

Institute of Materials Research



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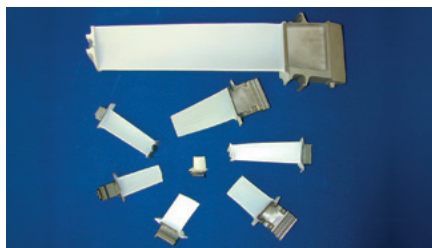


Materials technology – paving the way for complex component solutions

The main research focus of the Institute of Materials Research is the development of new material solutions and their processing techniques for applications in aerospace, in energy technology, and in automotive engineering.

In co-operation with DLR institutes as well as with national and international partners, the Institute of Materials Research is consistently working on fundamental and application-orientated topics. The research portfolio spreads across the fields of metallic structures and materials, hybrid material systems and intermetallics, ceramic matrix composites, aerogels and aerogel-composites, thermoelectric systems and high-temperature and functional coatings. The development of numerical methods to simulate the behaviour of materials and components completes these competencies aiming at supporting the transfer of materials into industrial applications.

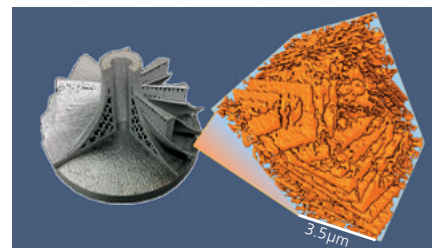
In addition to scientific research the institute is actively involved in the education and advanced training of young researchers at renowned universities in the form of professorships and teaching assignments.



Ni-based turbine blades for a variety of aero engines and gas turbines with PVD Thermal Barrier Coating system.



Re-entry capsule made of all-oxide ceramic matrix composite WHIPOX®



Metallic component produced by additive manufacturing

## High-temperature and functional coatings

The research and development work on major aero-engine components such as metallic and CMC parts for compressor, combustion chamber, and turbine offers a high potential for future generations of aero-engines. The work to improve thermal barrier coatings concentrates on the reduction of thermal conductivity, the rise of application temperature, and the protection of the coatings against aggressive combustion products. The research is centered on the understanding of failure mechanisms and targets the extension of lifetime. The influence of mineral deposits such as volcanic ash and CMAS on coatings and mitigation of damage is in the focus of the research. To be able to fully exploit the potential of modern titanium aluminides and upcoming silicide-based materials in aero engines, effective oxidation protection and thermal barrier coating systems are further developed.

Functional layers are synthesized for control of exhaust or polluted gas atmospheres. The developments not only aim at single components but also cover the integrated and intelligent design of thin layers as a basis for multifunctional systems that can efficiently operate at high temperatures. Functional layers are also under development for energy storage especially in miniaturized surface integrated self-subsistent systems.

## Structural and functional ceramics

Future energy-efficient and environmentally friendly turbine technologies in aeronautics and power generation require materials which combine superior high temperature stability of ceramics with non-brittle failure behaviour and thermal shock resistance typical of metallic systems. Similar requirements apply to re-usable thermal protection systems built into multiple use re-entry space vehicles.

The all-oxide, continuous fiber reinforced ceramic matrix composite WHIPOX® (Wound Highly Porous Oxide ceramic matrix composite), an original development of the Institute of Materials Research, ideally meets these requirements. WHIPOX® components can be manufactured by a simple and cost-effective process. The properties of all-oxide CMCs can be further tailored to specific requirements by additional functional coatings; thus considerably extending their field of application.

Functional ceramics to be used in concentrating solar-thermal processes are being developed in close co-operation with DLR's institutes of Solar Research and Engineering Thermodynamics. Materials include porous and particulate absorbers and redox ceramics to be used for generation of future solar fuels (hydrogen, hydrocarbons) as well as high-temperature heat storage.

## Metallic structures and hybrid materials systems

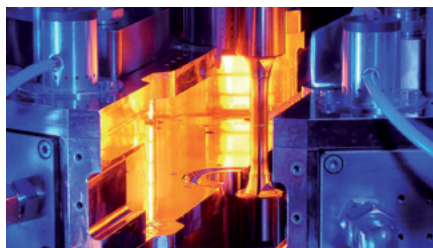
The research area of metallic and hybrid materials and structures is focused on the investigation of innovative manufacturing processes and new alloys to further optimize the manufacturing costs and the weight of materials and components for the transportation sector, especially for aeronautics and aerospace applications.

Additive manufacturing of metallic components constitutes one of the key research points. Here, the research activities of the institute concentrate on the understanding of the interaction between powder, process parameters, microstructure, properties and performance of printed alloys and components. The interplay with DLR system institutes such as the Institute of Structures and Design allows the transfer to the design, production and testing of full components.

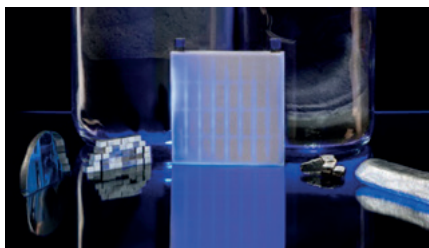
In a further research field, the performance and the damage tolerance of metallic materials and structures are investigated under fatigue conditions with multi-scale approaches that consider micro-mechanical characterization at coupon level up to biaxial testing of fuselage relevant structures in meter range. The combined experimental and simulation methods developed at the institute allow end-users a fast and cost efficient assessment in the stages of design, dimensioning and testing of diverse fuselage configurations.

Tailored hybrid structures formed by combining metals and polymers exploit the advantages of both worlds. In this context the institute works on the physicochemical understanding of interfaces and on the development of surface treatments that improve the long term performance of metal-polymer joints.

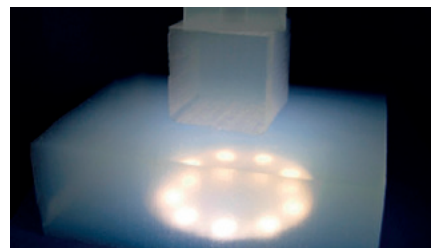




Test facility for thermomechanical testing of high-temperature materials



Technological steps towards TEG: gas atomizing fed by purified elements into thermoelectric powders, direct sintering into wafers, pellets for TEG modules



Light suffused silica aerogel

## Experimental and numerical methods

The demand for shorter development cycles for new components and technical products requires accelerated and accurate determination of material properties. With this background our research activities aim at making high performance materials for aerospace applications more predictable. Therefore, experimental and numerical methods are combined and further developed.

The typical workflow starts with characterizing the material by means of microscopic analysis and micromechanical tests on the microstructure level, which includes features from nanometre up to centimetre scale. Using this experimentally achieved data, numerical models are developed.

For generating virtual three dimensional microstructures increasingly tomographic methods are used. The digital images of real microstructures are then automatically analysed to achieve characteristic parameters describing the microstructure. Using this or systematically varied parameters it is possible by means of mathematical parameters to generate new microstructure models. Such models are used for calculating the materials behaviour in a component more precisely or for providing guidance for developing new materials with optimized microstructures.

The numerical models are validated by means of experiments with laboratory specimens or generic components under realistic loading conditions. Special non-standard test facilities are developed and manufactured in-house, for example test rigs for thermomechanical fatigue testing of internally cooled specimens, which represent gas turbine blades for aero engines.

## Thermoelectric materials and systems

Thermogenerators (TEG) are known from space applications to be long-life reliable sources of electrical power over decades free of failure. Terrestrial applications are evolving for utilization of secondary energies in the automotive, in high temperature industrial processes and energy machinery, in self-sufficient heating systems and stand-alone power units. TEG reduce the consumption of primary energy and hazardous emissions by conversion of waste heat into electricity. Efficiency of ten per cent and more can be reached over wide temperature ranges. The key to optimized applications is the development of efficient materials as well as of durable electrical contacts ensuring long-term stable operation. Novel materials – silicides, Skutterudites, chalcogenides, half-Heusler compounds – offer high potential for advanced efficiency and economic viability and will push the spread of thermoelectrics.

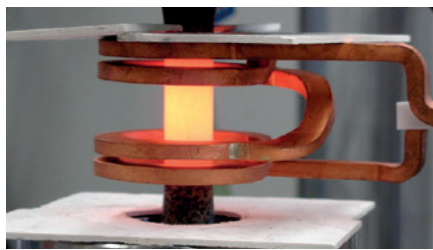
The department "Thermoelectric Materials and Systems" develops such materials and innovative technologies for intermediate and high temperatures. The team is contributing know-how to the field from continuous scientific progress over more than two decades. The method spectrum comprises materials synthesis by powder technology, contacting and joining, characterization of materials and systems as well as numerical simulation and design. Automatically controlled measuring devices for temperature dependent and locally resolving determination of thermoelectric properties are available. Simultaneous measurements are in the focus of method development. TEG module efficiency is measured by unique methods under realistic thermal and mechanical conditions with high accuracy.

## Aerogels and aerogel-composites

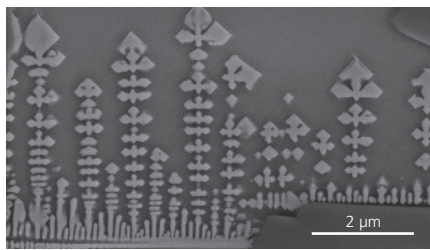
Aerogels are nanostructured, open-porous solids which are synthesized by a sol-gel process. All kinds of aerogels are low density materials, have a low thermal conductivity, possess a great inner surface, are good sound absorbers and can additionally be functionalized. The department of aerogels synthesizes organic and inorganic aerogels for more than twenty years and develops routines for manufacturing processes up to a pilot plant scale. In addition these aerogel materials can be used for the development of novel composites, even aerogel reinforced aerogel-matrix composites.

Based on the extraordinary combination of properties aerogels are able to push new solutions in the field of materials. Thus aerogels for lightweight construction of terrestrial vehicles and aircrafts are developed leading to completely new options of design. Based on siloxanes suitable aerogels for high temperature application are developed and generic parts are produced. For moderate and low temperature applications hybrid aerogels and organic ones based on thermosets as well as biopolymers such as cellulose, chitin or chitosan are developed.

Beside aerogels with insulating properties specific functionalized aerogels for adsorption of toxic gases, humidity or materials with high susceptibility to oxidation are developed and produced in a pilot plant scale. To advance future e-mobility carbon-based aerogels are developed with improved electrochemical efficiency in novel battery concepts.



Testing setup for high temperature tests at 1000°C



Processed Bauxite for CSP applications, SEM SE image

## Mechanical testing of materials

The team Mechanical Testing of Materials characterizes materials the institute is investigating and provides characterization procedures for external customers. Universal, servo hydraulic and resonance test facilities can run multiple mechanical tests under uni- and biaxial loading conditions. Experiments in air, vacuum and in corrosive environments as well as tests at different temperatures (-196°C up to 1400°C depending on material an setup) are possible. Testing equipment and setups for complex requirements are customized, developed and established by this team.

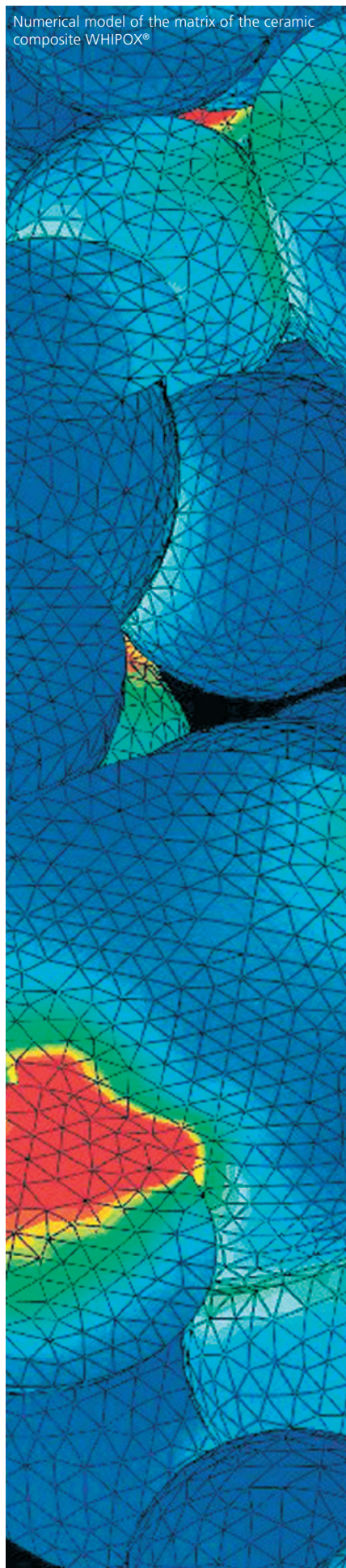
Near- service fatigue and fracture mechanics experiments on various materials are the main focus of the team. Materials like fiber reinforced ceramics, hybrid material systems, Ni –based superalloys, Al and Ti alloys used in space and aircraft applications as well as new developed Aerogel materials are investigated depending on the individual material requirements. The investigation of crack growth behavior including determination of crack initiation, evaluation of the threshold for crack propagation ( $\Delta K_{th}$ ), monitoring of  $da/dN$  -  $\Delta K$ -curves, determination of crack growth resistance curves and the critical stress intensity factor, especially for metallic materials, are part of the work. Special equipment can be used to apply different mixed-mode conditions for crack propagation investigations. Development and modification of setups and customized data evaluation for the use in simulation models are also part of the activities. The evaluation and data analysis includes the mechanical results as well as fracture surface investigations.

## Central analytical research and metallography

The macroscopic properties of materials are determined by its microstructure. This spans from the arrangement of the grains to the distribution of precipitates or inclusions and the structure of internal interfaces to the atomic structure including faults. Also, the spatial orientation of the microstructure in relation to a component part, called texture, is important.

Thus, preparation, documentation and analysis of the microstructure are required for purposive materials research. The results of the microscopic structural characterization allow for the understanding of the processes which are important for the properties, the production as well as the damage mechanisms of the materials investigated. The institute runs several X-ray diffractometers dedicated to powder and texture methods for phase determination and orientation analysis.

Indispensable for microscopic investigations is an effective and artefact free preparation of the samples, which is given by our metallographic laboratory. Microstructure investigations on surfaces are carried out by means of light as well as laser scanning microscopy (LSM) and analytical scanning electron microscopy (SEM). The preparation of metallographic and materialographic sections expands the applicability of these methods to volume materials. Direct volume information, as well as access to buried surfaces is possible by the analytical transmission electron microscope and our focused ion beam (FIB) system.



## DLR at a glance

The German Aerospace Center (DLR) is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport, digitalisation and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation's largest project management agency.

DLR has approximately 8000 employees at 20 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Bremerhaven, Dresden, Goettingen, Hamburg, Jena, Juelich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Oldenburg, Stade, Stuttgart, Trauen, and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.

DLR's mission comprises the exploration of Earth and the Solar System and research for protecting the environment. This includes the development of environment-friendly technologies for energy supply and future mobility, as well as for communications and security. DLR's research portfolio ranges from fundamental research to the development of products for tomorrow. In this way, DLR contributes the scientific and technical expertise that it has acquired to the enhancement of Germany as a location for industry and technology. DLR operates major research facilities for its own projects and as a service for clients and partners. It also fosters the development of the next generation of researchers, provides expert advisory services to government and is a driving force in the regions where its facilities are located.

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Linder Höhe  
51147 Köln, Germany

Prof. Dr.-Ing. Heinz Voggenreiter  
Phone: +49 (0) 2203 601-3570  
Fax: +49 (0) 2203 68936

## DLR.de/wf

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Cover image: Three-dimensional digital image of pores in a nickel-based superalloy for highly stressed components in aircraft turbine engines (colour is computer-generated)