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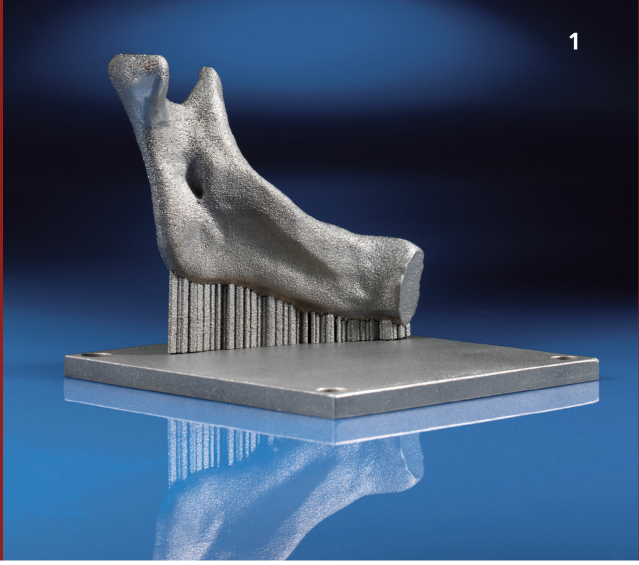
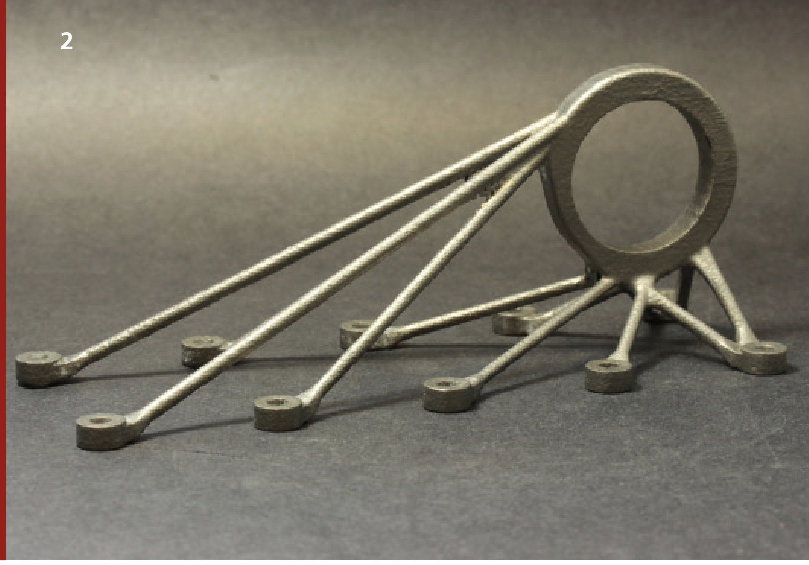
FRAUNHOFER INSTITUTE FOR MANUFACTURING TECHNOLOGY AND ADVANCED MATERIALS IFAM

ADDITIVE MANUFACTURING





Laser Beam Melting (LBM)

According to VDI Guideline 3404, Laser Beam Melting (LBM) is a beam-melting process and, depending on the equipment manufacturer, is also known as »Laser Forming«, »Selective Laser Melting« (SLM), »Laser Cusing«, or »Direct Metal Laser Sintering« (DMLS). LBM is currently the most commonly used method for the additive processing of metal powders.

During manufacturing, the material is completely melted by a laser beam and then immediately solidifies. Subsequent heat treatment enables further tailoring of the material properties, and then further methods of conventional processing are applied to produce the ready-to-use component.

The generative process of Laser Beam Melting can be used to manufacture components from metallic powders into almost any shape, even very complex ones, directly from 3D CAD data. The finished components attain their final properties directly during the process. Common to all commercial processing variants is the principle of tool-less, layer-by-layer build-up of the workpiece based on a three-dimensional CAD model.

The complete parameter development for various materials (titanium, aluminum or steel alloys) is carried out at Fraunhofer IFAM. Special material as magnetic or even thermo-caloric materials widens our field of experience.

When determining the necessary heat treatments, we draw on our analytical capabilities and many years of experience in metal processing. When carrying out investigations, we have an EOS M270 Dual Mode system and extensive analytical equipment at our disposal.

Selective Electron Beam Melting (SEBM)

Selective Electron Beam Melting (SEBM) is a powder bed based beam-melting process for additive manufacturing of metallic components with a complex shape. The powder is selectively melted layer by layer with an electron beam. The process is characterized by the following properties of the powder and the process:

- SEBM is a »hot« process, i.e. each powder layer is preheated before being melted by the electron beam. The material-dependent temperatures for currently processable materials range between approx. 700 °C (Ti-6Al-4V) and > 1000 °C (titanium aluminides). This is particularly advantageous for processing materials that are susceptible to cracking.
- SEBM uses a high vacuum as the processing atmosphere. This means that specific materials with very reactive elements (e.g. Ti, Al) can be processed and moisture from the powder is removed during the evacuation step.

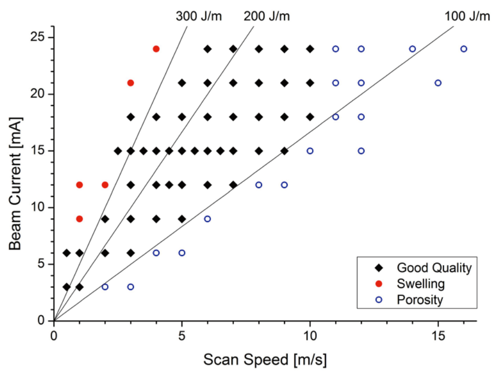


Fig. 1 Processing window for SEBM of Ti-6Al-4V. Blue circles indicate specimens with more than 1 % porosity; red circles indicate pronounced swelling of the surface.

1 *Replica - human jaw bone (study for a medical implant), material Ti-6Al-4V, LBM-generated.*

2 *Aerospace bracket (material Ti6Al4V).*

Metal Binder Jetting (MBJ)

Metal Binder Jetting is a layer-by-layer manufacturing process in which a binder is deposited using printer heads – similar to inkjet printing – to create a green body in which the binder acts as an adhesive for the metal powder. There are two methods of producing a consolidated component:

Option A
Debinding of the green body and infiltration with a low-melting material, e.g. bronze. This does not lead to shrinkage of the component and produces a mixed material.

Option B
Debinding of the green body and sintering of the starting material to full density. This leads to sintering shrinkage of the component.

Further differences distinguishing this method from the LBM and SEBM processes include the following:

- removal of supporting structures is not necessary because support is provided by the powder bed
- this method can be used to process non-weldable materials

Subsequent finishing treatment with conventional methods is applied to make components that are ready for use.

The main focus of Fraunhofer IFAM's research and development work on Metal Binder Jetting is on material and process optimization as well as binder development. The material palette includes all alloys that can be subjected to solid-phase sintering and which are available as a powder.

3D Screen Printing

Three-dimensional screen printing is unique in that it is the only additive process that is suitable for mass production. The 3D screen printing process involves printing layers of powder paste through a screen to produce a sinterable green body. Optional screen changes can be used to obtain the desired variety of shapes. The geometric resolution is about 100 µm. The target material properties are then tailored during the subsequent sintering step.

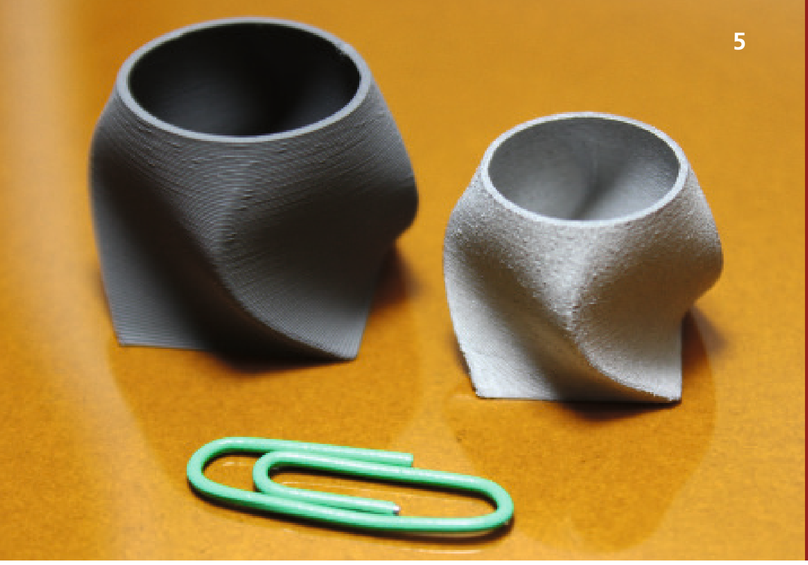
Since three-dimensional screen printing can be carried out as a semicontinuous process, it is possible to produce very large batch sizes of up to several million items annually, depending on the component. Three-dimensional screen printing thus ventures into fields previously restricted to processes such as injection molding.

The use of paste systems enables processing of almost any metal and its alloys as well as ceramics. Examples include materials based on steels, copper, titanium, tungsten, molybdenum, nickel, cobalt, aluminum, rare earths, carbides, and oxide ceramics. Furthermore, the process makes it possible to use different powders in the same object to produce multi-material components.

Fraunhofer IFAM is the global market leader in the development of three-dimensional screen printing. Together with our partners, we offer the complete process chain from materials to printing pastes, unique plant engineering, and printing development. Our services are supplemented by heat treatment of the finished component and its characterization.

3 *Study Metal Binder Jetting – ring-shaped nozzle, material 316L (stainless steel).*

4 *Demonstration parts for additive manufacturing via 3D Screen Printing.*



Fused Filament Fabrication (FFF) of Metals

The Fused Filament Fabrication (FFF) process for the additive manufacturing of plastic components is widely used in both industrial and private applications.

Fraunhofer IFAM Dresden has used its unique experience in powder metallurgy to develop Fused Filament Fabrication of metal parts. This is achieved by the use of newly developed filaments containing metal powder with high filling grades up to 60 vol.%. The filament is printed into a green body consisting of plastic and metal powder and can then be sintered by means of a heat treatment process into a plastic-free fully dense metallic component, analogous to conventional sintering processes such as metal powder injection molding (MIM). Fraunhofer IFAM deals with material and process development along the entire process chain of metal-based FFF, which includes the filament manufacturing and printing process as well as the debinding and sintering process. The process is characterized in particular by its relatively low investment costs and its comparatively complex freeform design compared to other processes. Additionally, it can cover the whole range of sinterable materials including multi-material systems and metal-matrix composites.

In detail we offer:

- Support in component selection and production-ready design
- Comprehensive material and process development along the process chain
- Material-specific filament development
- Market studies and comparisons with other AM technologies
- Training courses and workshops on the Fused Filament Fabrication process

New Technologies

Continuous Photopolymerization

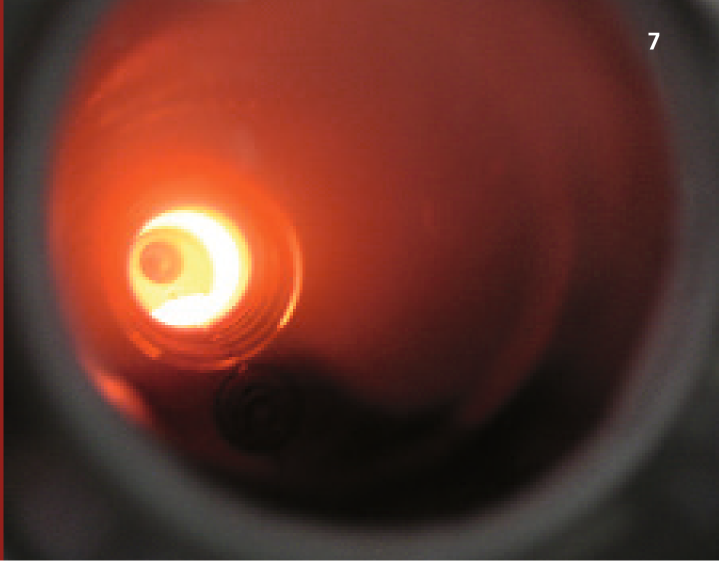
The patented (DE102012021284) process uses the technique of continuous photopolymerization according to the DLP principle. The difference to other 3D printing systems is the rotating roll as substrate, the lower part of which is immersed in a polymer bath. The polymer is cured by light sources at a precisely defined distance. During the step-by-step rotation of the roll, a three-dimensional component is built up layer by layer on the immersed roll area. Finished components can be cut off automatically on the top side of the roll and the process can be operated continuously.
The continuous photopolymerization process makes it possible to stabilize work processes because complete components continuously leave the production line and setup processes between individual construction jobs are no longer necessary. Until now, the production cycle times of conventional additive manufacturing processes have not been comparable to those of conventional mass production lines. The Fraunhofer IFAM approach forms the basis for cost-effective individual series production and will decisively improve the cost-effectiveness of the generative process.

3D Dispensing

Based on standard 2D micro dispensing processes, Fraunhofer IFAM develops a modified technology for 3D dispensed parts. In this enhanced version, micro drops of a newly developed ink containing metal powder and organic binder are emitted onto a substrate. Due to the tailored rheology of the ink and the adhesive behavior of the organic, a layer-by-layer printing leads to real three-dimensional parts. During a subsequent heat treatment the organic is completely removed and the remaining powder is sintered to a dense solid metal structure.

5 *FFF - demonstration parts, green and sintered, 316L.*

6 *Plant for continuous photopolymerization.*



Heat Treatment Process Control

Binder-based additive manufacturing methods for metal components typically require debinding and sintering processes. The proper parameterization of this heat treatment is an essential factor for the component quality and low scrap rates. An access to these processes is given by the composition of the process gas in the furnace. The qualitative and quantitative analysis of the gas composition provides an in-depth understanding of the reaction kinetics and the reaction mechanisms, thus allowing enormous improvement of the process control and final component quality.
At Fraunhofer IFAM, an in-situ technique for the monitoring of the process gas composition directly in the furnace has been developed. By using infrared spectroscopy and mass spectrometry, a deeper understanding of the organic component decomposition and the subsequent thermochemical reactions between process atmosphere and metal component is achieved. Such a knowledge enhances the production reliability by eliminating undesired effects like blistering or delamination. As a result, the process gas analysis allows for an efficient design of the temperature-time schedules and needed atmosphere composition in order to realize dense components with low contamination levels.

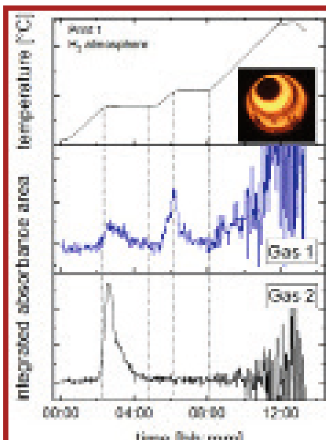


Fig. 2
Gas concentration curve of two process-determining gases with optimized debinding, components manufactured via Fused Filament Fabrication.

Powder Analysis

A detailed understanding of the relationship between powder properties and processing parameters is fundamental to further develop powder bed based additive manufacturing. Besides morphology and particle size distribution, the powders' ability to flow is a key parameter for the process. This means that powder properties have to be tested preferably in a manner which comes close to the actual processing conditions.

In summary, the following criteria must be met by a powder analyzing technique:

- ***Sensitivity***: the technique must be able to resolve variations in powder quality, which translate into the process and lead to variations in processability.
- ***Reproducibility***: the method should be operator and device independent.
- ***Representativeness***: the measured parameter must correlate with the parameters quantifying the processing quality of the powder.

At Fraunhofer IFAM, a broad range of analytics and equipment is available:

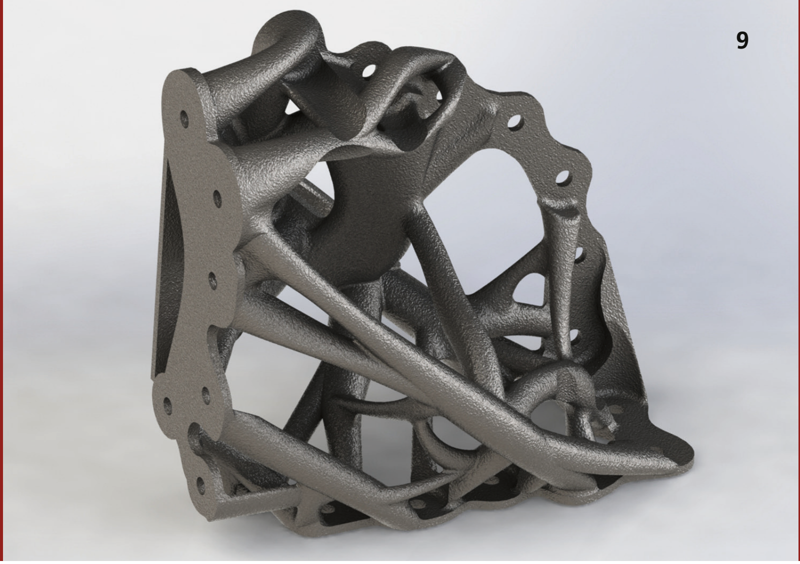
Standardized powder analytics at the accredited lab:

- Sampling (DIN ISO 3954)
- Bulk density (DIN ISO 3923/1)
- Angle of repose (DIN ISO 4324:1983-12)
- Flow rate through a calibrated funnel (DIN ISO 4490)
- Powder density (DIN 51913)
- Particle size distribution (ISO 13320)
- Impurities (DIN ISO 4491-4, DIN ISO 15350)

Special equipment:

- CAMSIZER X2 (Retsch)
- Powder Rheometer (Freeman FT4)
- Revolution Powder Analyzer (Mercury Scientific)

7 *Optical measuring access to the debinding furnace.*
8 *Formation of a Ti-6Al-4V powder cone of the fraction 50-110 µm for EBM applications.*



R&D Competence

- Materials development
- Consulting service for material selection and tailoring
- Development of filaments, pastes and inks
- Powder analysis
- Component design and manufacture
- Heat treatment
- Production of prototypes and small batches
- Support for implementation into series production
- Economic feasibility studies

The comprehensively equipped additive manufacturing application center at Fraunhofer IFAM in Bremen comprises the complete process chain for LBM and MBJ.
At Fraunhofer IFAM in Dresden, the Innovation Center Additive Manufacturing ICAM brings together SEBM, 3D Metal Printing and FFF under one roof to provide thorough access to the various possibilities of additive manufacturing technologies.

What We Offer

- We cover the complete value chain for the additive processes we have available at Fraunhofer IFAM, from the creation of 3D data models, through manufacturing, to final processing and inspection of the components.
- Technological benchmarking from material to component for all processes available at Fraunhofer IFAM – in comparison to conventional manufacturing as well as comparing between the additive processes.
- Materials development for all described processes, together with the necessary process adaptations – the material palette ranges from lightweight metals, such as aluminum and titanium, to hard metals and high-melting alloys.
- Support for process integration – execution of technology studies and market analyses.
- Comprehensive analysis from powder to component to ensure that the processing sequence is robust.
- Customer-specific training courses and workshops.

Owing to its far-reaching networking and active cooperation in national and international committees, Fraunhofer IFAM is directly involved in shaping the future of technological development in the field of additive manufacturing – for the benefit of our customers.

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9 Optimized component «Main gear bracket rear» (demonstrator). 10 Metal stents, electro-polishable later on, material: stainless steel 17-4 PH (1.4542) , LBM-generated. FRONT 3D screen printed structures (demonstrator).