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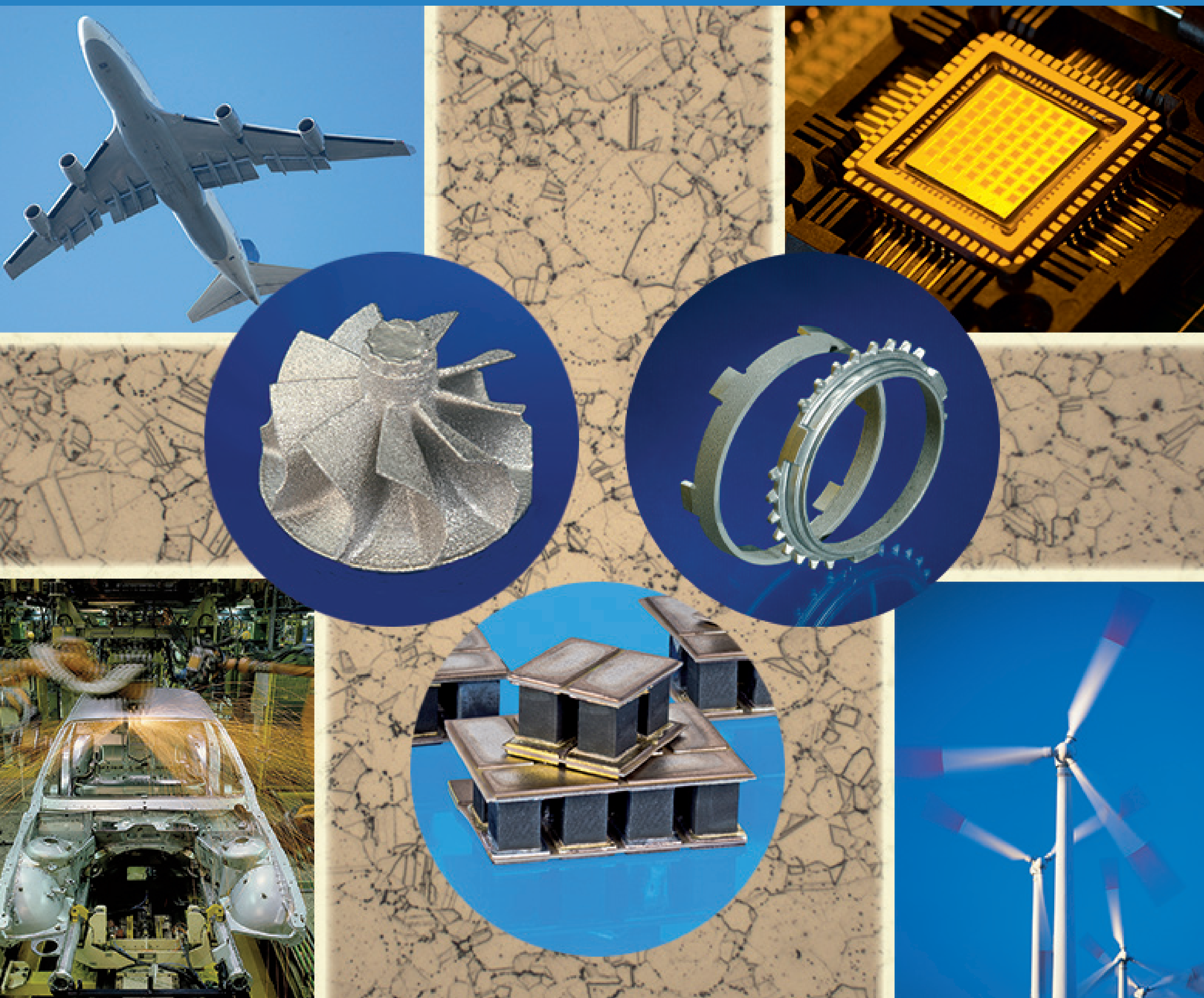
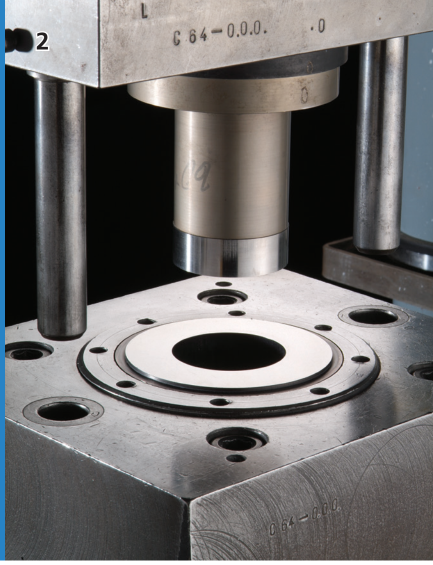
FRAUNHOFER INSTITUTE FOR MANUFACTURING TECHNOLOGY
AND ADVANCED MATERIALS IFAM, BRANCH LAB DRESDEN

SINTERED AND COMPOSITE MATERIALS

MATERIAL INNOVATION FOR TECHNICAL SOLUTIONS




FROM POWDER TO COMPONENT

Designing materials with tailored properties as well as the appropriate manufacturing technology are important issues to contribute to selected megatrends of our society.
In particular, powder metallurgy offers unique possibilities in terms of efficiency, productivity, reliability and added value. Materials can be designed with higher flexibility, parts can be produced with complex shapes and functions.
The material and product innovation at Fraunhofer IFAM Dresden is mainly focused on the following branches: automotive, aerospace, energy technology, electronics, mechanical and medical engineering. The close interaction of our competences in materials research (development, characterization, processing) together with the availability of a broad modern powder metallurgical infrastructure enables the transfer of our developments into practical applications. This synergical interaction allows us to cover the complete production chain from the manufacturing of adequate starting powders to the processing of prototype parts.

Materials and Components for Lightweight Construction

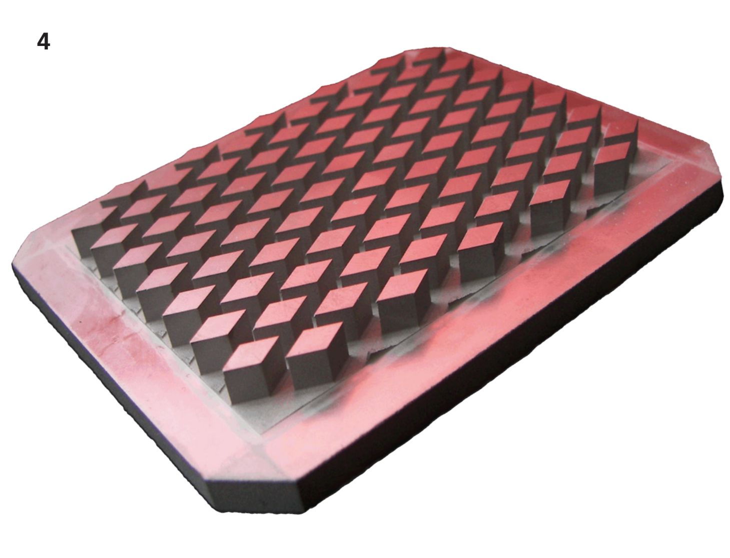
The development of Fiber Reinforced Plastics (FRP) offers a great opportunity for applications in automobile industry, aeronautics and consumer goods to achieve lightweight structures. However, the connection technology between FRP and mainly metallic based structures is the key to use the full potential of the FRP. Using the powder metallurgical approach to generate a metal/FRP connection module by spark plasma sintering, a great variety is possible by integration of different metal and/or fiber components.
The fibers integrated between the upper and lower metal can be glass, basalt and carbon fiber in one layer, two layers and mixed layer configuration.
To connect the sintered module to greater carbon fiber weaves conventional infiltration or laminate processes can be used. To connect the metal side to a metallic construction welding, screwing, size fitting or glueing are some options. Out of the predicted module shear strength, the connection module can be tailored to the needs of each application.
Additionally, further joining methods to produce material compounds are available at Fraunhofer IFAM Dresden. As an alternative to the conventional adhesive bonding the low temperature active soldering is utilized to produce thermally conductive joints of rather difficult-to-wet materials like ceramics and certain metals. The manufacturing of high temperature stable, planar joints is enabled by diffusion bonding technologies applying conventional hot pressing or innovative spark plasma sintering methods.

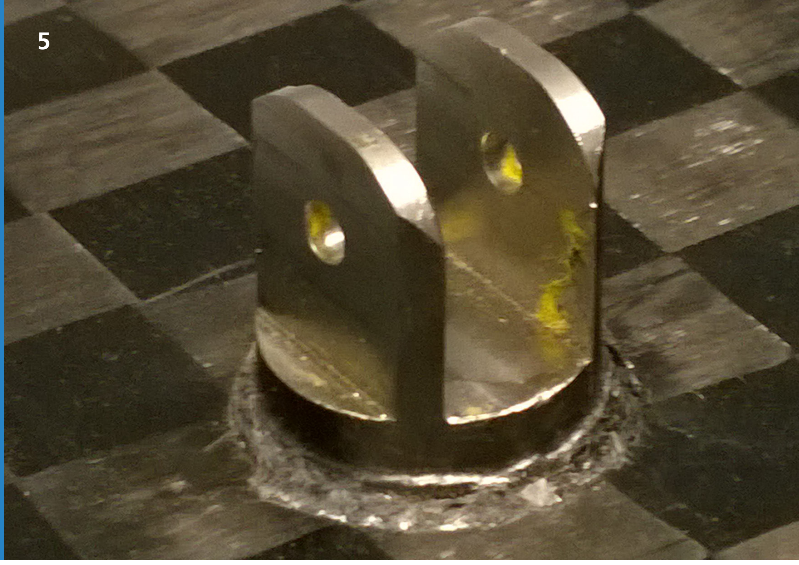
Furthermore, light alloys like aluminium or titanium offer a potential for weight reduction by substituting heavier metals like steel. In particular, powder-metallurgical technologies offer the unique potential to design aluminium alloys with enhanced mechanical and tribological as well as thermophysical properties. Beside the classical press-sinter route for manufacturing of net-shape parts the application of economical production routes has to be considered. Fast densification techniques of powders like spark plasma sintering with/without subsequent forming steps (extrusion, forging, thixo-forging) offer an efficient processing chain. Rapid solidification (e.g. melt spinning) or reinforcements with particles/fibers enable the fabrication of aluminium alloys/composites for high performance applications with tailored and superior properties.

Materials and Components for Thermal Management

Thermal management is an important issue in electronic packaging. Heat sinks are essential for preventing thermal damage to heat sensitive components and, thus, improving lifetime and reliability.

1 Rapid solidification via melt spinning, 2 Die pressing, 3 Field-assisted sintering





MATERIALS ARE OUR COMPETENCE

Metal matrix composites with high thermal conductivity combined with a tailorable coefficient of thermal expansion can contribute significantly to this challenge.
A wide variety of composite materials covering a broad spectrum of properties has been developed (Fig. 1).
Additionally, components with tailored geometries (integrated cooling fins) or specifically designed surfaces (e.g Ni or Ag plating, polished surfaces) or defined machinable areas can be delivered as prototypes.
PCM (phase change materials) filled composites can be used for the storage of latent heat or to stabilize the temperature of electrical assemblies.

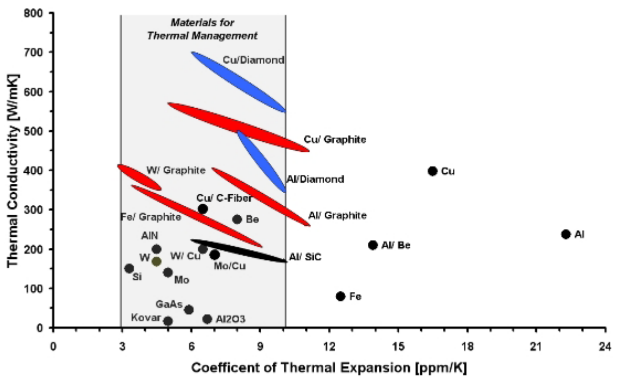


Fig. 1 Property profile of different composites for passive heat sinks.

Thermoelectric Materials and Modules

Converting lost heat energy to electrical power is one of the most interesting perspectives offered by thermoelectrics. Thermoelectrical Energy Harvesting – whether in power plants, industrial processes or automobiles – will provide a significant contribution to more efficient use of energy in the near future.

Based on the materials competence of the interdisciplinary research team, different compounds are developed in order to enhance their conversion efficiency (ZT-value).
Our aim is to create a technology compatible with an industrial application.

In terms of materials the focus lies on silicide materials (Mg_2(SiSn), MnSi). Compared to other materials, silicides have advantages in regard to raw material costs, availability and harmlessness.
With doping ZT values greater than 1 can be realized over a broad temperature range (200 - 600 °C).

Powder metallurgy, melt spinning and spark plasma sintering offer the capacity for scaling up the fabrication of thermoelectric materials and thermoelectric legs.
We have successfully increased the production of thermoelectric powders from laboratory to prototype scale (Kg/batch) and their processing into sintered bodies with diameters up to 6 cm and 3 cm height. These are the first requirements for a large scale production of thermoelectric modules. In parallel research, we develop contacting and assembling technologies for the production of thermoelectric modules and their protection from oxidation at high temperature.

The characterization (experimental and modelling) of thermoelectric modules and static and dynamic conditions is performed in cooperation with the business unit Energy and Thermal Management at Fraunhofer IFAM Dresden.

Tribology – Materials and Testing

Tribological requirements frequently occur in combination with high temperatures, chemically aggressive agents or dynamic loads. As a result, there is a demand for different, usually contradictory material characteristics.

4 *Highly conductive base plate for thermal management applications,*
5 *Metal/FRP connection module*

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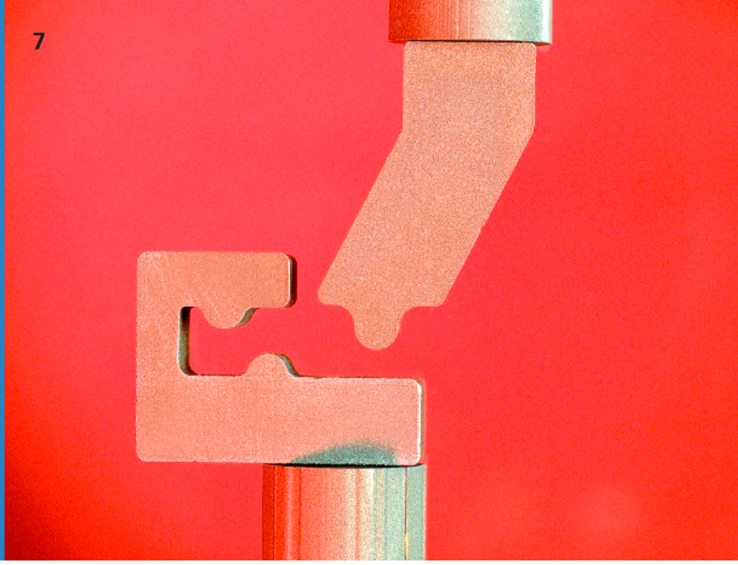


Powder metallurgy has an outstanding potential to produce tailored materials for tribological applications, not only because it allows for the choice of specific alloys as matrix material, but also since it provides the opportunity to incorporate hard materials and/or lubricants. Together with our customers we are optimizing and designing friction systems and offer analysis of tribological damages and consulting.

Fraunhofer IFAM's experience in this field is further enhanced by the ability to execute in-depth tribological investigations. To do so, Fraunhofer IFAM Dresden is equipped with two high-performance tribometers that offer both model and component tests.

Sputter Targets – Customized Solutions

Sputter targets are required as the initial material source for different coating techniques, such as PVD coating or laser beam technology. The targets' quality in terms of composition, purity and density is an essential precondition for high-quality coatings and new coating systems. Targets made from refractory materials, ceramic materials or composites that cannot be produced by ingot metallurgy can be manufactured alternatively by means of powder metallurgy: Powders or powder mixtures are pressed and sintered afterwards, or they are subjected to hot pressing (max. 1700 °C). Microstructure, homogeneity and purity can be tailored according to the requirements. Several geometries like rectangular, cylindric or cone-shaped parts can be produced based on your requirements. We are offering manufacturing of powder-metallurgical targets (prototypes, small series production) and alloy development for special target composition.

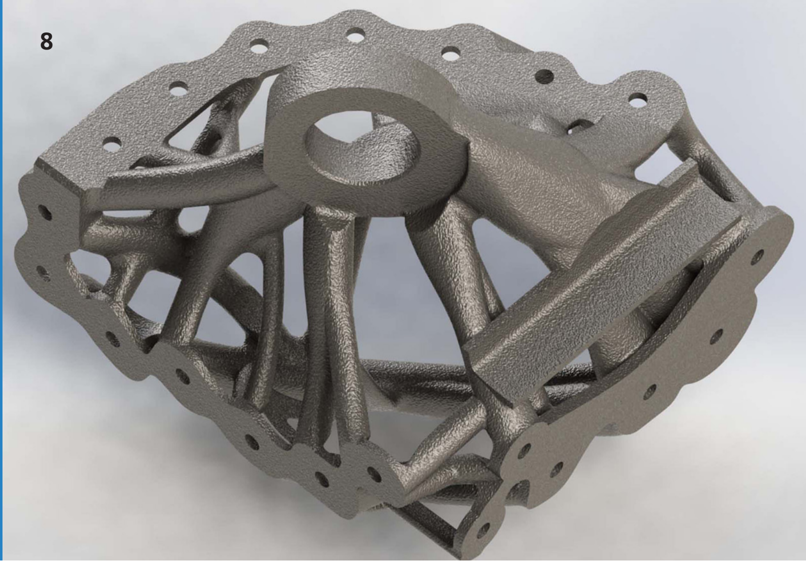
High Temperature Materials and Components

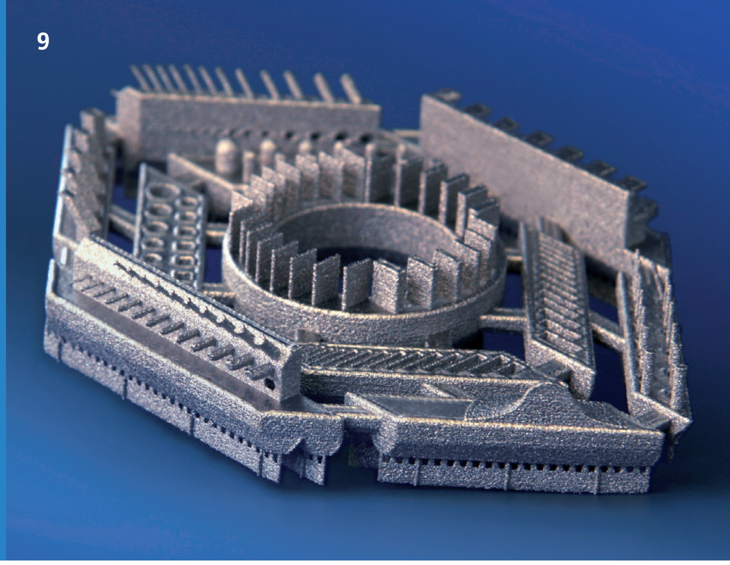
High temperature materials and components are needed in particular in power engineering, aircraft turbine or chemical industry. Combining high temperature strength with resistivity against corrosive atmosphere can be obtained by refractory metal based alloys, silicide materials (especially $MoSi_2$), metallic self-passivating Fe- and Ni-based super alloys or dispersion strengthened materials, which are all part of the portfolio of Fraunhofer IFAM Dresden. Powder metallurgy offers the unique option of short production cycles, compositional variety and effective material utilization due to near-net-shape processing. Fraunhofer IFAM produces components currently used, for example, in biomass gasification plants and high temperature mechanical testing devices.

Special thermal treatments can be used to passivate the alloys or parts in the final shape before usage. Such treatments are conducted in atmospheres containing a low oxygen partial pressure to ensure the formation of protective oxides. Self-healing properties after crack formation or scratches in oxidizing atmospheres have been demonstrated by diffusion controlled oxide formation. The strength of these alloys can be remarkably increased by the incorporation of oxide particles, which in several cases can be exclusively accomplished by powder metallurgy.

In cooperation with the company Alantum, Fraunhofer IFAM Dresden has developed a powder metallurgical coating and sintering process to transform nickel or iron foam into a high temperature and corrosion resistant alloy foam. This patented technology is now established in a commercial production line. The foam applications range from catalysts for exhaust after treatment and heterogeneous catalysis, filters, heat exchangers, electrolysers up to electrodes for batteries.

6 *Thermoelectric modules for Energy Harvesting,*
7 *Assembly for high-temperature bending test*





Selective Electron Beam Melting

Selective electron beam melting (SEBM) is a technology for additive manufacturing (AM), which is able to produce metallic components with a high degree of complexity using computer aided design (CAD) data. EBM is a powder-bed-based technology which creates high density parts by selectively melting the powder in a layer-by-layer way. Its main features, which make EBM unique among AM processes, are:

- The use of an electron beam which is employed for two process steps on each powder layer, namely pre-heating and melting. On the one hand this helps to reduce thermal stresses, because the build chamber can be held at elevated temperatures during the build process. On the other hand, there is a wide range of materials (e.g. Ti-based alloys, superalloys, intermetallics, refractory metals), which can in principle be fully densified due to the very high energy density.

- The process environment, which is high vacuum (HV), is a prerequisite to be able to use the electron beam, but is also beneficial for other reasons: (i) highly reactive metals and alloys can be processed, (ii) outgassing of impurities can take place and (iii) a high degree of thermal insulation is provided.

At Fraunhofer IFAM Dresden, our research is focused on the following areas:

- Powder: this includes the preparation of specifications for AM-ready powder as well as the analysis of fresh powder and surplus powder from the AM process (not restricted to SEBM). Our accredited lab for powder analysis constitutes an essential part in that respect.

- Process development: for standard materials (e.g. Ti-6Al-4V), the parameter and sample placement adjustment with respect to the specific part geometry is one major task. For non-standard materials, the process window and production of test samples for analysis are the first essential step before actual parts are produced. Several non-standard materials from the material classes of intermetallics and refractories were successfully qualified for SEBM. Additional material classes like steels and Ni-base superalloys are in the focus of current R&D work.

- Design: we are aiming at developing design guidelines for SEBM. Furthermore, optimization of current parts with tools like topology optimization is a major part of our work in this field. First successful case studies in the aerospace industry show that there is and will be a high demand also for this competence.

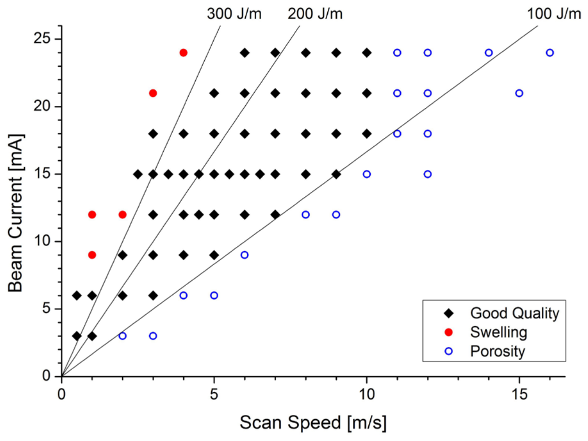
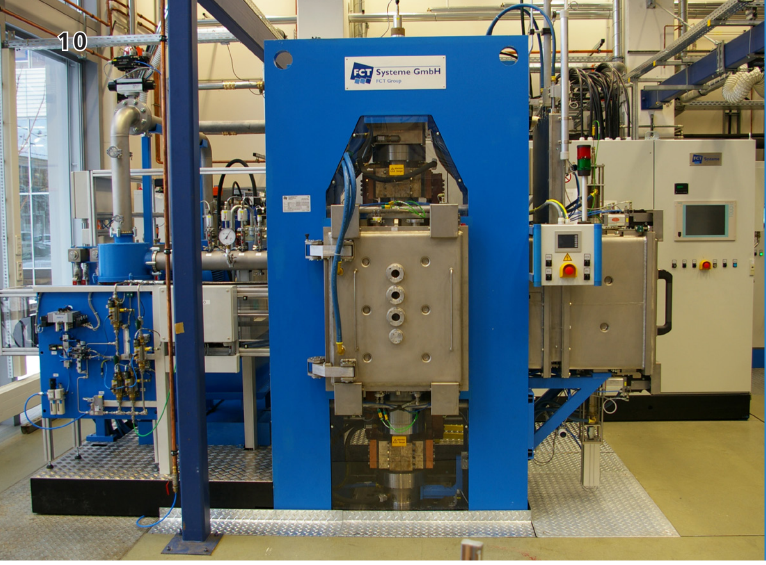


Fig. 2 Process window for SEBM of Ti-6Al-4V. Blue circles mark samples with more than 1% porosity, red circles mark considerable swelling at the surface.

8 *Optimized component „MG Bracket rear“ (demonstrator),*

9 *Design demonstrator for EBM (Ti-6Al-4V)*



Special Technologies

Beside conventional powder-metallurgical technologies, advanced and special technologies are installed at Fraunhofer IFAM. Melt spinning, as one technology example, offers the manufacturing of ribbons or flaky powders with an internal nanocrystalline or amorphous microstructure. Those rapidly solidified materials can be used for advanced Al and Mg alloys, catalyzer materials, braze materials, thermoelectric and magnetic materials or materials for hydrogen storage. The R&D team offers application oriented development of rapidly solidified alloys and utilisation of rapidly solidified materials for demonstration and prototypes.

Rapid sintering techniques, to mention another example, can be used to densify powder fast avoiding strong grain growth. Thus, highly alloyed and rapidly solidified pre-materials like gas atomized powder or melt spun flakes can be densified. Mate-r-ial properties, e.g. mechanical properties or thermophysical properties, can be enhanced. The systems installed also offer a semi-continuous production by using the adapted cooling chamber. The R&D team is working also on tool design to increase shape complexity of spark plasma sintering parts and productivity of the process.

For our material and technology developments, characterization techniques are essential. From powder characterization (accredited laboratory) up to microstructure investigation and property evaluation different advanced and up-to-date techniques are available like mechanical, thermal and electrical measuring methods.

Our Offer

Our highly motivated interdisciplinary team develops ideas and concepts for your specific requirements - everything, of course, strictly confidential. Powder-based technologies offer a unique freedom in designing materials and components.

Please contact us to discuss ideas for materials, parts and technologies to improve your products.

Our offer includes:

- Application oriented material synthesis and development
- Material characterization (e.g. thermal analysis, tribological testing, mechanical testing also at elevated temperatures, microstructure characterization)
- Development of materials processing technologies
- Powder processing, modification and characterization (certified test lab)
- Manufacturing of prototypes
- Developing production concepts
- Technology transfer, staff training
- Consultancy and analysis of material and component damages

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10 *Spark plasma sintering facility,* 11 *Melt spinning facility,*