Institute of Materials Research
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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, 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.
High-temperature and Functional Coatings

The research and development work on major aero-engine components like compressor and turbine blades or combustion chambers offer a high potential for the future generation of aero-engines.

The further development of thermal barrier coatings is concentrated on the reduction of thermal conductivity, the rise of application temperature and the understanding of damage mechanisms as well as the extension of lifetime.

To be able to fully exploit the potential of modern titanium aluminides in compressors or low-pressure turbines effective oxidation protection and thermal barrier coating systems are further developed.

Moreover, thin and nano-structured functional layers are synthesized for life-time control of exhaust gas catalytic converters, for efficiency rise of high-temperature gas sensors and of reformer catalysts producing syngas and H₂. The developments not only aim at single components but also cover the integrated and intelligent design of thin layers as a basis for efficient multifunctional systems.

Structural Ceramics

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

The all-oxide, long fiber reinforced ceramic matrix composite WHIPOX® (Wound Highly Porous Oxide ceramic matrix composite), an original development of the Institute of Materials Research, is an ideal solution for these requirements. WHIPOX® structures and components can be manufactured by an easy and cost-effective fabrication process.

The properties of all-oxide CMCs can be further tailored to requirements through functional coatings thus considerably expanding their application portfolio.

Metallic Materials and Structures

The research area of metallic materials and structures is focused on the investigation of innovative manufacturing processes and new alloys to further optimise both the manufacturing costs and the weight of primary structures of airplanes. In this context the “damage tolerance” properties are of special consideration. New and economical methods to determine the failure-relevant properties are developed and applied in this research area. The spectrum ranges from the micro-analytical characterisation of damage mechanisms at the level of the local microstructure to the assessment of the lifetime behaviour, crack propagation and remaining strength at the component level.

These experimental competencies are being complemented by numerical simulations that are used not only to model the behaviour of the specimen under testing conditions, but can also be used to bridge the gap to the real airplane structure. In particular stochastic methods are developed and applied.

For the manufacturing of cost-efficient, integral structures the process of friction stir welding is investigated. In this context the welding parameters, the microstructure of the weld seam and the strength and corrosion properties of friction stir welded joints are the topic of the investigations. In addition to that, procedures for non-destructive testing of friction stir welded joints are developed and applied.
Hybrid Material Systems and Intermetallics

Any material is marked by its specific properties and advantages. The best materials selection depends on the requirements of the component. Due to the increasing complexity and manifold requirements for components the choice of a material is often related to penalties under certain conditions. To avoid this drawback an intelligent combination of different materials to a hybrid material system can be preferred in such a way that the specific advantages of each material can be obtained.

An example for such a hybrid material system are metal matrix composites (MMC) or fibre metal laminates. The fibres are increasing the strength and stiffness while the metal contributes toughness and integrity in the case of fibre failure.

Titanium aluminides are intermetallic alloys with titanium and aluminium as mean alloying elements. Titanium aluminides are promising materials for high temperature and structural applications of the future. The Institute of Materials Research is collaborating with well-known German aeroengine companies for the optimisation and understanding of titanium aluminides. The research work is concentrated on microstructural characterisation and the relationship of microstructure and mechanical properties.

Experimental and Numerical Methods

The 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 characterising the material by means of microscopic analysis and (micro)mechanical tests on the microstructure level, which includes features from nanometre up to centimetre scale. Using this experimentally achieved data, numerical models are developed. With these models the behaviour of laboratory specimens and generic components under realistic loading conditions is simulated, and the calculations are validated through the respective laboratory tests.

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

Thermoelectric generators are widely known as very robust and reliable electrical power supplies for deep-space probes and planetary landers. The “Thermoelectric Materials and Systems” department is developing materials and technologies for thermal-to-electric energy conversion aimed at a wide application temperature range. Terrestrial use encompasses energy recovery in motor vehicles by means of exhaust heat-to-electricity power conversion, autarkic residential heat supplies and low-current power sources. The spectrum of methods in the department comprises materials synthesis, contacting and integration techniques, materials and system characterisation as well as numerical simulation and model-based system dimensioning.

Powder technology including suitability for upsizing to industrial manufacturing methods represents a key point here. The long-standing tradition in method development of functional characterisation is focussing on the material properties in the upper temperature range as well as precision measurements on thermogenerator modules. A main target is the development and implementation of standards for thermoelectric reference materials and measuring procedures.
Aerogels and Aerogel Composites

Lightweight construction with additional functionality, like excellent thermal or acoustical insulation for materials used in traffic vehicles, aircrafts or any thermal insulation applications for high temperature processes are challenging. Aerogels are able to push new solutions. They are nano-structured, open-porous solids which are synthesised 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 functionalised.

The department of aerogels synthesises organic and inorganic aerogels for more than ten years and develops routines for manufacturing processes up to a pilot plant scale. Based on siloxanes suitable aerogels for high temperature application are produced. For low temperature applications organic aerogels based on thermosets as well as biopolymers like cellulose, chitin or chitosan are developed.

These aerogel materials can be used for the development of novel composites, even aerogel reinforced aerogel-matrix composites.

Mechanical Testing of Materials

The team “Mechanical Testing of Materials” characterises materials for all departments of the institute as well as for external customers. Different mechanical test are performed under uni- and biaxial conditions. Experiments in air, vacuum and in corrosive environments as well as tests at different temperatures (-196°C up to 1400°C) are possible. Testing equipment for complex requirements is developed and established by this team. In-service fatigue and fracture mechanics experiments with various materials are the main focus of the team.

The investigation of crack growth behaviour including determination of crack initiation, evaluation of the threshold for crack propagation ($\Delta K_{th}$), monitoring of $\mathrm{da}/\mathrm{dN} - \Delta K$-curves, determination of crack growth resistance curves and the critical stress intensity factor are part of the work.

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, which spans from the arrangement of the grains to the atomic structure including inclusions, internal interfaces and faults. Also, the spatial orientation of the microstructure in relation to a component part is important. Thus, preparation, documentation and analysis of the microstructure are required for purposive materials research.

The results of the microscopic structural characterisation lead to the understanding of the processes which are important for the properties, the production as well as the damage mechanisms of the materials investigated.

Microstructure investigations are carried out by means of light as well as scanning electron microscopy, transmission electron microscopy and focused ion beam techniques. For phase and texture analysis, X-ray diffraction methods are used.

Indispensable for microstructure investigations is an effective and artefact free preparation of the samples, which is given by our metallographic laboratory.
DLR at a Glance

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 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 16 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Goettingen, Hamburg, Juelich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, 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.