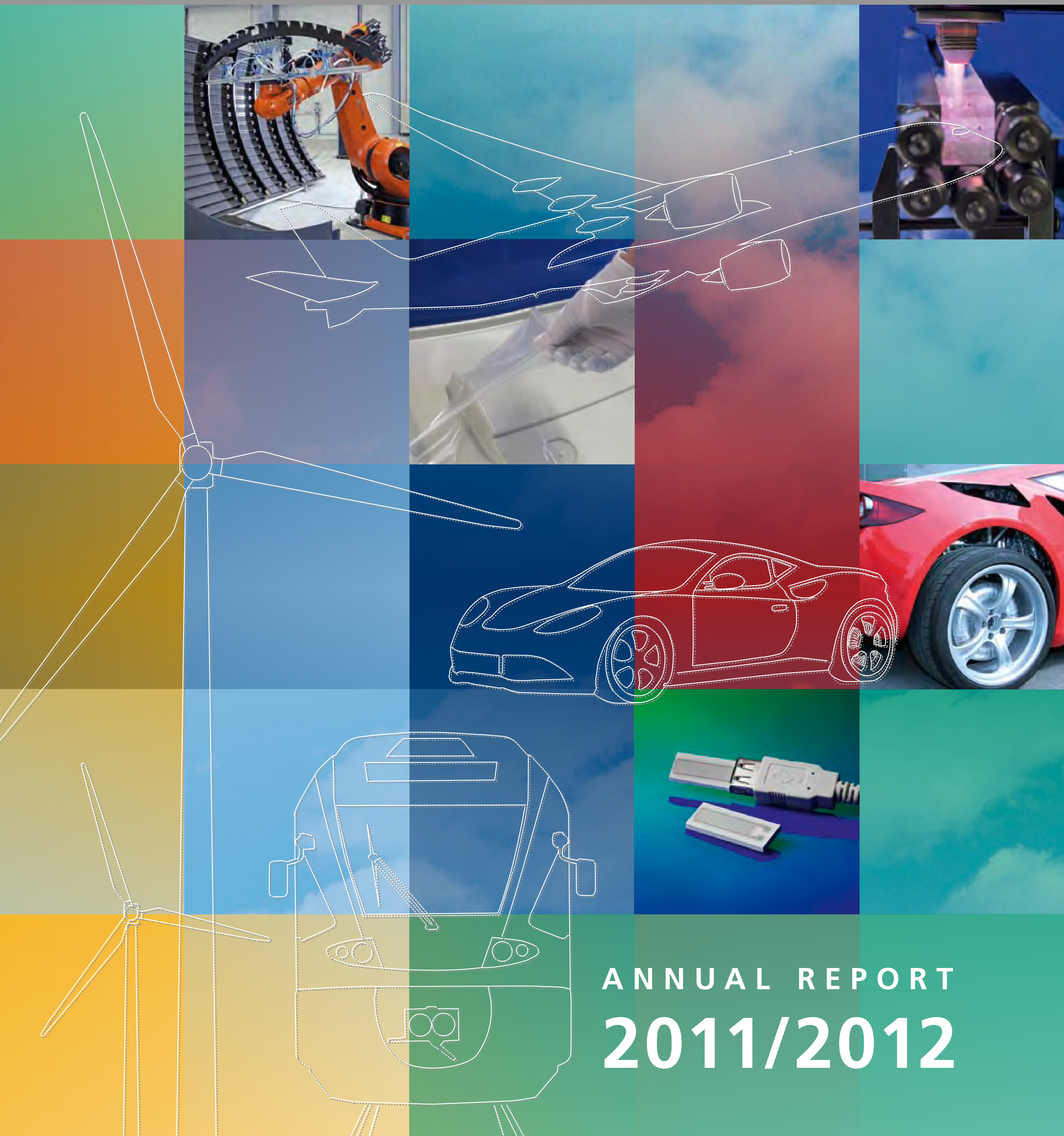
Fraunhofer IFAM

FRAUNHOFER INSTITUTE FOR MANUFACTURING TECHNOLOGY AND ADVANCED MATERIALS IFAM



ANNUAL REPORT

2011/2012

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PREFACE

Dear Sir or Madam,
Dear Business Friends and Cooperation Partners,
Dear Fraunhofer IFAM Sponsors,

It is always a pleasant task to report a successful year. And 2011 was in many respects a very successful year for Fraunhofer IFAM. The total budget of the institute passed the 40 million euros mark for the first time. Due to this impressive growth, staffing levels also reached a high of over 500 employees. 2012 is likely to be a year of consolidation, in which we aim to stabilize the extraordinary growth of previous years on a high level. Given the strong growth in personnel over the past years and the resulting need for additional work space, the expansion of our facility at Bremen will start in 2012.

In our foreword to the previous annual report, we stated our goal to increase the industry share of the institute's revenues which had receded due to the development of the general economy. We accomplished that target: Revenues from both industry and public sector projects increased significantly, a major success from our point of view. We express our gratitude to all project partners who contributed to this and who have consistently provided a high level of customer satisfaction in our surveys.

Along with growth, the second main theme of the year was marked by a series of successful cooperations. 2011 was the first full calendar year for the two of us with joint responsibility as directors of the institute. We have deliberately encouraged close ties between the two divisions to increase the institute's innovative power. We have experienced that, particularly in the context of new research topics, Fraunhofer IFAM's two divisions as well as the various facilities at different locations complement and reinforce each other in their set of competencies. An example for this are biomaterials for medical applications. Here, several teams from both divisions have already been cooperating very successfully.

1 *Directors Prof. Dr.-Ing. Matthias Busse and Prof. Dr. rer. nat. Bernd Mayer (left to right).*

1

Starting in 2012, the Fraunhofer-internal research project "Degralast" will center on the development of novel biodegradable bone implants based on metal-ceramic compositions.

Within the Fraunhofer-Gesellschaft, the spirit of cooperation is also evident in the collaboration of the various Fraunhofer institutes and research establishments, where the Fraunhofer IFAM is now one of the most networked institutes in this respect. In projects such as the "Fraunhofer Systems Research Electromobility – FSEM" (ongoing since 2009 and promoted by the federal government within the framework of the economic stimulus package II), or the "Clean Sky" project – the biggest EU research program so far to focus on the sustainable promotion of both environmental compatibility and competitiveness of the European aerospace industry – Fraunhofer IFAM has played a central role among participating organizations.

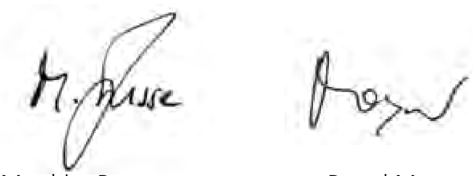
2011 was also characterized by intensive and successful cooperations at a regional level. We can point to a close and multifaceted cooperation with the University of Bremen, primarily in the MINT subjects, an evidence of which is in that more doctorates were conferred upon IFAM candidates in 2011 than ever before in a single calendar year. We also actively supported the University of Bremen's application within the BMBF (Federal Ministry of Education and Research)'s "Excellence Initiative", accompanied by a focus on sustainably high quality in teaching and research on the part of the university. Scientific excellence at the Fraunhofer IFAM was documented in 2011 by, amongst other things, two of our scientists being honored with the all-new "German High Tech Champion Award". In addition to the academic connection, Fraunhofer IFAM is also actively promoting young talents from high schools, for instance through Talent Schools.

Fraunhofer IFAM played a leading role in the recently completed Fraunhofer innovation cluster "MultiMaT" (Multi-functional Materials and Technologies), which was aimed at further reinforcing the Metropolitan Region Bremen/Oldenburg as a location for scientific innovation in material sciences. The local presence of Fraunhofer IFAM is reinforced by its active membership in the regional industry associations of the automotive and aerospace industries. Within AVIABELT e. V., for the aerospace industry, and Automotive Nordwest e. V., for the automotive industry, the goal is to regionally cluster competencies and to sustainably increase the competitiveness of all participating members.

Our Dresden branch is also strongly involved in a regional network, with the traditionally very close cooperation with the Technical University of Dresden at its heart. Beyond that, Fraunhofer IFAM significantly contributed to the success of the BMBF "Thale PM" project, completed in 2011, which successfully targeted the advancement of the existing regional competencies in powder metallurgy.

To finish on a personal note: We would like to thank all our employees at this point, because the successes of the past years would not have been possible without their scientific expertise and excellent qualification – but above all without their extraordinary commitment and cooperation. We are presenting a selection of our findings and key focus areas in the project and trend reports over the following pages.

We hope you enjoy your reading.



Matthias Busse　　　　Bernd Mayer

CONTENTS

1 *Fraunhofer IFAM, Dresden branch*

THE INSTITUTE IN PROFILE

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM carries out research and development work in the following areas.

Shaping and Functional Materials

The institute's Shaping and Functional Materials division concentrates on developing customized material solutions with optimized production methods and processes at its facilities in Bremen, Dresden and Oldenburg.

The research and development activities range from the materials themselves through shaping to the functionalization of components and systems. Customer-specific solutions are requested by such diverse sectors as the automotive industry, medical engineering, aerospace, machine and system engineering, environmental and energy technology, and the electronics industry.

Fraunhofer IFAM follows an integrated concept with three main core areas in the area of electromobility. Work focuses on the areas of energy storage and electrical drive technology, as well as the testing, verification, evaluation and optimization of complete systems. The Electromobility Model Region Bremen/Oldenburg is currently laying the foundation for new vehicle and traffic concepts.

The focus in Shaping lies in the development of economic and resource-efficient production processes for increasingly complex high-precision and standard components. Utilizing cutting edge powder and casting technologies, research work centers on increasing the functional density in components. The range of services includes component design and shaping process simulation, production engineering implementation and the appropriate training of company personnel.

The focus in Functional Materials is on advancements in improving or extending material properties and material processing. The functional materials can either be integrated directly in the component during the production process or applied to surfaces. They provide the component with additional or completely new properties, for example electronic or sensory functions.

By exploiting the specific properties of cellular materials, hybrid materials, fiber composites and biomaterials it is possible to realize a broad variety of applications.

Adhesive Bonding Technology and Surfaces

The Division of Adhesive Bonding Technology and Surfaces provides industry with qualified products and processes in the area of adhesive bonding technology, plasma technology, paint/lacquer technology, as well as fiber composite technology at Bremen and Stade.

The R&D services of the division are much in demand by a large number of partners in diverse sectors of industry. At present, the main markets and customers are the whole transport sector – manufacturers of aircraft, cars, rail vehicles, ships – and their suppliers, machine and plant construction, energy technology, construction industry, the packaging sector, textile industry, electronics industry, microsystem engineering, and medical technology.

One focus area is Adhesive Bonding Technology, which encompasses adhesives and polymer chemistry (adhesive formulation, composite materials, bio-inspired materials), adhesive bonding technology (bonding in microsystem engineering and medical technology, adhesives and analysis, process development and simulation, application methods), materials science and mechanical engineering (structural calculations and nu-

merical simulation, mechanical joining technology), joining and assembly of large fiber reinforced plastic structures on a 1:1 scale (joining technologies, precision processing, assembly and plant technology, measurement technology and robotics), and the Certification Body of the Federal Railway Authority in accordance with DIN 6701.

The second focus area covers plasma technology with its work groups atmospheric pressure plasma technology, low pressure plasma technology, VUV excimer technology, new surface technologies, and plant technology/plant construction; it also comprises paint/lacquer technology with the development of coating materials and functional coatings, as well as application and process engineering.

These two focus areas are complemented by adhesion and interface research with its work groups surface analysis and nanostructure analysis, applied computational chemistry, electrochemistry/corrosion protection, and quality assurance of surfaces.

All competencies from the work areas adhesive bonding technology, plasma technology, paint/lacquer technology and adhesion and interface research mentioned above are utilized for the R&D activities on fiber composite technology. The intensive work in this area covers matrix resin development, fiber-matrix adhesion, the processing of FRPs, and new production methods for manufacturing FRPs. The sizing of joints, process development and the automated assembly of large FRP structures complete the portfolio in this area.

Certifying training courses in adhesive bonding technology and fiber composite technology complement the R&D work and are of interest for all sectors of industry. Following the successful workforce training courses introduced by the Center for Adhesive Bonding Technology in German-speaking and other European countries, the courses are now being offered worldwide to multinational companies. Courses in fiber composite technology at the Plastics Competence Center complete the portfolio in workforce training.

Competence network at Fraunhofer IFAM

Shaping and Functional Materials

- Biomaterials Technology
- Electrical Energy Storage
- Electrical Systems
- Functional Structures
- Casting Technology and Component Development
- Materialography and Analytics
- Powder Technology
- Sinter and Composite Materials
- Thermic Management
- Cellular Metallic Materials

Adhesive Bonding Technology and Surfaces

- Certification Body of the Federal Railway Authority in accordance with DIN 6701
- Adhesion and Interface Research
- Adhesive Bonding Technology
- Adhesives and Polymer Chemistry
- Fraunhofer Project Group Joining and Assembly FFM
- Materials Science and Mechanical Engineering
- Paint/Lacquer Technology
- Plasma Technology and Surfaces PLATO
- Process Reviews
- Technology Broker
- Workforce Training and Technology Transfer

BRIEF PORTRAIT AND ORGANIGRAM

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM was set up in 1968 as a working group on Applied Material Research and incorporated as an institute in the Fraunhofer-Gesellschaft in 1974.

The institute collaborates closely with the University of Bremen as a contract research institute with new focal points and systematic expansion. The institute directors are appointed to chairs in the department of production technology at the University of Bremen. The institute has sites in Bremen and Dresden, as well as Fraunhofer Project Groups in Oldenburg and Stade.

Prof. Dr.-Ing. Matthias Busse has been managing the Shaping and Functional Materials division since 2003 as the director (executive) of the institute. Prof. Dr. rer. nat. Bernd Mayer has been a member of the management board and director of the Adhesive Bonding Technology and Surfaces division since 2010.

The institute, as a neutral and independent facility, is regarded as one of the biggest in Europe in the sectors of Shaping and Functional Materials, as well as Adhesive Bonding Technology and Surfaces.

Fraunhofer IFAM's total budget in 2011 was 40.4 million euros. The institute had 535 employees, more than 90 percent of which working directly in science and engineering.

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM

Institute directors

Prof. Dr.-Ing. Matthias Busse (executive)

Prof. Dr. rer. nat. Bernd Mayer

Division Shaping and Functional Materials	Division Adhesive Bonding Technology and Surfaces
Prof. Dr.-Ing. Matthias Busse	**Prof. Dr. rer. nat. Bernd Mayer**
Dr.-Ing. Frank Petzoldt Deputy director	**Priv.-Doz. Dr. Andreas Hartwig** Deputy director
Prof. Dr.-Ing. Bernd Kieback Head of Dresden branch	

Head of administration

Dipl.-Oec. Alexander Busk

THE INSTITUTE IN FIGURES

Fraunhofer IFAM's total budget (costs and investments) for 2011 comprises the budgets of its two divisions, Shaping and Functional Materials as well as Adhesive Bonding Technology and Surfaces.

Budget

The total budget in 2011 was 40.4 million euros. Divisions and units contributed as follows:

Shaping and Functional Materials, Bremen

Operating budget	10.7 million euros
Project revenue	10.0 million euros
Of which	
Industry Projects	3.3 million euros
Federal/State/EU/Other projects	6.7 million euros
Investment budget	2.8 million euros

Shaping and Functional Materials, Dresden

Operating budget	4.3 million euros
Project revenue	3.8 million euros
Of which	
Industry Projects	1.2 million euros
Federal/State/EU/Other projects	2.6 million euros
Investment budget	0.4 million euros

Adhesive Bonding Technology and Surfaces, Bremen

Operating budget	16.7 million euros
Project revenue	14.0 million euros
Of which	
Industry Projects	9.4 million euros
Federal/State/EU/Other projects	4.6 million euros
Investment budget	1.9 million euros

Fraunhofer Project Group Joining and Assembly FFM, Stade

Operating budget	2.2 million euros
Project revenue	2.2 million euros
Of which	
Industry Projects	0.3 million euros
Federal/State/EU/Other projects	1.9 million euros
Investment budget	1.4 million euros

INVESTMENTS

Fraunhofer IFAM made investments worth 6.5 million euros in 2011. These investments were divided as follows between the various units, with the main acquisitions listed.

Shaping and Functional Materials, Bremen
Investment Budget (2.8 million euros)

- Gildemeister solar fueling station with cellcube
- 2nd life container
- Solar plant with batteries
- Electric vehicles for fleet tests
- Potentiostat / Galvanostat
- Raman spectrometer AFM
- Glovebox
- Fuel cell test bench
- ENKAT test bench
- Battery tester

Adhesive Bonding Technology and Surfaces, Bremen
Investment Budget (1.9 million euros)

- Mobile atomic force microscope
- Vacuum-UV excimer system for functional coating
- Laboratory electroplating
- Inverse gas chromatography
- Digital microscope system
- Particle measurement device for gas analysis
- Dosing system for automatic application of 2C adhesives
- Tekscan pressure measuring film system
- GC-MS analysis for thermal gravimetrics
- Scattered light sensor OS 500

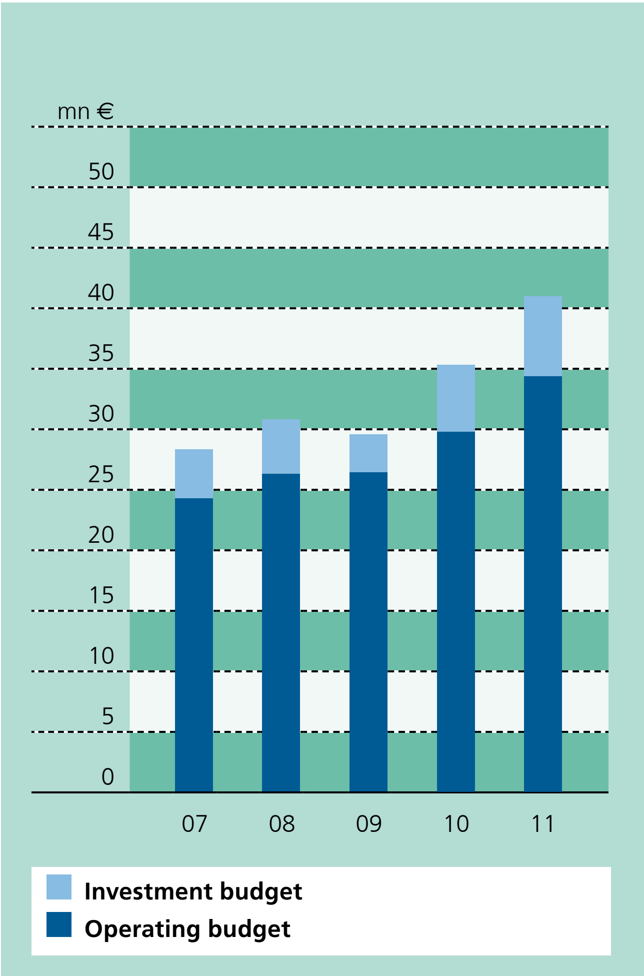
Shaping and Functional Materials, Dresden
Investment Budget (0.4 million euros)

- Multimode SPM system

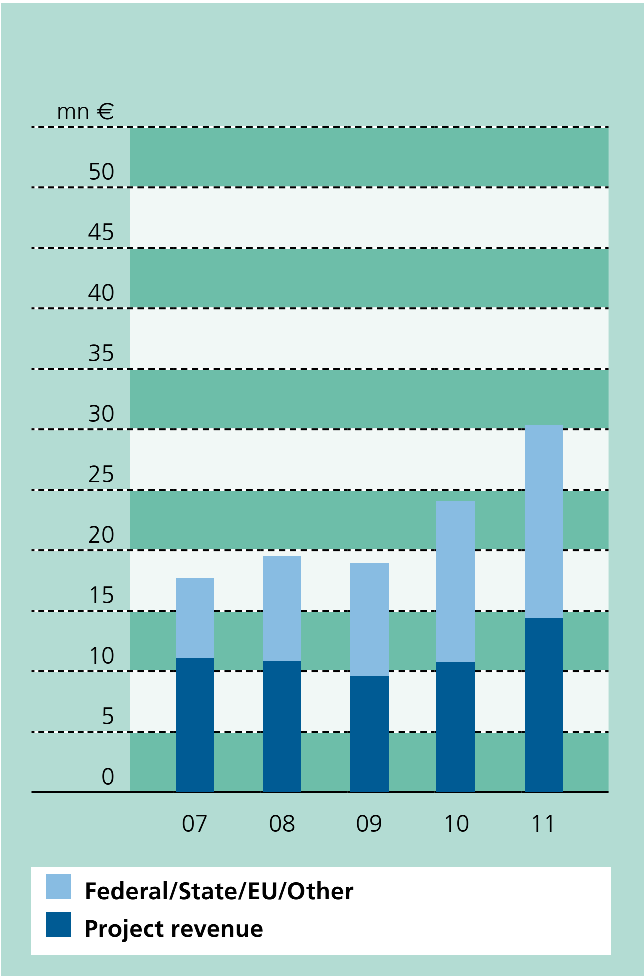
Fraunhofer Project Group Joining and Assembly FFM, Stade
Investment Budget (1.4 million euros)

- Assembly system for major FC structures, with two 6-axis robots
- Test bench for controlling the shape and position of large components
- Laser scanner and laser tracker for 3D measurement of components
- Modular 3D water cutting system

OPERATION AND INVESTMENT BUDGET



OPERATION BUDGET – PROJECT REVENUES

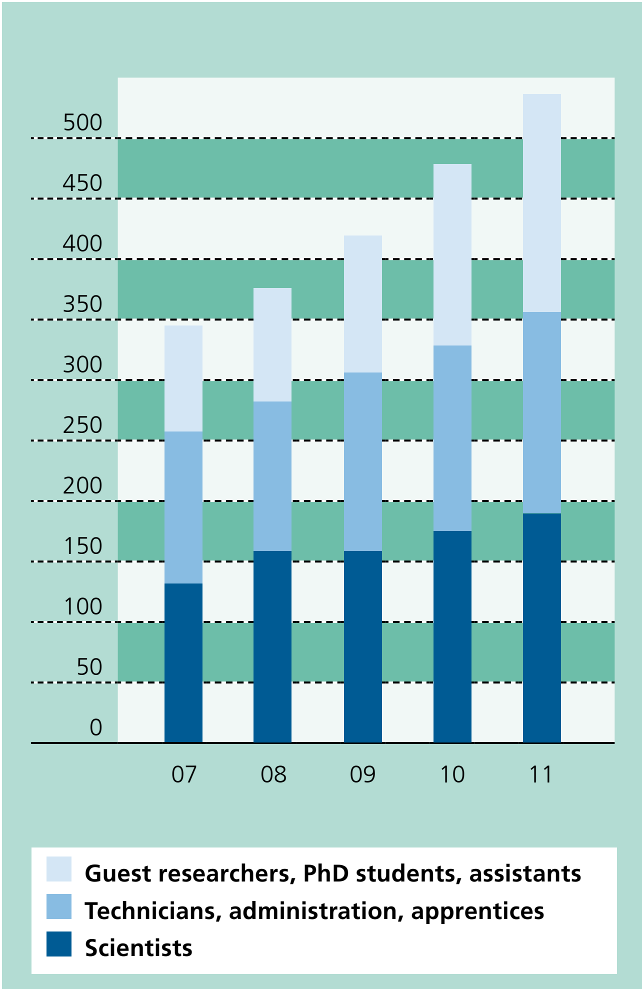


PERSONNEL DEVELOPMENT

A total of 535 persons (93 percent active in the scientific engineering sector) were employed as of December 31, 2011 by Fraunhofer IFAM at the Bremen and Dresden locations, and by the Fraunhofer Project Groups at Oldenburg and Stade. In comparison to the previous year, the institute saw an increase of 12 percent in permanently employed personnel.

Personnel structure 2011

Scientists	189
Technical personnel	112
Administration/Internal Services/Apprentices	54
PhD students/Trainees/Assistants	180
Total	535



THE ADVISORY BOARD OF THE INSTITUTE

Members

Dr. Rainer Rauh
Chair of the advisory board
(Chairman since May 2011)
Airbus Deutschland GmbH
Bremen

Prof. Dr. Ramon Bacardit
Henkel AG & Co. KGaA
Düsseldorf

Regierungsdirektorin Dr. Annerose Beck
Saxon State Ministry for
Science and the Arts
Dresden

Prof. Dr. Rolf Drechsler
University of Bremen
Bremen

Dr. Klaus Dröder
Volkswagen AG
Wolfsburg

Prof. Dr. Michael Dröscher
EVONIK Degussa GmbH
Essen
(until September 2011)

Prof. Dr. Reinhard X. Fischer
University of Bremen
Bremen
(until May 2011)

Michael Grau
Mankiewicz Gebr. & Co.
Hamburg

Dr. Stefan Kienzle
Daimler AG
Sindelfingen

Prof. Dr. Jürgen Klenner
Airbus Deutschland GmbH
Bremen
(Chairman until May 2011)

Dr. Johannes Kurth
KUKA Roboter GmbH
Augsburg

Carsten Meyer-Rackwitz
tesa SE
Hamburg

Dr. Matthias Müller
Robert Bosch GmbH
Stuttgart

Reinhard Nowak
Glatt GmbH
Binzen

Staatsrat Carl Othmer
Senator for Education and
Science of the Free and
Hanseatic City of Bremen
Bremen
(until August 2011)

Dr. Ralf-Jürgen Peters
TÜV Rheinland
Consulting GmbH
Köln

Staatsrat Dr. Joachim Schuster
Senator for Education and
Science of the Free and
Hanseatic City of Bremen
Bremen
(since August 2011)

Jan Tengzelius M. Sc.
Höganäs AB
Höganäs, Sweden

Christoph Weiss
BEGO Bremer Goldschlägerei
Wilh. Herbst GmbH & Co. KG
Bremen

Guests

Dr. Georg Oenbrink
Evonik Industries AG
Essen

Johann Wolf
BMW AG
Landshut

THE 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 more than 80 research units in Germany, including 60 Fraunhofer Institutes. The majority of the more than 20,000 staff are qualified scientists and engineers, who work with an annual research budget of € 1.8 billion. Of this sum, more than € 1.5 billion 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.

Affiliated international research centers and representative offices provide contact with the regions of 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 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.

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.

1 *Special stamp to commemorate the 225th birthday of Joseph von Fraunhofer (1787–1826) on March 6, 2012.*

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM

1
Wiener Strasse 12
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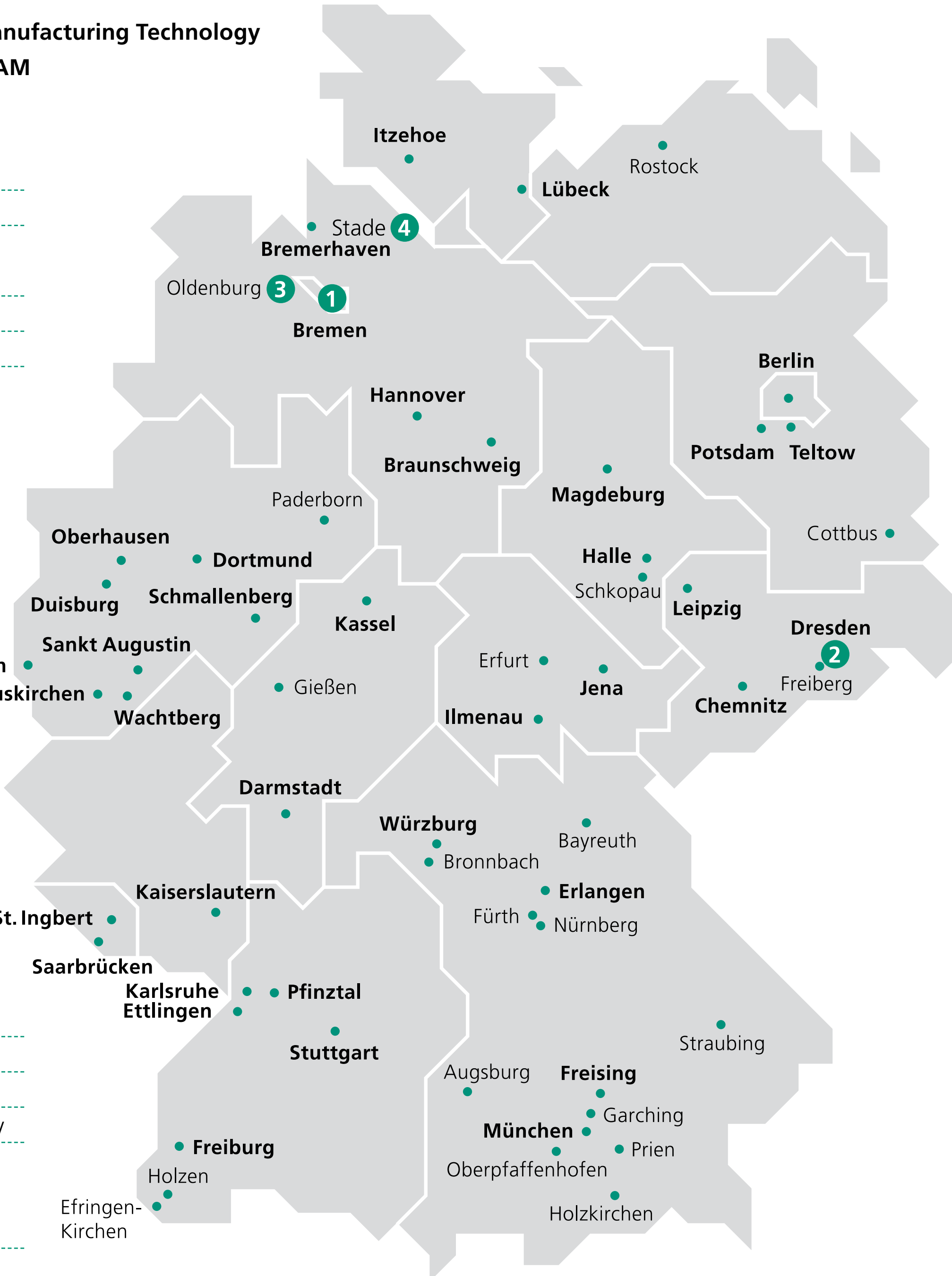
2
Winterbergstrasse 28
01277 Dresden, Germany



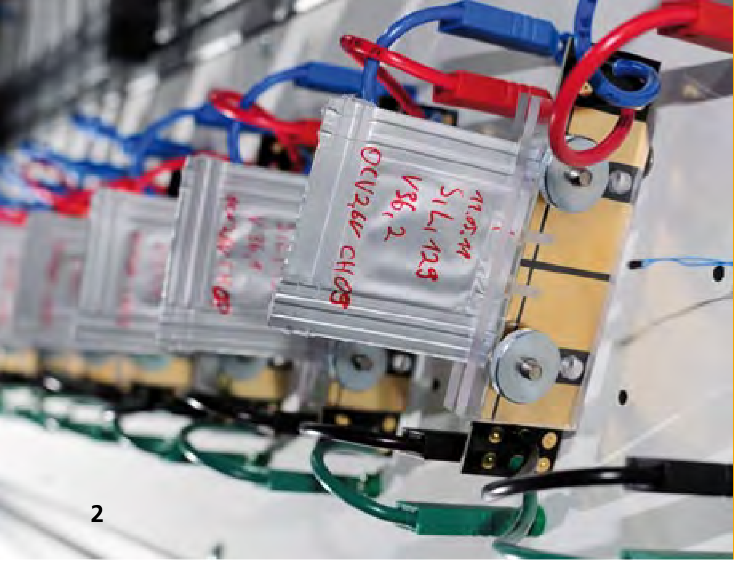
3
Fraunhofer Project Group
Electrical Energy Storage
Marie-Curie-Strasse 1–3
26129 Oldenburg, Germany

4
Fraunhofer Project Group
Joining and Assembly FFM
Research center CFK Nord
Ottenbecker Damm 12
21684 Stade, Germany

Institutes and Facilities
Other sites

SHAPING AND FUNCTIONAL MATERIALS

1



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EXPERTISE AND KNOW-HOW

Networks of business partners and research facilities play a decisive role in the development of complex system solutions. Methodological competence and excellent specialist knowledge are essential here, especially at the interfaces of the various fields. The competency of employees at Fraunhofer IFAM, combined with our network of contacts with industry and science partners, guarantees the development of innovative solutions for the economy.

Transforming basic application-oriented research into implementable production solutions or component development is a task that requires the constant advancement of know-how and methodological competencies. Therefore, the continuous expansion of specific competencies and know-how has a very high priority at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials – Shaping and Functional Materials division.

Our research and development work ranges from basic application-oriented research, right up to the implementation of new products and production launch support.

Multifunctional components with integrated sensor functions set specific requirements for the materials involved. Properties can be precisely customized by combining various materials within a component. A major task in enhancing competence is to refine and control such material combinations in the production process. Here, the material combination spectrum ranges from metal–metal and metal–ceramic, all the way to combinations with CFRP.

Today, manufacturing processes such as injection molding are used for the production of geometrically demanding components made from numerous metal alloys and ceramic materials. It has now become possible to specifically apply different properties of the materials to different parts of components. This allows, for instance, hard–soft, or dense–porous material property combinations, or even materials with sensory properties, to be custom-integrated in components. Such developments are of particular interest in micro-component production, where these integrated production solutions mean that micro-assembly work can be omitted.

Functional ink and paste formulations, and the relevant experience in applying them to components, have also been elaborated, especially for the development of the "INKtelligent printing®" process. This makes it possible to equip components with sensors for recording operating or ambient conditions, for example.

Fraunhofer IFAM maintains a strong market position, with the latest casting and analytical equipment, plus comprehensive know-how on diecasting processes for aluminum and magnesium alloys. In addition to the optimization of casting processes with permanent molds, we are also constantly upgrading our competency in lost-foam casting. A process engineering

1 *Fraunhofer demonstrator vehicle Frecc0 2.0 on a test run (Photo: Ingo Daute, © Fraunhofer).*
2 *Pouch bag cells serve as testsystem for battery materials.*
3 *Pouch bag cell for the material development of novel energy storage systems.*

4

5

approach is followed in the development of "CAST[tronics®] technology", which provides casting shops with the ability to integrate functional components directly in their casting process.

The implementation of cellular metallic materials into products is now at a high level of expertise, which allows us to develop special solutions for markets, such as diesel particulate filters, while at the same time expanding our process knowledge on a continual basis. Our portfolio of topics is continuously updated to meet market requirements, resulting in new technological challenges. Questions regarding product innovation under strict economic constraints play an essential role here, as do the contributions of our research to improving the quality of life and to sustainable development in the transport, energy, medicine, and environment sectors.

A significant success factor in all our product innovations continues to be the materials and their processing. This is particularly relevant for primary forming methods, as both material properties and component geometry can be influenced during the production process. The resulting market continues to grow due to the increasing product complexity involved.

Material properties and technologies are customized and characterized for structural and functional applications. High-performance materials, composite materials, gradient materials, and smart materials are all refined for this purpose, while we are also working on production technologies aimed at integrating their properties into components.

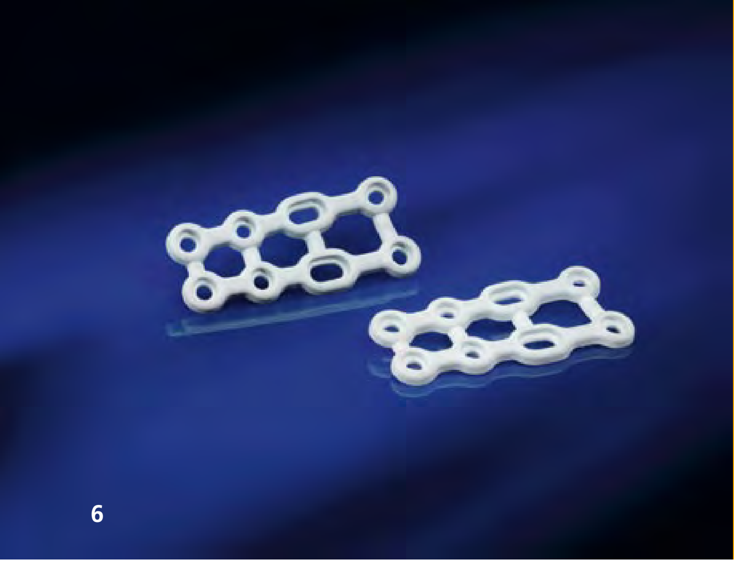
Our customers gain new opportunities for product development through this enhancement of material competence in the special fields of functional materials, such as magnets, thermal management materials, thermoelectric and magneto-caloric materials, and nanocomposites.

A highly dynamic area under development is the field of electromobility, particularly with regard to energy storage systems, drive technology, and system testing. This work focusses on the development, construction, and testing of components for electric vehicles and their integration into systems. An example of this is the Fraunhofer wheel hub motor, which was primarily developed by Fraunhofer IFAM. An evaluation center has already been set up for testing the complete electrical drive train. Its services include the specific investigation and evaluation of electric motors, power converters, control systems and traction batteries. They also include battery aging tests and the characterization of continuous operation properties for electrical drive systems, based on standardized and real driving cycles.

Perspectives

The ongoing development of complex drive systems such as wheel hub motors will continue to be an interesting area of activity for the Fraunhofer IFAM. The combination of the actual drive development with the implementation of a prototype and practical testing is worth mentioning here with regard to the utilization of IFAM production and testing technology competencies. Another interesting facet is the construction and inclusion of complete vehicle models in the investigation of batteries and drive motors, in the form of 'Hardware in the Loop' simulations on the Fraunhofer IFAM drive train test.

The development of new engineering options for the cost-effective production of components in electric vehicle drive trains is economically very attractive and presents a new challenge. The creation of a production cell for the functionalization of components and surfaces is the next step in the implementation and introduction of sensor integration using printing technologies in existing industrial production lines.



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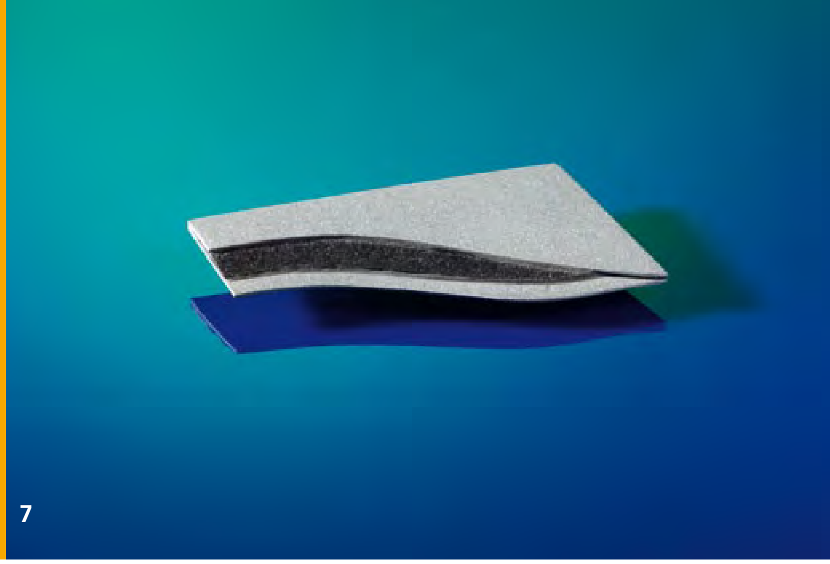

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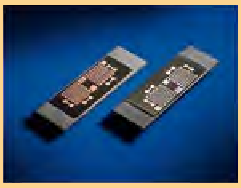
FROM MATERIAL TO RELIABLE APPLICATION

MATERIAL	SHAPING	FUNCTION	TESTING	APPLICATION
				
· Metals · Ceramics · Polymers · Structural Materials · Functional Materials · Composite Materials	· Powder Metallurgy · Casting · Freeform Fabrication · Nano- and Microstructuring	Integration of function during the manufacturing process · Sensors · Actors · Functional Coatings Energy Storage	· Material Analysis · Mechanical Testing · Performance tests · System checks · Expert reports	· Machine and Equipment Construction · Automotive · Electromobility · Environmental and Energy Technologies · Aerospace · Medical technology · Microsystems Technology

Competencies shaping and functional materials.

4 *Screen-printed interdigital structure for moisture or conductivity measurement (contacting via USB).*

5 *Additively (SLM) manufactured study of a wound spreader with internal channel (lower branch) and integrated RFID chip (upper Branch).*

6 *Trauma plates made of strongly-filled polylactic acid composite, e.g. for internal fixation of small hand long bones.*

7 *Composite material laminated into a sandwich for component monitoring.*

FIELDS OF ACTIVITY AND CONTACTS

Institute Director

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Electrical Energy Storage

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julian.schwenzel@ifam.fraunhofer.de
Cell chemistry; metal-air batteries; paste development and electrode production; cell assembly; electrocatalysis; battery test benches; in-situ analysis; Raman spectroscopy; simulation; cycle life and aging mechanisms.

Electrical Systems

Dr.-Ing. Gerald Rausch
Phone +49 421 2246-242
gerald.rausch@ifam.fraunhofer.de
Electromobility; electric vehicles; E-motor test bench up to 120 kW; test bench for batteries up to 50 kWh; driving cycle analysis; range determination; system testing of electric motor drive trains.

Functional Structures

Dr. Volker Zöllmer
Phone +49 421 2246-114
volker.zoellmer@ifam.fraunhofer.de
(Nano)-composites; nanodispersions; nanoporous coatings; functional integration; INKtelligent printing®; Inkjet printing and Aerosol-Jet®; dispensing methods; sputter technologies; special systems.

Casting Technology and Component Development

Dipl.-Ing. Franz-Josef Wöstmann
Phone +49 421 2246-225
franz-josef.woestmann@ifam.fraunhofer.de
Casting technologies: aluminum, magnesium and zinc diecasting; cast iron and cast steel; function integrated cast components (CAST$^{TRONICS®}$); lost-foam processes; simulation; rapid prototyping. Component development: design, production, and testing of electric machines and drive trains for electric vehicles.

Materialography and Analytics

Dr.-Ing. Andrea Berg
Phone +49 421 2246-146
andrea.berg@ifam.fraunhofer.de
Failure analysis; metallographic section analysis; powder characterization; scanning electron microscopy with EDX analysis; thermal analysis; dilatometry; trace analysis; emission spectrometry.

Powder Technology

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Powder-metallurgical shaping; metal powder injection molding; process and material development; rapid manufacturing; laser sintering; screen printing; production pocesses for metal foam components (FOAMINAL®); simulation.

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Biomaterials
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Biocompatible metals; resorbable composites; biopolymers; micro-injection molding; microstructuring; mechanical and biological testing; peptide synthesis; surface bio-functionalization; in-vitro cell tests.

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Cellular Metallic Materials

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Fiber metallurgy; highly porous structures; metallic hollow sphere structures; open-cell PM foams; 3D screen printed structures; 3D wire structures; sinter paper; functional coatings and surface technology.

Sintered and Composite Materials

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High-temperature materials; nanocrystalline materials; materials for tribological loading; sputter targets; PM light metals; metal-matrix composites; thermoelectric materials; dispersion-strengthened materials; materials for hydrogen storage.

Topic Areas

Energy and Thermal Management
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Thermo-technical and fluidic design of storage systems; measurement technology validation; characterization and mathematical description; numerical simulation of mass, material, impulse, and energy transport processes.

EQUIPMENT/FACILITIES

Component Manufacturing

- Metal powder injection molding plants (clamping force 20 t and 40 t)
- 2-component injection molding machine
- Single cavity injection molding
- Hot press (vacuum, inert gas, 1800 °C)
- Uniaxial powder presses (up to 1000 t)
- Powder press for thermal compaction (125 t)
- Extrusion press (5 MN)
- Rapid prototyping systems for laser sintering of metals; conceptual models via 3D printing, including colors
- Cold chamber diecasting machine (real-time control, clamping force 660 t)
- Hot chamber diecasting machine (real-time control, clamping force 315 t)
- Sand casting
- Precision casting systems for Al, Cu, Fe and special alloys
- Pilot systems for production of metal foam components
- Microwave system
- Screen printing machine
- CNC milling machine for model production
- Hot wire cutting system
- Model production with lost-foam processes
- Casting system with lost-foam processes (Al, Cu and Fe alloys)
- Spark-plasma sintering system (up to 300 mm component diameter)

Micro- and Nanostructuring

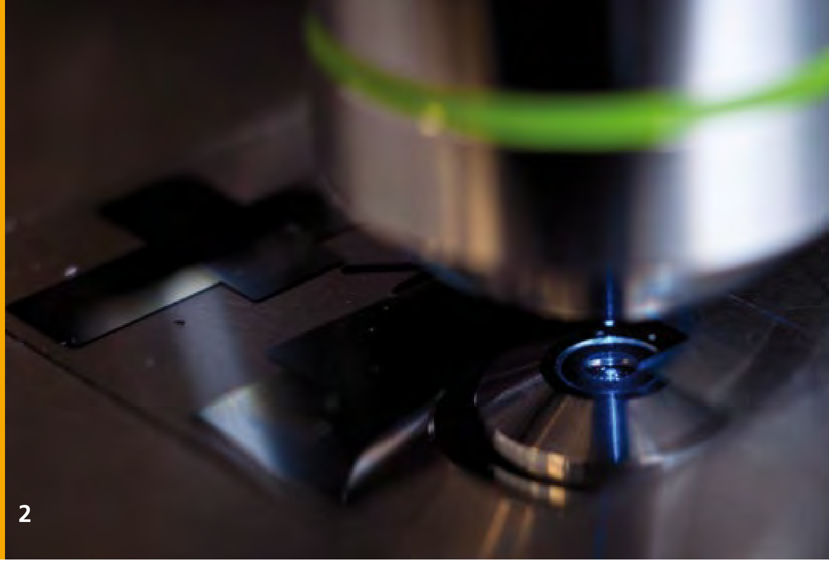
- Inkjet printing technologies
- Aerosol-Jet® technologies
- Dispensing methods
- Micro-injection molding system
- Four-point bend station
- Ink test bench
- Sputter technology
- Glovebox system

Thermal/Chemical Treatment of Formed Pieces

- Chemical dewaxing units for injection molded parts
- Diverse sintering furnaces (up to 2000 °C, inert gas, hydrogen, vacuum)

Material synthesis and processing

- Gradient material production systems (sedimentation, wet powder injection)
- Metallic nanopowder and nanosuspension production systems
- Test bench for characterization of functional inks for inkjet printing processes
- Melt extraction unit (metal fibers)
- Rapid solidification system for producing nanocrystalline or amorphous slivers or flakes



- Fast blender and shearing roller extruder for MIM feedstock production
- Twin screw extruder
- Compounding of biopolymers and composites
- Granulator

Instrumental analytics

- Rheometry
- Micro-tensile testing machine
- Tensiometer
- 2D/3D laser surface profilometry
- Thermal conductivity measurements of molding materials
- IR laser for translucent material density determination
- Magnetic measurement technology
- Electrical characterization
- Dynamic sensor characterization
- FIB – Focus Ion Beam with Cryo-Stage

Certified to DIN 9001:2008

- Scanning electron microscopy with EDX
- X-ray fine structure analysis
- Thermal analysis with DSC, DTA, TGA
- Sinter/Alpha-dilatometry (accredited)
- Powder measurement technology with BET and laser granulometry (particle size analysis)
- Trace element analysis (C, N, O, S)
- Materialography
- Emission spectrometer
- X-ray tomograph (160 kV)
- Gas permeability determination

Electrical Energy Storage

- Battery and cell test benches (cycling unit)
- Impedance spectroscopy (30 µHz … 40 MHz)
- Laser microscopy
- Raman spectrometer with integrated AFM
- Thermal analysis with integrated MS/IR
- Glove box system with integrated PVD unit for electrode coating and production of battery cells

Electromobility

- Two motor test benches up to 120 kW
- Battery test bench up to 50 kWh
- Test vehicle for component testing

Computer

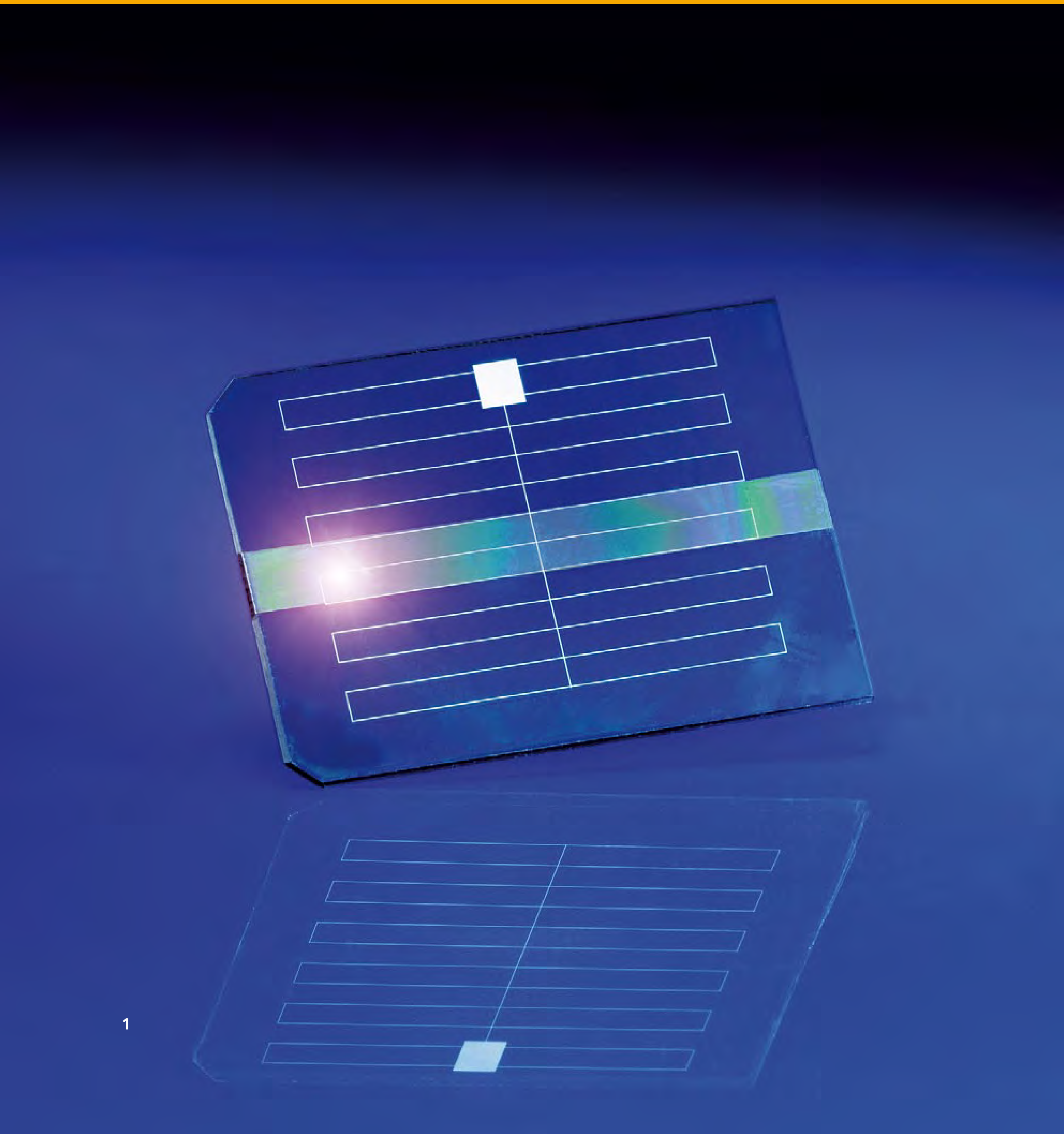
- High-performance workstations with software for non-linear FE analysis, mold filling and solidification simulation, and component optimization

1 *Fraunhofer IFAM employee at sinter furnace.*

2 *Raman spectrometer with in-situ measurement cell.*

SHAPING AND FUNCTIONAL MATERIALS

RESULTS FROM RESEARCH AND DEVELOPMENT



WIRELESS INTERLINK – ENERGY HARVESTING FOR SELF-SUFFICIENT SENSOR SYSTEMS

Wireless sensor networks that supply themselves with energy will simplify the monitoring of safety-relevant components in future. Sensors detect and evaluate various technical conditions in numerous applications. The sensors can then provide statements about temperature, position, pressure, or humidity. The measured values provide information about the condition of a component, and enable conclusions to be made about maintenance intervals or the service life of machines. The radio signals of the sensor systems assist in recognizing and thus avoiding possible risk scenarios. For optimum function, sensors need to be applied to surfaces or integrated in components. The necessary energy for the sensor, the processing unit, and the radio module for data transmission can then be "harvested" from their surroundings.

Sensor signals require energy

Sensors such as strain gages or humidity sensors require energy for the evaluation and transmission of their parameters. The supply of these sensors with the necessary energy occurs in most cases wire-based from a central energy source, or locally by the use of batteries. Although usually only several milliwatts of power are required, it is in fact the actual limited storage capacity and service life of batteries that represents a critical point for the use of sensors. Even the quality or reliability of a battery cannot always be guaranteed, depending on the ambient conditions. If batteries cannot be recharged, then they need to be replaced. This can be expensive or even impossible in inaccessible spots. Another aspect that will represent a great challenge in the future is poor recyclability. Only around 19 percent of batteries are recycled in Europe today [1]. Above all, a battery that needs replacing greatly affects the design of an application and therefore restricts the flexibility of construction.

[1] EBRA Annual Report 2009

Today, wireless networks can be found in numerous applications, including industrial production, logistics, and medical technology. The use of these technologies is also common in the private sector in wireless telephones, radio-controlled garage doors, or remote-controlled devices and machines. These are all based on wireless communication systems. It is obvious that the use of wireless network technologies will increase in future, and that new applications will be developed.

In addition to the technical advantages of using wireless sensors, there will also be a reduction in cost due to the greater level of application flexibility without the need for cables or connections. Estimates are looking at up to an 80 percent reduction in infrastructure costs for sensor applications. In addition, up to 100 percent of the costs of monitoring and maintaining sensors will be avoided. Wireless networking also

1 *Thin-film solar cell produced by combination of printing and PVD processes.*

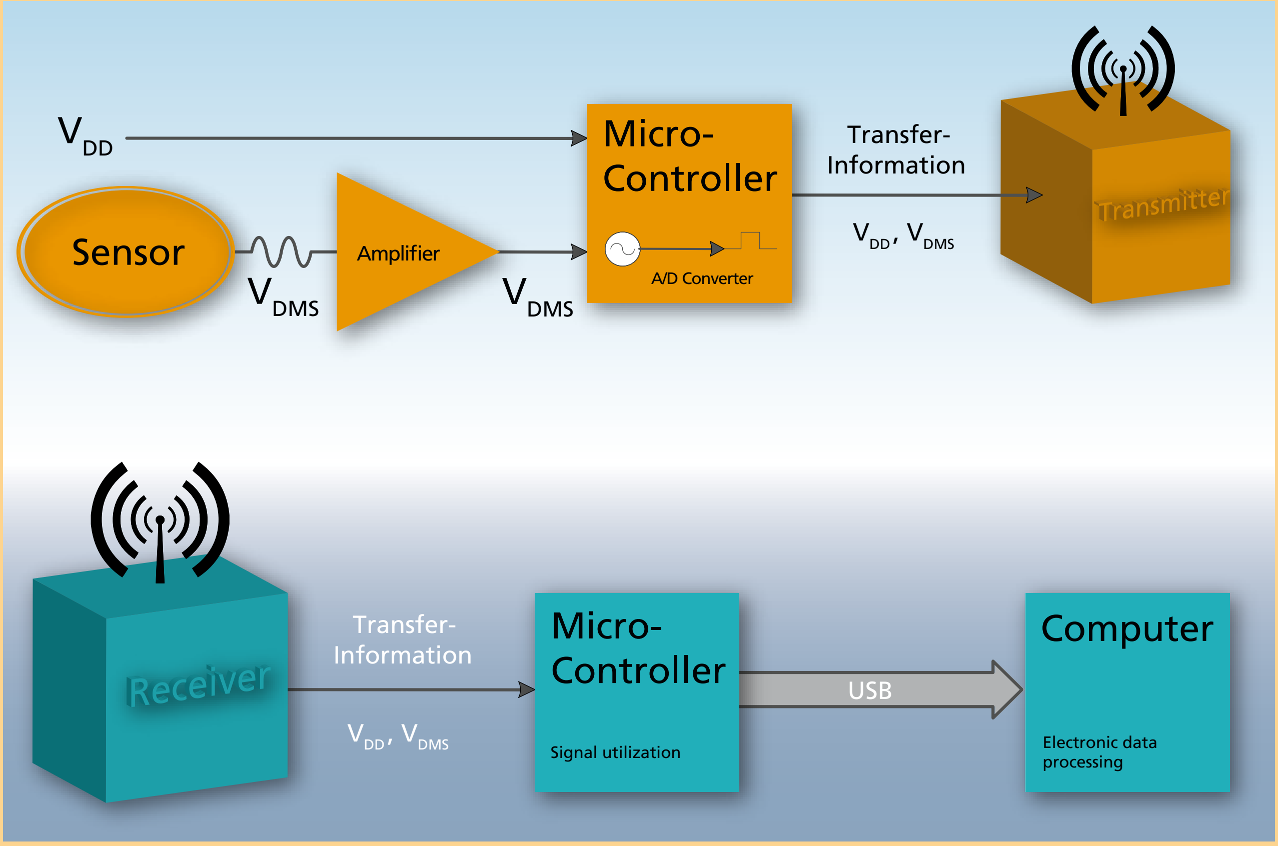
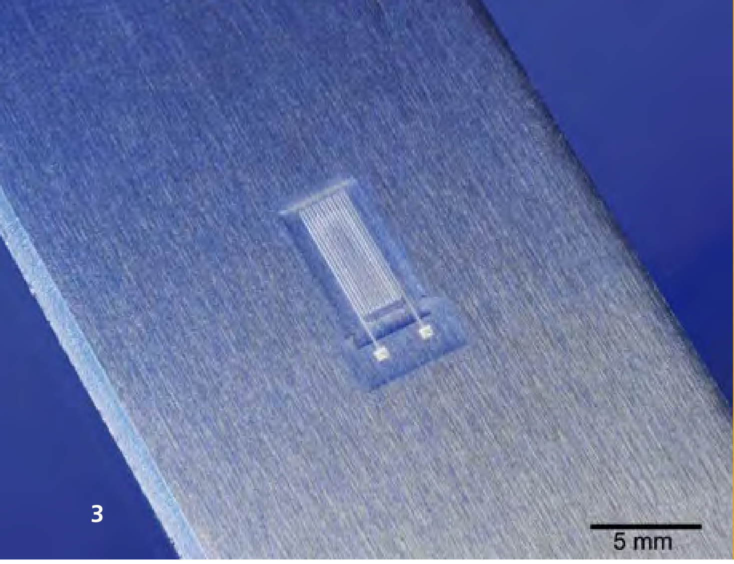


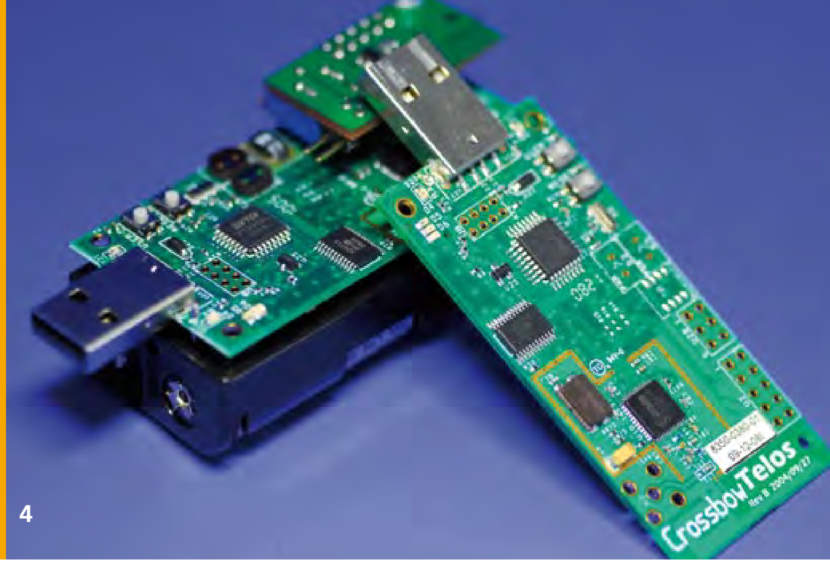
Fig. 2: Self-powered data transfer.

offers numerous construction advantages: maintenance-free sensors can be integrated in areas that are difficult to access. This possibility opens up far-reaching solutions for structural monitoring.

Wirelessly readable strain sensors

Within the framework of the innovation cluster "Multifunctional Materials and Technologies" (MultiMaT), Fraunhofer IFAM cooperated with the working group on Communication Engineering, in the Institute for Electrodynamics and Microelectronics (ITEM) at the University of Bremen, to develop solutions in order to transmit measurement signals of printed strain gage wirelessly over a distance of up to 100 meters.





Using a wireless standard data transmission (radio network standard ZigBee with 2.4 GHz), the sensors are able to transmit their measured signals to a central processing unit, laptop, or mobile phone where the data can then be precisely evaluated. This means that signals can be acquired and evaluated in real time, even in critical or inaccessible environments. Scientists at the University of Bremen have programmed the measured value acquisition and data transmission in such a way that they consume very little energy: Both the sensor and radio module are only active at the moment of measurement and new measured values are processed in order to transmit them with a reduced data volume. This allows the sensors to operate over a long period of time without the need of changing the battery of the radio module.

Supplying sensors through energy harvesting

Numerous approaches are currently being followed in which the energy for sensor applications and wireless communication of sensor signals can be obtained directly through the technical operation, by the so-called "energy harvesting". The greater the energy volume that can be obtained through harvesting, the smaller the batteries can be, right up to being fully omitted. Overall, the aim is to maximize the energy that can be gained through energy harvesting while simultaneously minimizing the application's energy consumption.

There are various means of obtaining energy for a device through its own technical operation: for instance, solar cells currently use the sunlight to generate energy. Thermoelectric materials use temperature gradients to obtain electrical energy. Piezoelectric and electromagnetic materials obtain energy from mechanical vibrations. Here, the energy necessary for status monitoring with sensors can then be obtained directly from the resulting vibrations. The great advantage here is that the energy for sensor detection is obtained directly from the parameter being monitored.

Depending on the harvesting method, the harvested energy is then, only available directly after its generation and for a few milliseconds. Thus, apart from the actual energy volume, the limited availabilty in terms of time and the need for a flexible energy storage must also be taken into account. The volume of energy that can be obtained through energy harvesting may be subject to fluctuations over time. Storage systems are required which can act as buffers or intermediate stores. These storage systems must evidence minimum self-discharging. One challenge is to utilize the energy obtained without losses and as efficiently as possible for the respective applications, while still enabling a high level of integration.

Research potential: additive manufacturing of highly-integrated sensors through functional printing

Additive manufacturing processes can offer a significant contribution to the production of sensors and sensor networks as well as to energy harvesting: The direct application of structures to functional materials based on inks or pastes using inkjet, aerosol jet, screen printing, or dispersion methods means that materials other than electrical circuits and sensor elements can also be applied to various surfaces.

It is also possible to produce structures that can be used for energy harvesting. Generative solutions for manufacturing can be directly designed as a comprehensive approach on the computer and implemented at a high level of integration. A manufacturing platform is thus available for the production engineering implementation of sensors and energy harvesting

3 *Aerosol printed strain gauge on aluminium surface.*

4 *Transmission and reception units for wireless sensor signal transmission.*

so allowing a wireless sensor signal communication system to be flexibly integrated in the component. Today, it is not only possible to print antennas, but also the printing of data carriers is subject-matter of current work. Fraunhofer IFAM is capable of investigating various materials holistically and generically, and can apply sensors directly onto surfaces as well as integrate them into components.

Outlook for the future: certainly self-sufficient

Batteries can in future be replaced by (thin layer) accumulators that are charged by, e. g., a solar cell. This means that a sensor module can operate whilst being completely energy-independent, as the required voltage, usually several volts, can now be 'harvested' from sunlight. Like the sensor, such solar cells can also be created as highly-integrated thin layer solutions. Piezoelectric materials which can be used for energy harvesting by means of additive processes are also currently under development. In addition to the sensors, this will enable solutions for energy harvesting to be integrated onto surfaces and in components using additive processes for wireless sensor communications.

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SUPERCAPACITORS – POWERFUL ENERGY STORAGE

New energy concepts require flexible and powerful energy storage systems. Electric storage systems with a high power and performance density are essential, particularly in the sector of electromobility, to leverage alternative drive technologies.

State of the art

Batteries are currently the most important storage media for electrical energy in numerous mobile and stationary applications. Even though these stores can achieve power densities of over 100 Wh/kg, high performance peaks – due to the relatively slow kinetics of the redox processes – pose a problem for many applications. Supercapacitors are a category of electrochemical energy storage systems with a higher power density, meaning higher charging/discharging currents can be achieved over shorter time periods (Fig. 1). This enables an increase in the performance capacity of electrical energy sources in applications where high capacities must be provided cyclically. In addition, improvement of capacity, in combination with batteries and fuel cells for a cost-efficient solution, can be realized to cover capacity requirements, for instance in hybrid and electric vehicles. Compared to batteries, the capacitors are also characterized, by a longer service life (more charging cycles) and improved behavior at low temperatures.

Supercapacitors based on activated carbon have meanwhile become established. Their specific capacity lies in a magnitude of 100 F/g with a specific surface of up to 3000 m²/g. The principle is based on the so-called double-layer effect. This concept is, however, almost fully optimized, so that the potential for further capacity optimization is limited.

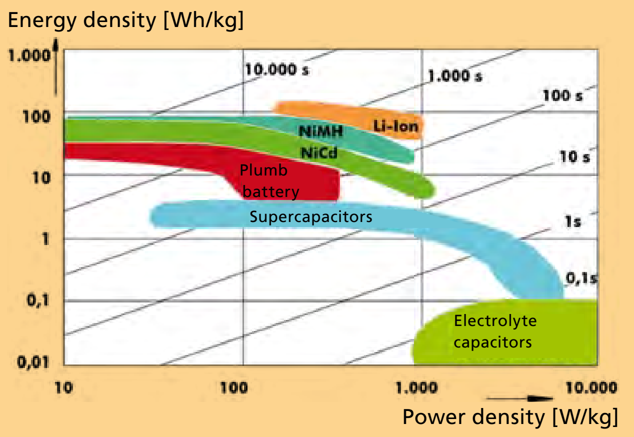
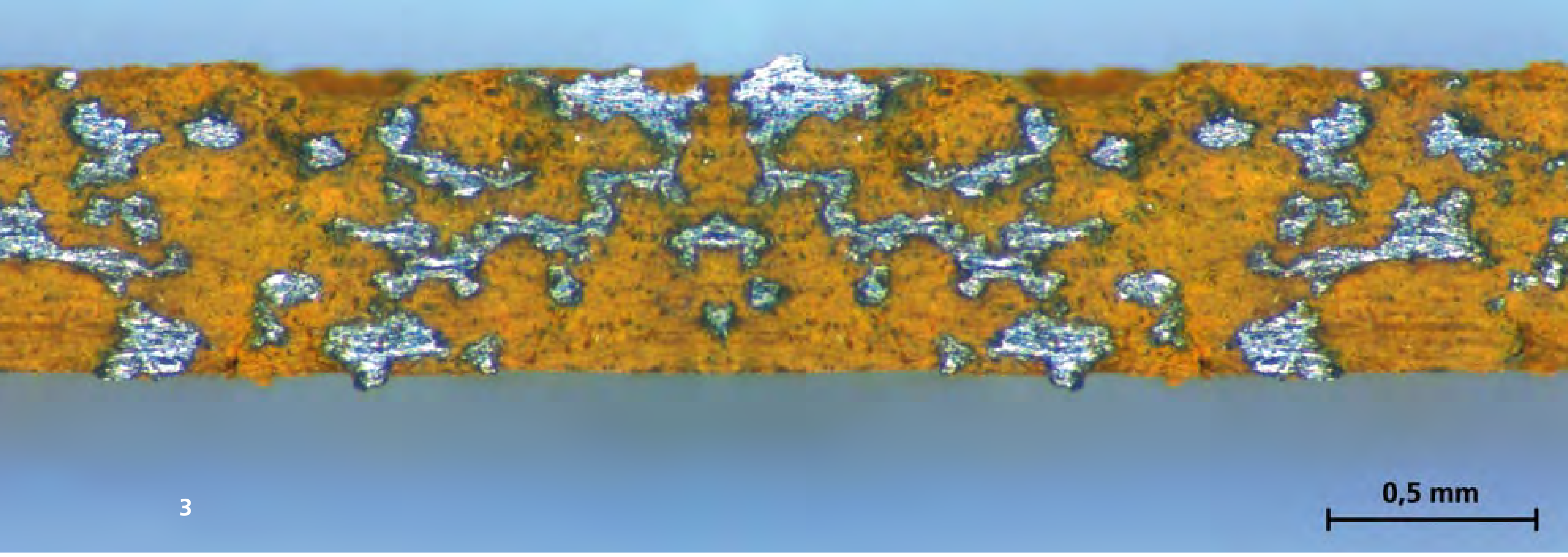


Fig. 1: Ragone schema - correlation between energy and power density of electrochemical storage systems (Source: www.itwissen.info).

Some materials evidence rapid reversible Faraday redox reactions in the first nanometers of their surfaces. This pseudocapacitive effect is shown by oxides, nitrides and carbides of transition metals. For instance, RuO_2 was demonstrated to have a specific capacity ranging from 720 to 1300 F/g. However, the raw material costs are a disadvantage.



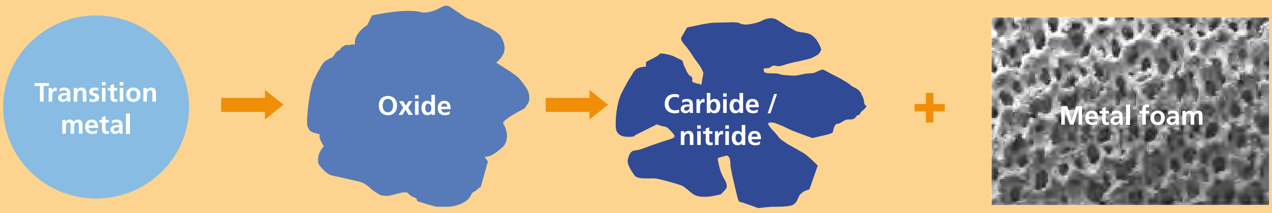


Fig. 2: Electrode concept for supercapacitors with pseudo-capacity.

New concept for supercapacitors

A new concept for supercapacitors has been developed within the framework of a cooperation between the Fraunhofer-Gesellschaft and the University of Michigan (Fig. 2). Cost-effective materials with a high pseudo-capacity include, for example, molybdenum and vanadium nitrides. The electrode and carrier for the active material is a metal foam, produced on the basis of a powder metallurgical technology, developed in cooperation with the company Alantum. The three-dimensional connection of the active material ensures good contact and even heat distribution at high capacity densities. During the production of the electrode material, the powder-based active material is processed to form a suspension and then infiltrated into the pores of the metal foam.

Figure 3 shows an Inconel foam infiltrated with vanadium oxide. The oxide is converted into a nitride in a subsequent synthesis process, whereby very high specific surfaces can be realized (Tab. 1). This synthesis from oxide to nitride can also be implemented in a separate synthesis process before infiltration. However, synthesis after infiltration has the advantage of achieving a particularly good connection and, therefore, contact of the active material with the metal foam structure (Fig. 4). Table 1 shows the capacities of transition metal nitrides and carbides. Molybdenum and vanadium nitrides achieve the highest values for specific capacity, while vanadium nitride has an even higher inherent potential through a possible

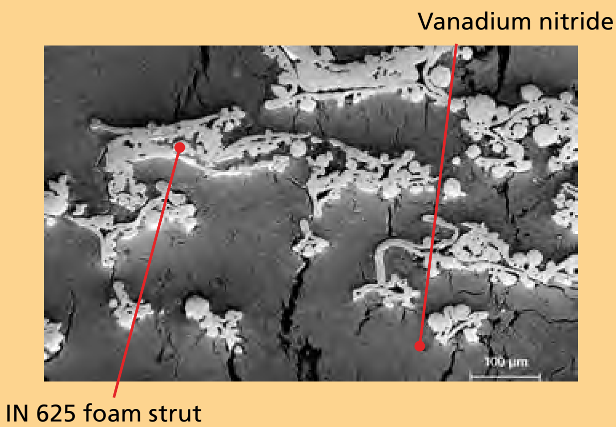
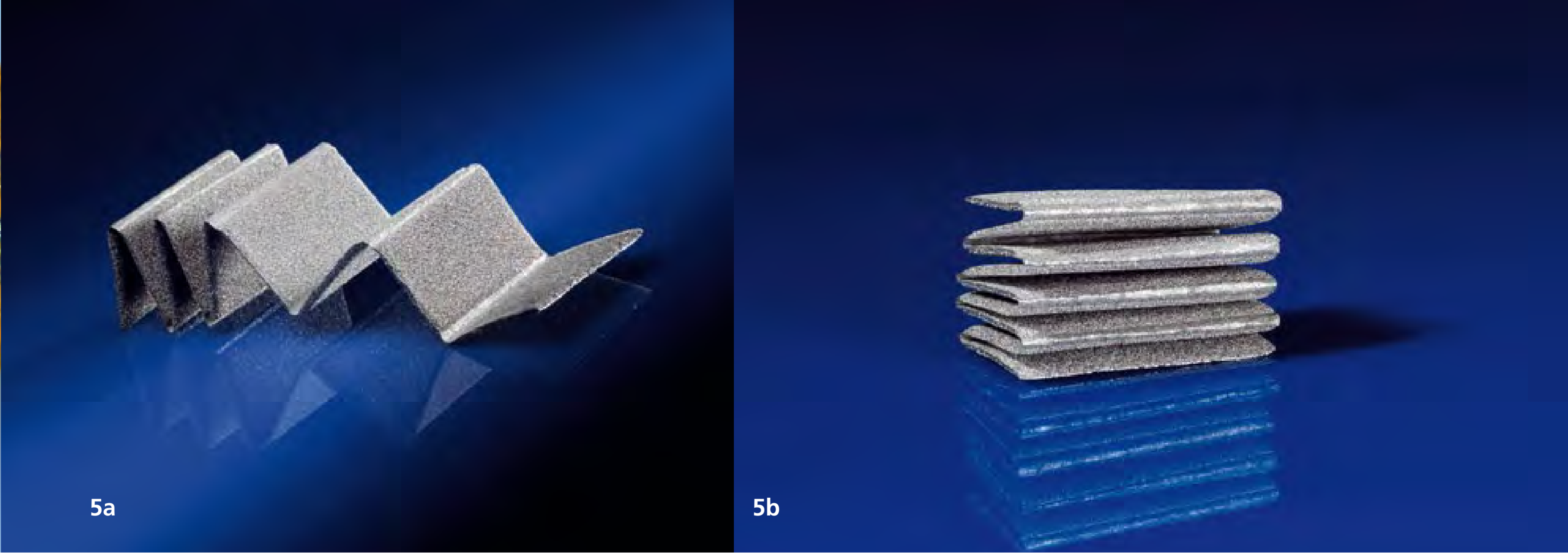


Fig. 4: Cross section of a metal foam electrode after infiltration and synthesis to vanadium nitride.

Material	Stability window (V)	Capacity (F/g)	Specific surface (m^2/g)	Double-layer capacity* (F/g)
VN	1,1 (KOH)	210	38	10
VC	0,8 (KOH)	2,6	6	1,3
Mo_2N	0,8 (H_2SO_4)	346	152	38
W_2C	0,7 (H_2SO_4)	79	16	4
W_2N	0,8 (KOH)	25	42	11

** Assumption: double layer capacitance of 25 µF/cm² (0,25 F/m²)*
B. E. Conway; Electrochemical Supercapacitors; Kluwer Academics/ Plenum Publisher; (1999).

Tab. 1: Capacities and specific surfaces of transition metal nitrides and carbides.



increase of the specific surface.

The capacity values also clearly indicate that the double-layer capacity only contributes a small percentage of the total capacity, the largest part of which comes from this pseudo-capacity.

Prospects

The values for specific capacities show the potential to significantly exceed the current energy densities of 2-5 Wh/kg. In addition, further work is planned on optimizing the synthesis for the active material, on maximizing the stability window for the electrode material, and on the cell design. Figure 5 shows the folded electrode material. The newly developed concept of supercapacitors has high potential and seems likely to achieve a leap in quality with regards to power and energy density, compared to conventional carbon-based double-layer capacitors.

Fraunhofer IFAM has made further contributions towards the development of sustainable energy storage systems with these promising solution approaches and results, which can be used in numerous application areas for both mobile and stationary systems.

Project funding

Supported by the University of Michigan, USA, and the Fraunhofer-Gesellschaft.

Project partners

University of Michigan, USA
Turtlerock Greentech, Michigan, USA
Fraunhofer IFAM, Branch Lab Dresden

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3 *Inconel foam infiltrated with vanadium oxide.*
5a + 5b *Foam electrodes, folded design for supercapacitors.*

1

"MINT-ONLINE": PREMIUM ON-THE-JOB COURSES IN MINT SUBJECTS

With its joint project "MINT-Online", the Fraunhofer Academy was selected to participate in the 'Advancement through Education: Open Universities' competition, run by the German Federal Ministry of Education and Research (BMBF) with the aim of developing innovative and demand-oriented concepts for professional qualifications. Project partners are the Carl-von-Ossietzky University of Oldenburg and the Fraunhofer institutes IFAM, IWES and UMSICHT. The participating institutes aim to offer high-quality and tailored advanced training in the subject areas of environment, sustainability and renewable energies for the specialist areas of mathematics, IT, natural sciences, and technology (MINT).

New technologies require new education concepts

Renewable energies, wind energy systems, construction physics, energy storage systems, and electromobility were identified as forward-looking topics for the "MINT-Online" project, as global growth is expected in these technologies. Within the joint project, Fraunhofer IFAM has taken to develop advanced training certificate courses in electromobility.

The transition from combustion engine to electromobility requires more than the development of a suitable infrastructure, powerful battery systems, or new vehicle concepts. Considered in its entirety, the transition to electric drives will also modify established supplier and vehicle manufacturer structures and impose new challenges on technical personnel. The sustainable introduction of these new technologies is therefore always linked with the training of personnel. For Germany to become the leading market in electromobility, industry will have to adapt. The "MINT-Online" concept shows how personnel can be prepared for the new structures in the value chain. The Masters degree and certificate programs are addressing part-time students, returnees and Bachelor students, as well as employees without formal [German] university entry qualifications.

Electromobility requires interdisciplinary knowledge

The conversion to electromobility requires qualified specialist personnel who are not only focused on the core business of developing a new technology and its maintenance, but who can also develop and sustain the relevant infrastructures. This change requires new and additional qualifications on the part of the specialist personnel concerned. These can only be achieved by retraining, by additional further education based on previously acquired knowledge, or by the creation of new occupational training programs. Advanced training must be seen as the primary means to cover short-term demand for specialist personnel, enabling experienced personnel to meet


2

Advisory Board

Project coordination and management
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Dr. Götter, Fraunhofer Academy

Continuing education Master's degree courses

Master Renewable Energy
Prof. Dr. Parisi, University of Oldenburg

Master Wind Energy Systems
Prof. Dr. Kuhl, University of Kassel;
Prof. Dr. Schmid, Fraunhofer IWES

Master Online Acoustics
Prof. Dr. Mehra, University of Stuttgart

Advanced training certificate programs

Certificate program Energy Storage Systems
Prof. Dr. Agert, Next Energy at the University of Oldenburg

Certificate program Electromobility
Prof. Dr.-Ing. Busse, Fraunhofer IFAM

Certificate in Advanced Wind Energy – Fluid and Systems Dynamics
Prof. Dr. Kühn, University of Oldenburg, ForWind

Certificate program Hearing, Apeech and Audio Technology
Prof. Dr. Dr. Kollmeier, University of Oldenburg

Upgrading of existing programs

Master Online Construction Physics
Prof. Dr. Mehra, University of Stuttgart

Interdisciplinary distance learning course Environmental Sciences
Prof. Dr. Breitmeier, FernUniversität in Hagen;
Prof. Dr. Deerberg, Fraunhofer UMSICHT

Tab. 1: "MINT-Online" education concept.

the changing requirements. The need for advanced training is evident in vehicle maintenance and repair shops, with first aiders, and in development and production.

In comparison to currently available programs, the advanced training programs under development must be interdisciplinary, combining automotive technology, automotive mechatronics, engineering disciplines, automotive engineering and production, electrical energy storage systems, high-voltage technology, and electric drive trains. This is not only relevant for the development and production of electric vehicles, but also for the sectors dealing with maintenance and repair or new mobility concepts.

In order to rapidly implement and provide advanced training opportunities, Fraunhofer IFAM has developed a certificate program for industry employees in the fields of automotive development and production, for trades such as automotive

1 *Construction and commissioning of the "Fraunhofer electric concept car – Frecc0". The experiences from various projects at Fraunhofer IFAM flow into the development of the certificate program in Electromobility.*

2 *Preparation for the first test run of the "Fraunhofer electric concept car – Frecc0".*

3

mechatronics, automotive mechanics and related occupations, electrical engineers and related occupations, as well as for job-returnees and first aiders. There is immediate demand in all of these areas.

With adapted course structures, new entrants can be raised to an equivalent education level regarding the subjects on offer, while simultaneously covering the content and curriculum defined by legislation.

An additional challenge in designing an advanced training portfolio is the need to take into account any scheduling conflicts or obstacles for participants who are employed and/or who have familial obligations.

The aim is to provide all participants, irrespective of their educational level and time commitments, with a practical and theoretical education in the necessary topics, and for this training to provide them with an additional qualification that may be necessary for them in the future.

CERTIFICATE COURSES IN E-MOBILITY

Vehicle concepts and technology

- Lightweight construction
- On-board networks (communication/voltage supply)
- Drive technology
- Power electronics
- Electromagnetic compatibility
- Supplementary units (e.g. heating/air-conditioning systems)

Energy storage systems for vehicle applications

- Fuel cell technology and energy storage systems
- Battery management
- Current battery systems and materials
- Capacitor technology and materials

Traffic concepts and infrastructure

- Carsharing
- Charging stations
- Norms and standards
- HV safety
- Range extender

Tab. 2: Potential course contents.

Development of the electromobility certificate program at Fraunhofer IFAM

The first phase of the project, with a set duration of three and a half years, consists of the scientifically based development and testing of the specified range of courses. The certificate course in Electromobility is currently being developed within a group project at Fraunhofer IFAM, while simultaneously a target group analysis is being conducted. Research here is focused on the analysis of target group heterogeneity and the corresponding course contents, together with the structure of the further education program. The use of Internet-supported training technology will enable flexible access to the program, regardless of time or physical location. At the same time, interested international students should also be able to access the Internet-supported courses. The accreditation of both formal and informally-acquired competencies enables horizontal permeability between courses on offer.

At the same time, a didactic concept needs to be developed to meet the new requirements of different teaching schedules and educational levels. This will be followed by an evaluation phase, during which courses will be tested through pilot modules and then assessed.

Upon completion of the first project phase, the project sponsor and an independent panel will then decide on the eligibility of each individual project for further funding. The second step will be the implementation phase, in which the individual offers will be put on the market. In parallel with this development of certificate courses, Fraunhofer IFAM will be implementing the installation of suitable teaching sites where concept cars, motor test benches and test equipment will be available for further training and for the research and development work carried out by Fraunhofer IFAM.

Project funding

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und Forschung

ESF
Europäischer Sozialfonds
für Deutschland

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3 *In-house employee training at Fraunhofer IFAM.*

ELECTROMOBILITY DEVELOPMENTS – ADVANCEMENT THROUGH SYSTEM RESEARCH

On September 2, 2011, the new components of the "Fraunhofer electric concept car" – Frecc0 – went on their first test drive. Numerous visitors were able to witness the successful electrification of the drive trains in two demonstrator vehicles at the final event in Papenburg on the ATP test track. The basis of both electric vehicles was the Artega GT. Market-available technology was integrated in the Frecc0 1.0, and the interaction of these components was optimized. The Frecc0 2.0 included components which had been newly designed by scientists at Fraunhofer. A functional electric vehicle was designed with vehicle components for drive, battery system, vehicle steering, and network integration. However the Frecc0 is not only intended for use as a test platform for Fraunhofer scientists: automotive manufacturers and suppliers can also use the Frecc0 in future to test or further develop new components.

Fraunhofer System Research Electromobility

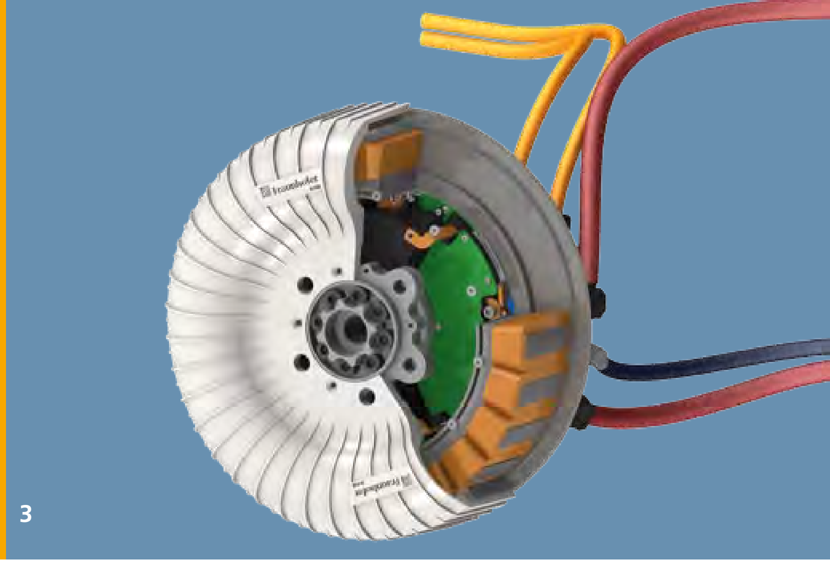
The goal of the "Fraunhofer System Research Electromobility project – FSEM" (ongoing since Summer 2009 and supported by the government within the framework of economic package II) was to create a greater understanding of the system of electromobility within just two years, with the cooperation of more than 30 Fraunhofer institutes. Fraunhofer IFAM has contributed significantly to the development of the wheel hub motors, the vehicle bodywork, and the system integration of the vehicle components developed within FSEM in the "Fraunhofer e-concept car type 0 – Frecc0". These wheel hub motors were developed in close cooperation between IFAM researchers and the Fraunhofer institutes LBF, IWM, and IISB. Scientists from the ESK, LBF and IISB worked together with Fraunhofer IFAM on the construction of the demonstrator vehicles.

Wheel hub motors

A new generation of wheel hub motors

A primary aim of the FSEM was to develop a wheel hub motor with integrated power electronics as a traction drive for electric vehicles, suitable for mass production. The greatest challenge was the development of a motor with a torque comparable to conventional drives but with minimum weight, in order to minimize the extent of the unsprung mass and therefore the dynamic drive force effects. Above all, the integration of the necessary power electronics in the space of the motor was a particular challenge, as the wheel hub motor had to be packed into a 15 inch rim.

1 *Fraunhofer demonstrator vehicle Frecc0 2.0 on a test run (Photo: Ingo Daute, © Fraunhofer).*



The freedom offered by the independent drive on each wheel, made possible by the use of wheel hub drives, leads to increased safety requirements for the drive system and for the entire vehicle. Suitable measures such as subsystem redundancy and appropriate fall-back levels need to be taken into account in terms of motor design and configuration, as well as for the systems of motor and vehicle control.

The necessarily high performance density makes liquid cooling of the motor and power electronics essential. A suitable seal system was developed, capable of withstanding the resulting high circumferential speeds. This meant it was necessary to construct special wheel-bearing units which could simultaneously withstand the resulting loads and be extremely smooth-running in operation. An important consideration during the production of all parts was to ensure that processes suitable for mass production could be used, so that the conversion of the new technologies for application in large-scale production could be implemented with a low effort.

Vehicle handling with wheel hub motors

Tests on real vehicles did not just start with the completion of the Frecc0 prototypes. During their development, comprehensive driving operation measurements were performed using a conventionally-driven Artega GT. The tests were carried out with the following questions in mind: what effect do the additional tire-sprung masses of the wheel hub motors have on the driving dynamics and on the chassis? What are the stresses on the individual components and on the complete vehicle during realistic driving operation? For these tests, the vehicles were equipped with additional masses in the wheels in order to simulate the influence of the hub motors. Comprehensive sensors were put on the suspension parts and wheels for the evaluation of load and drivability with measured data. One parameter study investigated the influence of the additional mass of the wheel hub motors on the chassis loads. These tests showed that forces on the wheel and the chassis are increased slightly by the additional mass. From a structural durability aspect, this increase needs to be taken into account, but does not require any significant constructional changes to the vehicle concept. The acceleration amplitudes of the wheel are actually reduced, which has a positive effect on the life time of the power electronics in the wheel hub motor. From a driving dynamics aspect, the mounting of the additional wheel hub motor mass on the rear axles does not lead to any detectable deterioration in drivability.

Production engineering optimization

The Fraunhofer wheel hub motor is designed as a permanent-magnet synchronous motor with external rotor. The high-performance magnets based on neodymium-iron-boron allow a high torque with low weight and good efficiency. The internal coils are cooled by a liquid-filled aluminum stator housing, so that the dissipated heat produced in the small space can be safely dispersed. The function-integrated stator housing serves to both hold and cool the electronic unit with its power electronics and motor control.

A “lost-foam casting process” was used to produce this stator housing. This enables the production of near-net-shape components with complex geometries, permitting the direct integration of cooling channels in the housing. The number of necessary sealing surfaces is reduced to a minimum, so the high cooling performance required for high performance density can be realized.

The “lost-foam process” is equally suitable for the production of prototypes and for large production runs, which facilitates a direct transfer to mass production of the stator housing.

2 *Stator of the wheel hub motor mounted on the Frecc0 2.0 without rotor bell.*

3 *Sectional view of the wheel hub motor in construction.*

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The rotor bell is designed to be produced in high pressure diecasting, in order to enable cost-effective production. The overall weight of the housing components was successfully reduced to a minimum by the weight optimization methods.

Construction space optimally utilized

To increase functional safety, the motor was developed with two subsystems that can essentially be operated independently from each other. Despite the increased degree of complexity due to the integration of two inverters and winding systems, installation was possible without any increase in the construction space requirements. Possible malfunctions were taken into consideration during the electromagnetic design phase so that impermissible braking or even blocking of the wheel, for instance during a short circuit, can be eliminated.

The number of supply lines necessary to operate the motor were reduced to a minimum due to the integrated power electronics developed by Fraunhofer IISB. A central control unit in the vehicle converts the driver requests based on the steering angle, gas and brake pedal to a torque signals and coordinates the battery status and current temperature of motor and power electronics to the wheel hub motors, while also taking the requirements of driving dynamics into consideration. The CAN bus established in the automotive sector is used for the transmission protocol. A modern, efficiency-optimized control method is used to regulate the motor. The relation between speed and torque-dependent and necessary current are determined by electromagnetic design calculations and measurements on the machine, taking temperature and electromagnetic influences into account. This ensures high accuracy as well as increased efficiency, which is also important in terms of safety and driving comfort.

Sealing concept challenge

A significant challenge was the development of a sealing concept for the wheel hub motor. Due to the external rotor design and the bell-shaped rotor construction, reliable sealing against penetration of dirt and moisture is necessary over a large external diameter, with correspondingly high circumferential speeds of up to 30 m/s. This sealing must be ensured not only for dynamic use, during driving operation, but also at standstill, e. g., if the vehicle is stopped in a puddle. Various sealing concepts and material combinations for the wheel hub motor were systematically investigated, optimized, and tested in practical operation.

Practical tests on the test bench

During the entire development and construction process, the wheel hub motor was exposed to the mechanical and electrical loads expected in the wheel using numerical simulations, in order to meet all structural, durability, and reliability requirements. The electromagnetic design was also realized using

Number of cores in the winding	6
Continuous rating	55 kW
Rated torque at 550 rpm	700 Nm
Maximum torque (brief overload)	900 Nm
Number of stator slots	24
Number of rotor poles	22
External diameter of complete wheel hub motor	364 mm
Total depth	105 mm
Axial construction depth (hub carrier distance from rim flange)	88 mm
Total mass	42 kg
Total efficiency at rated point	92 %

Tab. 1: Technical data of the Fraunhofer wheel hub motor.

numerical simulation methods to optimize the performance data under the given boundary conditions. Intensive test bench investigations completed this step. First of all, the behavior of the prototype was tested under realistic wheel contact and side force conditions on the Fraunhofer LBF six-axis tire test bench W/ALT. The resulting deformation of bearings and rotor bell and the deformation of the air gap could be recorded and compared with the numerical simulations. No impermissible deformations were recorded. Finally, the electrical operating behavior of the wheel hub motor was tested on a simulated battery in the Fraunhofer IFAM motor test bench.

Demonstrator vehicles Frecc0 1.0 and 2.0

Opportunity for a new vehicle concept

At present it seems the combustion engine will continue to be used and further optimized as a vehicle drive in the coming years. However, its significance as the sole solution for the generation of drive energy will decrease. Conversions of conventional vehicles or small production runs currently suffice to meet the demand for electric vehicles. This means that the majority of existing electric vehicles retain the drive topology which has been familiar since the beginnings of automotive manufacturing: a central motor generates the drive torque which is transferred to two or more driven wheels via gears and differentials. In consequence, the increasing electrification of the drive train means a shift in production and manufacturing technology and a changing product portfolio. Electromobility may lead to a rethinking and a new orientation in designing and building cars. This conversion will lead to the development of intelligent vehicle concepts, offering the opportunity of "re-inventing the vehicle".

Structure of the vehicles

The Frecc0 demonstrators are based on an Artega GT. For the Frecc0 1.0 vehicle, components available on the market were used to convert it into an electric vehicle. The battery system and charging infrastructure were also implemented using standard market technology. The Frecc0 1.0 has two gear transmission drive motors positioned close to the wheels. The Frecc0 2.0 is based on components developed during the Fraunhofer electromobility system research project. These include wheel hub motors with high torque densities, a battery system, an on-board charger device and an external quick-charger device. The components communicate with each other using a central control unit. Special modifications to the wheel hub motors were required for the Frecc0 2.0: together with Artega Automobil GmbH, the manufacturer of the base vehicle, Fraunhofer researchers developed a chassis concept that enabled the use of the mechanical standard brake system on the inner side of the wheel carrier. This made it possible to obtain driving dynamics equivalent to the behavior of a standard chassis.

Drive concepts with wheel hub motors and with two motors close to the wheels could be investigated for the first time with the two Frecc0 versions. As both concepts are different, the results of these tests on real vehicles provided useful knowledge for the optimal design of future electric vehicles. The charging infrastructure in the Frecc0 2.0 also enabled comprehensive network integration and the practical testing of a quick charging concept. For instance, "Torque Vectoring" can be implemented with several distributed motors in place

4 *Mounted wheel hub motor in Frecc0 2.0 with rim and tire.*

5 *Fraunhofer demonstrator vehicle Frecc0 2.0 on the ATP test track in Papenburg (Photo: Ingo Daute, © Fraunhofer).*

6 *Fraunhofer demonstrator vehicles Frecc0 1.0 and 2.0 in comparison on the ATP test track (Photo: Ingo Daute, © Fraunhofer).*

of a central motor. An adaptive torque distribution on the wheels of the rear axle allows this technology to produce improved drive behavior in curves. As the control system for this needs to be profoundly tested, both prototypes are equipped with multi-motor drives.

Functional safety

The Frecc0 has a modular on-board electronic system, based on the existing Artega GT on-board network, facilitating the simple integration of new components. This requires a detailed coordination of both the interfaces and the communication between components. The function of the higher-order vehicle control system in the Frecc0 is implemented by the central control unit (CCU) developed by Fraunhofer ESK. As the central control unit, it interprets the driver's requirements and implements them accordingly via the drive control unit in the vehicle. It controls the connection of the Fraunhofer components with the existing vehicle, implements central status management, activates the cooling systems for the wheel hub motors and battery systems, and controls the DC link upload.

In addition, it must be taken into account that safety-critical functions such as the motor control and the battery systems are increasingly actuated solely via software in electric vehicles. The on-board network architecture of the Frecc0 is thus so safely constructed that a component malfunction cannot influence any critical systems and faulty systems can be detected and switched off. This safety concept is based on a detailed risk analysis and risk assessment in accordance with the new ISO (DIS) Standard 26262 or IEC 61508 (DIN EN) for functional safety. A Failure Mode and Effects Analysis (FMEA) in accordance with the VDA standard was carried out for each of the Fraunhofer components - primarily by Fraunhofer LBF. The results are taken into account in the Frecc0 safety concept.

Added value through system research

Future generations of electric vehicles must be at least as reliable, safe, and comfortable for their users as conventionally operated vehicles. At the same time, their production should be economic. Numerous aspects need to be considered here – from new drive concepts and battery and charging systems, to vehicle control and the inclusion of the vehicles in the infrastructure.

Intensive communication between Fraunhofer employees has increased their mutual understanding of each department's respective contextual and technical challenges, while giving rise to synergy effects, facilitating the rapid maturation of new technical developments. This is the only way in which development aims can be identified and innovative Fraunhofer solutions for the construction and operation of vehicles can be developed.

One key to the formulation of new questions for research work on electromobility in general, and the development of components in particular, lies in the formation of thematic clusters and topic-specific cooperative projects within the Fraunhofer-Gesellschaft.

Both demonstrator vehicles were presented and tested during the grand finale on the ATP test track at Papenburg at the beginning of September 2011 by the Fraunhofer electromobility system research project.

Development platforms for electromobility

The future work will benefit greatly from the experiences gained from Frecco 1.0 and 2.0 as scientific integration and test platforms including the complete CAD data set for the

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'complete system electric vehicle', from access to the control software, and to the entire vehicle-internal communication structure. Current Fraunhofer developments in the field of electromobility can be tested and compared with corresponding products from commercial suppliers, and with any new developments arising from customer demand. The modular structure of the test platforms means that even externally designed vehicle components can in general be easily integrated into the system and tested in practical vehicle operations. Cross-institute competencies are pooled into thematically oriented Fraunhofer groups. Based on these groups and the development platforms, Fraunhofer researchers are working on ongoing in-house questions, such as optimized driving behaviour security in critical multi-motor drive situations. In addition, they are working on completely new electromobility development projects together with our industry partners.

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und Forschung

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7 *Mounted wheel hub motor in Frecc0 2.0 with rim and tire.*

8 *Fraunhofer demonstrator vehicle Frecc0 2.0 on the ATP test track in Papenburg (Photo: Ingo Daute, © Fraunhofer).*

1

ELECTROMOBILITY MODEL REGION BREMEN/OLDENBURG: E-MOBILITY IN FLEET TESTS

Mobile solutions for the world of today – that is the aim of the Electromobility Model Region Bremen/Oldenburg. Fraunhofer IFAM has taken a leading role in the development of new mobility concepts since July 2009. The core tasks are conducting and evaluating fleet tests, as well as a mobility analysis. The first project phase was completed successfully. The Federal Ministry of Transport, Building and Urban Development (BMVBS) has already decided to continue along the path and expand this model region, having approved new projects through 2014.

Electromobility in model regions

To optimally prepare for the market ramp-up, model regions were to serve for everyday and user-oriented demonstrations. A Germany-wide competition was launched, leading to the selection of eight model regions out of 130 applications. The regions selected included both metropolitan as well as rural areas. They were Berlin/Potsdam, Hamburg, Bremen/Oldenburg, Rhine-Ruhr, Saxony, Rhine-Main, the Stuttgart region and Munich. Tailored to local needs and characteristics, these model regions allowed for an ideal integration of the application-oriented research and development available. Across regions, this came about with different focal points and a wide range of different participants. In the Bremen/Oldenburg electromobility model region, a total of 25 individual projects with over 30 project- or associated partners were carried out during the first phase from October 2009 to November 2011. Numerous people within the region were able to test electric vehicles over the past two years and experience that there are alternatives to combustion engines which can easily be integrated into everyday life.

The project management center controls and coordinates at a regional level

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM and the German Research Center for Artificial Intelligence (DFKI) GmbH have jointly coordinated and scientifically guided the Bremen/Oldenburg model region, for which they created a regional project control center. The center took over coordination of the complete program at the regional level, and was the direct contact for NOW GmbH, the nationwide program coordinator commissioned by the BMVBS. All the project's administrative processes were managed from this center. The main tasks of the regional project management center were:

- Administration and coordination of the entire project
- Reporting to the nationwide program coordinator
- Coordination and organization of the partnership structure in the model region
- Networking activities, regional and beyond

- Interface with representatives of the Länder and communities in the model region
- Integration and coordination of regional participants
- Initiation of further projects within the framework of the model region

With their existing infrastucture and networks, the *Länder* of Bremen and Lower Saxony, together with the Bremen/ Oldenburg Metropolitan Region facilitated targeted interactions between community bodies, participating senatorial authorities, the Bremen and Oldenburg chambers of commerce, previously established networks (such as Automotive NordWest), and particularly regional businesses and research institutions.

Structure of the fleet tests

The Fraunhofer IFAM conducted experiments on the everyday suitability of the electric vehicles currently available on the market in two separately themed fleet tests. One aspect investigated whether such vehicles could meet the requirements of commercially operated fleets, while the other looked at the suitability of e-vehicles for "private carsharing". The main questions concerned the restrictions arising from the properties of the batteries, i.e. primarily their capacity, regarding range and charging times.

The "commercial users" fleet consisted of two-seaters, four seater/four door cars, as well as one light utility vehicle. Some of these vehicles were used to supplement an existing fleet of conventionally powered vehicles (e. g., Bremer Strassenbahn AG), but some were used by companies where an e-vehicle was the sole company car (e. g., E-Werk Ottersberg). Driving profiles were just as diverse: some vehicles were only used inside city limits (Bremen, Oldenburg), while others travelled throughout the region (Ottersberg, Wangerland). The pattern of utilization was therefore diverse, covering the entire spectrum of use for individual local passenger transport and allowing conclusions on the general suitability of electrically driven vehicles. The vehicles were equipped with data loggers so that vehicle-specific technical data and the driving profile (GPS data) could be obtained, in addition to driver surveys conducted throughout the overall project. The data were automatically transmitted to a server, then processed and evaluated in a project called "Intelligent Integration".

The "private carsharing" tests were also carried out with two- and four-seater vehicles. In addition to the obligatory data logger, some vehicles were equipped with an Internet-based booking system which allowed the respective user groups to manage their vehicles locally. The user groups were in turn divided into two sub-groups: neighbors with a permanent parking space in residential areas and groups of colleagues with a permanent parking space at work.

In addition to testing the vehicles themselves, the investigation looked at how the users evaluated the everyday suitability of the electric vehicles and what experiences were gained from the self-organized communal utilization of the vehicles.

1 *Electrically mobile around the world.*
2 *Models in the vehicle fleet.*

	Type	Speed	Battery	Range
Citroën Berlingo Electrique	2 seat	110 km/h	NaNiCl 23.5 kWh	approx. 120 km
German E-Cars Stromos	4 seat	120 km/h	Lithium ion 19 kWh	approx. 100 km
E-Wolf Delta 1	4 seat	110 km/h	Lithium ion 14 kWh	approx. 105 km
Think Global AS Th!nk City	2 seat	approx. 105 km/h	NaNiCl 23 kWh	approx. 160 km
Vectris VX-1	Scooter	approx. 110 km/h	Lithium ion	approx. 75 km
EcoCraft Automotive EcoCarrier	2 seat	approx. 75 km/h	Lead gel	approx. 50 km

Tab. 1: E-vehicles in use for the electromobility model region of Bremen/Oldenburg.

Results of the fleet tests: users confirm everyday suitability

A total of 27 electric vehicles were tested in everyday use for Fraunhofer IFAM. Over 250 drivers have used the vehicles for their daily journeys to work and for leisure, experiencing the everyday suitability of the electric vehicles over a total distance of over 200,000 km to date – i. e. five times around the globe. In addition, over 800 people have gained an initial impression of electric vehicles through test drives.

Across all eight model regions, a total of 2476 electric vehicles were in use. Data from all these regions have been evaluated and have provided a meaningful result [1]. The accompanying social science research investigation showed that electric vehicles for private use will make their way in larger numbers over the medium term only. Due to presently still low ranges and long charging times, the use of electric vehicles in the private sector is most suitable for city trips or commuters. The positive resonance in rural areas was surprising. The reasons for this included the availability of private parking spaces with access to electricity and precisely planned commuter routes, which were generally within the range of a charge cycle.

Another result of the user surveys must be given particular attention: test drivers viewed the integration of electric vehicles in broader mobility concepts, such as in combination with public transport or in car sharing, as particularly promising for the future. The electric vehicle is, therefore, not seen merely as a replacement for conventional private vehicles, but also as part of a sustainable mobility network.

According to the results so far, inner city commercial fleet operation appears to be a field of application with much potential for electric vehicles. This is due, on the one hand, to the

3 *Solar charging station at Fraunhofer IFAM.*
4 *Test driver for private carsharing (Photo: Markus Spiekermann).*

ease of planning and continuity of commercial routes, which are compatible with regular charging operations. On the other hand, the specialization of individual vehicle types can be considered to a greater extent in fleet operation in contrast to the private sector.

General statements regarding the length of trips, total daily distances traveled, and the charging volumes and behaviors could be derived from a detailed evaluation of the individual trips in the model regions. Most trips were short distance only. Every second trip was below 3.6 km and only every ninth trip was over 30 km. The average distance traveled was approx. 7.3 km. Half of all journeys were over after approx. 11 minutes, and about 90 percent were completed within 30 minutes. The average travel duration was approx. 17 minutes. 3.5 kWh or less was charged in 50 percent of all charging procedures, while 14.6 kWh or more was charged in 10 percent of cases. The average charging volume was 5.5 kWh. The charging duration in 50 percent of the cases was 75 minutes, while 10 percent exceeded 3.5 hours. The average charging duration was approx. 2.5 hours. This leads to the overall conclusion, based on the currently available data, that the range of the vehicles does not represent any limitations on their daily use [1].

Project funding

Supported by the Federal Ministry for Transport, Building and Urban Development (BMVBS).

Bundesministerium für Verkehr, Bau und Stadtentwicklung

Coordinated by the NOW GmbH (National Organisation for Hydrogen and Fuel Cell Technology) in Berlin.

[1] 2011 results report for the electromobility model regions, BMVBS.

Project partners

Project partners in the Electromobility Model Region Bremen/ Oldenburg:

- BIBA – Bremer Institut für Produktion und Logistik GmbH, Bremen
- Bremer Energie Institut (BEI), Bremen
- Bremer Straßenbahn AG, Bremen
- CRIE Centre for Regional and Innovation Economics, Bremen
- The Senator for Construction, Environment and Traffic, Bremen
- Deutsches Forschungszentrum für Künstliche Intelligenz GmbH DFKI, Bremen
- EWE AG, Oldenburg
- H²O e-mobile GmbH, Varel
- Jacobs University Bremen
- Move About GmbH, Bremen
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OXIDATION PROTECTION FOR METALLIC MATERIALS

Oxidation-resistant coatings that can withstand high temperatures significantly increase the application range of established metallic materials. This opens up new perspectives for their use as oxidation and corrosion protection, for instance in power stations and chemical plants.

The challenge: protection against corrosion and oxidation

Steels and inter-metallic alloys are materials with excellent properties and are used worldwide. However, their application range is restricted by the limited resistance of pure materials against corrosive and oxidative attacks. Damage caused by corrosion and high-temperature oxidation can result in high financial losses, e.g. for operators of power stations and chemical plants, due to long shutdown or maintenance times, and the cost of procuring spare parts, which can sometimes be high.

High temperature and corrosion resistance of protective coatings

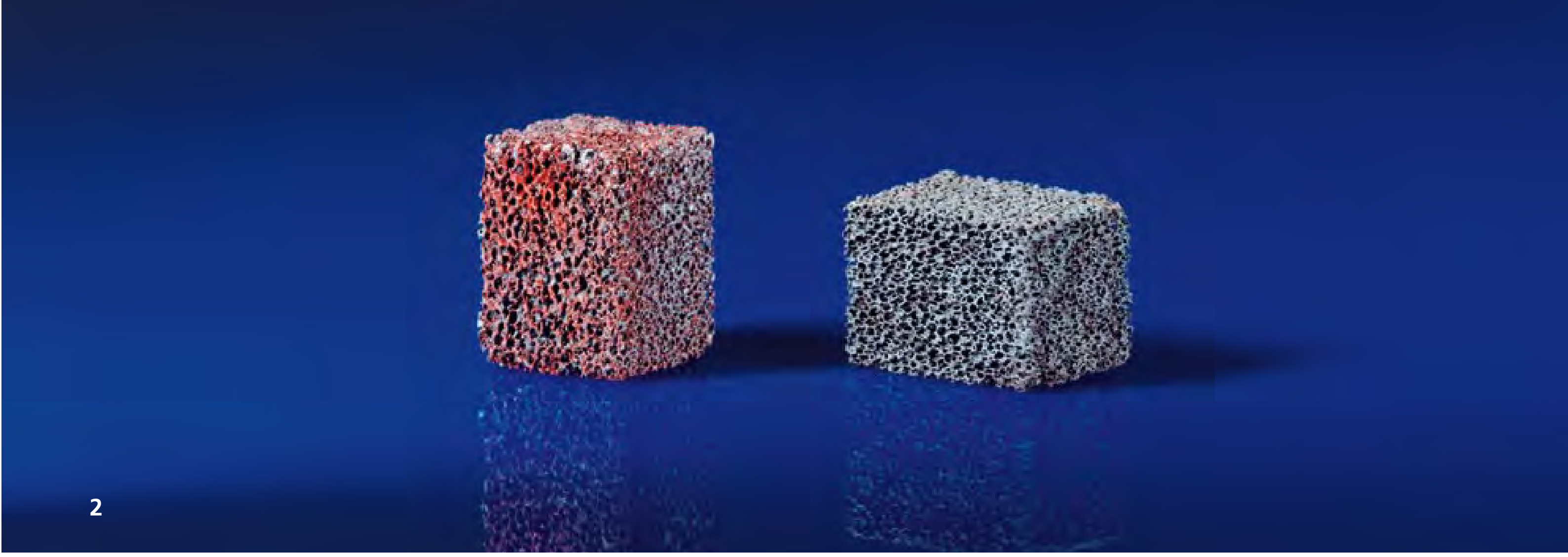
One solution for this problem is the development of protective coatings that can be applied to the metal. Polymer-derived ceramic materials (PDC) in SiOC, Si(B)CN and SiC systems are characterized by a high temperature and corrosion resistance. For instance, materials in the Si(B)CN system are temperature-stable in argon up to 1600 °C, and oxidation-resistant up to 1400 °C. Due to these properties, such materials are particularly suitable as coatings for oxidation and corrosion protection.

Current research examples

Starting materials for such coatings are commercially available inorganic polymers such as polysiloxanes, polysilazanes or polycarbosilanes that can be converted into inorganic solids in a thermal process. These polymer-derived ceramics are glassy in nature or nano-structured in composition.

The coating is carried out with liquid phase coating, using immersion or spray coating processes. The advantages of these coating technologies, well-known in paint/lacquer technology are that in comparison to PVD or CVD processes large components with complex geo-metries can also be coated with low technological outlay.

The components are initially coated with solutions or suspensions of the original polymers in the coating process. This forms a polymer film on the surface of the component which is then thermally decomposed and converted into the polymer ceramic during thermal treatment under inert gas or air. Fillers such as Al_2O_3 can also be included in the polymer



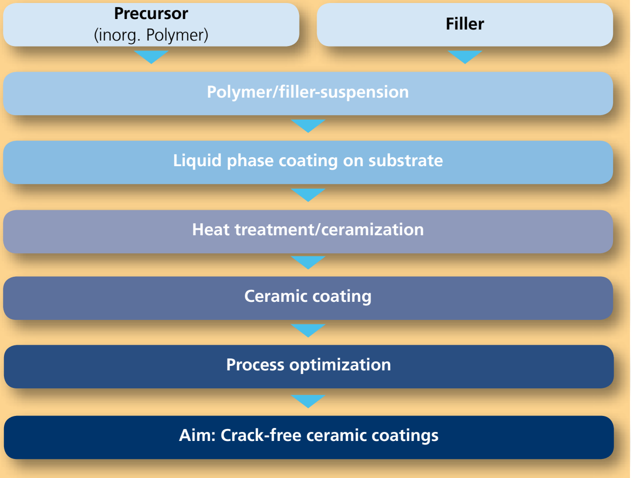


Fig. 3: Technological sequence for production of polymer-derived ceramic coatings.

suspension, leading to an increase in the maximum coating thicknesses that can be generated in simple coatings. In addition, the fillers can be selected to specifically influence the properties of the coating, such as hardness, thermal expansion, electric and thermal conductivity, etc. Figure 3 shows the technological procedure for the production of polymer-derived ceramic coatings.

Investigations into the pretreatment of the substrate show that a sufficient surface roughness is an important prerequisite for good coating adhesion. Sandblasting was selected as a necessary pretreatment, in particular for construction steel sheets.

The coating systems generated in this manner have a thickness of between 12 and 25 µm. They are tight, crack- and pore-free, and adapt extremely well to the surface of the substrate. ISO code 0 was achieved in the cross-cutting test as per DIN EN ISO 2409. Figures 4 and 5 show an example of an Al_2O_3-filled coating on a construction steel substrate.

Depth profile elemental analyses of coated construction steel samples using GDOES (Glow Discharge Optical Emission Spectroscopy) show that a diffusion of elements from the coating into the substrate occurs during the thermal treatment. This forms an intermediate layer between the coating and the sub-

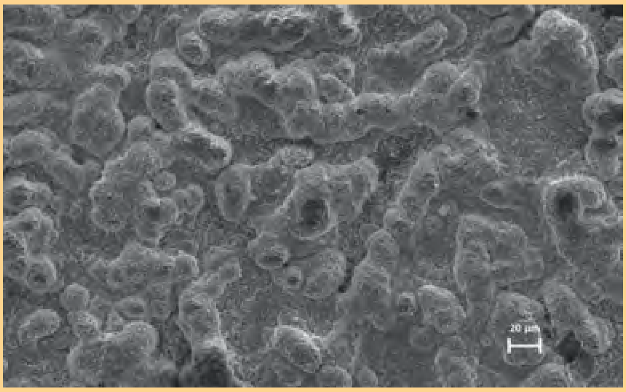


Fig. 4: REM image of an Al_2O_3-filled coating on a construction steel substrate.

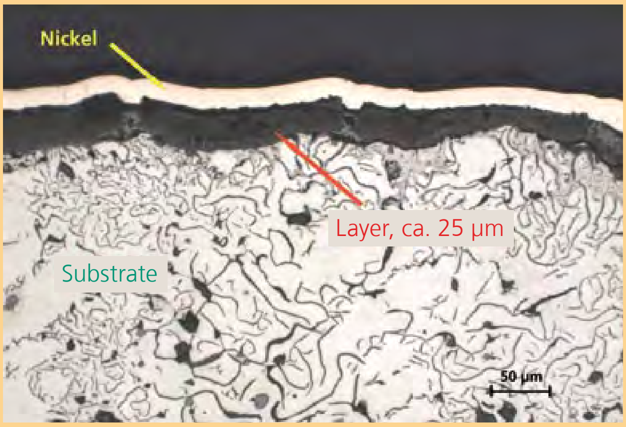


Fig. 5: Al_2O_3-filled coating on a construction steel substrate: Cross-section, 900x magnification, coating thickness approx. 25 µm.

1 *ZrO_2-filled SiCN coating on metallic hollow spheres (316L).*

2 *Coated (right) and uncoated (left) open-cell metal foam after oxidation test.*

strate. This intermediate layer reduces the differences in the thermal expansion coefficients of the coating and substrate; further, it forms direct chemical bonds between them. As a result, such coatings are characterized by very high adhesiveness and thermal shock resistance, particularly in comparison to physically applied ceramic coating systems.

The coated samples were subjected to oxidation tests at 800 °C in air to test the operational suitability of the coating system. The results are shown in Figure 7. The coatings showed a slight discoloration after the oxidation tests, but retained good adhesiveness. Cracks or flaking were not observed. The oxidation (mass increase) of the uncoated samples was approx. 20 times higher than that of the coated samples.

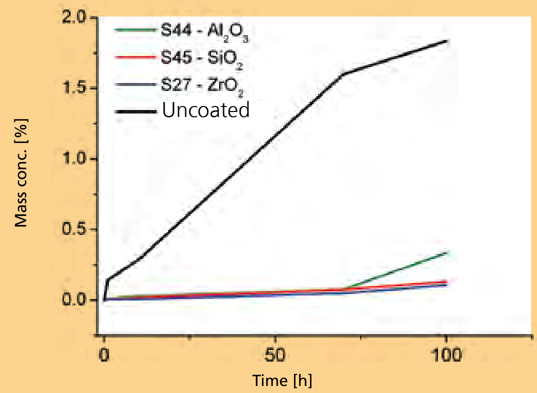


Fig. 7: Mass increase after 100 hours test.

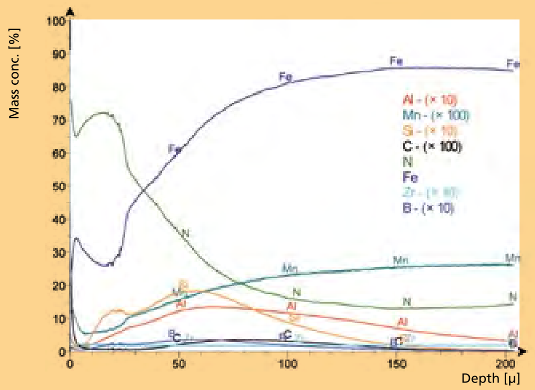


Fig. 6: Result of a depth profile GDOES-element analysis of a coated construction steel sample.

Since FeCrAl steels can be used as high-temperature materials, the oxidation tests were also carried out on sintered hollow sphere structures made of this material (1.4767 / CrAl 20-5) at 1100 °C in air for 400 hours. The test results (Fig. 10) demonstrate that after 50 hours uncoated materials will begin to show an increase in mass which rises drastically after 100 hours. The experiment was stopped after 300 hours and an increase in mass of over 40 percent. In comparison, the mass of the

Coated open-cell metal foams made of carbonyl iron powder were also tested under similar conditions. Due to the large surface area of the metal foams, the differences between coated and uncoated samples were particularly striking. As can be seen in Figure 8, the oxidation of the open-cell metal foams can also be reduced ten-fold.

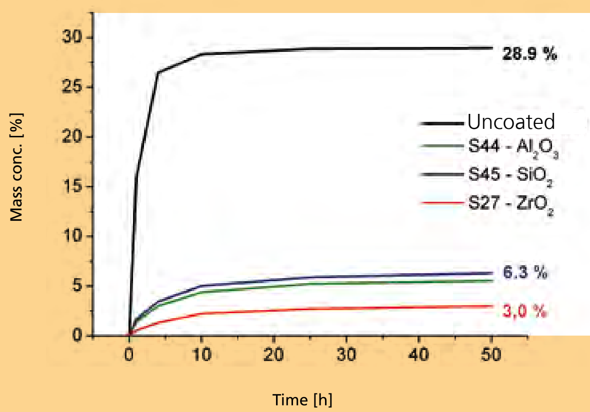


Fig. 8: Results of oxidation test after 50 hours at 800 °C in air.

9

coated samples remained almost constant over 400 hours following a slight increase in mass at the start of the experiment. The increase in mass never exceeded the threshold calculated for the complete oxidation of the aluminum in the alloy.

Application areas

Applied high-temperature oxidation protection coatings are suitable for numerous different metallic materials and have been successfully tested, e. g., on gray cast iron and the stainless steels 316L and 430L. However, coating systems need to be adapted to each application case through development and testing.

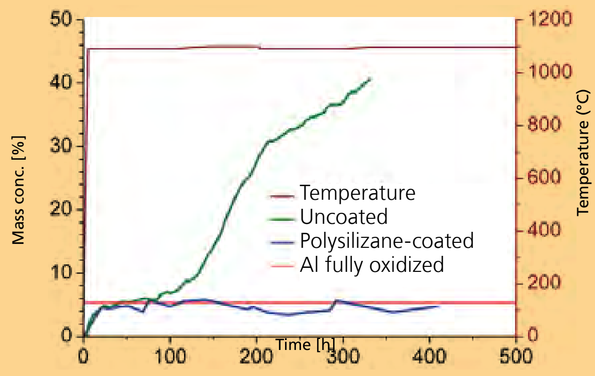


Fig. 10: Results of oxidation tests at 1100 °C in air for 400 hours.

The advantages of such oxidation protection systems lie in the extension of service life for components and systems, the possibility of raising operating temperatures whilst retaining the materials used, or the use of less oxidation-resistant and therefore cheaper steels under the same application conditions. Application areas for such coating systems include power stations, chemical plants, and metallurgy. These oxidation protection systems are currently being tested in waste incineration plants.

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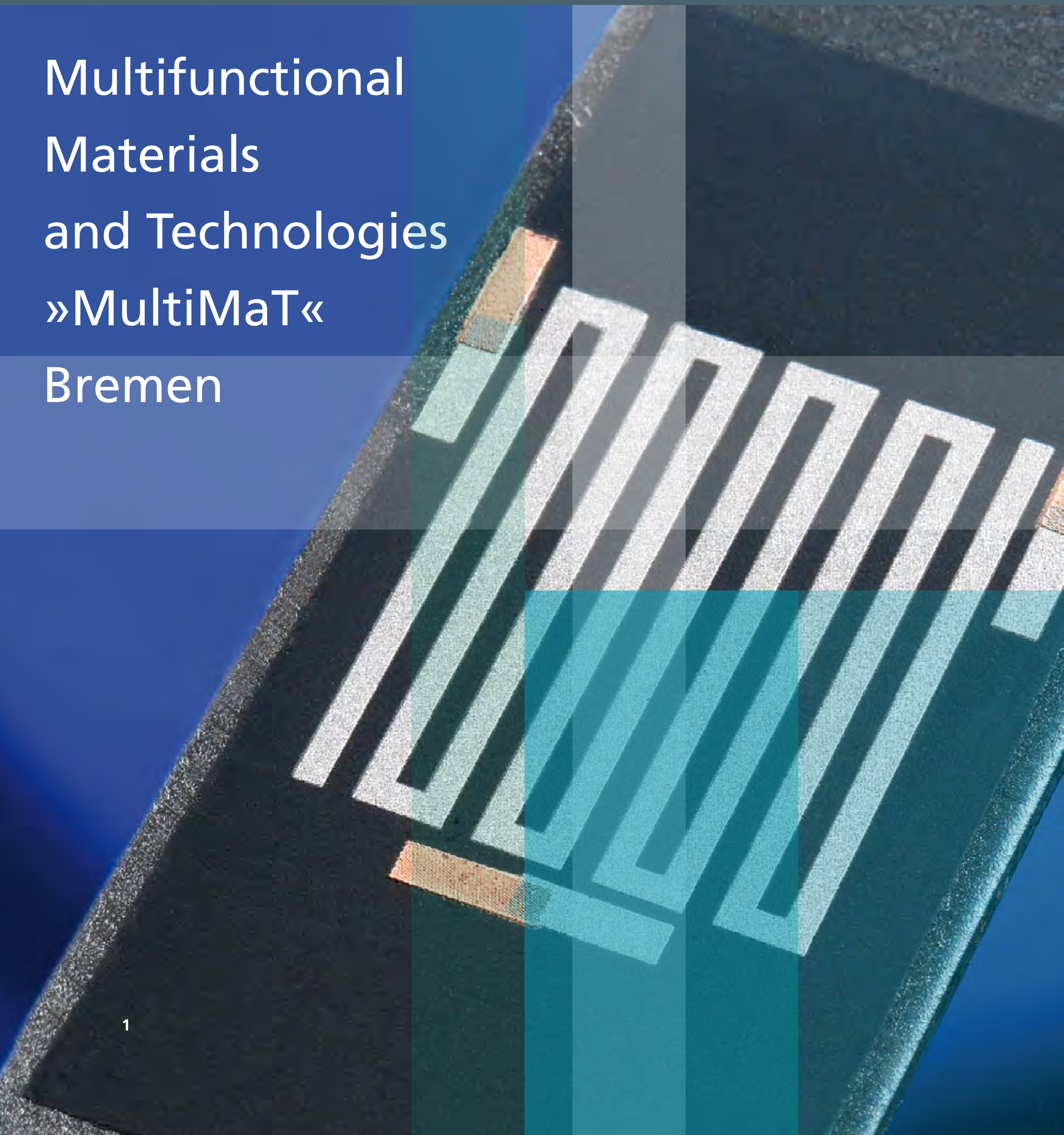
9 *Holders for SiC cladding in combustion vessels for waste power stations: Al-oxide filled SiCN layer, Zr-oxide filled SiCN layer, unfilled SiCN (from left to right).*

Multifunctional Materials and Technologies »MultiMaT« Bremen



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MultiMaT Innovationscluster

BREMEN INNOVATION CLUSTER: MULTIFUNCTIONAL MATERIALS AND TECHNOLOGIES "MULTIMAT"

For four years now, economy and sciences of the Metropolitan Region Bremen/Oldenburg have been co-operating in the innovation cluster "MultiMaT", jointly developing material solutions for the key branches automotives, wind energy, and aerospace. An excellent network has been formed in this period and the research results from the innovation cluster establish the base for further interesting innovations. "MultiMaT" is funded by the Free Hanseatic City of Bremen from the European Fund for Regional Development (EFRE), the Fraunhofer-Gesellschaft, and an industry consortium.

The Bremen innovation cluster "MultiMaT"

Bremen is an industrial location characterized by important industries such as aircraft construction, aerospace, the automotive industry, shipbuilding, logistics, wind energy plant construction, and maritime technologies. Constant innovations in material technologies are an essential requirement for these companies and their medium to long-term international competitiveness; particularly for the suppliers and service companies that depend on high-technology companies. In order to maintain and build on a competitive advantage, it is necessary to develop, under constant time pressure, technological and structural gains as unique selling points that differentiate the company from its competitors. These companies therefore require very efficient and innovative infrastructures of supply, research, development, and services which they can rapidly and flexibly access at all times. Well over 40 partners have joined this cluster. Topics covered in the pilot projects included: sensors for use in the offshore sector, miniaturized sensors and sensor integration, long-life functional surfaces and joining of fiber compound structures. Numerous other bilateral projects from these areas were also discussed.

The cluster is formed of a closely-knit core of 25 full members from research and industry, who actively work on scientific issues in the topic areas of the five pilot projects. There is also another broader circle of so-called associated members who are not currently active participants in the project work, but who are regularly informed about the cluster's activities and are included in its networking.

1 *Screen-printed thermocouple.*

Structure	Contents	Results	Effect
Free Hanseatic City of Bremen Finances	**Basic research**	**Open exchange** For full members and associated members Workshops Project meetings Publications Reports	**Accelerates innovation processes** Cooperation in the cluster Cross-sectional know-how Networking - New partnerships - New business relationships Simplified access to R&D services
Fraunhofer-Gesellschaft Finances	**Methods and process development**		
Industry Finances	**Specific application-related developments**	**Product-related implementation** For full members	**Competitive advantages** New/improved products Patents/licenses

Tab. 1: Structure of the innovation cluster "MultiMaT".

Highlights from the "MultiMaT" pilot projects

Effective anti-ice coating for rocket launcher systems

A study was carried out within the framework of the "MultiMaT" project in close cooperation between Fraunhofer IFAM, EADS/Astrium and the Center of Applied Space Technology and Microgravity (ZARM), looking at the problem of ice on Ariane carrier rockets. During the first step of this cooperation, an expert report was drawn up in which possible technologies for anti-ice coatings for rocket launcher systems were investigated. An overview was thus obtained of the available anti-ice coatings suitable for this specific problem. During initial icing tests, the most promising materials were examined with regards to their anti-ice effect and ice-adhesion behavior. It was shown that no commercially available coatings could meet the tough requirements of these tests.

Based on these results, an innovative model coating material was developed at Fraunhofer IFAM, which showed excellent results in the ZARM icing tests. The temporary coating enabled significantly lower ice adhesion and reduced ice formation. In further tests, simulating the start phase of the Ariane system, the ice proved easy to remove.

Materials testing at sea

Wind energy plants at offshore locations differ from onshore plants in numerous technical details. The external walls of the tower, nacelle, and rotor blades are protected with special coatings against the high salt content in the air and water, while electrical contacts and mechanical components also need special protection. The application or use of the correct materials, techniques and procedures during maintenance and servicing can mean significant savings.

If materials are to be used for the first time in an offshore area, it is necessary to retest service life and fatigue at the application site. The combination of factors at sea results in a load spectrum which will be simulated in future through a combination of investigations, both at sea and in laboratory conditions. However, the specific loads vary from location to location. The field tests will therefore need to cover a wide range of possible application locations, each with a different specific loading potential.

The scientists at Fraunhofer IWES used four offshore locations: Helgoland Westmole (breakwater west),"Alte Weser" lighthouse, Hörnum on the island of Sylt, and the Jade in

2 *Ariane 5 rocket being launched (© ESA-CNES-ARIANESPACE/ Optique Vidéo du CSG).*

3 *Attachment of sensor samples on an offshore location (© Fraunhofer IWES).*

Wilhelmshaven. In December 2008, over 30 steel sheets with various sensor samples were placed in the so-called "changing water zone" (tidal zone) by Helgoland. They were collected at least twice a year and checked for damage in the laboratory. A real-time measurement system was installed on the Westmole breakwater, using a UMTS connection to monitor some of the sensors for function and for any deviations from expected operating behavior.

New generation of thin-layer solar cells for transparent roof and facade structures

Together with the company Vector Foiltec GmbH, Fraunhofer IFAM has developed flexible solar cells that can be applied, for example, to plastic films made of the high-tech material ETFE (ethylene tetrafluoroethylene). The basis for this innovative approach is a novel semi-conductor material developed by the University of Oldenburg: it does not contain any indium, a very expensive but much-used raw material, and it also promises high solar cell efficiency.

Vector Foiltec GmbH, Fraunhofer IFAM, and the University of Oldenburg are working hand-in-hand within the innovation cluster "MultiMaT" to jointly develop this material and produce new thin-layer solar cells. The company Vector Foiltec GmbH is counting on a number of advantages of these new thin-layer solar cells, particularly the possibility to replace passive-printed cells, which are currently applied to films to shade interiors, with active structures that can process solar energy.

The University of Oldenburg, working as part of "MultiMaT", has already developed an innovative semi-conductor material which has been successfully processed to create the first solar cells. Three partner organizations are currently working cooperatively to further advance its performance capability, by specifically tailoring it to the requirements of Vector Foiltec GmbH. The aim of this group cooperation is to find solutions enabling the integration of thin-layer solar cells in attractive and sustainable film architecture structures which can then be used over large-scale areas on various buildings.

Quality-assured adhesive bonding of CFRP components

The aim of the "Joining of fiber reinforced structures" project was the development of essential material and production engineering principles, required for the introduction of a consistent process chain for the automatic and quality-assuring long-life adhesive bonding of CFRP components (carbon fiber reinforced plastic). Here, a fundamental understanding of the adhesion mechanisms prevalent in these adhesive bonds could be developed, together with measures for specific control or optimization. Ambient conditions during the application of paste-like two-component epoxy adhesives play a particular role in determining the quality and long-term stability of the resulting CFRP adhesive bond.

The surface condition of the CFRP component before application of the adhesive proved to be another key factor in ensuring the high strength of CFRP adhesive bonds.

Manufacturing-based contamination of CFRP surfaces by production process materials, such as release agents, lead to a failure of the adhesive bond if surface pretreatment is not adequate. It is therefore necessary to either select suitable release agents during the production of the CFRP components, or to combine surface treatment methods so that the release agents are thoroughly removed.

The surface condition is monitored by means of an aerosol wetting test, which characterizes the wetting properties of

4 *Facade: "Eden Project" in Cornwall, GB (© Vector Foiltec GmbH).*

5 *National Swimming Center, Peking (© Vector Foiltec GmbH).*

the component surfaces in the production line. This method was developed at Fraunhofer IFAM in cooperation with the company OptoPrecision. It was then further developed and evaluated within the "MultiMaT" innovation cluster.

Conclusion

Both with regards to the contextual implementation of scientific results and the level of networking between business and science, the cluster has been a success for the Metropolitan Region Bremen/Oldenburg and for all participating partners. The network will continue to exist past the funding period.

Project funding

Supported by the Free Hanseatic City of Bremen from the European Fund for Regional Development (EFRE), the Fraunhofer-Gesellschaft, and an industry consortium.
Funding period: Jan. 1, 2008–Dec. 31, 2011

Freie Hansestadt Bremen

EUROPÄISCHE UNION:
Investition in Ihre Zukunft
Europäischer Fonds für regionale Entwicklung

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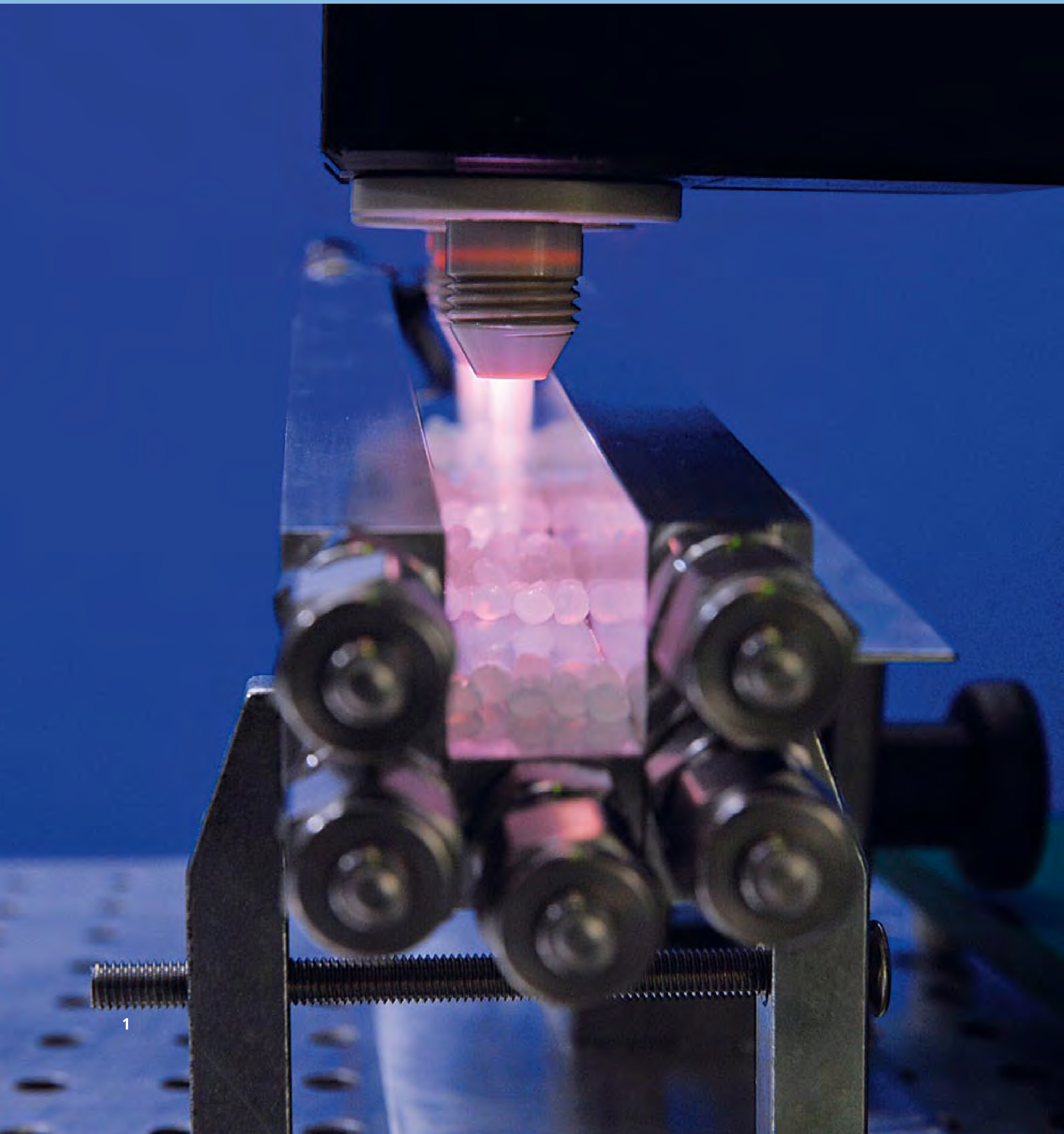
6 *Investigation into the wetting properties of surfaces using aerosol wetting test.*

ADHESIVE BONDING TECHNOLOGY AND SURFACES



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EXPERTISE AND KNOW-HOW

The Division of Adhesive Bonding Technology and Surfaces at Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM is the largest independent research institution in Europe working in the area of industrial adhesive bonding technology and has about 300 employees. The R&D activities focus on adhesive bonding technology, surface technology, and fiber composite technology. The objective is to supply industry with application-oriented system solutions.

Multifunctional products, lightweight design, and miniaturization – achieved via the intelligent combination of materials and joining techniques – are opening up new opportunities which are being exploited by the Division of Adhesive Bonding Technology and Surfaces. The activities range from fundamental research through production right up to the market introduction of new products. Industrial applications are mainly found in car, rail vehicle, ship and aircraft manufacture, plant construction, energy technology, construction industry, the packaging sector, textile industry, electronics industry, microsystem engineering, and medical technology.

The work in the Adhesive Bonding Technology focus area involves the development and characterization of adhesives and matrix resins for fiber composites, the design and simulation of bonded, riveted, and hybrid joints, as well as the characterization, testing, and qualification of such joints. Planning and automation of industrial adhesive bonding processes are also undertaken. Other key activities are process reviews and providing certifying training courses in adhesive bonding technology and fiber composite technology.

The work in the Surface Technology focus area is subdivided into plasma technology, paint/lacquer technology, as well as Adhesion and Interface Research. Customized surface modifications – for example surface pre-treatment and functional coatings – considerably expand the industrial uses of many materials and in some cases are vital for the use of those materials. The focus here is on, amongst other things, the optimization of the long-term stability of bonded joints and coatings, including early detection of degradation and corrosion phenomena, the validation of aging tests, and inline surface monitoring. The research results in the area of aging and surface pre-treatment provide important fundamental knowledge for both adhesive bonding and coating technology, and so contribute to the safety and reliability of bonded joints and coatings.

The Fraunhofer Project Group Joining and Assembly FFM at Forschungszentrum CFK Nord (Research Center CFRP North) in Stade, which is part of the Fraunhofer IFAM, is carrying out ground-breaking work on large fiber reinforced plastic structures (FRPs; such as carbon fiber reinforced plastics – CFRPs –, and glass fiber reinforced plastics – GFRPs). The Fraunhofer FFM is able to join, assemble, process, repair, and carry out non-destructive tests on large 1:1 scale FRP structures, thus closing the gap between the laboratory/small pilot-plant scale and industrial scale in the area of FRP technology.

The core expertise from the focus areas adhesive bonding technology, plasma technology, paint/lacquer technology,

1 *Atmospheric pressure plasma treatment of temperature-sensitive bulk goods (e. g. small plastic parts, seed).*

2 *Casting an electronic component.*

adhesion and interface research, as well as of Fraunhofer FFM mentioned above is utilized for the R&D activities on fiber composite technology. The intensive work in this area covers matrix resin development, fiber-matrix adhesion, the processing of FRPs, and new production methods for manufacturing FRPs. The sizing of joints, process development and the automated assembly of large FRP structures complete the portfolio in this area.

The entire Division of Adhesive Bonding Technology and Surfaces is certified according to DIN EN ISO 9001. The laboratories for materials testing, corrosion testing, and paint/lacquer technology are further accredited in accordance with DIN EN ISO/IEC 17025. The Center for Adhesive Bonding Technology has an international reputation for its training courses in adhesive bonding technology and is accredited via DVS-PersZert® in accordance with DIN EN ISO/IEC 17024. It is accredited in accordance with the German quality standard for further training, AZWV. The Plastics Competence Center is also accredited in accordance with AZWV and meets the quality requirements of DIN EN ISO/IEC 17024. The Certification Body for the Manufacture of Adhesive Bonds on Rail Vehicles and Parts of Rail Vehicles is accredited by the Federal Railway Authority (FRA; Eisenbahn-Bundesamt) in accordance with DIN 6701-2 and following DIN EN ISO/IEC 17021.

Perspectives

Industry puts high demands on process reliability when introducing new technologies and modifying existing technologies. These demands are the benchmark for the R&D activities in the Divison of Adhesive Bonding Technology and Surfaces. Working with customers, Fraunhofer IFAM develops innovative products which are later successfully introduced into the marketplace by the companies.

Manufacturing technologies are playing an ever more important role here, because high product quality and the reproducibility of production processes are key requirements for success in the marketplace.

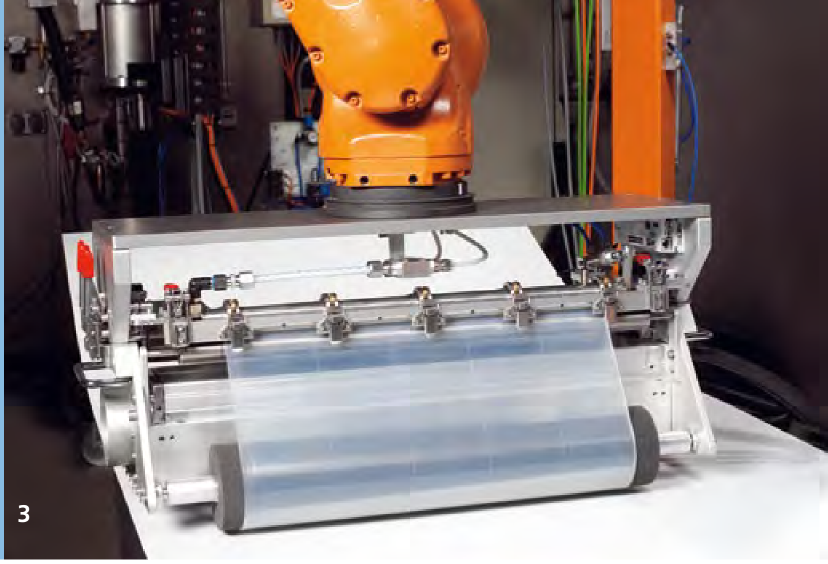
Adhesive bonding technology has been used in vehicle construction for a long time, its potential has, however, not yet been fully utilized. Lightweight construction for vehicles as a means of saving resources, adhesive bonding in medicine and medical technology, as well as the use of nanoscale materials in the development of adhesives are just a few examples of the broad activities of the institute.

In order to interest more sectors of industry in adhesive bonding technology, the motto for all the institute’s activities is: Make the bonding process and the bonded product more reliable! This objective can only be achieved if all the steps in the bonding process chain are considered as an integral whole.

These include:

- Application-specific adhesive selection and qualification, and if necessary modification
- Design and dimensioning of structures using numerical methods (e. g. FEM)
- Surface pre-treatment and development of corrosion-protection concepts
- Development of adhesive bonding process steps via simulation and integration into production processes
- Selection and dimensioning of application units
- Training courses in adhesive bonding technology for all staff involved in the development and manufacture of bonded products, as well as training courses in fiber composite technology for production staff

In all areas Fraunhofer IFAM is making increasing use of computer-aided methods, for example the numerical description of flow processes in dosing pumps/valves, multiscale simulation of the dynamics at a molecular level, and macroscopic finite element methods for the numerical description of materials and components.



A variety of spectroscopic, microscopic, and electrochemical methods are used in order to give insight into the processes involved in the degradation and corrosion of composite materials. Using these "instrumental methods" and the accompanying simulations, Fraunhofer IFAM acquires information which empirical test methods based on standardized aging and corrosion procedures cannot provide.

Other key questions for the future include the following: Where and how is adhesive bonding accomplished in nature? What can we learn from nature for industrial adhesive bonding technology? The experts are already studying how bio-adhesion at a molecular level can be utilized to make medical adhesives with protein components.

However, the requirement to make processes and products more reliable is not only limited to adhesive bonding technology. It also applies to plasma and paint/lacquer technology.

Industries with very stringent requirements on surface technology make use of the in-depth expertise and technological know-how of Fraunhofer IFAM. Notable customers include leading companies particularly in the aircraft and car manufacturing sectors.

Key activities

- Formulation and testing of new polymers for adhesives, laminating/cast resins, including industrial implementation
- Development of additives (nanofillers, initiators, etc.) for adhesives
- Synthesis of polymers with a superstructure and biopolymers
- Computer-aided material development using quantum-mechanical and molecular-mechanical methods
- Development and qualification of adhesive bonding production processes
- Development of innovative joining concepts, e.g. for aircraft and car manufacture (bonding, hybrid joints)
- Application of adhesives/sealants, casting compounds (mixing, dosing, application)
- Bonding in microproduction (e.g. electronics, optics, adaptronics)
- Computer-aided production planning
- Economic aspects of bonding/hybrid joining technology
- Design of bonded structures (simulation of the mechanical behavior of bonded joints and components using finite element methods, prototype construction)
- Development of industrially viable and environmentally compatible pre-treatment methods for the bonding and coating of plastics and metals
- Functional coatings using plasma and combined methods
- Testing and qualification of coating materials, raw materials, and lacquering methods
- Development of functional paints/lacquers for special applications
- Development of special test methods (e.g. formation and adhesion of ice on anti-icing coatings)

3 *The riblet coating system developed by Fraunhofer IFAM: The coating, which reduces drag, is applied automatically to a component using a roller applicator.*

- Parameter determination, fatigue strength, and alternating fatigue strength of bonded and hybrid joints
- Material models for adhesives and polymers (quasi-static and crash states)
- Evaluation of aging and degradation processes in composite materials
- Electrochemical analysis
- Evaluation and development of new anti-corrosion systems
- Analysis of development and production processes involving adhesive bonding
- Quality assurance concepts for adhesive and lacquer/paint applications via in-line analysis of component surfaces
- National and international training courses for European Adhesive Bonder – EAB, European Adhesive Specialist – EAS, and European Adhesive Engineer – EAE
- Training courses for Fiber Reinforced Plastic Technician and Fiber Reinforced Plastic Remanufacturer

FIELDS OF ACTIVITY AND CONTACTS

Institute Director

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Adhesive Bonding Technology

Dipl.-Ing. Manfred Peschka MBA
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Production planning; dosing and application technology; automation; hybrid joining; production of prototypes; selection, characterization, and qualification of adhesives, sealants, and coatings; damage analysis; electrically/optically conductive contacts; adaptive microsystems; dosing ultra small quantities; properties of polymers in thin films; production concepts.

- Microsystem engineering and medical technology
- Adhesives and analysis
- Process development and simulation
- Application methods

Plasma Technology and Surfaces PLATO

Dr. Ralph Wilken
Phone +49 421 2246-448
ralph.wilken@ifam.fraunhofer.de

Surface modification (cleaning and activation for bonding, printing, painting/lacquering etc.) and functional coatings (e. g. adhesion promotion, release coatings, easy-to-clean coatings, corrosion protection, permeation barriers, abrasion protection, friction reduction, antimicrobial effect) for 3D components, bulk products, web materials; plant concepts and pilot plant construction.

- Atmospheric pressure plasma technology
- Low pressure plasma technology
- VUV excimer technology
- New surface technologies
- Plant technology/Plant construction

Adhesives and Polymer Chemistry

Priv.-Doz. Dr. Andreas Hartwig
Phone +49 421 2246-470
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Development and characterization of polymers; nanocomposites; formulation of adhesives, matrix resins, and functional polymers; pre-applicable adhesives; conducting adhesives; improvement of long-term stability; bonding without pretreatment (polyolefins, light metals, oil-containing sheets with 2-C systems, thermoplastic composites); photocuring; curing at low temperature, but with longer open time; curing on demand; rapid curing; pressure-sensitive adhesives; casting compounds; selection and qualification of adhesives; failure analysis; adhesives based on natural raw materials; peptide-polymer hybrids; bonding in medicine; biofunctionalized and biofunctional surfaces.

- Adhesive formulation
- Composite materials
- Bio-inspired materials

Paint/Lacquer Technology

Dr. Volkmar Stenzel
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Development of functional coatings, e. g. anti-icing paints, anti-fouling systems, dirt-repellant systems, self-healing protective coatings, low-drag coatings; formulation optimization (wet and powder coatings); raw material testing; development of guide formulations; characterization and qualification of paint/lacquer systems as well as raw materials; release of products; color management; optimization of coating plants; qualification of coating plants (pre-treatment, application, drying); damage analysis; application-related method development; accredited Paint/Lacquer Technology Testing Laboratory.

- Development of coating materials and functional coatings
- Application technology and process engineering

Adhesion and Interface Research

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Analysis and development of interface-determining processes, technologies, and materials; surface, interface, and film analysis; damage analysis; quality assurance via in-line analyses of component surfaces; customer-specific development of concepts for adhesive, paint/lacquer and surface applications; corrosion protection concepts for metals; wet-chemical and electrochemical surface pre-treatment techniques; analysis of adhesion and degradation mechanisms; analysis of reactive interactions at material surfaces; modeling the molecular mechanisms of adhesion and degradation phenomena; structure formation at interfaces; concentration and transport processes in adhesives and coatings; accredited Corrosion Testing Laboratory.

- Surface and nanostructure analysis
- Applied Computational Chemistry
- Electrochemistry/Corrosion protection
- Quality assurance of surfaces

Materials Science and Mechanical Engineering

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Testing materials and components; crash and fatigue behavior of bolted and bonded joints; fiber composite components; lightweight and hybrid constructions; design and dimensioning of bonded joints; qualification of mechanical fasteners; optimization of mechanical joining processes; design and dimensioning of bolted joints; accredited Materials Testing Laboratory.

- Structural calculations and numerical simulation
- Mechanical joining technology

Workforce Training and Technology Transfer

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www.bremen-plastics.com

Training courses for European Adhesive Bonder (EAB), European Adhesive Specialist (EAS), and European Adhesive Engineer (EAE) with Europe-wide certification via DVS®/EWF; in-house courses; consultancy; qualification of production processes; studies; health, work safety, and environment; training courses for Fiber Reinforced Plastic Technician and Fiber Reinforced Plastic Remanufacturer.

- Center for Adhesive Bonding Technology
- Plastics Competence Center

Fraunhofer Project Group Joining and Assembly FFM

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Automated assembly of large fiber reinforced plastic (FRP) structures up to a 1:1 scale: adhesive bonding, combined adhesive bonding and bolting; adaptive precision machining; automated measuring and positioning processes; shape and positional correction of flexible large structures in assembly processes.

- Joining technologies
- Precision machining
- Assembly and plant technology
- Measurement technology and robotics

Technology Broker

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Certification Body of the Federal Railway Authority in accordance with DIN 6701-2

Dipl.-Ing. (FH) Andrea Paul
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Consultancy; testing and approval of rail vehicle manufacturing companies and their suppliers with regard to their ability to produce adhesive bonds in accordance with the requirements of DIN 6701.

Process Reviews

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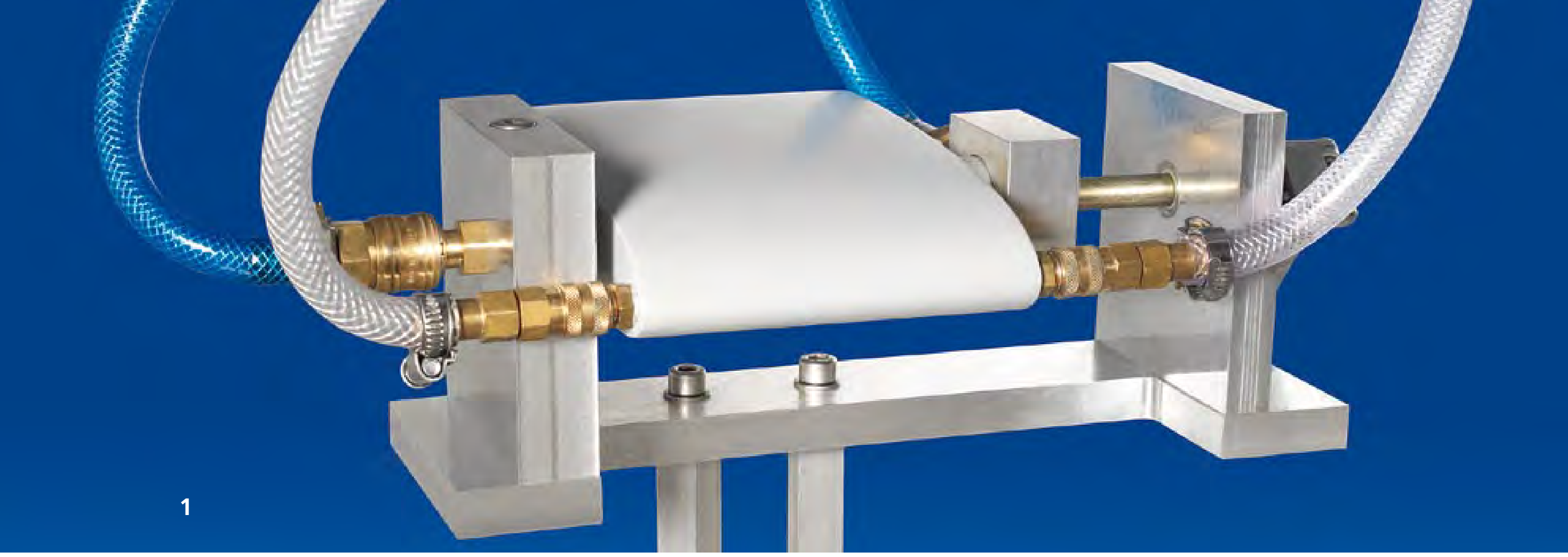
Analysis of development and/or production processes taking into account adhesive bonding aspects and DVS® 3310; processing steps and interfaces; design; products; proof of usage safety; documentation; production environments.



EQUIPMENT/FACILITIES

Adhesive Bonding Technology and Surfaces

- Low pressure plasma plants up to 3 m³ for 3D components, bulk products, and web materials (HF, MW)
- Atmospheric pressure plasma plants for 3D components and web materials
- Robot-controlled atmospheric pressure plasma plant (6-axis) for laminar and line treatment as well as coating
- VUV excimer plant for surface treatment and coating
- CO_2 snow jet units
- Mobile laser unit for surface pre-treatment
- Tribometer in combination with nanoindentation
- Laser scanner for 3D measurement of components up to 3500 mm
- Universal testing machines up to 400 kN
- Units for testing materials and components under high rates of loading and deformation under uniaxial and multiaxial stress conditions
- All-electric laboratory bolting machine with semi-automatic installation of one-piece and two-piece fasteners, C-frame construction with 1.5 m frame depth, maximum compressive force: 70 kN, drill spindle for speeds up to 18,000 rpm and internal lubrication as well as high speed workplace monitoring
- Laboratory vacuum press with PC control for manufacturing multilayer prototypes
- 200 kV FEG transmission electron microscope with EDX, EELS, EFTEM, as well as 3D tomography and cryo and heating options
- Focused Ion Beam (FIB) for in-situ preparation of cross-sections and TEM lamellae
- High resolution scanning electron microscope (HRSEM) with cryro-preparation chamber
- Inverse gas chromatography (IGC)
- Confocal laser microscope
- Laboratory galvanizing unit
- High-performance potentiostat, 30 V, 20 A
- High-performance potentiostat, 100 V, 20 A
- MultiEchem(TM) potentiostat system with 4 independent Reference 600 potentiostats
- Salt spray unit
- LIF (Laser Induced Fluorescence)
- Thermography
- XRF hand unit (x-ray fluorescence analysis)
- Surface analysis systems and polymer analysis using XPS, UPS, TOF-SIMS, AES, and AFM, contact angle
- Chromatography (GC-MS, headspace, thermal desorption, HPLC)
- Thermal analysis (DSC, modulated DSC, DMA, TMA, TGA, torsion pendulum)
- MALDI-TOF-MS for protein and polymer characterization
- Automatic equipment for peptide synthesis
- Light scattering for characterizing turbid dispersions
- Spectroscopic ellipsometer
- Laser induced Breakdown Spectroscopy (LIBS)
- Small-scale pilot plant for organic syntheses
- IR, Raman and UV-VIS spectrometers
- IR-VCD spectrometer (Infrared Vibrational Dichroism)
- Rheology (Rheolyst AR 1000 N, ARES – Advanced Rheometric Expansion System)
- Equipment for measuring heat conductivity
- Dielectrometer
- Electrochemical impedance spectroscopy (EIS) and noise analysis (ENA)
- Twin-screw extruder (25/48D) and kneader for incorporating fillers into polymers
- Single-screw extruder (19/25D) for characterizing the processing properties of polymer composites
- 12-axis robot for manufacturing micro bonded joints
- 2 Linux PC cluster with 176 CPUs

1 *Test device developed at Fraunhofer IFAM for carrying out the runback ice test on wing profile.*

- Various dispersion units
- Automatic paint application equipment
- Fully conditioned spraying booth
- Paint dryer with moisture-free air
- UV curing technology
- Powder coating extruder
- Grinding technology for powder coating manufacture
- Mechanical-technological tests
- Color measurement unit MA 68 II
- Optical testing technology
- Test equipment for anti-icing paints
- Wave tank simulation chamber
- Test loop for measuring the loads on paints
- Miniature test loop for measuring the loads on paints
- Outdoor weathering at various locations
- Scanning Kelvin probe
- Coating pilot plant (Coatema Deskcoater)
- 6-axis industrial robot, 125 kg bearing load, on additional linear axis, 3000 mm
- 1-C piston dosing system SCA SYS 3000/SYS 300 Air
- 1-C/2-C geared dosing system t-s-i, can be adapted to eccentric screw pumps
- Freely configurable 1-C/2-C dosing technology, adaptable to specific tasks, with comprehensive measurement technology (own development)
- Phased-array ultrasound measuring device Olympus OmniScan MX PA
- Fluorescence microscope
- Rheometer Bohlin Gemini 200
- Climate test chambers for standard and special tests
- Hall for large structure assembly, 80 × 50 m², two 20 metric ton cranes, 15 m height under crane hooks
- Modular flexible assembly plant for large CFRP structures with two precisely calibrated 6-axis robots on a 15 m linear axis and automated tool change
- Test stand for regulating the shape and position of large components; it comprises 6 industrial robots with parallel kinematics and a precisely calibrated 6-axis robot on a 4 m linear axis
- Combined laser-scanner and laser-tracker for 3D measurement of components of length up to 30 m
- Laser-tracker for 3D measurements, range 80 m
- Laser-radar for 3D measurement of components, range 30 m
- Modular 3D water jet cutting plant, 6000 bar, with laser positioning and drilling unit

Certification and Accreditation

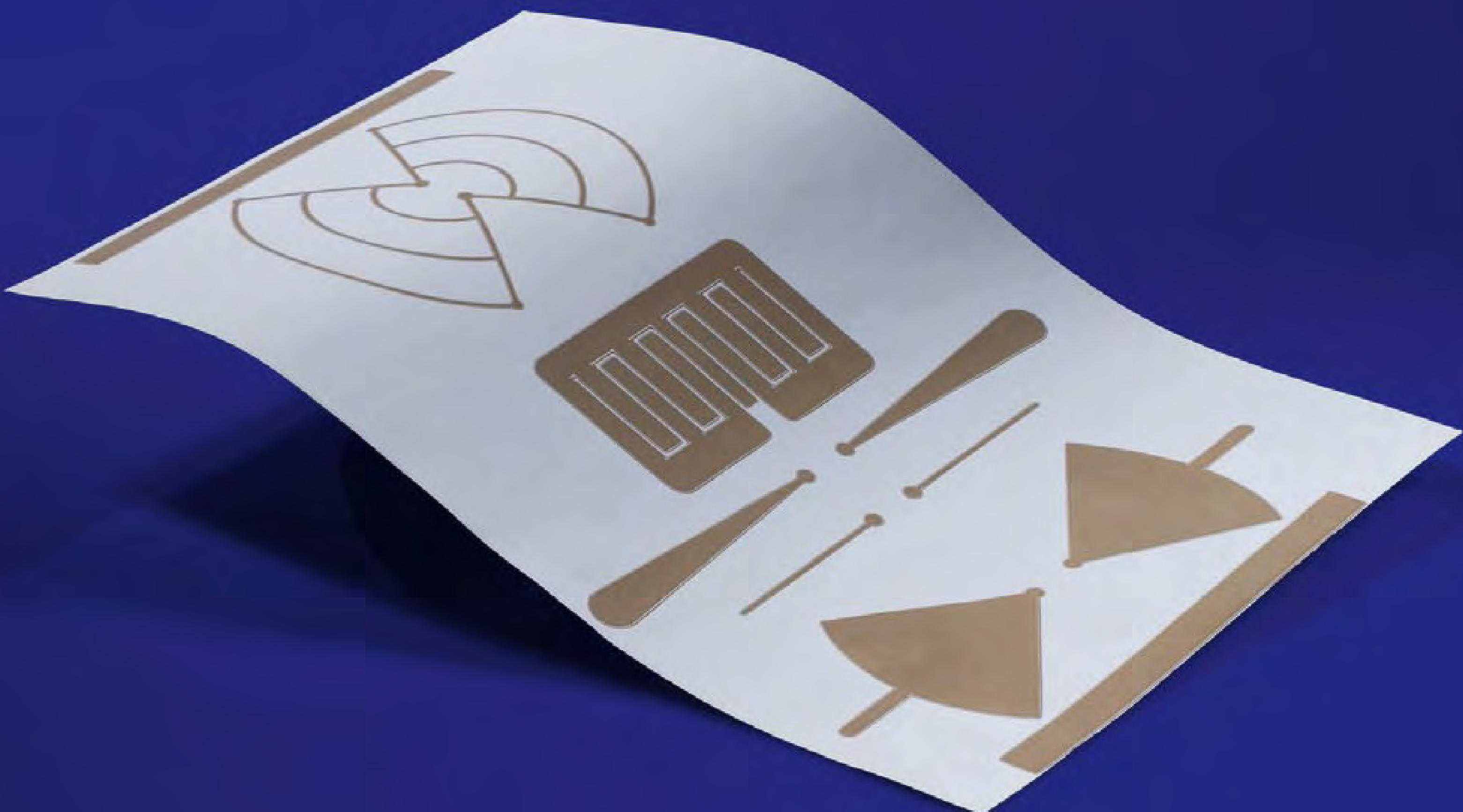
- The entire Division of Adhesive Bonding Technology and Surfaces is certified according to DIN EN ISO 9001. The laboratories for materials testing, corrosion testing, and paint/lacquer technology are further accredited in accordance with DIN EN ISO/IEC 17025.
- The Center for Adhesive Bonding Technology has an international reputation for its training courses in adhesive bonding technology and is accredited via DVS-PersZert® in accordance with DIN EN ISO/IEC 17024. It is accredited in accordance with the German quality standard for further training, AZWV.
- The Plastics Competence Center is also accredited in accordance with AZWV and meets the quality requirements of DIN EN ISO/IEC 17024.
- The Certification Body for the Manufacture of Adhesive Bonds on Rail Vehicles and Parts of Rail Vehicles is accredited by the Federal Railway Authority (FRA; Eisenbahn-Bundesamt) in accordance with DIN 6701-2 and following DIN EN ISO/IEC 17021.

2 *System with 4 potentiostats for electrochemical characterization of coatings and bonded joints.*

3 *Tailor-made electrically conductive adhesive formulations for various manufacturing processes and requirements, such as flexographic and offset printing.*

ADHESIVE BONDING TECHNOLOGY AND SURFACES

RESULTS FROM RESEARCH AND DEVELOPMENT



FASTER, LOWER COSTS, AND IMPROVED QUALITY: FRAUNHOFER IFAM ACCELERATES INDUSTRIAL PROCESSES

The Dubai Airshow in November 2011 was hugely successful for Airbus, the European aircraft manufacturer. The Airbus representatives were able to fill up their order books, with 175 new orders alone for the environmentally friendly A320neo model. This good news for the company also brings problems: Customers expect fast delivery and high demand stretches production to its limits. Up until now the aim of Airbus was to build 42 A320 aircraft per month up to the end of 2012. This plan has now to be revised in the light of the Dubai orders: John Leahy, Chief Operating Officer-Customers at Airbus, spoke of 50 aircraft per month now having to be produced.

Examples such as this from the aviation industry are also encountered in many other sectors of industry. When the general economic situation is favorable, companies receive lots of orders. This then stretches their production, with additional production capacity not possible to realize at short notice. Germany is a producer of many high-tech products, whilst mass-produced goods are today often made in countries that have lower labor costs. Additional investment in new production facilities is only undertaken cautiously: Facilities that are in full use one day can quickly fall into disuse if there is a recession and this can be a financial drain on the company. The solution for many companies is “process acceleration”: Optimally harmonized materials and processing steps, an increased degree of automation, rising reproducibility, and improved quality monitoring – even during the production. Such approaches often allow manufacturers to quickly achieve significant gains in efficiency and profitability.

Accelerated processes also allow the problem of order surges, such as described at the beginning of this article, to be overcome. The Division of Adhesive Bonding Technology and Surfaces at Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM is the ideal partner here: The scientific work areas in this division have many years of experience working with industrial companies to optimize and accelerate production processes and getting excellent results. This may, for example, concern optimizing the use of adhesive bonding technology, new paint/lacquers and paint/lacquer methods, surface pre-treatment and coating, or the automation of processing and assembly steps. The Fraunhofer IFAM, Europe’s largest independent R&D organization in the area of adhesive bonding technology, offers industry solutions for making production processes faster, more efficient, and cheaper – usually also with improved quality and higher reliability of production.

1 *Airbus A350 XWB (Xtra Wide Body; Source: AIRBUS S.A.S. 2010 – Computer Rendering by FIXON – GWLNSD).*

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3

Joining and assembly: Previously manual tasks, today automated

In the area of machining, processing, joining, and assembly, the Fraunhofer IFAM has been involved in many successful projects concerned with replacing manual steps with automated processes. Nowadays robots and machines are often used for work which was previously carried out by people, such as complex surface pre-treatment, quality monitoring, adhesive application, drilling, milling, and joining. The robots and machines carry out the work 24/7 and their efficiency and precision are often far superior to what people could achieve. An example from the aircraft manufacturing industry is used to highlight the potential acceleration of production that could be achieved in the future via automation. That industry is using more carbon fiber reinforced plastics (CFRPs) than ever before, as evidenced by the new A350 XWB (Xtra Wide Body; Fig. 1).

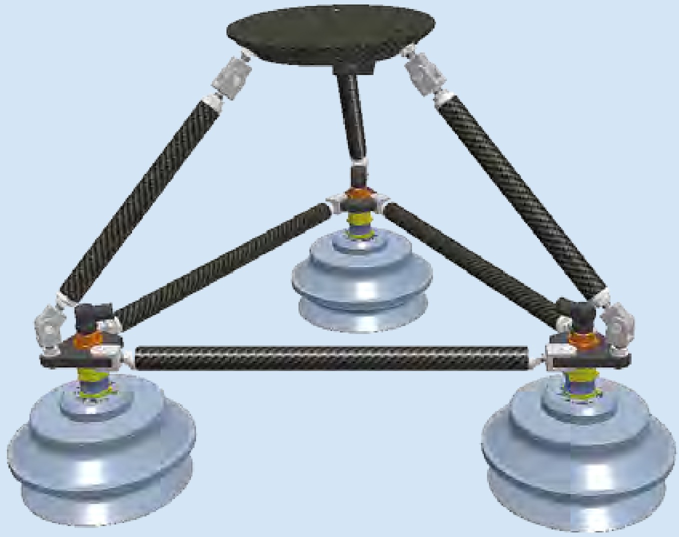
Joining two load-transmitting CFRP components has up until now been undertaken using traditional rivets. The adhesive here only acts as a shim. The shim material fills the space between the components. As these are irregular and as no more shim material than absolutely necessary must be used for reasons of weight, the current shim process involving in some cases several manual measurement and adjustment steps is extremely demanding on time and resources. In Bremen and in the research center CFK Nord (CFRP North) in Stade, a novel gap filling method has been developed by the experts of Fraunhofer IFAM in collaboration with aircraft manufacturers. This method can measure large components using advanced laser technology so accurately that the 3D gap geometry is known to fractions of a millimeter prior to joining and in addition deformation due to the joining pressure can be taken into account. The advantage: The shim material can be applied with perfect fit in an automated process. The result is an enormous acceleration of the production process (Fig. 2).

The use of laser measurement methods also allows manual, tactile steps to be replaced in other processes. For drilling, milling, and joining large structures, self-orienting robot systems now have an accuracy equal or superior to that of conventional manual processes (Fig. 3). The unavoidable shape deviations of large components are a special challenge. These deviations do not allow the robots to be programmed for fixed machining paths, as is the practice, – for example, in the car manufacturing industry. Contactless measurement methods and monitoring by optical, force, and torque sensors nowadays even allow large flexible components to be correctly and quickly positioned and formed, whereas previously this required a complex, manual step-by-step approach. Processes which hitherto have been carried out in sequence can now be undertaken in parallel, for example using several robots to simultaneously carry out different processing steps at the same workplace, such as surface pre-treatment of one component and joining of the other components.

The Fraunhofer IFAM has in-depth expertise developing such automated process steps. In the area of machining and robotics there is close collaboration with the Institute for Production Management and Technology IPMT of the Technical University of Hamburg-Harburg. The experts of Fraunhofer IFAM work continuously on developing processes for faster curing of adhesives and shims. More rapid curing means that there is no need to use the fixation aids that are necessary when curing is slower. This cuts out a whole manual work step, so benefiting the speed of the process.

2 *Automated adhesive bonding of a frame onto a CFRP aircraft fuselage.*

3 *Automated high-precision milling of the window opening on a CFRP aircraft fuselage.*



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At a different level, more flexible design of production plants also allows acceleration of processes. The Fraunhofer IFAM is working, for example, on solutions for using production plants for a diverse range of component geometries. This will avoid the time-consuming and costly refitting or even new installation of production lines when there is a change of product model, as it happened a lot in the past. Modern sensors and actuators make it possible for machine-driven manipulating arms or robots with their tools to be reprogrammed for other tasks and different geometries, materials, and processing steps. With the focus on aircraft manufacture, the Fraunhofer Project Group Joining and Assembly FFM of the Fraunhofer IFAM at CFK Nord in Stade has, for example, developed a carbon fiber reinforced plastic manipulator that can readily hold or pick up aircraft components having different geometries (Fig. 4). It adapts to the various fuselage of differing curvature that are used to build an aircraft. This is achieved by using movable suction cups arranged on a lightweight frame girder structure.

Surface pre-treatment:
In-line processes with multiple applications

Fraunhofer IFAM is also developing surface pre-treatment steps which make processes faster and less complex. This has mainly been achieved by carrying out the pre-treatment steps during the actual production process, and not separately as previously. In many industries, for example the aircraft manufacturing industry, materials and components often have to be cleaned using complex manual procedures and then pre-treated prior to bonding or paint/lacquering, before finally being transferred to the actual production process. The goal for competitive and economical processes must, however, be to directly integrate the pre-treatment steps into process lines using automatically controlled methods adapted to specific needs. If, for example, the substrate must be grit-blasted prior to bonding, then various techniques can be used to carry this out reliably and efficiently, even for mass production (see Page 84; "Cleaning and activation prior to painting/lacquering and bonding: Surfaces are the key issue for fiber composite materials").

Another example of the R&D activities of the experts of Plasma Technology and Surfaces – PLATO – at Fraunhofer IFAM involves so-called transfer films for manufacturing molded components. These are web materials that are inserted into molds and can adapt to the geometry of the mold. The web material not only has a "releasing" effect, which allows the component to be easily removed from the mold, it is simultaneously able to give the component surface other functions. For example, effective scratch protection can be provided by a plasma polymer transfer coating on the transfer film. Whereas the conventional process for an injection molded component

4 *Modular carbon fiber reinforced plastic lightweight structure manipulator which can pick up and manipulate aircraft components – developed by the Fraunhofer Project Group Joining and Assembly FFM.*

involves three steps – namely the molding of the component, the removal of release agent residues, and the application of a scratch protection coating – the process developed at Fraunhofer IFAM allows a component to be manufactured in a single step. Here, the film remains on the manufactured component for protection right to the end of the process or even up to delivery to the end customer, potentially saving further processing costs and work steps.

These "in-mold processes" can also be integrated with other functions, such as the lacquering/painting of CFRP components. The molded component is then completely finished when it comes out of the molding press because the desired lacquer/paint has been applied to the release layer in advance. The transfer films developed by the Fraunhofer IFAM can also prevent contamination of the manufactured components. The customer then simply removes the film prior to use. The films also prevent damage during further processing steps and therefore ensure high product quality (Fig. 5).

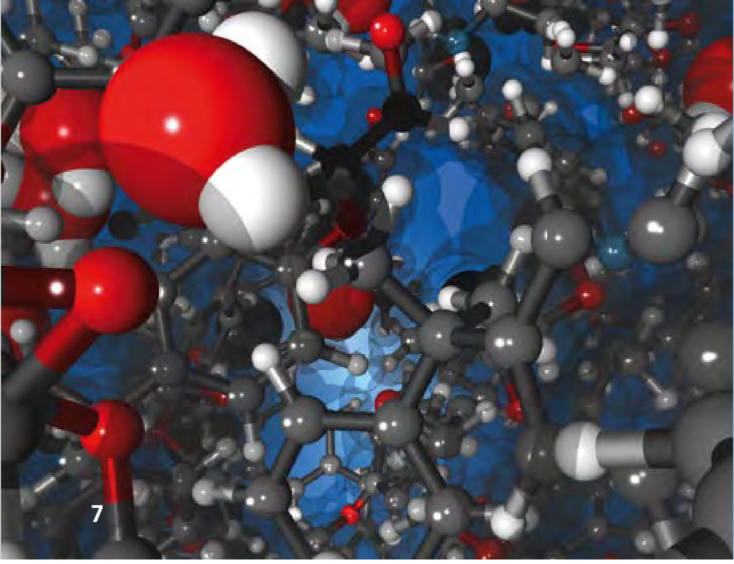
PLATO is also elaborating in-line plasma coating processes which allow targeted local coating using plasma nozzles (Fig. 6). These are being optimized for the needs of customers. A process was, for example, developed for a company in the automotive sector which allowed precise application of a corrosion protection coating on relevant areas of the servo gearboxes. At an interval of just a few seconds, one plasma nozzle cleans the material before another nozzle applies the protective coating. Just a few years ago, such a procedure would have required time-consuming wet-chemical treatment along with subsequent drying and expensive disposal of environmentally hazardous chemicals. Nowadays the procedure is carried out in a fraction of that time and with guaranteed quality, meaning not only that process costs are significantly reduced but also making Germany an increasingly attractive production location.

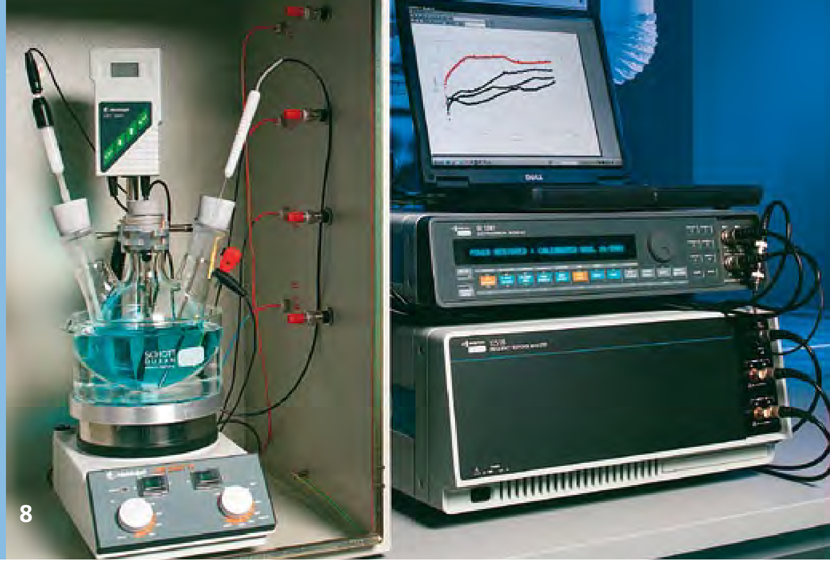
The Plato scientists have also undertaken similar development work on functional atmospheric pressure (AP) plasma coatings for the solar energy sector. These make the surfaces of the materials and components tougher and improve their aging properties, at the same time requiring less maintenance and prologing their functional effectiveness and service life. For solar modules this highly efficient coating reduces the corrosion and increases the service life by up to 20 percent. Compared to earlier methods that used low pressure (LP) plasma, coating at atmospheric pressure considerably accelerates the production. Also here, the coating can be applied fully automatically – and also selectively. The process can be readily integrated into existing production processes. This development is not restricted to solar modules. Indeed, all materials including metals, ceramics, glass, and polymers can be provided with AP plasma protective coatings. For this application with its high innovation potential Dr. Uwe Lommatzsch and Dr. Jörg Ihde of the Fraunhofer IFAM received the German High Tech Champions Award 2011 in the area of solar energy/photovoltaic technology (see page 108 – People and awards; "GHTC Award for Dr. Uwe Lommatzsch and Dr. Jörg Ihde in Boston for the plasma-polymer protection layer for solar modules").

PLATO has also developed a novel highly efficient process for pre-treating carbon nanotubes (CNTs), namely materials that have experienced a boom in industry in recent years. The plasma pre-treatment at atmospheric pressure takes just a few seconds, compared to the former wet-chemical pre-treatment in acids that took over 24 hours. This eco-friendly process has significantly improved the marketability of CNTs.

5 *Removal, transfer, and protection of molded components using Flex$^{Plas®}$ technology from the Fraunhofer IFAM.*

6 *Localized, suitable for in-line application, and environmentally friendly: Atmospheric pressure plasma coatings for adhesion promotion and corrosion protection.*





In the area of low pressure plasma coatings, the PLATO experts have also been successful in considerably accelerating the application of functional coatings. The lower time requirement for this means higher production rates and lower production costs. For example, anti-abrasion layers, which only have an effect for layer thicknesses greater than one micron, can be competitively applied at favorable cost.

Adhesion and interface research: Small dimensions, large effect

The scientists at Fraunhofer IFAM are not only involved in projects which accelerate the actual production processes – they also ensure that the development of new materials and components and even the "design" are undertaken in as short a time as possible. For example, the experts of Adhesion and Interface Research have built up in-depth expertise in recent years in the area of computer simulation. Simulation of the chemical properties or aging of materials helps, for example, to considerably shorten the traditionally employed empirical test procedures. Numerical simulation allows a great deal of information to be acquired in a short time for which, a few years ago, test methods with longer procedure were required (Fig. 7). Simulation cannot completely replace testing work, rather it helps to streamline development processes and so accelerate them. One example of experimental simulation is accelerated corrosion testing of more materials. Test methods are being developed at Fraunhofer IFAM which allow conclusions to be drawn about corrosion behavior within a few hours or days (Fig. 8). Conventional test methods require up to a few months for this. When developing new corrosion protection paints/lacquers, for example, this means an enormous time saving for companies.

Although companies strive to minimize elaboration times when changing products or models, increasing emphasis is being put on effective simulation. In the automobile industry, structures must nowadays be able to be readily simulated in order, for example, to demonstrate the crash behavior by computer simulation and so minimize the number of expensive "real" crash tests. The scientists of Materials Science and Mechanical Engineering at Fraunhofer IFAM are largely responsible for this simulation, whilst Adhesion and Interface Research experts are primarily involved with the technical effects of the material properties at the microscopic and molecular level.

Adhesion and Interface Research is also involved with developments to accelerate production processes. One example is the development of chromate-free wet-chemical pretreatment methods for lightweight metals. These methods pre-treat metal structures to provide corrosion protection and simultaneously improve the adhesion for subsequent primer or adhesive application. The scientists of Adhesion and Interface Research thus guaranteed that despite the adjustments to new processes and the shorter treatment time, produced materials have equivalent or even better quality than those produced using conventional processes. In such development work the key is always to quickly transfer the results from the laboratory scale to industrial production. To achieve this, Fraunhofer IFAM constantly adapts its laboratory and small pilot plant equipment to this development work.

One discovery made by Adhesion and Interface Research to improve the rate of curing of adhesives and paint/lacquer systems concerned microscopically small capsules down to the nanometer range. These contain active agents which, when commanded – for example by a temperature impulse – are released, so causing rapid curing of the adhesive. For this,

7 *Simulation of the uptake of a water molecule (red-white; top left) into a polymer network.*

8 *Electrochemical tests to evaluate corrosion protection layers.*

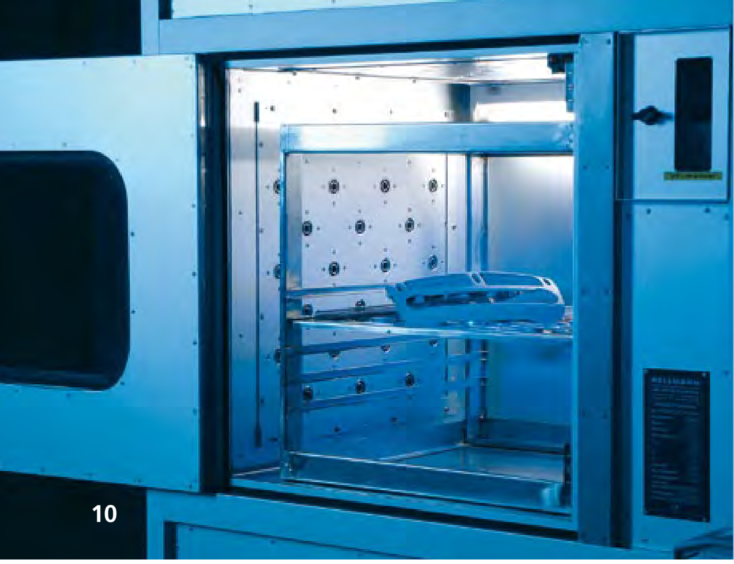
curing reagents are being incorporated at the molecular level into the voids of nano-zeolites. After the scientists had obtained excellent results using simulation, it was possible for a project partner to design suitable zeolite cage structures on the basis of these calculations. Other potential applications of the capsules are for the self-healing of paint/lacquer and for corrosion protection. Here the capsules with active agents only open when the surface is damaged. An example application: For offshore wind turbines such self-healing coatings could prolong the service lives of key components.

The considerable acceleration of production processes also requires a variety of approaches for in-line quality assurance. Adhesion and Interface Research is actively involved in this work. The aim here is to monitor the various stages of production processes involving bonding and painting/lacquering. The quality of the substrate surface or coated material is monitored here directly after the processing step (Fig. 9). The advantage: In-line monitoring of every process step means that there is no need to monitor the finished component. In most cases this was hitherto not possible to carry out in a non-destructive way and hence was only carried out on random samples. In-line monitoring primarily involves measuring the chemical state or roughness and structure of a component surface. Monitoring the chemical state not only involves detecting contaminants but also checking whether the pre-treatment was successful. Various techniques, customized for a particular application, are used for this, and these include, e. g. spectroscopic and optical methods.

Optical methods are very suitable for determining the wetting properties of surfaces. The scientists at Fraunhofer IFAM have optimized this application of in-line monitoring in a project concerned with bonding windscreens. This involved the application of primers which could not be checked with the naked eye. The method developed by Fraunhofer IFAM for this is so advanced that it is suitable for quality assurance.

Another example is the detection of release agent residues or production material residues on carbon fiber reinforced plastics (CFRPs). Even tiny, invisible amounts of contaminants can lead to significant impairment of the adhesion properties. Adhesion and Interface Research has developed laser spectroscopy methods with high proof of accuracy that can detect very small amounts of contaminants. These methods can be directly integrated into the production to monitor large surfaces and also small localized areas. In general, the main challenge is to develop methods which allow rapid detection in a production environment and have high proof of accuracy. However, they must also be very robust. Production cycle times must not be lengthened due to the use of in-line methods.

9 *Identification of residual contamination on an aluminum pressure-cast component using Optically Stimulated Electron Emission (OSEE).*



Paint technology:
From more rapid drying to color matching

Fraunhofer IFAM has also developed various solutions in the area of paint/lacquer technology for accelerating these important processes. A good example concerns a solution developed in a research project funded by the Federal Ministry of Education and Research (BMBF). Working together with various industrial partners – including paint manufacturers, painting and drying plant manufacturers, and end users – the paint/lacquer experts at Fraunhofer IFAM elaborated a rapid drying process for lacquered/painted plastic parts in the automobile industry. This involves the use of ultraviolet radiation for rapid curing of painted/lacquered parts.

This work was carried out in close collaboration with Adhesion and Interface Research. By using computer simulation it was possible to customize formulations for this application. The correlation between theoretical and practical findings quickly resulted in concrete improvements in the industrial production process. Conventional lacquering/painting processes for mirrors, bumpers, and interior parts require the parts to be cured for between 20 and 60 minutes in the oven after application of the lacquer/paint. The R&D work at Fraunhofer IFAM allowed the drying time with UV curing to be reduced to less than five minutes. This not only means a huge time saving, but also a significant reduction in the energy requirement.

Another approach being developed by Paint/Lacquer Technology at Fraunhofer IFAM for industrial application is the so-called "cold drying" (Fig. 10). In contrast to drying with warm air, involving heating the component and curing of the paint/lacquer due to the increased temperature, cold drying involves cold, dry air. If a component covered with water-based paint is exposed to this air, the dry air takes up moisture – and so dries the paint on the component. This process is not only efficient, but saves energy because there is no need for heating and cooling the component. Energy is solely required to remove moisture from the air. Due to the technological process improvements made at Fraunhofer IFAM, this long-known process has recently been made very efficient. The drying of a painted/lacquered component only takes a few minutes.

A further example of process acceleration involves the use of infrared drying, which in particular allows large lacquered components to be dried in a much shorter time. Whereas aircraft components, rail vehicles, and wind turbine rotor blades traditionally have to be dried for between six and twelve hours after lacquering/painting, this time is reduced to 30 minutes by infrared drying. Paint/Lacquer Technology is highly involved in designing effective processes in this area – from selection of suitable IR emitters to specification of wavelengths and qualification of the relevant paints/lacquers and materials.

Automobile technology is benefiting from a new, faster color matching method designed and developed by Fraunhofer IFAM. Color matching allows time-consuming processes in everyday production in the automotive sector to be considerably reduced. Vehicle bodies are painted in the factory, as are many other components – but with different batches of paint – while other parts are painted by suppliers. In particular for special effect colors such as metallic paints, it was common for supposedly the same colors not to exactly match one another after assembly. In order to avoid this, a complex color matching procedure was undertaken at the different paint users: Specimens were painted by the

10 *Laboratory unit for effective and energy-efficient drying of water-based paints using cold, dry air.*

11 *Improved color matching, even for "difficult paints", allows optimal matching of vehicle bodies and components painted at different locations.*

12

paint manufacturer and individual users and these were exchanged by post and evaluated. Paint/Lacquer Technology at Fraunhofer IFAM successfully accelerated this process: They developed an electronic system that can measure colors and convert them into electronic data – itself not a novelty because this procedure was already known. However, the solution of the experts of Paint/Lacquer Technology also integrated other aspects into the evaluation, for example the coarseness of the effect paint and the degree of gloss (Fig. 11). This made it possible to measure "difficult paints", to define suitable tolerances, to virtually compare the paint colors, to adapt the colors, and finally to release the colors for production at the respective user.

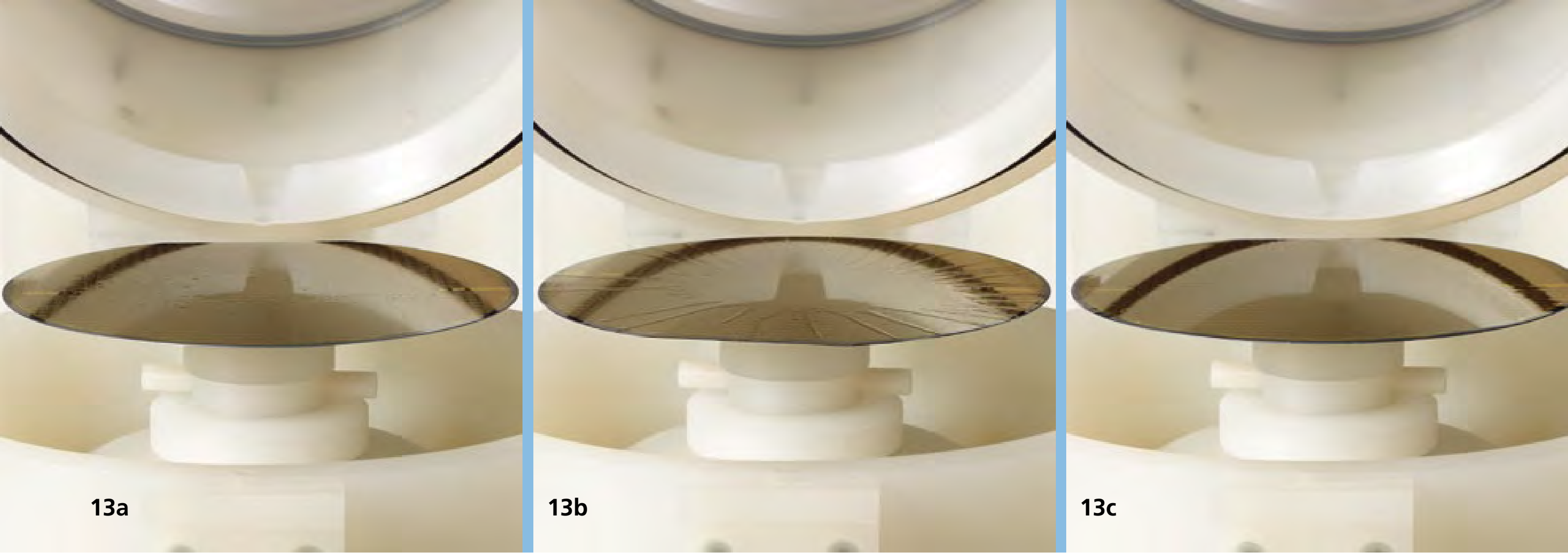
Adhesive bonding technology: Faster production using pre-applicable adhesives PASA®

New developments at Fraunhofer IFAM in the field of Adhesives and Polymer Chemistry are also making industrial processes considerably faster. For adhesive development, one aspect that has to be taken into account is optimized suitability for machine-based mass production at high cycle rates: The adhesives are customized so that they can be effectively used in production lines operating at ever higher rates. Another aspect is the curing rate: Faster curing processes mean significantly faster production.

Rapid curing processes are nowadays essential if companies want to achieve higher cycle rates. Whereas two-component adhesives from the building center take 24 hours to attain their final strength, industry uses adhesives that fully cure in a few seconds. This is the case, for example, with adhesives which cure when exposed to ultraviolet radiation (UV). As the strength of these bonds is not overly high, however, this method cannot be used in the automobile industry. UV curing is though highly suitable for electronic components and for bonding canulas in disposable syringes.

A groundbreaking development from Fraunhofer IFAM concerns Pre-Applicable Structural Adhesives (PASA®; Fig. 12). The PASA® adhesive is applied to the component and then partially pre-cured so that the component is not tacky. The advantage: The components – for example adhesive-covered fastening bolts which are used in the automobile industry as anchor points for the interior furnishing of the vehicle – can be stored for a long period of fluctuating temperatures in boxes without sticking to each other. To be used, the pre-applied adhesive, which is still chemically reactive, is activated

12 *Pre-applicable adhesive PASA® on metal fasteners.*



by a magnetic field in a matter of seconds. The magnetic field heats the "solid" pre-applied adhesive film for a short period, making it a liquid and so initiating its adhesive effect. This principle is similar to towel hooks whose adhesive films are covered by protective paper. The paper is only removed shortly before the hooks are bonded into position. In the case of adhesive-covered fastening bolts, the rapid activation allows them to be used in mass production.

Pre-applicable adhesives have the advantage that they are not applied to the components in sensitive areas of the production facility. They are applied at another location and ideally not by the end user but by upstream service suppliers. In situations where many small components have to be covered with adhesive, this can even be undertaken in a single step – for example for chips. Indeed, even at the wafer level these can be coated with adhesive (Fig. 13 a–c). These adhesive coatings were developed by the Adhesive Bonding Technology scientists at Fraunhofer IFAM using the example of transponders with radio frequency identification, so-called RFIDs. Whereas up until now chips have been bonded into plastic packaging with hot curing adhesives, the use of pre-applicable adhesives allows the adhesive application to be carried out away from the production line and allows the temperatures to be reduced. The result is significantly increased cycle rates with lower production complexity (see page 90; "Development of new adhesives: Making impossible property combinations possible").

13a–c *Applying a pre-applicable adhesive to a processed wafer via spin-coating.*

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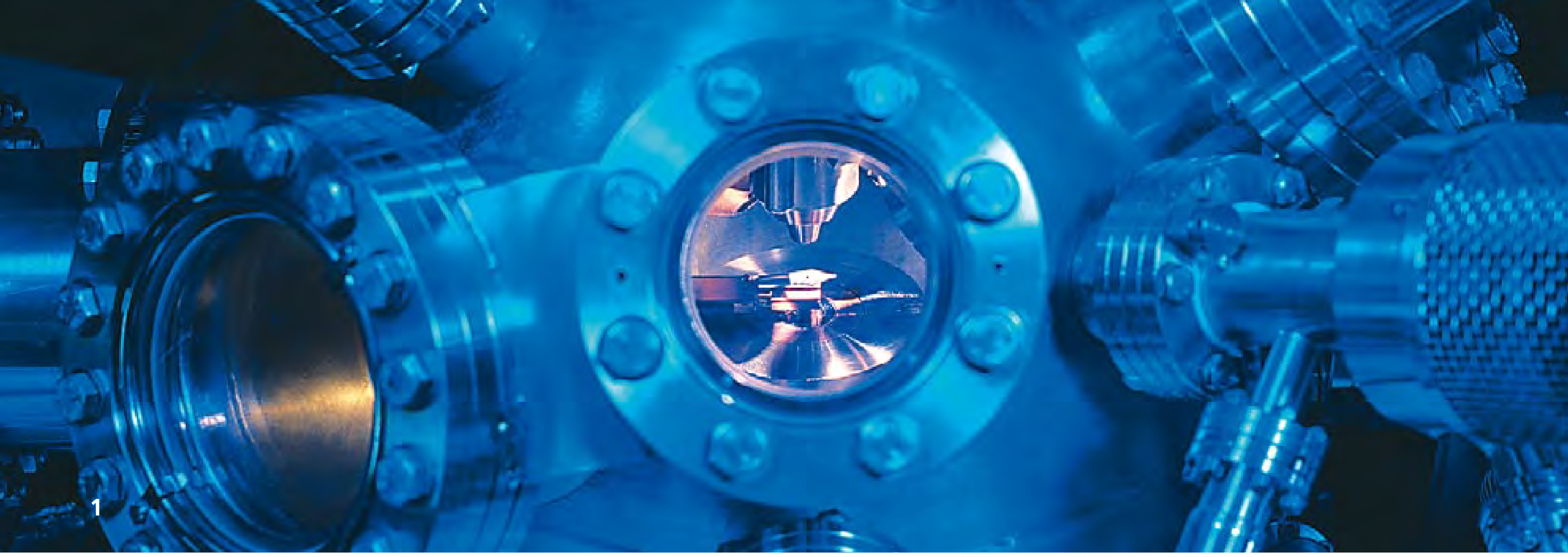


1

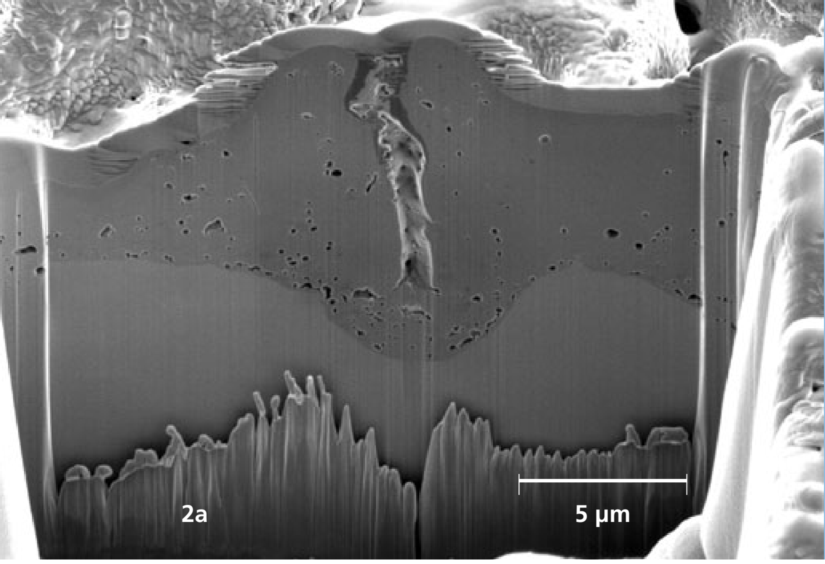
ADHESION AND INTERFACE RESEARCH – FROM ANALYSIS AND SIMULATION TO MATERIALS, PROCESS DEVELOPMENT, AND QUALITY MONITORING

The term "surface" – or more precisely "interface" – is usually considered to be the two-dimensional boundary of three-dimensional objects. In addition, interfaces have a variety of functional properties. This is demonstrated in everyday life by various phenomena such as the antireflective properties of lenses in spectacles or the wetting of surfaces by water droplets. Less obvious but of huge importance for technological progress are the functional interfaces and boundary layers or interphases in technical products. The properties and functions of many of these products are determined on the one hand by the materials from which they are made and on the other hand by the microstructure of the relevant surfaces. This particularly also concerns the interfaces respectively interphases between the different materials which make up the products or between the different materials with which they are coated.

Interfaces in multifunctional materials

In bonded joints the interfaces or interphases are responsible for the adhesion and, for example, for the insulating and attenuating properties between two substrates. The same is true for multilayer surface protection systems for metal structures. These multilayer systems must not only offer effective adhesion between the individual layers, but they must also act as an effective barrier to external influences and in some cases are required to provide other functions, for example corrosion protection. Interfaces also play a key role in novel composite materials for lightweight structures, for example in carbon fiber reinforced plastics (CFRPs). Here the adhesive interaction between the fiber surfaces and the matrix resin determines the special mechanical properties of these materials.

The production process involves treating the material surfaces using customized methods in order to optimize the properties for a specific application. In most cases the result of the modification cannot be detected or evaluated by the human senses. These surface properties, which are responsible for example for adhesion, corrosion protection, and slip properties, usually manifest themselves in an extremely thin surface layer having dimensions of just a few nanometers or molecule layers. The chemical composition of the layers and the surface roughness are important for subsequent processing steps, such as bonding or coating.



Interface-specific know-how at Fraunhofer IFAM

Detecting and understanding the technical effects of the properties of surfaces and interfaces and using this knowledge to develop surface treatment techniques, new applications for adhesives as well as coatings, new materials, and quality assurance concepts is the focus of the work of Adhesion and Interface Research at Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM. This R&D work is undertaken using a variety of advanced analytical techniques (Fig. 1, 2a + b), computer-aided simulation methods, wet chemical surface pre-treatment procedures, as well as test methods.

Customers are able to make use of the expertise and equipment of the various competences in Surface and Nanostructure Analysis, Applied Computational Chemistry, Quality Assurance of Surfaces, as well as Electrochemistry and Corrosion Protection for the development of application-oriented solutions. In addition, the expert knowledge of all other branches at Fraunhofer IFAM is also available where necessary. The know-how is constantly being updated and expanded as a result of participation in national and international research projects.

Wet chemical surface pre-treatment methods – successful materials and process development work

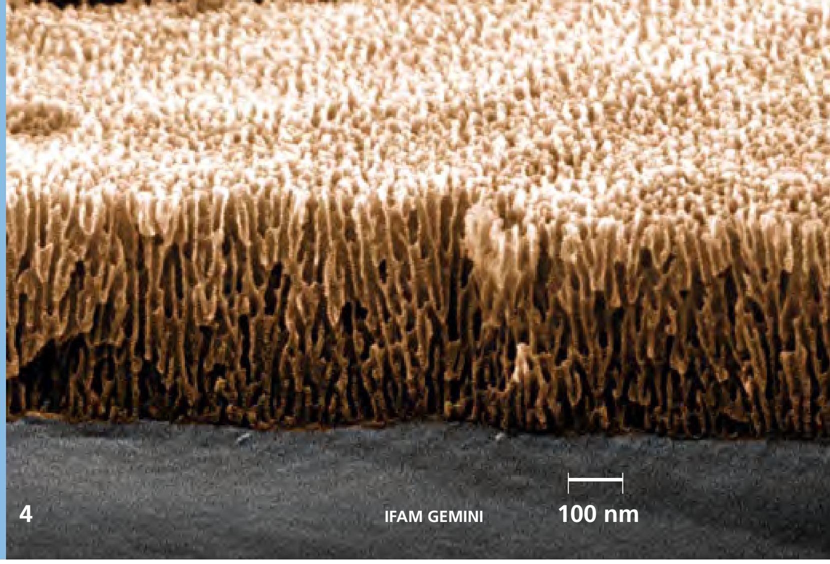
To complement the existing facilities for dry chemical pre-treatment used by Plasma Technology and Surfaces at Fraunhofer IFAM, the facilities for wet chemical pre-treatment of metallic materials are being further expanded (Fig. 3). Effective pre-treatment of these materials is essential prior to coating or bonding. This can be done by mechanical, dry chemical, or wet chemical means. The latter methods are still widely used by industry. On account of risks to health and statutory restrictions, wet chemical pre-treatment processes involving chromate (Cr(VI) are being used less and less – even though they provide excellent surface properties with regards to corrosion resistance and the adhesion strength of coatings and adhesives.

Although the switch to Cr(VI)-free methods is already complete in many sectors, e. g. the car manufacturing industry, the changeover is still ongoing in other sectors. The latter include the architecture sector and the aircraft industry where surfaces having long service lives and high effectiveness are required.

1 *X-ray photoelectron spectroscopy (XPS) analyzes the chemistry of surfaces and interfaces.*

2a + 2b *Latest analytical techniques give insight at a micro and nano level – focused ion beam preparation (FIB) in combination with scanning and transmission electron microscopy (SEM, TEM):*
2a: SEM image of the cross-section of an oxidized titanium material. The in-situ preparation of the cross-section was undertaken using FIB.
2b: Cross-section (cryofracture) of a spherical seawater alga as an example of cryo-SEM of biological samples.

3



4

Fraunhofer IFAM has worked closely for many years with partners in the aircraft industry on the development of Cr(VI)-free methods for pre-treating metals prior to bonding and coating. The focus here has been on the lightweight metals aluminum and titanium, and also steel. The whole pre-treatment process was considered in this work, with the focus being on etching, passivation, and anodization (Fig. 4).

Future developments will include local Cr(VI)-free pre-treatment for repair and finishing work, adhesive tapes with integrated etching and anodizing functions, advanced sealing processes for anodized layers, and the treatment of new metallic materials.

Prediction of residual stresses and deformation in bonded components using simulation methods

Besides the development of surface treatment processes, coating materials, and adhesives, the influence of the production respectively manufacturing processes on product quality must also be carefully considered. The samples that are manufactured during the product development phase often only give limited insight into the complex factors that can occur in the later industrial manufacturing process.

One example is the curing of reactive adhesives, which undergo crosslinking during the production and hence undergo a decrease in volume. This "curing shrinkage" has not been able to be predicted up until now, and its effect on the component properties has to be determined by undertaking costly and time-consuming test series. It is desirable to be able to take this shrinkage into account when bonded joints are being designed in order to take account of the stresses that arise in the substrates during curing respectively any movements in the bonded substrates relative to the rest of the assembly.

Such issues – and the need for suitable simulation methods – arise, for example, when lenses have to be adhesively bonded with high positional accuracy in optical instruments or when bonding sensors in the measuring technology and microengineering areas. For these applications, high precision and effective adhesion down to the nano-level are essential. By correlating various simulation and analytical methods, the specialists at Fraunhofer IFAM were able to develop a simulation tool for predicting volume changes in adhesives (Fig. 5).

To this aim, a macrokinetic reaction model was developed to describe the crosslinking reactions in the adhesives. In combination with thermokinetic measurements, this model allows the number of reactive groups at any time to be calculated, and hence the extent of reaction. Molecular modeling methods allow the simulation of polymer networks at a molecular level and calculation of the relevant density and polymer volume. For an adhesive of known composition this means that the curing-related volume change can be predicted at any desired moment in time. The effect of shrinkage on the component design can then be predicted by using the parameters determined at the molecular level in finite element methods and can be taken into account when designing a real component (Fig. 6).

3 *Rapid and versatile – the mini galvanic line of Fraunhofer IFAM for customer-specific development and optimization of pre-treatment processes for metallic materials.*

4 *Anodized layer on the surface of an aluminum material. SEM image of the fracture surface showing a cross-section of the nano-porous oxide structure.*

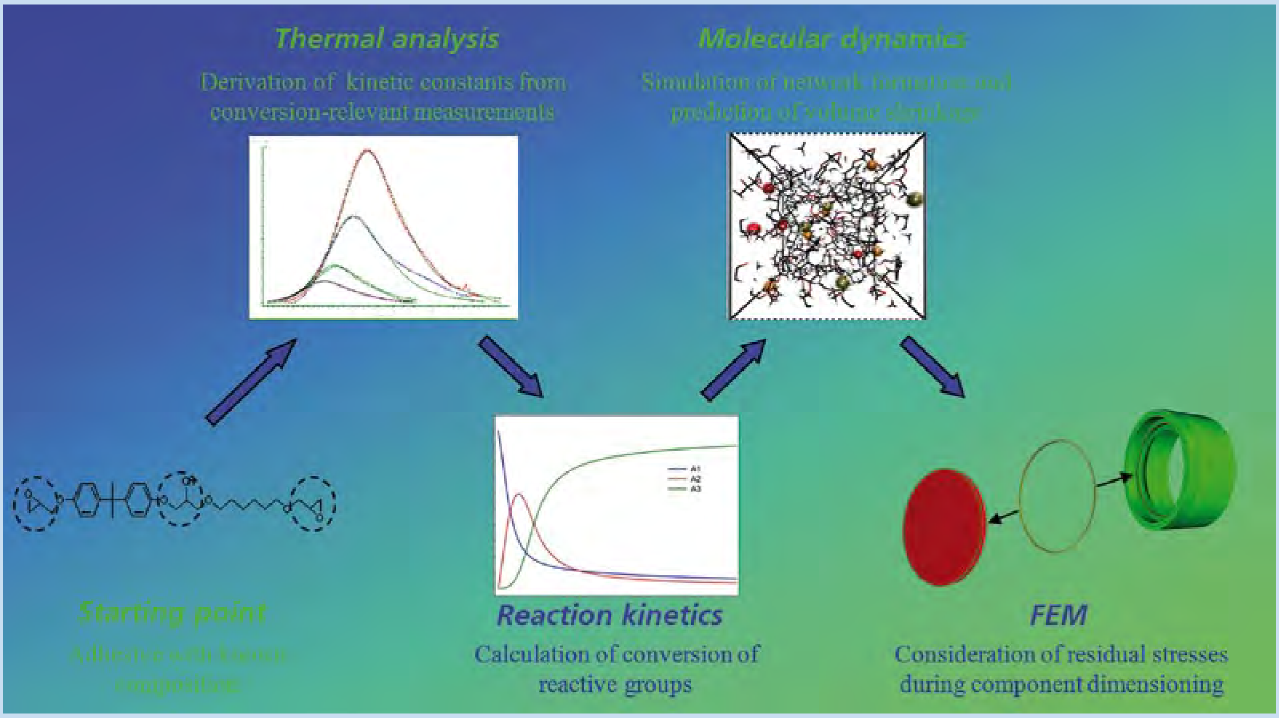


Fig. 5: Simulation tool developed at Fraunhofer IFAM for predicting volume shrinkage and the resulting residual stresses in an adhesive.

This approach allows a correlation to be made between the macroscopically measured residual stresses and deformation in bonded components and the chemistry of the network formation. The method is therefore not dependent on shrinkage measurements and can be used for a wide variety of adhesives and applications. Besides being useful for precision bonding at the micro-level, this simulation approach is also of interest for the bonding or curing of matrix resins in large components. For this reason, future work will transfer this method to the joining and manufacture of large structures – for example rotor blades for wind turbines, structural components for aircraft, and components for car and rail vehicle manufacture and shipbuilding.


7


8

Quality assurance concepts

In addition to analyzing production-related effects, there is much interest in in-line monitoring of the properties of surfaces in many sectors of industry and areas of production. The activation and pre-treatment of material surfaces are as important in the transport sector – car, commercial vehicle, aircraft, rail vehicle, and ship manufacture – as they are for the production of electronic assemblies and in medical technology. Large wind turbines, both onshore and offshore, often require high-quality, defect-free coatings and paint/lacquer layers, for example for corrosion protection. The aim of the developed in-line methods is to efficiently monitor the relevant production processes without any gaps. This allows continuous monitoring systems to be integrated into the specific production processes of customers.

Within Adhesion and Interface Research of Fraunhofer IFAM, the experts of Quality Assurance of Surfaces develop new innovative methods for continuous monitoring of surfaces right through to industrial application. One example of successful implementation of an in-line measurement method concerns measurement of release agent residues on fiber reinforced composites using laser induced plasma spectroscopy (LIPS). This monitoring allows to avoid subsequent ineffective adhesion of adhesives or coatings (Fig. 7). Another example is the aerosol wetting test that was developed at Fraunhofer IFAM to monitor the quality of pre-treatment of large surfaces (Fig. 8). Specially developed imaging systems and analysis routines allow reliable statements to be made about the surfaces and these systems can be optimally integrated into existing production processes.

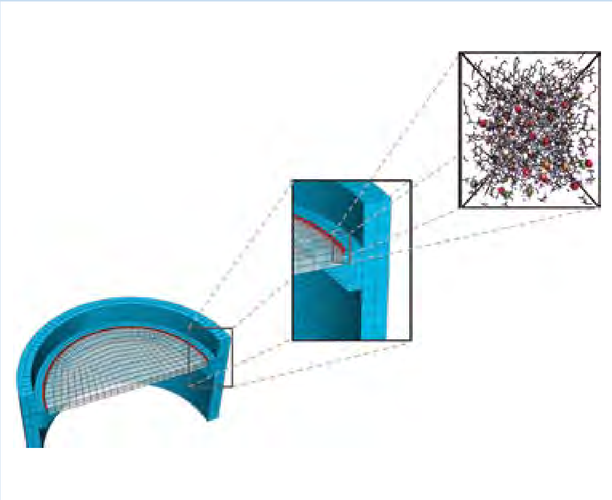
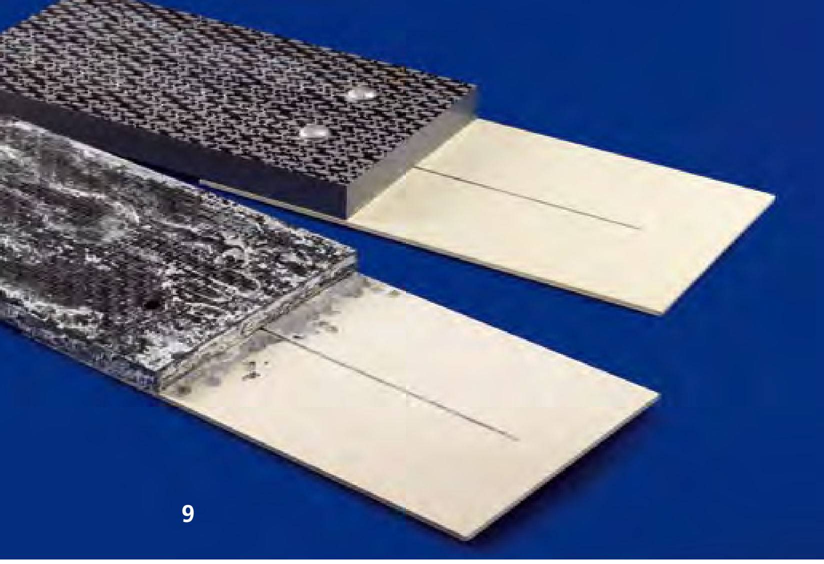


Fig. 6: The volume shrinkage calculated from the atomic structural model of the adhesive (top right) is used directly as a parameter for designing the component (bottom left). This allows prediction of the volume change of the adhesive in the bonded joint (center, red) and the internal stress in the component.

7 *Laser induced plasma spectroscopy (LIPS) for studying the elemental composition of sample surfaces.*

8 *Evaluation of the wetting properties of surfaces using the aerosol wetting test developed at Fraunhofer IFAM.*



Corrosion protection

Due to the increasing use of carbon fiber reinforced composite materials for lightweight structures, there is a need to develop effective concepts to prevent contact corrosion between CFRPs and metallic materials (Fig. 9). The latter would otherwise be inevitable, in particular for joints between CFRP and aluminum alloys, and would lead to rapid corrosion damage to the aluminum material. Of help here are both adhesive-based solutions and also customized corrosion protection concepts developed by the experts of Electrochemistry and Corrosion Protection.

Corrosion is also a decisive limiting factor for the use of offshore wind turbines (Fig. 10). Guaranteeing and prolonging the service lives of wind turbines is a key goal that has to be achieved by suitable corrosion protection measures. The in-depth expertise of Electrochemistry and Corrosion Protection is utilized here to evaluate suitable corrosion protection coatings ("monitoring") and to develop concepts for regular monitoring of the actual state of the protective function and, where necessary, the maintenance. Sustainable repair concepts for offshore wind turbines are currently being planned in collaboration with developers of coating materials, maintenance companies, wind farm operators, steel manufacturers, and design engineers.

Adhesion and Interface Research of Fraunhofer IFAM is also developing new corrosion inhibitors which comply with the EU regulation on chemicals REACH (Registration, Evaluation, Authorization and Restriction of CHemicals). In this area, for example, polymeric agents having corrosion protection properties for a wide range of metals are being developed and tested as part of a publicly funded project (Fig. 11).

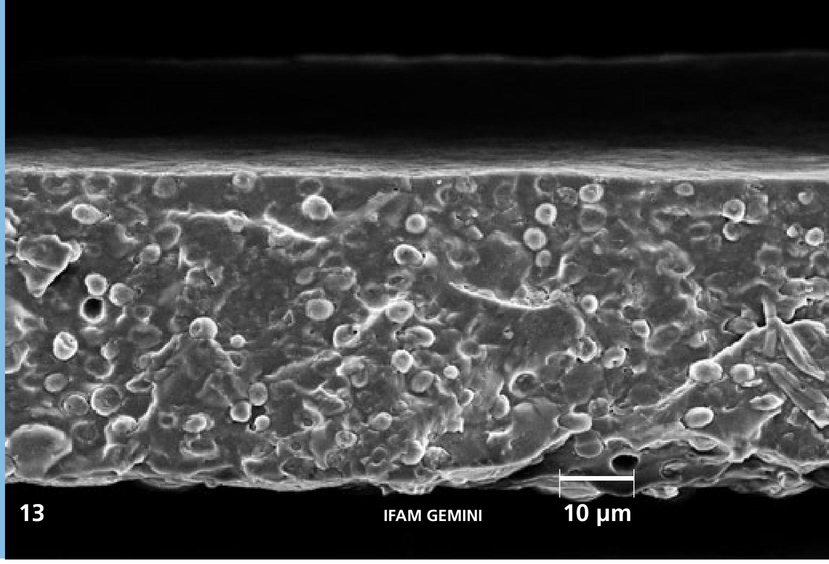
Active agent encapsulation

Strategies for encapsulating active agents for incorporation into polymers and coatings are also being developed. These active agents, which may for example be corrosion inhibitors, substances for preventing ice formation, or fragrances, are released from their encapsulated state on demand – namely by an external stimulus such as mechanical damage or a temperature change. Capsule materials being used for this include nano-scale zeolites (Fig. 12) and functional biocapsules (Fig. 13). The latter are renewable raw materials and make a contribution to environmental protection and sustainable use of materials. They have advantageous processing and usage properties over synthetic polymer capsules such as their size distribution, strength, and storage properties.

In the mentioned examples – as in much of the work of Adhesion and Interface Research at Fraunhofer IFAM – the physical and chemical microstructure of the surfaces or interfaces is vitally important for the properties and functions of the relevant materials, components, and products. Detecting and understanding these relationships allows the customized development of new materials and surface treatment processes, allows the use of tailored quality assurance and corrosion protection concepts, and allows expedient damage analyses to be reasoned. Expert knowledge, in-depth expertise, and advanced equipment and facilities are the basis for successful development of customized solutions in the area of adhesive bonding and surfaces.

9 *The corrosion protection concepts developed by Fraunhofer IFAM help to prevent contact corrosion between the CFRP and aluminum.*

10 *Corrosion protection concepts for offshore wind turbines – expertise from Fraunhofer IFAM (Source: REpower Thornton Bank 12; Photo: Christian Eiche).*



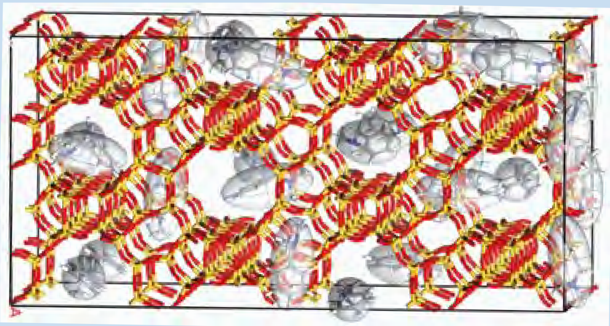


Fig. 12: Estimation of the spatial and chemical requirements for incorporating molecules of active agents in zeolite host systems and determination of the loading as well as distribution via "molecular modeling".

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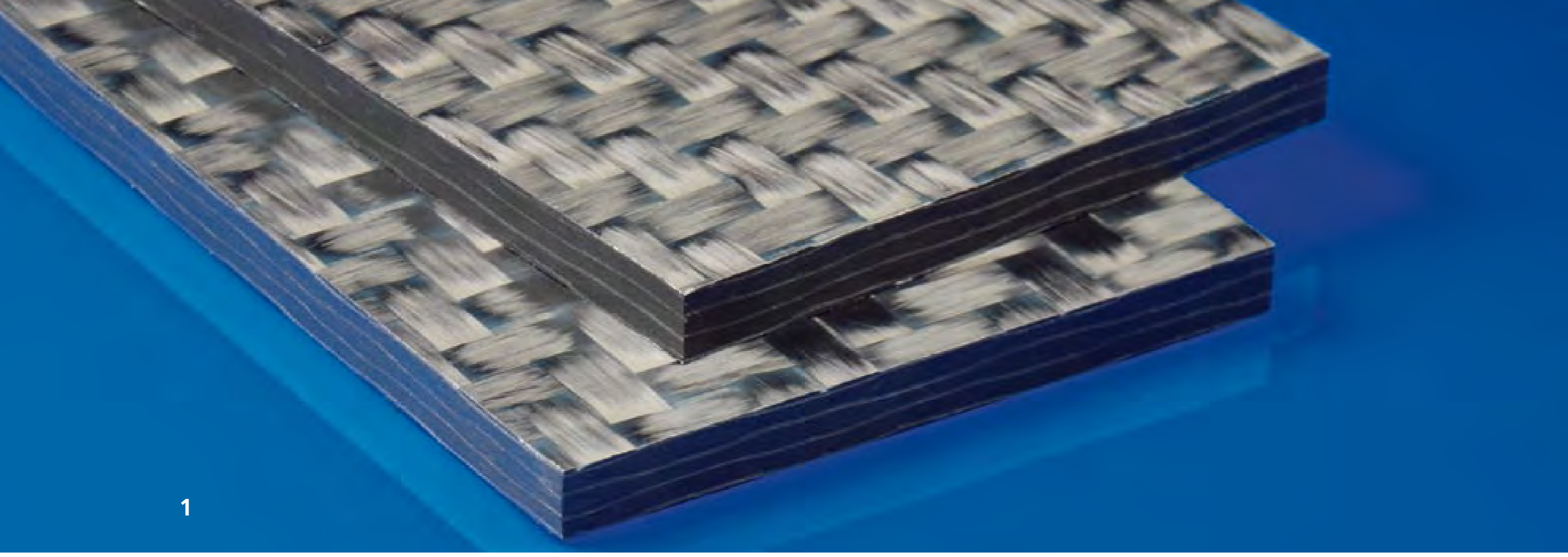
11 *Salt spray test unit in the accredited corrosion test laboratory at Fraunhofer IFAM.*

13 *Coating layer with biocapsules, suitable for an active agent load of up to 50 mass percent, for providing coatings with, for example, corrosion inhibiting or antimicrobial functionality. The SEM image of the fracture surface shows the cross-section of a coating with finely distributed biocapsules of uniform size.*



1

CLEANING AND ACTIVATION PRIOR TO PAINTING/LACQUERING AND BONDING: SURFACES ARE THE KEY ISSUE FOR FIBER COMPOSITE MATERIALS

They are the reason for technological breakthroughs and totally new industrial applications: Carbon or glass fiber reinforced plastics have truly made their noteworthy mark over the last 25 years. Whenever low weight and high rigidity are required, it is fiber reinforced plastics (FRPs) – and in particular carbon fiber reinforced plastics (CFRP; Fig. 1) and glass fiber reinforced plastic (GFRP) – that are nowadays the likely choice.
It is thanks to FRPs that lightweight design has taken off in major industries. These materials have made resource-friendly production and hence eco-friendly products possible.

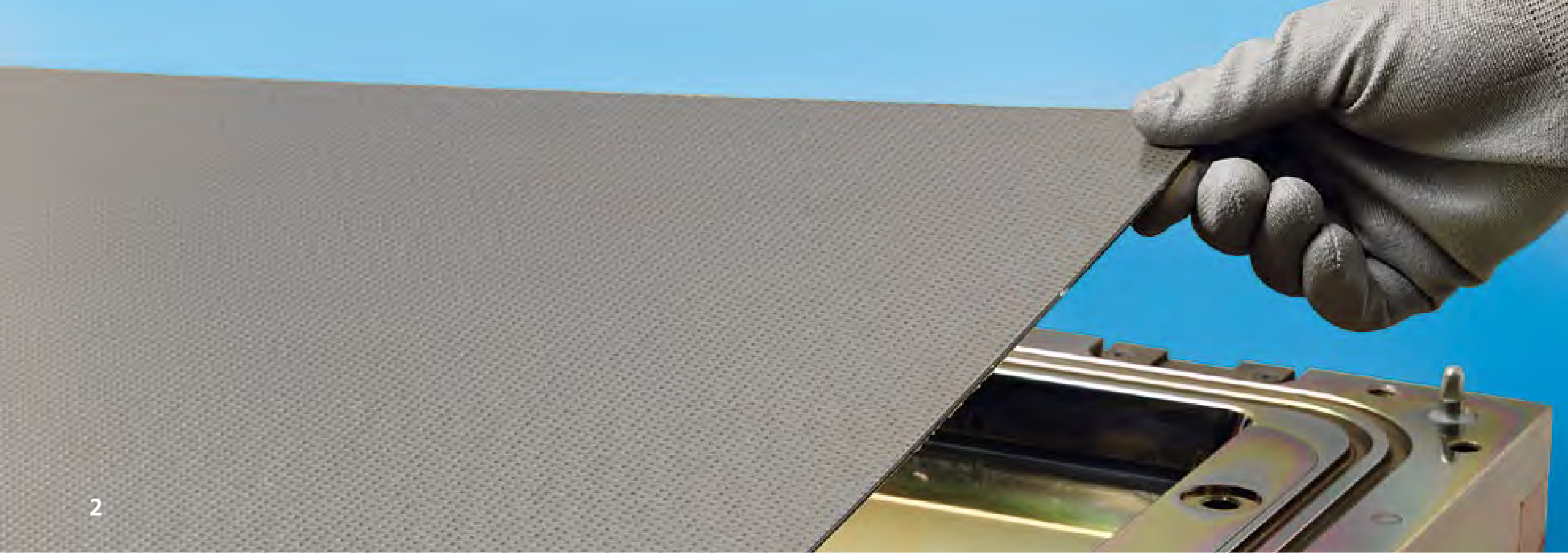
In the aviation sector, aircraft wing components and tailfins are made of CFRP, whilst GFRP components are commonly found in the automobile industry as roofs, trunk covers and are used for making rotor blades for wind turbines. The weight reduction has enormous benefits. For example, lightweight design improves efficiency and for means of transport it lowers fuel consumption and hence CO_2 emissions. Extremely hard, rigid, and yet light tennis racquets and bike frames have enhanced to aspired performance in sport as an optimal "tool" for maximum performance. In short: CFRPs have assumed an established place in modern industry – and have a very promising future. Soon, more than 50 percent of an aircraft will consist of CFRPs. New aircraft such as the Airbus A 350 and Boeing 787 are leading the way.

Although CFRPs have already made their breakthrough in the automobile and aircraft manufacturing industries, in many other sectors the use of these materials is still in its infancy, but offers enormous potential. Wherever FRPs are used, there is one key prerequisite in addition to meet the required mechanical properties: The application must be economically viable. This viability is often only achievable via automated mass production and processing of FRPs. High and efficient cycle rates are required in particular in the automobile manufacturing industry. And also in aircraft manufacture the trend, despite the size of the components, is to move from individual component manufacture to series production.

Contamination by release agents – a necessary evil?

There is a major innate challenge when manufacturing FRP components. Almost all FRP components are made in metal molds. They are cured in these molds to obtain their final

1 *Ideally suited for lightweight structures – carbon fiber reinforced plastic (CFRP).*



structure and stability. In order to prevent the components becoming stuck in the molds, so-called release agents are usually used to facilitate the removal of components, some of which can be several meters long, from their molds without being damaged. Nevertheless, residues of release agents are transferred to the components and this makes subsequent cleaning of the surfaces necessary. The nature, quantity, and method of application of the release agent determine the complexity of the cleaning step. The rule is: As much as necessary but as little as possible.

There have been a variety of developments in this area. In recent years, for example, internal release agents for FRP components have been developed to replace coating of the mold. In this case the components in effect have their own in-built release agent. The release agents are incorporated into the starting materials used to form the polymer matrix. However, in order here for the components to be easily removed from the mold, the release agents must act at the surface. This in turn means that the release agents must be made "harmless" prior to subsequent painting/lacquering or bonding.

Instead of release agents, alternative processes utilize permanent release layers (Fig. 2) or release films placed in the molds. This increases the work for preparing the molds, but the costs for post-treatment are considerably lower.

The experts of Plasma Technology and Surfaces – PLATO – at Fraunhofer IFAM have carried out much R&D work in this area in recent years. They have developed, for example, flexible deep-drawable release films which can totally replace release agents (see page 67; "Faster, lower costs, and improved quality: Fraunhofer IFAM accelerates industrial processes").

Surface pre-treatment for fiber reinforced plastics: Cleaning and activation

If it is not possible to do without release agents for FRP component manufacture, they must be removed prior to further processing. This cleaning process must be monitored. Only release agent free FRP components have good bonding and painting/lacquering properties. This is particularly important because adhesive bonding, and not mechanical riveting, is the ideal joining technique for FRPs. Mechanical joining methods require complex and costly holes to first of all be drilled in the FRP materials. This causes local structural damage to the FRP and substantial strength loss, as well as high wear to tools.

In contrast, adhesive bonding is ideally suited for joining these materials. It allows damage-free, planar transfer of forces and is more economical. In addition, for CFRPs there is complete prevention of contact corrosion between the carbon fibers and metallic rivets. Suitable surfaces are, however, required in order to utilize these benefits.

The PLATO scientists at Fraunhofer IFAM are also involved in this area. PLATO has broad expertise and has undertaken many projects in recent years to optimize FRPs and make their use possible.

The challenge is a demanding one: The surfaces of FRPs must be pre-treated in such a way that effective bonding and defect-free painting/lacquering are subsequently guaranteed. Time, cost, and quality are the parameters by which the use of FRPs is measured and which determine the pre-treatment of the materials. Up until now time-consuming manual work has often been used to clean components for aircraft and wind turbine manufacture, thus preparing them for bonding

2 *Release agent free removal of FRP components from molds using permanent plasma-polymer release layers.*

or painting/lacquering. This manual work includes sanding, cleaning with solvents and is sometimes assisted with laser beam cleaning which – like the manual work – brings the risk of defects and damage to sensitive materials.

The aim of PLATO is to automate the pre-treatment processes and so enhance the reliability and quality of FRP usage and reduce costs. Various pre-treatment processes can be used depending on what must happen to the FRP component in the next step of the processing. In collaboration with the customers, suitable solutions for the particular application can be identified. Of advantage here is that this work is also undertaken in close collaboration with other specialists at Fraunhofer IFAM – for example the adhesion and interface research, adhesive bonding technology, and paint/lacquer technology.

A further challenge is that there are thermoplastic CFRP materials which, even when clean, do not have good bonding or lacquering properties. The majority of CFRP components are still made with epoxides. However, there is a trend towards thermoplastic materials in the aircraft and car manufacturing industries. These CFRP-containing plastic sheets can be pressed into any desired shape under the effect of heat – just like metal sheets are for example pressed for car manufacture. The disadvantage is that thermoplastic materials are not ideal for coating and bonding. They have hydrophobic surfaces which, even when totally clean, are difficult to coat and bond. Besides being cleaned, the surfaces of these materials must therefore also be activated.

What pre-treatment is the most suitable?

What pre-treatment is best for what kind of contamination and for what kind of production process or production step? These are the key questions the PLATO experts are trying to answer. The ideal solution is in some cases to combine two pre-treatment processes and so have the best technical and economically viable solution. The pre-treatment must be adapted and safe – for the production, for the service life of the component, and for the customer.

CO_2 snow cleaning – gentle and thorough cleaning …

In situations where release agents cannot be avoided in the production, CO_2 snow cleaning has been used as successful cleaning method in recent times. This uses carbon dioxide (CO_2), a non-combustible colorless and odorless gas that is present in air and which can be isolated in an environmentally-friendly way. It is stored as a liquid in a tank and when being used is converted into small snow crystals by special nozzles. The snow crystals hit the component surface under high pressure (Fig. 3).

This cleans the surface of contaminants in a gentle and environmentally responsible way. As the snow crystals revert to the gaseous state and truly "dissolve in air", there are no residues. The process is very gentle for the surfaces yet cleans them thoroughly. Major automobile companies, such as BMW, already use CO_2 snow cleaning in their production prior to painting/lacquering plastic components. This obviates the need for time-consuming cleaning with water – and also means car manufacturers can be sure that the cleaned components meet the high requirements for painting/lacquering.

3 *Gentle, thorough, and residue-free – removal of release agents using CO_2 snow.*

The big advantage of CO_2 snow cleaning is hence the cleaning effect. However, polymers that are often naturally hydrophobic cannot be effectively wetted with water after CO_2 snow cleaning.

… which in combination with atmospheric pressure plasma provides an optimum surface for bonding and painting/lacquering

The treatment with atmospheric pressure (AP) plasma can be used to make polymers easier to bond and coat (Fig. 4). Thermoplastic materials, such as polyphenylsulfide (PPS), which are difficult to paint/lacquer can be advantageously modified by AP plasma treatment. This incorporates oxygen into the surface of the material. This, however, is only sensible when there is minor contamination: Plasma can remove organic contaminants, e. g. thin oil film. If there is more major contamination then other pre-treatment methods must also be used in addition: For example a combination of CO_2 snow cleaning – to remove the coarse contamination – and AP plasma treatment – for fine cleaning and functionalization of the surface. Both processes can be automated and coupled to each other in series production lines.

Cleaning and activation with light – VUV excimer technology

A relatively new technology in the PLATO portfolio is the cleaning, activation, and coating of surfaces using vacuum ultra violet radiation, in short VUV radiation. Here, so-called "excimer lamps" emitting radiation at a wavelength of 172 nanometers are passed across a surface. The intense radiation removes release agent residues or converts them into adhesion promoters. PLATO is currently working on integrating VUV systems into production lines, so allowing high-precision and effective surface treatment (Fig. 5).

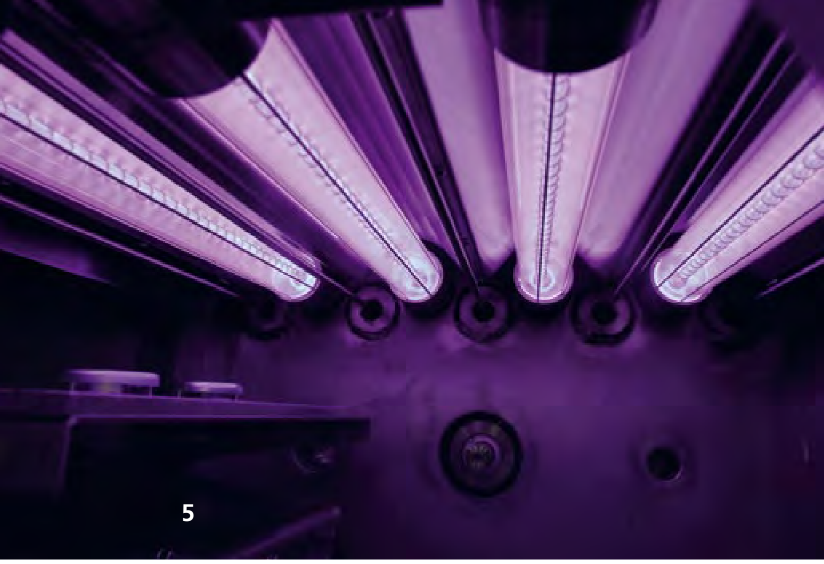
4 *Cleaning and activation of complex FRP surfaces using atmospheric pressure plasma.*

Vacuum suction blasting – a universal technique for cleaning and abrasion …

Another proven method for treating components prior to subsequent bonding and painting processes is jet cleaning with solid particles. In conventional compressed air blasting, solid particles hit the material surface at high speed and abrade the surface. The disadvantage is that the particles become airborne and that is why the method is usually carried out in blasting booths.

An alternative method to this is vacuum suction blasting in which the blasting is carried out under a bell which is connected to an industrial vacuum cleaner. So a differential pressure is produced, which accelerates the blasting medium towards the surface and removes the particles directly in the vacuum cleaner. The method is hence suitable in situations where the blasting and painting/lacquering have to be carried out in the same production area. It utilizes the effect of classical compressed air blasting but avoids contamination – and there is no need to transport components to blasting booths. It also allows very large components to be pre-treated directly in a production line. Any dust that forms is immediately extracted and this is also of benefit for the environment and workplace safety: The liberation of harmful epoxide dusts from FRP components can hence be efficiently negated.

In addition, the method which is adopted by Fraunhofer IFAM can also be used for localized application. In the vacuum suction blasting process, a nozzle travels across a surface and there is no contact with the surface; the particle beam roughens the surface in a defined way, for example for subsequent bonding. PLATO is developing vacuum suction blasting processes with effective extraction for industrial use – adapted to the specific applications of customers (Fig. 6).



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… and with quality assurance

In collaboration with experts in the Adhesion and Interface Research, integrated in-line monitoring systems are being developed to allow process monitoring and if necessary adjustment of process parameters. The work involves the development of robust methods suitable for an industrial production environment, customized and optimized for specific applications in order to achieve the best as well as most economically favorable results (Fig. 7).

Customized combinations of surface pre-treatment

A combination of methods is often required in order to achieve the ideal solution for a specific application. For example, regions of components that need to be bonded can be roughened by laser beam treatment or vacuum suction blasting. The regions where a smooth CFRP surface is required for painting/lacquering can be realized by CO_2 snow cleaning or AP plasma treatment. In practice, the processing unit in a robot cell takes the tools it requires for the specific region. In series production this occurs in own stations for the various steps.

When manufacturing large aircraft components, it generally makes sense for a robot to clean the whole surface first with CO_2 snow and then to activate defined regions with a plasma nozzle or vacuum suction blasting nozzle. An example of such a procedure on aircraft is when small components – such as cable holders – have to be affixed at certain intervals. In conventional manufacturing these places are manually roughened and cleaned with solvent. In the future this work will be automated by targeted vacuum suction blasting.

Actively involved in European research projects

The expertise of PLATO is being utilized in European projects. For example, as a partner in the ABITAS project (Advanced Bonding Technologies for Aircraft Structures) with Airbus and other companies from all over Europe to lower the costs for the development of new aircraft by 20 to 50 percent in the medium to long term. The experts of Fraunhofer IFAM were mainly involved here with surface pre-treatment using atmospheric pressure plasma. Compared to other pre-treatment techniques it has been demonstrated that this technique can replace manual activation methods. PLATO tested various CFRP surfaces and pre-treated these with AP plasma. Different methods for removing components from molds and hence various types of contamination were considered in the studies. It was demonstrated that AP plasma pre-treatment is suitable for realizing bonded joints with good long-term stability for aircraft manufacture. The bonded joints were tested for their resistance to aging and excellent results were obtained.

A key R&D topic is also the repair of CFRP components. The more intense the usage of the material, the greater the probability of damage during everyday use. Repair processes for CFRPs must be understood and then developed for specific situations. PLATO is developing robust processes that are suitable for on-site environments – for example at the airport, where damage to the CFRP outer skin of an aircraft has to be repaired efficiently and with effective quality control but with as little complexity as possible. This does not concern components just "out of the production" but rather components that have already been under considerable stress, are contaminated, and have undergone aging. Here PLATO is also

5 *Cleaning and activation of surfaces with VUV radiation using excimer technology.*

6 *Contactless vacuum suction blasting of FRP components prior to bonding.*

highly engaged in a major European R&D project, CleanSky. Fraunhofer IFAM is developing potential processes for this in the SFWA sub-project (Smart Fixed Wing Aircraft) along with well-known players in the European aircraft manufacturing industry.

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7 *In-line quality assurance using thermography.*

DEVELOPMENT OF NEW ADHESIVES: MAKING IMPOSSIBLE PROPERTY COMBINATIONS POSSIBLE

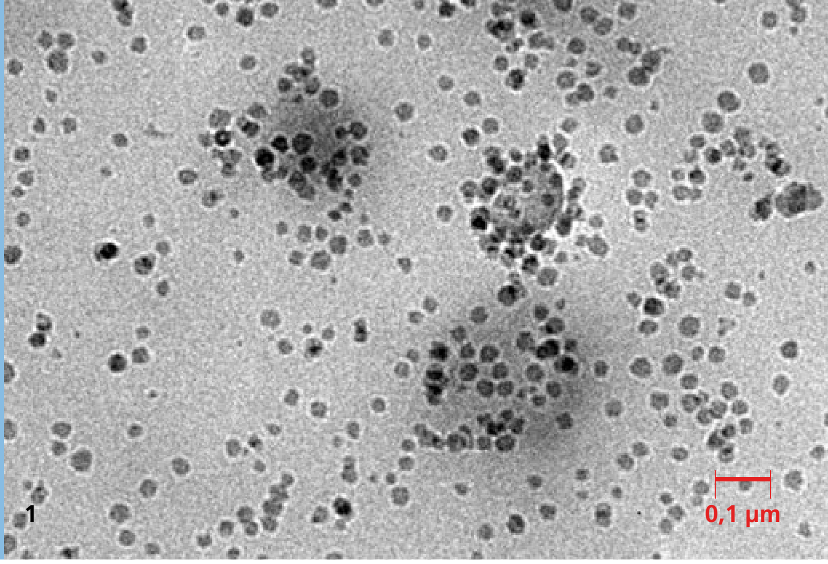
Thousands of adhesives are commercially available. A considerable number of "in-house formulations" are also used by companies. So, are further adhesives really necessary? The truth is that there are many situations for which the currently available adhesives are not suitable: Either they do not have the required resistance to aging or they do not allow the required productivity, for example because the rate of curing is too slow, or they do not have the required biocompatibility. Frequently an adhesive will fulfill most requirements, yet lacks a decisive property. And indeed it is often a combination of unusual properties that is the key to that adhesive being able to be used for industrial production.

Adhesives as key components

In many cases, the amounts of adhesive that are required are very small – with sometimes the annual requirement being only a few grams. The availability of these customized adhesives does, however, mean high value-creation for the users. The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM is the ideal R&D partner for developing such special products, because the development of niche products by the adhesives industry is usually not commercially viable. Fraunhofer IFAM can also ensure that the special material is available to the customer in sufficient quantities for his production by, for example, jointly finding and qualifying a commission manufacturer.

New adhesive concepts pave the way for the future

A research project does not always involve developing a specific product. Sometimes completely new pathways and concepts are also required in order to answer fundamental questions about adhesive bonding. Such work is often undertaken as part of publicly funded research projects. The objective here is for the subsequent results to be used by industry as a basis for developing products themselves as well as for others to develop products for industry. Regardless of whether it concerns the development of a specific product or demonstrating a new general concept – the focus is usually on improving the productivity of processes involving adhesives.



Rapid adhesive curing using modified adhesives

An essential aspect for high productivity is the rate of curing of adhesives. The curing must also be carried out under as mild conditions as possible, in particular with regard to the temperature, and reactive adhesives must have good storage properties under ambient conditions. Finding an ever better compromise between these opposing requirements is the goal.

The requirement of rapid curing in combination with good storage stability is ideally met by photo-curing adhesives. This is why these adhesives have long been a key work area of Adhesives and Polymer Chemistry of Fraunhofer IFAM. They are, however, only suitable for a small number of applications because very few substrates are sufficiently transparent to allow curing light to pass through to the adhesive.

In the case of conventional heat-curing adhesives, the heat must be transferred to the substrates and the adhesive by alternative means. Methods used by Fraunhofer IFAM include induction, microwaves, hot air, and IR emitters. Identifying the optimum method for rapid curing by heating in an oven to a temperature considerably above the curing temperature is, however, the smaller challenge. More problematic are the material properties of the cured adhesive: In the case of most commercial adhesives, one obtains a foamy, mechanically unstable polymerizate when the adhesive cures within a few seconds, even though the same chemical reactions have taken place as in normal oven curing. The foaming is caused by evaporation or decomposition of components. In order to achieve good mechanical properties, a defined morphology is required, and this cannot form in the short curing time.

Nevertheless, the required mechanical properties can be realized by first of all selecting reactive systems that are able to react adequately quickly with each other and which also have a defined heterogeneity. As the latter cannot be produced via mixture separation processes, the domains must be predefined e. g. in the form of nanoparticles or microscopic elastomer particles (Fig. 1). One example where rapid thermal curing is required, is when using components precoated with adhesive. The productivity advantage resulting from the precoating is often lost without the use of rapid curing.

PASA® technology from Fraunhofer IFAM – substrates pre-applied with adhesive

The assembly and bonding of components can be accelerated if there is no longer a need to apply an adhesive, namely if the adhesive is already present on the components as a dry layer. This strategy is sensible when the application of an adhesive under the given production conditions would not be favorable.

An example of this is the local strengthening of sheet components in press shops in the automobile industry – a work environment where handling liquid adhesives would be very difficult. Figure 2 (a-d) shows this application for the example of an engine hood component with bonded on lock reinforcement, for which a pre-applicable adhesive was used.

Another example is bonding studs, which are used in the automobile industry when the bodywork is made of carbon fiber reinforced plastic (CFRP) and standard welding studs cannot be used. If precoated studs were not used, a small amount of liquid adhesive would have to be applied to the studs. Although the necessary application technology is known from micro-bonding, it would be an enormous challenge to efficiently implement this in car bodywork manufacture.

1 *Adhesives with improved mechanical properties: Nanoparticles – e. g. a combination of small inorganic and large organic particles – can be used to generate elastic toughness (transmission electron micrograph).*

Fig. 2a: Engine hood component with adhesively bonded on lock reinforcement. 2b: Detailed view of the lock reinforcement using PASA® technology from Fraunhofer IFAM after e-coating and the e-coat oven: The adhesive is an epoxy resin which was pre-applied to the reinforcing sheet. 2c: Specimen preparation. 2d: Detailed cross-section of the lock reinforcement to visualize the homogeneity of the bonded joint.

The uses for pre-applicable adhesives cover all areas of modern adhesive bonding technology and are thus a main field of work of Adhesive Bonding Technology and Surfaces within the Fraunhofer IFAM. The institute has registered the trade name PASA® for these adhesives, namely "Pre-Applicable Structural Adhesives".

3

Quality assurance via color reactions

Key questions regarding quality assurance in adhesive bonding technology are whether an adhesive has been stored for too long and whether it has actually cured after a curing process. In order to check this for epoxy resins, a color reaction was developed. If the adhesive is stored for too long then the color changes. A second color reaction demonstrates that curing has taken place (Fig. 3). This strategy for quality control is ideal as well as future-oriented and particularly suitable for components supplied with a pre-applied adhesive.

Not only stronger, but also more elastic

High fracture strength and high elongation at break are often contradictory requirements. Indeed, cationic curing epoxy resins are deemed to be brittle, and not strong and elastic. By incorporating a certain heterogeneity, the fracture strength and elongation at break have been significantly increased, and values typical of commercial structural epoxy resin adhesives have been exceeded (Fig. 4). The photo in the figure shows the heterogeneity of an epoxy resin under a polarizing microscope. The knowledge about the material we have in the meantime acquired makes us certain that further increases are possible in the direction of the arrow on the graph.

3 *Monitoring the condition of an epoxy resin adhesive using a color reaction: bright red color (left beaker) indicating good adhesive and dark red color (right beaker) indicating an adhesive that has been stored for too long. The brown-colored cured adhesive can be seen on the front of the substrates.*

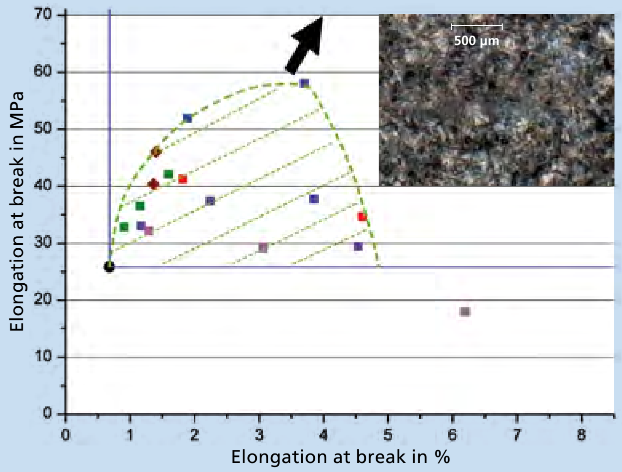


Fig. 4: Improvement of the fracture properties of a cationic curing epoxy resin adhesive by introducing a certain hetero-geneity. Values to the right and above the blue line indicate simultaneous improvement in the strength and elasticity. The values for two representative commercial structural adhesives are shown as brown diamonds. The photo insert shows an example of the heterogeneous structure under a polarized microscope.

Resistance to aging

In microsystems and medical technology, bonded joints must be resistant to media and conditions which far exceed normal test conditions. As an example new sterilization methods are mentioned here, which are also effective against multiresistant germs, or sensors which must efficiently function in hot oils and being suitable for Structural Health Monitoring (SHM) of large structures over long periods of time. In addition, there is the fact that in medical devices it is often desirable to have a bonded joint thickness of just a few microns and the substrates often have very different coefficients of heat expansion. In combination with the temperature changes that occur in most sterilization methods, the result is considerable mechanical stress. In order to combat these challenges, new

5

methods for improving the elastic toughness of adhesives are a major field of R&D work of the Adhesives and Polymer Chemistry section at Fraunhofer IFAM.

Adhesives are also exposed to extreme stress in space. A project is undertaken, for example, to develop new adhesives for solar cells on satellites. Besides rapid temperature changes of several hundred degrees Celsius, materials in space are exposed to very high levels of radiation. In addition, one requirement was constant, very high transparency. Due to the large adhesively bonding areas, high strength adhesives were not necessary for this application and the problem was solved by using specially synthesized silicones.

Pressure sensitive adhesives

High strength is likewise often not required for pressure sensitive adhesives, but nevertheless there are sometimes special requirements that cannot be met by commercial systems. For example, one project involved the development of a pressure sensitive adhesive system for a self-adhesive till roll (Fig. 5) without release paper with the aim of obtaining self-adhesive till receipts. The required bonding properties were similar to those of the familiar sticky notes used in offices. However, no adhesive must be transferred, because the adhesive side of the paper has to pass across various printer rollers in the till. The challenge was solved by using a nanoparticle modified pressure sensitive adhesive – a principle which can certainly be used for many other applications.

5 *A new pressure sensitive adhesive was developed for a self-adhesive till roll without release paper (source: Sigrid Reinichs/brandeins).*

Adhesives for medicine

When bonding soft body tissue for medical purposes, high adhesive strength is also not of primary necessity. Important – in addition to a flexible adaptation to the body tissue – is that the adhesive is tolerant to moisture during and after the application. Also essential are the biocompatibility and biodegradation of the adhesive system in the human body. The natural healing process must not be disturbed. Dental implants are a main area of application for biocompatible adhesives. A joint project was undertaken with partners from the medical sector (University Hospital Frankfurt am Main) and a material testing organization (Staatliche Materialprüfungsanstalt Darmstadt) to develop an adhesive system which allowed affixing of the connective tissue layer to titanium implants. This has, amongst other things, to prevent the penetration of bacteria and hence inflammation at the point of insertion. The starting point for the development work was the adhesive produced by the blue mussel. Parts of the protein-based adhesive were synthesized and then bonded to a classic polymer as a support. Laboratory tests demonstrated the biocompatibility and suitability of the adhesive system for the task in hand. Further development steps are at present being undertaken with industrial partners.

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PREDICTION AND EVALUATION OF RIVETING PROCESSES IN AIRCRAFT MANUFACTURE USING NEW SIMULATION METHODS

Riveting is the most widely used mechanical joining process in aircraft manufacture. Environmental requirements, new materials and technologies, new designs and high manufacturing output are challenges for the future application of riveting technology in the aircraft industry. An increasing need for better prediction of the mechanical properties of riveted structures is driving manufacturers to acquire a greater understanding of the riveting process itself. This will enable, for example, the effect of deviations from default specifications during the installation process on the mechanical performance of the joint to be determined. Further experimental and theoretical research work is necessary in order to understand how process parameters such as squeeze force, the fit between bolt and hole, etc., affect the stress state in and around the rivets.

Experimental tests on riveted structures give a rough and overall consideration of the structures. However, numerical simulation methods allow more detailed analysis of the mechanisms that occur during the riveting process and of the mechanical properties of riveted structures. Over the last three years, experts of the Materials Science and Mechanical Engineering at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM have used simulation methods to study process parameters for rivet installation and to implement them in several scenarios on riveted structures to define tolerable process parameters.

Rivet installation

As the fastener and the riveting process can be considered to be a rotation symmetric issue, a 2D finite element model (FEM, Fig. 1) was developed to study the effects, which occur during the rivet installation. The considered riveted joint consists of a solid rivet with a universal head in accordance with EN6081 made of aluminum AA7050 with a shank diameter of 4.0 mm, and two aluminum (AA2024-T351) adherends, each 3.0 mm thick.

The rivet material model was obtained by performing a compression test on specimens prepared from fasteners. The effect of friction between rivet, tool, and adherends was studied and a suitable friction coefficient was identified. The FE model that was developed for the rivet installation was validated by

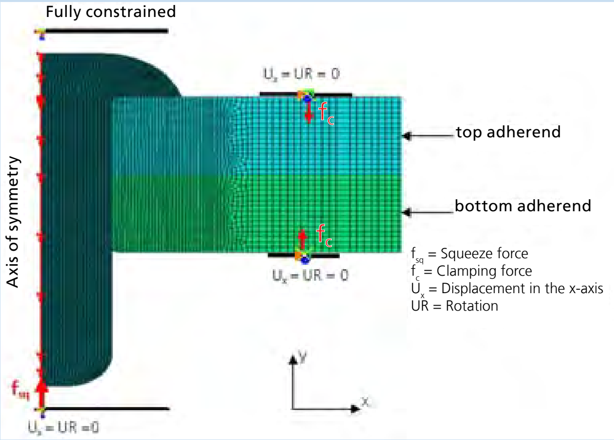

Fig. 1: FE model used to investigate rivet installation.

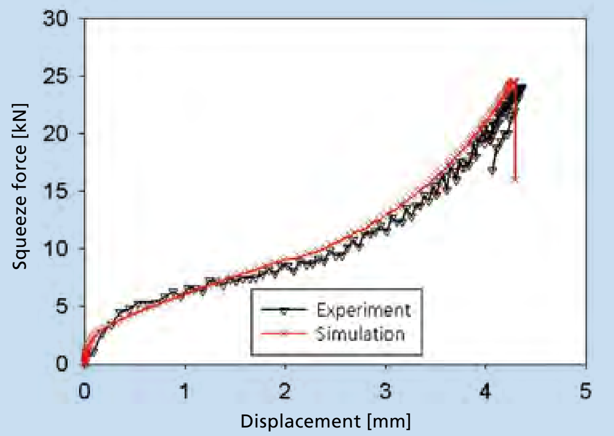

Fig. 2: Typical squeeze force-displacement curves – measured and simulated.

comparing the simulation with different experimental results. This involved the geometrical characteristics of the formed rivet head, the squeeze force-displacement curves, and the residual surface strain of an adherend. A typical measured force-displacement curve and a simulated one are compared in Figure 2.

After a suitable friction coefficient of μ = 0.2 had been chosen, which reveals a good agreement between the simulated and the observed closing head geometry (Fig. 4, middle), the clearance fit between the rivet shank and the hole, the rivet's grip length, and the squeeze force were numerically studied in order to determine their effects on the joint. The effects of these parameters were evaluated considering the adjusting and residual axial forces along the adherends and the relevant

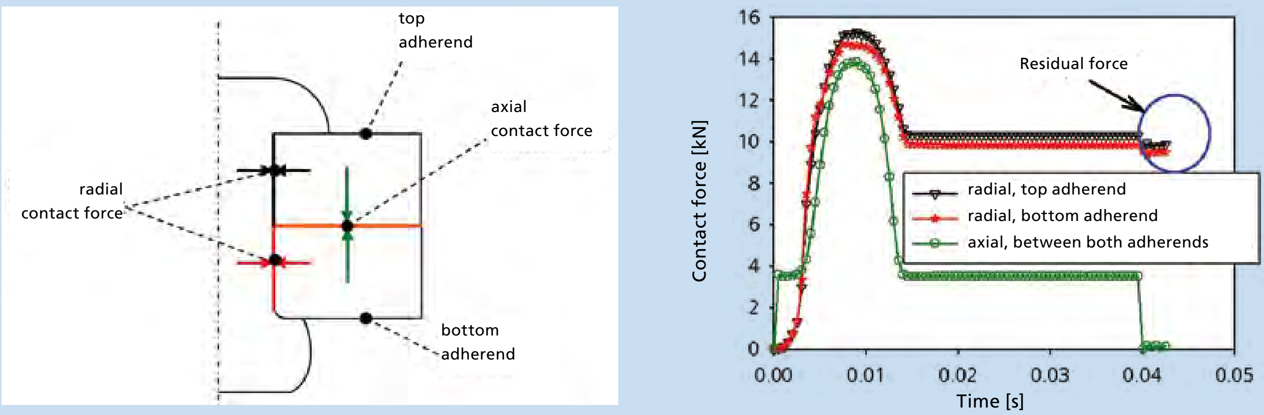

Fig. 3: Contact forces during the installation process.

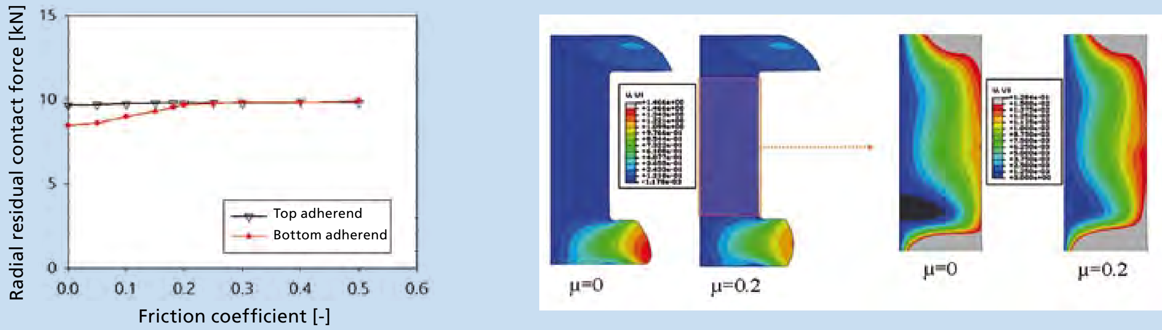

Fig. 4: Effect of the friction coefficient μ on the residual contact force and shank expansion.

residual radial contact forces between shank and adherends. Typical progressions of the contact forces during the installation of the aforementioned solid rivet and the areas that were evaluated are shown in Figure 3. The effect of the friction coefficient on the radial contact force and the shank expansion is illustrated in Figure 4.

Investigation of the mechanical joint behavior considering the installation processs

As the rivet installation process has a major effect on the residual stress state in the fastener and the surrounding structure, it is necessary to transfer this stress state to a suitable finite element model (FE model) that can be used for further investigations of the joint's mechanical properties. As mentioned above, the rivet installation was simulated using a 2D model. However, for investigation of the mechanical behavior a 3D model is essential. For this reason, a method was developed for transferring the joint's stress state from a 2D model to a 3D model. This was called "Symmetric Model Generation" method (SMG method). The main advantages of the SMG method are the reduction of the simulation time due to the usage of a 2D model for the rivet installation and the use of the same element discretization for both the model for the rivet installation and the model for the investigation of joint performance.

The implementation of the SMG method to generate a 3D model was performed on the joint configuration that was previously used for the rivet installation process, however, designed in this case as a single lap shear joint as presented in Figure 5.

The principle of the SMG method involves simulating the rivet installation with a 2D model, then applying the SMG method to create a 3D part by rotating the 2D results, and finally inserting the generated 3D part in a 3D model to simulate the joint's mechanical properties (Fig.6). The 3D part generated by the SMG method keeps up the stress state that occurs during

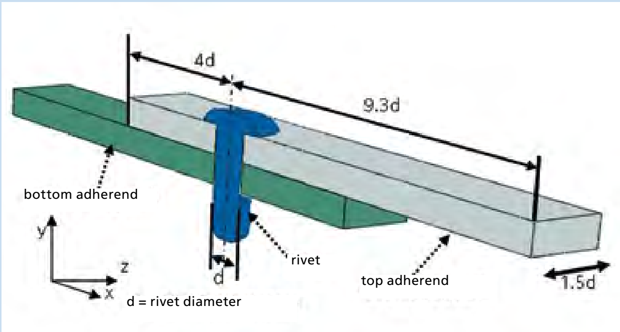

Fig. 5: Configuration of the modeled single lap joint.

the installation process and the contact conditions used during rivet installation.

The results of the simulations using the SMG method have been confirmed by comparing them to the results of the 3D simulation, which is considered to be the current state-of-the-art method. A good conformity had been ascertained. Specimens for experiments were manufactured with the Fraunhofer IFAM's full automatic C-frame riveting machine (Fig. 7a + 7b).

Figure 8 (left) compares the force-displacement curves obtained from the SMG method, from a full 3D model, and from experiments. Figure 8 (right) shows the joint stiffness and joint yield load obtained from simulations using the SMG method and compares them to values obtained from experiments. The results all show a good agreement.

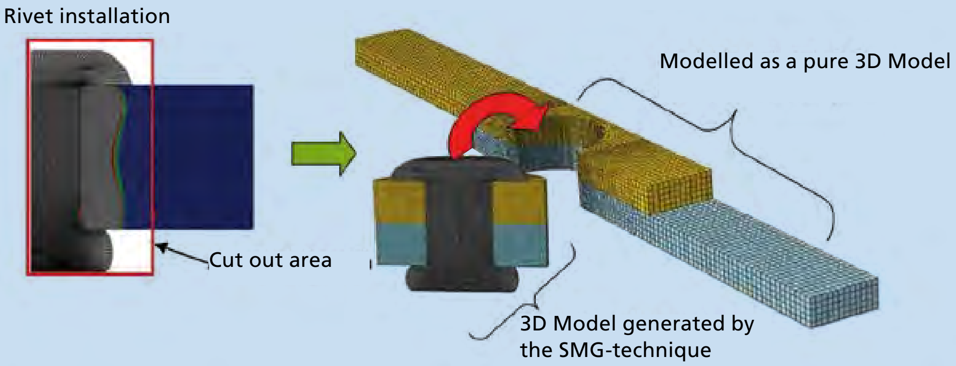

Fig. 6: Principle and use of the SMG method.

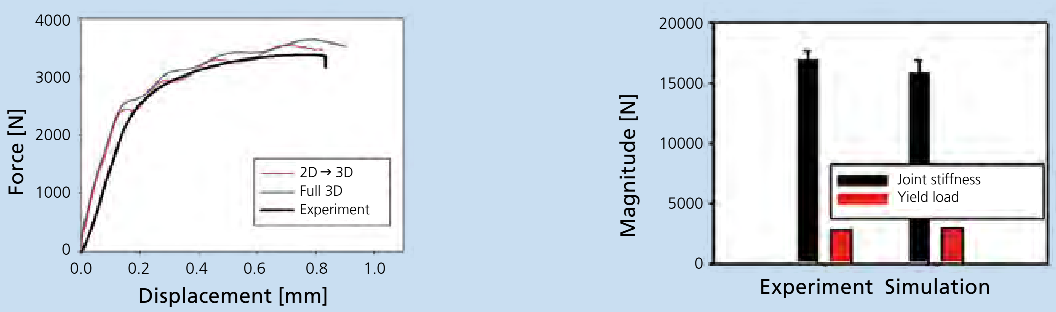

Fig. 8: Force-displacement curves (left), joint stiffness, and yield load.

7a *Fully automated C-frame riveting machine of Fraunhofer IFAM (left).*
7b *Riveted lap shear specimen during testing (right).*

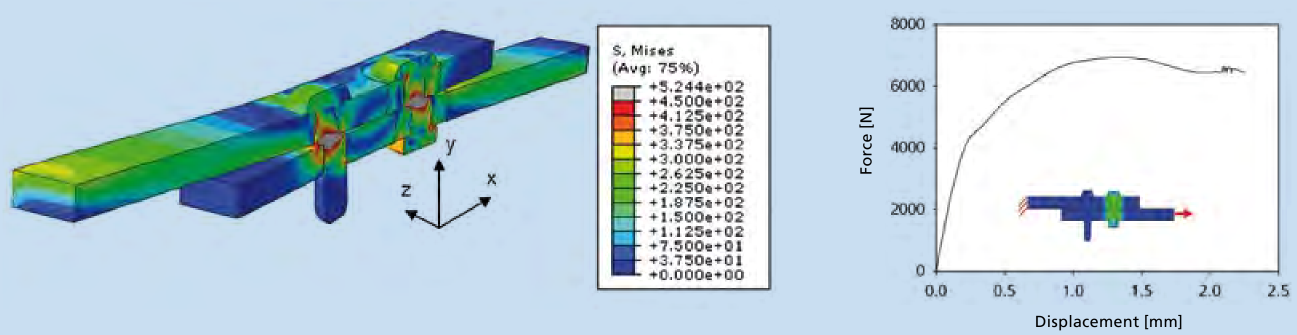

Fig. 9: Stress distribution and force-displacement curve for a single lap shear test with one squeezed and one not squeezed rivet using the SMG method.

Summary and outlook

The method developed by Fraunhofer IFAM and the results presented here focus on the use of numerical methods to predict and evaluate the mechanical performance of riveted joints. The effects of the rivet installation parameters on the joint's stress state and its mechanical behavior under shear load were investigated.

The SMG method reduces the computational effort. The SMG method also makes it possible to investigate riveted joints involving multiple rivets with different installation parameters in a very easy and time-saving way. Figure 9 illustrates a simple example of a riveted lap shear joint consisting of two rivets, showing how different installation parameters can be modeled. The first rivet is normally squeezed, whereas the second one is only inserted and not squeezed. Even though such a scenario is not of primary practical interest, it illustrates the possibilities and advantages of the SMG method.

The ongoing work of the scientists of Material Science and Mechanical Engineering at Fraunhofer IFAM is focusing on more relevant scenarios involving multi-fastener joints with different stress states resulting from different installation parameters.

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1

INNOVATIVE PLASTICS OFFER FUTURE PROSPECTS: TRAINING COURSES AT FRAUNHOFER IFAM IN FIBER REINFORCED PLASTICS

The Workforce Training and Technology Transfer activities of Fraunhofer IFAM are being expanded to meet the growing trend towards resource-friendly and environmentally-friendly lightweight design. Not only is there a need for employees to be trained in adhesive bonding technology – the predestined joining method for many lightweight construction materials – but in addition there is a need to qualify specialists in the manufacture and repair of fiber composite components.

Robust lightweight design – not without FRPs

They are already being used for diverse applications and are becoming ever more popular: All the talk is about fiber reinforced plastics (FRPs). The unique feature of these materials is that they are both light and highly stable and can be individually adapted for specific applications. Almost all of today's ground-breaking products use these materials.

The weight-saving compared to metals makes FRPs of special interest for means of transport. However, it is not only the aviation, aerospace, and automobile industry which use FRPs. They are also used in shipbuilding and rail vehicle manufacture, because the resulting lower fuel consumption and environmental protection play an important role here.

Innovative plastic composites are also used for construction to generate energy from renewables. Regardless of whether onshore or offshore: The rotor blades of wind turbines depend on fiber reinforced plastics. Wind turbines are becoming larger and larger, and rotor blades are becoming ever longer in order to generate more power. This can only be achieved using state-of-the-art powerful materials, namely materials which can easily be moved by the wind but which can withstand severe storms.

A wide range of starting materials can be used to make FRPs, and this is the reason for their diverse applications. Both the plastic and fiber material can be varied to customize FRPs for specific applications. Furthermore, several layers of fibers can be embedded in the plastic and these can have different orientations. This alters the subsequent component properties and differs depending on requirements.

2

No quality without qualified workers

The quality of an FRP component is highly dependent on the processing. This is because fiber composites are so-called “processed materials”: The material normally forms during component manufacture, namely on curing of the plastic matrix with the embedded fibers. Despite the diversity of manufacturing methods, all the manufacturing processes require qualified workers who are able to effectively monitor the processes and prevent the manufacture of costly defective products. During the manufacture, many parameters affect the resulting properties of the components. The sectors of industry which manufacture FRPs therefore have high staff requirements and a low degree of automation.

These sectors of industry require qualified employees in order to be able to guarantee high-quality components. This was the reason for the establishment of the Plastics Competence Center in Bremen in November 2006 under the direction of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM with the support of *Land* Bremen (Senator for Employment and Senator for Economic Affairs) and the Fraunhofer-Gesellschaft. The aim was to allow people employed in the FRP sector and also people seeking work to obtain a qualification in the manufacture of FRPs. As was done for welding technology and adhesive bonding technology, a training course was first of all developed and implemented at the technician level.

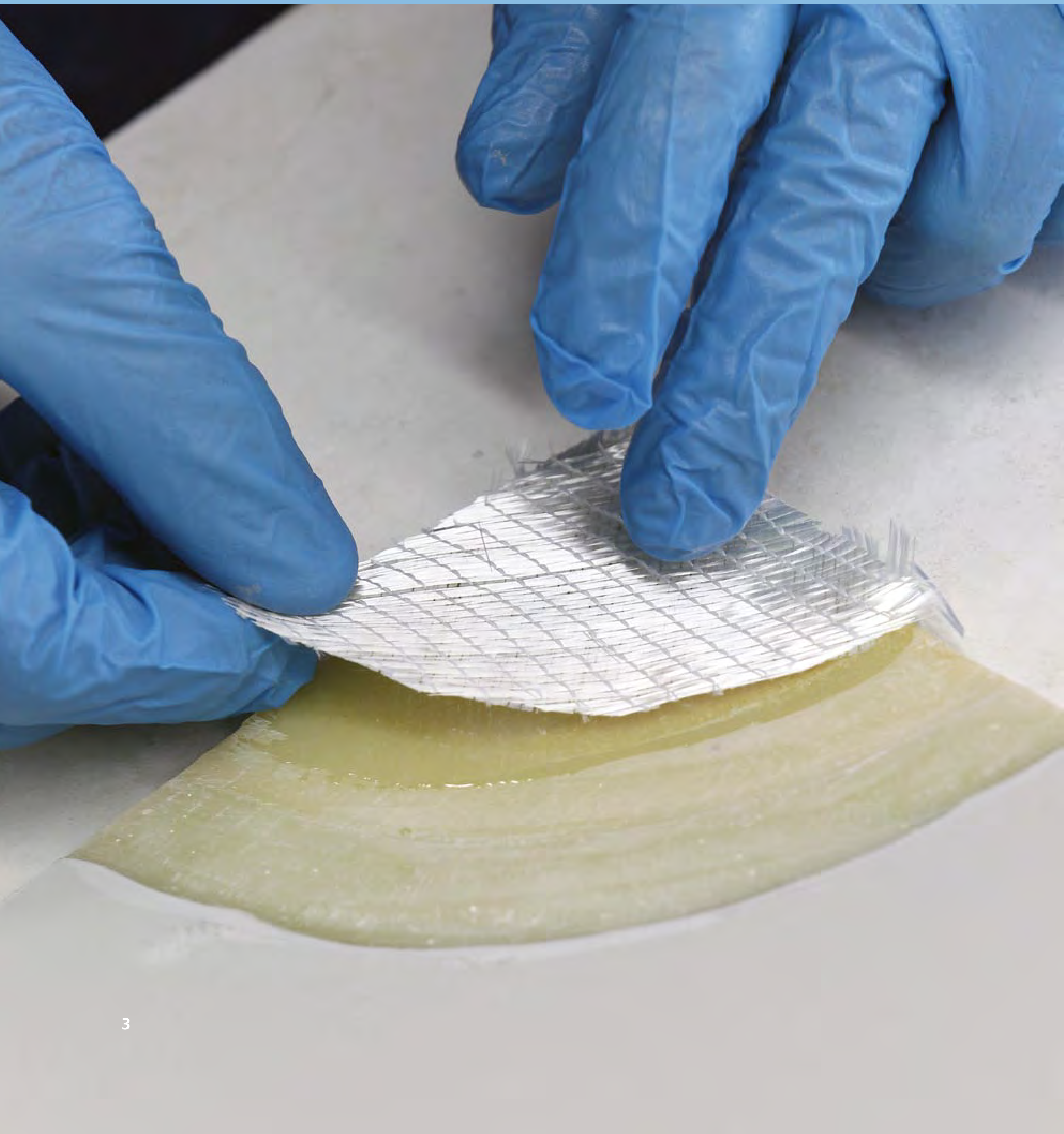
Award-winning training course – Fiber Reinforced Plastic Technician

The Fiber Reinforced Plastic Technician (FRP-Technician) is a four-week training course that is split into four individual modules and ends with a certifying final examination. It is a supracompany, cross-sector training course with a high practical content. This approach allows various manufacturing processes to be learned at first hand and theoretical knowledge to be reinforced (Fig. 1).

The training course was developed in collaboration with the “Plastics Training Partnership” which comprises SGL ROTEC GmbH & Co. KG, PowerBlades GmbH, Airbus Deutschland GmbH, bfw – Unternehmen für Bildung, HAINDL Kunststoffverarbeitung GmbH, the Stiftung Institut für Werkstofftechnik IWT, as well as Faserinstitut Bremen e. V., and the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM. Experts from these companies and organizations pass on the latest theoretical knowledge as well as practical developments and bring their expertise directly to the course. This close collaboration of R&D and industry benefits the course participants, as evidenced by the some 600 people who have taken the Fiber Reinforced Plastic Technician course since its inception and now use this know-how in industry (Fig. 2).

1 *Manual lamination as an introduction to manufacturing FRPs – one aspect covered in the Fiber Reinforced Plastic Technician course at the Fraunhofer IFAM.*

2 *The high practical content of the FRP-Technician course reinforces the theoretical content, for example here with autoclave technology.*



In order to respond to the need for qualified employees in the wind energy sector, the focus was initially on training people seeking work. For this reason, the course was accredited in accordance with the German quality standard for further training (AZWV) – a precondition for the Bundesagentur für Arbeit (Employment Office) to pay the course costs. Also an eight-week course was developed in order to qualify participants without any prior knowledge. The course was highly conciliated by the Empolyment Office, so that course places were swiftly taken up in order to meet the demand course, other venues were also arranged in the vicinity of Bremen.

By the end of 2009 some 70 percent of the course participants had found employment, emphasizing the quality of the training course and the demand of industry. The training course concept for Fiber Reinforced Plastic Technician was awarded the Training Course Innovation Prize 2009 by the Federal Institute for Vocational Education and Training (Bundesinstitut für Berufsbildung BIBB). The Lower Saxony Minister of Culture, Elisabeth Heister-Neumann, and the President of BIBB, Manfred Kremer, presented the Innovation Prize at the "didacta" trade fair in Hannover on February 12, 2009 to Dr. Silke Mai, head of the Plastics Competence Center, Dr. Daniela Harkensee, and Prof. Dr. Andreas Groß, who leads the Workforce Training and Technology Transfer activities at Fraunhofer IFAM.

The situation in the employment market has in the meantime become stable, meaning that the Plastics Competence Center can once again focus on providing training for employees of companies that presently manufacture FRPs or intend to do so in the future. Besides giving courses at the Plastics Competence Center in Bremen, in-house courses are also offered at companies when an employer wishes a larger number of employees to take the course at the same time. In addition, this also allows customer-specific topics related to their production to be included in the course.

Playing a key role –
the Fiber Reinforced Plastic Remanufacturer

Besides being able to manufacture high-quality FRP components, another key aspect is the repair of these complex materials (Fig. 3). Fiber reinforced plastics often have safety functions and hence the material properties must also be guaranteed after carrying out repairs to components.

Pioneering here was the rail vehicle construction sector which specified what requirements must be fulfilled in order for the quality standards to be guaranteed. The coming into force of DIN 6701 introduced binding standards for adhesive bonding work in rail vehicle construction. This will be followed in the near future by DIN 27201 "State of rail vehicles – base principles and production technologies", which will lay down similar regulations for repairing rail vehicles. In addition to adhesive bonding technology, the special requirements for the repair and maintenance of fiber composites play a key role here. Part 13 of DIN 27201 "Repair and maintenance of fiber reinforced plastic components", which is due to be published in 2012, will hence specify the special requirements concerning both the remanufacturing process and the qualification of employees undertaking the work.

In order to meet the qualification requirements, from 2012 Fraunhofer IFAM will also offer a new training course for Fiber Reinforced Plastic Remanufacturer (FRP-Remanufacturer). This is directed at employees from companies who independently maintain, repair, and process components made of fiber reinforced plastics. The focus of this training course is on recreating the full functionality of FRP components and will cover a range of repair methods (Fig. 4).

3 *Reconstruction of the layer structure for the repair of a glass fiber composite – skills learned in the FRP-Remanufacturer training course at the Fraunhofer IFAM.*

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This strategically expands the range of training courses offered by the Fraunhofer IFAM. It complements the FRP-Technician training course, which covers the principles of manufacturing FRPs and manufacturing methods, with further key knowledge.

The division of Adhesive Bonding Technology and Surfaces of Fraunhofer IFAM will continue to further develop its training courses to include the latest know-how and to meet the future needs of the market. This is vital because processes and applications for fiber composites are continually changing – as is common with innovative materials and methods.

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4 *Precise work is the key to successful remanufacture of fiber reinforced plastics.*

PEOPLE AND MOMENTS

1

PREMIERE FOR FRAUNHOFER IFAM: THE PRESIDENT OF GERMANY AND MINISTER-PRESIDENT OF LOWER SAXONY VISIT STADE TO LEARN ABOUT R&D ACTIVITIES

The Fraunhofer Project Group Joining and Assembly FFM of Fraunhofer IFAM is working with industrial partners to develop innovative automated assembly technologies for large FRP components up to an XXL scale. This work is being carried out in Stade, where the facilities cover 4000 square meters of floor space. This was the reason for Christian Wulff, the then President of Germany, and David McAllister, Minister-President of Lower Saxony, to visit the research center CFK Nord (CFRP North) in Stade – the first visit of a head of state to Fraunhofer IFAM.

The Fraunhofer FFM at research center CFK Nord (CFRP North) collaborates directly with companies in, for example, the transport sector – in particular the aircraft manufacturing industry – and the wind energy sector in order to develop customized processes and automated systems. Under the leadership of Dr. Dirk Niermann, scientists and technicians are developing integrated system solutions for industry and optimally adapted production as well as plant technology on a 1:1 scale. The use of existing automation solutions is not possible because the assembly of large structures requires, on account of the unavoidable shape deviations of the components, special optical measurement technology, absolute robot precision, and constant adaptation of processing and machining paths.

The aim of the R&D work is to increase productivity and simultaneously reduce costs. In the area of assembly involving bonding processes, there is precise application of the quantity of adhesive as determined by the actual gap size. Conventional test substrate joining is avoided. Accelerated adhesive curing is a further benefit. In high precision processing, the focus is on fault prevention using measurement data acquired from the ongoing process, and also on the simultaneous execution of several process steps on the same component (see page 67; "Faster, lower costs, and improved quality: Fraunhofer IFAM accelerates industrial processes").

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1 *Institute Director Prof. Dr. Bernd Mayer, and head of Fraunhofer FFM, Dr. Dirk Niermann, show the President of Germany, the Minister-President of Lower Saxony, and invited guests from the worlds of commerce, politics, and science the automated assembly involving adhesive bonding on a CFRP aircraft fuselage.*

IN-LINE PLASMA COATINGS FOR EFFICIENT CORROSION PROTECTION: COSI INNOVATION AWARD 2011 FOR CHRISTOPH REGULA

In July 2011 physicist Christoph Regula was presented with the Innovation Award 2011 at the 7th Coating Science International Conference (CoSi) in Nordwijk (Netherlands) for his talk on the development of in-line atmospheric pressure (AP) plasma processes for depositing corrosion protection layers on metal substrates. More than 110 delegates from R&D organizations and industry from 23 countries attended the conference.

The use of AP plasma technology for the low-cost and environmentally friendly pre-treatment and coating of copper and aluminum surfaces was developed by the experts of Plasma Technology and Surfaces – PLATO – at Fraunhofer IFAM. The talk by Christoph Regula was deemed to be most innovative at the conference, from over 70 talks and posters, due to its linking of fundamental research results with industrial applications.

Corrosion protection at the nano-level

The protection of metal surfaces is essential for, in particular, the long life service of electronic components because corrosion can quickly lead to total failure, e. g. in automobiles. The plasma-polymer layers that have been developed are an efficient and eco-friendly protective system that can be applied at high processing rates and by automated technology, without baths and drying ovens. The layer thickness is less than a micron, meaning there is better heat dissipation from the components than when using protective lacquers. The result is a longer service life. The additional incorporation of corrosion inhibitors into the plasma-polymer layers also provides active corrosion protection, intending that the component surface is protected against corrosion even in the event of damage to the layer.

A particular feature of the technology is its suitability for in-line integration and its compactness. This allows the use in existing process lines. This means that there is no need for energy-intensive and space-consuming baths or lacquering processes, thus reducing production costs and solvent emissions.

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1 *The CoSi Innovation Award 2011.*

2 *Christoph Regula (left) receives the CoSi Innovation Award from Prof. Dr. Gijsberthus de With, professor at the Technical University of Eindhoven and co-organizer of the 7th Coating Science International Conference.*

GHTC AWARD FOR DR. UWE LOMMATZSCH AND DR. JÖRG IHDE IN BOSTON FOR THE PLASMA-POLYMER PROTECTION LAYER FOR SOLAR MODULES

The "German High Tech Champions Award (GHTC) 2011" in the area of solar energy/photovoltaic technology was presented on June 15, 2011 in Boston, USA, to Dr. Uwe Lommatzsch and Dr. Jörg Ihde. The two researchers and their team at the Fraunhofer Institute for Manufacturing Technology and Advanced Material IFAM developed atmospheric pressure (AP) plasma processes which allow materials to be provided with functional surfaces.

The award-winning AP plasma coating prevents corrosion damage to solar modules by hindering delamination processes and the penetration of water. The extremely thin layer (50–300 nm), which is applied without further curing processes, has a high UV stability and does not impair the electrical conductivity or optical properties. The maintenance requirements are reduced and the functional reliability as well as the service life of the solar modules are enhanced.

In addition to the corrosion protection effect, AP plasma coatings can also provide dirt-repelling functions and adhesion promotion properties. The coating processes can be customized to special product requirements and can be integrated inline into process chains in industrial production. They can be fully automated and can – if desired – be selectively applied. The coating process at atmospheric pressure requires little space, does not involve baths, is eco-friendly, energy-efficient, and offers a safe working environment.

AP plasma coatings are suitable for almost all substrate materials including metals, ceramics, glass, and polymers. Practical experience has already been acquired in many sectors of industry – from car production to high-end photovoltaic products: Atmospheric pressure plasma technology provides a cost-efficient innovation potential for improved respectively new technologies, materials, and products for today and the future.

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1 *Less corrosion and lower maintenance requirements plus high functional reliability and longer service life: AP plasma protective layer for solar cells from the Fraunhofer IFAM (Source: MEV-Verlag).*

BERND-ARTIN WESSELS PRIZE FOR EXCELLENT RESEARCH COOPERATION

On November 16, 2011, the research team working with Dr.-Ing. Philipp Imgrund at Fraunhofer IFAM was awarded the "Bernd-Artin Wessels Prize" by Unifreunde Bremen. The selection criteria for this prize are: a high level of innovation, usefulness of the project for the business, and successful cooperation with partners. Together with the project partners Prof. Dr.-Ing. Kurosch Rezwan (University of Bremen), Prof. Dr. med. Ulrich Wagner (Medical Clinic Wesermünde-Seepark), and Dipl.-Ing. Martin Ellerhorst (BEGO Implant Systems GmbH & Co), the team successfully developed and tested an innovative bioceramic bone screw within two years for the treatment of torn cruciate ligaments.

In contrast to the metal or plastic-based screws currently available on the market, this bioceramic bone screw corresponds almost completely in its chemical composition to the main component in bone: calcium phosphate. This bone-like composition enables a biologically optimal integration of the screw into the bone. The bone is therefore capable of resorbing the screw, i.e. by dissolving it through the body's natural biological processes. The released calcium can be directly integrated into the newly formed bone and even effect a potentially accelerated healing process. In addition, the resorption of the screw means that the otherwise necessary and expensive follow-up operation to remove the screw is no longer required.

The engineers at Fraunhofer IFAM developed a granular form of the biomaterials, which can be precisely processed using conventional injection molding methods. This means that post-processing, such as milling, is also not necessary. The complex geometry can be directly formed and then heat-treated at 1400 °C (sintered). The result is a robust, dense screw made of pure calcium phosphate. The properties of this prototype are very close to those of bone: its pressure resistance is over 130 Newton per square millimeter (N/mm^2) – a natural dense bone can withstand pressure values between 130 and 180 N/mm^2.

Based on this prototype series, the first tests successfully established that this method could meet the high medical, biological and mechanical requirements necessary. The bio-resorbable bone screw is currently in the process of being patented and has an estimated global market potential of approx. € 400 million.

CONTACT

Institute

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Shaping and Functional Materials Division, Bremen

1 *The prize winners and the sponsor: Prof. Dr. med. Ulrich Wagner, Dr.-Ing. Philipp Imgrund, Prof. Dr. h. c. Bernd-Artin Wessels, Prof. Dr.-Ing. Kurosch Rezwan (from the left).*

GROUPS | ALLIANCES | ACADEMY

NETWORKED AT FRAUNHOFER

1

FRAUNHOFER GROUPS

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.

Fraunhofer Group for Materials and Components – MATERIALS

The Fraunhofer Group for Materials and Components – MATERIALS pools the competencies of the Fraunhofer-Gesellschaft institutes working in the field of materials science.

Materials science and material engineering cover the entire value chain from innovative material advancement and the improvement of existing materials to production technology at industry-level scales. In addition, they encompass the characterization of properties up to the evaluation of application behavior. The same applies to the components made from these materials and their behavior in systems. In addition to experimental studies in laboratories and technical centers, numerical simulation and modeling processes are equally implemented in all fields. The Fraunhofer Group for Materials and Components – MATERIALS is responsible for the entire sector of semi-conductor materials and all materials produced using metallic, inorganic-non-metallic, polymeric, and renewable raw materials.

The Group focus is on applying their expertise within the business areas of energy and environment, mobility, health, machine and plant engineering, construction and housing, microsystem technology, as well as safety. The Group achieves system advances using customized material and component development, in consideration of the evaluation of customer-specific application performance.

Primary topics of the Group include:

- Improving safety and comfort, and reducing resource consumption in the sectors of traffic engineering, machine and plant engineering
- Increasing system efficiency for energy generation, energy conversion, and energy storage; improving biocompatibility and the function of materials used in medicine or biotechnology
- Raising integration density and refining usage properties of components in microelectronics and microsystem technology
- Enhancing the use of raw materials and bettering the quaity of the products made from these materials

The Group includes the following Fraunhofer institutes:

- Applied Polymer Research IAP
- Building Physics IBP
- Structural Durability and System Reliability LBF
- Chemical Technology ICT
- Manufacturing Technology and Advanced Materials IFAM
- Wood Research, Wilhelm-Klauditz-Institut, WKI
- Ceramic Technologies and Systems IKTS
- High-Speed Dynamics, Ernst-Mach-Institut, EMI
- Silicate Research ISC
- Solar Energy Systems ISE
- Systems and Innovation Research ISI

1 *Well connected within the framework of Fraunhofer-internal research programs MAVO and WISA.*

- Mechanics of Materials IWM
- Non-Destructive Testing IZFP

Actively participating permanent guest member institutes:
- Interfacial Engineering and Biotechnology IGB
- Industrial Mathematics ITWM

www.materials.fraunhofer.de

Group Chairman
Prof. Dr.-Ing. Holger Hanselka

Deputy Group Chairman
Prof. Dr.-Ing. Peter Elsner

Executive Director
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Prof. Dr. rer. nat. Bernd Mayer
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FRAUNHOFER ALLIANCES

The Fraunhofer Alliances facilitate customer access to the services and research results of the Fraunhofer-Gesellschaft. Institutes, or divisions of institutes, cooperate to find marketable solutions to complex issues.

Fraunhofer Adaptronics Alliance

The adaptive structure technology, in short Adaptronics, integrates actuator and sensor functions into structures and links these functions through (often adaptive) control 'intelligence'. This allows structures to recognize their own condition and actively react to it, leading to the realization of adaptive structure systems. With this background, light and compact as well as vibration-free and dimensionally stable modern structures can be designed that optimally adapt to their changing operating environment.

This leads to the conservation of raw materials, reduced environmental pollution such as noise and emissions, reduced system and operating costs, and increased functionality and performance of systems. Adaptronics has a particular application potential in the fields of automotive engineering, machine tool manufacture and plant construction, medicine and space technology, optics, and defense technology.

The mechanical properties, efficiency and performance capability of systems can be improved. These include economic material utilization, function enhancement and increased comfort and safety aspects, such as optimization of vehicle crash characteristics or damage monitoring.

www.adaptronik.fraunhofer.de

Speaker of the Alliance
Prof. Dr.-Ing. Holger Hanselka

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Fraunhofer autoMOBILproduction Alliance

Carmakers, their suppliers, and those equipping the automotive industry, represent a decisive economic factor in Germany. Significant changes to the entire concept of mobility are ultimately being driven by global trends, such as dwindling natural resources, an increasing need for mobility, urbanization and megacities. In addition, German carmakers and their suppliers are facing increasingly tough competition as the trend towards low-cost vehicles takes hold.

The Fraunhofer Alliance pools the expertise of 17 institutes, who collectively provide the German automotive industry with a competent single-source partner for its research and development needs. The complementary effect, achieved by combining the individual institutes' key areas of research, makes it possible to generate rapid, integrated and sustainable innovations along the entire process chain of vehicle manufacturing – from the planning stage right through to the finished vehicle.

The Alliance tackles the challenges posed by environmental policies (reducing fuel consumption and CO_2; electromobility; cutting material consumption) while taking full account of commercial imperatives (ongoing pressure to cut costs).

Key tasks performed by the Alliance:

- Consistent use of virtualization, and simulation of the entire process chain
- Reduction in the amount of required materials (use of recyclable materials with long-term availability)
- Use of innovative technologies that save resources
- Low-energy plant technologies

www.automobil.fraunhofer.de

Speaker of the Alliance
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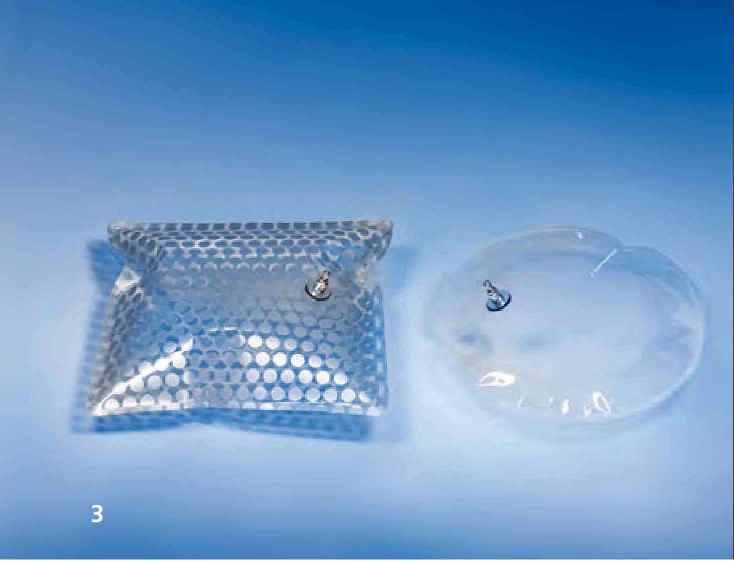
2 *Production and assembly processes.*

3 *Adhesively bonded membrane cushions made of ethylene-tetrafluoroethylene film (ETFE film) for use in facade design..*

4 *Additively manufactured calibration tool with internal vacuum and cooling channels..*



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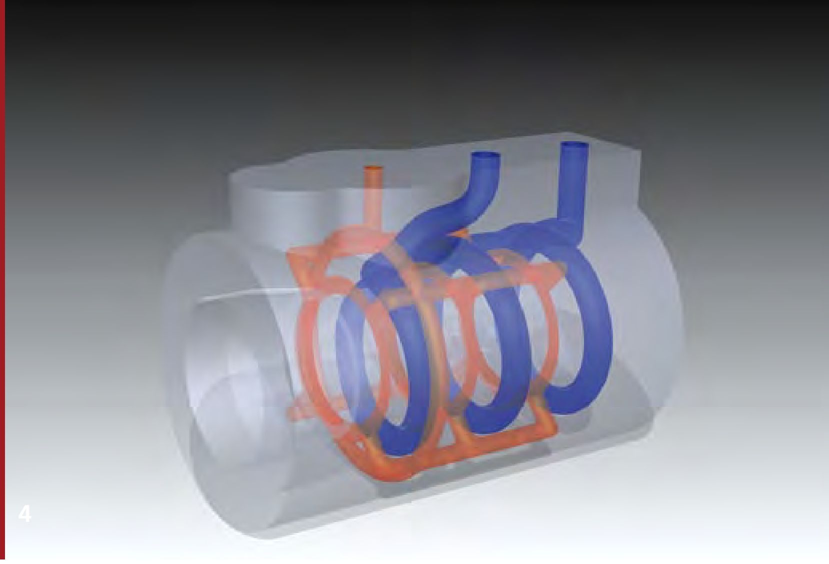

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Fraunhofer Building Innovation Alliance

The construction industry has high potential for innovation, and it is with the aim of tapping this potential that several institutes have pooled their resources in the Fraunhofer Building Innovation Alliance. The Alliance offers single-source construction expertise by means of integrated systems solutions. Its portfolio encompasses not only the systematic consideration of buildings, from materials and components to rooms, buildings and entire housing estates, but also the chronological consideration of buildings – that is, their entire life cycle from the initial idea through to final recycling.

Opportunities for rationalization and potential for optimization can be found throughout the construction process chain, starting with the original construction, including building materials and systems, and extending through to the conversion and dismantling of a building. In this era of exploding energy prices, the energy efficiency of buildings is a key issue for both residential and industrial buildings. However, the focus of the alliance reaches much further than this. It aims to assure sustainability, careful use of resources, and healthy construction methods in building and living, and to address issues such as product, system, and process optimization. Construction research shares common ground with the Fraunhofer expertise in the areas of energy, information and communication technology, materials and components, life sciences, production, microelectronics, and defense or security research.

www.bau.fraunhofer.de

Speaker of the Alliance
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Fraunhofer Additive Manufacturing Alliance

The generic term "Additive Manufacturing" describes processes for the manufacturing of models, shapes, tools, and functional components. Additive manufacturing offers a high success potential for the rapid and efficient conversion of product innovations for prototypes and small production series.

The Fraunhofer Additive Manufacturing Alliance pools the competencies of nine Fraunhofer institutes, developing innovative concepts for the application of additive production technologies. This Alliance puts the Fraunhofer-Gesellschaft in a position to offer complete solutions in product development by depicting the entire process chain. In addition to the additive core processes, it encompasses both up and downstream processes: From process preparation, including the acquisition and preparation of data, to the final development of properties for products ready for use.

Together with national and international partners, the Alliance develops individual concepts, technologies, and processes for improving the performance and competitive ability of small and medium-sized businesses. The Fraunhofer Additive Manufacturing Alliance is a member of the management in the EU Rapid Manufacturing platform in Brussels and is responsible for the organization of the "German" working group within this EU platform.

www.generativ.fraunhofer.de

Speaker of the Alliance
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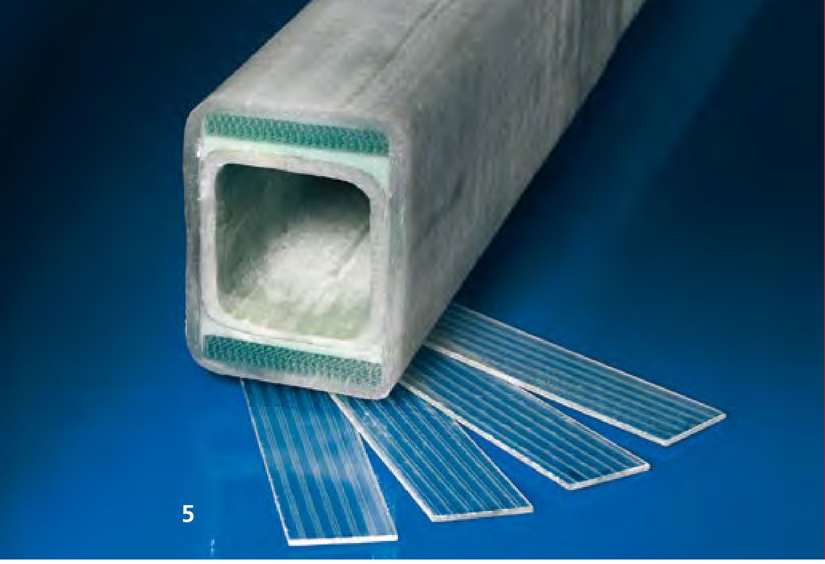

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Fraunhofer Lightweight Construction Alliance

Creating lightweight structures means reducing weight whilst retaining sufficient rigidity, dynamic stability and strength. It must be ensured that the components and structures developed here fulfill their objective safely over the period of application.

Lightweight structure quality is primarily dependent on the material properties, the constructive shaping process, and the design and production process. It is therefore necessary to examine the entire development chain, from material and product development to approval, mass production, and product application.

The institutes collaborating in the Fraunhofer Lightweight Construction Alliance have the necessary expertise in the following areas:

- Materials and material composites for lightweight construction
- Joining and production processes in lightweight construction
- Numerical and experimental simulation in lightweight construction
- Evaluation of components and systems

www.leichtbau.fraunhofer.de

Speaker of the Alliance
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Fraunhofer Nanotechnology Alliance

Nanotechnology, comprises a range of crosscutting new technologies for the next years to come, dealing with materials, systems and devices in which something very small (below 100 nm) determines functions and applications.

Nanotechnology is an integral part of our everyday life: As an example, nanoparticles in suntan lotions protect the skin against UV radiation, and they are used to reinforce car tires; nanotechnology can help to produce easy-care scratch-resistant surfaces, while ultra-thin coatings are an important element in data storage media. The technology is already in use for a wide variety of applications across all sectors of industry, generating a worldwide sales volume of 80 to 100 billion euros.

Nearly a third of all Fraunhofer institutes are active in this field. The activities of the Alliance focus on multifunctional coatings for use in such areas as the optical industries, the design of special nanoparticles for use as fillers and functional materials in biomedical applications, and a novel type of actuators based on carbon nanotubes. In national and European research projects, the Alliance also treats questions regarding toxicology and operational safety while dealing with nanoparticles.

www.nano.fraunhofer.de

Speaker of the Alliance
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7

Fraunhofer Photocatalysis Alliance

Photocatalytic active coating systems with self-cleaning, antibacterial, foul-resistant, or fog-reducing characteristics are the central focus of the R&D work carried out by the Fraunhofer Photocatalysis Alliance.

The aim of the Alliance is the development of new material and coating concepts for higher-performance photocatalysts and their application on various surfaces such as glass, plastics, and metals.

The eight participating institutes bring a comprehensive, diverse set of competencies to the Alliance: material, coating and process development, analysis techniques, as well as test and measurement systems for assessing biological activity and also ecotoxicological environmental impact.

www.photokatalyse.fraunhofer.de

Speaker of the Alliance
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Fraunhofer Polymer Surfaces Alliance (POLO)

The Polymeric Surfaces Alliance (POLO) pools the core competences of seven Fraunhofer institutes in the development of polymer products with functional surfaces, barrier layers, or thin films. This strategic and operative collaboration is supported by a joint marketing approach. The Alliance thus broadens significantly the range of activities that can be offered by each individual institute.

The Alliance works to achieve concrete results in preliminary development and secures the relevant industrial property rights for polymer products that have new or significantly enhanced properties. Products already developed in the areas of "flexible ultra-barriers" and "anti-microbial polymer surfaces" are targeted at the optical and optoelectronic industry, the building and construction industry, and the packaging, textile, medical, and automobile industry.

www.polo.fraunhofer.de

Speaker of the Alliance
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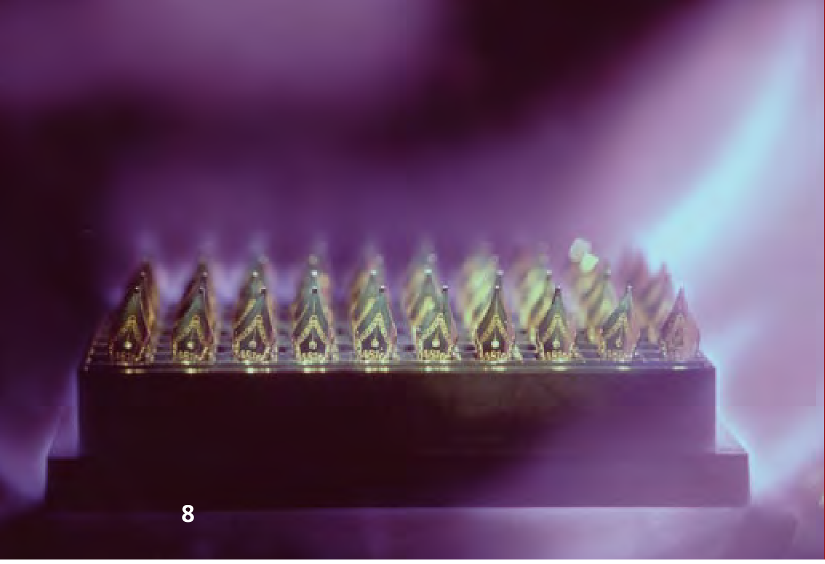
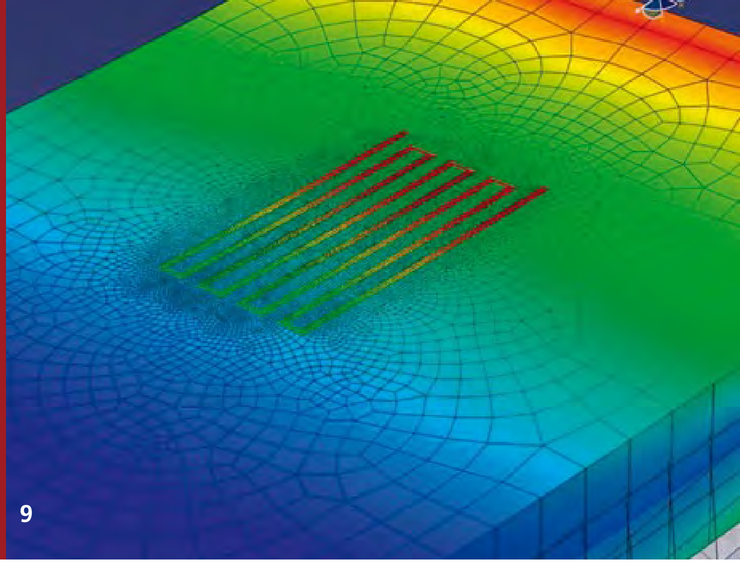
5 *Bonded beam made of glass fiber reinforced plastic (GFRP) for determining the fatigue strength of rotor blade materials.*

6 *Enhanced dispersibility of nanoparticles (color particles) by plasma treatment at atmospheric pressure (plasma-treated right).*

7 *Filter material with improved chemical resistance and increased service life due to an ultra-thin plasma-polymer coating.*





Fraunhofer Cleaning Technology Alliance

The cleaning of surfaces is the subject of research at a number of Fraunhofer institutes engaged in different spheres of activity. No single institute focuses exclusively on cleaning technology. The capabilities of the individual institutes are pooled in the Alliance, so that the entire process chain relating to cleaning can be addressed. In addition to different cleaning techniques, the chain of activity involved in cleaning technology also encompasses the upstream and downstream processes.

Upstream processes deal with process analysis, where the emphasis lies on preventive measures to avoid contamination and reduce the necessity and cost of cleaning. Downstream processes include quality assurance of the cleaning work, drying technology for wet-chemical cleaning processes, and the environmentally compatible disposal of waste products and used solvents. To cover the entire range of cleaning technologies used in different sectors of industry, the Alliance has defined separate areas of business focusing on the cleaning of buildings and structures, sanitation and hygiene, cleaning in microsystems engineering, surface cleaning prior to coating, and cleaning of electronic components.

www.allianz-reinigungstechnik.de

Speaker of the Alliance
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Fraunhofer Numerical Simulation of Products, Processes Alliance

In the Fraunhofer Alliance for Numerical Simulation of Products and Processes, twenty institutes pool their expertise in the development and improvement of simulation techniques.

The simulation of products and processes today plays a decisive role in all phases of the product life cycle, from model-based materials development and simulation of manufacturing processes to operating characteristics and product placement on the market.

The object of the Alliance is to address institute-overarching issues and to represent the interests of the member institutes as a central point of contact for public sector and industrial customers. In particular, the pooling of expertise from the I&C sector with materials and components know-how as well as with surface technology, production, and microelectronic engineering promises to yield innovative results.

www.simulation.fraunhofer.de

Speaker of the Alliance
Andreas Burblies

Fraunhofer IFAM contact
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8 *Fine cleaning of nibs.*
9 *Numerical stress simulation of a strain gauge.*

Fraunhofer Traffic and Transportation Alliance

The Fraunhofer Traffic and Transportation Alliance develops technical and conceptual solutions for customers from the public sector and industry and translates them into practical applications. It does this by identifying future developments and guiding the focus of sponsored research programs.

The Alliance analyzes market requirements and develops system solutions in multi-institute collaborative projects. It also draws together and markets the expertise of its members in the field of traffic and transportation. Work groups such as FVV-Automotive, FVV-Rail, FVV-Aviation and FVV-Waterborne help to assure a close relationship with the sector. International research programs and contracts from around the world ensure that the member institutes maintain links to companies and research organizations involved in traffic and transportation worldwide. The Alliance's central office brings together suitable partners.

www.verkehr.fraunhofer.de

Speaker of the Alliance
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Fraunhofer Academy – research know-how for your success

The Fraunhofer Academy consolidates all advanced training courses offered by the Fraunhofer-Gesellschaft under one roof, offering excellent further education options for technical and business staff. Cutting-edge science and research results are integrated immediately in course teaching materials – a genuine pact for research and innovation. First-class training is a foundation for future careers – continuous advanced training is an absolute necessity for staying on top.

- **Industrial adhesive bonding technology – Workforce qualification at the Center for Adhesive Bonding Technology, Bremen**

Adhesive bonding has become the main bonding technology of the 21st century. The transfer of the entire potential inherent in adhesive bonding technology into commercial applications is ensured through specific, customized advanced training courses for European Adhesive Bonder (EAB), European Adhesive Specialist (EAS), and European Adhesive Engineer (EAE) in the Center for Adhesive Bonding Technology, Bremen.

- **Fiber composite technology – Workforce qualification at the Plastics Competence Center**

The Fiber Reinforced Plastic Technician training course awarded with the Training Course Innovation Prize 2009 is highly relevant for future multi-functional products and lightweight constructions, particularly for the transportation sector and the manufactures of wind turbines. As of 2012, training courses for Fiber Reinforced Plastic Remanufacturer complement the portfolio of the Plastics Competence Center.

www.academy.fraunhofer.de

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www.kleben-in-bremen.de | www.kunststoff-in-bremen.de

NAMES | DATES | EVENTS


1

1 *Fraunhofer IFAM, Bremen.*

Conferences | Congresses | Workshops

Workshop
Funktionsintegrierte Bauteile durch 2K-Pulverspritzgießen
Fraunhofer IFAM, Bremen
24./25.5.2011

Industry day
Hochdämpfende Werkstoffe im Maschinen- und Gerätebau
Fraunhofer IFAM, Dresden
16.6.2011

Workshop
10. Bremer Klebtage Klebtechnische Fortbildung im Rahmen der DVS®/EWF-Personalqualifizierung
Fraunhofer IFAM, Bremen
21./22.6.2011

Seminar
Summer School EPMA Powder Metallurgy Summer School 2011
Fraunhofer IFAM, Dresden
27.6.–1.7.2011

Workshop
Abschlussveranstaltung Fraunhofer Systemforschung Elektromobilität
Papenburg, ATP Proving Grounds
2./3.9.2011

Expert conference
Fachtagung Elektromobilität: Erfahrungen – Entwicklungen – Erwartungen
Park Hotel, Bremen
14./15.9.2011

Workshop
Bioinspired and Biobased Materials
Fraunhofer IFAM, Bremen
27.10.2011

Workshop
4. Workshop Innovationscluster »MultiMaT«
Fraunhofer IFAM, Bremen
7.12.2011

Scientific publications

PhD theses

S. N. Shirazi
Wet chemical surface modifications of titanium and Ti6Al4V alloy and their effect on the hydrothermical aging mechanisms and adhesion properties
Universität Bremen

Experts:
Priv.-Doz. Dr. Andreas Hartwig
Prof. Dr. Petra Swiderek
Date of exam:
21.1.2011

M. Müller
Herstellung und Charakterisierung von gemahlenen CuNi- und NiCr-Legierungssuspensionen für das Aerosoldruckverfahren
Universität Bremen

Experts:
Prof. Dr.-Ing. M. Busse
Prof. Dr.-Ing. W. Lang
Date of exam:
6.4.2011

D. Yu
Improvements of flame retardancy and heat resistance of epoxy composites with additives containing phosphorus and silicon
Chinese Academy of Sciences, Guangzhou Institute of Chemistry, Chinese Academy of Sciences, Tianhe District, 510650 Guangzhou, China

Experts:
Priv.-Doz. Dr. Andreas Hartwig
Prof. Dr. Wie Qu Liu
Date of exam:
17.5.2011

D. Kolacyak
Funktionalisierung mehrwandiger Kohlenstoffnanoröhren mit Atmosphärendruckplasma
Universität Bremen

Experts:
Priv.-Doz. Dr. Andreas Hartwig
Prof. Dr. Franz-Peter Montforts
Date of exam:
27.5.2011

G. Benedet Dutra
Thermodynamic and one-dimensional kinetic simulations applied to material interfaces produced via powder metallurgy processes
Universität Bremen

Experts:
Prof. Dr.-Ing. M. Busse
Prof. Dr.-Ing. F. Hoffmann
Date of exam:
30.6.2011

S. Schrübbers
Gezielt abbaubare Polymersysteme – Synthese und Degradationsmechanismen
Universität Bremen

Experts:
Priv.-Doz. Dr. Andreas Hartwig
Prof. Dr. Dieter Wöhrle
Date of exam:
22.8.2011

C. Drescher
Einfluss der Herstellungsparameter auf die Eigenschaften gedruckter Dickschicht-Thermoelemente und -Dehnungsmessstreifen aus pulvergefüllten Pasten
Universität Bremen

Experts:
Prof. Dr.-Ing. M. Busse
Prof. Dr.-Ing. W. Tillmann
Date of exam:
13.9.2011

C. Regula
Schichtbildung von Plasmapolymeren bei Atmosphärendruck am Beispiel von Hexamethyldisiloxan (HMDSO) als Monomer
Universität Bremen

Experts
Priv.-Doz. Dr. Andreas Hartwig
Prof. Dr. Dieter Wöhrle
Date of exam:
16.12.2011

Lectures

M. Busse
Forschung und Entwicklung im Automobilbau
Universität Bremen
Summer 2011

M. Busse
Leadership im Automobilbau
Universität Bremen
Winter 2011/2012

S. Dieckhoff
Oberflächentechnik
Fachhochschule Bremerhaven
Summer 2011

H. Fricke
Simultaneous engineering and rapid prototyping
Hochschule Bremen
Winter 2011/2012

I. Grunwald
Analytische Chemie
Universität Bremen
Winter 2011/2012

I. Grunwald
Einführung in die Chromatographie
Universität Bremen
Winter 2011/2012

I. Grunwald
Praktikum Chromatographie
Universität Bremen
Winter 2011/2012

I. Grunwald, R. Dringen
Bioorganic chemistry
Universität Bremen
Winter 2011/2012

B. Günther, M. Busse
Funktionswerkstoffe im Automobilbau
Universität Bremen
Summer 2011

A. Hartwig
Makromolekulare Chemie – Grundlagen
Universität Bremen
Summer 2011

A. Hartwig
Vertiefung Makromolekulare Chemie
Universität Bremen
Summer 2011

A. Hartwig
Vertiefungspraktikum Makromolekulare Chemie
Universität Bremen
Summer 2011

A. Hartwig
Polymere Funktionsmaterialien
Universität Bremen
Summer 2011

A. Hartwig
Moderne Schwingungsspektroskopie – mehr als der Nachweis von Carbonylgruppen
Universität Bremen
Winter 2011/2012

A. Hartwig
Vernetzte Funktionspolymere
Universität Bremen
Winter 2011/2012

A. Hartwig
Forschungspraktikum
Universität Bremen
Winter 2011/2012

A. Hartwig
Ringvorlesung/Übung Analytik
Universität Bremen
Winter 2011/2012

A. Hartwig
Oberflächen und Polymere
Universität Bremen
Winter 2011/2012

A. Hartwig, J. Beckmann, F.-P. Montforts, M. Hesse
Integriertes Synthesepraktikum
Universität Bremen
Winter 2011/2012

B. Kieback
Festkörperchemie II
Technische Universität Dresden
Summer 2011

B. Kieback, T. Schubert
Verbundwerkstoffe
Technische Universität Dresden
Summer 2011

B. Kieback, T. Weißgärber
Pulvermetallurgie und Sinterwerkstoffe I
Technische Universität Dresden
Winter 2011/2012

B. Kieback
Technologien zur Werkstoffherstellung und -verarbeitung
Technische Universität Dresden
Winter 2011/2012

B. Kieback
Festkörperchemie I
Technische Universität Dresden
Winter 2011/2012

B. Kieback, T. Weißgärber
Pulvermetallurgie und Sinterwerkstoffe II
Technische Universität Dresden
Summer 2011

U. Lommatzsch
Oberflächentechnik
Hochschule Bremerhaven
Summer 2011

S. Lösch
Technische Mechanik
Hochschule Bremen
Winter 2011/2012

B. Mayer
Kleben und Hybridfügen
Universität Bremen
Summer 2011

B. Mayer
Polymere
Universität Bremen
Summer 2011

B. Mayer
Werkstofftechnik Polymere
Universität Bremen
Winter 2011/2012

J. Meinert
Technische Thermodynamik
Dresden International
University
Summer 2011

J. Meinert
Grundkonzepte der Energie-
technik – Kraftwerkstechnik I
Hochschule Zittau/Görlitz
Summer 2011

U. Meyer
Festigkeitslehre II
Hochschule Bremen
Summer 2011

U. Meyer
Angewandte Mathematik
Hochschule Bremen
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C. Borrmann, J. Wollnack
Adaptive Bearbeitung von Faserverbund-Großbauteilen mit Industrierobotern
Composites Roadshow 2011
Stade
11.5.2011

S. Buchbach
Neue innovative Lacksysteme mit neuen Funktionseigenschaften
NRW Infoforum Energieeffizienz
Paderborn
19.10.2011

S. Buchbach, H. Fricke
Strömungssimulation lacktechnischer Komponenten
DFO Qualitätstage
Köln
29./30.11.2011

S. Buchbach, H. Kordy
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BMWi-Status-Tagung Schifffahrt und Meerestechnik
Rostock
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J. Clausen, U. Specht, M. Haesche, F.-J. Wöstmann, J. Ihde, M. Busse, B. Mayer
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European Aluminium Congress (EAC)
Düsseldorf
22.–23.11.2011

C. Dölle, R. Wilken
Licht als Werkzeug: Einsatz von Vakuum-UV-Excimerstrahlung zur Aktivierung von Polymeren – ExAkt –
11. Dechema-Kolloquium Gemeinsame Forschung in der Klebtechnik
Frankfurt am Main
22./23.2.2011

C. Dölle, D. Salz, C. Schmüser, K. Vissing, M. Ott
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2nd International Symposium on Functional Surfaces
Aachen
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Licht als Werkzeug: Einsatz von Vakuum-UV-Excimerstrahlung zur Aktivierung von Polymeren
Fachtagung Applikations- und Prozesstechnik für Kleb- und Dichtstoffe
Essen
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18. DGM-Symposium Verbundwerkstoffe und Werkstoffverbunde
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Sensors produced by powder-filled pastes
LOPE-C
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4th Symp. on Energy Storage: Beyond Lithium Ion
Pacific Northwest Natl. Lab., Richland, USA
7.–9.6.2011

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GDCh-Wissenschaftsforum Chemie
Bremen
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Fachtagung Applikations- und Prozesstechnik für Kleb- und Dichtstoffe
Essen
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Köln
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Garbsen
6./7.12.2011

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Euro BioMat 2011
Jena
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Aachen
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Kiel
30.3.2011

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Hydrogen storage properties of transition metal-doped lithium alanate
Euromat 2011
Montpellier, France
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A. Groß
Materialmix: Die Rolle von Klebtechnologie in zukünftigen Leichtbau-Konzepten
4. Materialica Metall-Leichtbau Kongress – Elektromobilität als Impulsgeber – Metall bleibt!
München
20.10.2011

B. Günther
Entwicklung aktueller und zukünftiger Batteriesysteme
Roadshow des Forums Elektromobilität e. V.
Bremen
23.3.2011

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Metall/Luft-Batterien als Range Extender in BEVs – Vision oder Fiktion?
Kolloquiumsvortrag TU-BS
Braunschweig
9.6.2011

T. Hartwig, R. Muller Schroeder
Analyse des Entbinderns und Sinterns vom MIM-Teilen mittels Massenspektroskopie
30. Hagener Symposium
Hagen
24./25.11.2011

R. Hauser, S. Prasse, T. Hutsch, G. Stephani, B. Kieback
Hochtemperaturoxidationsbeständige PDC – Schichten für Metallstrukturen
Tagung Arbeitskreis Hochtemperaturkorrosion der GfKorr
Frankfurt am Main
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Functional ceramic coatings for cellular metals
Workshop Funktionelle Materialien für die chemische Technik
Dresden
6.10.2011

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Hochtemperaturoxidationsbeständige PDC – Schichten für Metallstrukturen
5. Fachtagung Dampferzeugerkorrosion in Freiberg
Freiberg
20./21.10.2011

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Thermoplastic chitosan – Conventional processing of an innovative biomaterial
Euro BioMat 2011
Jena
13.4.2011

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Powder processing of polymer ceramic composites for bone scaffolds
Euromat 2011
Montpellier, France
12.9.2011

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Powder processing of polymer ceramic composites for bone scaffolds
Forum High-tech for Medical Devices, CompaMed 2011
Düsseldorf
16.11.2011

M. Herrmann, M. Wirts-Rütters, J. Kolbe, J. Jonuscheit, R. Beigang
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International Terahertz Conference 2011
Villach, Austria
24./25.11.2011

T. Hutsch, T. Schubert, T. Weißgärber, B. Kieback, H. Graafsma, K. Hansen, H. Hirsemann, C. B. Wunderer
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Dresden
4.2.2011

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18. Symposium Verbundwerkstoffe und Werkstoffverbunde
Chemnitz
30.3.–1.4.2011

T. Hutsch, T. Weißgärber, B. Kieback, B. Lenczowski, A. Leonhardt, S. Hampel, J. Freudenberger
Herstellung und mechanische Eigenschaften von Kohlenstoffnanoröhren-Metall-Verbundwerkstoffen
18. Symposium Verbundwerkstoffe und Werkstoffverbunde
Chemnitz
30.3.–1.4.2011

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Euromat 2011
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Einsatz von Plasma-Jet-Quellen zur Behandlung von CFK-Großstrukturen
Workshop Atmosphärendruck – Plasmatechnologien zur Großflächenbehandlung
Dresden
27.1.2011

J. Ihde, U. Lommatzsch, C. Müller-Reich, R. Wilken
Vorbehandlung mittels AD-Plasma für langzeitstabile Klebverbindungen
Workshop Optimierung von Klebprozessen durch den Einsatz von Atmosphärendruckplasma
Jena
17.3.2011

J. Ihde, U. Lommatzsch, A. Baalmann, R. Wilken
Korrosionsschutz durch polymere Beschichtungen mit Niederdruck- und Atmosphärendruck-Plasmen
OTTI-Kolleg Metallkorrosion – eine vermeidbare Materialzerstörung!
Regensburg
7.4.2011

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Reinigung und Aktivierung mit Plasma-Verfahren
Otti-Fachtagung Reinigen und Vorbehandeln vor der Beschichtung
Neu-Ulm
19.5.2011

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Workshop Plasmaquellen und Anlagentechnik der Atmosphärendruck-Plasmatechnologien
Wörlitz
7.6.2011

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Plasmareinigung und Aktivierung
Grundlagenseminar Reinigungstechnik – Reinigung in der Produktion
Dresden
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Landshut
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V2011
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Euro BioMat 2011
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24th European Conference on Biomaterials
Dublin, Ireland
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OrthoTec Europe
Zurich, Switzerland
12./13.9.2011

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EuroPM 2011
Barcelona, Spain
16.–19.9.2011

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Nolamp Conference on Laser Materials Processing in the Nordic Countries
Trondheim, Norway
27.–29.6.2011

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Hamburg
26.–29.9.2011

U. Jehring, P. Quadbeck, G. Stephani, B. Kieback
Schwingungsdämpfung und Leichtbau – kein Gegensatz mehr!
Innomateria 2011
Köln
16.3.2011

S. Kaina, B. Kieback, W. Hufenbach, C. Cherif, G. Hoffmann, C. Kowtsch, R. Boehm, M. Thieme, A. Gruhl, D. Weck
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Dresdner Werkstoffsymposium 2011
Dresden
8./9.12.2011

S. Kalinichenka, L. Röntzsch, C. Baehtz, T. Riedl, T. Gemming, T. Weißgärber, B. Kieback
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14th International Conference on Rapidly Quenched & Metastable Materials
Salvador, Brazil
28.8.–2.9.2011

B. Kieback
Powder metallurgy research and development in germany and europe
University of Waikato
Hamilton, New Zealand
8.6.2011

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Powder metallurgy industry advances including medical, industrial, aerospace and automotive
Bay of Plenty Polytechnic
Hamilton, New Zealand
9.6.2011

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Rapid prototyping applications in the area of powder metallurgy
Auckland Institute of Technology (AUT)
Tauranga, New Zealand
10.6.2011

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Liquid phase sintering
EPMA Summer School
Dresden
28.6.2011

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Sintering principles
EPMA Summer School
Dresden
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Sintering 2011
Jeju, South Korea
28.8.2011

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Grundlegende Prozesse beim Spark-Plasma-Sintern
Hagener Symposium 2011
Hagen
24.11.2011

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Sinterwerkstoffe für die Verminderung von Emissionen von Verbrennungsmotoren
2. Dresdner Werkstoffsymposium – Werkstoffe für die Mobilität
Dresden
8.12.2011

B. Klöden
Metallische Schäume als PM-Produkt für die Automobil- und Energietechnik
3. Thale PM Symposium
Thale
19./20.10.2011

A. Kock
Aspekte der Auslegung fehlertoleranter Antriebe
Leistungselektronisches Kolloquium
Erlangen
21.2.2011

A. Kock, M. Gröninger, H. Pleteit, F. Horch, F.-J. Wöstmann
Concept of a wheel hub drive with integrated converter
ECPE-Workshop: Converter-Drive Interactions
Hamburg
3.5.2011

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Electric Drives Production Conference
Nürnberg
28./29.9.2011

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Herstellung magnetischer Sensorelemente in Dickschichttechnologie
18. DGM-Symposium Verbundwerkstoffe und Werkstoffverbunde
Chemnitz
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Joining dies to RFID transponders via pre-applied adhesives
European Microelectronics and Packaging Conference 2011
Brighton, Great Britain
12.9.–15.9.2011

T. Kowalik
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Afera Technical Seminar
Brussels, Belgium
13.–15.4.2011

C. Kügeler, M. Schmerling, F. Peters, F. Andre, A. Struck
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GDCh-Wissenschaftsforum Chemie
Bremen
4.–7.9.2011

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Abrafati Conference
Sao Paulo, Brazil
21.–23.11.2011

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Dresden
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Frankfurt am Main
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International Conference MRO Maintenance, Repair and Overhaul
Berlin
24./25.3.2011

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Improving eco- & energy-efficiency in the transportation sector by atmospheric pressure plasma jet treatment: Nanocoatings and carbon nanotubes
Euronanoforum 2011 – Leading the nanotechnology era
Budapest, Hungary
30.5.–1.6.2011

U. Lommatzsch, J. Ihde
Adding lifetime to your photovoltaic modules (in connection with the German High Tech Champion Award Session)
5th Annual Clean Technology Conference & Expo
Boston, USA
13.–16.6.2011

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Euromat 2011
Montpellier, France
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4th International Symposium on Physical Sciences in Space (ISPS-4)
Bonn
11.–15.7.2011

A. Lühring, M. Peschka
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22./23.2.2011

S. Marzi, C. Nagel, L. Ramon-Villalonga, A. Schick, F. Kleiner
Prediction of the mechanical behavior of adhesively bonded car bodies using the finite element method
Automotive Circle International, Absicherung der Fahrzeugeigenschaften
Bad Nauheim
7.9.2011

S. Marzi, T. Gesang
Einsatzmöglichkeiten von faserverstärkten Leichtbaumaterialien und biokompatibler Klebtechnik im Hinblick auf die orthopädische Medizintechnik
7. Stuttgarter Gespräche über Technologien für die Orthopädietechnik
Stuttgart
14.10.2011

B. Mayer
Innovative technologies for surface treatment and adhesive bonding
Eisenmann Technology Forum 2011
Holzgerlingen
23.2.2011

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Innovative Klebtechnologien für Leichtbaukonzepte
VDI-Konferenz Leichtbaustrategien für den Automobilbau
Ludwigsburg
7./8.7.2011

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Innovative Technologien für Oberflächentechnik, Kleben und Faserverbundwerkstoffe
Kolloquium Werkstofftechnik der Bundesanstalt für Materialforschung und -prüfung
Berlin
29.9.2011

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Driving innovation by new joining techniques
European Science and Technology Conference
Brussels, Belgium
24.11.2011

J. Meinert
Wärmespeicherung
Preisverleihung »Grünes Haus Wärme 2011«
Berlin
3.2.2011

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Material innovations in energy management
Dutch-German Seminar on Energy Innovations
Dresden
14.4.2011

J. Meinert
Wärme- und strömungstechnische Simulation
ECEMP-Doktorandenseminar
Dresden
15.4.2011

J. Meinert
Material innovations in energy management
Konferenz Zukunft Energie
Dresden
11.–13.5.2011

J. Meinert, O. Andersen, P. Quadbeck
Zellulare Metalle für maßgeschneiderte thermische Speicher
Workshop Funktionelle Materialien für die chemische Technik
Dresden
6.10.2011

J. Meinert, B. Kieback, S. Synowzik
Vergleichende Betrachtung zu thermischen Speicheranlagen
Tagung Nachhaltiges Bauen und Energieeffizienz
21. Wissenschaftliche Konferenz an der Hochschule Mittweida
Mittweida
27.10.2011

R. Meißner
A reactive forcefield (REAxFF) for systems containing silicon, oxygen and hydrogen – Functional form and applications of REAxFF
ADGLASS General Assembly
Trieste, Italy
13.5.2011

A. Momber, S. Buchbach, P. Plagemann
Effects on the edge corrosion protection capacity of organic coatings
SSPC Conference
Las Vegas, USA
31.1.–3.2.2011

M. Monno, M. Goletti, V. Mussi, J. Baumeister, J. Weise
Dynamic behavior of hybrid APM and aluminum foam filled structures
7th International Conference on Porous Metals and Metallic Foams Metfoam 2011
Busan, Korea
18.–21.9.2011

T. Müller
Elektromobilität 2020: Stand der Technik; Potenziale für die Zukunft; Gefährdung oder Chance?
7. Symposium Verkehrssicherheit
Bremen
9.11.2011

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Fatigue life evaluation of adhesive joints in rotor blades for wind energy converters
European Coatings Conference
Berlin
8./9.2.2011

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Bonded inserts as blade to hub connections for wind energy converters
34th Annual Meeting of the Adhesion Society
Savannah, USA
13.–16.2.2011

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Bremen
21./22.6.2011

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Falzklebprozess im automobilen Rohbau
11. Dechema-Kolloquium Gemeinsame Forschung in der Klebtechnik
Frankfurt am Main
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D. Niermann
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Bremen
21./22.6.2011

B. Oberschachtsiek, D. Lemken, A. Heinzel, L. Röntzsch, S. Mauermann
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Berlin
30.11.2011

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15. Fachtagung für Plasmatechnologie – PT15
Stuttgart
28.2.–2.3.2011

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Plasma hybrid coating – Functional surfaces by plasma supported nano technology
2nd International Symposium on Functional Surfaces
Aachen
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A. Paul
Kleben in der Elektronik – Grundlagen
OTTI-Fachforum Kleben in der Elektronik – Grundlagen, Herausforderungen und Lösungen
Regensburg
28.2.2011

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Isgatec GmbH
Mannheim
6.4.2011

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Isgatec GmbH
Mannheim
21.9.2011

A. Paul
Voraussetzungen für das Kleben
Polytec PT-Seminar Kleben in der Mikroelektronik
Waldbronn
28.9.2011

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Kleben – aber sicher!
Composites Europe
Stuttgart
29.9.2011

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Kleben – aber sicher!
Bondexpo
Stuttgart
13.10.2011

D. Paulkowski, K. Vissing
Tribological improvement of elastomers using plasmapolymeric coatings
52. GfT-Fachtagung – Reibung, Schmierung und Verschleiß
Göttingen
27.9.2011

L. Peroni, M. Scapin, M. Avalle, J. Weise, D. Lehmhus
Dynamic mechanical behaviour of syntactic iron foams with micro glass bubbles
3rd International Conference on Impact Loading of Lightweight Structures (ICILLS' 2011)
Valenciennes, France
28.6.–1.7. 2011

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27./28.10.2011

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Hydrogen and Fuel Cells Conference 2011
Xcaret, Mexico
1.–5.12.2011

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Metal hydrides for thermochemical energy storage in automotive systems
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