Fraunhofer
MATERIALS

FRAUNHOFER GROUP FOR MATERIALS AND COMPONENTS

... FOR TOMORROW.

Dear readers,

Whether at the office, in the laboratory or on the road, we are constantly surrounded with materials. Every time we use our smartphones, or enjoy the optimal temperatures and lighting conditions in our offices (the latter provided by photochromic window glass) or comfortable driving conditions on our way home, we are naturally making use of material innovations and successful material developments. Even if we are not consciously aware of them, these materials are often the real key to product innovation.

The availability of appropriate materials and the mastery of material technologies have always been great competitive factors for industrial societies and have considerable influence on technical, economic and societal progress. The success of a strong export economy in a country like Germany, in which a large share of the gross domestic product is generated by manufacturing industries, is particularly shaped by material innovations.

Material innovations are based on successful interdisciplinary R&D cooperations and strong added-value networks. The Fraunhofer Group for Materials and Components – MATERIALS represents a broad, interdisciplinary spectrum of competency. This brochure displays some examples of the work within the Group. The institutes of the Group work together in networks to ensure the best possible solutions for their customers. Please feel free to contact us!

Prof. Dr. Peter Elsner
Chairman of the Fraunhofer Group for Materials and Components – MATERIALS

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FRAUNHOFER MATERIALS – A STRONG GROUP

The institutes of the Fraunhofer-Gesellschaft are organized into seven thematically structured groups of institutes in order to strengthen professional cooperations and to offer joint and co-ordinated services.

Fraunhofer MATERIALS pools the expertise of 15 material sciences and engineering institutes of the Fraunhofer-Gesellschaft.

The Group applies its know-how primarily in the following economically significant **business areas** in order to realize system innovations by means of tailored material and component development:

- Energy and Environment
- Mobility
- Health
- Machinery and Plant engineering
- Construction and Living
- Microsystems technology
- Safety

The **core competencies** of Fraunhofer material research cover the entire value chain:

- Material development
- Technology development
- Evaluation of application behavior
- Material modeling and simulation

The Group covers the entire area of metallics, inorganic / non-metallics, polymers and materials made of renewables. The overall budget of Fraunhofer MATERIALS was over 515 million euros in 2015. The Group currently has more than 4,500 employees, about 2400 of which are scientists.

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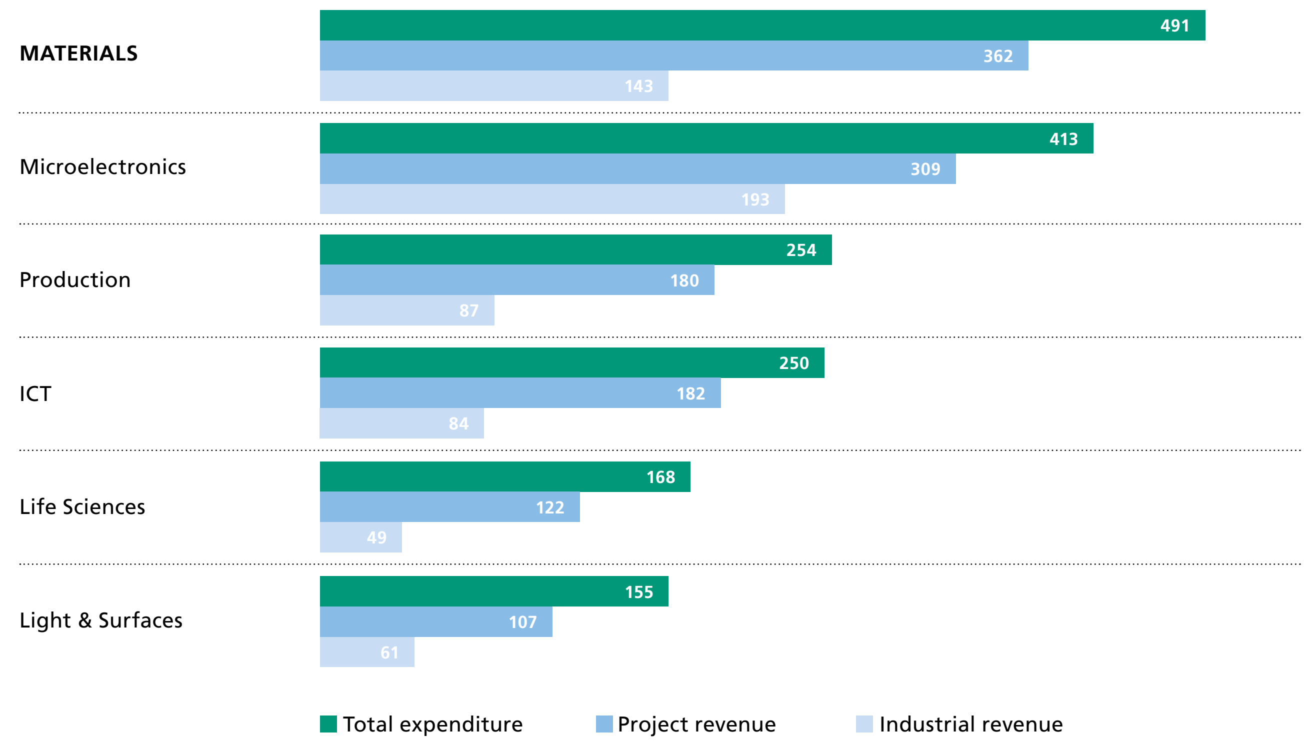
Tasks and Functions

Material research and technology at Fraunhofer encompasses the entire value chain, running the gamut from the development of new and improvement of existing materials, industrial-scale manufacturing technologies, characterization of properties to the evaluation of application characteristics. This applies to components made of these materials and their behavior within the system.

- Cooperative platform with contact to the market
- Coherent communication with the market
- Initialization and implementation of group projects and R&D cooperations
- Strategic pooling and further development of Fraunhofer competencies
- Coordination of internal Fraunhofer research programs
- Coordination of strategic investment planning of institutes in the group
- Advisory support for national and international R&D policies
- Advisory support and involvement in decisions made by the Fraunhofer executive board
- Implementation of decisions made by the executive board within the group
- Long-term, joint planning and operational platform

Budgeted expenditure, project and industrial revenues in the contract research segment in 2015, in € million



FRAUNHOFER MATERIALS – ADDED VALUE WITHIN A NETWORK

Fraunhofer EMI
Fraunhofer Institute for High-Speed Dynamics
www.emi.fraunhofer.de

Fraunhofer IAP
Fraunhofer Institute for Applied Polymer Research
www.iap.fraunhofer.de

Fraunhofer IBP
Fraunhofer Institute for Building Physics
www.ibp.fraunhofer.de

Fraunhofer ICT
Fraunhofer Institute for Chemical Technology
www.ict.fraunhofer.de

Fraunhofer ICT-IMM
Fraunhofer Institute for Chemical Technology, Branch ICT-IMM
www.imm.fraunhofer.de

Fraunhofer IFAM
Fraunhofer Institute for Manufacturing Technology and Advanced Materials
www.ifam.fraunhofer.de

Fraunhofer IKTS
Fraunhofer Institute for Ceramic Technologies and Systems
www.ikts.fraunhofer.de

Fraunhofer IMWS
Fraunhofer Institute for Microstructure of Materials and Systems
www.imws.fraunhofer.de

Fraunhofer ISC
Fraunhofer Institute for Silicate Research
www.isc.fraunhofer.de

Fraunhofer ISE
Fraunhofer Institute for Solar Energy Systems
www.ise.fraunhofer.de

Fraunhofer ISI
Fraunhofer Institute for Systems and Innovation Research
www.isi.fraunhofer.de

Fraunhofer IWES
Fraunhofer Institute for Wind Energy and Energy System Technology
www.iwes.fraunhofer.de

Fraunhofer IWES Northwest
Fraunhofer Institute for Wind Energy and Energy System Technology
www.windenergie.iwes.fraunhofer.de

Fraunhofer IWM
Fraunhofer Institute for Mechanics of Materials
www.iwm.fraunhofer.de

Fraunhofer IZFP
Fraunhofer Institute for Nondestructive Testing
www.izfp.fraunhofer.de

Fraunhofer LBF
Fraunhofer Institute for Structural Durability and System Reliability
www.lbf.fraunhofer.de

Fraunhofer WKI
Fraunhofer Institute for Wood Research
www.wki.fraunhofer.de

Host Institutes:
Fraunhofer IGB
Fraunhofer Institute for Interfacial Engineering and Biotechnology
www.igb.fraunhofer.de

Fraunhofer IIS
Fraunhofer Institute for Integrated Circuits
www.iis.fraunhofer.de

Fraunhofer ITWM
Fraunhofer Institute for Industrial Mathematics
www.itwm.fraunhofer.de

The institutes within Fraunhofer MATERIALS make an important contribution to meeting economic and societal challenges.

Prof. Dr. Peter Elsner
Chairman of the Fraunhofer Group for Materials and Components – MATERIALS

4563 employees*

2390 scientific staff*

15 member institutes + 3 associated members*

Research budget of 515 million euros*

* by 12/31/2015

OUR CORE COMPETENCIES

Primarily institutes from the Fraunhofer-Gesellschaft that are specialized in material science and engineering have joined Fraunhofer MATERIALS. Also, additional host institutes participate in the Group with expertise on systems and process engineering from their individual areas of application. In this manner, the Group pools together very wide-ranging knowledge and experience along the entire value chain and in all classes of materials.

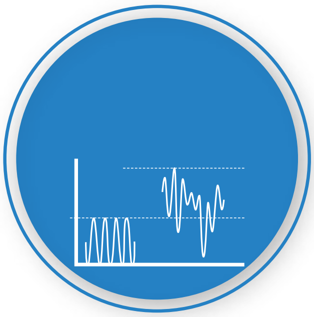
MATERIAL DEVELOPMENT

Materials play a special role in most product innovations. Material innovations either provide impetus for the development of a new product or the product development itself defines a specific profile of requirements for developing or improving new materials. According to studies made on the subject, approx. 70 percent of all new products are based on new materials. In addition, new materials are increasing in significance in terms of cost.

The institutes of Fraunhofer MATERIALS contribute extensively to innovation processes in the field of material development. Some examples for successful material development at Fraunhofer are high-performance polymer fibers for lightweight construction, ceramic fibers for high-temperature applications and matrix or composite fibers optimized for special areas of application. Further developments are found in nanoscale, semi-conductor, phase change or “smart” materials. Special ceramics also belong in the R&D range as well as functional polymers with specific properties (electric, electro-optical, optical and mechanical) or the specific adjustment of property profiles by means of new additives. Particular emphasis is placed on the development of bio-based and recycled materials.

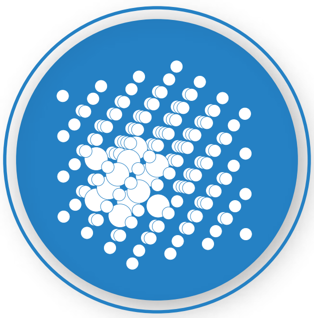
TECHNOLOGY DEVELOPMENT

Modern materials must meet the high standards in terms of their properties of characteristic profiles. Not only should they be light, resistant strong to loads, bio-compatible, durable, and “smart”, but also their manufacture, processing and disposal should be economic and resource- and material-efficient. In order to achieve these and similarly complex requirements, a wide spectrum of sophisticated material technologies is necessary in addition to the material development itself. The manufacture, treatment and processing steps are often decisive as to how efficient and competitive a material and the final product made from this material finally are in practice. With the development of advanced material technologies, the institutes of Fraunhofer MATERIALS make considerable contributions to meeting economic and societal challenges. Among the institutes’ areas of operation are the development and the application of selected technologies for surface finishing, coating and the functionalization of materials as well as the further development and optimization of joining and processing techniques or the development of entirely new processes and methods such as in the area of polymer synthesis, microforming, rapid prototyping and recycling.



EVALUATION OF THE APPLICATION BEHAVIOR

Fraunhofer scientists are commissioned by their customers to develop materials and technologies suited to individual application purposes, whether for vehicle construction, medical technology, energy production, or for static or highly dynamic stress. In order for the material and the components made from this material to actually prevail in practice, the different stages of the development process are accompanied by the appropriate method of analysis, characterization, testing and, finally, quality control and field tests. The Fraunhofer institutes within the Group offer a comprehensive range of methods and tests for the testing and evaluation of the functionality of structural durability on the one hand, and system reliability on the other. A number of numerical and experimental methods – destructive as well as non-destructive methods – are available on the micro and macro scale during the entire material and product life cycle. This also includes the "intelligent" methods of structural health monitoring or the in-line monitoring of production processes, i. e. by means of computer tomography. By further developing materials and products, testing procedures and evaluation methods likewise form part of the innovation process.



MATERIAL MODELING AND SIMULATION

Modern materials are developed with regard to their future application in products. This is based on a clear definition of the target properties for the materials. These target properties can ideally be broken down to the microstructural scale. Fraunhofer scientists design new materials on computers using simulation technology and virtually test their properties on micro as well as on macro scale. They collect data, work on corresponding material models and roughly predict how a polymer composite will react in an injection molding process. They carry out computer-based research to determine whether the customized anti-reflex coating for solar cells maintains the required properties during application or how the safety-critical zones of a lightweight body will react upon impact with an obstacle. Using material modeling methods, suitable simulation instruments and corresponding expert knowledge, it is possible to reduce the extent of cost and time-intensive tests series and to considerably shorten development time. Modeling and simulation techniques are applied and are further developed for specific applications at institutes of the Fraunhofer MATERIALS Group.

OUR BUSINESS AREAS

Advances in materials science and engineering are essential for innovations in all fields of technology and often provide the necessary impetus. The availability of optimized materials and the related manufacturing and processing technologies are decisive factors for the competitiveness of economic areas. Fraunhofer MATERIALS deals with a multitude of challenges and works on tailored solutions in the following key areas.

ENERGY AND ENVIRONMENT

Energy and resource efficiency to ensure an affordable, reliable and at the same time environmentally-friendly energy supply for a growing world population is not conceivable without material innovations. The requirements for a transformation of the energy system with regard to energy production, transport, supply and storage are defined by particular challenges for materials and material technologies. The availability of certain raw materials for a number of high-tech applications also plays a key role. The development of efficient recycling methods and widely-available, efficient substitute materials are urgent research issues.

MOBILITY

An efficient transportation system is essential for a modern society, economic growth, employment and prosperity. In addition to electronics, materials are essential innovation drivers for mobility and transportation. Competitive material and system solutions for road- and rail-bound vehicles, in aviation and in shipbuilding must meet specific requirement profiles for resource- and energy-efficiency, lightweight construction, safety, system reliability and comfort. This applies to electric vehicles as well as to combustion engines or hybrids.

HEALTH

Demographic change, the spread of new types of diseases as well as increasing individual health consciousness create high demands on an efficient and affordable health care system. This results in a greater need for innovative material systems for prevention, diagnosis and therapy. Material innovations enable new approaches in drug research and increase the lifespan and bio-compatibility of medical products.

MECHANICAL AND PLANT ENGINEERING

The ratio of material expenses in Germany's manufacturing sector is considerable. Materials, processing and manufacturing techniques are closely intertwined. Coordinated modifications of material properties, processing and production methods are key to improving the performance of products. Optimized material application on the one hand and the product-ready development of new materials on the other can considerably increase productivity and quality. The modeling and integrated simulation of materials and processing steps together with a continuous flow of material data speed up the innovation process.

CONSTRUCTION AND LIVING

Housing is one of man's basic needs. In order to create affordable housing at a high standard of living while simultaneously realizing energy-efficient, sustainable construction methods requires a strategically intelligent application of materials and material systems. This applies to new constructions as well as to the renovation of old buildings. Important goals during the development of new materials and production methods are saving energy and reducing CO_2 emissions as well as the recycling and the recovery of raw materials.

MICROSYSTEMS TECHNOLOGY

The market for microelectronics and microsystems technology is highly dynamic. Innovation cycles are quite short and the added value of material application is extremely high. Further increase of the integration density, on the one hand, and the application of scarce, expensive or toxic raw materials on the other are central themes that require a very high functional and performance capability of the applied material systems. The decisive factor in many cases is their structure and composition on the atomic scale.

SECURITY

Protecting people, buildings and infrastructure from natural catastrophes, accidents or terror attacks is becoming an increasingly challenging task. Efficient materials within specific protection concepts can contribute considerably to greater security and damage control. The prerequisite for their development is an in-depth understanding of the behavior of materials, components and structures under extreme stress conditions such as impact or explosions.

Reactor for biodiesel synthesis under supercritical reaction conditions.
© Fraunhofer ICT-IMM

ENERGY AND ENVIRONMENT

- **Manufacture of Biodiesel in a Supercritical Process – New Methods Promise Increase in Efficiency, Environmental Benefits and Cost Reduction – To be Demonstrated on Laboratory Scale**

In this project, which is financed by the Energy and Climate Fund of the Federal government via the Agency of Renewable Resources (FNR), the usual transesterification of plant oils that takes place during the manufacture of biodiesel is carried out using supercritical methanol. Instead of the conventional fluid reaction accelerator, Fraunhofer ICT-IMM uses innovative, heterogeneous catalysts that are applied as a coating in microscale reactors.

Supercritical – this is the thermodynamic condition which materials reach at a certain constellation of temperature and pressure, and at which the properties of fluid and gas merge without phase separation.

A small laboratory installation is to be tested that manufactures biodiesel from different plant oils at considerably higher reaction speeds. A result of the supercritical process management is that reaction time is shortened and several process steps such as recovery of the catalyst are eliminated. By means of the concept presented here, the transesterification rates are increased, the size of the reactor and water consumption are decreased and, simultaneously, the sensitivity of the process to traces of water in the raw material decreases as well.

Also the reduced need for methanol, the greater purity of the by-product glycerin and the high long-term stability of the catalyst are further advantages. The process does require greater pressure and higher temperatures but, due to the process optimization, the overall energy consumption is still lower than with conventional methods. The supercritical process offers great economic potential.

Demonstration plant. © Fraunhofer ICT-IMM

BladeMaker – integration, evaluation and demonstration of industrialized manufacturing processes for rotor blades. © Fraunhofer IWES Northwest / photographer: Harry Zier

BladeMaker – Industrialized Rotor Blade Manufacturing

The BladeMaker center has been set up as an open platform to the industry for the joint development and testing of innovations together with Fraunhofer IWES and 15 partners. The goal is to achieve savings of up to 10 percent through more efficient production processes, the use of innovative materials and carefully selected automation approaches. A verified cost model that has been developed in close collaboration with a large number of blade manufacturers has confirmed the feasibility of this aim.

Blade sections measuring up to 25 meters (scale 1:1) for blades in the 50-meter class can be used in the workshop. The L-shaped design of both gantry systems offers two advantages: First, loading and unloading from the side is possible. Secondly, the robot combines the precision of a milling machine with a load-bearing capacity of up to 500 kg. Contrary to the general trend in composite manufacturing, linear drives with additional rotational degrees of freedom are preferred to a robot solution. This concept offers advantages with regard to precision and flexibility in setting up new processes. The next milestone will be the production of a model blade which will pass through the various production steps. This will provide an opportunity to identify areas for improvement as well as compare and assess results.

Integrated machinery concept

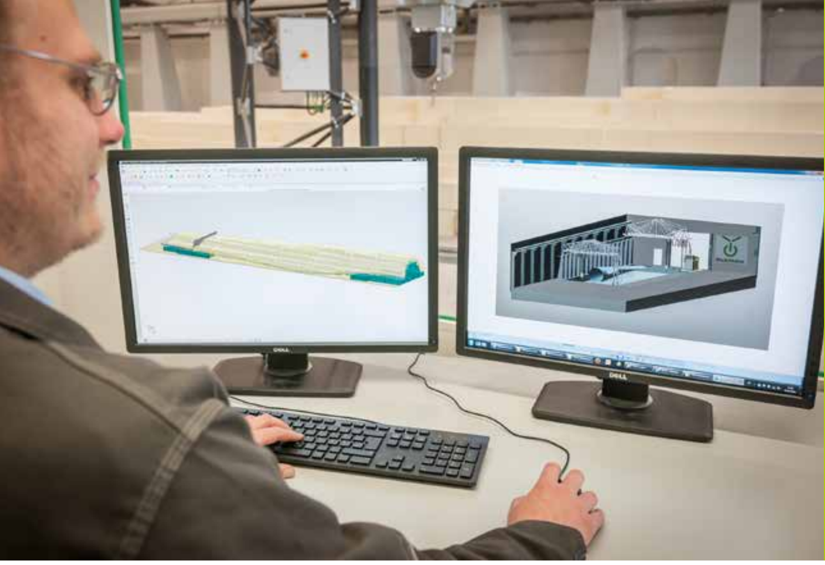
The opening of the "BladeMaker Demonstration Center" marks a major milestone for the publicly funded "BladeMaker" research project. In addition to investing in infrastructure, innovations along the complete process chain of blade manufacturing are also to be developed. The requirements of an integral solution for the industrialization of the entire rotor blade manufacturing process are in part contradictory. The key processes involved in the manufacturing of the rotor blade structure made of fiber composites require high loading of the machine for the semi-finished products to be processed, after all a rotor blade in the 50 m class can weigh up to 12 tonnes. Yet, on the other hand, the prerequisites in terms of accuracy are not as demanding as for subsequent machining; here tolerances of just a few fractions of a millimeter are necessary at times. The integrated machine concept with its high speed and low tolerances is able to satisfy the demands of both production and further processing.

Vertical integration of design and production

The two gantry robots made of fiber composite serve to frame the working area for blade sections.

They move along the lines at a maximum speed of 2.5 m/second. A heavy-load platform for transporting the semi-finished products and materials is towed along the floor to facilitate the setting up of the gantry. The CNC control from one of the project partners allows the design and production stage to be linked.

The machine is programmed and operated via a CNC control, which, in this form, represents a new approach. The advantages of simple handling and vertical integration of design and production in order to simulate the process steps in advance can now be exploited for the very first time. Given the structural design of the former building, integration of the portal system presented no problems at all.



© Fraunhofer IWES Northwest / photographer: Harry Zier

One gantry robot fits various production steps

In contrast to a purely automated approach, "BladeMaker" is focused on the industrialization of the entire process. In this context, new materials or the application of the semi-finished products have to be improved to open up further opportunities for reducing costs and manufacturing time. In addition to the direct tooling approach, Fraunhofer IWES has set up an innovative process chain together with specialized partners for the manufacturing of rotor blade molds. Thanks to the special gantry robots made of fiber composite structures, various production steps, which would normally be conducted at different machines, can be performed at the same workstation by simply changing the process head.

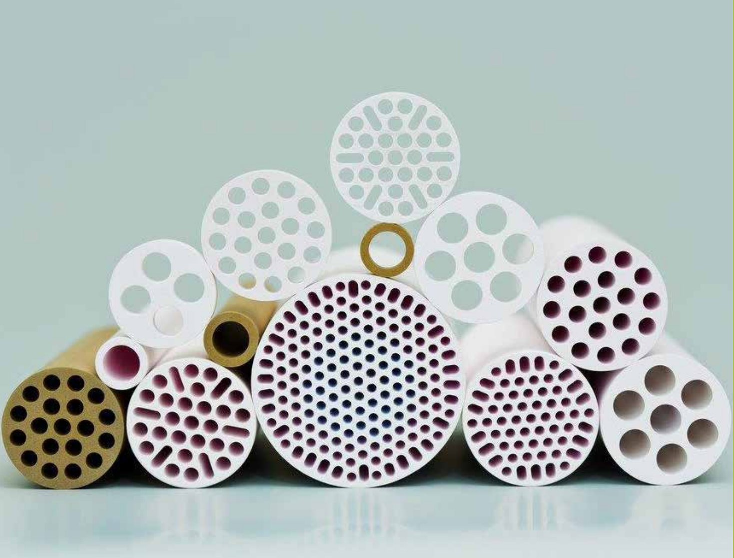
Based on the results of the generic cost model for rotor blade production, the main cost drivers have been identified. The production of the spar cap, positioning of the textile blanks for the root area in the mold through to alignment of the layers, innovative in-situ core concepts, direct infusion of the resin, application of the adhesive, and surface finishing to prepare for varnishing, all offer potential for cost savings.

The manufacturing of rotor blades still demands a high degree of manual labor. This is due to the low number of pieces in each production lot compared to the automotive industry for example: Whilst in the latter sector, models roll off the line hundreds of thousands of times, the tool mold for a rotor blade is only used as a template a few hundred times. Comparing the weights of components from blade and automotive production, the former are much heavier. Yet, for manufacturers, the ability to produce parts more quickly and with a constantly higher level of precision can result in significant cost advantages.

Full-scale demonstration in 2017

The project will end in fall 2017 with a full-scale process demonstration using a blade design developed by Fraunhofer IWES that will be available to interested parties. The results of the "BladeMaker" project will give quality-conscious manufacturers a competitive edge and, ultimately, also render the generation of wind energy more cost-efficient. The equipment in the "BladeMaker Demonstration Center" is available to the blade industry as well as material suppliers and mechanical engineering companies.

The project is funded by the German Federal Ministry for Economic Affairs and Energy to the tune of around € 8 million.



Ceramic membranes of varying tube geometries.
© Fraunhofer IKTS

Quantum dots enable the manufacture of any color in a highly brilliant quality.
© Fraunhofer IAP

Ceramic Membranes for Waste Water Management and Water Treatment

Water is indispensable as a foodstuff as well as for agricultural and industrial production. It is therefore paramount to use this important resource with care. In this context, the processing industry is in need of safe and fully multifunctional components for water treatment which are lightweight and allow integration into the companies' existing supply infrastructures as well as into modern manufacturing concepts. In addition, these components should not only do without chemicals as operating materials, they should also be able to recover valuable constituents, concentrate any contaminants occurring in the process and break them down without residues.

While industrial processes are characterized by high salt loads and persistent organic residual materials from production and cleaning processes, which stand in the way of any effective closed-loop circulation, urban waste water treatment is more concerned with microbiological pollutants from pharmaceuticals, technical microplastics and nutrients, all in low concentration. Ceramic membranes provide technological solutions for the manifold issues that arise in water and waste water treatment. These are characterized by their high flow rates as well as by their reliability under extreme chemical and thermal conditions.

The objective of membrane development at Fraunhofer IKTS is to further improve separation efficiency and selectivity, to increase the membrane surface per ceramic element and to synthesize membranes for new separation tasks. In a group project, for example, it was possible to develop a separation limit of 200D that could be successfully implemented in the treatment of mercerization solution, in the cleaning and recycling of wash water from textile finishing and in the treatment of bleaching solutions.

Highly Efficient, Cadmium-Free Quantum Dots for QLEDs and Solar Cells

Quantum dots (QD) are a new class of fluorescent nanomaterials. Extremely brilliant colors can be created very efficiently with the tiny nanocrystals. Their absorption and emission properties can be customized in a unique way by changing the particle size. Modifying the surface of the particle tailors it to its chemical environment. Almost the entire spectral range is available by means of targeted synthesis.

These unusual properties enable applications in very different areas such as in luminescent materials, display technology, for upconversion in photovoltaics, or for security features in banknotes.

However, conventional QDs contain the toxic heavy metal cadmium. The synthesis of cadmium-free quantum dots is developed at Fraunhofer IAP for this reason. These are based on environmentally friendly indium phosphide (InP / ZnS multishell QDs) and can be used as fluorescent material for LEDs, as emitting material in OLEDs or as filters for the LED back lighting of LCDs, with which a higher color brilliance of the LCD display is achieved.

Infrared-active QDs based on copper indium sulfide ($CuInS_2$-QDs) can also be used in solar cells to increase efficiency.

In comparison to conventional QDs, the cadmium-free materials from Fraunhofer IAP also attain high quantum yields. Up to several grams of cadmium-free QDs can be manufactured per hour with the aid of a flow-through reactor that can run continuously.

These can then be printed on solid and flexible carrier materials, just as in an inkjet process. A pilot facility is available at Fraunhofer IAP.

Rotor blades, solar modules and winter sports articles can be equipped with anti-icing coatings.
© Fraunhofer IGB (host institute)

Newly developed PLAs are processed at Fraunhofer IAP by means of extrusion.
© Fraunhofer IAP

Anti-Ice Coatings

The icing of surfaces is a widespread problem. The Fraunhofer Institute for Interfacial Engineering and Biotechnology uses plasma technology to apply water resistant micro- and nano-structured coatings to polymer films made of impact and shockproof polyurethane (PU) or other material surfaces for effective anti-icing.

The coatings, only a few nanometers thick, change the wetting process of surfaces in that the water is repelled from the surface. This way the water remains fluid on the coated surfaces even at temperatures below zero degrees since the coatings prevent the formation of crystal nuclei, thus leaving the water in a super-cooled state.

In ice chambers at temperatures of minus 30 degrees it can be seen that the anti-ice coating reduces the adhesion of ice by more than 90 percent. The coating is weather-resistant, dirt repellent and easy to clean in addition to being environmentally friendly and inexpensive to manufacture.

Flat materials like textiles and three-dimensional moldings up to a certain size with surfaces made of different materials like lacquers, metals and polymers can be directly coated. Even the anti-icing of outdoor and winter sports articles such as ski goggles, winter sportswear and tents or rucksacks is possible with this method.

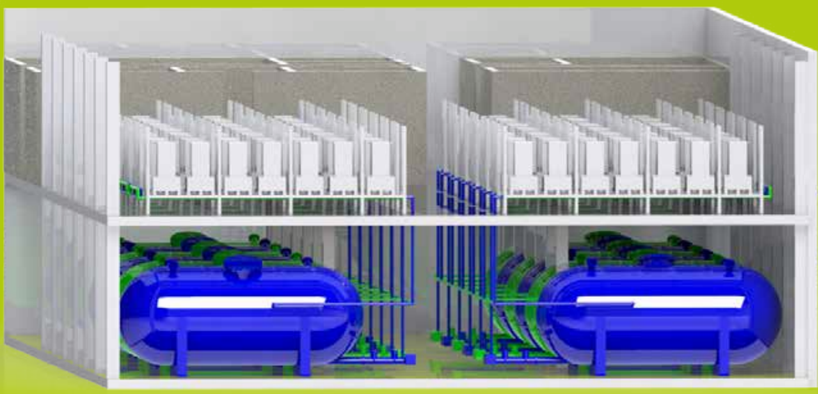
Functionalized films can be applied to aircraft wings, rotor blades of wind turbine plants, solar modules, overhead electric lines, buildings parts and facades, and even on sports equipment such as skis and snow boards. Anti-ice films can also be easily applied to cooling units or in refrigerators and can be replaced any time.

Making Biopolymers Suitable for Industrial Application

Even though the share of biopolymers on the entire polymer market is still marginal, the exceptionally high growth rates are an indication of a greater acceptance of this class of materials. The industrialization of bio-based polymers is currently most advanced in the field of polyactide (PLA). PLA is a thermoplastic polymer based on renewable resources. Its basic building block, lactic acid, is obtained by the fermentation of glucose or starch. With respect to its mechanical properties, PLA attains a level that corresponds to that of conventional mass polymers. Combining this with the unique barrier characteristics and biodegradability of PLA opens up a wide range of applications for PLA in the packaging sector.

New types of PLA and their applications are being developed at Fraunhofer IAP. This includes not only films but also fibers, fiber composites, non-wovens and molded parts. The focus is on optimizing the performance characteristics of the material and on making manufacturing processes suitable for the industry.

Structural variations of PLA that are suitable for industrial application are being developed to improve barrier characteristics, heat resistance, thermal stability and mechanical properties while taking into account the effect on processability under near-real conditions. The developed synthesis processes are additionally checked for their scale-up potential. A mini-plant synthesis facility enables the manufacture of up to 5 kilograms of PLA per batch.



Redox flow battery.
© Fraunhofer ICT

Redox Flow Batteries for the Storage of Renewable Energy

Energy provided by sun and wind rarely corresponds to the actual demand at a given point in time. This is the reason why the storage of electrical energy, particularly for large-scale application, has become one of the greatest challenges in energy technology. A better adaptation of stored reserves to changing needs is economically possible, particularly when decentralized storage facilities with a cost-efficient battery capacity are implemented.

The power output and energy of redox flow batteries can be individually scaled, enabling decentralized energy storage in the range of a few kilowatts up to several megawatts. The advantages of this type of battery are the large and flexible storage capacity, potentially low storage costs as well as a long lifespan. The current state of the art is the storage of surplus energy in lead accumulators. However, these only last for a limited number of cycles and usually have to be replaced after three to five years. Depending on the chemistry, redox flow batteries have a comparable energy density; however, their life span is several times greater than that of lead accumulators.

The principle of redox flow batteries is the storage of chemical energy in dissolved redox pairs in external tanks. Power conversion takes place in a separate power module. During discharge the electrodes are continuously supplied with the solutions from the storage tanks, and the resulting product is discharged into the same tanks. Charging can be carried out by simply reversing the direction of the current. This type of storage could be used for hourly storage in large applications of several megawatts, since the storage capacity is largely determined by the amount of electrolyte solution, and the efficiency is over 75 percent.

Redox flow batteries have been developed and researched at Fraunhofer ICT since 2006. In the area of materials, research focuses on active substances such as electrolyte formulations as well as the modification of electrodes and membrane material. In order to manufacture cell stacks more economically, high-performance carbon-polymer composites for electricity conductors – so-called bipolar plates – are developed at Fraunhofer ICT. In addition to the membranes, these materials are the current cost drivers of flow batteries. In addition, methods are being developed for the characterization and classification of materials. This enables the comparison of different redox flow batteries and their materials in one installation, in order to evaluate the advantages and disadvantages of each system.

The objective of the large-scale redoxWind project is the practical implementation of a redox flow battery within an existing electricity network, for the storage of fluctuating energies from wind or photovoltaic parks. A redox flow battery with a performance of 2 megawatts and storage capacity of 20 MWh is being developed at the institute for this purpose. A 2-megawatt wind turbine with a hub height of 100 meters is being built directly next to the large battery to supply electricity. This system will be integrated into the institute's network to supply different consumers.

Advances achieved by Fraunhofer ICT compared to the state of the art:

- Modular concept of a large-scale storage system in megawatts / megawatt hours
- Cell frame design and production in polymer injection molding suitable for large-scale use
- Cost-optimized, highly conductive polymer carbon composites as bipolar plate materials for new production technologies (e. g. 2-component injection molding)
- Flow battery certification according to IEC standards
- Optimized electrolyte formulations for vanadium and bromine systems; development of specifications and special analytics
- Development of demonstrators for special applications, e. g. hybrid storage as an uninterruptible power supply (UPS) with low self-discharge.

Example of magnetic scrap material.
© Fraunhofer IFAM

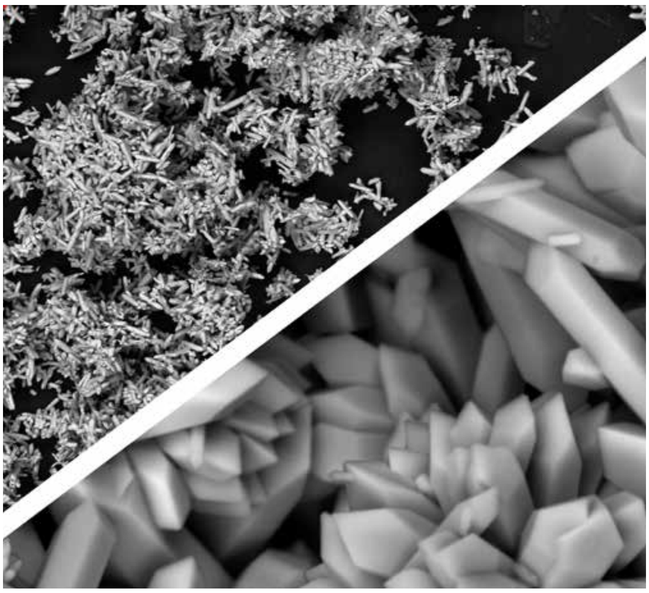
Recycling of Rare-Earth Magnets and Production Waste

Ever since China imposed export duties on certain rare earths in 2010 and 2011, an important economic strategy of the German government has been to decrease dependence on the import of these rare earths. The three most important options for achieving this goal are for Germany to develop its own primary deposits, the reduction and substitution of certain rare earths, and the recovery of secondary raw materials by means of recycling.

Although neodymium, praseodymium and dysprosium are the most economically significant of all rare earths due to their importance in the manufacture of high-performance NdFeb magnets, efforts, thus far, for a targeted recovery of these elements have been insufficient. In particular, only few promising approaches exist for the processing of old magnets and magnet waste that, on the one hand, exploit the full potential of the already separated rare earth elements they contain and, on the other, are able to remove unwanted impurities (e. g. oxide, organic compounds).

This is where the hydrometallurgical recycling process developed by Fraunhofer IFAM Dresden comes in, achieving the targeted recovery of the elements neodymium, praseodymium and dysprosium from material mixes. The process is based on the idea that by skillfully exploiting physical correlations and by optimized process control it is possible to attain a selectivity high enough to eliminate a time-consuming and costly precision separation process of the rare earths involving ion exchangers or fluid-fluid extraction plants. However, for the production of new, higher-grade NdFeB magnets, it is essential that particularly samarium, which is contained in magnet material mixes, as well as oxide and organic impurities, are separated.

It could be shown in the framework of development projects that this necessary selectivity during the recycling of magnet material mixes can be realized on a laboratory scale, particularly by means of appropriate physical pretreatment and pre-separation as well as by means of a controlled hydrometallurgical process. A corresponding recycling process has already been registered for patent approval.



Product containing neodymium during the recycling process.
© Fraunhofer IFAM

Composite rotor blade: cross section (above) and shredded (below).
© Fraunhofer ICT

Recycling of Large-Scale Composite Components – Rotor Blades

Composites made of reinforced fibers with thermosetting polymers as a matrix material have been the center of new material developments for a number of years, due to their enormous lightweight construction potential and high economic efficiency. Composites are increasingly being incorporated into new products and, consequently, large quantities of these materials will need to be recycled in the future. In addition to fiber-reinforced polymers, filling materials like balsa wood or polymer foam as a sandwich construction are applied to the rotor blades of wind turbines to save additional weight. The advantage of hybrid materials – that, with the right mix of materials in the composite, they can be adapted to individual requirements – has turned out to be a disadvantage with regard to disposal. The recycling of these composite materials, and in particular the separation of the components without forfeiting the desirable properties, is still an unresolved problem.

The development of an economical and ecological recycling solution for composites must take into account the entire recycling chain, from dismantling and treatment through to the provision of processable secondary raw materials. However, these steps prove to be difficult, particularly with large-scale components like rotor blades. With today's state-of-the-art technology, dismantling only enables the transport of rotor blade segments that do not require authorization. It does not serve the purpose of separating them into individual fractions. Rotor blades currently requiring disposal are made of glass-fiber-reinforced polymers containing a polymer foam or basal wood sandwich construction. Large metal bolts are located at the flange, which connects the rotor, and copper lines are contained inside the blades to act as lightning conductors. Some manufacturers also integrate carbon-fiber-reinforced polymers into particularly stressed areas in some of the latest generation of rotor blades. Current research work also focuses on the application of thermoplastic structures in rotor blades, which further contributes to the existing material mix. A separation of individual fractions at the contact point would make the subsequent processing and material recovery more efficient. Up to now, the recycling process for rotor blade materials was a mechanical shredding of the entire composite, which was then used as a combustible or sand substitute in the cement industry, or for thermal recovery in waste incineration plants.

The use of energetic dismantling to separate rotor blade materials into different fractions, as well as the subsequent material-specific processing, are being researched at Fraunhofer ICT within the framework of the ForCycle project on "Recycling of Composite Components made of Polymers as Matrix Material". The objective of the project is the recovery of secondary raw materials for renewed, high-quality application. The technological possibilities for recovering fiber material comprise mechanical, thermal and also chemical processes. In cooperation with the Technische Hochschule Nürnberg, the separation of fibers from the matrix material is researched in addition to the recovery of these resins and fillers, in order to achieve an ecologically and economically efficient recycling process. The sustainability of the new developments is shown in a final evaluation of the new processes and materials as well as through a comparison with the state of the art in the recycling of rotor blades.

Molecular sorting.
© Fraunhofer IBP

Prospects in the Recycling Economy

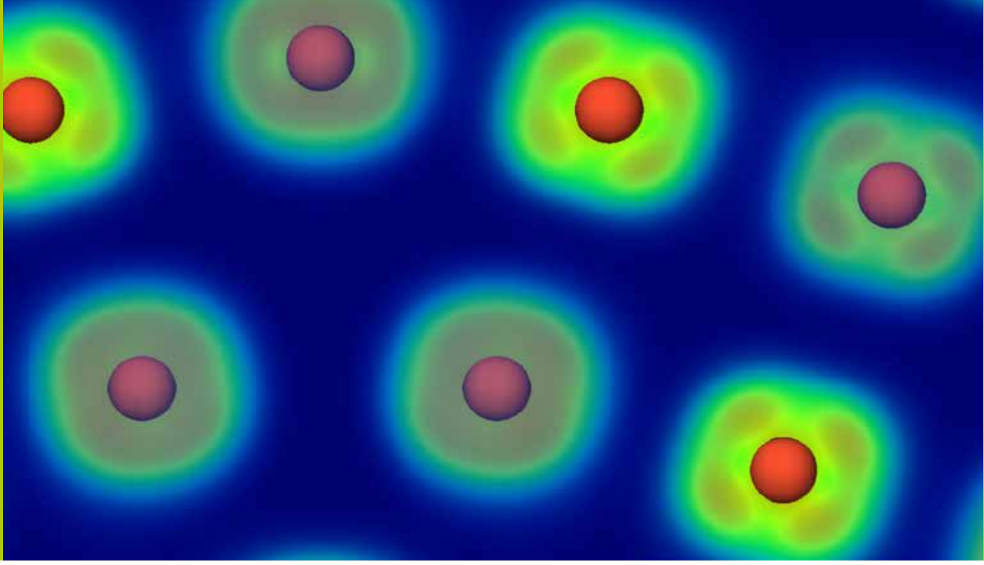
Be it rubble, scrap wood, waste incineration slag, carbon-fiber-reinforced composite materials or electronic scrap, several million tonnes of these types of waste are produced worldwide every year. The Fraunhofer Institute for Building Physics conducts research on the method of electrodynamic fragmentation for the recycling of composite materials. The method is based on the principle that ultra-short (<500 nsec) underwater impulses cause selective fragmentation of composite materials. The electrical discharge runs along phase boundaries, thus disassembling the composite material into its components. The advantage of this method is a dust- and contamination-free separating process and, unlike in a mechanical process, no abrasion occurs.

Concrete is the most commonly used building material in the world. It is made of cement, water and aggregate like gravel or limestone with different sized grains. Mineral construction waste amounted to a total of 186.5 million tonnes in 2010, 53.1 million tonnes of which was rubble (this corresponds to 28.5 percent). Up to now, concrete rubble has produced enormous amounts of dust when crushed, and it mainly ends up as a sub-base for roads. However, with electrodynamic fragmentation, construction and demolition waste can be recycled to produce high-quality aggregates for the production of fresh concrete and a raw material for the production of cement.

Fraunhofer scientists see great potential in the recycling of waste incineration slag. 420 million tonnes of this material is produced worldwide every year. Applying electrodynamic fragmentation would not only preserve increasingly scarce landfill space but also attain a considerably higher recovery rate of valuable secondary raw materials and metals.

An additional area of application is the aviation industry. The increasing installation of carbon-fiber-reinforced polymers in aircraft calls for a recycling technology that conserves important resources and reintroduces recycled carbon fibers into new products in an economical manner. The same applies to electronic scrap as well as many other composite materials that, up to the present, could not be disassembled cleanly enough or not at all.

Parallel to the development of the process, scientists are creating an ecological balance sheet for the product system of every method developed in the Fraunhofer-internal project "Molecular Sorting". The obtained information is fed back to the developers in several iteration loops. The end result is processes in which ecological analyses play a key role.



Magnetic spin polarization at a grain boundary in a ferromagnetic metal on an atomic scale. © Fraunhofer IWM

High Throughput Screening for the Development of New Permanent Magnets

Dynamic growth in the field of electromobility and renewable energy has greatly increased the demand for permanent magnets made of rare earths (RE) and transition metals (TM). Due to the scarcity of the RE resources required for these technologies, attempts are being made to identify new, intermetallic RE-TM phases. These should have good magnetic properties, and should be made of sustainable and cost-effective raw materials and be less dependent on individual RE elements.

The crystal structures of the most common permanent magnets such as $Nd_2Fe_{14}B$ are variants of the "topologically densely packed" (TCP) phases. These TCP phases offer many possibilities for new magnetic phases: RE atoms are surrounded with TM atoms to the extent that large, direction- and temperature-stable magnetic moments are created. Such magnets can fill the gap between cost-effective ferrites and $Nd_2Fe_{14}B$ high-performance magnets, while having the lowest RE content possible.

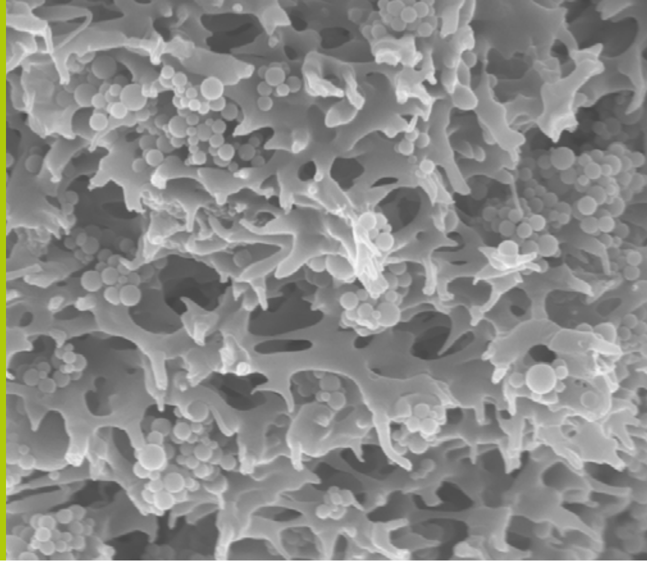
Simulative and experimental high throughput screening methods are applied in order to systematically examine the numerous possible RE-TM combinations for good, magnetically hard properties. The intrinsic magnetic properties, local magnetic moments and effective exchange integrals are computed or predicted at Fraunhofer IWM with a quick density functional theory (DFT) method for real and hypothetical magnet phases. Literature and data bases provide many crystal structures for TCP phases as input data for DFT simulators. A first new RE-TM phase could be theoretically predicted and experimentally confirmed. This is an indication of a high success potential of physical material modeling with regard to new high-performance magnets.

Rapid Test Development for the Potential-Induced Degradation of Solar Modules

Potential-induced degradation (PID) is currently one of the detrimental and frequent causes of performance loss in photovoltaic modules with crystalline silicon solar cells. PID leads to a significant decrease of the power output and even to a complete destruction of the module. Fraunhofer IMWS has clarified the physical principles of the defect mechanism. It was found that minute defects on the nanoscale level are the cause of performance loss and even total failure in large solar modules. PID is caused by silicon decorated crystal defects crossing the p-n junction of the solar cells. The silicon decoration leads to an electroconductive change through the p-n junction and thus to a shortening of the p-n junction leading to a decrease of the power output of the affected solar cells within the module. A test procedure on the cell level was developed and patented based on this basic understanding of the PID effect.

Fraunhofer CSP has developed a method and a test apparatus to create PID in the laboratory and to study material influence on solar cells and encapsulation material. Its partner Freiberg Instruments GmbH developed the "PIDcon" appliance to market maturity. This appliance is based on the test procedure that is registered for patent approval. With this method, the cost of research on solar cells for PID vulnerability, a procedure that is of great interest for solar cell and module manufacturers, is reduced to a fraction of the cost of regular PID tests on solar modules in climatic chambers. With the objective of contributing to production with PID stable and yet more cost-effective photovoltaic modules, Fraunhofer IMWS is working on the development of new encapsulation material, surface textures and coating processes for solar cells.

Molecular sorting – selective recovery and separation of metals.
© Fraunhofer IGB (host institute)



Molecular Sorting – Selective Recovery and Separation of Metals

Because of their value (precious metals), availability (rare earths) or toxicity (heavy metals), the recycling of raw materials, particularly special metals, is of great importance, both for industrial production and for the environment. Even if present in small concentrations, the overall amount of metals contained in process and wastewaters may be significant. In order to close material cycles in production and recycling, even low concentrated dissolved metals must therefore be recovered and processed.

Need for new recycling technologies

When processing secondary raw materials, new technologies must be developed that are efficient, easy to integrate and flexibly applicable to different groups of metals in order to achieve a quality level equal to that of primary raw materials. Fraunhofer IGB has carried out research on technologies that are exemplary for the recovery of metals in the "Molecular Sorting" project which forms part of the Fraunhofer "Markets Beyond Tomorrow" initiative. In this project, technologies for the process steps of extraction (bioleaching), concentration (adsorption and membrane filtration), separation (electrophoresis) and deposition are examined, further developed and integrated into an overall process.

Biotechnical metal extraction

For the efficient processing of solid materials like electronic scraps or ash it can be advantageous to first convert metals into a water-soluble form before they can be extracted, separated and released as solid matter. This is called biotechnical metal extraction when microorganisms are involved in the process. A well-researched process is so-called bioleaching with acid-forming, aerobic microorganisms that oxidize iron (II) or sulfur compounds to metal ions and sulfate in an acid solution. At Fraunhofer IGB, appropriate microbial mixed populations were enriched in aerobic as well as anaerobic approaches, and technical processes were developed in which microorganisms were immobilized for a sufficiently high catalyst density und thus retained in the reactor.

Selective removal and concentration with membrane adsorbers

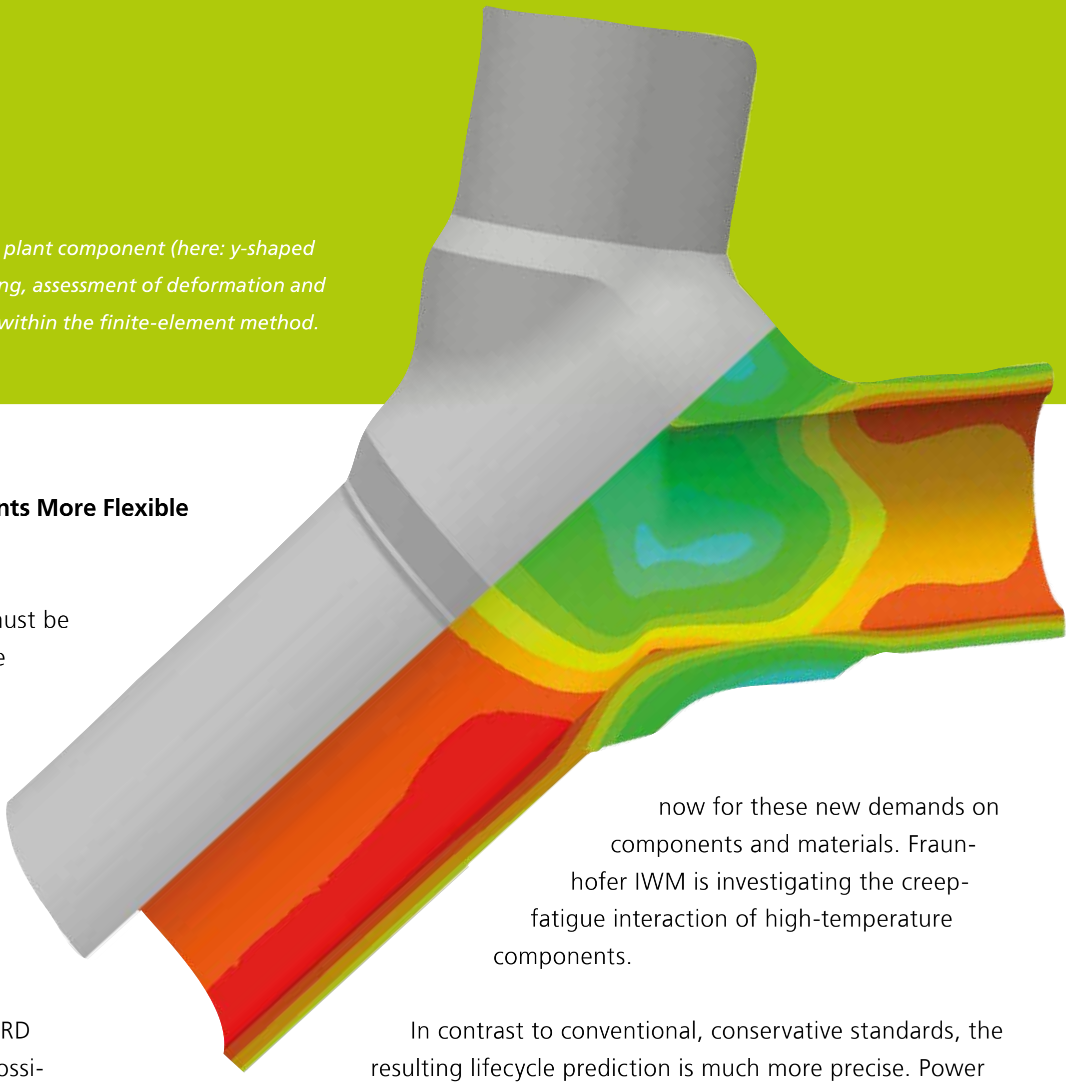
Polymer adsorber materials were developed for the selective separation and concentration of metal ions and integrated into the porous structure of filtration membranes in order to combine adsorption with membrane separation, with the aim of process intensification. By varying the particle surfaces and combining different functionalized particles, the separation properties of the completely regenerable membrane adsorbers can be adapted flexibly for applications in the areas of drinking water, process water and waste water. For example, membrane adsorbers with thiourea groups selectively bind over 0.8 g silver per m^2 whereas copper and lead adsorb very well on a phosphonate membrane adsorber (5g lead per m^2).

Fractionation and deposition with electrophysical processes

Metal ions, which are very similar due to their chemical and physical properties, can only be partially separated with conventional technologies. However, this is possible with a high degree of selectivity using a free-flow electrophoresis prototype developed at Fraunhofer IGB. In research carried out with exemplary metal ion mixtures (copper – iron, neodymium – iron, iron – copper – neodymium), we were able to increase the metal ion purity to over 90 percent within a single cycle. The addition of complexing agents led to an almost complete separation of substance mixtures.

Ionic liquids were selected as electrochemically stable electrolytes for the galvanic deposition of metals following fractionation and were successfully applied in a reactor system for the metallic deposition of rare earth metals.

Analysis of a thick-walled power plant component (here: y-shaped piece) under creep-fatigue loading, assessment of deformation and lifetime using advanced models within the finite-element method.
© Fraunhofer IWM



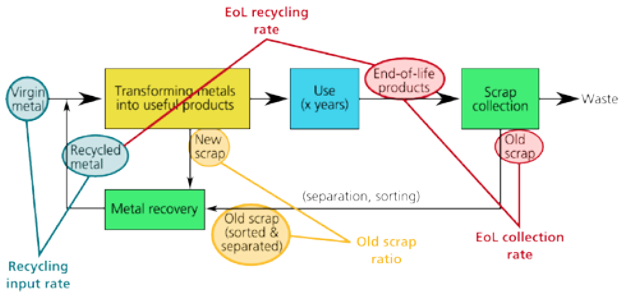
Making Coal Power Plants More Flexible and Durable

Existing coal power plants must be operated more flexibly in the future. A central question here is what influence the flexible operation mode has on the remaining service life of the power plant components. In the past, these have almost exclusively been designed against creep rupture with TRD or EN standards. Now it is possible to make more precise service life predictions using a new method developed by Fraunhofer IWM taking into account the complex interaction between creep arising from steady state operation and fatigue due to thermal transients generated by flexible operation. Power plant operators will be able to save money, optimize their operations and make their facilities fit for the future using Retro-Fit.

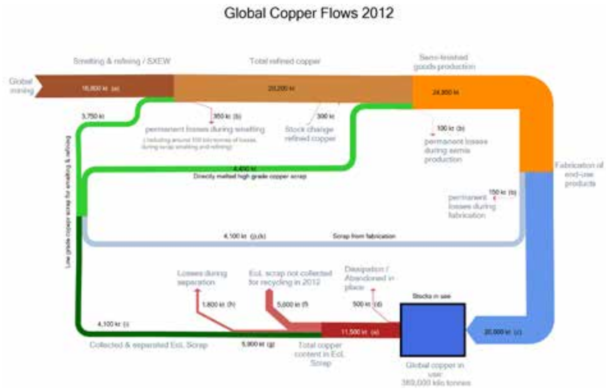
In order to balance out electricity fluctuations coming from regenerative energy sources, conventional power plants will increasingly have to be started up and shut down more quickly in the future. Long-term research and reliable computation methods, however, have not existed up to now for these new demands on components and materials. Fraunhofer IWM is investigating the creep-fatigue interaction of high-temperature components.

In contrast to conventional, conservative standards, the resulting lifecycle prediction is much more precise. Power plant operators can avoid the early and expensive replacement of components and can make more solid business decisions on modes of operation.

New materials hold the promise of extending the lifetime of steam cycle components. According to experiments and results of the advanced simulation methods, components made of the nickel-based Alloy 617B last up to six times longer than the same components made of traditional (ferritic-martensitic) power plant steels. In addition, the power plant may be operated more flexibly by lining the component with thinner walls. A longer lifetime and the reduced amount of material make up for the higher per ton price of the alloy.



Simplified cycle for metals and quality (green-yellow-red) of recycling indicators without dynamic material flow model.
© Fraunhofer ISI / POLINARES Project



Global copper flows 2012.
© Fraunhofer ISI

Evaluating and Improving the Reliability of Raw Material Supply

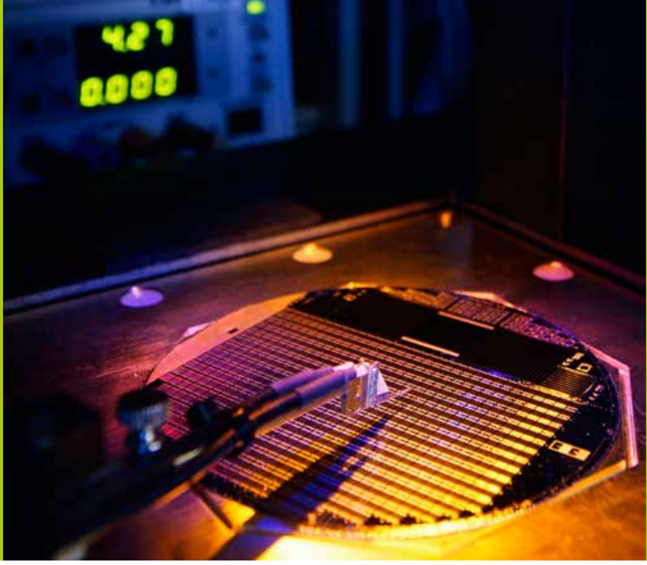
A reliable supply of raw materials is necessary for the EU and especially for German industry. To be able to react appropriately to the challenges posed by changing international raw materials markets, both an understanding of the challenges and an evaluation of potential solutions are necessary. An important step in this assessment is the identification of critical raw materials, where both the likelihood of a supply shortage and the consequences of such a shortage are seen as high. Fraunhofer ISI has supported this identification process particularly at the EU level by playing a key role in the compilation of the lists of raw materials for the EU in 2010 and 2014. These analyses had – and still have – an important influence on the actions of the EU for improving the supply of raw materials, including EU research funding.

Future developments are also important for a successful positioning in changing markets. Fraunhofer ISI supports this positioning with studies on the demand of raw materials for emerging technologies, with the creation of (technology) road maps and with modeling tools that incorporate increases in efficiency, substitution, recycling and the contribution of primary raw materials. This makes it possible not only to estimate the effect of individual developments but also to consider the multiple facets of raw material extraction and usage. This includes, for example, miniaturization and recycling technologies as well as new materials and products, which can in part substitute for others, as well as changes in the relevant policy framework. By determining together with its clients the most important research issues for each project, Fraunhofer ISI can provide relevant information and tailored analyses for governments, industrial associations and individual companies.

Dynamic Modeling of Anthropogenic Material Cycles

The material basis of modern economies can be better understood, evaluated and optimized by using dynamic material flow modeling applied to global, regional and national material flows. Particularly in view of conserving finite resources, dynamic material flow models based on historical data can help identify worthwhile approaches to improving recycling systems. In the case of copper, Fraunhofer ISI has been commissioned by the industry to develop global and regional models with which robust statements are possible regarding copper stocks and recycling worldwide and in selected regions. The results from the global model are included in the yearly World Copper Factbook of the International Copper Study Group (ICSG).

The sound system description and plausible future scenarios of dynamic material flow models also make them an important source of information for strategic decisions. In the Fraunhofer Lighthouse Project "The Criticality of Rare Earths", for example, researchers estimate the expected demand for neodymium and dysprosium, differentiated according to sectors and product groups, as well as their future occurrence in manufacturing scrap and end-of-life products using a global and a German model. These estimations support decisions for technology development (in which areas can greater savings be achieved with more efficient technologies or alternative materials?), necessary collection systems (what amount of which end-of-life products should be collected in the future?) as well as investments in (recycling) facilities (what type of facility and capacity will be needed?).



III-V world record solar cells (46 percent) on a 100 mm wafer with approx. 500 concentrator solar cells.

Small Cells – Big Effect: III-V High-Efficiency Solar Cells

Multi-junction solar cells are used in concentrator photovoltaics (CPV) in regions with high direct normal irradiation such as South Africa, China or the USA to produce renewable electricity at a low cost. They are primarily used in large power plant parks of up to 100 megawatts. Fraunhofer ISE has been working together with partners for many years to further increase the efficiency of multi-junction solar cells and lower the costs. Multi-junction solar cells are based on a combination of different III-V semiconductor compounds such as gallium indium phosphide (GalnP), gallium indium arsenide (GalnAs) or germanium (Ge). Each of these semiconductors converts a different wavelength range of sunlight into electricity. Together the sub-cells produce a high overall efficiency. III-V multi-junction solar cells were originally used for powering satellites. Fraunhofer also performs research and develops solar cells for space applications.

For terrestrial applications in concentrator photovoltaic plants, III-V multi-junction solar cells are built into modules and then integrated into a complete concentrator system. The III-V multi-junction solar cells are placed at the focal point of optically concentrating lenses – so-called Fresnel lenses – that enable a 500-fold concentration of the light. The concentrator modules are placed on a biaxial tracker that follows the position of the sun throughout the day.

Fraunhofer ISE's current world record solar cell is a four-junction solar cell. Each of the four sub-cells converts exactly one fourth of the photons in the wavelength range between 300 and 1750 nm into electric energy. A particular challenge which was successfully met with these solar cells was the even distribution of photons on the four sub cells. This was achieved by scientists at Fraunhofer ISE by precisely adjusting the material composition and density to each individual semiconductor layer in the solar cell. The new record level was measured at a concentration of 508 suns, i. e. the 508-fold bundling of incident light.

Together with Soitec Solar, Fraunhofer ISE was awarded the German Environmental Award in 2012 by German President Joachim Gauck for the development, market launch and commercialization of concentrator photovoltaic.

Organic Solar Cells

Organic solar cells are a comparatively young technology that uses organic semi-conductors for the conversion of (sun)light into electric power. These materials can be applied at low temperatures to flexible substrates in a continuous process. In order to achieve very high throughput rates, the manufacturing costs are almost solely determined by the material costs. Due to the small thickness of the individual layers in the range of 100 nm, the material requirement is in the magnitude of less than 1 g per m². By scaling up the technology, a reduction in the photoactive material costs can be expected. Thus a great cost reduction potential can be attributed to organic photovoltaics.

Despite having achieved an increase in efficiency of <11 percent to date, further progress is necessary not only in efficiency but also in the manufacturing technology and in encapsulation. Another aspect is that all organic high-efficiency solar cells use indium tin oxide (ITO) as transparent electrodes. Since the price of ITO is comparatively high, other suitable alternatives must be found. Among other things, the objective of the work carried out at Fraunhofer ISE is to replace ITO with other materials that also enable high efficiency, are cost effective and have long-term stability as well as compatibility with roll-to-roll processing methods. If successful, it will then be possible to manufacture light, flexible organic solar modules that have long-term stability and a high degree of efficiency.

Valuable raw materials can be recovered from different types of waste (example: electronic scraps, copper slag, tea fibers).
© Fraunhofer Project Group IWKS

Efficient Recycling and Optimized Material Cycles for Sustainable Competitiveness

Scarcity of resources is a central theme for global economic and societal development. An improvement in the recycling of raw materials and an optimization of the material cycles is therefore not only important for environmental protection. An increase in the resource efficiency, recycling and reutilization of raw materials after usage as well as the substitution of rare and critical substances are the prerequisites for maintaining productivity and the competitive edge of the industrial location of Germany.

Recycling valuable materials, replacing critical raw materials

Within Fraunhofer MATERIALS, the Fraunhofer Project Group Materials Recycling and Resource Strategies IWKS researches and develops new recycling technologies and substitutes for raw and processed materials. This type of closed cycle is especially aimed at critical supply elements and material systems. Concepts for the sustainable use of recyclable and waste material from glass manufacture, waste incineration and industrial production are developed and implemented for this purpose. The focal points of research work are glass, slag, ash, biomaterials and foods as well as the recycling of other materials such as production residue and former consumer goods.

Further emphasis is placed on the availability, recycling and substitution of raw materials in electronic components, parts and appliances. The focus is on material flow analyses of recycling processes, analysis and assessment of electronic appliances and the development of new types of fragmentation and sorting methods. The main point here is the selective processing of electric appliances and their components.

Particularly significant in the area of biomaterials and food products are composite materials, cellulose fibers, the use of food scraps and sustainability certifications. Analysis, pre-treatment and recycling methods for natural fibers are developed, value chains for biophenols are examined, and the resource efficiency of small and medium-sized companies in the food industry is improved in research cooperations.

Developing and implementing specific strategies

The Fraunhofer Project Group IWKS supports companies with comprehensive knowledge on criticality analyses, markets, trends and technologies that are important for meaningful recycling and for successfully operating recovery substance cycles. In terms of methods the advisory concept ranges from analysis of the situation and strategy development to concepts for measures and implementation. The advantage for contracting companies is that they work together with scientists on strategic as well as technological and organizational recommendations and on their implementation. Among other things, this is founded on concept and feasibility studies, profitability assessments, system analyses for increasing raw material and energy efficiency, optimization of waste and resource management, and improvement of all relevant process steps along the value chain. New recovery substance cycles can thus be defined and implemented.

Manufacture of a new magnet alloy in an electric arc furnace. @ Fraunhofer Project Group IWKS

Substitution of Critical Raw Materials – New Permanent Magnets for the Change in Energy Policy

With its research work, the Fraunhofer Project Group for Materials Recycling and Resource Strategies IWKS of Fraunhofer ISC has set itself the goal of contributing to securing raw materials that are economically significant for Germany. The availability of strategic metals such as the metals of rare earths is increasingly becoming the focus of politics and industry. With the aid of new approaches to raw materials strategies, recycling and possible substitution materials, production costs can be reduced, supply reliability improved, and also a decisive contribution to protecting the environment can be made.

Rare earth metals play a particularly significant role in high performance magnets. Neodymium iron-boron-magnets have by far the highest energy density of all currently known permanent magnets and make up about two thirds of market turnover worldwide. Minute quantities, for example, are used in loudspeakers and hard drives as well as in wind turbines (> 600 kg/MW). Particularly the rising numbers of hybrid and electrovehicles in the automobile industry have increased the demand for rare earths. Magnet systems have, for this reason, become a work priority of the IWKS Project Group. The main focus lies on the substitution of metals that are classified as critical. Theoretical predictions and proposals are made on the basis of simulations for new types of ferromagnetic phases without neodymium (Nd) and dysprosium (Dy) but with equivalent magnetic properties. The predictions serve as a basis for the synthesis of new magnet materials. Here, the Fraunhofer Project Group IWKS can draw on cutting-edge equipment and diverse synthesis routes that include electric arc furnaces, the method of rapid solidification and sintering. The latest method for the manufacture of high-performance magnets is directed at nanocrystalline structures, e.g. by hot pressing and hot forming, among others.

In addition to the actual substitution of materials, the efficient application of raw materials also plays a major role. With the development of manufacturing methods for the final product shaping, it is possible to eliminate costly and, therefore, material-intensive post-processing and thus, effectively, save material. In addition, the project group IWKS is working on optimizing the microstructure in order to more selectively distribute particularly critical elements like Dy within the structure, but most importantly, on parts where it optimally influences the properties of the magnet. These measures can reduce the application of Dy by up to 50 percent.

Which branches of industry benefit from this?

High-performance magnets play a prominent role particularly in the area of generators and electronic motors. Electromobility, the automobile industry and wind turbine plants especially benefit from more readily available replacement materials. These technologies are predicted to grow strongly in the future, and an enormous rise in the demand for Nd and Dy is expected. High-performance magnets play an important role in the electronics and computer industry as well as in medical science. Uncertainties about raw material supply could slow down developments in future technologies.

Electro-chemical process laboratory.
© Fraunhofer ISC

Electro hydraulic fragmentation device at Project Group IWKS: phase selective separation of recycling goods.
© ImpulsTec GmbH

Energy Storage – from Material Development to Recycling

The efficient and secure storage of electric energy is a major technical challenge and an important prerequisite for the sustainable success of portable and stationary energy supply systems. These, for example, are necessary for the expansion of regenerative energy usage and electromobility. The development of new materials for high-performance batteries and work on efficient battery concepts play an important role. Moreover, established and cost-effective systems such as lead-acid batteries also have a great potential for stationary energy storage and automotives (start-stop automatic and mild hybrid vehicles) by improving their lifespan and performance, e.g. with dynamic loading and in partially charged conditions. Intelligent recycling methods and the reprocessing of certain components (“second life”) are additionally increasing in significance with regard to the efficient use of raw materials. Competent contact persons from the Center of Applied Electrochemistry ZfAE and the Fraunhofer ISC Project Group Materials Recycling and Resource Strategies IWKS are available for all aspects on the topic of energy storage.

Battery materials and components

In the field of material research the focus is on the development of components for energy storage of current and future generations, as well as the manufacturing and processing of these components up to pilot plant scale for electrochemical energy storage systems such as:

- lithium-ion batteries (LIB) – including the modification of high-energy cathodes (lithium-rich layer-oxides) and anodes (silicon-based), solid electrolytes
- metal-air batteries – including catalyst development, boundary layer design
- lead-acid batteries – including additives for electrode masses
- solid state batteries
- double layer capacitors – LIB supercapacitor
- sodium-based technologies – including sodium-air cells

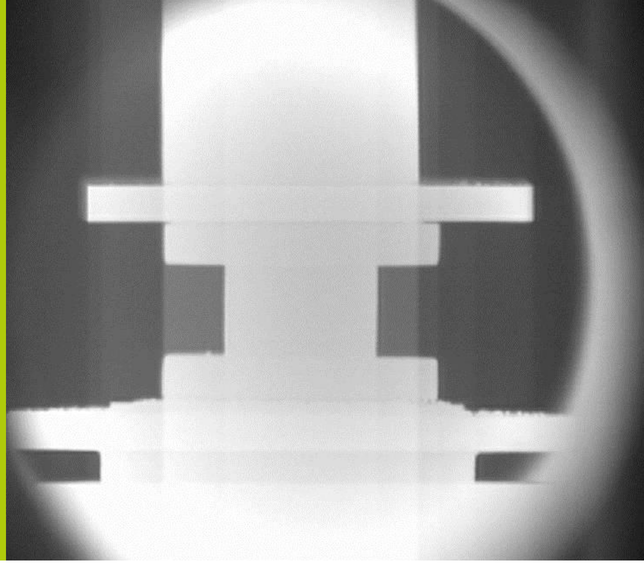
Material characterization and testing

The performance and resistance of battery components and systems are examined in an excellently equipped electrochemical test environment. This enables, among other things, battery charging and unloading cycles on over 200 channels from the femtoampere up to the kiloampere range under controlled climate conditions. Aging processes that lead to a decrease in performance can thus be simulated under defined conditions and used for material optimization. A specialized post mortem analysis, as well as electron microscopy accredited according to DIN EN ISO / IEC 17025-2005 with a unique micro laboratory in the scanning electron microscope, enable precise analysis on micro and nano levels.

Battery recycling

The project group IWKS within Fraunhofer MATERIALS is developing new and intelligent methods for the appropriate and energy-efficient recycling of electrochemical energy storage systems, particularly for lithium-ion batteries. The safe and efficient fragmentation and separation of the individual components are particularly important. The materials should not just be recovered on an elemental level but preferably in the form of an already synthesized compound. Either an equivalent or an even better functioning of the recycled material is required for this process along with cost neutrality compared to conventional raw materials and greater environmental friendliness and economic efficiency compared to common metallurgical methods.

In-situ measurements of sintering processes in a thermo optical measuring system – survey photograph for the analysis of changes in dimension (right).



Energy Efficiency in High Temperature Processes

In Germany, approx. seven percent of primary energy is used for the thermal treatment of materials in temperature ranges of above 1000 °C. This corresponds to a total energy of 1000 PJ per year or the equivalent of 30 power plants with an average power of 1 GW. The iron and steel industries consume the most energy but also the “stones and earth“ sector as well as the glass and ceramic industry contribute considerably to the highest consumption levels in high-temperature areas.

Power generated from fossil energy sources also improves efficiency in high-temperature areas. Thus the efficiency level of gas turbines increases significantly with the turbine inlet temperature. This does not only apply to stationary but also to aero gas turbines. Improving the energy efficiency of high temperature processes would also have a lasting effect on the CO_2 footprint. This could be implemented very quickly without first having to create a new infrastructure for energy distribution and storage as in the case of generating regenerative energy.

Within Fraunhofer MATERIALS, the Fraunhofer Center for High Temperature Materials and Design HTL of Fraunhofer ISC focuses on the following three points for improving the energy efficiency of high-temperature processes in the industry:

Material development

The HTL Center develops high-temperature-resistant ceramic composites, fibers and coatings to increase the energy efficiency of thermo-technical systems and aero gas turbines. This includes the chemical synthesis of the starting material as well as the upscaling of the manufacture up to pilot-plant scale and computer-based material design. Either oxide ceramic fibers such as aluminum oxide and zirconium oxide or mullite are used as well as non-toxic fibers made of silicon carbide and oxidic and non-oxidic matrix materials.

Components and systems for high-temperature applications

Components made of ceramic matrix composites (CMC) are designed at the HTL Center in sizes up to approx. 700 mm and are manufactured as prototypes or in small series. The component design is based on the computer simulation of the application behavior, component testing and non-destructive testing methods like computer tomography. All types of fibers, continuous filaments or short fibers can be manufactured with different textile processes. The matrix is set up with ceramic slurries, polymers or silicon melt. Methods and infrastructure for ceramic prepreg manufacturing are also available, so that safe and easily processed semi-finished textile products can be made available to producers for small series production.

Characterization and optimization of high-temperature processes

The HTL Center has developed special thermo-optical test methods for the characterization of materials at high temperatures. The thermal and mechanical material parameters of small components or large samples with temperatures up to 2100 °C can be determined with this method. Sintering and other heat treating processes can be analyzed in these devices, thus enabling the in-situ measurement of changes in the material during heat treatment processes. As a result, heat treatment processes can be generated that are optimized with regard to energy efficiency, required time and product quality by means of computer simulation.

Carbon and hemp-fiber-reinforced composite.
© Fraunhofer WKI

MOBILITY

New Natural-Fiber-Reinforced Hybrid Materials

Enterprises in the automobile and aerospace industries use fiber-reinforced plastics to produce light and stiff components. The material used depends on the final application. For example, carbon fibers (CF) are expensive and difficult to process and are therefore rarely used in series production any more. Glass fibers, on the other hand, are inexpensive but heavy by comparison. Researchers at the Application Center for Wood Fiber Research HOFZET of the Fraunhofer Institute for Wood Research now combine natural-fiber-based textiles and carbon fibers to obtain new hybrid materials.

By applying carbon fibers where components are heavily stressed and natural or polymer fibers in the other areas, scientists are able to unite the strengths of the individual fibers and largely eliminate the disadvantages. The result: The components are cost-effective, very durable, have good acoustic properties and are much more ecological than pure carbon components.

Special coatings ensure that the natural fibers bind as well as possible with the polymer matrix. This type of pretreatment, which is optimized from a materials technology point of view, for the most part is still uncharted territory. The strength of the material increases by up to 50 percent with an optimal fiber matrix adhesion compared with a poor interface quality. Researchers also investigate how to implement the processing steps for the new materials. They also take into consideration in advance how developed hybrid materials can be processed or how individual material components can be recovered for a new application.

Different physical, thermal and chemical recycling approaches are taken depending on the material composition. As a final step, an ecological, economic and technical evaluation of the process chain is carried out.

Common and biobased composite fiber materials
© Fraunhofer WKI

Manufacture of structural components for automotive lightweight construction. © Fraunhofer ICT

Process Development for the Sequential Preforming of Semi-Finished Products

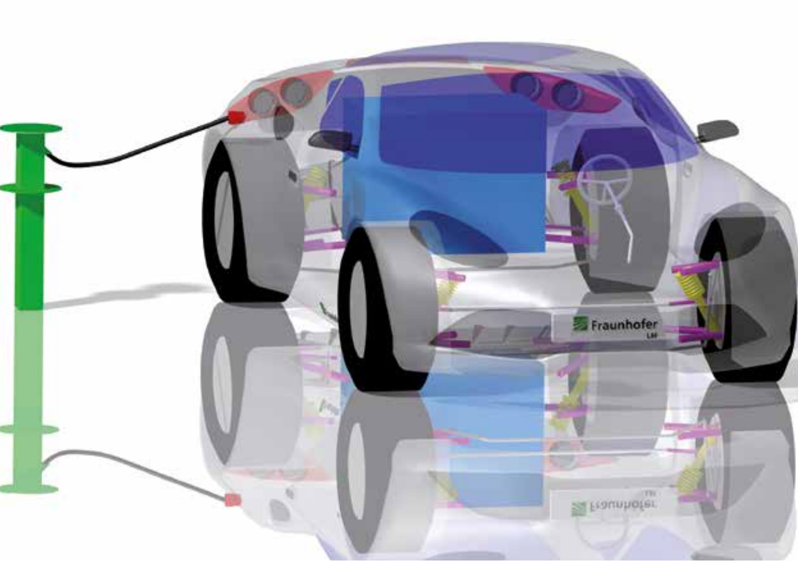
Climate change and its consequences are pushing societies worldwide to adopt a more energy- and resource-efficient lifestyle. Global warming can only be curbed in the long term if the emission of greenhouse gases is greatly reduced over the next years. Since the energy consumption of vehicles directly determines the amount of pollutants that are emitted, the strategic relevance of lightweight construction in the automobile industry will increase in the future.

Fiber-reinforced polymers are being used with greater frequency in addition to established lightweight construction materials. These polymers have great potential due to their density-specific material properties. High-performance composites with a high fiber volume are of especial interest because of their excellent mechanical properties. In particular anisotropic layer constructions, oriented according to the load path, enable the production of high-strength structural components suitable for lightweight applications. Automated, robust and quality-assured manufacturing technologies are needed in the future in order to successfully introduce this material system to large-scale automotive production.

The Technology Cluster Composites (TC2) focused, among other things, on the industrialization of RTM process chains for the manufacture of structural components for automotive lightweight construction. An outstanding feature of TC2 was an integrated approach to technological challenges that was not based on individual problems but focused on connections and interactions within continuous process chains.

The cost structure of the RTM process chain is a strong argument for the implementation of automated preforming. The automatization of handling operations as well as the reshaping process (draping) within the preforming procedure can drastically reduce production cycle times, which leads to a significant reduction in overall RTM production costs. At the same time, the reproducibility of component quality increases as the degree of automation becomes greater which, in turn, results in a noticeable decrease in the rate of production waste.

Fundamental draping and fixation strategies for preform manufacturing were developed and validated within the framework of TC2 by the participating group partners Fraunhofer ICT, the Institute of Aircraft Design of the University of Stuttgart (IFB), the Institute of Textile Technology and Process Engineering Denkendorf, the Institute of Production Science (wbk) and the Institute of Vehicle Systems Technology of the Karlsruhe Institute of Technology. The sequential reshaping of entire layer constructions using a multiple-stamp mold has proven to be the best method for the automated manufacture of components with complex geometries. In this method, the layer constructions are locally prestressed. The local application of reactive binding systems has proven to work best for fixing the shape and position of textile semi-finished products. Dieffenbacher GmbH created a PreformCenter at Fraunhofer ICT for automated preform manufacturing on the basis of this preliminary work. The new technology makes it possible to investigate the complete preform manufacturing process from layer cutting and the application of binders through to shaping. The individual processing steps are linked by a handling technology consisting of selected grippers acting as robot end effectors.



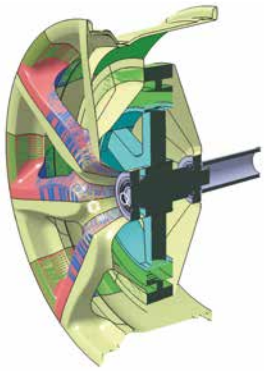
FreccO.
© Fraunhofer LBF

”Pre-applicable structural adhesives« – *bonding without applying adhesives.*
© Fraunhofer IFAM

Functionally Integrated Lightweight Design

Active lightweight structures have great future potential. Even with additional functions, this complex system helps keep the total weight low since the carrying structure is supplemented with an additional function without introducing too much additional mass or load paths. One example of lightweight design with integrated functions is a polymer wheel with electric wheel hub motors in the automobile sector.

In contrast to existing metallic constructions, the structure must be appropriately designed for fibers. Softer radii and fluent transitions are necessary since the material is not suitable for sharp edges and angles. Additionally integrated objects must be adapted in this regard since these have an effect on the structural integration as a notch in the construction. The interaction of active and passive materials is analyzed and assessed during integration. The integration of active elements while taking the structural durability of the entire system into account, the evaluation and increase of reliability and the lightweight potential and energy demand of these lightweight structures are the focus of Fraunhofer research.



Lightweight design (wheel) with integrated functions.
© Fraunhofer LBF

Bonding with Pre-Applicable Adhesives

Adhesives are the choice method of bonding, particularly in lightweight construction, since many of the applied materials are hard to bond with other methods. However, it is not possible in every production step to apply fluid adhesive material and then wait until it dries. This is why automobile supplier STANLEY Engineered Fastening – Tucker GmbH from Giessen is looking for a way to bond bolts without having to deal with fluid adhesives during the production process. A solution was developed at Fraunhofer IFAM in which the adhesive is first applied to a component and creates a non-adhesive coating. The actual hardening of the adhesive and the bonding take place in a later production step and takes less than 10 seconds. The new technology is called ”Pre-Applicable Structural Adhesives”, PASA® for short.

During the development process, account must be taken of the fact that the additives must sometimes fulfill contradicting requirements. After the adhesive has been applied, it should no longer be adherent and must be storable for a long period of time without initiation of the hardening process. On the other hand, it has to be very reactive during the bonding process and should harden soon there after. The solution: a combination of resins and hardeners with different melting points combined with a micro dispersion of the hardeners.

The reactive melting adhesive is, for example, used in the manufacture of mounting bolts. The material is melted and applied. After it has cooled, it becomes hard again. Thus the coated bolts can be transported and stored without any problem. In order to harden the adhesive, it is heated up to 150°C under controlled conditions. This way the hardener also melts and the actual adhesive hardener is activated so that two components can be firmly bonded with each other.

UER III on a trolley.
© Fraunhofer IZFP

Non-Destructive Testing Procedure in the Rail Industry: Fraunhofer IZFP Ensures Your Safety in Rail Vehicles – 3rd Generation UER Systems

Block brakes are primarily still used in railway freight cars. The condition for using this type of brake is that a warm up and cooling process must take place in the wheel set before and after the braking process. This means that the compressive stress applied to the wheels in the peripheral direction during manufacturing is changed to tensile stress. Under this influence, even the smallest cracks in the tread of the wheel can lead to a break in the wheel.

In order to counteract this type of damage, Fraunhofer IZFP has been developing and producing industrially capable testing systems for ultrasound residual stress measurements on wheel rims (UER). Portable systems are now available in addition to the original floor-mounted devices. In order to take into account the realities of the ever-changing electronics and software market, an initial comprehensive redesign was made in 2004. After this first update, a further adaptation to the state of the art of hardware and software technology was made to ensure the future sustainability of the appliance system that, by now, has become established as the testing standard in 50 locations of 15 different countries worldwide.

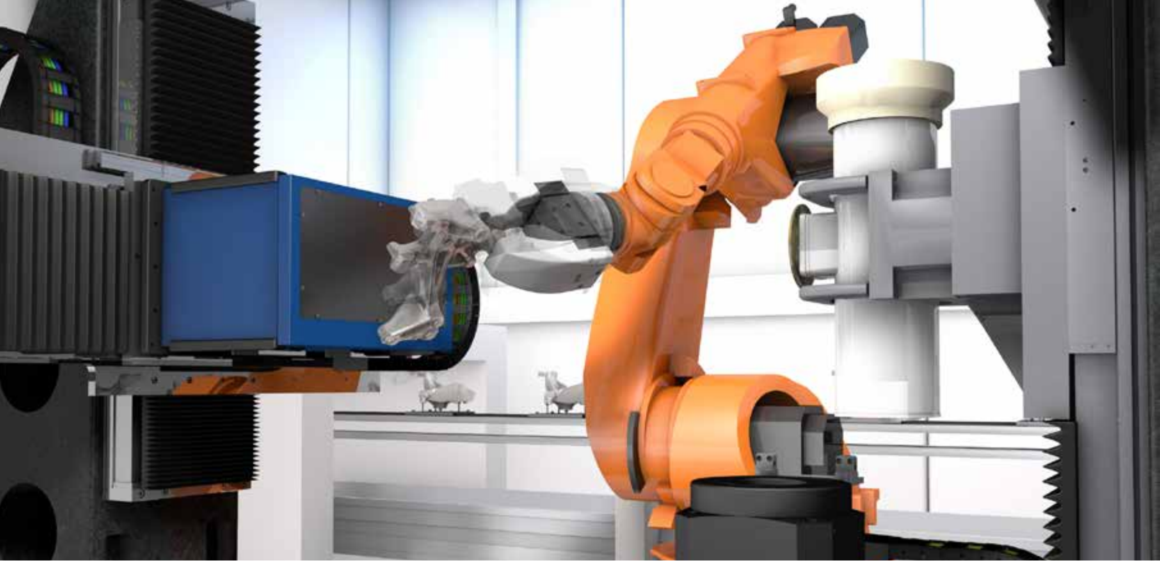
In order to determine residual stress in freight cars, the UER test systems apply the acusto-elastic effect, which is the influence of the strain and stress conditions on the propagation speed of ultrasound waves. The magnitude of the effect depends on the direction of the propagation and vibration in relation to the main direction of strain or tension. A linearly polarized transverse wave is insonificated in the inner surface of the wheel rim by means of an electromagnetic ultrasound converter without any coupling.

Innovation cycles in the area of electronics hardware and software made it necessary to redesign the UER test system a second time in 2013. Within this further development process, an analog signal transfer was reduced to a minimum and largely replaced by a digital signal transfer, which resulted in considerably less interference of the system in the industrial environment.

The minimization of analog signal paths made it necessary to redevelop the complete ultrasound transmitter and receiver electronics including signal processing and digitalization and to adjust the minimum spatial conditions in the manipulation unit. Also, the entire control technology is now located in the inner volume of the manipulator so that the transfer of the signal to the actual operating panel is a completely digital process. The system's hard- and software enable the integration into the network structures of the facilities and have a number of logging capabilities. An additional evaluation module is available for the analysis of newly manufactured wheels, and carries out parametrizable evaluations in compliance with the specifications of EN 13262 in different depth ranges of the tension profile.

All new UER systems, as well as those that have already been delivered, are included in the remote maintenance network of Fraunhofer IZFP. This enables the service team to conduct comprehensive failure analyses via the internet in the case of failure.

With the experience gained from two generations of devices, the UER test system has been brought up to a future-proof technical level while maintaining its simple software operation and simultaneously developing the testing documentation possibilities.



The newly developed DRAGON-FLY X-ray technology reduces the testing time of cast components by half.
© Fraunhofer EZRT

Non-Destructive Testing – Industrial X-Ray Testing Methods of Tomorrow

The Fraunhofer Development Center for X-ray Technology EZRT, a division of Fraunhofer IIS, is working on the research area of non-destructive testing in close cooperation with Fraunhofer IZFP.

Price pressure in the automobile industry is just as high as the quality standards. The suppliers of components like light alloy cast wheels, chassis components, cylinder heads or crankcases must develop their parts quickly and cost-effectively and, above all, must deliver flawless products. This is where quality control plays a central role. Large quantities must be checked rapidly and reliably to make sure that no embrittlement or fine hairline fractures are present in the components. In the future, the results of the inline monitoring of production processes and product quality will also be applied for production and parameter optimization by means of intelligent feedback loops. The problem with current procedures is that in order to X-ray larger components, they must be moved between the X-ray source and the detector by a robot.

Up to now, the robot has always had to stop its movement in order to make X-rays of the specimen. A new technology development by Fraunhofer EZRT now makes it possible for high-resolution X-rays to be made from different perspectives while the component is moving. This drastically saves time: The exposure time for a picture of one position now only lasts around five milliseconds whereas it took approx. eighty times longer with conventional technology. The name of this method is "Dragonfly" – named after an insect that is fast and agile and that can abruptly change the direction of its movements. A robot turns the part to be inspected into different positions, and X-ray images are taken while it is moving. The exposure time of the applied X-ray source is as short as that of conventional photography. In addition, the XEye-Detector (also a development of Fraunhofer EZRT) is distinguished by a spontaneous and freely adjustable exposure time as well as a long service life. The testing time of a cast component is thus cut by about half, which is a big step in mass production.

Large and thick-walled objects such as automobiles, freight containers and aircraft parts, could only be examined up to now using X-ray computed tomography, after being disassembled into smaller parts. Fraunhofer EZRT has a worldwide unique XXL computed tomography, scanner made for this purpose. Objects up to 4.60 meters high and with a diameter of up to 3.20 meters can be examined with the XXL CT technology. The test facility has an area of 400 square meters and is 16 meters high. Enough space is therefore available for examining large objects. The task here is the non-destructive examination of objects like automobiles, aircraft parts or freight containers including cargo. The facility enables the quality control of objects that, up to now, could only be checked partially or not at all with conventional methods.

Further applications are the analysis of art-historical objects as well as crash analyses and the resulting stiffness optimization of automobile bodies. Energies of a maximum of 9 MeV can be attained, which corresponds to approximately the 20-fold of conventional industrial X-ray systems. This enables the X-ray analysis of 30-cm thick steel objects or a maximum of 60 cm thick aluminum structures. Construction errors, material defects or other areas that are difficult to access from the outside can be precisely detected, characterized and evaluated with this method. With an effective resolution of below 0.4 mm, even the smallest defects can be recognized in large objects.

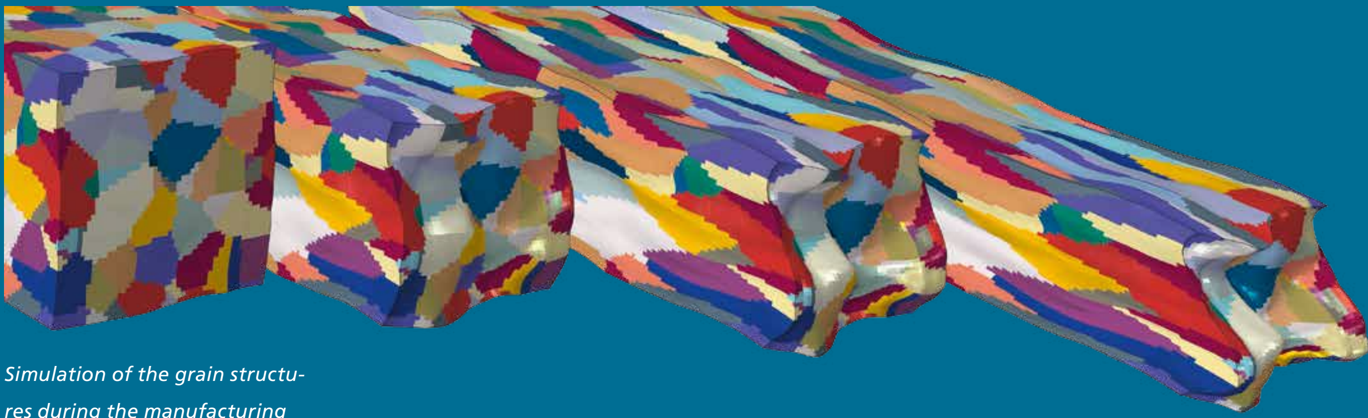
Droop nose demonstrator with a moveable wing leading edge and integrated future-oriented technologies. © Fraunhofer LBF

Structurally Durable Integration of Active Materials, Lightweight Design for Future Aircraft Wings: Moveable Wing Leading Edge with Morphing Skin and Integrated Functions

What will aircraft wings of the future have to achieve? The Fraunhofer Institute of Structural Durability and System Reliability LBF is researching this question within the framework of the European research program Clean Sky Green Regional Aircraft. The latest result is a three-meter wide 1:1 wind tunnel model of a possible future wing, which the institute developed and manufactured together with the Fraunhofer Institutes ENAS, IBP and IGD. The scientists integrated several potential future technologies into this demonstrator, which was created as a technology platform. These include a droop nose (moveable leading edge), a measurement and control system, a variable ice protection system as well as actuators based on shape memory alloys.

The 1:1 droop nose demonstrator was set up at and tested at Fraunhofer LBF in a climatic wind tunnel under icing conditions. The scientists developed kinematics for lowering the wing's leading edge on the basis of aerodynamic specifications. The special feature of this high-lift device in the area of the leading edge is that it prevents cracking since the skin deforms with it. This is particularly important for future laminar wings as they can only be realized with smooth surfaces. Another advantage is reduced noise emissions during the landing approach thanks to the lack of gaps. The extensive morphing of the skin, however, which occurs during every operation, necessitates an adequate structural durability. An electromechanical actuator causes the skin to deform. In addition, several smart memory alloy actuators tested by Fraunhofer IBP are used. Fraunhofer LBF is developing a process for reconstructing the wing geometry based on sensor signals to control the kinematics in the future. Almost 50 fiber-optical strain sensors were integrated into the skin of the movable leading edge for this purpose, and routed to the outside via a newly developed, structurally integrated connector concept developed by Fraunhofer LBF. Fraunhofer ENAS provided synthetic jet actuators for the "Wing" technology platform. These are able to exert a positive effect on the airstream. For the first time, Fraunhofer LBF additionally integrated a thermal ice protection system in a highly strained wing leading edge. The extensive deformation of the skin previously made it impossible to solve this design concept satisfactorily. During the Clean Sky project, Fraunhofer LBF was able to develop a flexible heating system based on carbon nano tubes (CNTs). Thermal sensors integrated in the model regulate the temperature.

During initial testing of the model, there was good conformity in the wing deformations between the results of the FE simulations and the manufactured model. The de-icing possibilities of the demonstrator were then tested in the climatic wind tunnel. As expected, the structure and the different technologies functioned well. As a result of the successful test in the wind tunnel, Fraunhofer LBF was able to prove the technology's degree of maturity. This new technology is the result of a large-scale research project. The development of the technology is not finished yet and is to be continued in future projects.



Simulation of the grain structures during the manufacturing process – wire drawing. © Fraunhofer IWM

From Grain Boundary to Crash Safety: Process Chain Simulation for Component Development

Simulation experts at Fraunhofer IWM have been able to simulate continuous manufacturing processes from semi-finished material to the end product, for example for components manufactured with sheet metal, forging, welded or powder technology. The prerequisite is to identify possible weak points in the material such as cracks or undesirable properties as well as their propagation in the process chain. These can then be removed and the components can be optimally qualified for their application.

The fact that the microstructure of a material changes strongly during the treatment process, and has a decisive influence on the application behavior of the finished component, calls for new simulation concepts.

While the numerical description of individual process steps is established for the most part, Fraunhofer IWM offers its customers multi-scale simulations that are seamlessly linked with each other along the entire process chain. The integration of the process history, the structure and properties of a material all have an impact and enable scientists to precisely predict the operational behavior of a component. This gives customers the knowhow for adapting process parameters to a given situation, and gives them competent support for model development or for the optimization of specific process chains.

Particularly in the steel and metal-working industries, automobile supply, automotive and plant engineering and in the manufacture of ceramic components, this can lead to considerable savings in cost and time, since product development cycles are reduced considerably. In order to meet the central requirements of lightweight construction, crash safety and longer life spans, simulations along the process chain are accompanied in parallel by experimental tests and validations on several scales. For example, the conversion of hot rolled steel strip into a supporting pillar of an automobile body made of dual phase steel entails cold rolls, heat treatment and deep drawing into the finished component. The structure of the hot rolled steel strip that is recreated on the computer serves as an input data set for the cold roll simulation. This finite element solution illustrates the development of the structure during the rolling process and the related material properties. The results are processed in the annealing simulations that follow.

On the basis of the microstructure from the annealing simulation, the team is currently working on more closely determining the macroscopic material parameters with the "virtual laboratory" developed by Fraunhofer IWM. Virtual, macroscopic stress-strain curves supply the material parameters for the models used in the ensuing reshaping simulations. The special feature of the intermediate step with the virtual laboratory is the possibility of reproducing tests in the simulation, which, in practice, is difficult or not feasible at all with sheet materials.

The final simulation of the fatigue strength or crash safety of the component evaluates the causes of failure while taking into account any possible pre-existing loads such as sheet thinning or local damage stemming from previous process steps.

Solar hydrogen fueling station at Fraunhofer ISE in Freiburg. © Fraunhofer ISE

The "Fraunhofer Solar Module" prototype integrates all components developed in the project. © Fraunhofer

Solar Hydrogen Fueling Stations – Driving a Car Fueled by Water and Sun

Fraunhofer ISE has been operating a solar hydrogen fueling station in Freiburg since March 2012. The hydrogen is produced on location. The average amount of power required annually for the fueling station is met by the station's own PV system, thus demonstrating the possibility of sustainable hydrogen production by means of renewable resources. Refueling at 700 bar storage pressure takes three to five minutes. Two fuel cell vehicles are available for research purposes and also serve as company cars. This proves the suitability of this technology for daily use.

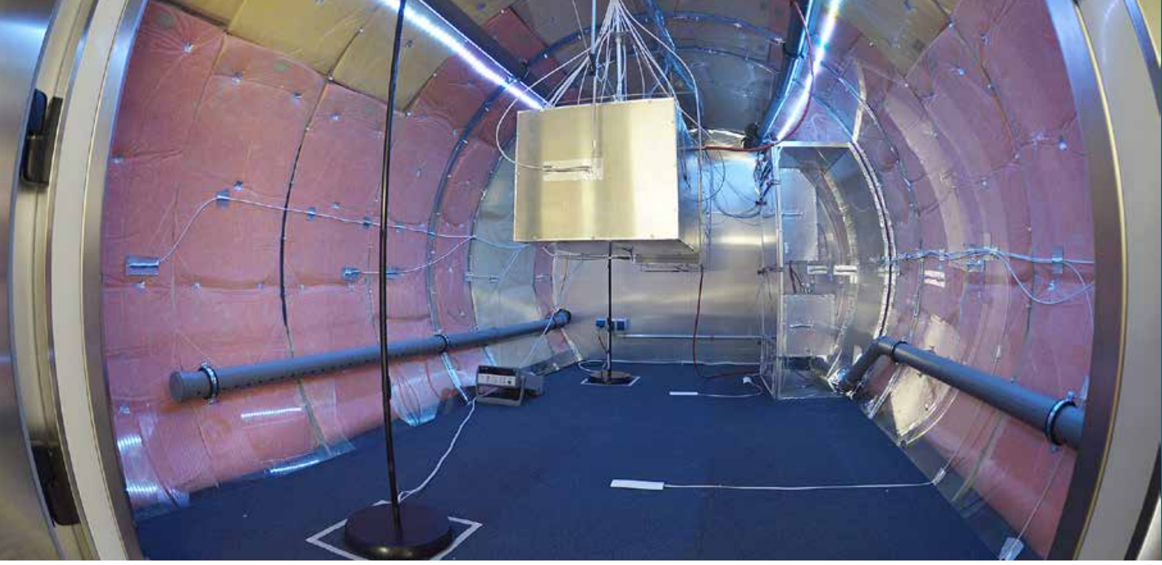
The design of the fueling station is based on modular containers. In the electrolysis container, hydrogen is produced and treated using a modern membrane process at 30 bar. Two compressors, the hydrogen pre-cooling unit and the control panel are located in the second container. In the first stage, the hydrogen is compressed to 450 bar and temporarily stored. The gas is compressed to 950 bar and stored in a high-pressure tank for refueling at 700-bar.

Freiburg is an ideal location for a fueling station within the network of hydrogen fueling stations which is currently being established in Baden-Württemberg. With its location in a TEN-T corridor, the station is also an important connection to future European fueling stations in France and Switzerland. The fueling station serves as a research and technology platform in addition to its task of providing hydrogen vehicles with fuel. A number of components were designed so that, among other things, tests on fueling station components as well as R&D projects on demand-side management or from the area of power-to-gas can be carried out. The solar hydrogen fueling station has comprehensive measurement technology for the monitoring. The control panel allows for flexible operation of the facility.

Lightweight Solar Modules

Photovoltaic power generation is one of the pillars of environmentally-friendly power generation. The well-known problems of German and European PV module manufacturers are that the modules for electricity parks and roof installations are, for the most part, based on the state of technology of the past millennium and that manufacturing in Asia is preferred because of high cost pressure. The Fraunhofer institutes ISE, FEP, IZM and IFAM have been working on a new module concept that brings together the development of highly-efficient solar cells and photovoltaic technology from other sources. At comparable calculated costs, it enables state-of-the-art modules to be built with efficiencies of over 20 percent and around 45 percent less weight. This allows more electricity to be produced over ever smaller areas as well as permitting PV installations on roofs with low loading capacity.

Many development details lead to efficiency increases in solar cell modules: On the one hand, the new type of lightweight solar cells with distributed contacts connected to the back of the module minimizes electricity losses and weight. On the other hand, a specially fitted polymer film is used instead of a front glass. The highly UV-resistant film has the necessary barrier properties and is highly transparent. A composite material on the back provides the necessary mechanical properties. In addition, the new module concept allows for the application of interconnection technologies on the circuit carriers as well as the implementation of bypass diodes to protect the solar cells on an individual basis.



Scientists from Fraunhofer IBP carry out tests on indoor climate and comfort in the cabin demonstrator of the Ground Thermal Test Bench. © Fraunhofer IBP

Ground Thermal Test Bench

Air travel is becoming more environmentally friendly: by 2020, jets will produce 50 percent less CO_2, 80 percent less nitrogen oxide and make only half as much noise as jets in the year 2000. Also, it will be necessary to develop innovative solutions for the areas of design, manufacture, maintenance and recycling as well as for life span of aircraft.

The EU project Clean Sky has set itself these ambitious goals. This EU joint technology initiative (JTI), the largest of its kind so far, was launched in 2008. The development, construction and operation of the Ground Thermal Test Bench were commissioned within this framework. Innovative aircraft architectures and appliances as well as new design tools are validated in this test facility. With success: The demonstrator was put into operation in 2014 and has successfully completed the test programs since then. This makes it possible to test the architectures of complete business jet sections for their thermal and functional efficiency, which, particularly with the transition to "more electric aircraft architecture" is an increasingly important topic.

The following mock-ups are available:
Carbon cockpit:
It enables analysis of the thermal behavior of carbon structures.

Cabin section:
It enables the examination of the climate and comfort in the business jet cabin as well as the underbody appliances and usage of the tanks as heat accumulators.

Aft fuselage:
Primarily avionics bay architecture is tested here and systems with extreme heat development are integrated.

These three fuselage parts can be exposed to environmental conditions that occur on the ground and in the air in order to test flight situations safely on the ground. Precise air conditioning technology conditions the air of the interior space. This enables a wide range of air temperatures, humidity and air volume for the cabin ventilation. Furthermore, the scientists develop and optimize the control and adjustment of the Ground Thermal Test Bench. The result: the required testing conditions are attained very precisely and evenly, hence making it possible to carry out tests in accordance with aviation standard Do160. Such a test was carried out for the first time in the test campaign for the "heatpipe" technology demonstrator. At the same time, the Fraunhofer thermal model was further developed and validated on the Ground Thermal Test Bench. Spatially resolved temperature distributions are needed to calculate cabin temperature applications, which, up to now, could not be made with classical computing methods. Even elaborate simulations for advanced calculations like Computation Fluid Dynamics (CFD) only yield minimal results at this stage: They display chaotic flow behavior in large spaces and have only little practical added value despite a very high computational effort.

The model developed at Fraunhofer IBP typically subdivides a space into 20 to 500 zones that exchange air with each other. Heat sources, ventilation openings, walls and windows can be placed here and connected with the neighboring zones. The influence of heat radiation on all available surfaces is also taken into consideration, including the influence of sun radiation depending on time and place. This approach reduces computing time by a factor of 1000 to 10 000 with comparably significant results. When engineers design an aircraft, they can now compare many different architectural designs and identify the most promising approach. The Thermal Model Generation Tool and the Ecolonomic Analysis Tool ensure that this process runs automatically.

Improved rolling properties with a constant grip – achieved by optimizing the »filler network«. © istock / santiphotois

However, are the results representative of realistic applications? This must be determined if this tool chain is to be introduced into aviation. The climatic conditions are extreme and the geometric structures are complicated. The climate in the aircraft therefore has to be regulated by elaborate air conditioning systems. However, the Ground Thermal Test Bench enables representative tests to be carried out on the ground. Test campaigns on the cockpit and cabin mockups showed that the predictions of the thermal model are clearly within the range of the required and validatable accuracy and delivered more realistic results than CFD computations that were carried out simultaneously.

The underbody of the cabin demonstrator offers manifold possibilities for carrying out thermal tests with the aid of so-called equipment simulators.
© Fraunhofer IBP

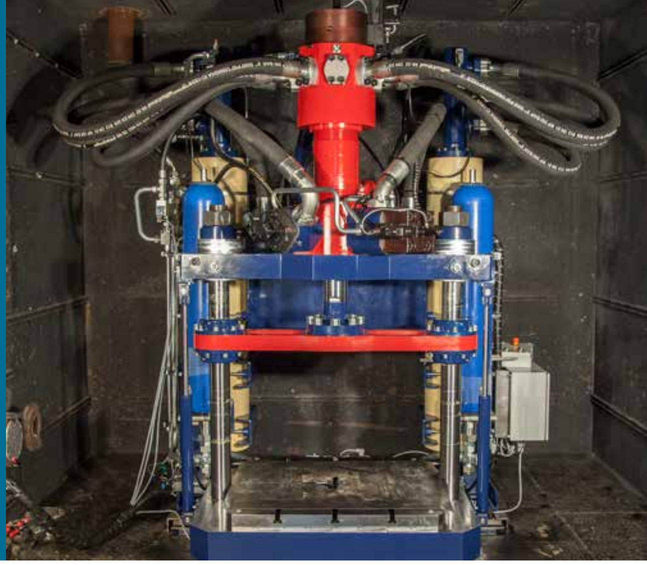
Microstructural Evaluation of Energy Efficient and Wear Resistant Tire Materials

Rubber-based composites, like those used for tire treads, are complex materials that, in addition to rubber, contain several other components. Whereas the rubber fraction gives the composite material its typical rubber-like properties such as high elasticity, the addition of nanofillers – like carbon black or silica – influence other essential properties like hardness or abrasion resistance. These parameters can be adjusted by type and fraction of the used nanofiller. The filler fraction in rubber composites for tires is so high that a continuous "filler network" is formed, which dominates the mechanical properties. Hence, detailed understanding and controlled manipulation of the filler network are important topics for the development of optimized rubber composites for tire treads, and are the focus of major research activities at Fraunhofer IMWS.

Research at Fraunhofer IMWS on different rubber composites shows that the filler network contains not only aggregated filler particles but also viscoelastic elements formed by a small immobilized, glassy rubber fraction located on the surface of the filler particles. Although the immobilized segments make up only 1-3 percent of the entire rubber fraction in the composite, their influence on the mechanical properties is significant. Glassy rubber bridges between the filler particles soften successively with increasing temperature. This effect significantly reduces the elastic modulus of the entire composite material and has to be taken into consideration during recipe optimization. Otherwise, the rolling resistance increases if the selected filler fraction is too large, which, in turn, leads to an increase in fuel consumption. This interrelation demonstrates the great relevance of research carried out at Fraunhofer IMWS on the microstructure of the filler network for the application-related optimization of rubber composites for tire treads.

Research crash-test facility at Fraunhofer EMI in Efringen-Kirchen.
© Thomas Ernsting

Battery test bench for dynamic tests of loaded cells.
© Fraunhofer EMI



The Crash Center of the Fraunhofer-Gesellschaft at Fraunhofer EMI

Modern vehicles have to become more safe and, at the same time, more energy-efficient. To achieve this goal, the automobile industry focusses on new, lightweight materials like composites and foamed materials as well as on alternate drives. One of the central areas of research at Fraunhofer EMI is the testing of new materials.

Despite the increasing application of numerical simulation methods, crash tests are still an indispensable part of vehicle development. They supply the basic data for simulation computations and are important for verifying the results. The new research crash-test facility considerably expands the experimental portfolio of the Crash Center of the Fraunhofer-Gesellschaft. Together with the component crash-test facility, it forms the core of the Crash Center. Both facilities can be used flexibly for current issues from the areas of vehicle safety and material research.

Research Crash-Test Facility

The research crash-test facility with a length of 42 meters is operated with a servo-hydraulic catapult. Tests at velocities of up to 80 kilometers per hour and a maximum payload of 3000 kilograms are possible. Different crash variations – frontal, rear and side impact – can be carried out in this facility. With high-speed cameras and 3D deformation analysis, the special measurement and evaluation methods developed at EMI allow for a precise observation of material and component behavior under crash-relevant conditions.

Component Crash-Test Facility

For over ten years, the versatile component crash test facility has been used to test vehicle components such as bumper structures or crash elements for their energy absorption capacity as well as for their deformation and failure behavior at velocities of up to 22 meters per second and a weight of up to 800 kilograms. The 16-meter-long facility is operated with compressed air and also serves to characterize and examine the crash capability of novel materials or material combinations.

Mechanical Behavior of Batteries Under Dynamic Loading – Battery Test Bench

The call for an increase in electric vehicles on our roads requires the application of efficient mobile sources of energy. As a result, electric energy storage systems are growing in importance in the field of mobility. However, as energy density and the overall capacity of available energy storage continually increase, so does their risk potential.

A special test bench for the characterization of lithium ion cells at Fraunhofer EMI allows for the destructive testing of charged battery cells at different load modes from the static to the dynamic range with load velocities of up to 10 meters per second and loads of up to 50 tonnes. Different cell types can be examined with this apparatus with respect to their deformation behavior under various conditions.

A further effective possibility of researching batteries that have undergone compression, crushing or other types of destruction is by computed tomography (CT). This allows the visualization of the interior of a cell before and after a test and enables the analysis of damage.

Gesture-controlled prototype of a utility vehicle seat.
© Isringhausen GmbH & Co. KG

Gesture Control – Intelligent Man-to-Machine Interfaces

Modern utility vehicle seats help drivers to concentrate and drive long distances without tiring, while pneumatic vibration systems help protect them from damaging vibrations. The ergonomic shape and design as well as the correct positioning of the seats are important for optimal comfort. The Center Smart Materials CeSMa of Fraunhofer ISC has developed a contactless gesture control for the driver seats of trucks, with which it is possible to adjust the optimal seating position using only hand gestures.

Intuitive contactless communication

Research on professional truck drivers shows that individual seat positions can only be correctly made if the driver is familiar with all of the settings and if he can operate them intuitively. The new type of gesture control enables a number of intuitive adjustment and comfort functions with which the seat position as well as sections of contour configurations can be adapted to the individual needs and physical requirements of the driver.

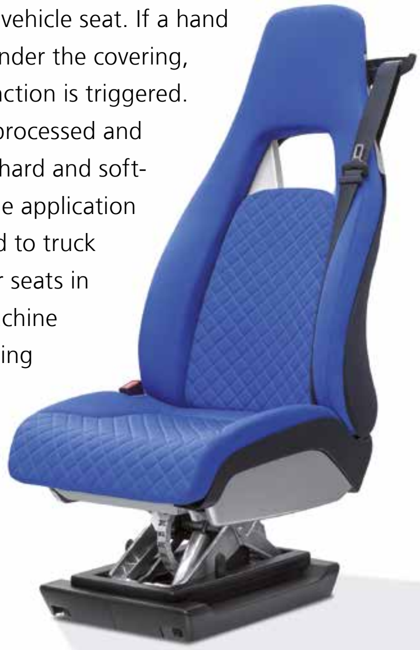
The seat simply follows the natural movement of the hand – there is no need to learn special gestures. If the seat needs to be elevated, the hand moves up; if it has to be moved forward, the hand moves forward. Further diagonal upward or downward gestures adjust the backrest and thigh support. A man-to-machine communication has thus been realized that is easy to learn and easy to operate. Operating errors can additionally be excluded electronically.

Cost-effective manufacture and freedom in design

An additional benefit: Factors like switches and buttons that can be damaged or soiled in daily operation are eliminated. This means a simplification of the seat structure and, therefore, lower production costs. In addition, individual seat positions of different drivers can be saved with simple movements and retrieved at any time when needed. The large-surface, buttonless control panel is located in an easily accessible area on the side of the driver seat – invisible under a covering. It is dirt resistant, robust and can be operated when wearing gloves. This opens up whole new areas of possibilities for the designers of seats and vehicles: Since all the components are located behind the plastic side cover of the driver seat, the outer shape and design of the side cladding for the operating side can be freely selected.

Hand movements trigger switch function

The side covering is furnished with electrodes for capacitive proximity sensors based on charge-transfer principles for the contactless gesture control of the vehicle seat. If a hand or finger come near the sensor field under the covering, the capacity changes and a switch function is triggered. The sensory information is recorded, processed and transferred in switch commands with hard and software developed by Fraunhofer ISC. The application of this operating concept is not limited to truck seats. The sensors are also suitable for seats in cars, trains or aircraft. The man-to-machine technology is also conceivable in housing technology, such as in the operation of window blinds or household appliances, or even in the operation of robots and machines via motion patterns in production technology.



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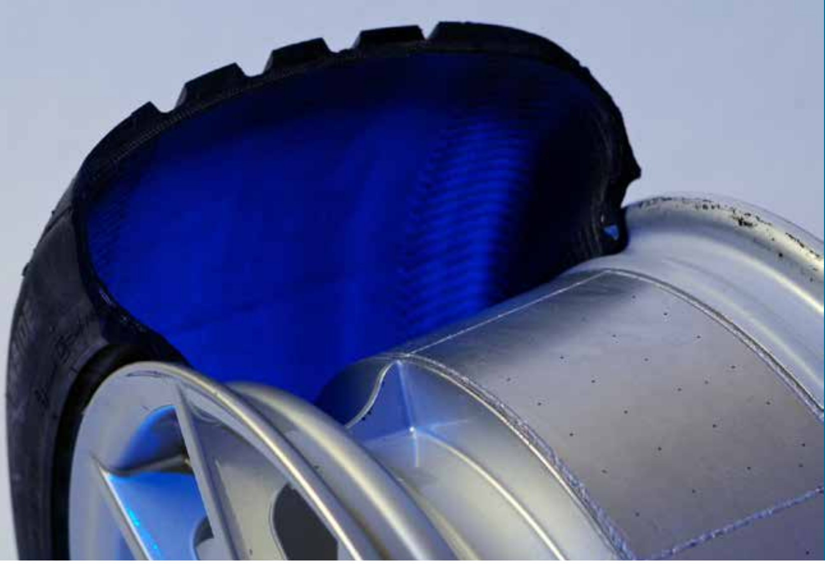


Rim with integrated micro-perforated absorber. © Fraunhofer EMI

Micro-Perforated Rim as Sound Absorber

The noise levels of vehicles are being reduced and optimized more and more. Rolling noise contributes to the exterior noise that can dominate even at low speeds from approximately 40 to 50 km/h. In addition to the wheel house shell, the combination of tire and rim has potential for the integration of absorbers. However, the use of fibrous materials in this context is not possible, as these materials cannot permanently withstand the handling when changing tires. Additionally, the absorber must not interfere with the vehicle handling and driving safety. The solution presented here follows the approach of integrating a robust, purely metallic cavity with micro-perforation in the rim.

The focus is on the standing wave emerging in the surrounding air cavity of the tire, also called the torus mode. It leads to a frequency of approximately 200 Hz for standard tire sizes, at which a measurable and unpleasant increase of the noise level is perceived in the passenger compartment. For the integration of the absorber, the rim is refactored to create a deepening that is covered by a metal strip with micro-perforation. The form is chosen so that it does not impede the tire replacement.

A complete set of tires was produced as a prototype for the measurements inside the vehicle. The measurements were carried out on the road as well as on the acoustic roller dynamometer at the IBP, with mounted shells for the simulation of rough asphalt providing increased noise excitation. The levels were recorded with a dummy head at the passenger seat next to the driver. Compared to the standard wheel, a reduction of the torus mode by 5 dB was achieved both on the test bench as well as on the street and has thus proven effective.

New Methods for Improved Simulation of Bird Strike

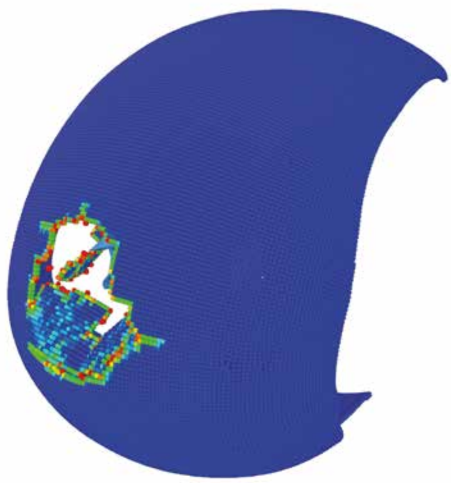


Fig. 2: Novel type of bird strike modeling. The windshield of a helicopter is modeled with the meshfree SPH method. The crack patterns that develop here show considerably improved agreement with the behavior observed in experiments. The colors of the material points correspond to a failure index: Here, blue indicates no failure, and red indicates complete failure. © Fraunhofer EMI

Bird strike is the collision of a bird with an aircraft. Although a bird is considerably lighter, smaller and softer than the exposed parts of an aircraft, birds turn into dangerous projectiles with enormous penetrating power at relative velocities of up to 300 kilometers per hour, a speed that is typically reached during take-off and landing phases near the ground. Helicopters are more endangered than other aircraft because of their low altitudes and comparatively very large windows. Figure 1 (top right) shows a typical scenario of bird strike: The substitute bird model penetrates the windshield of a helicopter, and the person who is struck can be seriously injured.

Fig. 1: Bird strike scenario: Coming from the left, a substitute bird model (blue particles) smashes through the windshield of a Bell MH-6 "Little Bird" helicopter. The acceleration of the crash-test dummy visualizes the remaining kinetic energy of the bird after windshield penetration.
© Fraunhofer EMI

This is why the constructive design of a helicopter cockpit to safeguard against bird strike is particularly important. However, this requires precise information on expected loading which can only be delivered by a combination of very extensive experiments and simulations. There is considerable interest, therefore, in minimizing experimental time and effort and in using more numerical models. This is only possible if the predictive

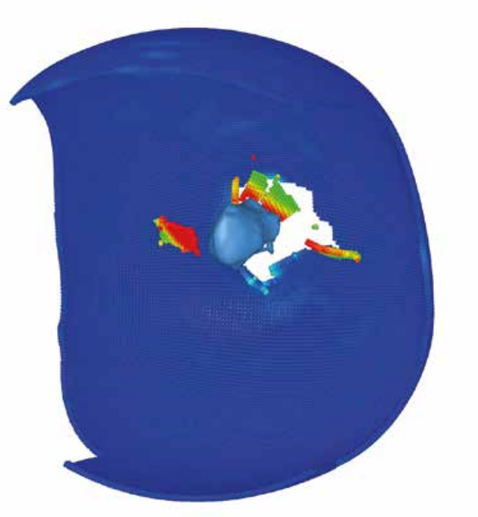


Fig. 3: Novel type of bird strike modeling. The windshield of a helicopter is modeled with the meshfree SPH method. As opposed to the finite-element method, realistic debris originating from the windshield can be tracked since it is not necessary to delete these partially failed material points. The color scale shows the velocity of the material points, red corresponding to a velocity of 150 kilometers per hour. © Fraunhofer EMI

quality of the simulation is high enough to rate the results as trustworthy and reliable.

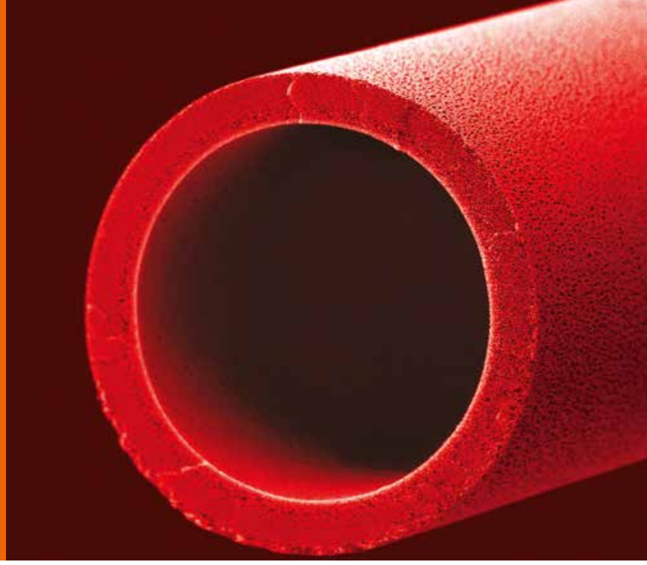
The finite-element method that is usually used for the simulation of mechanical structural loading is not suitable for dynamic loading cases with extreme failure patterns. So-called meshfree methods are more suitable. Here, the numerical model of the body that is to be computed is discretized by material points that only serve as temporary nodes for the solution of the Euler equation. A meshfree method is the so-called smooth particle hydrodynamics (SPH) method which has been intensively refined at Fraunhofer EMI over the past two decades. A breakthrough in 2014 [1] made it possible to also model the failure patterns of comparably brittle material with good precision. Figure 2 shows the result of bird strike modeling that was achieved with this meshfree method. Here, the failure patterns occurring in crack propagation correlate very well with experimental observations.

In Figure 3, a second view of this scenario of the cockpit interior additionally shows the debris of the smashed windshield that can reach different parts of the interior at high speeds. This new simulation approach shows an improved predictive quality for the analysis of danger to the passengers so that a reduction of the danger potential can be achieved more easily by adjusting the structural design. The depicted simulation results gained from meshfree methods were computed with the smooth Mach hydrodynamics simulation program developed at EMI. In addition to the stabilization algorithms published in [1], this program contains the state of the art for simulations of very strong deformations with meshfree methods. Because of the specific program architecture that was designed for massive parallel computations, it also allows the simulation of very large systems with millions of discrete material points.

*[1] Ganzenmüller G. C. (2014), An Hourglass Control Algorithm for Lagrangian Smooth Particle Hydrodynamics.
Computer Methods in Applied Mechanics and Engineering, in press, DOI 10.1016 / j.cma.2014.12.005*

ArtCornea®, an artificial cornea, has already helped a number of people recover their eyesight. © Fraunhofer IAP

Regioselectively equipped hollow fiber membrane for blood cleansing. © Fraunhofer IGB (host institute)



HEALTH

Biomaterials Recover Eyesight

Diseases and injuries of the cornea are often the cause of blindness. The established form of therapy is transplantation of the cornea; however, there are cases in which this is not possible. Corneas from donors are usually rare. In the future, artificial corneas should be able to compensate this deficiency and help recover the eyesight of the patients concerned. Biomaterials for artificial corneas and their manufacturing processes are being developed at Fraunhofer IAP in close cooperation with ophthalmologists and medical technology companies.

The requirements for this type of prosthesis are very high since they often must fulfil contradicting tasks. The scientists have developed a prosthesis for this purpose based on a water-resistant polymer to ensure anchorage in the host tissue. The haptic edge was chemically altered to encourage local cell growth. A special, ultra-thin hydrogel layer that is polymerized into the front optical part prevents the growth of cells on the center of the prosthesis in order to guarantee clear eyesight. Tear film and medication are able to moisten the area well and the eyelid does not react to the implantation as a foreign object. In addition, the prosthesis must be heat resistant for sterilization purposes.

The artificial cornea MIRO®Cornea UR has already recovered the eyesight of a number of patients. Not only ultima-ratio patients can benefit from research carried out at Fraunhofer IAP. A further development, the ArtCornea® artificial cornea, is currently being developed and the ACTO TexKPro, which is primarily suitable for first aid application such as when the cornea is destroyed by chronic inflammation, serious accidents, chemical or thermal burns, was further developed with ACTO e.V. in a joint project.

Regioselectively Equipped Hollow Fiber Membrane for Blood Purification

A specially developed plasma process enables the manufacture of hollow fiber membranes allowing one-step dialysis, for example, in the case of sepsis: The filtering of blood cells and the purification of blood plasma take place in a single step.

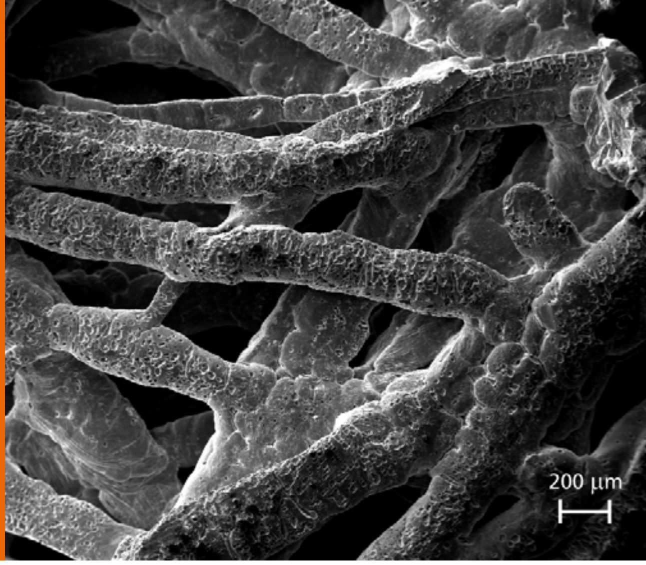
The hollow fibers are regioselectively functionalized – i.e. only in the pores: Sensitive blood cells are washed through the unmodified lumen of the hollow fibers without being affected (they cannot pass through the membrane pores because of their size). The blood plasma, on the other hand, is filtered through the nanoscale membrane pores. Their inner surface and the outside of the membrane are functionalized in such a way that inflammatory endotoxins like lipopolysaccharides (LPS) adhere to them. The purified blood plasma is reunited with the blood cells after passing through the membrane.

To achieve such a selective membrane structure, the nanopores have been provided with functional groups in a dry plasma chemical process and equipped with bioactive molecules in a subsequent wet chemical treatment.

In this case, plasma functionalization took place with amino groups, whereby a functionalization density of around 50 plasma µmol/g fiber was achieved. The functional groups are only located either on the inside or outside – this selectivity cannot be attained with wet chemical methods! However, the processes are not only limited to amino groups. Customized membrane structures can be used for different applications beyond the field of medicine as well.

Fibers (demonstrator).
© Fraunhofer IFAM

REM images of
magnesium fibers
© Fraunhofer IFAM



Metallic Implant Material – Highly Porous and Degradable

A problem that still hasn't completely been resolved in the field of medicine is the treatment of large bone defects. These types of lesions do not heal spontaneously and have to be treated with implants. Using the patient´s own bone is the first method of choice for extended bone augmentation, however, the available amount is limited and its removal from the iliac crest poses additional risks. On the other hand, frequent operations that are necessary for removing a synthetic bone replacement create risks in addition to a permanent disruption of the imaging. Degradable materials, i.e. implants that disappear after healing, are considered an ideal solution.

Magnesium Fiber Structures as Materials that are Adaptive to Bones

Magnesium is an almost ideal material. It degrades in a biological environment, has excellent biocompatibility and contains particularly bone-adhering properties.

A magnesium implant has now been developed at Fraunhofer IFAM in Dresden that has favorable characteristics due to its structure. Metallic fiber structures form a highly porous framework that serves as a growth guiding structure for the bone, thus enabling the ingrowth of the blood vessels. Such structures are particularly interesting because of their reduced stiffness; they are very similar to the biomechanical properties of bones. This has a particularly stimulating effect on bone growth.

The starting point for the technological development is the manufacture of short magnesium fibers by extraction from the melt. These fibers are laid down homogeneously and sintered. A particular challenge in the manufacture of magnesium fiber structures is the sintering, which, as a result of the stabile surface oxides, is resistant to the high oxygen affinity of the material. The heat treatment is therefore carried out with a partial melting phase in which precise knowledge of the correct melting point for the sinter result is essential. The appropriate sinter regimes are calculated by simulative methods.

The implants manufactured with this method have good mechanical properties and, above all, very good corrosion properties. As the result of increased separations of Y_2O_3 on the grain boundaries, a degradation behavior with reduced corrosion rates could be attained that in particular meets physiological requirements. In animal experiments, a slow rate of corrosion could initially be determined after 12 weeks and a large part of the metallic implant disappeared after 24 weeks.

As a winner of the Innovation Competition in Medical Technology, this approach was funded by the German Federal Ministry of Education and Research (BMBF). In the meantime, these favorable characteristics have convinced enterprises as well. Botiss Dental GmbH has become a licensee for the patent that has, in the meantime, already been granted. The company is planning to implement the material in oral surgery and is presently evaluating the development of a suitable production chain.

Porous disc and dense trauma implant made of biodegradable iron-TCP composite.
© Fraunhofer IFAM

Infection control with antibacterial bone implants.
© Fraunhofer IGB (host institute)

Degradable, Load-Bearing Implants – New Material Development for People

The advancement of implant treatment is a continuous process to improve people's quality of life. In order to avoid operations for removing implants after healing, which further burden those involved and generate costs for the health care system, degradable implant material is increasingly becoming the focus of research and development in medical technology.

To advance progress in this area, a material and technology platform for the manufacture of new types of load-bearing bone implants is being developed within the framework of the internal Fraunhofer project "DegraLast". Materials with mechanical properties and degradation behavior that can be adjusted for application in orthopedics and traumatology are being developed for this purpose. A central challenge to ensure the mechanical stability of the whole system of implant and bones during the entire period of implant degradation and healing. In order to meet these demands, the project group carries out research on innovative composite materials based on biodegradable metals and bio-ceramics.

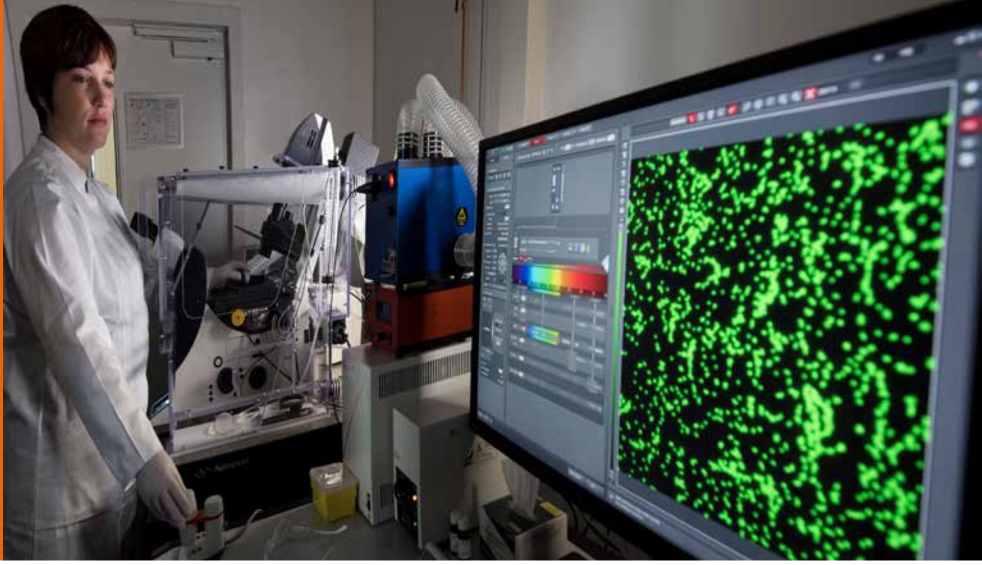
Modern, generative molding procedures are used to manufacture implants. The Fraunhofer institutes IFAM, IGB, ILT and IBMT, however, are focusing on further aspects: In order to ensure the applicability of the new materials for implants, they are simultaneously working on biological test systems that enable the analysis of the ingrowth behavior of the bone and the degradability of the implant on cell levels in physiological media. In addition, monitoring systems based on optoacoustic imaging are being developed to track the degradation of implants and the healing of bones for clinical application later on.

Protection Against Infection Using Antibacterial Bone Implants

During implantation of bone material, it may happen that germs penetrate the body. Infections of the bones are particularly problematic since antibiotics, which are conveyed by blood, only reach the implants in very low concentrations. The best protection would be to avoid infections all together. In cooperation with the French CIRIMAT Carnot Institute in Toulouse, the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB has developed bone substitutes with integrated protection against infection.

The novel bone implants are made of calcium phosphate apatite crystals, which are very similar in composition and structure to natural bone material. In order to reduce or suppress the growth of bacteria on calcium phosphate crystals, different materials and combinations were examined, such as silver, copper and zinc ions as well as antimicrobial enzymes and peptides. Antibiotics were not used since their application is problematic due to the development of bacterial resistance.

Samples of specially modified and antibacterially functionalized apatite crystals were infected in the laboratory with bacteria including typical hospital germs like several species of Staphylococcus. After cultivation for several days the functionalized apatite crystals were examined for antibacterial properties and cytotoxicity. With different metal ions, the amount of bacteria in the immediate vicinity of the apatites was reduced by more than 90 percent. A peptide coating proved to be equally effective for inhibiting the growth of bacteria on the surface of apatite pellets and granules.



Fluorescent nanoparticles in a STED microscope.
© Fraunhofer ISC

Development and Evaluation of New Forms of Therapy for Chronic Skin Diseases

Chronically open wounds are one of the most frequent diseases and burden the German health system with eight million euro per year. They are caused by widely spread diseases such as diabetes, and mostly affect older people. A proper, reliable and, above all, timely therapy is able to reduce the number of amputations by half, such as in the case of diabetic foot syndrome. Coordinated by Fraunhofer ISC, researchers at five Fraunhofer institutes have pooled their competencies for the evaluation and development of effective and affordable forms of chronic wound therapy.

An essential element is an in-vitro wound model for chronic wounds on the basis of an already existing model of healthy skin. By injecting cytokine proteins, which regulate growth and the differentiation of the cells, a special wound environment is created in the model that is characteristic for chronic wounds. The prepared skin model is standardized and reproducibly wounded. The result is the desired chronic wound model. Fraunhofer ISC designed and built the "ARTcut® – Artificial Tissue Cutter" appliance for this purpose.

The new in-vitro wound model allows the testing of different forms of therapy in very early stages. Wound dressings as well as silica gel fiber fleece developed by Fraunhofer ISC, pharmaceutical ingredients or a combination of both can be tested for their effectiveness. In addition, these types of models are a long-term alternative to animal testing.

Monitoring wounds with biofunctionalized nanoparticles via smartphone

A further development in the "SkinHeal" project serves the improvement of fluorescence-based imaging which provides doctors, medical personnel and, in the long term, the patients themselves with information on whether the wound is healing as expected. Surface-modified luminescent nanoparticles developed at Fraunhofer ISC that bind on biomarkers characteristic for wound healing are applied for an effective optical imaging. A certain ratio of these biomarkers identifies the healing status of the wound and provides an indicator for a normal, i.e. healthy, or chronic progression. If the fluorescent particles cannot form a bond due to missing biomarkers, they are eliminated by the body. In the long term, regular pictures of the wound situation made by the patient or their carers would be possible, e.g. via smartphone, so that the situation can be further monitored from home. A first prototype has been developed that makes analysis possible with images of the macrophages´ distribution.

Cost reduction in material development

The new in-vitro wound model can, of course, also be used in other areas of research such as in the development of new substances and medication. An immense savings potential per substance is possible as the result of a faster and more efficient selection of suitable substances. In addition, clinical studies can be much more efficiently planned with the results of corresponding in vitro pretests, and necessary animal tests can be reduced to a minimum.

Pressure measurement stocking with integrated elastomer sensors – trade fair demonstrator without a second outer textile layer.
© Fraunhofer ISC

Preventive Wound Protection – Pressure Monitoring Stockings for Diabetics

Diabetes is one of the most widespread diseases and can lead to serious consequences. According to the German Health Report on Diabetes 2014 of the German Diabetes Association, statutory health insurance companies estimate that approx. 20 percent of their annual costs are spent on the treatment of diabetes. In the advanced stages of the disease, many diabetics no longer have feeling in their feet and, therefore, cannot register pressure or temperature signals. They do not notice it when there is too much pressure in certain areas of their feet. Even small uneven spots or shoe pressure can cause open wounds or tissue damage, which can lead to chronic wounds, if noticed too late. As a result, many diabetes patients have to have their toes or feet amputated. A new type of pressure monitoring stockings can prevent this. A sensor system integrated into the stocking warns the person wearing it of pressure sores.

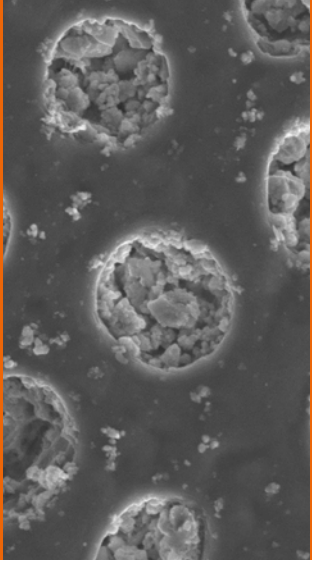
Smart phones evaluate signals

The sensors are made of a very elastic, soft silicon film. This makes them easy to integrate into textiles without disturbing the wearer. The film is coated with highly flexible electrodes on both sides. If the film is deformed by pressure or stretching, its density decreases and its surface simultaneously expands. The result: The electric capacity increases. The change in the capacity of the 40 sensors is transmitted by conductive and elastic threads to an electronic evaluation unit. The evaluated data is transmitted wirelessly to a smartphone or tablet, which shows the diabetes patient whether he/she should change his/her foot position or weight distribution. This way the patient can react quickly and protect himself/herself from dangerous pressure sores.

Outlook

In order to guarantee washability, the project partners are now developing stockings from which the electronics can simply be removed like a Velcro fastener. However, commercial disinfectants already allow a hygienic treatment of the pressure monitoring stocking.

An additional area of application for sensors integrated into textiles is the area of fitness. Joggers, for example, would be able to check their running style and foot position when wearing the socks. It is also possible to manufacture gloves with sensors to equip robot grippers or prostheses. Further future developments make it possible to measure a person's posture in order for example, to prevent biomechanical stress due to prolonged sitting.



Electron microscopic images of dentine after treatment with a desensitizing toothpaste. © Fraunhofer IMWS

Lower jawbones produced using additive manufacturing. © Fraunhofer IKTS

Microstructural Evaluation of the Application Behavior of Dental Products

"Twice a day for at least two minutes" – Every child in Germany is familiar with this maxim and understands the significance of dental hygiene for his or her own well-being.

Fraunhofer IMWS has approached this topic – that for decades was primarily regarded from the point of view of dental medicine and biosciences – more intensively at the material level, with remarkable results. Based on microstructural tests, scientists in Halle were able to evaluate the influence of the filament geometries of tooth brushes on the cleaning result and explain the discoloration processes from mouthwash.

The latest work in Halle deals with the widespread problem of hypersensitive teeth and treatment methods. The industry is looking for models to test materials and formulas already during development and before elaborate clinical tests. Most existing products for sensitive teeth aim at sealing the exposed dentinal tubules of the tooth necks in order to interrupt the transmission of pain impulses.

Researchers at Fraunhofer IMWS were able to establish a model in which the sealing is chemically imaged and characterized and can be combined with a flow measurement at the dentine. It also allows the integration of mechanical and acid attacks in the test sequence and thus offers excellent possibilities for the assessment of pain-reducing products.

Ceramic Materials for Additive Manufacturing

Difficult ceramic components were previously injection molded requiring intensive use of tools, or manufactured with high material losses from green, isostatic moldings. New additive manufacturing methods open up completely new paths for ceramics. These enable the production of components without additional tools and with complex geometries that up to now could not be achieved by any other shaping method. What was exclusively possible in the plastics and metal industry so far is now utilized by Fraunhofer researchers for the production of complicated geometries made of long-term stable, temperature, wear and corrosion resistant ceramics.

Solely from CAD data, free-form surfaces, undercuts, inner channels or hollow structures are built layer by layer, resulting in individual components. At the same time, small series can be realized quickly and economically for the jewelry and microreaction industries, equipment or medical technology. For example, patient-specific implants, whose form and quality are adapted to individual requirements, can be efficiently manufactured. In addition, scientists develop customized instruments for minimally invasive surgery that in the future can serve different functions in one step by means of integrated fluidic, sensor or thermal elements.

Currently, research also focuses on developing material systems for multifunctional components from material and shape combinations. Soon, porous, permeable components could be added with solid housing structures. Individual bone structures can be recreated in this manner in order to specifically realize implants for bone cancer patients.

New kilo laboratory for the manufacture of innovative materials and components at Fraunhofer LBF.
© Hessen-schafft-Wissen, Fraunhofer LBF

MECHANICAL AND PLANT ENGINEERING

Developing More Efficient Polymers on the Kilogram Scale

New polymers and additives for practical tests
There is almost no limit to the selection of different polymers available on the market. So the right types of materials are available for a large majority of application areas. In addition, the property profiles of a polymer can be precisely customized for each application by applying the right additives.

Despite or precisely because of these myriad possibilities, new questions keep occurring such as how polymers can be designed more inexpensively, more efficiently or with more resistance compared to commercially available polymers and additives.

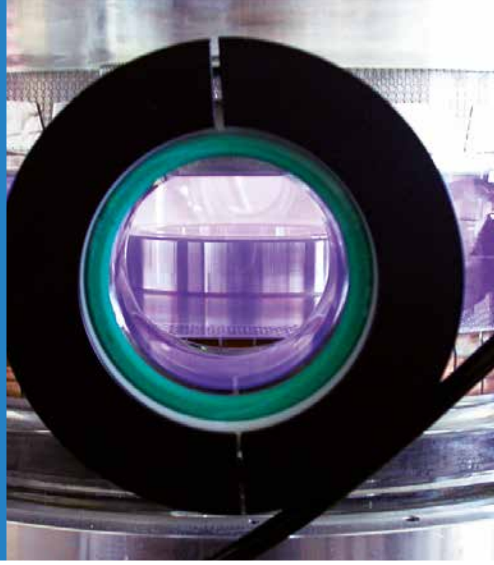
In the area of polymers, Fraunhofer LBF is creating and testing new polymers and additives by means of chemical synthesis in order to provide solutions. Normally, first chemical experiments are carried out with small amounts in a synthesis laboratory to spare resources, avoid waste and to detect potential danger at an early stage. The result is approximately a few grams of substance, which is enough for first application-oriented tests.

However, this amount is not enough for practical tests carried out with customers or at the institute. In order to bridge this gap, a kilo laboratory in the field of polymers was set up which enables the synthesis of several kilograms of polymers and additives that were previously developed in conventional laboratories.

The kilo laboratory is equipped with different reactors that allow for reactions under different conditions, like inert gas atmosphere, pressure or under very low or very high temperatures. A corresponding periphery for the reconditioning and cleansing of the reaction products is available as well. Classical organic syntheses as well as different polymerization methods, particularly controlled radical and live ionic polymerization, are possible.

This method enables the manufacture of, among other things, polymers with special architectures that are suitable as bonding agents and compatibilizers. The kilo laboratory is used to work on customized solutions for the manufacture of innovative components and materials.

Multiaxial laboratory table.
© Fraunhofer LBF



Plasma reactor with ball bearing.
© Fraunhofer IGB (host institute)

Compact Vibration Isolation Table for Sensitive Appliances

A platform for active vibration isolation was set up at Fraunhofer LBF that can reduce the transmission of ambient vibrations to sensitive appliances. Functionally integrated, multi-axial bearing units were developed to take over the structural, actuator and sensory tasks. The modular setup of the platform and use of the rapid control prototype (RCP) on the basis of a digital control platform makes flexible adaptation to different isolation tasks and a networking of the bearing unit possible.

The demonstrator is a self-contained, adaptronic system that reduces the transmission of vibrations in three dimensions. The control actuators are integrated into the system's stiffness. This helps attain a particularly low passive system eigenfrequency that enables isolation in the high-frequency range. Specially built sensors and sensor electronics are used because of the high requirements. A digitally implemented control algorithm causes active damping of the system resonance. An active vibration isolation of about -18 dB is achieved by the entire internally coordinated system.

Friction-Reducing Layers

According to estimates, losses equal to 5 percent of the gross national product occur in the industrialized countries due to friction and wear of machine parts (in which heat is produced and emitted). A specific change in the physical-chemical properties of the material surface could reduce friction and wear and thus considerably reduce these losses. A promising approach is to change the wetting behavior of surfaces in contact with agents such as lubricants, humidity, water and cleaning products by means of a plasma modification.

In cooperation with partners from research and industry, the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB has developed micro- and nanoscale structured layers with which the wetting properties of surfaces can be controlled. Micro- and nano-structured surfaces show ordered structures with a magnitude of only a few nanometers. The structuring of the surfaces influences the wetting as well as chemical properties.

We were able to specifically adapt both the chemistry as well as the topography of the surfaces to the desired application via a plasma coating. The result was a reduction of the friction in coated roller bearings by up to 30 percent.

Sample quantities up to ton scale can be synthesized with the flexible polymerization pilot plant of the Fraunhofer PAZ.
© Fraunhofer IAP / photographer: Till Budde

Tonne-Scale and Serial Production – Polymer Synthesis and Processing on an Industrial Scale

Scaling up is a decisive step during the commercialization of new technologies and products. Both the materials and manufacturing processes have to be suitable for industrial use. But the design, realization and operation of pilot plants are costly. Here, the Fraunhofer Pilot Plant Center for Polymer Synthesis and Processing PAZ in Schkopau, close to Halle and Leipzig, offers facilities, infrastructure and experience. The PAZ tailors its scale up of a wide range of polymer synthesis processes and processing methods to an industry-relevant scale in order to meet the requirements of its customers from the plastics and automotive industries. Its service spectrum extends from monomers, to pilot-scale polymer synthesis and plastic processing, and made-to-measure component testing. It also works with lightweight and biobased materials that can replace petroleum-based polymers.

Fraunhofer PAZ is a joint initiative of the Fraunhofer Institute for Applied Polymer Research IAP in Potsdam-Golm and the Fraunhofer Institute for Microstructure of Materials and Systems IMWS in Halle. The PAZ bundles the competencies of both institutions – polymer synthesis (IAP) and polymer processing (IMWS) – in a unique way. This collaboration, the technical possibilities on a pilot scale, and the high flexibility of its plants constitute its unique selling point on the R&D market. This combination and scale make the Fraunhofer PAZ unique throughout Europe.

Polymer synthesis

The polymerization pilot plant is designed to be a flexible, multiproduct, multipurpose pilot plant. A broad range of polymerization processes of industrial importance, such as (anionic) solution polymerization, emulsion polymerization, suspension polymerization as well as polycondensations or catalytic polymerizations, can be achieved on different lines in the pilot plant.

The volumes of the main reactors range from 50 liters to 1 m³, and both batch-wise and continuous operation are possible. Reaction pressures range from a vacuum of below 1 mbar to up to 100 bars and temperatures range from ambient to 300 °C. Its high degree of flexibility is one of the pilot plant center's particular advantages. By combining equipment from different lines, it is possible to implement new, client-specific processes.

Project objectives include scaling up from laboratory scale to pilot scale, as well as technology development and preparation of sample material, e.g. for product development and application testing. One field of activity is scaling up and process development in the area of synthetic rubber.

Polymer processing

In the Polymer Processing Department, the Fraunhofer Pilot Plant Center PAZ has extensive knowledge in all areas of polymer processing as well as in the characterization of structure-feature relationships for thermoplastics, thermosets, elastomers and fiber composites. Our core competencies are in material, procedure and component development of long-fiber-reinforced thermoplastics (LFT), continuous-fiber-reinforced thermoplastic composites (TPC), highly filled plastics, and blends. We take into special consideration the properties of the resulting materials and components. We focus on the systematic evaluation of the influence of material systems and manufacturing conditions on the mechanical characteristics of unidirectional-fiber-reinforced semi-finished products, and multidirectional-fiber-reinforced laminates. Thus, we are able to determine the performance and reliability of the produced synthetic materials through experimental characterization and numerical description of the materials' behavior.

Fraunhofer PAZ evaluates the use of long-fiber-reinforced thermoplastic components for lightweight design.

Modular high-temperature reactor for the continuous synthesis of nanoparticles.
© Fraunhofer ICT-IMM

Finishing CFRP components by plasma spraying.
© Fraunhofer IKTS

Modular, High-Temperature Reactor for the Continuous Synthesis of Nanoparticles

Fraunhofer ICT-IMM has developed an innovative modular reactor for continuous flow synthesis that is designed for the synthesis of nanoparticles at elevated temperatures. The reactor is able to withstand liquid-phase reactions of up to 400°C. Standard hot injection synthesis protocols for the synthesis of nanomaterials can be transferred from a batch to a continuous process. The central part of our reactor is a microfluidic mixer developed by Fraunhofer ICT-IMM and a temperature-controlled delay element. Integrated optical flow-through cells allow for in-situ optical detection at different positions and at high temperatures on location and thus lay a foundation for online process monitoring.

The modular design of the reactor allows it to be adapted to specific needs, since both the design and the construction are carried out at Fraunhofer ICT-IMM. Because of its compact size, the reactor module takes up little space in the laboratory or fume hood and can be integrated into already existing setups. Its design enables the transfer of batches to continuous processes, especially synthesis paths for nanoparticles that require higher temperatures and fast mixing (hot injection). These conditions are usually available in high quality during the synthesis of monodisperse nanoparticles. Examples for this are organometallic syntheses such as those used for CdSe quantum dots, Pt and other metallic nanoparticles or oxide metals.

With our knowhow in continuous flow chemistry, microreaction technology and plant engineering, this reactor represents the centerpiece of a complete, customized system in laboratory scale for the synthesis of nanomaterials. We offer tailored services with regard to the design and construction of prototypes or feasibility studies while taking customer needs and specifications into consideration.

Finishing and Testing of CFRP Components

Energy-efficient, lightweight construction with carbon- or glass-fiber-reinforced plastics (CFRP, GFRP) is of increasing importance for mechanical engineering. Components made of CFRP or GFRP are high-strength and light, but less resistant under chemical and tribological load. Ceramic coatings can noticeably improve the surface resistance and quality of CFRP and GFRP components, for example with regard to wear protection, non-stick effects or insulation behavior. At Fraunhofer IKTS, surfaces are coated by atmospheric plasma spraying. The resulting material composites solve the conflict between light, high-strength components and high surface resistance as well as high surface quality.

Not only the finishing but also the further development of non-destructive test methods for CFRP components is particularly relevant from an economic and technical point of view. An important step towards the production-integrated diagnosis of CFRP components was accomplished with the development of eddy current-based diagnosis systems. CFRP components can now be tested along the entire process chain, from the raw carbon fiber material to the production of entire assemblies. The component to be tested is digitalized with a stripe light camera. Based on an automatically calculated path, the robot guides the eddy current sensor orthogonally across the component surface. The measurement results are composed to a scanning image. In addition to the high scanning velocity at high resolution, sensor tracking on sloped, planar surfaces and the flexible parameterization of the easily interchangeable sensors are also advantages. Furthermore, a software together with direction-dependent probes allow an exact differentiation of defect types.

Removal of Flex$^{PLAS®}$ release film from a fiber-reinforced component that has been coated in-mold with a gelcoat.
© Fraunhofer IFAM

Flex$^{PLAS®}$ Release Film – FRP Component Manufacturing Without Release Agent

Manufacturing large fiber-reinforced composite (FRC) structures is an everyday part of aircraft and wind turbine engineering. To manufacture these components without using a release agent is the next step into the future. At the Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM), experts in the areas of plasma technology and surfaces have combined their knowledge and expertise with that of the experts from automation and production technology to develop Flex$^{PLAS®}$, a deep-drawable plastic film functionalized with plasma technology.

This plastic film, with its strongly adherent plasma polymer separating layer less than 0.3 micrometers thick (also developed by the Fraunhofer IFAM) can be used with complex tools. This allows simple demolding and doesn't leave residue on the component surfaces. It is also especially durable and stretchable. Flex$^{PLAS®}$ release film can be stretched with little effort and can withstand extreme stretching of up to 300% without affecting its functionality. This means it can be used on bent or structured forms and parts without creating wrinkles. This is particularly useful when making super-sized FRC components without a release agent.

Using a special deep-drawing technique, Flex$^{PLAS®}$ can be used with both female and male tools without any structural changes. It has already been used in a prepreg process at 180 °C to produce large, 1:1-scale carbon-fiber reinforced plastic (CFRP) structures without a release agent. Following this step, the large components can go straight to coating without any pretreatment, because demolding with the innovative film doesn't leave any residue.

In addition to its implementation in prepreg technology, Flex$^{PLAS®}$ can also be used in other manufacturing processes like vacuum infusion and manual lamination processes. The flexible film's properties don't limit its use to carbon fiber or fiberglass matrix resins.

This innovative technology also allows for in-mold coating of FRC components, where the part is coated by means of a gelcoat already applied to the film. The degree of mattness versus glossiness of the coated surface can be adjusted by the roughness of the Flex$^{PLAS®}$ film being used. This also significantly reduces the risk of flaws in the coating.

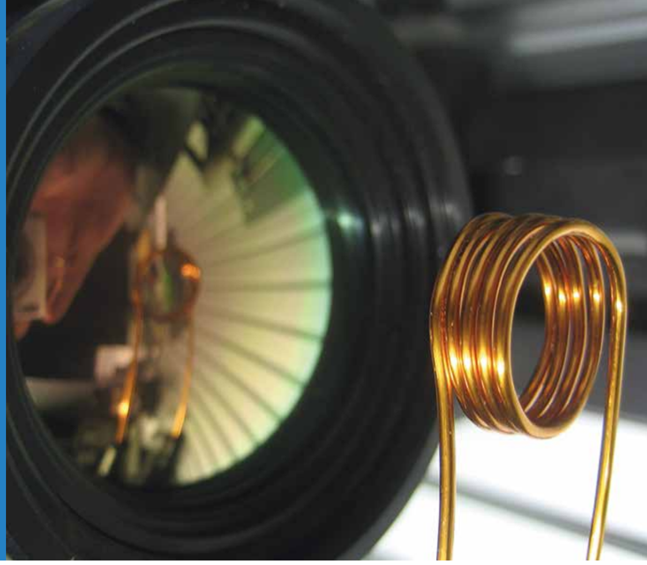
The FRC structures can also be sent for coating or painting without the need to remove any release agent residue. It also serves as a protective film if left on until the end of the process or even until delivery to the customer.

In addition to replacing the release agent on tool surfaces, Flex$^{PLAS®}$ film also increases productivity in other steps down the line in the process chain. Specifically, it reduces downtime due to cleaning release agent residue off the forms, which significantly increases tool life and availability.

Flex$^{PLAS®}$ release film was awarded with the AVK (German Federation of Reinforced Plastics) Innovation Award of 2012 and the Composite Innovations Award of 2013. Further development is focused not only on other FRC manufacturing processes such as infusion and prepreg processes, but also on the preparation of glossy CFRP surfaces, which would make costly grinding and polishing processes obsolete.

Demonstrator for active thermography on rail wheels.
© Fraunhofer IZFP

Copper coil.
© Fraunhofer IZFP



Tracking Down Minute Cracks – Active Thermography with Inductive Excitation

In many branches of industry safety-relevant components have to undergo a one hundred percent check in order to exclude surface cracks during manufacture. In the future, all procedures that do not require special surface treatment, that work reliably and objectively and that enable a fully automatic examination of components are given a competitive edge. Inductively excited thermography permits surface inspections for cracks without surface treatment; it is fast and fit for automatization. It is an objective procedure that provides reliable test results and additionally makes it possible to determine the location of the defect (crack depth). Thus it is suited for fully automatic test facilities that carry out a one hundred percent testing of components in industrial production lines.

Fraunhofer IZFP has a comprehensive range of technical equipment for different variations of active thermography:
- optical impulse and "lock-in" excitation (periodic excitation)
- ultrasonic excitation
- inductive excitation by electromagnetic alternating fields
- noncontact infrared measurement technology with infrared camera system for close, medium and long-wave infrared radiation area with temperature resolutions up to approx. 15 mK and image frequencies up to 20 kHz (time resolutions up to 50 µs) at image resolutions up to 1024 x 768 pixels
- robots and linear adjustment units for fast automated testing with integrated thermographic systems
- software for testing system control, and data processing and measurement data evaluation as well as for automatic defect detection and defect reconstruction
- theoretical and experimental tests concerning the physical principles and application possibilities of different active thermal testing technologies

Range of services
- test measurements and feasibility studies for industrial applications
- tests based on the accreditation of the institute's test and application center
- conception, planning and construction of mobile test systems
- conception, planning and construction of fully automated test facilities for the online testing of components in the production line, including robot-assisted test systems

Advantages
- non-destructive, contactless and fast examination method for surface crack testing
- testing of components with complex geometries
- possibility of determining crack depths
- possibility of verifying hidden defects
- objective and reliable testing of components in industrial manufacture
- capacity for easy automation without greater mechanical effort
- suited for fully automated testing facilities for one hundred percent testing of components in industrial production lines

Applications
- crack detection on forging parts
- in-process crack detection on long products made of steel
- tests for surface cracks on railway tracks and wheels
- detection of delamination in metallic material compounds
- replacement for magnetic particle inspection
- crack detection in photovoltaic cells
- crack detection in turbine components
- detection of fiber breakage in CFRP

Ball-disc friction test in a vibration friction wear tribometer. © Fraunhofer IWM

Liquid Crystals as Lubricants in Small Drive Units

Although lubricants provide for a smooth running of almost all machines, there have not been any fundamental innovations in this field over the past two decades. Together with a consortium, Fraunhofer IWM has now developed a completely new class of substances that could lead to a breakthrough: liquid crystal-based lubricants. They are liquid but also show the same anisotropic physical characteristics as crystals.

Liquid crystals are primarily known for their application in LCD TV screens of televisions, cell phones or touch screens. Nematel GmbH had the unconventional idea of using them as lubricants and approached Fraunhofer IWM with this concept. Tribology experts tested the mostly organic, rod-shaped molecules there with surprising success: When two metallic friction partners move against each other with a liquid-based layer of lubricant between them, the molecule rods align themselves parallel to each other in stable layers. This reduces friction and wear to a minimum and enables an almost smooth sliding.

The background: When a liquid crystalline substance is sheared into friction contact between two surfaces, the molecules are spontaneously aligned so that the shearing movement counters the lowest resistance – the viscosity becomes minimal in the friction direction. The viscosity coefficients vertical to the friction direction are inevitably much larger. Even this condition is useful because the surfaces sliding against each other are better separated from each other, resulting in less wear.

Fraunhofer IWM determined that liquid crystals containing rod-shaped molecules are suitable as lubricants. However, a lot more work was needed to make a practicable lubricant out of the liquid crystals. Together with Nematel GmbH and lubricant expert Dr. Tillwich GmbH, Fraunhofer IWM started a project that was funded by the Federal Ministry of Education and Research. The lubricant developers at Tillwich improved the stability of the fluid crystal lubricants with the aid of additives. They also built a test stand with which they could carry out contactless measurements of the extremely low friction values with laser technology.

Fraunhofer IWM decoded the material-mechanical mechanisms that lead to the ultra low friction values with tests and simulations and specifically found out how the new lubricants could be further improved. In addition, the scientists examined the chemical mechanisms in frictional contact and the effect of mixing different liquid crystal molecules.

At the end of the project, the partners had the prototype of a liquid crystal lubricant that showed its best effect on bearings made of iron. In 2014, the consortium received the science award of the Stifterverband for their pioneering achievement. This award is presented every two years for excellent collaborative projects in applied research.

Together with further partners in the industry, the next steps will be to develop innovative bearings lubricated with liquid crystals for small electronic motors in cars, such as those used in generators or to power windshield wipers. Because of the (still) expensive synthesis compared to standard lubricants, suitable areas of application are those in which only small quantities of lubricants are required.

Micromechanical fatigue testing. © Fraunhofer IWM

Novel Experiments on the Microscale for the Enhanced Reliability of Small and Large Components

Worldwide leaders are pushing the boundaries of conventional experimental mechanics: Scientists at Fraunhofer IWM determine the mechanical material properties of human hair-sized samples with the same rigorous quality standards set by testing practices in the macroscopic world. These novel techniques make it possible to predict the lifetime of small components, coatings of large components, and welding seams, in order to improve product reliability down the line.

Examinations of the tiny samples are necessary for two reasons: firstly, materials in small components respond in a very different way to external loads than materials in large components. Secondly, damage in large components typically occurs within a small, highly-stressed volume. To date, corresponding tests on the microscale level have been lacking – the material samples for the investigation of micro-components have often been larger than the component of interest. It simply was not possible to assess local properties in an appropriate way, or to precisely measure the behavior of special coatings under loading. One knew that they would "hold up", but not exactly why or for how long.

The reasons for local damage come from heavily varying material properties that occur due to component geometry requirements, strong, local deformations during manufacturing, or from welding. For example, manufacturers apply local coatings to large components in order to prevent initial cracks, and harden the component by carburization, nitriding, or cold forming, or they introduce compressive stress to the surface. It is often difficult to use macroscopic testing techniques to clearly validate the effects of a certain fabrication parameter and thus optimize the overall process. Measurements made at Fraunhofer IWM of localized material properties deliver exact microscale characterizations. The scientists additionally support the micro- and macroscopic tests with simulations. This enables customers to optimize their manufacturing processes and considerably increase the reliability of their components.

The smaller the component and the material sample, the greater the effect of, for example, size or anisotropic properties on material behavior. This is especially true for components in the medical, communication and automobile industries that are continuously decreasing in size. Concrete mechanical performance extremes of such miniaturized components can be precisely determined in the micro- and mesoscale laboratory at the Fraunhofer IWM. By transferring test capabilities from the macro to the micro world, the scientists are able to draw conclusions on lifespan, optimum design of miniature components, as well as protective layers, and thus help the industry reduce failure rates. Because only the "Meso- and Micromechanics" group is able to so precisely characterize the fatigue behavior of very thin materials, Fraunhofer IWM also works together with top international universities in addition to its numerous industrial partners.

IWM's team of scientists develops and builds individual micro measurement equipment for almost every type of material and situation. They measure the elasto-plastic material properties under static and dynamic loading – depending on what is needed – in different gas environments and, in the future, also at temperatures from minus 40 to 1000 degrees Celsius. For the industry, this means miniature components with better reliability and products with improved protective layers.

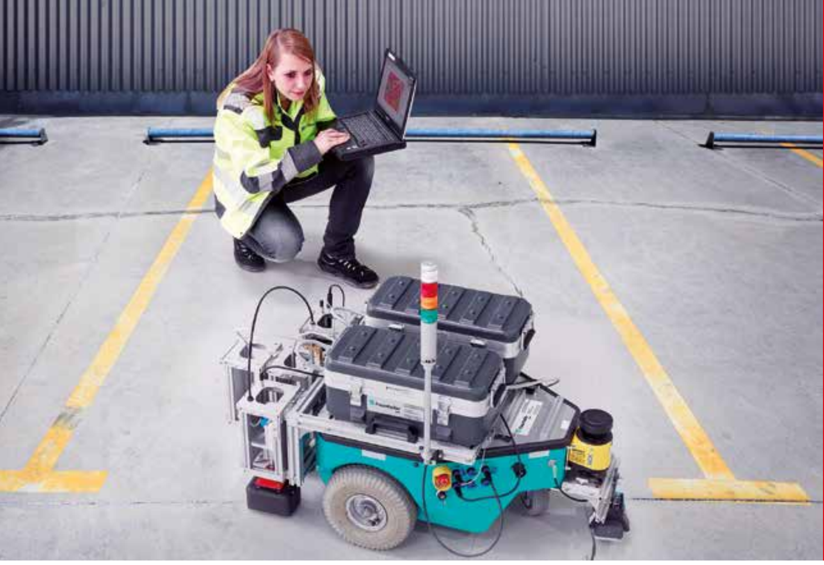
QR code based on ceramic luminescent materials for batch tracking.
© Fraunhofer IKTS

Ceramic Luminescent Materials for Product Labeling

For the reliable, clear and tamper-proof labeling of semi-finished and end products, there are a variety of labeling solutions on the market. These range from a simple serial number to integrated RFID chips. However, these solutions usually do not meet the specific requirements of metal processing since they are not able to withstand extreme processing conditions. Ceramic luminescent materials developed by Fraunhofer IKTS enable completely new systems for product labeling or batch tracking since they are very robust: they withstand high temperatures and are resistant to chemical influence, high humidity and electromagnetic fields.

Ceramic luminescent materials react to optical excitation, such as laser irradiation, with a pronounced luminescence. Both the spectral properties and the luminescence decay time of the labeling can be customized. Since this adjustment can take place during as well as after the synthesis of the luminescent materials, properties arise that can only be copied at a considerable cost of time and money and are thus secure against forgery. This advantage can be used in the labeling of spare parts or other components.

Ceramic luminescent materials can simply be incorporated into inks or pastes so that they can be applied directly onto components via screen or inkjet printing. An influence on the material properties or on the adhesion of coatings can be excluded as only a minimal amount of material is printed. Inks and pastes dosed with luminescent materials are safe and environmentally friendly so that no additional health and safety measures are necessary. Due to the high contrast between labeling and substrate, automated readout is possible in all lighting situations.



BetoScan – self-navigating robot for quick scans of large concrete surfaces.
© Fraunhofer IZFP

CONSTRUCTION AND LIVING

Concrete Robot for Damage Detection in Parking Decks and Bridges

Reinforced concrete as used for example in highway bridges, parking decks, underground car parks or industrial floors is versatile and robust but by no means indestructible. Moisture, de-icing salt and strongly varying climatic conditions exert an especially negative impact on the material. The reinforcement is damaged and starts to corrode, which affects the stability of the construction.

Bridges and other building structures made of reinforced concrete are subject to frequent periodical inspections in order to ensure their safety. Since abrasion and defects can hardly be seen from the outside, only random spots are usually checked. For this purpose, random samples are taken and analyzed. This method, however, is time-consuming and quite expensive.

An inspection system for the non-destructive testing of concrete structures that was developed by employees of the Fraunhofer Institute for Nondestructive Testing IZFP, the Bundesanstalt für Materialforschung und -prüfung (BAM) and experts from companies reveals a much faster and more effective method. "BetoScan" was designed and implemented as a self-propelled and self-navigating robot platform for non-destructive test sensors. This inspection system scans concrete surfaces to scrutinize them for damage without impairing them. The robot is able to independently inspect several hundred square meters of parking levels per day and only a single person is required to operate and monitor it.

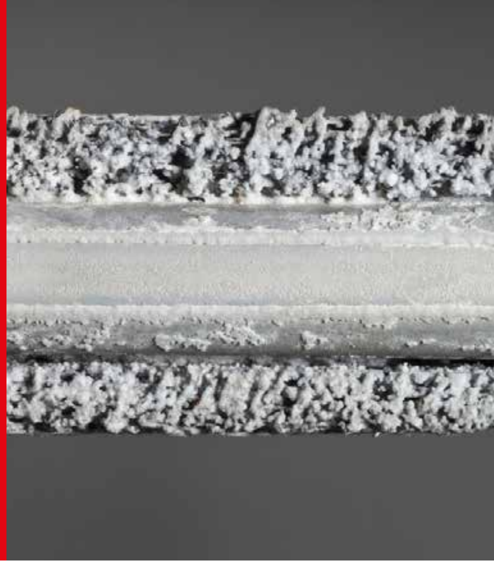
The "BetoScan" concrete robot can move on unobstructed concrete surfaces along preset patterns while operating different testing procedures. The measurement data are recorded in parallel. The cascadable sensor holder system enables the application of standard sensors and their fast replacement. Besides automation of the measuring data acquisition the sensor selection was designed with regard to the use of already established inspection procedures.

This allows for comprehensive condition assessment and damage detection at an early stage. In addition, the current layout of the inspected structure is generated. Furthermore, the robot system's ability to combine and to integrate non-destructive test methods turns out to be a significant advantage. The sensors analyze moisture and the thickness of the concrete, among other things, as well as the depth and condition of the reinforcement. The results can be depicted as 2D graphics. A corresponding measuring data management tool completes the system.

The BetoScan project was supported by the Federal Ministry for Economic Affairs and Energy (BMWi) within the framework of the "Support of Innovative Networks" (InnoNet) program.

Multifunctional facade elements with insulation panels (EPS) and integrated ducts made of polymer pipes. © Fraunhofer ISE

Detailed image of adsorption heat exchanger with zeolite. © Fraunhofer ISE



Flexible and Functional: Prefabricated Facade Elements Facilitate Building Renovation

Reduction in energy consumption and an increase in energy efficiency are important prerequisites for a climate-neutral building stock. For many years now, experts from Fraunhofer ISE have been pushing forward developments that combine the thermal renovation of building envelopes with the optimization of building service installations. Facade elements made of multifunctional insulation panels and prefabricated window modules were developed in the "Retrokit" project. These elements are primarily suited for retrofitting existing and old buildings to improve the energy efficiency. The applied materials and integrated technology can be combined based on the customer's needs. Supply lines for electricity, data, heat and sanitation can be integrated as technical components into the facade.

One big advantage of the multifunctional facade elements: They can be applied from the outside onto the original facade; the inhabitants are less disturbed by the renovation work as a result. The craftsmen also need less time to complete their work. The window modules are first mounted onto the facade, and then a first layer of insulation containing integrated ducts is mounted. The pipes for the building technology and sanitation systems are installed using a simple click system. A second insulation layer is mounted afterwards and then plaster is applied. Finally, the old windows are removed from the inside. The process enables fast, cost-effective and high-quality renovation.

Adsorption Development: Adsorption Heat Pumps and Cooling Units

In the area of thermally driven heat pumps and chillers, Fraunhofer ISE is working on a compact adsorption heat exchanger in which standard concepts for heat exchangers are combined with a new adsorption metal composite.

Heat dissipation during the adsorption process is very important for the adsorber operation. The power density of the adsorber is also dependent on the amount of sorption material per volume. One possibility to optimize the adsorption process is to apply porous metal carrier structures with a high specific surface area and good thermal conductivity.

A composite material made of sintered aluminum fibers and zeolite was developed in the Fraunhofer research project "THOKA". A first test sample of an adsorption heat exchanger was created. The heat exchanger structure is based on flat pipes made of aluminum that are manufactured in an extrusion molding process and coated with soldering agents. One considerable advantage of this type of construction is the large surface contact of the composite material with the heat-exchanger surface that enables the heat to dissipate over short distances from the active material. Measurement results from the adsorber test stand at Fraunhofer ISE show that, with enough vapor availability and good thermal contact between the heat exchanger and composite material, this adsorber concept shows great potential for improvements in performance density.

Further developments on composite materials and their integration into standard heat exchanger concepts are presently underway. Alternative carrier materials such as wire mesh or foams as well as new classes of adsorption materials like metal organic frameworks are promising future candidates.

WPC panels (above) and with flame retardants (below).
© Fraunhofer WKI

Adsorber-based coating with zeolite sorption material on an industrial-scale air-air-heat exchanger for the air conditioning of buildings.
© Fraunhofer ISE

Wood-Polymer Materials (WPC) with Flame Retardants

Within the framework of the EU-funded "LIMOWOOD" project, researchers at the Fraunhofer Institute for Wood Research WKI and partners from the industry have developed WPC panels for furniture that are flame retardant and moisture-resistant.

The material is composed of up to 60 percent wood particles and 40 percent thermoplastics, particularly polypropylene and polyethylene. The raw materials can stem from recycling streams. Other raw materials containing lignocellulose like rice hulls can be used to manufacture the panels. Researchers at WKI produce WPC panels by press molding without using formaldehyde-containing glue. The materials are 100 percent recyclable.

Commercial, halogen-free flame protection agents were added during compound production. Researchers obtained the best results with a combination of flame protection agents like red phosphorous and expandable graphite. These WPC formulations displayed oxygen indexes of up to 38 percent when flame-protected wood particles were added at the same time. For comparison: The oxygen index of a non-flame protected WPC panel is only at 19 percent. In a small burner test, the flame-protected panels did not ignite even after exposure to the flame for 300 seconds.

Additionally, the WPC panels absorb only little water and are therefore particularly suitable in humid environments. The application of WPC reaches its limits only where high static loads occur.

A skillful selection of components made it possible to achieve a high bending strength that exceeds the requirements for particleboards. This makes the application of flame-protected WPC possible not only in furniture but also for facade cladding, exhibition stand construction and in the building and transportation industries.

Highly Porous Coatings for Thermal Cooling Units and Heat Pumps

Thermally powered cooling units are an alternative to regular air conditioners. They evaporate liquids, such as water at low pressure and thereby extract warmth from the air. Fraunhofer ISE is working on new types of sorption materials that can absorb a particularly high amount of water. The researchers use metal organic frameworks (MOFs) for this purpose. These consist of a metal complex and an organic part. They typically have an inner surface of up to 4000 m^2 per gram and can bind up to 1.4 grams of water per gram of material. Up to now, MOFs have been used as a filling. However, a filling made of MOF granulates prevents thermal conduction. But if the material is used in a thin layer on metal slats, heat dissipation is increased and, as a result, the performance of the appliance as well.

Researchers have developed two complementary methods for coating heat exchangers and other components with highly porous metal organic frameworks – a direct crystallization method and a binder-based coating. These enable the application of different MOFs or adsorbents such as silica gels, zeolite or silica-aluminum phosphates to components.

This is not only interesting for application in buildings but also in areas in which reversible chemistry or physical reactions take place with heat transformation. Chemical processes often use catalysts with large inner surfaces. A coating of MOF or zeolite can improve the flow rate or temperature stabilization.

Wood foam developed at Fraunhofer WKI consisting of 100 percent renewable resources.
© Fraunhofer WKI

Wood Foam – From Tree to Foam

Foams are usually made of petrochemical-based polymers. Researchers at the Fraunhofer Institute for Wood Research WKI in Braunschweig (Brunswick) have developed a new foam material. It consists of 100 percent renewable resources, is climate friendly and recyclable. In the long term, wood foams could replace conventional petroleum-oil based foams, whether for thermal insulation, as packaging material or in lightweight construction.

Researchers at WKI are working on methods for manufacturing foam out of wood particles. In order to create this foam, the wood is first ground with a high water content to fine particles until a fiber suspension is obtained. This suspension can be chemically or physically foamed using internal or external gas producers such as CO_2. The foamed suspension is then hardened in a drying chamber. The strength of the foam results from the wood´s own bonding forces, so that no synthetic adhesives are necessary and any possible health risks due to emissions from the adhesive are excluded. The result of the processing is a light base material with a porous, open-cell structure and low bulk density. Foams made of beech wood can, for example, be manufactured in a density range of 40 kg/m^3 and 280 kg/m^3. The material can be further processed as hard foam boards or as elastic foam and can be machined like wood materials, with hardly any dust formation. Furthermore, the wood foam is odor-neutral.

Wood foams are applicable as building insulation material. Some insulation material is already made of wood, but this has the disadvantage of being less dimensionally stable than insulation material made of polymers. The foam products have already been tested according to current standards for insulating products. Promising results were achieved with the thermal insulation as well as with the physical-technological properties. The compressive strength for 10 percent compression was 20 kPa to 190 kPa, depending on the density. The thermal conductivities also depend on the density. The values are below 0.04 W/mK and are therefore comparable with the values of polystyrene and wood fiber insulation panels. The thickness swelling is <1 percent after 24 hours of water storage and the foams remain dimensionally stable. The fire behavior is similar to that of natural fiber insulation materials. The materials burn and glow, and the flame partially extinguishes itself. Additives necessary for flame protection can be easily and efficiently mixed into the fiber materials during the manufacturing process. Furthermore, recycling of the wood foam is easily feasible and, after use as packaging, the material can be disposed of in the same way as waste paper.

Currently, the process technology is being optimized and the application of other lignocellulosic materials is also examined. In just a few years the large-scale industrial manufacture of wood products made of wood foam should be possible and established in the market.

The great potential of this innovative material is evidenced by the awards the wood foam has already received. The development was nominated in 2014 for the German Raw Materials Efficiency Prize and in 2015 won both the Interzum Award "Best of the Best" and the GreenTec Award in the category of "Building and Living".

Starting material for wood foam: wood fibers and water are ground to a suspension and foamed.
© Fraunhofer WKI

IBP photogoniometer for measuring the directionally resolved transmission and reflection properties of innovative facade components.
© Fraunhofer IBP

Cooling Fountain.
© Fraunhofer IBP

Assessing the Optical Properties of Innovative Facade Systems

Facade technology is an important sector regarding the energy efficient and biologically effective supply of light to buildings. Carefully planned complex fenestration systems allow the use of interior spaces (such as offices) without supplying artificial light for about 80% of the time, thus significantly reducing the energy need for lighting as well as the use of light sources. Moreover, daylight (human centric lighting) has a direct biological effect on human beings, for instance on controlling the circadian rhythm.

Fraunhofer IBP cooperates with the facade industry, planners and software producers to develop innovative building components, to characterize their properties with regard to building planning and to integrate these components in planning tools that will facilitate designing and dimensioning. In this way, specific component data will be made available to planners, enabling them to perform detailed calculations, conduct analyses and optimize solutions for building-related facade planning. The photometric description of solar shading and glare protection components provides the basis. A goniophotometer combines collection and automatic measurement of the basic data. Depending on the mounting position of the systems in the facade, the exterior lighting conditions will be numerically superimposed. The luminous intensity distribution curves obtained from this will be used to perform visualizations and numerical assessments of the interior lighting conditions.

In conjunction with partners from industry, this approach was implemented in the light planning software DIALux (distribution > 600 000 users). This solution will allow better comparability of different facade solutions on the market, thus encouraging further innovation in facade technology. This may result in noticeable differences regarding various planning solutions and qualities in the planning market.

Cooling Fountain – Air-Conditioning Using a Chilled Film of Water

Air conditioning systems (AC) are used in many buildings to achieve the desired indoor climate by regulating temperature, humidity and air quality. However, users frequently complain about draft and annoying noise. Additionally, in warm and humid climates the temperature in air-conditioned rooms is often experienced as too cold, since the AC is not only temperature-controlled but the chillers also run in order to dehumidify the air. Systems based on radiant cooling, e.g. chilled ceilings, have advantages in terms of comfort and energy efficiency. However, they are not appropriate for dehumidification and the specific cooling capability is limited, since condensation on the radiant surface needs to be prevented.

The patented cooling fountain of the Fraunhofer IBP is a new kind of radiant-cooling system which eliminates the drawbacks of conventional air conditioners. The invention uses chilled water that flows down on a vertical surface area – the fountain. Convective and radiant energy exchange provides cooling effects while the water simultaneously absorbs dust and pollen from the circulating air. However, the most striking feature is its dehumidification capacity: moisture of the air condenses on the water film if the temperature of the water is below the dew point temperature of the room air.

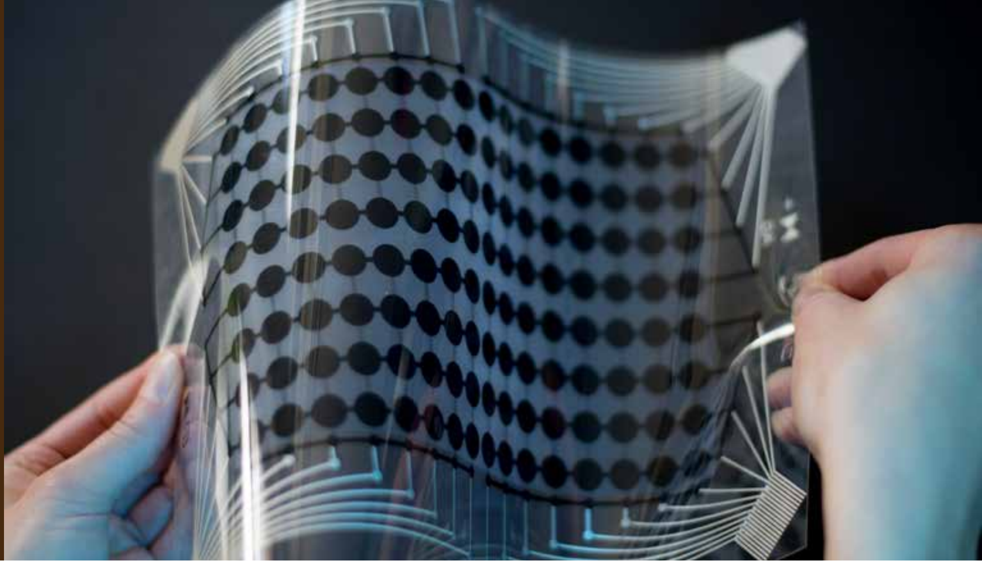
Unlike a cooling ceiling, the cooling fountain can easily be operated at temperatures below the dew point since condensate is carried away with the cycling water. Due to the lower operation temperature the cooling capacity is up to four times higher than that of ceiling cooling of equal size. In the case of too low relative humidity, i.e. in well-ventilated open space offices in winter, humidification is possible with the same device if the cycling water is not chilled. By controlling the water temperature it is possible to control the performance of cooling, dehumidification or humidification. For sizing and configuration of HVAC systems that include the cooling fountain, the Fraunhofer IBP has developed a specific model for building simulation tools.

Typha-House as a self-supporting construction during Expo2016 at Cascina Cuccagna; Centre of Milan.
© Fraunhofer IBP

Innovative Building Material made of Cattail (Typha)

Due to an enormous productivity cattail is predestined as raw material for industrial application. The large-scale use of typha plants supports many environmental policy aims simultaneously. By re-wetting dried fens for the typha cultivation, carbon dioxide will be absorbed by the plant instead of being released in large quantities. Besides, typha cultivation serves to efficiently clean nutrient polluted surface water. The leaf mass of typha is especially suited to produce innovative building materials due the structure of the plant. The leaves have a fiber-reinforced supporting tissue filled with soft open-cell spongy tissue providing remarkable statics and an excellent insulating effect. In the past few years, the Fraunhofer IBP developed a mineral-bound isotropic material for board production. The newly developed magnesite-bound typha board has an extremely high strength and dynamic stability despite a low thermal conductivity of 0.052 W/mK so that it is also suited to solve static problems. Moreover, this innovative building material possesses a lot of other positive properties: it is a renewable building material with high resistance to mold growth, good fire and noise protection and easy processability with all common tools. It is also relatively diffusible and capillary active, has a low energy consumption in production and can be recycled. The most important advantage of this material is that it enables simple building techniques, since Typhaboard unites all the qualities relevant for construction.

Typha plant.
© Fraunhofer IBP



Sensitive, flexible film for touch displays.
© Fraunhofer ISC

MICROSYSTEMS TECHNOLOGY

- **New Sensor Materials Enable Flexible and Light Touchscreens for Displays**

Although flexible and cost-effective printed touch displays are still a vision of the future, they are predicted to have a wide range of application. Their advantage is freedom of design their easy adaption since it is possible to roll out, so to speak, the display film. In addition, the cost-effective manufacturing process has low material costs compared to other methods while maintaining the good sensor characteristics. The material can also be produced on a large scale. Last, but not least, the polymer-based touch displays are lighter and more robust than the conventional hard glass-based displays available today.

A new material development from Fraunhofer ISC takes the flexible display technology one big step forward. Printable sensor materials applied to a film can register deformations and transmit their signal directly and in high resolution to a computer. Combined with a flexible display, both tablet PCs and smartphones will not only be operable via virtual switches and buttons but also by means of bending and moving the film.

Signal by means of deformation

The sensors that were developed within the framework of the EU project “Flashed” are made from innovative piezoelectric printing pastes. They can be extensively applied to a flexible polymer film and allow for the installation of electronic printing sensors with a simple printing process. The sensitive surface of the film – when it is connected to a display, for example – measures the deformation when touched. The resulting signal can be digitalized and spatially depicted. The new touch sensor technology will fundamentally change the operation of mobile end devices since the new types of sensors enable a more intuitive control – without switches, buttons or swiping function.

Not only pressure but also temperature sensitive

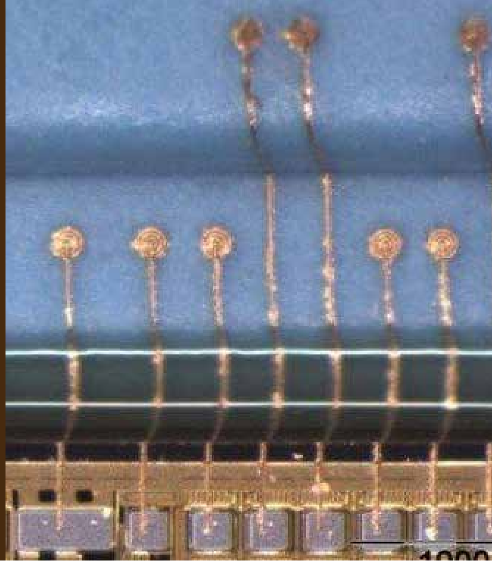
The sensors, which are inexpensive to manufacture, register not only changes in the mechanical pressure – for example when the flexible display is bent and moved – but also changes in temperature. This also makes them applicable as proximity sensors. Even the smallest change in temperature – such as when a hand approaches the sensor – triggers a corresponding signal. However, this effect can also be suppressed by the developers, if it is not needed. In the case of the FLEX SENSE display, it is advantageous to completely switch off the temperature sensitivity in order to attain a higher local resolution. In addition, the sensors can also be used as actuators to enable haptic feedback. The combination of sensor characteristics with haptic feedback can improve the user-friendliness of many applications and increase the range of functions.

Lead-free in the future

Lead titanates have been used in sensors up to now. This material, which has been classified as harmful to health, is to be eliminated in the future. Therefore, an important goal is to replace piezo materials containing lead with other materials without losing too much of the sensitivity. New ferroelectric particle matrix systems are being developed within the framework of the project and are being adapted to current screen printing processes.

Modern ultrasound microscopes open up manifold areas of application in microelectronics.
© Fraunhofer IMWS

Printed precious metal contacting.
© Fraunhofer IKTS



Novel Failure Analysis Process for 3D Integration of Microelectronic Systems

In order to increase the package density and performance of microelectronic components, many manufacturers extend the architecture to the third dimension with stacked chip setups. These novel component architectures that contain newly developed interconnection technologies entail enormous technical challenges along the production chain. A number of new failure mechanisms must be investigated and clarified. A group at the Fraunhofer Institute for Microstructure of Materials and Systems IMWS in Halle has specialized in this area and in the development of sophisticated analysis techniques and equipment.

Scanning acoustic microscopy is a non-destructive technique and plays an important role in defect detection and failure analysis. Together with the appliance manufacturer PVA Tepla Analytical Systems GmbH, Fraunhofer IMWS has developed a new, internationally unique, acoustic microscope in the ultra-high-frequency range of up to 2 GHz.

The capability of defect analysis in thin layer systems, the metrological acquisition of mechanical parameters as well as a very high lateral resolution and sub-surface sensitivity in single-digit micrometer areas open up new fields of application for acoustic microscopy. In collaboration with the Belgian research center IMEC, the recently developed GHz ultrasound microscope was successfully used for the verification and localization of defects in innovative 3D contacting microelectronic chips: Through Silicon Vias (TSV). Together with PVA Tepla as well as additional partners from the industry and Fraunhofer, further areas of application will be opened up in the future for the method that PVA Tepla introduced onto the market in 2014.

Precious Metal Inks for Microelectronics

The digital printing of functional materials has great potential for the production of electronic and sensor components. Processes like inkjet and aerosol printing are characterized by their high flexibility, speed and scalability. In contrast to classical semi-conductor methods, material inks are used for the direct printing of circuit components onto the target substrate. This development has already led to a number of innovative applications, such as flexible electric circuits, miniaturized and cost-effective sensors or wafer/chip rewiring and contacting.

In order to tap into this potential and other applications, researchers at Fraunhofer IKTS are developing suitable materials on the basis of gold, silver, platinum, palladium, rhodium, copper as well as carbon and glass. The technical requirements are high since the inks have to be compatible with current printing technologies and suitable for new substrates like polymers. In contrast to ceramic substrates, these are already fired at temperatures considerably lower than 180°C, which requires a specific setting of the sintering characteristics.

With the aid of special nanoparticles synthesis as well as appropriate dissolvents and organic additives, the researchers have developed inks with particles significantly smaller than one micrometer. The inks are characterized by low viscosity and surface tension with a simultaneously high electrical conductivity. This way the inks can be deposited with extremely fine and thin structure widths, considerably reducing the use of expensive materials.

Sensor platform.
© Fraunhofer ICT-IMM

SECURITY

Finding the Right Escape Route with the New Sensor Platform

One of the worst situations subway passengers can imagine: A fire breaks out in a subway station, there is smoke everywhere, and the only thought is to "get back up to the surface where there is fresh air". But what is the safest escape route for passengers to use in a subway station or tunnel without endangering themselves? Usually there are not that many alternatives, and when these escape routes simultaneously are the flow paths for smoke and other toxic gases, the passengers may soon find themselves caught in a deadly trap. In the MAusKat project funded by the Federal Ministry for Education and Research, researchers from Fraunhofer ICT-IMM have, together with other partners, developed a measurement and analysis system with which the propagation paths of gaseous hazardous substances can be traced in complex building structures. Emergency and escape routes can only be planned efficiently if this information is available. There have been a number of terror attacks in subway systems in the past, like the sarin gas attack in Tokyo in 1995 with 13 dead and thousands injured, or at the Domodedowo Airport in Moscow in 2011 (36 dead, 152 injured) but also fires in high-rises (Shanghai in 2010 with 53 dead) that have shown how complex the task of planning escape routes in fact is. Thus it is clear that it cannot be carried out adequately and comprehensively enough solely on the drawing board. Infrastructure operating organizations and emergency personnel require precise and reliable information before an incident occurs. This is where the measurement and analysis systems developed by Fraunhofer ICT-IMM in the MAusKat project come into play: the heart of the project is a mobile and infrastructure-independent sensor platform. In a test situation, a non-toxic tracer gas, usually SF6, is introduced into existing buildings and then the flow, distribution and concentration of the gas is registered at different measurement points. Based on this data, the flow and concentration are computed in a simulation and the danger zones within the building are identified. Existing escape routes can then be scrutinized and, based on the results, new emergency and escape routes can be planned.

Sensor platforms register SF6 and climate data

The sensor platform developed by Fraunhofer ICT-IMM is equipped with sensors and, in addition to the concentration of the SF6 tracer gas, also collects climate variables like temperature, humidity, air pressure and wind speeds in the x, y and z directions.

Sulfur hexafluoride is a synthetic gas – an inorganic, chemical compound made up of a single sulfur atom that is bound to six fluorine atoms (SF6). Under normal conditions, it is colorless and odorless, extremely inert, non-flammable and non-toxic. Because of its physical properties, SF6 is primarily used as an insulation gas, for example in medium- and high-voltage technology. Since the background concentration in the earth's atmosphere is very low (approx. 0.005 ppb) and because of very good traceability with reliable gas sensors, SF6 is also used as a tracer gas to register and evaluate air streams. However, the problem with using SF6 is that it has an immense global warming potential (GWP) of 22,800. For

the sake of the environment, it is better to apply and emit only small concentrations of the SF6 gas. In contrast to earlier tests in which samples were obtained manually in complex and expensive processes and had to be examined in a laboratory with a gas chromatograph, the measured variables can be automatically processed and saved in an interval of one second with the sensor platform. Because seconds are decisive in measurements, a high-precision clock with an accuracy of ± 3.5 ppm was installed that marks the individual measurement data with a time stamp in order to allow comparison between the data of the individual platforms. At the end of the measurement cycle, the stored measurement data can be saved on a USB stick or, depending on the setup, transferred wirelessly to the analysis system. The device is equipped with a network-independent power supply, which guarantees operation of 24 to 48 hours.

In the MAusKat project, tests were carried out, among other places, in department stores, lecture halls and, of course, subway systems. The results showed that with the aid of the new analysis system, a more precise and timely representation of the climatological conditions is possible even in complex infrastructures over a long period of time. “Personnel expenditure is limited to installation of the measurement system and the subsequent evaluation of the measurement data. This greatly reduces the costs of a test compared to manual sampling and analysis in a laboratory”, explains Dr. Karin Potje-Kamloth, Head of Method Development Analytics and Simulation at Fraunhofer ICT-IMM.

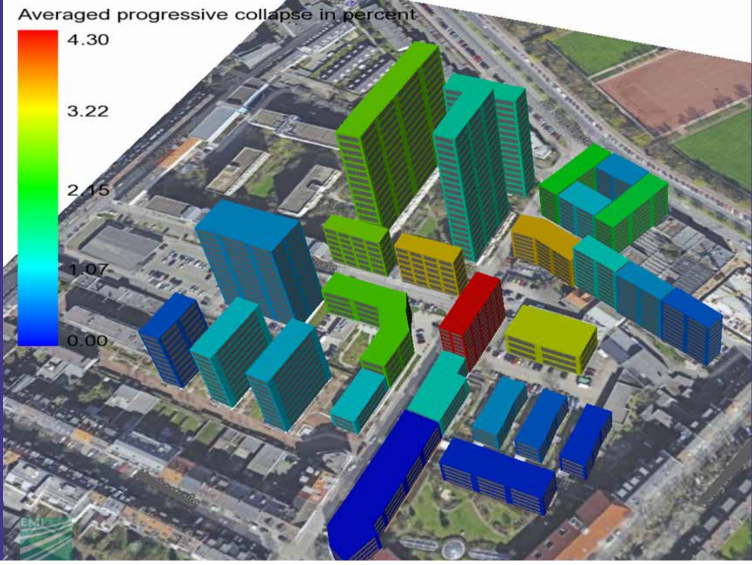
Smallest amounts in the lower ppm range

In view of the described cases and environmental policy aspects, it becomes clear that the gas sensors must be particularly sensitive to be able to record even the smallest amounts in the lower ppm range. A robust and highly sensitive SF6 sensor was developed by the company smartGAS Mikrosensorik GmbH in Heilbronn with which tracer gas can be detected in the sub-ppm range on a long-term basis in a stationary, power grid independent and time-resolved setting. According to Christian Stein, Managing Director of smartGAS, a number of practice tests and comparisons with gas chromatography have shown that reliable SF6 tracer gas concentrations from 50 ppb (0.05 ppm) can be detected with a resolution of 10 ppb.

As many areas of application as sensors on the market

A particular strength of Fraunhofer ICT –IMM is to develop systems in such a way that they are perfectly suited to the customers’ requirements or projects while being modular and flexible. The application of sensor platforms as a leak detection appliance, for example, is possible in all application areas of SF6. “SF6 serves as a cooling agent in transformer stations but also as insulation in high-voltage power lines or it is used in AWACS aircraft”, Dr. Potje-Kamloth adds.

When it is permanently installed, the sensor platform can serve as a continuous surveillance / control system. As mentioned earlier, the sensor could particularly serve to protect the public from terror attacks. In 2011 the OrGaMir project funded by the Federal Ministry for Education and Research already showed how the sensor platform could be used as a prognosis and decision-making tool for the operator and emergency personnel on-site. When installed in a subway system and equipped with sensors to detect gases and vapors that are identified as particularly critical, in the event of an emergency the system quickly shows whether and where toxic gases have been released and how they are currently spreading



Weighted vulnerability of a city area considering all possible sources of danger (position, intensity).
© Fraunhofer EMI

■ The Licensed Software "VITRUV"

The licensed software VITRUV (Vulnerability Identification Tools for Resilience Enhancements of Urban Environments) enables the direct inclusion of safety and security aspects into city planning processes. This makes it possible to plan cities more sustainably and robustly already in the development stages and, additionally, to identify weak spots in urban areas.

In cooperation with potential users like city planners, architects and the police, a user-friendly software was developed in the EU project VITRUV. The graphic user interface (GUI) contains a three-dimensional visualization of the city areas and uses common data formats (JPEG, DXF, CityGML). The city under consideration can be quickly reproduced with retrievable, pre-defined building types.

Different approaches are integrated into the vulnerability analysis of urban areas. As the first step, an empirical risk analysis enables an evaluation of the predisposition of certain areas by processing historical data. Statistical frequencies (susceptibilities) are visualized depending on the type of danger, endangered object, region and exposure. Possible damage can then be computed with the aid of a validated physical engineering model within the framework of a quantitative risk analysis.

Different performance criteria like the number of affected persons, structural or monetary damage are retrievable for buildings and traffic infrastructure elements. Different protection measures are implemented and enable an increase in the urban resilience, i.e. the robustness of cities to disturbances. These measures additionally provide decision makers with a basis for cost-benefit analyses.

Further information at www.vitruv-tool.eu

Empirical frequency distribution of potential sources of danger.
© Fraunhofer EMI

Transparent ceramics for ballistic protection.
© Fraunhofer IKTS

Transparent Ceramics for Ballistic Protection

Ceramic materials are constantly being further developed, and currently show property profiles that would have been unthinkable just a few years ago. The manufacturing methods, which are increasingly becoming more specialized, and customized raw materials, contribute considerably to this development. Transparent ceramic materials place very high demands on manufacturing technology with regard to purity, homogeneity as well as absence of porosity and defects. However, with special optical parameters combined with the typical parameter properties mentioned above, they offer innovation potential and interesting alternatives to common optical glass. Transparent protective ceramics, for example, enable maximum ballistic protection of civil and military personnel, vehicles and equipment at a minimal weight.

For many years now, Fraunhofer IKTS has been a worldwide leader in the manufacture of transparent ceramics with particularly fine crystalline microstructures and particularly good mechanical parameters. In the manufacture of ceramic backing composites, the protective ceramics are applied to a metallic backing and covered with splinter protection on the outside. The backing for transparent safety windows is made of glass. The particular effect is that, upon impact of a penetrating object, the ceramic material itself breaks but the sharp-edged fragments wear down the object. Only a few millimeters of sintered ceramics provide a stronger protective function than thick armor steel or 10 cm thick bulletproof glass with a surface weight of 150 kg/m^2. In comparison, the ceramic material in the composite with a backing reduces the total mass of the protective system by nearly 50 percent – with corresponding advantages regarding moveability, range and the safety of vehicles and passengers.

Textiles with InnoSolTex® coating.
© Fraunhofer ISC

InnoSolTEX® – Functionalized Textiles

Textiles today must meet a number of high requirements. They are not only used for clothing but, as high-tech materials, also fulfill technical or protective functions. The manifold areas of application pose new challenges since there are specific standards protective clothing must meet in accordance with their area of application. Depending on what is required, the textiles must offer protection from mechanical influence, heat or flames, moisture, chemical substances as well as microorganisms and also contain anti-static function. Protective clothing can be designed in a number of different ways to protect against one or several of these influences.

Six functions in one textile coating

Since fibers and textile structures cannot fulfill all requirements, they have to be processed. Up to now, it has not been possible to include all protective properties in one product. Together with its cooperation partner, Fraunhofer ISC has now developed a new hybrid coating sol based on inorganic-organic hybrid polymers.

The InnoSolTex® coating system enables six functions to be combined. The basis for the coating is the ORMOCER® inorganic-organic hybrid polymer class of materials developed at Fraunhofer ISC. The properties of these polymers can be varied in accordance with requirements. They fulfill hydrophobic, flame-resistant and wash-resistant functions and simultaneously provide an anti-static surface, improved wear resistance and an antimicrobial effect. The coating properties can be specifically arranged with a modular system according to customer requirements.

Only one step in the production sequence

The new coating can be applied either on the yarn or on the finished material. An additional benefit: Already existing production facilities can be upgraded with the system. It is also possible to coat the textiles in only one production step. The new InnoSolTex® lacquers can be diluted with water and stored for several weeks without any problem at a temperature of 6 °C.

In parallel to these material developments at Fraunhofer ISC, the production of its partners was scaled up to manufacture batch sizes of 30 kilograms. First industrial tests show that the coated yarns can be excellently processed to flat textile fabrics. They do not stick or tear and can be easily unwound from the spool, even at higher machine speeds. The textiles can be washed with mild detergents or disinfectants, keep their shape even after several washing cycles and maintain their antimicrobial function.

The new InnoSolTex® coating system thus combines several advantages: fewer process steps during production, lower energy and production costs and a high-performance product that can be processed in conventional industrial facilities without any problem.

© Fraunhofer ISC

The One World Trade Center in New York – DUCON® was applied here for more safety.
© Fraunhofer EMI

DUCON®: A High-Performance Material in the Face of Dynamic Effects

In cities increasing numbers of people live in close proximity to each other. The danger resulting from extreme situations such as natural catastrophes, accidents and terrorist attacks increases as a result. During the construction of large apartment buildings or critical infrastructure, new materials can contribute to making buildings safer in the face of such extreme conditions. A prominent example for this is the One World Trade Center in New York City, which was completed on Ground Zero in 2013.

Safety aspects also played a large role in the selection of building materials. The high-performance material DUCON®, which was developed and optimized by Fraunhofer EMI and the company DUCON, was applied there.

This material is a composite material, in which a micro steel reinforcement is imbedded in a highly resistant concrete matrix. It provides a high amount of protection under dynamic influences. With a compressive strength of over 150 megapascals and a high tensile strength of more than 6 megapascals, the concrete matrix is also characterized by an optimized microstructure with low porosity. This leads to an excellent composite with the steel reinforcement, which is essential to achieving the desired properties. The use of high-performance components and the addition of fine supplements lead to an optimization of the packing density. The low porosity but also the high strength properties can considerably enlarge the application range of the concrete materials.

The use of reinforcements in the form of micro steel mats not only has the effect of reducing brittleness but also improves the behavior at maximum loading and leads to a considerable increase of the fracture energy.

Because of its special microstructure, DUCON® is also suitable for application in aggressive environments such as sea water. Tests at Fraunhofer EMI have shown that the application of the material in critical building components provides a significantly higher level of protection.

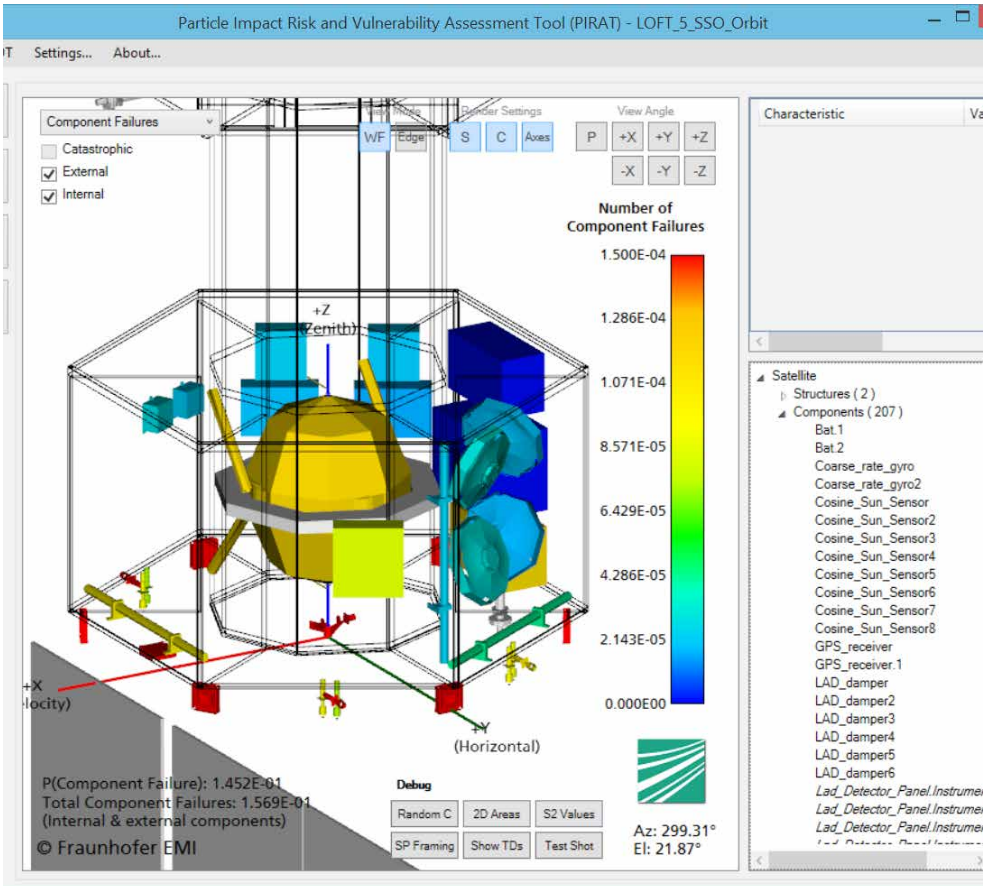
The One World Trade Center in New York City.
© Fraunhofer EMI

Satellite Vulnerability Analysis Software PIRAT

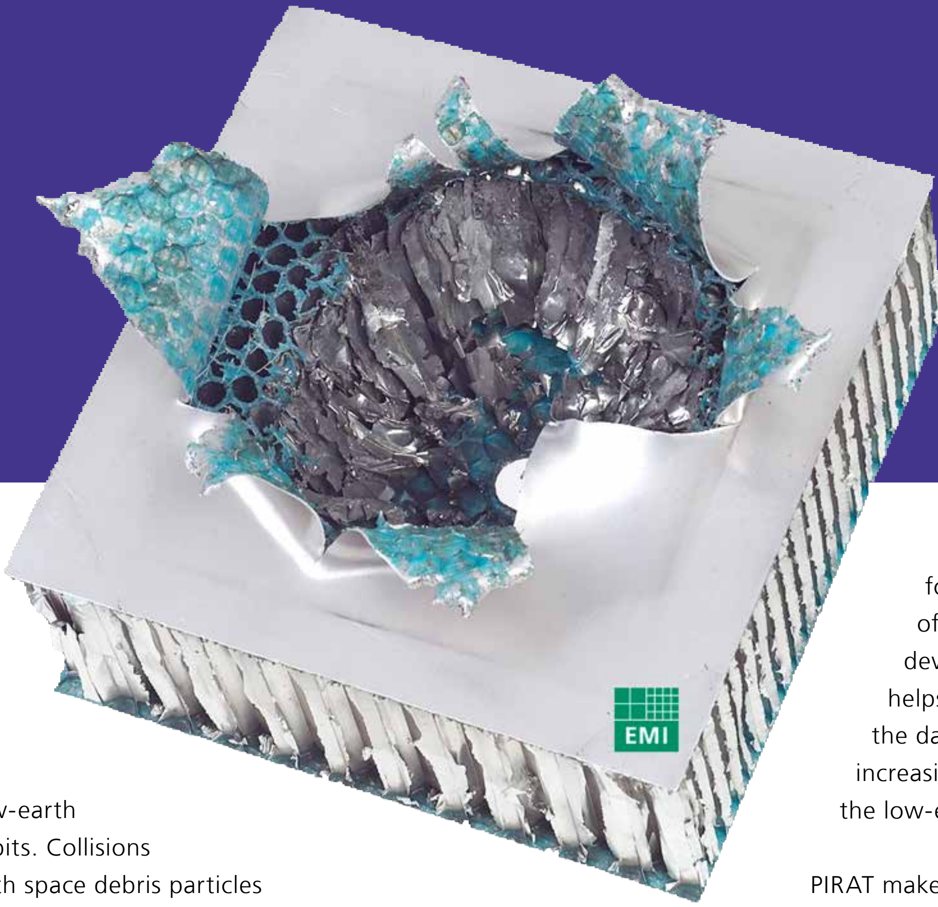
Space debris is a generic term for objects in the earth's orbit that represent a danger to spacecraft. Space debris occurs, among other things, as waste products at rocket launches, when the upper stages separate, when satellites are released or when spacecraft are disassembled by the explosion of residual fuel or batteries and also when objects collide with each other in low-earth orbits. An additional cause is burnt fuel from solid-fuel motors.

Space debris can destroy satellites and damage other objects.

The relative velocity between space debris and a spacecraft can amount to 16 kilometers per second in



PIRAT software tool from EMI for examining the vulnerability of satellite components to impact from space debris and micrometeoroids.
© Fraunhofer EMI



Aluminum structural wall for satellites after impact of an aluminum pellet.
© Fraunhofer EMI

low-earth orbits. Collisions with space debris particles as small as one millimeter can have serious consequences for satellites. Particles from this size range can penetrate satellite walls and crash into parts like pressure lines and tanks, fuel tanks, cables and electronic equipment, damaging or destroying them. Components on the outer side of the satellites are particularly affected by impact but are hard to protect.

The probability of the parts of a satellite being destroyed by space debris could only be estimated up to now. With the recently developed vulnerability analysis software PIRAT (Particle Impact Risk and Vulnerability Assessment Tool), it is now possible to compute the probability of failure due to space debris and micrometeoroid impact for every individual component of the spacecraft. The software developed at Fraunhofer EMI helps to quantitatively calculate the danger to spacecraft from increasing space debris pollution in the low-earth orbit.

PIRAT makes it possible to register the vulnerability of individual components as well as the entire spacecraft system during early development stages (phases O/A/B) and to include protection measures for particularly exposed spacecraft components early enough in the design. PIRAT was introduced to the Concurrent Design Facility of the European Space Agency (ESA) in 2014 as a software tool to support ESA engineers during the O/A phases of the spacecraft design. PIRAT is also a method for both examining the effects that occur as a result of the impact of space debris particles and micrometeoroids and predicting them at the system level in satellites.

Licenses for the PIRAT software are available at Fraunhofer EMI.

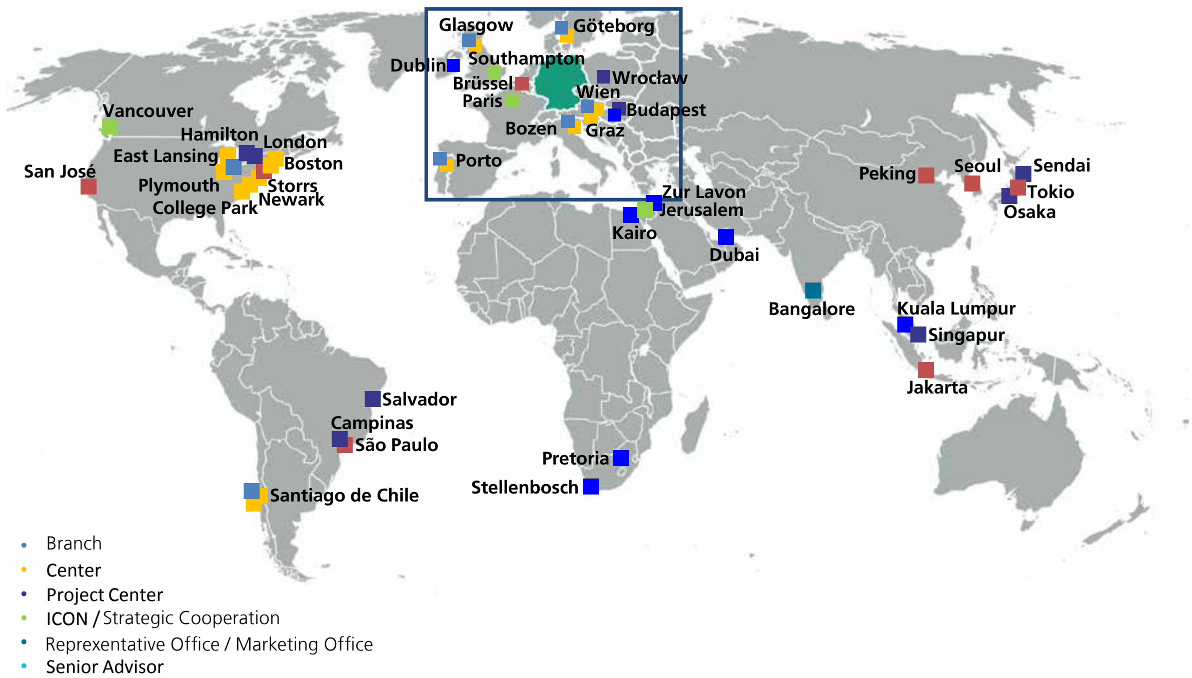
FRAUNHOFER-GESELLSCHAFT

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains 67 institutes and research units. The majority of the nearly 24,000 staff are qualified scientists and engineers, who work with an annual research budget of more than 2.1 billion euros. Of this sum, around 1.8 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits



FRAUNHOFER-GESELLSCHAFT

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

Pooling expertise

Institutes working in related subject areas cooperate in Fraunhofer Groups and foster a joint presence on the R&D market. They help to define the Fraunhofer-Gesellschaft's business policy and act to implement the organizational and funding principles of the Fraunhofer model.

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