinding and polishing technologies. The LBM surface is polished to a roughness better than R_a of 0,1 µm.



Surface profile



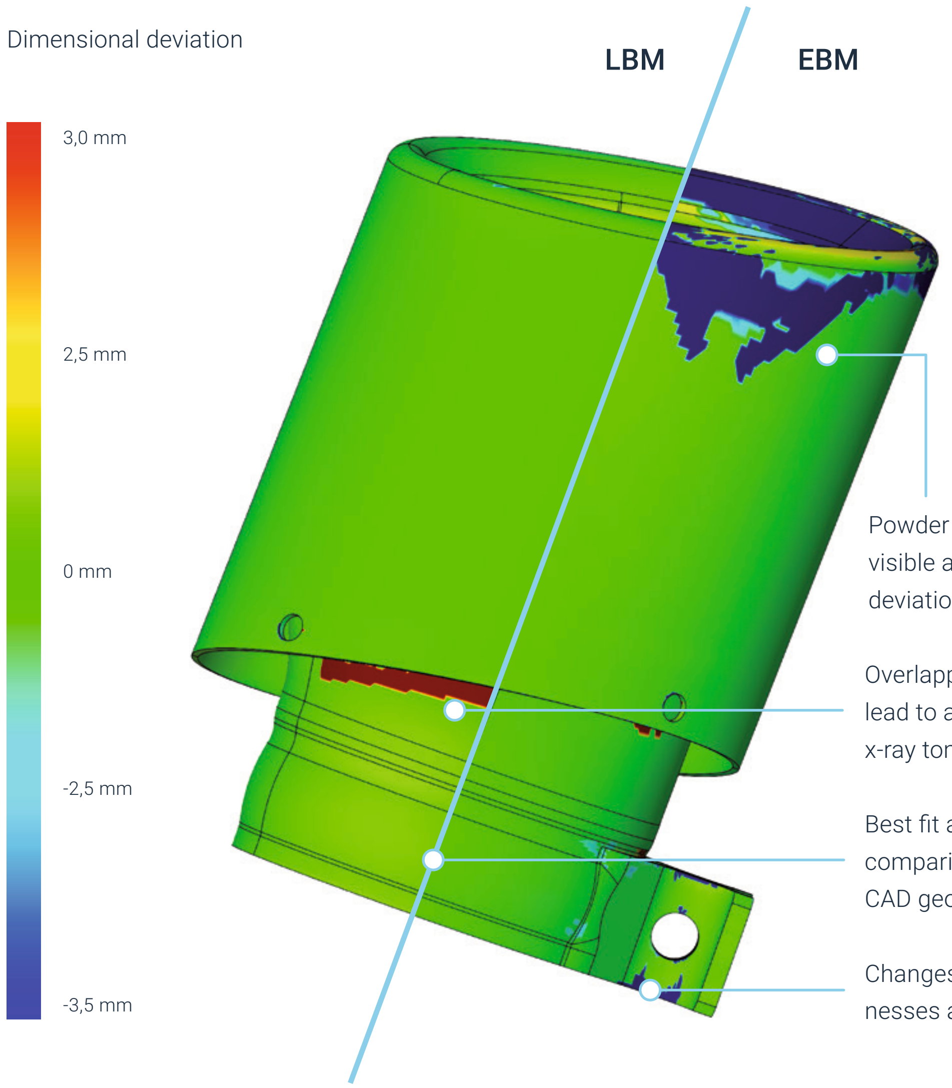


As build Vibration grinding 10h Polished

A close look at the surface profile reveals the effects of grinding and polishing on the surface structure. Deep grooves and pinholes remain visible on the EBM part. To remove these defects, the material has to be machined by at least 0,1 to 0,2 mm.

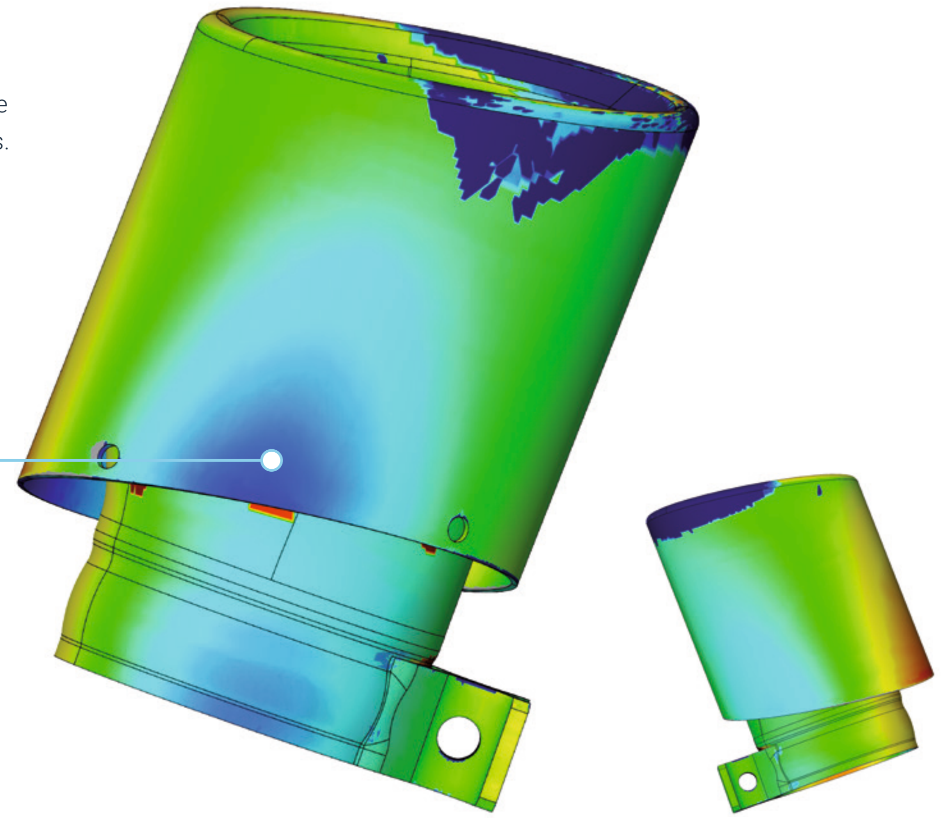
Dimensional accuracy

For complex free-form surfaces optical 3D scanning and X-ray tomography analysis are well-suited methods to accurately measure the resulting geometry. The overall accuracy is mostly affected by distortion and part shrinkage.



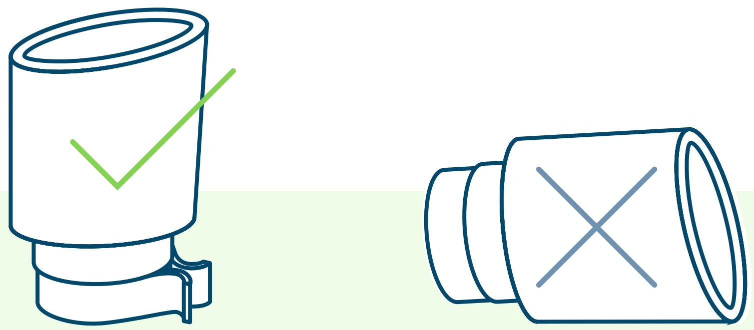
The maximum dimensional deviations are below ±1 mm. The circular shape of the tail pipe blend leads to a stable build process with minimal distortion.

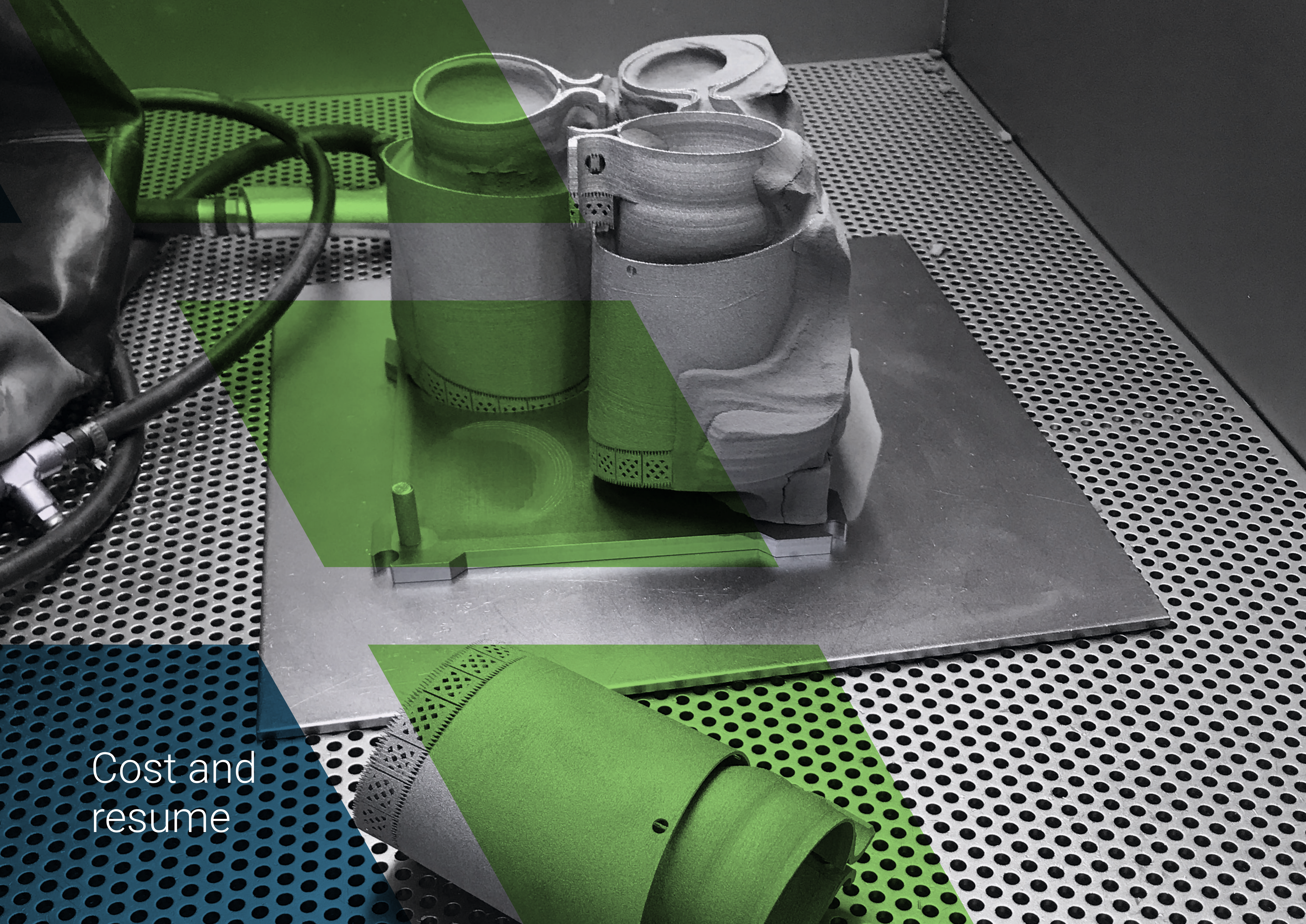
Influence of hot isostatic pressing on dimensional accuracy



Hot isostatic pressing applies even pressure on the parts. However, the process often leads to distortions due to incorrect loading, phase transformation or uneven cooling. To show the effect of incorrect loading, the study evaluates different part orientations.

The tail pipe blend deforms significantly by well over 2,5 mm if the part is placed sideways. Hot isostatic pressing is mandatory for load critical parts. Therefore, the effect on distortion should not be underestimated and investigated thoroughly. This underlines the need of a process qualification including a strict definition of all relevant parameters beforehand.

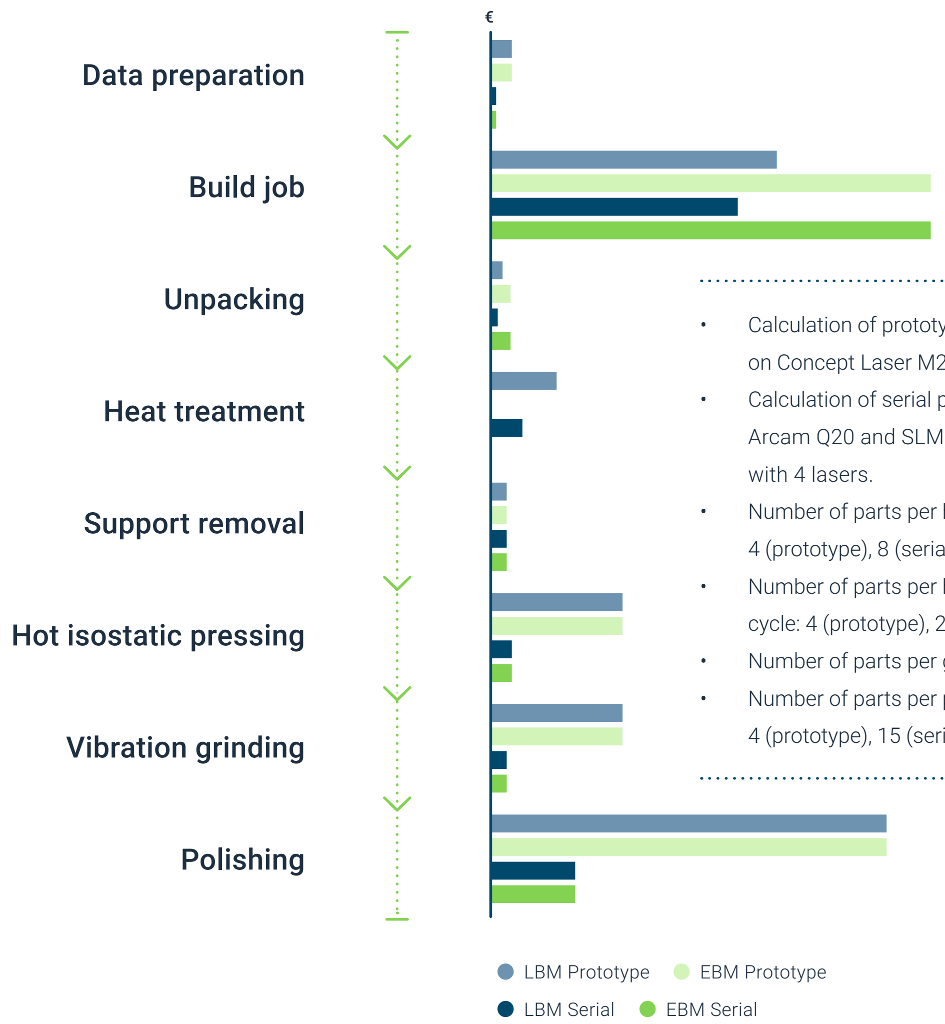




Cost and resume

Cost and time

Cost remains to be the main barrier for Additive Manufacturing to enter serial production. EBM usually offers significant advantages, however, the LBM process proves to be more cost-efficient for the given geometry.

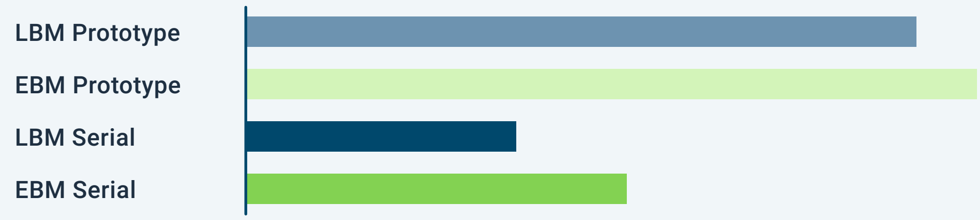


- Calculation of prototype production based on Concept Laser M2 dual and Arcam Q20.
- Calculation of serial production based on Arcam Q20 and SLM Solutions SLM500HL with 4 lasers.
- Number of parts per heat treatment cycle: 4 (prototype), 8 (serial)
- Number of parts per hot isostatic pressing cycle: 4 (prototype), 25 (serial)
- Number of parts per grinding: 4
- Number of parts per polishing: 4 (prototype), 15 (serial)

The analysis of the cost structure reveals that over 60 % of the manufacturing cost are related to the Additive Manufacturing process. It also becomes evident that the EBM technology is significantly more expensive for this application.

The reason lies in the low part volume due to the thin walled design. Here, the benefits of high build rate of EBM machines cannot be applied. High utilization of a quad laser system results in a high effective build rate of the LBM machine technology.

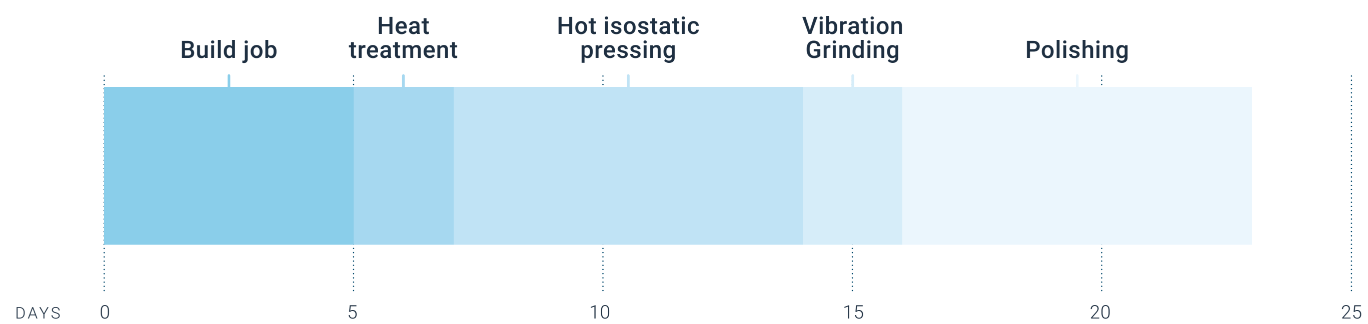
Production cost per part



The cost for the finished tail pipe blend is reduced by around 50 % when manufactured in quantities of more than 20 pieces per year. This reduction is mostly due to economies of scale in post processing.

It should be noted that additional costs for qualification and quality assurance have to be taken into account when Additive Manufacturing technology is used in serial production.

Investigation of lead time for a batch of 8 parts in serial production



External post processes such as hot isostatic pressing and polishing contribute the largest time span to the overall lead time. Depending on supplier contracts or amount of vertical integration the lead time can be reduced further.

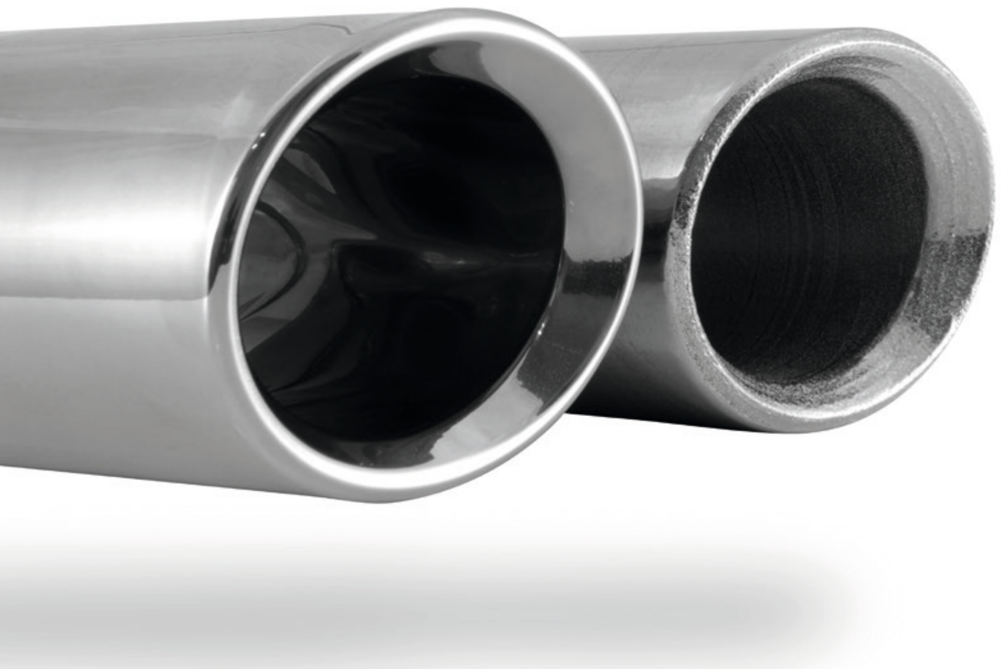
In summary, the tool free production results in a lead time of under 25 working days. Compared to conventional tool-bound manufacturing of tail pipe blends, the Additive Manufacturing process chain yields a reduction of several months.

Resume

Manufacturing automotive parts additively is still at its beginning. The conventional powder bed fusion processes limit the possible applications to high performance cars with small lot sizes. However, this study shows that manufacturing of parts with high requirements on mechanical properties and optical finishing is feasible. For these applications Additive Manufacturing offers great potential to reduce the lead time and enable new designs.

This study reveals both strengths and weaknesses of the examined powder bed fusion technologies. It becomes evident that EBM is not a suitable technology for the identified part. Cost advantages with EBM technology would be achieved, if parts with higher wall thicknesses are chosen. However, visible components will require extensive finish with complete machining.

LBM proves to be suitable for the presented application. The surface quality of the finished part meets the given requirements. Minor macroscopic defects seen in this study can be controlled by further design alterations. The overall results predict a more extensive use of Additive Manufacturing technology in high performance cars in the near future.



Challenges and potential

1.

Cost

The cost of conventional powder bed fusion processes is currently too high for a large number of promising automotive applications. New additive technologies, using multiple step sintering processes, suggest a massive reduction of cost and an increase in output. These technologies might enable a wider range of applications in the near future.

2.

Qualification

The production of Additive Manufacturing parts is still accompanied by many technology related challenges.
For a successful implementation, the automotive OEMs are bound to define extensive specifications and qualification methods for their internal and external supply chain.

3.

Knowledge

All major automotive OEMs are already committed to large investments in the Additive Manufacturing technology.
While the knowledge base is growing on OEM side, the automotive suppliers are just at the beginning.

Ampower Insights Vol. 3

Learn more about the potential of the emerging metal AM technologies in our next publication of Ampower Insights Vol. 3.
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About the authors

Dr.-Ing. Maximilian Munsch

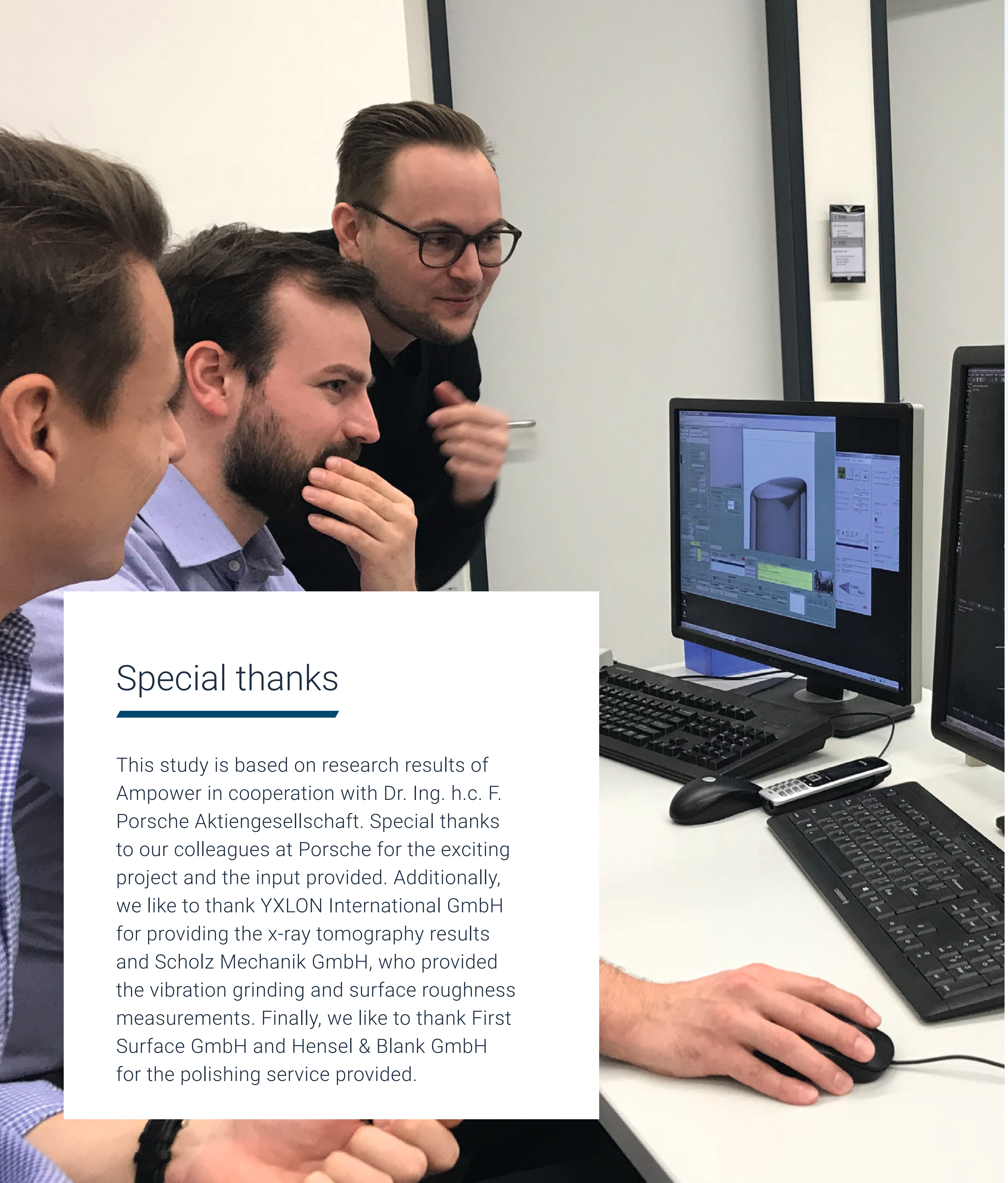
Since 2007, Maximilian Munsch is a professional user of Additive Manufacturing. After finishing his dissertation on reduction of residual stresses in metal Additive Manufacturing in 2012, he acquired extensive hands-on experience with metal powder bed based Laser and Electron Beam Melting processes in 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.



Special thanks

This study is based on research results of Ampower in cooperation with Dr. Ing. h.c. F. Porsche Aktiengesellschaft. Special thanks to our colleagues at Porsche for the exciting project and the input provided. Additionally, we like to thank YXLON International GmbH for providing the x-ray tomography results and Scholz Mechanik GmbH, who provided the vibration grinding and surface roughness measurements. Finally, we like to thank First Surface GmbH and Hensel & Blank GmbH for the polishing service provided.

Missed out on our previous Issue?

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.

Download **Ampower Insights Vol. 1**
"Additive Manufacturing – Make or Buy" at
www.am-power.de/insights

SOURCES

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