Fraunhofer

IFAM

FRAUNHOFER INSTITUTE FOR MANUFACTURING TECHNOLOGY AND ADVANCED MATERIALS IFAM

ANNUAL REPORT 2012/2013

ANNUAL REPORT

2012/2013

FOREWORD

Dear Reader,

Our balance sheet is positive and once again we can look back on a highly successful business year. The figures for 2011 were the best in our 40 plus year history and 2012 was also very good. Fraunhofer IFAM is one of the largest institutes of the Fraunhofer-Gesellschaft and has more than 500 highly qualified employees. Its headquarters are in Bremen, with external branches in Dresden, Oldenburg, and Stade. In all these cities the Fraunhofer IFAM is an important employer in the field of high technology.

A key prerequisite for our profitable activities is providing our customers with an attractive and technology-leading range of services. In 2012 we undertook a strategic review involving all work areas and locations. We aim to focus our resources and competencies ever more closely on the medium and long term needs of industry and hence expand our strengths. In the future, internal work factors will be matched more closely to the external situation, so making us more versatile, faster, and more efficient. The results of the strategic review provided valuable guidance for the future course of the institute. The results were presented to independent auditors from the worlds of industry and science. Their feedback has been very positive: We are well equipped for the challenges we face in the years ahead. One result of the strategic review will be even closer collaboration between our various units in order to develop synergies and to generate new ideas. Fraunhofer IFAM, with its seven core areas of expertise, is far more than merely the sum of its individual parts.

Our close collaboration with the University of Bremen and University of Dresden has been intensified further, with Fraunhofer IFAM making important contributions to the success of these two elite establishments. With several Fraunhofer IFAM scientists already giving lectures, we are pleased to announce that Dr. Andreas Hartwig now also teaches at the University of Bremen having been appointed Professor of Macromolecular Chemistry.

1 *Institute directors: Prof. Dr.-Ing. Matthias Busse (left) and Prof. Dr. Bernd Mayer (right).*

A key area of work in 2012 was once again electromobility. The successful collaboration of various Fraunhofer institutes in the "Fraunhofer System Research for Electromobility" (FSEM) will be continued in a further 3-year program. Fraunhofer IFAM will now be responsible for the overall strategic and technological coordination of this program. One objective of FSEM II is to intensify collaboration with industry and the well-established network of Fraunhofer IFAM with the automobile industry is the perfect basis for this. Within the framework of FSEM II, Fraunhofer IFAM will predominantly be involved with developing components for the electrical drive train. This research work is possible due to the rapid expansion of expertise within Fraunhofer IFAM. This expanded expertise includes casting technology, surface technology for insulating coatings, functional materials for energy storage, the Project Group for Electrical Energy Storage Systems in Oldenburg, and the external branch in Dresden which researches thermochemical hydrogen storage for fuel cells and combustion engines in collaboration with partners.

Against this background, several new projects have been started on the development of production technologies for the versatile manufacture of stator and rotor packs for E-drives, as well as large-scale processes for the production of electric vehicles.

Our collaboration with the European aviation industry also continues: Our successful research activities on sustainable improvement of environmental friendliness and competitiveness contributed to the conception of the "CleanSky II" project in 2012. This project will start in 2014, and Fraunhofer will be a leading project partner.

The Fraunhofer Project Group Joining and Assembly FFM in Stade has also made major progress. Several special plants for robot-operated processes have been designed, built, and commissioned at the Forschungszentrum CFK NORD (Research Center CFRP North) in Stade. Automation of the construction, precision machining, and assembling of large FRP structures is starting – one step towards future automated assembly of XXL components, e. g., for the aviation and wind energy industries.

There are further projects which would also deserve to be highlighted here. The success of all these projects is due to the motivation and enthusiasm of our employees and to them we wish to express our special thanks. It is particularly pleasing when the efforts and innovation of our scientists are recognized in awards. Examples of such awards are the Joseph von Fraunhofer Prize which was won in 2012 by Fraunhofer IFAM scientists for pioneering development work on atmospheric pressure plasma processes and the AVK Innovation Prize which was awarded for the deep-drawn release film Flex$^{PLAS®}$.

Our R&D services are in increasing demand. Construction work began a short time ago on an extension building in Bremen. This will allow us to quickly adapt our technological facilities and space to future needs.

This annual report gives you an overview of our seven core competencies and describes objectives, challenges, and solutions.

We hope you enjoy reading about our work.

M. Busse Mayer

Matthias Busse Bernd Mayer

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1 *Großforschungszentrum CFK Nord in Stade.*

PROFILE OF FRAUNHOFER IFAM

Research and development activities of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM are organized within its two divisions.

Shaping and Functional Materials

The Shaping and Functional Materials division has facilities in Bremen, Dresden, and Oldenburg and develops customized materials using optimized manufacturing methods and processes.

The R&D activities range from materials and shaping to functionalization of components and systems. This results in customer-specific solutions for a range of industries including automotive, medical technology, aviation and aerospace, environmental and energy technology, machine and plant construction, and the electronics industry.

In Shaping the focus is on economic and resource-friendly production of highly complex precision components. Utilizing expertise in powder technology and casting technology, the development work focuses on increasing the functional density of components. The services include component design, simulation of shaping processes, implementation in production, and appropriate training of industry personnel.

The emphasis regarding Functional Materials is to improve or extend the properties and processing of materials. The functional materials can either be integrated directly into the component during the production process or can be applied to surfaces. They provide the component with additional or completely new properties, such as electrical or sensory functions.

The area of sintered, composite, and cellular materials involves the development and qualification of such materials and also power metallurgical processes and sintering techniques. The portfolio is completed with biomaterials, light metals, and functional materials for energy storage and conversion.

The area of electrical components and systems typifies the holistic approach with regards to electromobility. This covers the development of electrical energy storage systems (batteries and hydrogen storage systems), the development of electrical drive technology, and also the testing, evaluation, and optimization of the whole system. The Bremen/Oldenburg model region for electromobility is also developing the basis for new vehicle and traffic concepts.

Adhesive Bonding Technology and Surfaces

At its sites in Bremen and Stade, the Adhesive Bonding Technology and Surfaces division provides industry with qualified solutions in the area of adhesive bonding technology, surface technology, paint/lacquer technology, and fiber composite technology.

The R&D services are sought after by a large number of partners in diverse sectors of industry, with the main customers being the transport sector (manufacturers of aircraft, cars, rail vehicles, ships) and its suppliers, energy technology, medical technology, microsystem engineering, the packaging sector, textile industry, electronics industry, and the construction sector.

The core competence adhesive bonding technology covers materials development (adhesive formulations, bioinspired materials), material characterization (parameter determination, analytics), adhesive bonding technology in production processes (application methods, process development, automation, simulation), calculation/design and numerical simulation of structures, material and component testing, as well as the

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

The core competence in surface technology includes plasma technology (atmospheric pressure and low pressure plasma technology, VUV excimer technology), paint/lacquer technology (coating materials, functional coatings, and their application and processing technology), as well as adhesion and interface research (surface and nanostructure analysis, computational chemistry, electrochemistry, quality assurance of surfaces).

The complete range of expertise from adhesive bonding technology, surface technology, and paint/lacquer technology comes together in R&D activities on fiber composite technology. Within this core competence, the focus is on matrix resin development, fiber-matrix adhesion, and the processing of FRPs. The sizing of joints, process development, and the automated joining and assembly of large structures – including precision machining and plant technology, measurement technology, and robotics – complete the portfolio.

The Center for Adhesive Bonding Technology and the Plastics Competence Center complement the R&D work by providing certifying training courses in adhesive bonding technology and fiber composite technology. The training courses of the Center for Adhesive Bonding Technology are offered worldwide in German and English. Customized courses can also be organized for multinational companies.

Network of expertise at Fraunhofer IFAM

Shaping and Functional Materials

- Biomaterial Technology
- Casting Technology and Component Development
- Cellular Metallic Materials
- Electrical Energy Storage Systems
- Electrical Systems
- Functional Structures
- Hydrogen Technology
- Materialography and Analytics
- Powder Technology
- Technical Training Electromobility
- Thermal Management
- Sintered and Composite Materials

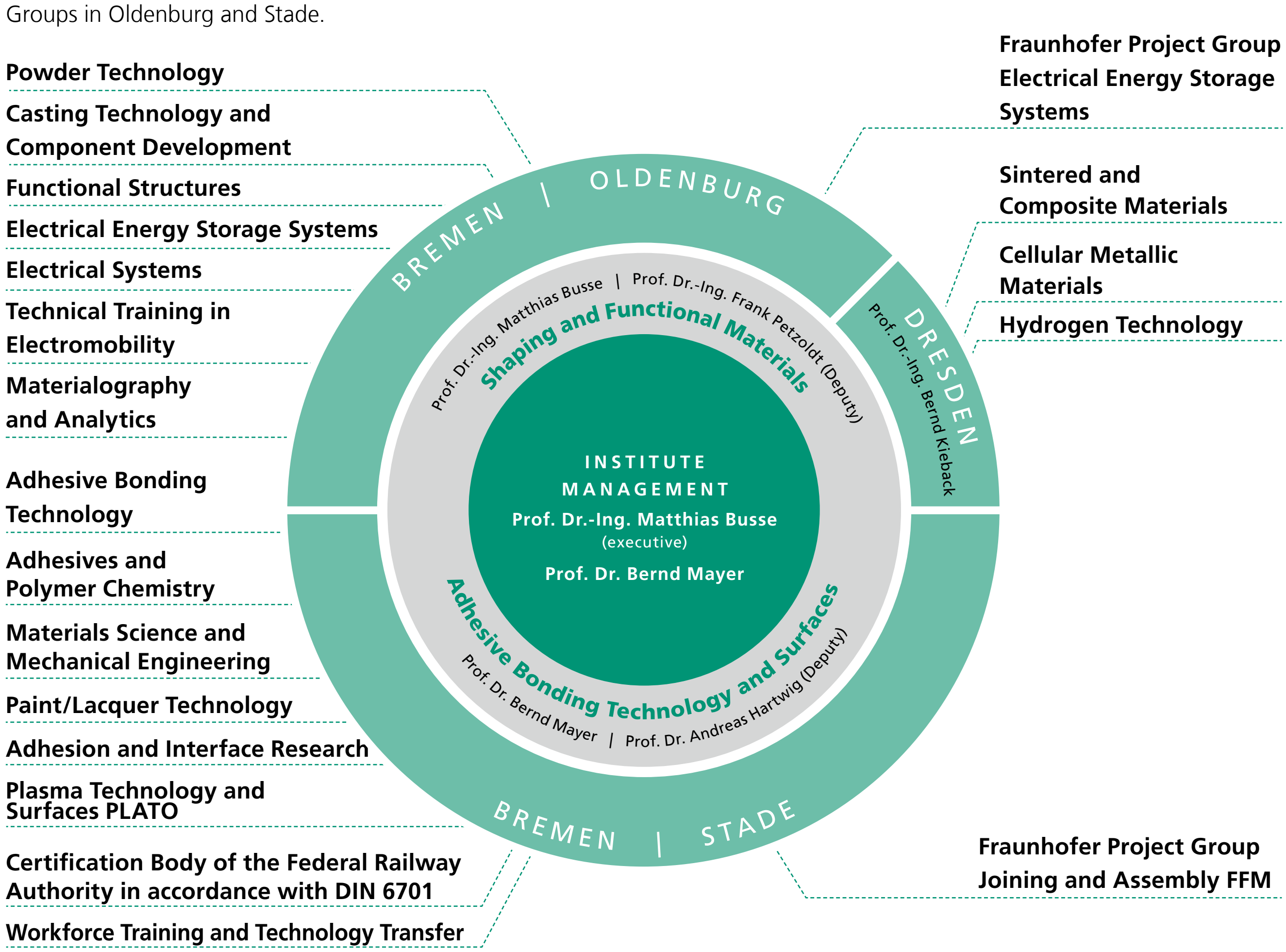
Adhesive Bonding Technology and Surfaces

- 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
- Workforce Training and Technology Transfer

BRIEF PORTRAIT AND ORGANIGRAM

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM was founded in 1968 as a work group in applied materials research. It was incorporated into the Fraunhofer-Gesellschaft as an institute in 1974. The institute initially carried out contract research in nine key areas. Systematic expansion resulted in close collaboration with the University of Bremen, which continues to this day. The current institute directors are professors in the Production Technology department at the University of Bremen. The institute has major sites in Bremen and Dresden, plus Fraunhofer Project Groups in Oldenburg and Stade.

Prof. Dr.-Ing. Matthias Busse has acted as executive institute director since 2003, leading the Shaping and Functional Materials division. Prof. Dr. Bernd Mayer has been an institute director since 2010 and heads the Adhesive Bonding Technology and Surfaces division. In both its divisions, Fraunhofer IFAM as a neutral and independent body counts among the largest R&D establishments in Europe. In 2012, Fraunhofer IFAM employed 569 staff and had an overall budget of 42.3 million euros.



THE INSTITUTE IN FIGURES

The overall operating budget of Fraunhofer IFAM (expenditure and investment) in 2012 was made up of the budgets of the two divisions: the Shaping and Functional Materials division and the Adhesive Bonding Technology and Surfaces division.

Budget

The provisional overall budget for 2012 was 42.3 million euros. The budgets for the divisions were as follows:

Shaping and Functional Materials (Bremen)

Operating budget	10.0 million €
Project revenues	7.7 million €
of which:	
Industrial projects	4.2 million €
Federal/state/EU/other projects	3.5 million €
Investment budget	2.4 million €

Shaping and Functional Materials (Dresden)

Operating budget	4.6 million €
Project revenues	4.1 million €
of which:	
Industrial projects	1.5 million €
Federal/state/EU/other projects	2.6 million €
Investment budget	0.4 million €

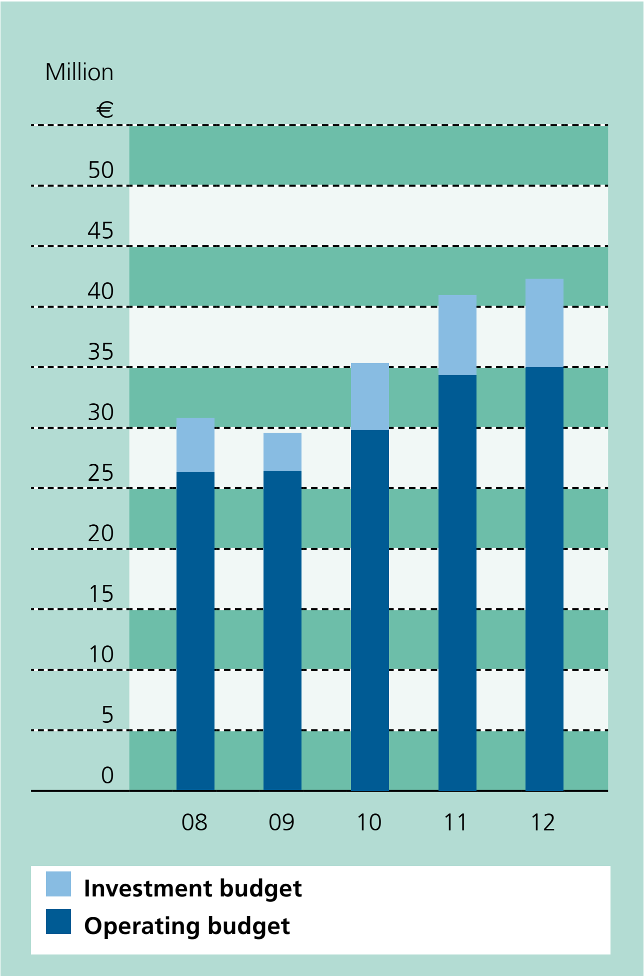
Adhesive Bonding Technology and Surfaces (Bremen)

Operating budget	18.1 million €
Project revenues	14.4 million €
of which	
Industrial projects	10.3 million €
Federal/state/EU/other projects	4.1 million €
Investment budget	2.5 million €

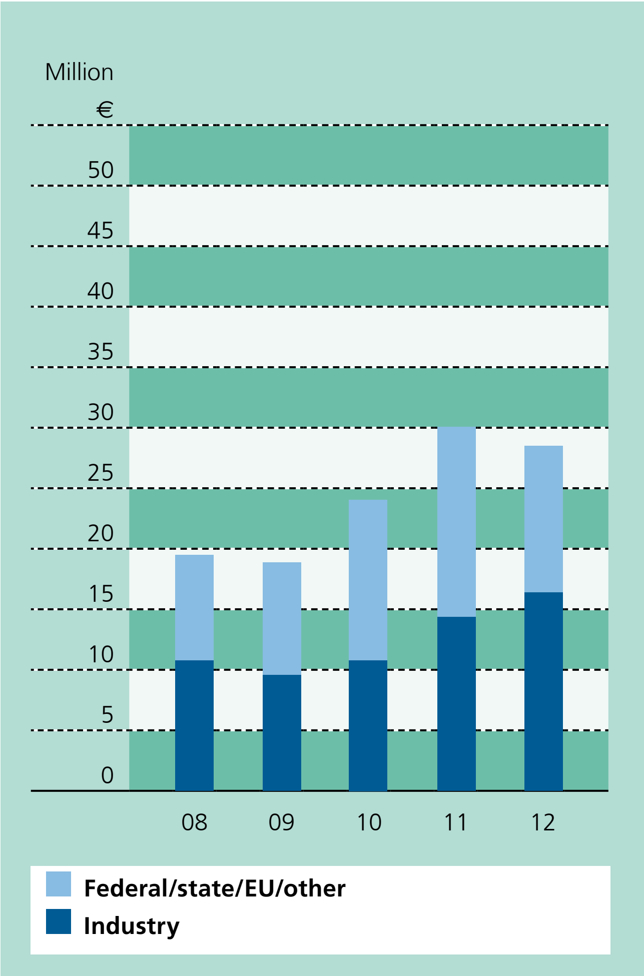
Fraunhofer Project Group Joining and Assembly FFM (Stade)

Operating budget	2.3 million €
Project revenues	2.3 million €
of which:	
Industrial projects	0.4 million €
Federal/state/EU/other projects	1.9 million €
Investment budget	2.0 million €

OPERATING AND INVESTMENT BUDGET



PROJECT REVENUES

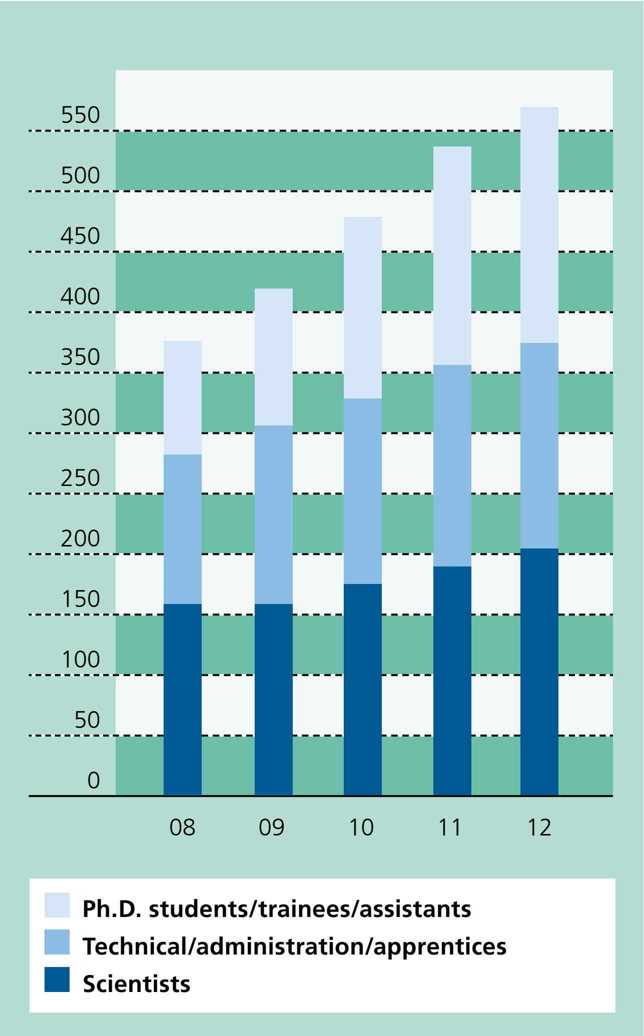


PERSONNEL DEVELOPMENT

On December 31, 2012 a total of 569 staff were employed by Fraunhofer IFAM in Bremen, Dresden, Oldenburg, and Stade. About 92 percent of the workforce was engaged in scientific or technical work. Compared to the previous year, the number of permanent employees grew by 6 percent.

Personnel structure 2012

Scientists	204
Technical staff	120
Administration/internal services/apprentices	50
Ph.D. students/trainees/assistants	195
Total	569



PROFILE OF FRAUNHOFER IFAM

1

ADVISORY BOARD

Members

Dr. Rainer Rauh
Chair of the advisory board
Airbus Deutschland GmbH
Bremen

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

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
(until June 2012)

Michael Grau
Mankiewicz Gebr. & Co.
Hamburg

Dr. Stefan Kienzle
Daimler AG
Sindelfingen

Prof. Dr. Jürgen Klenner
Airbus Deutschland GmbH
Bremen

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
(until March 2012)

Dr. Ralf-Jürgen Peters
TÜV Rheinland
Consulting GmbH
Cologne

Dr. Joachim Schuster
Senator for Education and
Science of the Free
Hanseatic City of Bremen
Bremen

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

1 *Fraunhofer IFAM, Bremen.*

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 66 institutes and independent research units. The majority of the more than 22,000 staff are qualified scientists and engineers, who work with an annual research budget of 1.9 billion euros. Of this sum, more than 1.6 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and *Länder* governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

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.

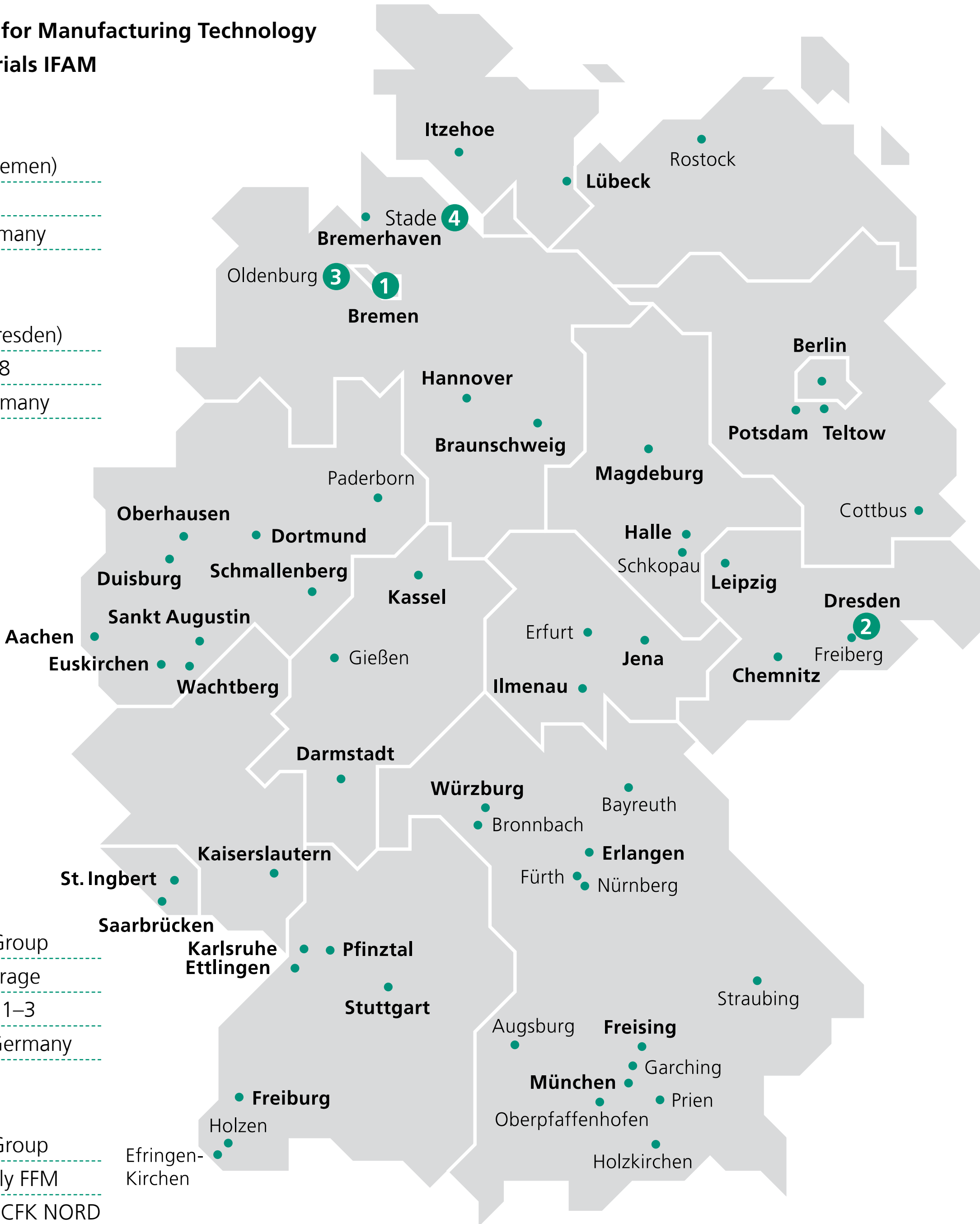
The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

www.fraunhofer.de

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM

1
Fraunhofer IFAM (Bremen)
Wiener Strasse 12
28359 Bremen, Germany

2
Fraunhofer IFAM (Dresden)
Winterbergstrasse 28
01277 Dresden, Germany



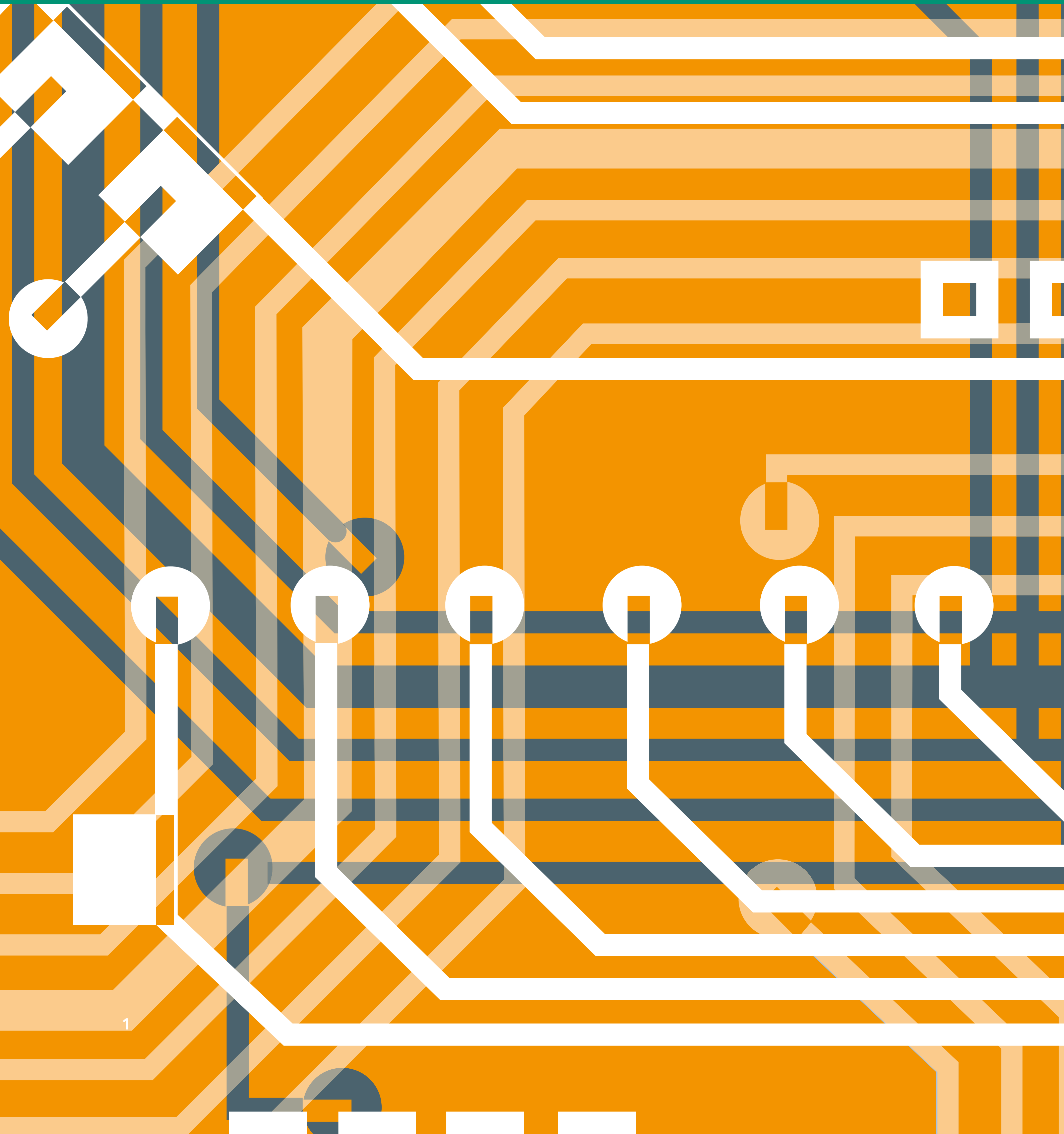
3
Fraunhofer Project Group
Electrical Energy Storage
Marie-Curie-Strasse 1–3
26129 Oldenburg, Germany

4
Fraunhofer Project Group
Joining and Assembly FFM
Forschungszentrum CFK NORD
Ottenbecker Damm 12
21684 Stade, Germany

Fraunhofer institutes and facilities
Other sites

GROUPS | ALLIANCES | ACADEMY

NETWORKS AT FRAUNHOFER



FRAUNHOFER GROUP FOR MATERIALS AND COMPONENTS – MATERIALS

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

The Fraunhofer Group for Materials and Components – MATERIALS pools the expertise of the Fraunhofer institutes that work in the field of materials science.

Materials science research within the Fraunhofer-Gesellschaft covers the entire value-creation chain from the development of new materials and improvement of existing materials through to manufacturing technology on an industry scale, characterization of properties and evaluation of applications. The same applies for components and systems made from these materials. In addition to experimental studies in laboratories and pilot plants, numerical simulation and modeling methods are also employed. The Fraunhofer Group for Materials and Components – MATERIALS covers metals, inorganics/non-metals, polymers, renewable raw materials, and semiconductors.

The Group applies its expertise within a range of business areas including energy and environment, mobility, health, machine and plant engineering, construction and housing, microsystem engineering, and safety.

Key work areas of the Group include:

- Improving safety/comfort and reducing resource usage in transport technology, machine and plant engineering
- Increasing the efficiency of systems for energy generation, energy conversion, and energy storage
- Improving biocompatibility and the functionality of materials used in medicine and biotechnology
- Enhancing integration density and usage properties of components in microelectronics and microsystem engineering
- Improved usage of raw materials and improved product quality

www.materials.fraunhofer.de

Chairman of the Group
Prof. Dr.-Ing. Peter Elsner

Deputy chairman of the Group
Prof. Dr. Peter Gumbsch

Contact at Fraunhofer IFAM
Prof. Dr.-Ing. Matthias Busse
matthias.busse@ifam.fraunhofer.de
Prof. Dr. Bernd Mayer
bernd.mayer@ifam.fraunhofer.de

1 *Key visual of the Fraunhofer symposium "Netzwert" 2012 (Source: MEV).*

FRAUNHOFER ALLIANCES

Fraunhofer institutes or divisions of institutes having differing expertise collaborate in Fraunhofer alliances in order to jointly develop and market a specific field of business.

Fraunhofer Adaptronics Alliance

www.adaptronik.fraunhofer.de

Contact at Fraunhofer IFAM
Dipl.-Ing. Franz-Josef Wöstmann
franz-josef.woestmann@ifam.fraunhofer.de

Fraunhofer AutoMOBILE Production Alliance

www.automobil.fraunhofer.de

Contact at Fraunhofer IFAM
Dipl.-Ing. Franz-Josef Wöstmann
franz-josef.woestmann@ifam.fraunhofer.de
Dipl.-Ing. Manfred Peschka MBA
manfred.peschka@ifam.fraunhofer.de

Fraunhofer Battery Alliance

www.batterien.fraunhofer.de

Contact at Fraunhofer IFAM
Dr. Julian Schwenzel
julian.schwenzel@ifam.fraunhofer.de

Fraunhofer Building Innovation Alliance

www.bau.fraunhofer.de

Contact at Fraunhofer IFAM
Dr. Till Vallée
till.vallee@ifam.fraunhofer.de
Dipl.-Ing. Franz-Josef Wöstmann
franz-josef.woestmann@ifam.fraunhofer.de

Fraunhofer Additive Manufacturing Alliance

www.generativ.fraunhofer.de

Contact at Fraunhofer IFAM
Prof. Dr.-Ing. Frank Petzoldt
frank.petzoldt@ifam.fraunhofer.de

Fraunhofer Lightweight Structures Alliance

www.leichtbau.fraunhofer.de

Contact at Fraunhofer IFAM
Dr. Markus Brede
markus.brede@ifam.fraunhofer.de
Dr. Günter Stephani
guenter.stephani@ifam-dd.fraunhofer.de

Fraunhofer Nanotechnology Alliance

www.nano.fraunhofer.de

Contact at Fraunhofer IFAM
Prof. Dr. Andreas Hartwig
andreas.hartwig@ifam.fraunhofer.de
Prof. Dr. Bernd Günther
bernd.guenther@ifam.fraunhofer.de

Fraunhofer Photocatalysis Alliance

www.photokatalyse.fraunhofer.de

Contact at Fraunhofer IFAM
Dr. Dirk Salz
dirk.salz@ifam.fraunhofer.de

Fraunhofer Polymer Surfaces Alliance (POLO)

www.polo.fraunhofer.de

Contact at Fraunhofer IFAM
Dr. Uwe Lommatzsch
uwe.lommatzsch@ifam.fraunhofer.de

Fraunhofer Cleaning Technology Alliance

www.allianz-reinigungstechnik.de

Contact at Fraunhofer IFAM
Dipl.-Ing. (FH) Sascha Buchbach
sascha.buchbach@ifam.fraunhofer.de

Fraunhofer Simulation Alliance

www.simulation.fraunhofer.de

Spokesperson for the Alliance and contact at Fraunhofer IFAM
Dipl.-Ing. (FH) Andreas Burblies
andreas.burblies@ifam.fraunhofer.de

Fraunhofer Traffic and Transportation Alliance

www.verkehr.fraunhofer.de

Contact at Fraunhofer IFAM
Dr.-Ing. Gerald Rausch
gerald.rausch@ifam.fraunhofer.de

FRAUNHOFER ACADEMY

Fraunhofer Academy is the umbrella organization for training courses that are offered by the Fraunhofer-Gesellschaft.

www.academy.fraunhofer.de

Contacts at Fraunhofer IFAM
Prof. Dr. Andreas Groß
andreas.gross@ifam.fraunhofer.de
www.bremen-bonding.com | www.bremen-plastics.com

Dr.-Ing. Marcus Maiwald
marcus.maiwald@ifam.fraunhofer.de
www.ifam.fraunhofer.de/fachkraft-emobility

COMPETENCIES AND KNOW-HOW

1

2

3

SHAPING AND FUNCTIONAL MATERIALS

In developing complex system solutions, networks between industry and research organizations play a pivotal role. Technological expertise and in-depth specialist knowledge are essential here, especially at the interfaces between different disciplines. The competencies of the Fraunhofer IFAM staff, in conjunction with a broad network of partners from industry and science, guarantees the development of innovative business solutions.

Transferring basic application-oriented research into actual production solutions or component developments is a task that requires the constant advancement of know-how and technical expertise. This is why high priority is put on continually expanding competencies and know-how of the Shaping and Functional Materials division at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM.

Our portfolio in research and development work stretches from basic application-oriented research right through to actual new products and support in production launch.

Multifunctional components with integrated sensor functions put specific requirements on the relevant materials being used. The properties can be precisely customized by combining various materials within a component, for example metal-metal, metal-ceramic, and combinations with CFRPs.

The core competence "Powder technology" covers production processes, such as injection molding, which nowadays are used to shape geometrically complex components from a range of metal alloys and ceramic materials. It has now become possible to utilize the different properties of materials within different parts of components. This allows, for instance, hard-soft or dense-porous property combinations, or even materials with sensory properties, to be custom-integrated into components. Such developments are of particular interest in micro-component production, where such 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 developed, especially for the “INKtelligent printing®” process. This makes it possible to equip components with sensors to record, for example, operating or ambient conditions.

With its advanced casting and analytical equipment and in-depth know-how of high pressure die casting processes for aluminum and magnesium alloys, Fraunhofer IFAM commands a strong market position. In addition to the optimization of casting processes with permanent molds as well as in lost-foam casting, we are constantly upgrading our core compe-

1 *Combining printing and PVD technologies to manufacture thin film solar cells.*

2 *Heat-conducting composite pipes for seawater desalination.*

3 *Additively (SLM) manufactured calibration tool with internal vacuum and cooling channels.*

tence "Casting technology". A process engineering approach is being pursued with the development of CAST$^{tronics®}$ technology which provides casting shops with the ability to integrate functional components directly into their casting process.

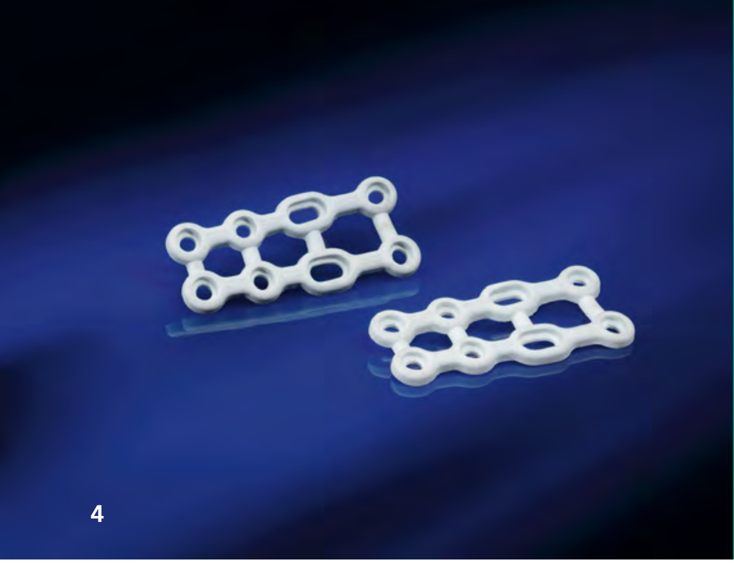
We have considerable know-how regarding the conversion of cellular metallic materials into products. This allows us to develop special solutions for markets such as diesel particulate filters and also to continuously expand our knowledge. Our portfolio of methods is continuously matched to market requirements, resulting in new technological challenges. Product innovation under strict economic constraints plays an important role here as does the contribution of our research to improving the quality of life and to sustainable developments in the area of transport, energy, medicine, and the environment.

A significant success factor in all our product innovation 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 is growing due to the increasing complexity of these products.

Material properties and technologies for structural and functional applications are being customized and characterized. High performance materials, composite materials, gradient materials, and smart materials are all being developed for this purpose, along with production technologies for integrating the properties into components.

Our in-depth knowledge of special functional materials such as magnets, thermal management materials, thermoelectric and magnetocaloric materials, and nanocomposites is opening up new product development opportunities for our customers and completes our competence "Metallic sintered, composite, and cellular materials".

Electromobility continues to be a highly dynamic work area, particularly with regard to energy storage systems, drive technology, and system testing. These are key elements of the relatively new core competence “Electrical components and systems”. This work is focusing 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 largely 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. This also includes battery ageing tests and characterization of the continuous operation of electrical drive systems based on standardized and real driving cycles.



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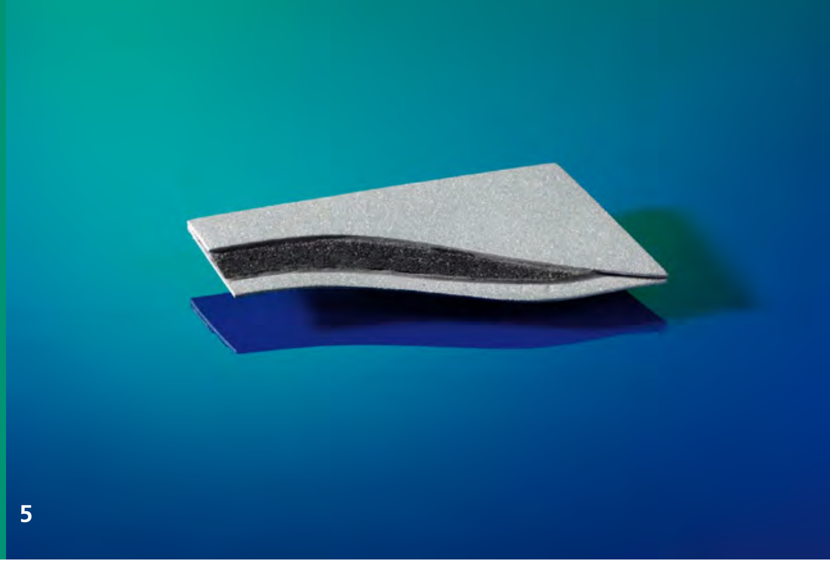


5

Perspectives

The further development of complex drive systems such as wheel hub motors will continue to be an interesting area of work of the Shaping and Functional Materials division of Fraunhofer IFAM. The actual drive development with the implementation of a prototype and practical testing will utilize Fraunhofer IFAM's manufacturing and testing expertise. Another interesting area is the construction and inclusion of complete vehicle models in the studies on batteries and drive motors in the form of Hardware in the Loop simulations on the Fraunhofer IFAM drive train test stand.

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

Key areas of work

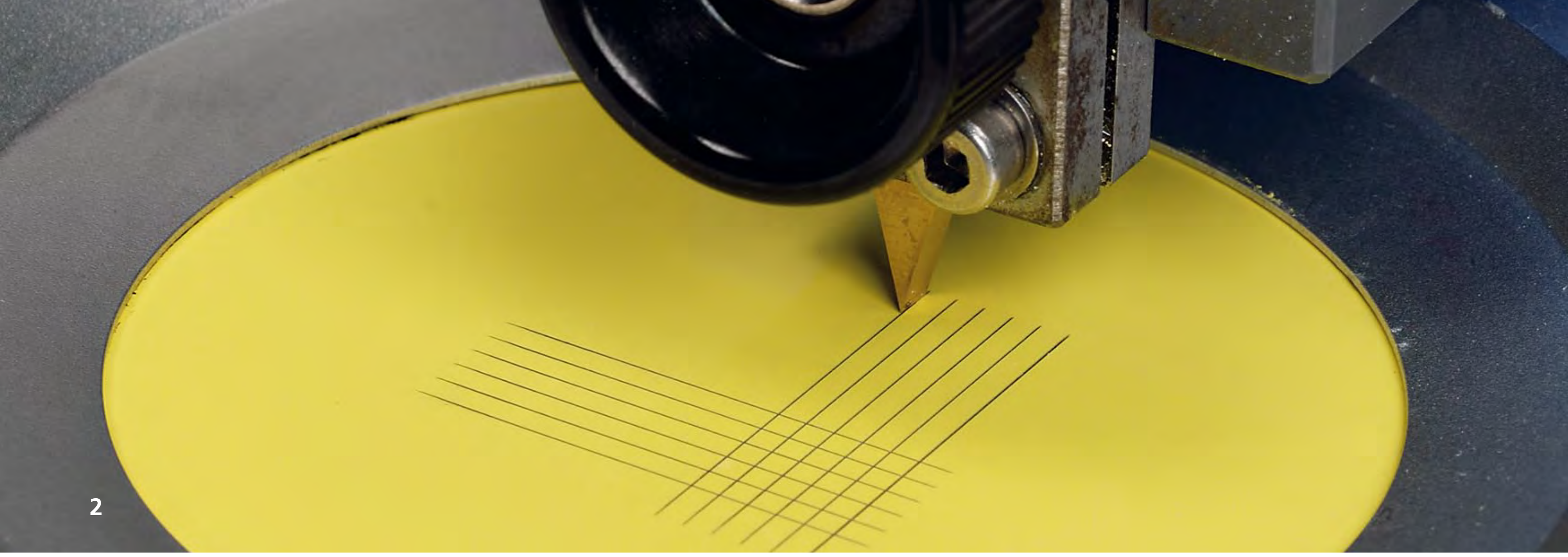
- Development and modification of materials: metallic materials, structural materials, functional materials, composite materials, cellular materials, thermal management, thermoelectric systems
- Powder metallurgy technologies: Special sintering processes, metal injection molding, generative processes, nanostructuring and microstructuring
- Casting technologies: Die casting, investment casting, lost-foam casting
- Functionalization of components: Sensors, actuators, nanostructuring and microstructuring
- Material analysis and materialography
- Development and construction of electrical components and integration of these into systems, testing of components for the drive train of electric motors
- Material and process development for novel energy storage systems: nanostructured electrodes, production of cell components, battery testing technology, electrochemical analysis
- Hydrogen technology
- Testing of charging infrastructures for electromobility, analysis of fleet tests, technical training courses – national and international

4 *Trauma plates made of highly-filled polylactic acid composite for, for example, internally securing small bones in the hand.*

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

COMPETENCIES AND KNOW-HOW

1



2

ADHESIVE BONDING TECHNOLOGY AND SURFACES

The Adhesive Bonding Technology and Surfaces division at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM has more than 300 employees and is the largest independent research institution in Europe working in the area of industrial adhesive bonding technology. 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 Adhesive Bonding Technology and Surfaces division. The activities range from fundamental research through to production right up to the market introduction of new products with partners. Industrial applications are mainly found in the transport sector – manufacturers of aircraft, cars, rail vehicles, ships – and their suppliers, energy technology, the construction industry, the packaging sector, textile industry, electronics industry, microsystem engineering, and medical technology.

"Adhesive bonding technology", a core competence, involves the development and characterization of adhesives, the design and simulation of bonded and hybrid joints, as well as the characterization, testing, and qualification of such joints. The planning and automation of industrial production as well as process reviews and certifying training courses in adhesive bonding technology and fiber composite technology are additional provided services.

The core competence "surface technology" covers plasma technology, paint/lacquer technology, as well as adhesion and interface research. Customized surface modification – 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 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 a part of Fraunhofer IFAM, is carrying out forward-looking work on large fiber reinforced plastic structures. The Fraunhofer FFM is able to join, assemble, process, repair, and carry out non-destructive tests on large 1:1 scale structures. The "fiber composite technology" core competence thus closes the gap between the laboratory/small pilot-plant scale and industrial scale FRP applications. The aspects mentioned above concerning adhesive bonding technology, plasma technology, paint/lacquer technology, as well as adhesion and interface research are also key aspects of this core competence. Know-how about matrix resin development, fiber-matrix adhesion, up to the sizing of joints is also important here.

1 *Lower energy loss via a friction-reducing silicon-organic plasma polymer layer on a radial shaft seal for drive shafts.*
2 *Testing the adhesion of coatings using the cross-cut test.*

The entire Adhesive Bonding Technology and Surfaces division is certified according to DIN EN ISO 9001. The laboratories for material 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, respectively funding to attend courses is available under the German regulation for employment promotion, AZAV. The Plastics Competence Center is also accredited in accordance with AZWV respectively AZAV 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.

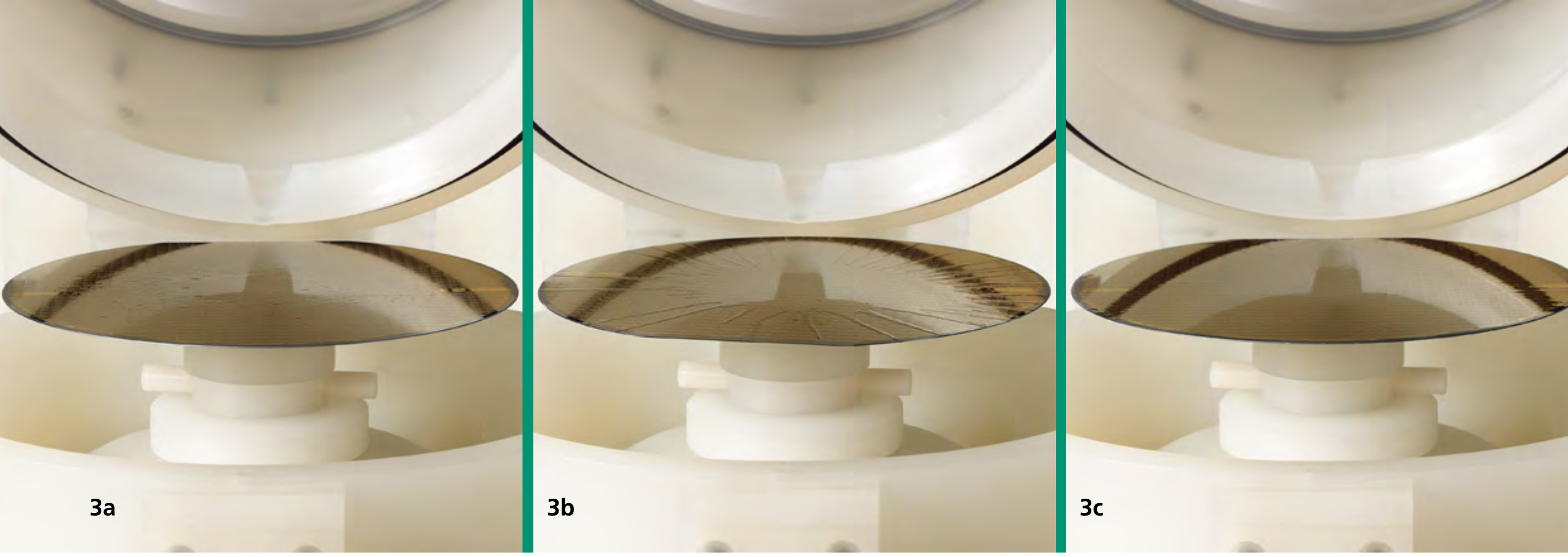
Perspectives

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 Adhesive Bonding Technology and Surfaces division. 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, yet its potential has not nearly 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 and modification 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 activities is: Make the bonding process and the bonded product even safer! This objective can only be achieved if all the steps in the bonding process chain are considered as an integral whole.

In all areas, Fraunhofer IFAM is making increasing use of computer-aided methodologies, for example, the numerical description of flow processes in dosing pumps/valves, multiscale simulation of the molecular 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. 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

- Synthesis, formulation, and testing of new polymers for adhesives, laminating/casting resins
- Development of additives (nanofillers, initiators, etc.) for adhesives and coatings
- Development and qualification of adhesive bonding production processes; computer-aided production planning
- Application of adhesives/sealants, casting compounds (mixing, dosing, application)
- Development of innovative joining concepts (bonding, hybrid joints)
- Design of bonded structures (simulation of the mechanical behavior of bonded joints and components using finite element methods, prototype construction)
- Parameter determination, fatigue strength and alternating fatigue strength of bonded and hybrid joints; material models for adhesives and polymers
- Development of environmentally compatible pre-treatment methods and corrosion protection systems for long-term stable bonding and coating of plastics and metals
- Functional coatings using plasma and combined methods as well as functional coating systems
- Development of special test methods (e. g. formation and adhesion of ice on surfaces, resistance to aging)
- Evaluation of aging and degradation processes in composite materials; electrochemical analysis
- Computer-aided material development using quantum-mechanical and molecular-mechanical methods
- Automation and parallelization of processes in FRP technology
- Processing of FRP materials
- 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 Starter,
  Fiber Reinforced Plastic Technician, and
  Fiber Reinforced Plastic Remanufacturer

3a–c *Coating a processed wafer with a pre-applicable adhesive via spin-coating.*

FIELDS OF ACTIVITY AND CONTACTS

Institute Directors

Prof. Dr.-Ing. Matthias Busse (executive)
matthias.busse@ifam.fraunhofer.de

Prof. Dr. Bernd Mayer
bernd.mayer@ifam.fraunhofer.de

Shaping and Functional Materials Division

Prof. Dr.-Ing. Matthias Busse
Phone +49 421 2246-100
matthias.busse@ifam.fraunhofer.de

Dresden branch

Prof. Dr.-Ing. Bernd Kieback
Phone +49 351 2537-300
bernd.kieback@ifam-dd.fraunhofer.de

Adhesive Bonding Technology and Surfaces Division

Prof. Dr. Bernd Mayer
Phone +49 421 2246-419
bernd.mayer@ifam.fraunhofer.de

Adhesion and Interface Research

Dr. Stefan Dieckhoff
Phone +49 421 2246-469
stefan.dieckhoff@ifam.fraunhofer.de
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 of 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

Adhesive Bonding Technology

Dipl.-Ing. Manfred Peschka MBA
Phone +49 421 2246-524
manfred.peschka@ifam.fraunhofer.de
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.

- Micro-production and application methods
- Processes and automation
- Adhesives and analysis

Adhesives and Polymer Chemistry

Prof. Dr. Andreas Hartwig
Phone +49 421 2246-470
andreas.hartwig@ifam.fraunhofer.de
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
- Adhesives and analytics
- Bio-inspired materials

Casting Technology and Component Development

Dipl.-Ing. Franz-Josef Wöstmann
Phone +49 421 2246-225
franz-josef.woestmann@ifam.fraunhofer.de
Casting technology: aluminum, magnesium and zinc die casting; 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.

Cellular Metallic Materials

Dr.-Ing. Olaf Andersen
Phone +49 351 2537-319
olaf.andersen@ifam-dd.fraunhofer.de
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.

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

Dipl.-Ing. (FH) Andrea Paul
Phone +49 421 2246-520
andrea.paul@ifam.fraunhofer.de
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.

Electrical Energy Storage

Prof. Dr. Bernd H. Günther, Dr. Julian Schwenzel
Phone +49 441 36116-262
julian.schwenzel@ifam.fraunhofer.de
Cell chemistry; metal-air batteries; paste development and electrode manufacture; cell assembly; electrocatalysis; battery testingstands; in-situ analysis; Raman spectroscopy; simulation; service 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 stand up to 120 kW; test stand for batteries up to 50 kWh; driving cycle analysis; range determination; system testing of electric motor drive trains.

Fraunhofer Project Group Joining and Assembly FFM

Dr. Dirk Niermann
Phone +49 4141 78707-101
dirk.niermann@ifam.fraunhofer.de
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
- Machining technologies
- Assembly and plant technology
- Measurement technology and robotics

Functional Structures

Dr. Volker Zöllmer
Phone +49 421 2246-114
volker.zoellmer@ifam.fraunhofer.de
Printed electronics; 3D integration – functional printing; functionintegration; energy harvesting; (nano)-composites; nanostructuredfunctional materials; INKtelligent printing®; ink-jet and aerosol-jet® printing; dispensing methods; sputtertechnologies; special systems.

Hydrogen Technology

Dr. Lars Röntzsch
Phone +49 351 2537-411
lars.roentzsch@ifam-dd.fraunhofer.de
H_2 storage, metal hydrides, complex hydrides, hydride composites, metal-organic frameworks (MOFs), fixed bed reactors, H_2 storage systems, electrolysis, electrode development, cell design and construction, in-situ nano-analysis, H_2 analysis, simulation.

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.

Materials Science and Mechanical Engineering

Dr. Markus Brede
Phone +49 421 2246-476
markus.brede@ifam.fraunhofer.de
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 technologies

Paint/Lacquer Technology

Dr. Volkmar Stenzel
Phone +49 421 2246-407
volkmar.stenzel@ifam.fraunhofer.de

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

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

Powder Technology

Prof. Dr.-Ing. Frank Petzoldt
Phone +49 421 2246-134
frank.petzoldt@ifam.fraunhofer.de

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

Process Reviews

Dipl.-Ing. (FH) Uwe Maurieschat M. Sc.
Phone +49 421 2246-491
uwe.maurieschat@ifam.fraunhofer.de

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.

Sintered and Composite Materials

Dr.-Ing. Thomas Weißgärber
Phone +49 351 2537-305
thomas.weissgaerber@ifam-dd.fraunhofer.de

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

Technical Training for Electromobility

Dr.-Ing. Marcus Maiwald
Phone + 49 421 2246-124
marcus.maiwald@ifam.fraunhofer.de
Customer-specific training in the area of electromobility: Electromobility Specialist Training seminar: Mobility in the future

Workforce Training and Technology Transfer

Prof. Dr. Andreas Groß
Phone +49 421 2246-437
andreas.gross@ifam.fraunhofer.de
www.bremen-bonding.com
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 environmental protection; training courses for Fiber Reinforced Plastic Starter, Fiber Reinforced Plastic Technician, and Fiber Reinforced Plastic Remanufacturer.

- Center for Adhesive Bonding Technology
- Plastics Competence Center

ADDITIONAL RESEARCH AREAS AND CENTERS

Biomaterials

Dr.-Ing. Philipp Imgrund
Phone +49 421 2246-216
philipp.imgrund@ifam.fraunhofer.de
Biocompatible metals; resorbable composites; biopolymers; micro-injection molding; microstructuring; mechanical and biological testing; peptide synthesis; surface bio-functionalization; in-vitro cell tests.

Energy and Thermal Management

Dr.-Ing. Jens Meinert
Phone +49 351 2537-357
jens.meinert@ifam-dd.fraunhofer.de
Heat and flow design of storage systems; measurement technology validation; characterization and mathematical description; numerical simulation of mass, material, impulse, and energy transport processes.

Application Center for Metal Powder Injection Molding

Dipl.-Ing. Lutz Kramer
Phone +49 421 2246-217
forming@ifam.fraunhofer.de

Application Center for Functional Printing

Dr.-Ing. Dirk Godlinski
Phone +49 421 2246-230
printing@ifam.fraunhofer.de

Application Center for Additive Technologies

Dipl.-Ing. Claus Aumund-Kopp
Phone +49 421 2246-226
rapid@ifam.fraunhofer.de

Service Center for Materialography and Analytics

Dr.-Ing. Andrea Berg
Phone +49 421 2246-146
andrea.berg@ifam.fraunhofer.de

Demonstration Center SIMTOP

Numerical Simulation Techniques for Process and Component Optimization

Andreas Burblies
Phone +49 421 2246-183
info@simtop.de

SHAPING AND FUNCTIONAL MATERIALS

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 die casting machine (real-time control, clamping force 660 t)
- Hot chamber die casting 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)
- Production line for partly automated component production

1 *Manufacture of battery test cells under inert conditions.*
2 *Electrochemical analysis of battery electrodes.*

Microstructuring and nanostructuring

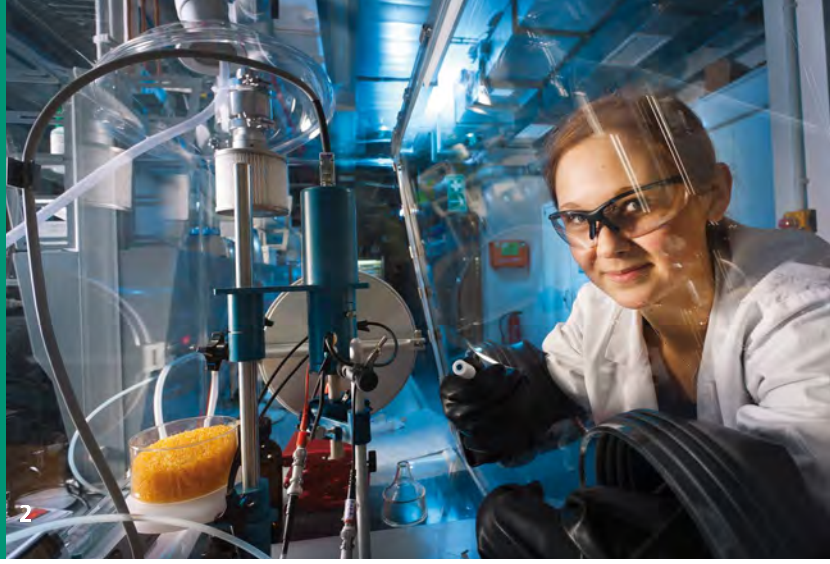
- Ink-jet printing technologies
- Aerosol-Jet® technology
- Dispensing methods
- Production line for partly automated microstructuring
- Micro-injection molding system
- Four-point bend station
- Ink test bench
- Sputter technology
- Glovebox system

Thermal/Chemical treatment of formed components

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

Material synthesis and processing

- Plants for manufacturing gradient materials (sedimentation, wet powder injection)
- Test stand for characterizing functional inks for ink-jet printing processes
- Melt extraction unit (metal fibers)
- Rapid solidification system (melt-spinning) for producing nanocrystalline or amorphous films or flakes
- Fast blender and shearing roller extruder for MIM-



feedstock production
- Grinding technologies
- Twin screw extruder
- Compounding of biopolymers and composites
- Granulator

Instrumental analytics

- Rheometry
- Micro tensile testing machine
- Tensiometer
- 2D/3D laser surface profilometry
- Laser confocal microscope
- Electrochemical STM/AFM
- Hydrogen analytics
- Thermal conductivity measurements on molding materials
- IR laser for translucent material density determination
- Magnetic measurement technology
- Electrical characterization
- Dynamic sensor characterization
- FIB – Focussed Ion Beam for the in-situ preparation of cross-sections and TEM lamellae
- High resolution scanning electron microscopy (HRSEM) with cryo preparation chamber
- Resonance Frequency Damping Analysis (RFDA)
- Scanning electron microscope (SEM) with EDX analysis (accredited)
- X-ray fine structure analysis
- Thermal analysis with DSC, DTA, TGA, PCT
- Sinter/alpha dilatometry (accredited)
- Powder analysis technology with BET and laser granulometry (particle size analysis)
- Trace element analysis (H, C, N, O, S)
- Emission spectrometer
- X-ray tomograph (160 kV)
- Gas permeability determination

Electrical Energy Storage

- Battery and cell test stands (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 stand up to 50 kWh
- Test vehicle for component testing
- Test stand for hydrogen storage systems

Computer

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

New equipment acquired in 2012

- Pixdro LP50 ink-jet printer
- Kuka robot system
- IPETRONIK FLEETlog data logger
- Wax injection molding machine
- Mathis laboratory coating plant KTF-S 350 roll-to-roll
- Simultaneous thermal analysis system (TG-DSC/DTA)
- Simultaneous ICP-OES spectrometer

ADHESIVE BONDING TECHNOLOGY AND SURFACES

Analytics

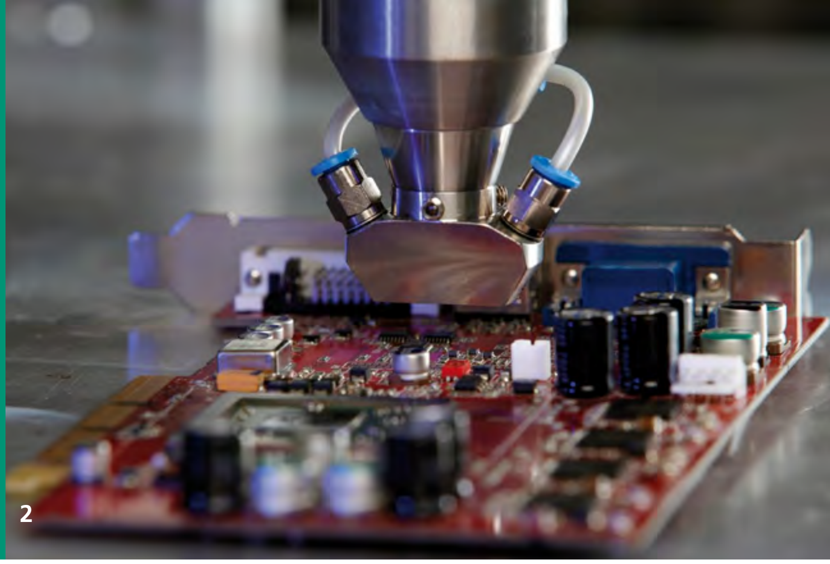
- 200 kV FEG transmission electron microscope with EDX, EELS, EFTEM, as well as 3D tomography plus cryo and heating options
- Focused Ion Beam (FIB) for in-situ preparation of cross-sections and TEM lamellae
- High resolution scanning electron microscope (HRSEM) with cryro-preparation chamber
- Confocal laser microscope
- Surface analysis systems: XPS, UPS, TOF-SIMS, AES, and AFM
- Laser-induced Fluorescence (LIF)
- Laser-induced Breakdown Spectroscopy (LIBS)
- XRF hand unit (x-ray fluorescence analysis)
- Inverse Gas Chromatography (IGC)
- Chromatography (GC-MS and pyrolysis GC-MS)
- Chemiluminescence for analysis of aging processes
- Thermal analysis (DSC, modulated DSC, DMA, TMA, TGA, torsion pendulum)
- MALDI-TOF-MS for protein and polymer characterization
- Light scattering for characterizing turbid dispersions
- Spectroscopic ellipsometry
- Thermography
- Laser-induced plasma spectroscopy (LIPS)
- 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)
- High-performance potentiostat, 30 V, 20 A
- High-performance potentiostat, 100 V, 20 A
- MultEchem™ potentiostat system with 4 independent Reference 600 potentiostats
- Ion chromatograph and auto-titration system
- Instruments for measuring contact angles
- Scanning Kelvin probe
- Phased-array ultrasound measuring device (Olympus OmniScan MX PA)
- Fluorescence microscope
- Bohlin Gemini 200 rheometer

Computer-aided simulation methods

- High performance cluster with a total of 240 computing nodes and high-speed interconnect
- High performance cluster with a total of 112 computing nodes
- Simulation applications: Gaussian®, Turbomole®, LAMMPS, Accelrys Materials Studio®, Scienomics MAPS®, Culgi multiscale modeling library®, COMSOL Multiphysics®

Test methods

- Tribometer in combination with nano-indentation
- 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

- Mechanical-technological tests
- Salt spray unit
- 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
- Climate test chambers for standard and special tests

Equipment for material synthesis

- Small-scale pilot plant for organic syntheses
- Automatic equipment for peptide synthesis

Surface treatment

- 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-operated atmospheric pressure plasma plant (6-axis) for planar and line treatment and coating
- VUV excimer plant for surface treatment and coating
- CO_2 snow jet units
- Mobile laser unit for surface pre-treatment
- Laboratory electroplating unit for the wet-chemical pre-treatment of light metals and steel

Formulation | Production

- 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
- Laboratory vacuum press with PC control for manufacturing multilayer prototypes
- Coating pilot plant (Coatema Deskcoater)
- 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)
- UV curing technology
- Various dispersion units

Paint/Lacquer technology

- Automatic paint application equipment
- Fully conditioned spraying booth
- Paint dryer with moisture-free air
- UV curing technology
- Grinding technology for powder coating manufacture
- Powder coating extruder

1 *Mobile x-ray fluorescence analyzer for surface analysis of metals and plastics.*

2 *Customized aging protection for electronic components via local atmospheric pressure plasma coatings.*

Mechanical joining techniques

- All-electric laboratory riveting 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

Small pilot plant facilities | Material processing

- Hall for large structure assembly, 80 × 50 m², two 20 tonne cranes, 15 m height under crane hooks
- Laser-tracker for 3D measurements, range 80 m
- Laser-radar for 3D measurement of components, range 30 m
- Combined laser-scanner and laser-tracker for 3D measurement of components of length up to 30 m
- Modular 3D waterjet cutting plant, 6000 bar, with laser positioning and drilling unit for components of up to 3 m length, 2 m width, and 0.5 m height
- Test stand for machining FRP components of up to 13 m length and 6 m diameter using several robots simultaneously and for the development of effective process monitoring and efficient dust extraction; it comprises 3 calibrated 6-axis robots (Stäubli, ABB, KuKa) on 6 m linear axis and a stationary robot station
- Modular flexible assembly plant for large CFRP structures with 2 calibrated 6-axis robots on 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
- 6 axis industrial robot, 125 kg bearing load, on additional linear axis, 3000 mm

New equipment acquired in 2012

- Sorption measurement unit
- Computer cluster
- Automatic evaluation unit for filiform corrosion samples
- Transmitted light microscope
- UV excimer laser
- 3D profilometer Plµ Neox
- IR spectrometer with Raman module
- Spectrometer for chemiluminescence
- Electrodynamic fatigue testing maschine E 3000 – ElectroPuls™
- Modular and versatile assembly plant
- Kuka Quantec KR 240 R3100 ultra k – control module for system integration of measurement technology

QUALITY MANAGEMENT

Certified in accordance with DIN EN ISO 9001

Fraunhofer IFAM has been certified in accordance with DIN EN ISO 9001 since 1995. Certified areas at Bremen and Stade include:

- Product-oriented development of materials, mechanical engineering, processes and production technologies for adhesive bonding technology, surface technology, and paint/lacquer technology
- Characterization and simulation of materials and technologies
- Adhesives development
- Training courses in adhesive bonding technology, fiber reinforced plastics, and electromobility
- Casting technologies and component development
- Metallography, thermal analysis, powder measurement technology, and trace analysis
- Methods for manufacturing and processing nanodispersions
- Computer modeling and simulation

Certification in accordance with DIN EN ISO/ IEC 17025

At the Bremen site, the laboratories for material testing, corrosion testing, paint/lacquer technology, and materialography and analysis have also been certified in accordance with DIN EN ISO/IEC 17025 since 1996.

At Fraunhofer IFAM's Dresden Branch Lab, certification in accordance with DIN EN ISO/IEC 17025 includes laboratories for powder metallurgy, special tests for characterizing inorganic powders and sintered materials, and for material tests on metallic materials.

Certification in accordance with DIN EN ISO/IEC 17024 and accreditation in accordance with the German quality standard for further training (AZWV)

The Center for Adhesive Bonding Technology is internationally recognized for its training courses and since 1998 has been accredited via DVS-PersZert® in accordance with DIN EN ISO/IEC 17024. Since 2009 it has been accredited in accordance with the German quality standard for further training, AZWV.

Accreditation in accordance with AZWV

Since 2007 the Plastics Competence Center of the Fraunhofer IFAM has been accredited in accordance with the German quality standard for further training (AZWV) and meets the quality requirements of DIN EN ISO/IEC 17024.

Certification in accordance with DIN 6701-2 and DIN EN ISO/IEC 17021

The Certification Body for the Manufacture of Adhesive Bonds on Rail Vehicles and Parts of Rail Vehicles has been accredited by the Federal Railway Authority (Eisenbahn-Bundesamt) in accordance with DIN 6701-2 and following DIN EN ISO/IEC 17021 since 2006.

STRATEGIC PLANNING – „THE JOURNEY IS THE REWARD“

Fraunhofer IFAM has grown considerably over the last five years. Our know-how and expertise have made the institute a key R&D partner for industry. This has provided a sound and confident basis for its presence in the marketplace – but does not automatically guarantee a positive development. The key objective of the strategic planning process carried out in 2012 was to set guidelines to build on the achievements to date and guarantee future success

The Fraunhofer strategic planning process

Quality assurance and self-evaluation are important principles that the Fraunhofer-Gesellschaft must demonstrate to its funding bodies. In order to ensure uniform strategic planning across all the institutes, the Fraunhofer-Gesellschaft developed the "Fraunhofer strategic planning process" with external auditing back in 2004. The implementation and application of this process in a consequent way guarantees quality assured strategic planning in the individual institutes. According to the results of an internal study, there is also a direct positive relationship between the success of the institutes and effective application of the Fraunhofer strategic planning process.

Success of individual Fraunhofer institutes depends largely on the interplay of business segments aligned to market needs on the one hand and scientific and technological core competencies on the other.

The relationship between business units, which are focused on the commercial marketplace, and the core areas of scientific and technical expertise has a major effect on the success of the Fraunhofer institutes. Carefully analyzing and linking business segments and core compentencies of the institute are therefore a key aspect of the strategic planning process.

Core competencies

In a series of internal workshops, competencies present within the institute were evaluated. On this basis, seven broad core competencies were (newly) defined:

- Metallic sintered, composite, and cellular materials
- Powder technology
- Casting technology
- Adhesive bonding technology
- Surface technology
- Fiber reinforced plastics
- Electrical components and systems

The further development of these core competencies over the long term is vital in order to correspondingly allow for a successful evolution of the business segments.

Business segments

Technologies and products developed at the Fraunhofer IFAM are generally aimed at wide-scale application in a range of industries. The strategic focus of the institute is thus to make available innovative products and technologies for diverse industrial applications. At the same time, the focus is also on customized solutions for specific industries, considered to be key sectors. The institute's business segments are therefore defined as industrial sectors (or industry groups adhering to a similar industrial logic):

- Automotive
- Aviation
- Energy and environment
- Medical technology and life sciences
- Railways and shipping
- Electrical engineering and electronics
- Raw and basic materials

From workshops to strategic planning

Scientists from all divisions and locations actively participated in the workshops. A series of workshops addressed the description, analysis, and future development of each core competency and business segment. This was undertaken by making thorough inventories and evaluating the market environment using SWOT analyses and competitor benchmarking. Building on the "Fraunhofer Orientation Scenario 2025", a vision was formulated for each core competency and business segment for 2025. In addition, specific strategic objectives were set for 2018 and a roadmap was laid out for reaching these objectives. The results were consolidated, incorporated into a strategic plan, and made available to the auditors selected for the hearing.

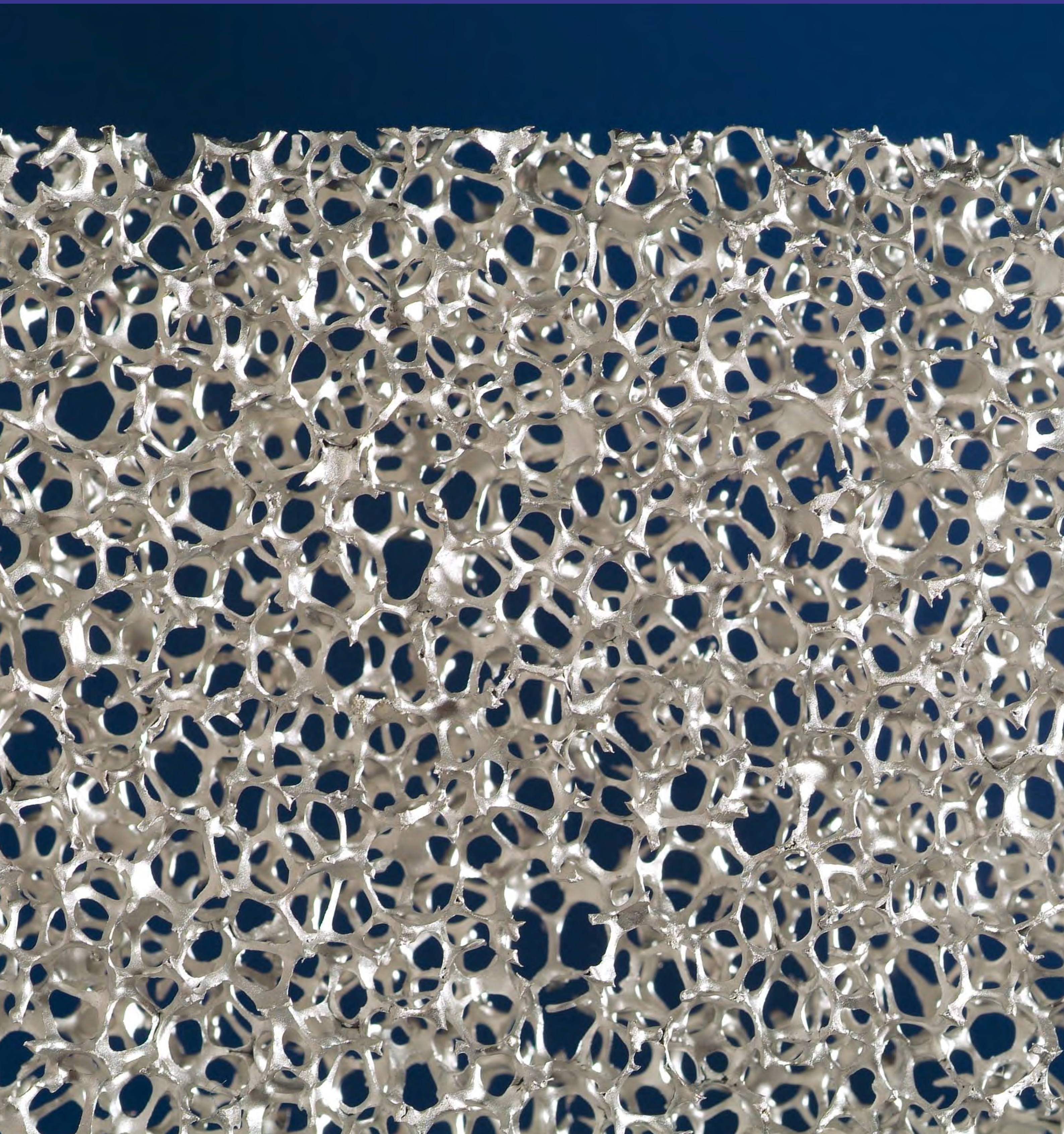
The strategy audit

A milestone in the Fraunhofer strategic planning process is the evaluation of the strategy plan by a group of external auditors. This group consisted of high-level experts from industry and the world of science. In the strategy audit at Fraunhofer IFAM, the overall strategy, core competencies, and business segments were presented to the auditors and extensively discussed. This resulted in valuable suggestions and comments. The auditors particularly praised the integrated approach of the strategy and the dedicated application focus of the institute.

Experience

As experience in the Fraunhofer-Gesellschaft demonstrates, the biggest benefit of strategy definition comes from the process itself. This has also been the case for Fraunhofer IFAM. The internal workshops highlighted opportunities for further synergies and gave rise to ideas for new projects. An increased "best practice sharing" between the individual units is another result from this process.

METALLIC SINTERED, COMPOSITE, AND CELLULAR MATERIALS



CORE COMPETENCE METALLIC SINTERED, COMPOSITE, AND CELLULAR MATERIALS

The development of materials with customized properties and combinations of properties and efficient manufacturing technologies are key activities of Fraunhofer IFAM. The utilization and tailored development of sintering and shaping processes create numerous opportunities for the manufacture and optimization of innovative metallic materials with unusual property profiles, in particular by combining properties in novel composite materials or by creating highly porous or cellular structures.

In the area of metallic and intermetallic sintered and composite materials for functional and structural applications, Fraunhofer IFAM possesses in-depth understanding of structure-property relationships and how to optimize these for specific applications. The complete powder-metallurgical technology chain from powder preparation and characterization through to various shaping and thermal treatment methods is covered. This is now being further expanded by methods such as rapid solidification of metallic melts (melt spinning and extraction) and special sintering processes (e. g. spark plasma sintering) as well as innovative oven analysis.

Fraunhofer IFAM has comprehensive knowledge of alloys and processes for manufacturing light metal components, in particular made of aluminum, for weight reduction in car manufacture. Regarding metallic composites, the focus is on materials development for thermal management of electronics, friction materials and sliding materials for high tribological loads, and special materials for mechanical and corrosive stresses at high temperature (> 800°C). The manufacture and testing of functional materials for energy storage and conversion is of growing importance. Key areas here are new and, in particular, nano-structured materials for hydrogen generation and storage, for heat storage, for efficient thermoelectric generators, and for supercapacitors.

Cellular metallic materials are another key development area. Prudent selection of materials and a wide range of customizable cell and pore structures allow a wide spectrum of application-specific properties and material savings to be realized. For example, highly porous metallic materials such as fiber-metallurgical materials, hollow sphere structures, open-cell metallic foams, 3D screen-printed structures, 3D wire structures, and porous metal papers can be used for applications such as noise absorption, heat insulation, energy absorption, mechanical damping, and material and energy transport as well as for achieving catalytic effects.

1 *Open-cell metallic foam structure.*

ELECTROMOBILITY: LONGER RANGE THROUGH LOWER WEIGHT

European countries are obliged to reduce CO_2 emissions in order to combat climate change. Electric vehicles, powered by electricity that is generated in an environmentally friendly way, offer huge promise for protecting the environment. The low energy density of batteries and the desire for as high a travel range as possible mean that in the near future battery packs will remain large and heavy, even if the improvements hoped for with lithium ion batteries are achieved. A major objective here is thus weight reduction via lightweight vehicle construction.

Lightweight design and maximum safety

The objective of the EU funded project "Smart and Safe Integration of Batteries in Electric Vehicles – SmartBatt" is to develop and test an innovative, multifunctional, lightweight, and reliable energy storage system that is fully integrated into the vehicle body of a purely electric car. The battery housing here is no longer a separate component, rather it is an integral load-bearing structural component of the car chassis, for example the floor of the car. The basis for the car chassis is the SuperLIGHT-CAR (SLC), a concept funded under the 6th EU Framework Programme for an optimized lightweight C-class car chassis. The biggest challenges in the integration work were coupling the lightweight design with maximum safety with respect to a wide range of risk and accident scenarios and also intelligent design of the interfaces to the other vehicle systems. To tackle these challenges, a consortium was formed comprising four companies and five research organizations. The expertise of these nine partners covered vehicle technology, electronics, batteries, design, lightweight structures, materials, and testing.

New material concepts for weight reduction

Considering the individual components of the battery packs in currently available electric vehicles, the average weights of the components in a 20 kWh battery (~200 kg) in an example vehicle are as follows:

- Cells (60–70%) = 120–140 kg
- Components (10–15%) = 20–30 kg
- Housing (15–30%) = 30–60 kg

The SmartBatt project had the ambitious aim of reducing the overall weight of the battery pack by 10–15 percent by developing an alternative design for the housing. The target weight was 170–180 kg, namely:

- Cells (60–70%) = 120–140 kg (unchanged)
- Components (10–15 %) = 20–30 kg (essentially unchanged)
- Housing (15–30%) = 10–20 kg (minus 66%)

The task of Fraunhofer IFAM was to propose innovative material concepts for achieving the desired weight reduction. A utility analysis was carried out to evaluate aluminum, steel, and various other materials including:

- FOAMINAL aluminum foam
- AFS aluminum foam sandwich
- Open-porous aluminum foam
- APM aluminum foam
- APM aluminum hybrid foam sandwich
- Syntactic foam

The result of this evaluation was that the APM hybrid foam sandwich was selected for the lower tray of the battery pack. This material has a core layer of aluminum foam spheres, which are embedded in a matrix of foamed epoxy resin adhesive, between two outer layers of conventional aluminum (Fig. 2). The foamed epoxy resin bonds the spheres and outer layers to each other, resulting in a sandwich structure. For this application, the outer layers have a thickness of 0.5 mm. The aluminum foam spheres for the core layer with a diameter of 4 mm were coated with a foamable epoxy resin adhesive.

The integral density of such a 5 mm sandwich material is only 0.94 g/cm^3, which is about a third of the density of conventional aluminum (ρ = 2.7 g/cm^3).

The material has high bending stiffness and low weight: a square meter of the APM hybrid foam sandwich has a bending stiffness of 3.54 x 108 Nmm^2 and a mass of 4.72 kg. Compare this to a conventional sheet of aluminum of 3.3 mm thickness which has a bending stiffness of only 2.1 x 108 Nmm^2 (41% less) and a mass of 8.91 kg (89% more). Due to its thickness and the energy absorption properties of the core layer of aluminum foam, the sandwich structure also provides good protection against external influences (fire, stone damage, etc.).

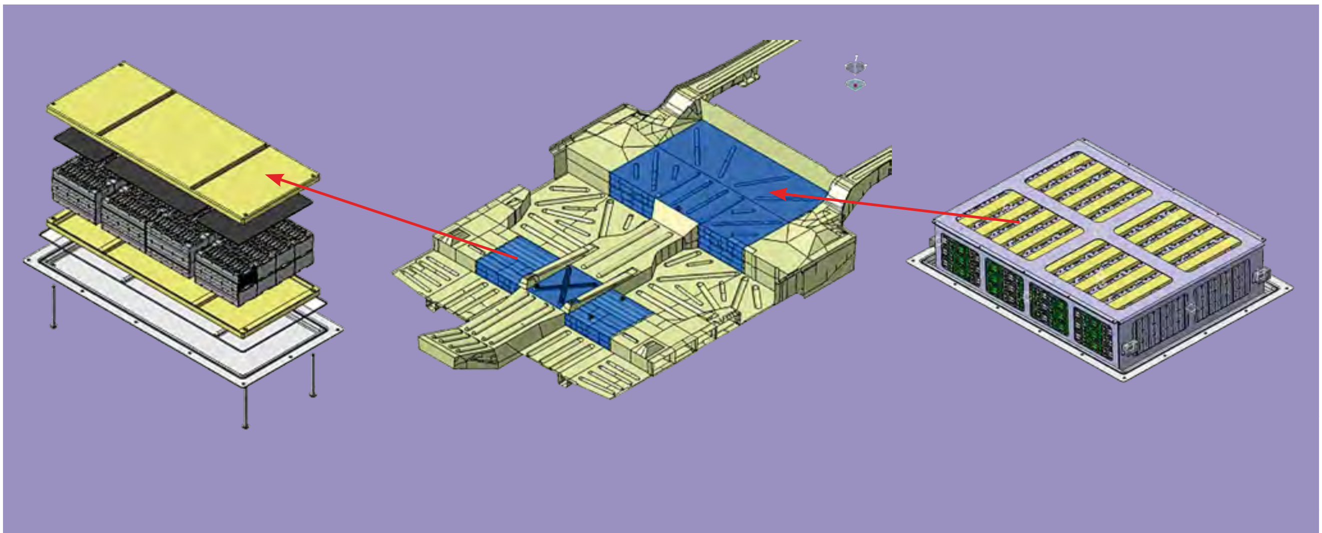


***Fig. 1:** Floor assembly of the SLC with position of the front and back battery packs.*

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Project results: lighter and safer

Compared to state-of-the-art systems, the project partners were successful in halving the weight of the housing and hence making the total battery system 20% lighter by using an integrated design approach and innovative materials. Extensive crash simulations and laboratory tests in the development and validation phases showed that smart battery integration into the chassis of the SuperLIGHT-CAR considerably improves the torsional stiffness, bending strength, and hence also the crash safety of the whole vehicle frame. The lithium ion battery pack (350 V system voltage) provides 36 kW for constant operation and 70 kW for peak operation (for 30 seconds) and has a capacity of 22.9 kWh. This amount of energy allows a weight-optimized vehicle such as the SuperLIGHT-CAR to achieve a travel distance of 120 km in the NEDC (New European Driving Cycle).

The fully functional model prototype attracted much attention from an international audience at the EEVC (European Electric Vehicle Congress) 2012 in Brussels.

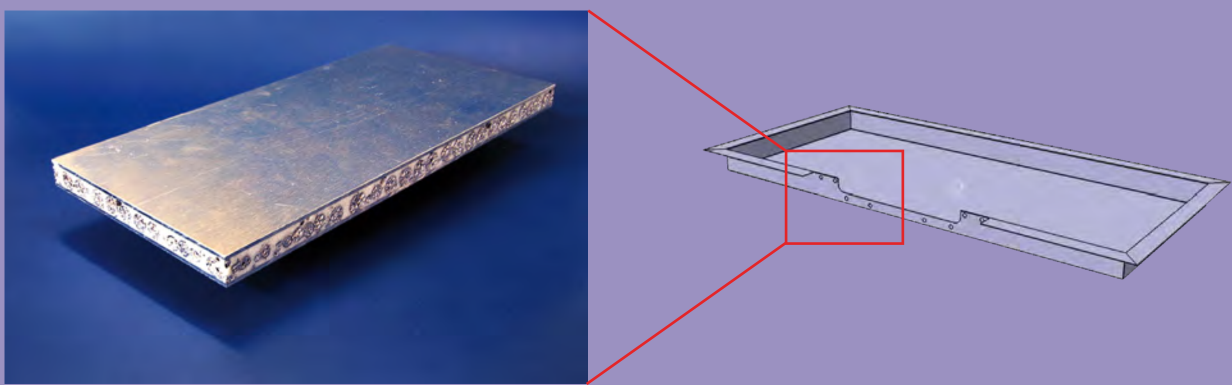


Fig. 2: The bottom trays of the front and back SmartBatt battery pack are made of aluminum hybrid foam sandwich material.

Project funding

European Union
Contract No. SCPO-GA-2010-266074

Project partners

- AIT Mobility, Austria
- AIT LKR, Austria
- Axeon, UK
- Fraunhofer, Germany
- Impact Design, Poland
- Ricardo, UK
- SP, Sweden
- TU Graz, Austria
- VOLKSWAGEN, Germany

CONTACT

Dipl.-Phys. Joachim Baumeister
Powder Technology
Phone +49 421 2246-181
joachim.baumeister@ifam.fraunhofer.de

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

3 *The battery pack is an integral part of the chassis of the SLC.*
4 *Fully assembled and wired battery pack prototype with the development team.*

ENERGY FROM WASTE HEAT – THERMOELECTRIC MATERIALS FOR INDUSTRIAL APPLICATIONS

The growing need for more energy is one of the biggest challenges our modern world has to face, yet up to 50% of the primary energy that is utilized is lost as heat. Thermoelectric materials enable heat to be directly converted into electricity and can, therefore, contribute to a more efficient energy utilization.

Electricity from heat

Today's world faces the challenge of growing energy requirements and decreasing reserves of fossil fuels. Moreover, almost half of the primary energy that is used is lost as heat. There is no all-embracing solution for this problem. Current work is focusing on developing renewable energy sources and more efficient processes for energy transport, conversion, and generation. One approach for recovering energy from waste heat is to use thermoelectric materials. These are able to directly convert heat from various sources (for example geothermal, solar, and waste heat) into electricity. The efficiency of this so-called energy harvesting is at the present stage of technology at about 7 percent. A variety of different types of materials are currently being investigated in order to improve this efficiency. Examples are oxides, Half-Heusler alloys, clathrates, silicides, antimonides, tellurides, and others. High thermoelectric efficiency is, however, not the only criterion for effec-tive applications. Indeed, the requirements put on thermoelectric materials are very complex. They must be favorable in cost, for example as well as non-toxic, while the raw materials must be widely available. The final thermoelectric material also needs to have good mechanical properties, because it is constantly exposed to temperature fluctuations which can impair the mechanical stability.

Optimization of the thermoelectric efficiency and scale-up of the material manufacture

At the fundamental research level, the trend in international research programs is towards nano-structuring of the thermoelectric materials. The second funding period of the DFG Key Research Program (SPP1386) is currently underway in Germany. Fraunhofer IFAM is coordinating one project on the nano-structuring of clathrates and is involved in a second project on nano-structured bismuth telluride materials. The objective of these projects is to increase the thermoelectric efficiency by reducing the heat conductivity of the materials.

1 *Mg and Mn silicides of various diameters (1 cm, 2 cm, 4.5 cm, 6 cm) produced via high energy milling and SPS.*

The applied research work is focusing on scaling up the material manufacture and identifying cost-efficient thermoelectric materials. Magnesium and manganese silicides are composed of low cost elements of low toxicity. They have moderate efficiency (~5 percent) in a temperature range from 300°C to 650°C. This performance can be improved by adjusting the properties via doping. Fraunhofer IFAM is involved in two projects here, one optimizing the thermoelectric efficiency and the other scaling up the material manufacture using powder-metallurgical processes. In order to cover the whole production chain, processes for creating good electrical contact in order to assemble silicide-based thermoelectric modules are also being developed.

Results

Regarding the project on clathrates, an innovative synthesis route for manufacturing clathrate nanoparticles - from sol-gel via calcination to reduction - has been developed. Within the ongoing project on bismuth telluride (Bi_2Te_3), nanoparticles are manufactured by high energy ball milling of a commercially available material. In both cases the compacting of the nanopowder into a nano-structured bulk material with low heat conductivity is carried out via spark plasma sintering (SPS) (Fig. 2). Compared to macrocrystalline materials, the heat conductivity can be decreased by 20 percent (clathrates) and 60 percent (Bi_2Te_3). The influence of the nano-structuring on the Seebeck coefficients and the electrical conductivity of these materials is currently being evaluated in further studies.

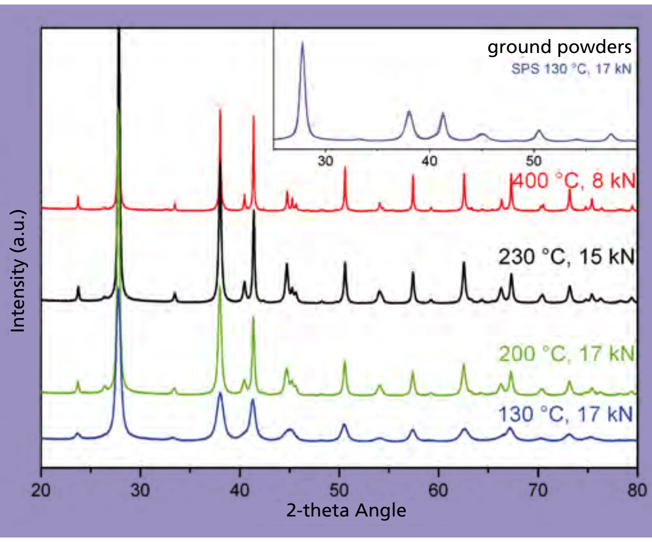


Fig. 2: XRD pattern of n-Bi_2Te_3 sintered via SPS under different process conditions. Top right: XRD patterns of the powder and sintered material are identical; crystal size = 20 nm.

The production of magnesium and manganese silicides on a large scale is difficult due to their brittle character. Samples of 4.5 cm and 6 cm diameter were successfully prepared using powder-metallurgical methods. These are the largest samples produced worldwide up until now. The thermoelectric properties of these large manganese silicide samples match those of the best laboratory samples referred to in the literature (Fig. 3).

Electrical precontacting of silicides via spark plasma sintering was developed so as to have a technology (Fig. 4) that could later be transferred to the industrial-scale module production. In addition, a process was developed for simultaneously welding the precontacted silicide element using a specially designed tool for the final module assembly (Fig. 5).

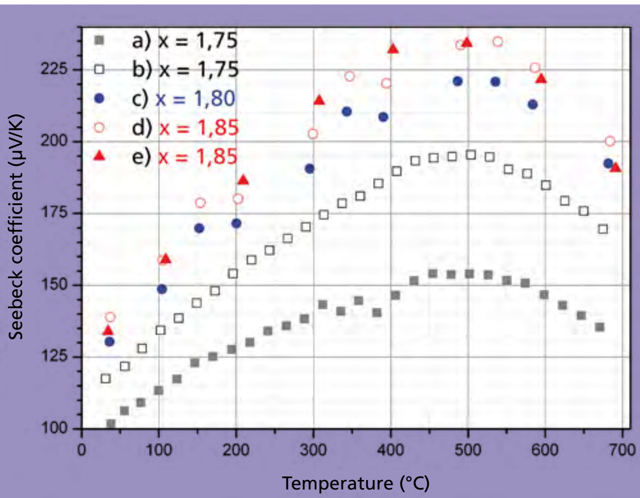


Fig. 3: Seebeck coefficients of $MnSi_x$ samples of differing silicon content.

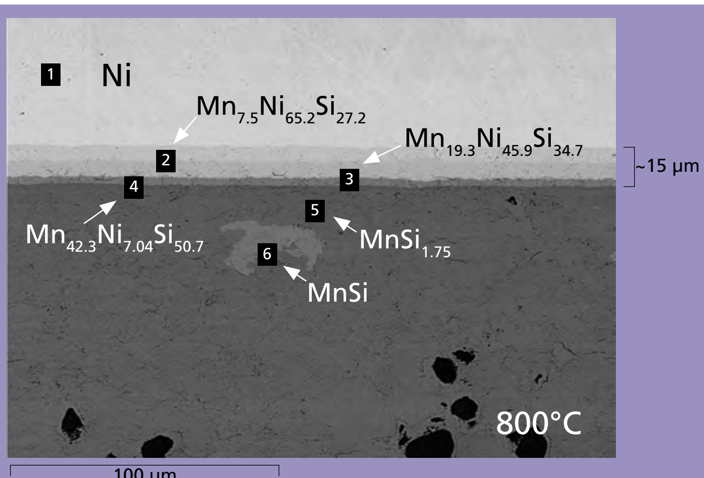
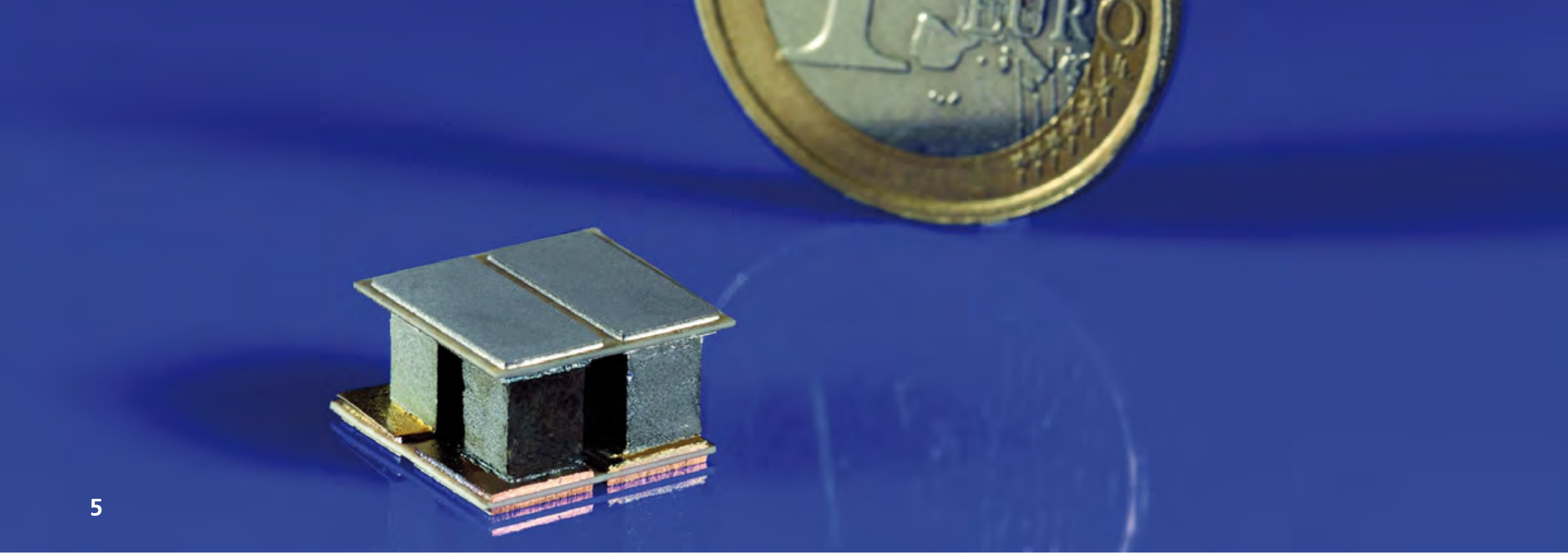


Fig. 4: SEM analysis of the reaction layers after precontacting $MnSi_{1.75}$ with Ni-foil via SPS at 800°C.



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Perspectives

Energy recovery from waste heat using thermoelectric materials is a strategy for improving energy utilization. Silicide materials are made from cost-effective elements of low toxicity and have optimum thermoelectric efficiency in a temperature range from 300°C to 650°C. The production of the silicides on a large scale and their assembly into thermoelectric modules will promote their use in a variety of industrial processes where large quantities of waste heat are generated. Silicides are also highly interesting materials for the automobile industry, where energy harvesting can lead to more efficient fuel consumption and reduced CO_2 emissions.

Project funding

- DFG Deutsche Forschungsgemeinschaft e.V.
- BMBF Federal Ministry for Education and Research
- SAB Sächsische Aufbaubank

Project partners

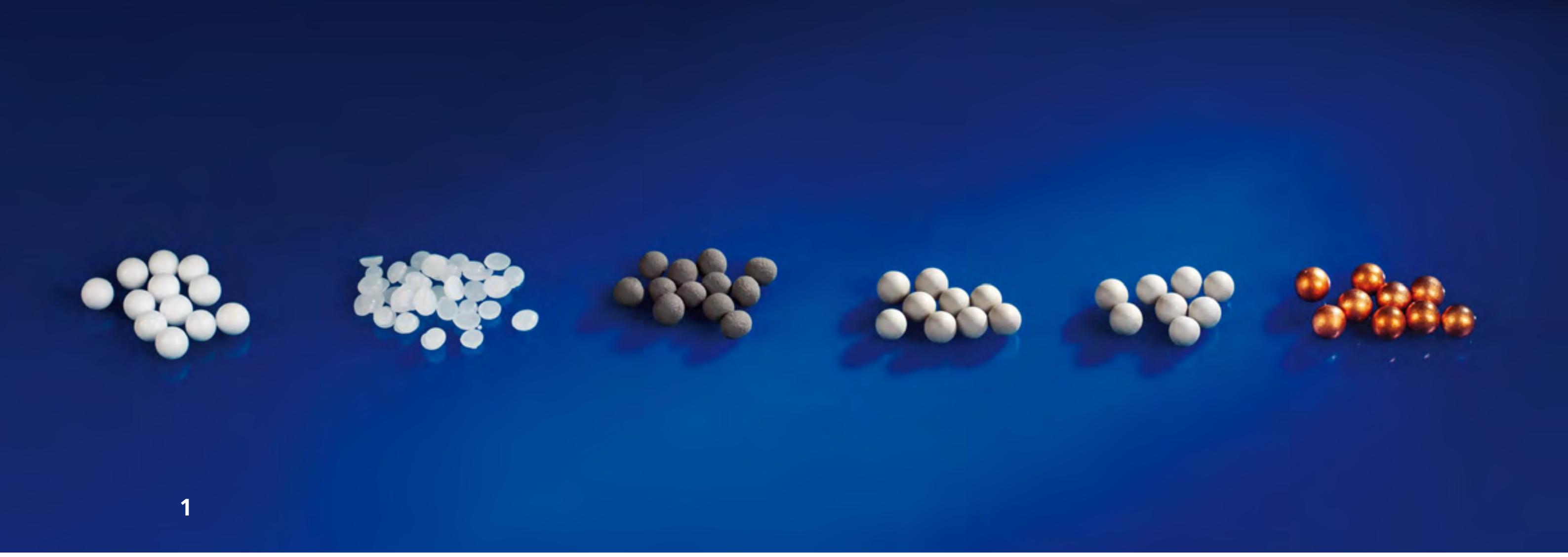
- DFG project: MPI-CPfS, FZJ, Uni Tübingen, Uni Hamburg, TU Chemnitz, Fraunhofer IWM
- BMBF project: Fraunhofer IPM, Behr, Tenneco, Curamik
- SAB: Fh-IKTS, TU-Dresden, MPI-CPfS

CONTACT

Dr. Vicente Pacheco
Phone +49 351 2537-342
Vicente.pacheco@ifam-dd.fraunhofer.de

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

5 *Thermoelectric module (model prototype) made from two Mg and two Mn silicide elements.*



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HIGH-PERFORMANCE ENERGY STORAGE SYSTEMS TO FACILITATE THE TRANSITION TO RENEWABLE ENERGIES

The long-term energy goal of the German government is to substitute both nuclear and fossil fuels by renewable energy sources – for both stationary and mobile energy consumption. Fraunhofer IFAM is making a key contribution here by developing high-performance energy storage systems.

Challenging situation

The planned substitution of nuclear and fossil fuels by renewable and hence CO_2-neutral energy sources over the next years requires innovative energy storage systems to be developed in order to:

- Balance renewable sources (centralized or decentralized) that fluctuate over time (smart grid technology)
- Increase energy efficiency by utilization of energy from waste heat
- Provide long-range energy storage systems for mobile applications

The development of energy storage systems essentially focuses on increasing the storage density (amount of energy per volume, see qualitative overview in Figure 2) and the storage capacity (energy transport per time, charge/discharge cycles). Storage systems having high energy density and performance are the most cost-favorable (due to their small size and large number of cycles) but are currently virtually unavailable in the marketplace.

Expertise to meet the challenge

Innovative and versatile energy storage systems require optimization of the energy density. Fraunhofer IFAM in Dresden is taking on this challenge by developing thermal (latent, sorptive, chemical), material (hydrogen / metal hydride), and electrical high-performance storage systems (supercaps).

There is a special requirement regarding the power density of thermal and material storage systems. For storage systems, the achievable energy density is essentially set, but the power density (kinetics) can be customized over a wide range. Depending on the nature of the storage system, powder-metallurgical methods are used to process the storage materials in order to optimize the diffusive and convective material transport and introduce heat conducting structures (metal,

1 *Production sequence through to PCM-filled metal spheres (from left to right): Styrofoam spheres as support material – paraffin-granulate RT65 as phase change material (PCM) – green spheres – hollow metallic spheres after heat treatment – paraffin-filled metallic spheres – filled spheres galvanically sealed with copper.*

graphite) for customization of the heat conduction properties. The in-depth expertise available at Fraunhofer IFAM provides an excellent basis for successful development work.

Next generation of latent heat storage systems

Various physical effects can be utilized in order to develop thermal energy storage systems (heat/cold) (Fig. 2). Latent heat storage systems have good storage density in relation to their manufacturing complexity (costs). In these systems, the solid/liquid phase transition of a so-called PCM (phase change material) is utilized for the storage. Figure 3 shows the melting temperatures and storage densities of typical PCMs. All PCMs have poor heat conductivity, which severely limits the storage kinetics.

Fraunhofer IFAM is investigating two routes for developing high-performance latent heat storage systems. The first is encapsulation in the millimeter range using hollow metal spheres. The production sequence through to the PCM-filled metal sphere is shown in Figure 1: Coating of styrofoam spheres with a metal powder / binder suspension – drying – heat treatment – infiltration with liquid PCM through the porous skin – galvanic sealing. This technology has been optimized for paraffins as PCMs and will be transferred to salts and salt mixtures in the next step. Uses of the PCM-filled spheres – in fluid-conveying static bulk materials or as "floating additional capacitance" in liquid heat sources – are being tested in the laboratory and thermotechnically modeled.

A second option is to incorporate heat conducting metallic structures (open-cell metals – foam, fiber, wire structures) into the PCM. There is a small loss of storage capacity, but an increase in the heat conductivity by up to two orders of magnitude. Current research projects are combining highly porous fiber and foam structures made of aluminum with paraffins (Fig. 4). Prototype heat storage modules are being designed, produced, and very successfully validated in the laboratory.

The next step is to combine 3D wire structures with PCMs based on salts for process temperature applications. This approach can

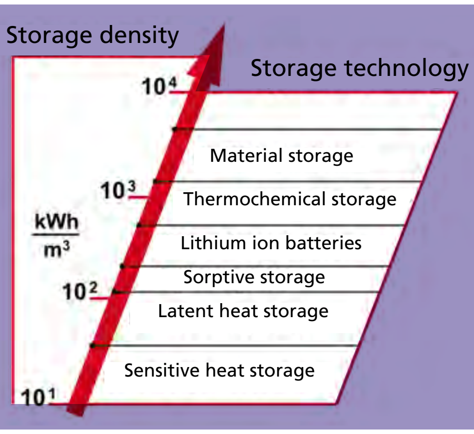

Fig. 2: Qualitative overview of the volume-based energy storage densities achievable with different technologies.

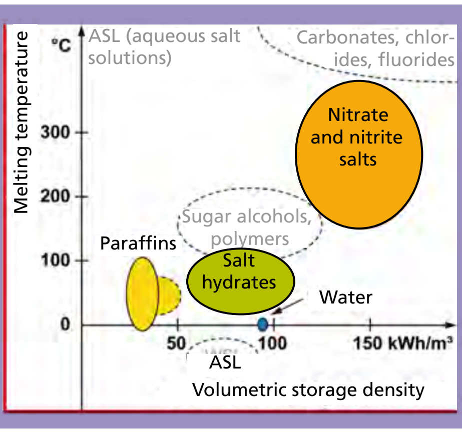

Fig. 3: Melting temperatures and storage densities of typical phase change materials (colored background = used at present).

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in principle also be transferred to sorptive storage systems (coating of the metal structures with zeolites) and thermochemical storage systems (graphite as heat conducting matrix).

Thermochemical energy storage systems

Energy storage via reversible gas-solid reactions is growing rapidly in importance. This is because this form of thermochemical energy storage provides very high specific storage capacities, can be used over a wide temperature range, and has very low energy losses. Prominent examples of such heterogeneous reversible gas-solid reactions are:

- Dehydrogenation of metal hydrides
- Dehydration of salt hydrates or metal hydroxides
- Decarboxylation of metal carbonates
- Deammonation of salt ammoniates

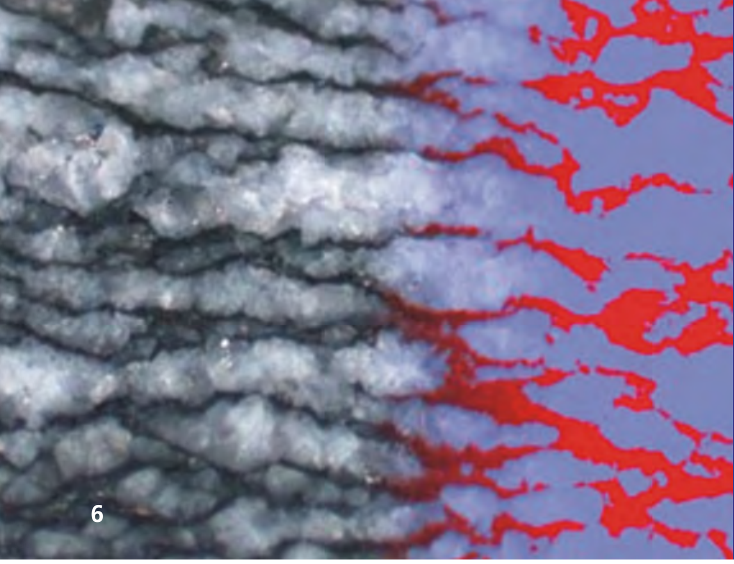
The first type of reaction, involving the hydrogenation/dehydrogenation of metal alloys, is not only useful for thermochemical heat storage but also for reversible hydrogen storage. Besides the high hydrogen storage densities of metal hydrides, the charging pressures are much lower than for high pressure hydrogen storage systems. The kinetics of the hydrogenation/dehydrogenation of metal alloys and their cycle stability depend on a variety of factors, such as the microstructure of the alloys, the morphology of the generally powder-form materials, the presence of nano-catalysts on the surface of the storage materials, the homogeneity of the element distribution, and the degree of contamination of the gas phase. Fraunhofer IFAM in Dresden is developing metal alloys suitable for hydrogenation and the relevant production processes. From a materials standpoint, special attention is being paid to the structure-property relationships. Novel analytical methods achieving a high time and spatial resolution are being used for this, such as in-situ electron microscopy and tomography. These are enabling time and spatial changes in the storage material (reaction fronts, changes in the powder morphology, etc.) to be directly observed, so enhancing our understanding of the microkinetics. These results are allowing specifications to be derived for the improved design of highly efficient and cycle-stable thermochemical energy storage materials and are providing additional impetus for production and processing technologies.

In order to achieve the required high dynamics for a hydride-based storage tank, the long-term stability of the heat transfer and also gas permeation through the reaction bed must be improved. Here, various projects are looking at the strategy of mixing hydrides with other materials (e. g. graphite) and converting them into a composite via uniaxial compaction. The graphite therein accelerates the hydrogen permeation and, due to its extremely high heat conductivity, increases the effective heat conductivity from just below 1 W/(mK) in the pure hydride to 10–60 W/(mK) in the hydride-graphite composite. This is of practical importance, particularly for highly dynamic thermochemical energy storage systems.

Hydrogen storage materials are being tested at Fraunhofer IFAM in prototype storage tanks operated under realistic conditions, for example coupled with fuel cells to generate electrical energy. The first model prototype energy system was presented during the Elbhangfest in Dresden in June 2012. This was developed in collaboration with Fraunhofer ISE. The integrated PEM (polymer electrolyte) fuel cell drive of the pedelec (pedal electric cycle) "Hydrogenia" was connected to a specially designed metal hydride tank for effective, space-sav-

4 *Combining a metal fiber structure (heat conducting matrix) with a heat transfer pipe for the design of high-performance latent heat storage systems as pipe nests (left: untreated fiber disc; front: paraffin granulate as PCM).*

5 *Rapidly solidified magnesium-nickel flakes for hydrogen storage.*



ing hydrogen storage. Not only could the pedelec travel longer distances than with batteries, but it could also be refuelled considerably faster – and more safely. Stationary applications, for example hydrogen supply for fuel cell powered auxiliary power units (APUs), are also being developed, showing the versatility of applications for hydrogen storage materials.

Outlook

Although the focus in recent years has been on electrical energy storage, innovative thermal and material storage technologies are becoming increasingly important as the switchover to renewable energies gathers pace. Fraunhofer IFAM is becoming ever more engaged in this area and, in particular, is developing storage systems with customized power densities.

CONTACT

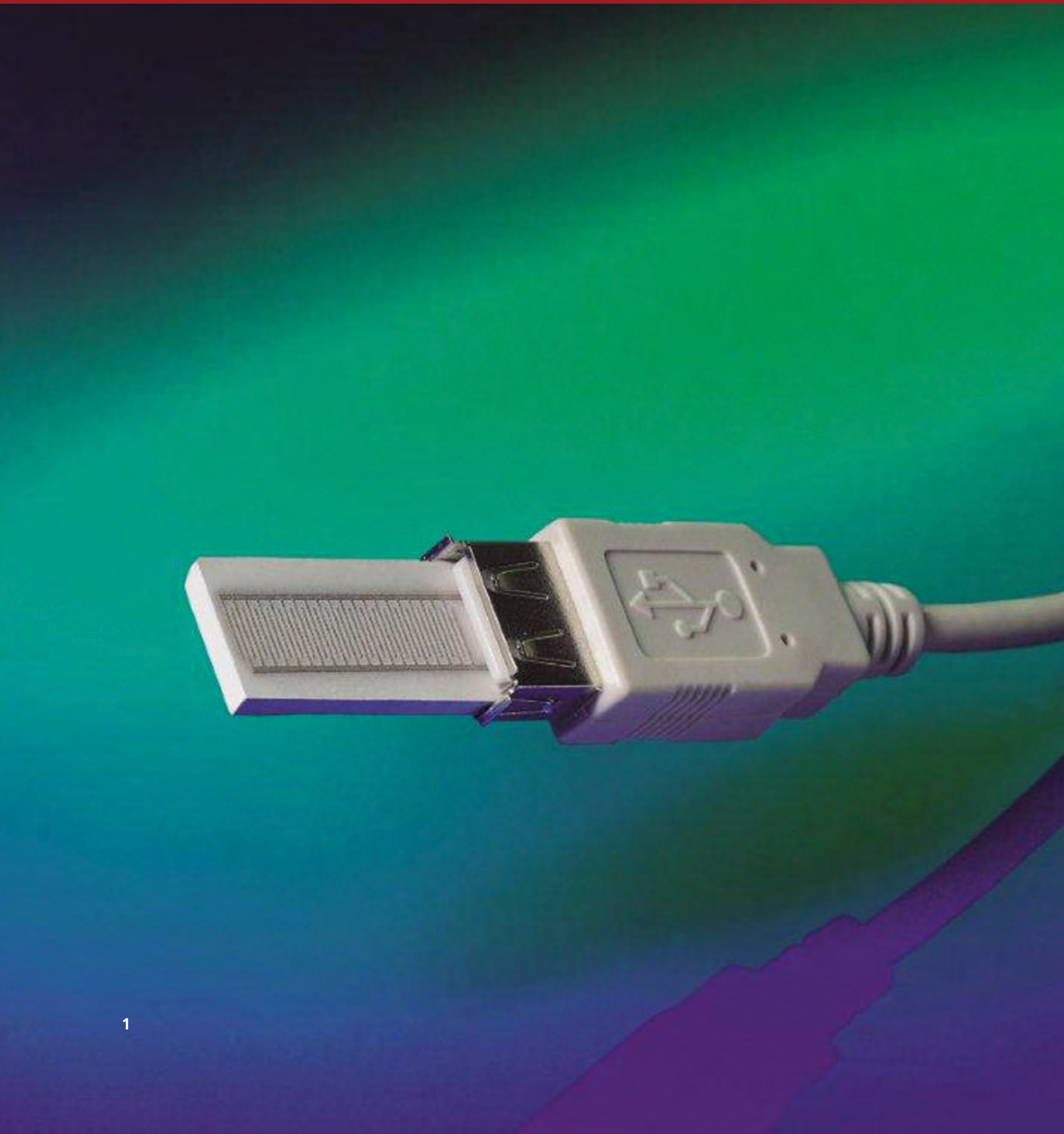
Dr. Jens Meinert
Latent Heat Storage Systems
Phone +49 351 2537-357
jens.meinert@ifam-dd.fraunhofer.de

Dr. Lars Röntzsch
Thermochemical Energy Storage Systems
Phone +49 351 2537-411
lars.roentzsch@ifam-dd.fraunhofer.de

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

6 *MgH_2-graphite composite (blue-red) with optimized heat transfer properties.*

7 *Hydrogenia.*



CORE COMPETENCE POWDER TECHNOLOGY

Powder technology has long been successfully used by industry. Component manufacture using powder technology is unique in allowing the simultaneous customization of material properties and geometry. Powder technology is a core competence of Fraunhofer IFAM. Our expertise here extends from the powder to the product on all matters concerning the materials, shaping, tolerances, process safety, and special requirements.

The basis for power technology solutions are the starting materials. Required property profiles can be achieved by the mixing of powders. For example, properties such as hardness, toughness, Youngs modulus, wear properties, and thermal expansion can be adapted to requirements. New soft magnetic materials and hard magnetic materials are gaining increasing importance.

A key aspect is knowledge of various shaping and production processes. Shaping and sintering are key processes for component manufacture.

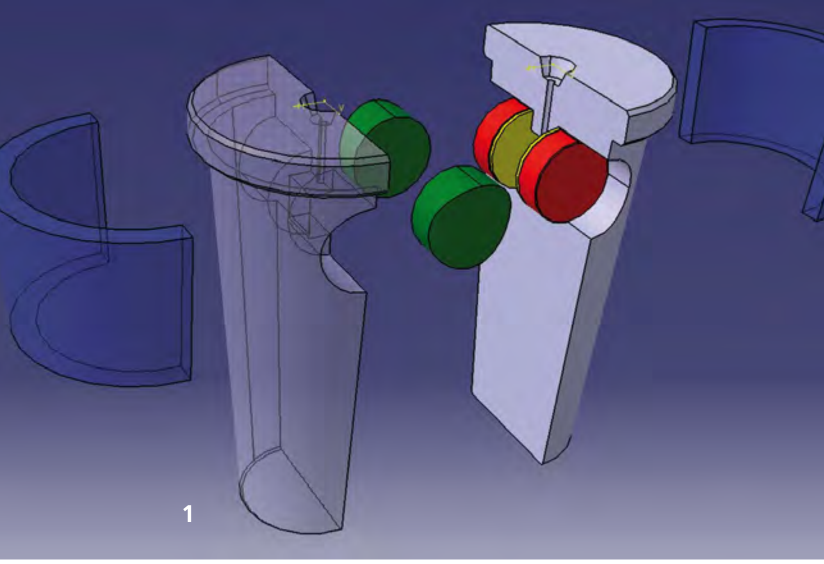
Metal injection molding (MIM) is an example of an established and important shaping process. The experts at Fraunhofer IFAM possess an in-depth understanding of the whole process chain, from the starting powder to feedstock systems and injection molding through to the sintered product. Our range of services includes component development, the production of pilot series, knowledge transfer, and training of production personnel. Also covered are shaping processes for special products such as micro MIM, two component MIM, and extrusion.

Fraunhofer IFAM also has comprehensive expertise in additive manufacturing, where products are made from metal powders without molds being required and are manufactured in virtually any desired shape from 3D CAD data. This method is now not only being used for rapid product development but increasingly also for the production of high-quality, individualized products for end-users.

Functional printing is used to add functions to components. Various powder-based printing technologies therefore also form part of our expertise in powder technology. The methods are being transferred to an industrial scale using a specially designed production line.

Supporting technologies are also important. These include the simulation of shaping processes, as for topology optimization, as well as analytical technologies for powder characterization and rheology.

1 *Screen-printed interdigital structure for moisture or conductivity measurement (electrical contact via USB).*



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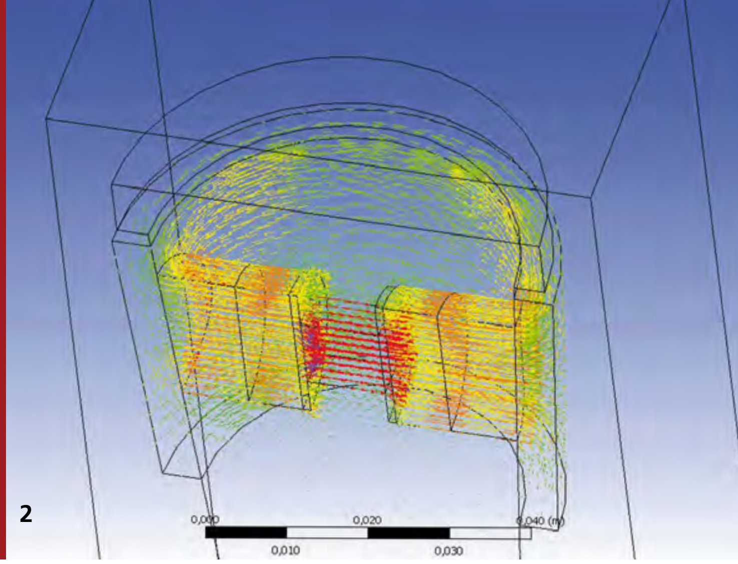


2

MAGNETIC FORCES: HARD AND SOFT MAGNETIC MATERIALS FOR ELECTROMOBILITY AND GREEN ENERGY TECHNOLOGIES

Magnetic materials have been key materials for energy and drive technology ever since electricity was discovered. Hard and soft magnetic materials convert kinetic energy to electrical energy in generators and convert electrical energy into mechanical energy and momentum in motors. Both types of materials are at an advanced stage of development. The requirements of modern energy technology in the area of renewable and green energy sources as well as electromobility have opened up new challenges to further improve the materials for these new applications.

Hard magnetic materials – customized by metal injection molding

For hard magnetic materials, the main challenge is processing the materials, in particular hard rare earth magnets (NdFeB, CoSm), into more complex shapes. The required shaping is not as complex as for other powder-metallurgical materials, but rather concerns the fact that the machining of hard magnets is complex and only grinding with very low depth of cut is possible. There is a need for real net shape processing to obviate all need for grinding.

Metal powder injection molding offers this, along with the ability to manufacture very powerful anisotropic magnets. On applying magnetic fields during the injection molding step, the powder particles are aligned in their preferred direction (Fig. 1, 2). This results in anisotropic, plastic-bonded hard magnets (when used after the injection molding and curing of the binder) or anisotropic, sintered hard magnets (if the binder is removed by sintering at high temperature). The preferred orientation remains largely intact during the sintering process.

1 *Injection mold with hard magnets (red) and pole pieces (green) for anisotropic molding.*

2 *Simulation of the field distribution in the injection mold. The field concentration in the cavity can be seen by the red color.*

Recycling of valuable elements

Another key aspect for hard magnets is recycling: High-performance magnets contain a high fraction of rare earth elements. There is only a finite resource of many of these elements and in some cases geopolitical situations mean that their supply is limited. There is hence a need to recycle these elements from end-of-life products. The recycling of rare earth hard magnets is being investigated by Fraunhofer IFAM.

Soft magnetic materials for high power densities

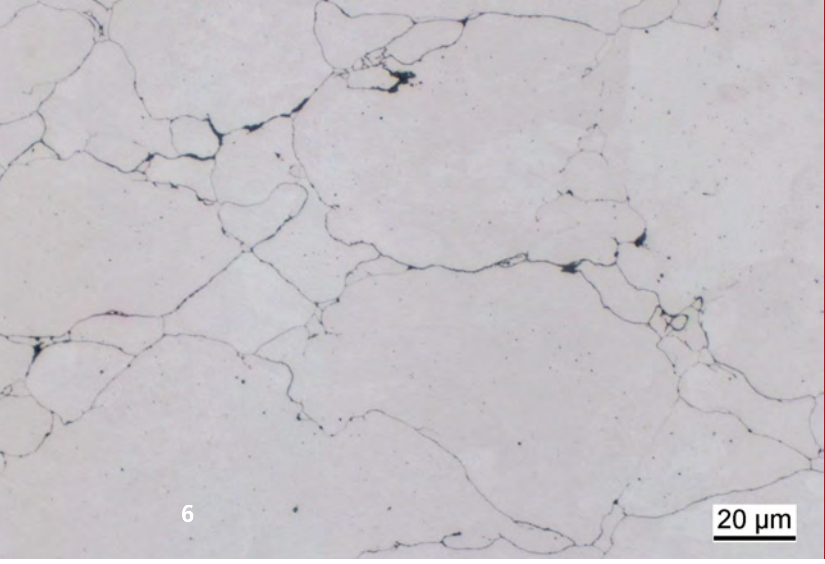
The situation is different for soft magnetic materials. The widely-used electric transformer sheets are highly advanced materials. High purity, preferred grain orientation, and advanced alloying technology have given rise to high-quality products at a reasonable price.

Soft magnetic materials serve to guide the magnetic flux so that it can be optimally used by machines to generate torque. For magnetic fields, the soft magnetic materials have the same function as a cable for an electric field. In hard magnets, the magnetic forces act directly on magnetic materials (Fig. 3). In order for the force to act at a different location, soft magnetic materials are required (Fig. 4).

Modern drive technology is demanding higher torque densities and higher power densities. Furthermore, drivers of cars expect modestly priced but powerful motors, and also high drive comfort. This requires new motor concepts and designs which, although already known, cannot utilize the existing laminated sheet technology because the materials have poor magnetic properties perpendicular to their surfaces. They have extremely anisotropic properties. Magnetically isotropic materials are required, and powder metallurgy is the ideal production technology for these, bearing in mind that the continuous electromagnetic force is generated by alternating magnetic fields. The varying magnetic fields are not only generating forces and torques at the free ends of the laminated packages but also lead to high currents inside the material, so-called eddy currents, which must be included in the losses of the magnetic system in the energy balance.

3 *Injection molded hard magnet with attached magnetic objects.*

4 *Magnetic conductance from the magnet (top) to magnetic objects.*



6 *Micrograph of a particle composite with electrically insulating material on the grain boundaries.*

Reduced losses using particle composites by powder-metallurgical processes

An effective approach for reducing losses due to eddy currents, whilst at the same time having isotropic magnetic properties, is to use particle composites produced using powder-metallurgical processes (Fig. 5). Although large eddy currents arise in conventional materials, leading to large losses, electrically insulating layers on/at the surfaces/interfaces in the composite material essentially limit the eddy currents to the individual particles. The electric transformer sheet does nothing different perpendicular to its surface. In the composite materials, all the spatial directions are insulated from each other. Figure 6 shows the microstructure of such a composite made from very pure iron powder particles. It has very good magnetic properties and the particles are separated from one another by a thin film of plastic or ceramic material. The challenge is not only to give these composites good magnetic properties but also to ensure they have adequate mechanical strength for the high requirements in moving systems for actuators, electric mobiles, and green energy generation.

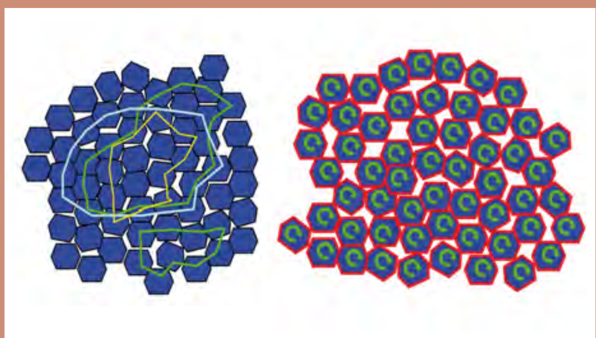


Fig.5: Eddy currents in a non-insulated particle composite (left); Eddy currents in an insulated particle composite are limited to the particles (right).

CONTACT

Hard Magnetic Materials

Dr. Thomas Hartwig
Powder Technology
Phone +49 421 2246-156
thomas.hartwig@ifam.fraunhofer.de

Soft Magnetic Materials

Dr. Georg Veltl
Powder Technology
Phone +49 421 2246-148
georg.veltl@ifam.fraunhofer.de

Dipl.-Ing. Christian Weck
Powder Technology
Phone +49 421 2246-103
christian.weck@ifam.fraunhofer.de

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

1

INTELLIGENT STRUCTURES FOR ROBOT SYSTEMS

Technological progress in robotics is such that robots are increasingly being used in areas that are difficult for people to access and for tasks that are strenuous for the human body. Complex tasks still require a robot to be controlled remotely by a person. As an aid when undertaking certain steps, such as grab operations, the robot operator can observe the process. For a greater degree of automation, the state of the material or structure must be measured. The number and position of sensors is important here for effective control. Fraunhofer IFAM is developing energy-autonomous (energy harvesting) sensor systems for robots.

Feedback from strain gauges

For a high degree of automation, it is vital that the robot gives the operator suitable feedback, for example about the forces during grabbing operations. High local resolution of the force measurement requires many sensors. One alternative here is to use strain gauges which record the loads acting on a robot component. Conventional film strain gauges are bonded to the component surface using a special adhesive. This conventional approach is limited by the thickness of the strain gauges that can be used. Thermogenerators can be used on robots for energy harvesting. These can be installed near motors or on circuit boards and can hence supply part of the required energy. The application of both sensors and thermogenerators using printing methods is a versatile way of introducing these functional structures.

Versatile manufacture using printing methods

Functional structures such as sensors and thermogenerators can nowadays be applied to components and surfaces using printing methods. The processing steps required for this can be carried out at Fraunhofer IFAM using the INKtelligent printing® technology platform. This comprises ink formulation and the printing of the inks using digital printing methods such as aerosol printing and inkjet printing. Subsequent thermal treatment activates the printed functional structure. The aerosol printing process is used for functional structures on complex geometric surfaces. Functional inks are used for this, in some cases filled with metallic nanoparticles. Besides sensors and thermogenerators, it is also possible to print conductive tracks, so reducing the work for contacting and wiring individual components.

1 *Printed strain gauge on hexapod for measuring force transfer, developed in the SeeGrip project funded by DFKI Robotics Innovation Center (© DFKI GmbH).*

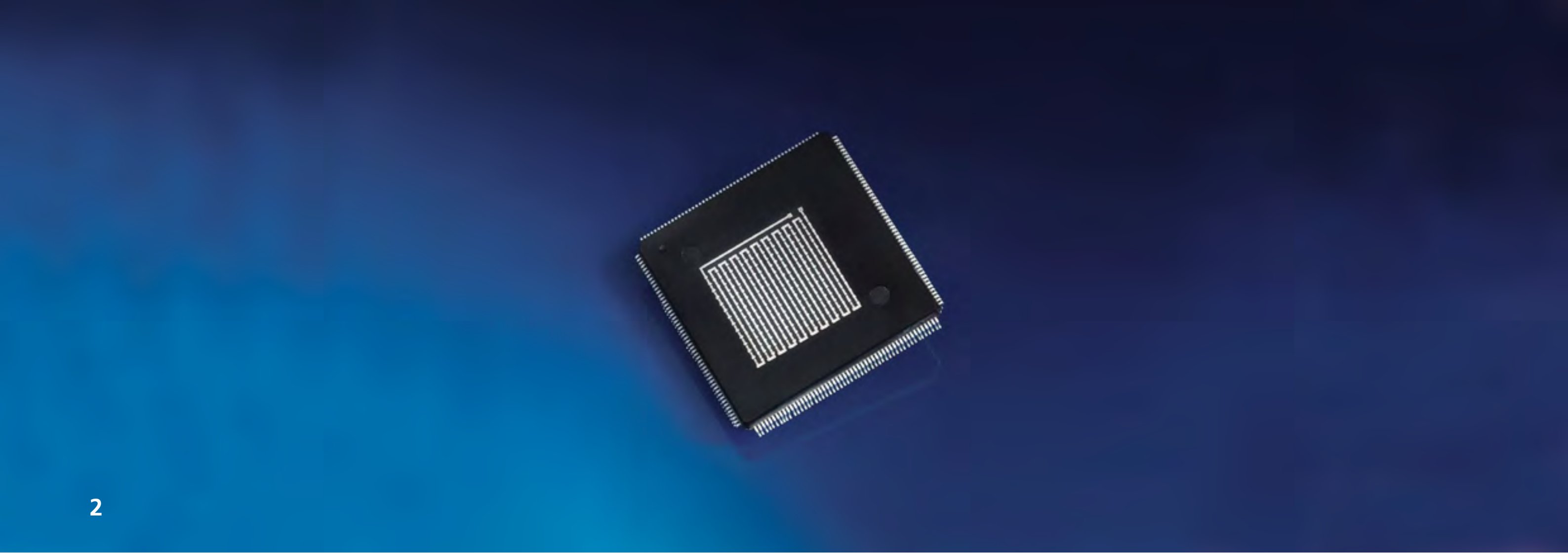
In order to create strain gauges on robot components, functional inks must be used whose properties in the final state are the same as those of conventional strain gauges. Various materials can be used for printed sensors, namely silver, constantan, and an electrically conducting polymer. Silver and the electrically conducting polymer are commercially available functional inks, but printable constantan inks are currently not available and so are manufactured at Fraunhofer IFAM. Thus three inks with different properties can be used for manufacturing aerosol printed strain gauges on robot components. When applying the sensors, the properties of the ink and component surface are adapted to each other. A special coating system was selected for this. This was applied to the aluminum components used in this project and also guaranteed the necessary electrical insulation to the substrate.

These materials were printed as strain gauges on relevant robot components, with several strain gauges being applied. The application of the sensors was demonstrated using two example robot components: a hexapod for force transfer to a robot hand and a component of the robot skeleton (upper arm). Printed thermogenerators are an attractive way of recovering energy from heated components of the robot, to feed back to the system. For this, a thermogenerator is printed directly onto an electronic component by inkjet printing. In order to generate an induced voltage on being heated, organic and inorganic materials are combined in the thermogenerator layout. The generators produced with this structure are a way of supplying electronic components with decentralized energy.

Result: Precise functionalization of robot components

Sensors and thermogenerators can be applied directly to components by printing methods. Aerosol printing is suitable for the functionalization of complex component geometries, whilst inkjet printing is best for flat components. Aerosol printing is therefore best used for applying strain gauges to robot components bearing mechanical loads. Strain gauges made of metals and polymers are applied to the coated aluminum components using printing methods. Although the quality of the measurement signal depends on the material used, the material can be selected and adapted depending on the substrate properties.

As for sensors, the advantage of printed thermogenerators is that they can be directly applied to a component. Using digital printing methods the layout of the thermogenerator can be precisely adapted to the component, for example to benefit from local heating of the component. In the project, a thermogenerator was successfully applied to a circuit board in the robot by inkjet printing. Printed thermogenerators already provide adequate power for technical applications. New materials under development will, however, allow for a significant improvement in the performance of printed thermogenerators in the future.



2

Project funding

Deutsches Forschungszentrum für Künstliche Intelligenz (DFKI) GmbH, Bremen

CONTACT

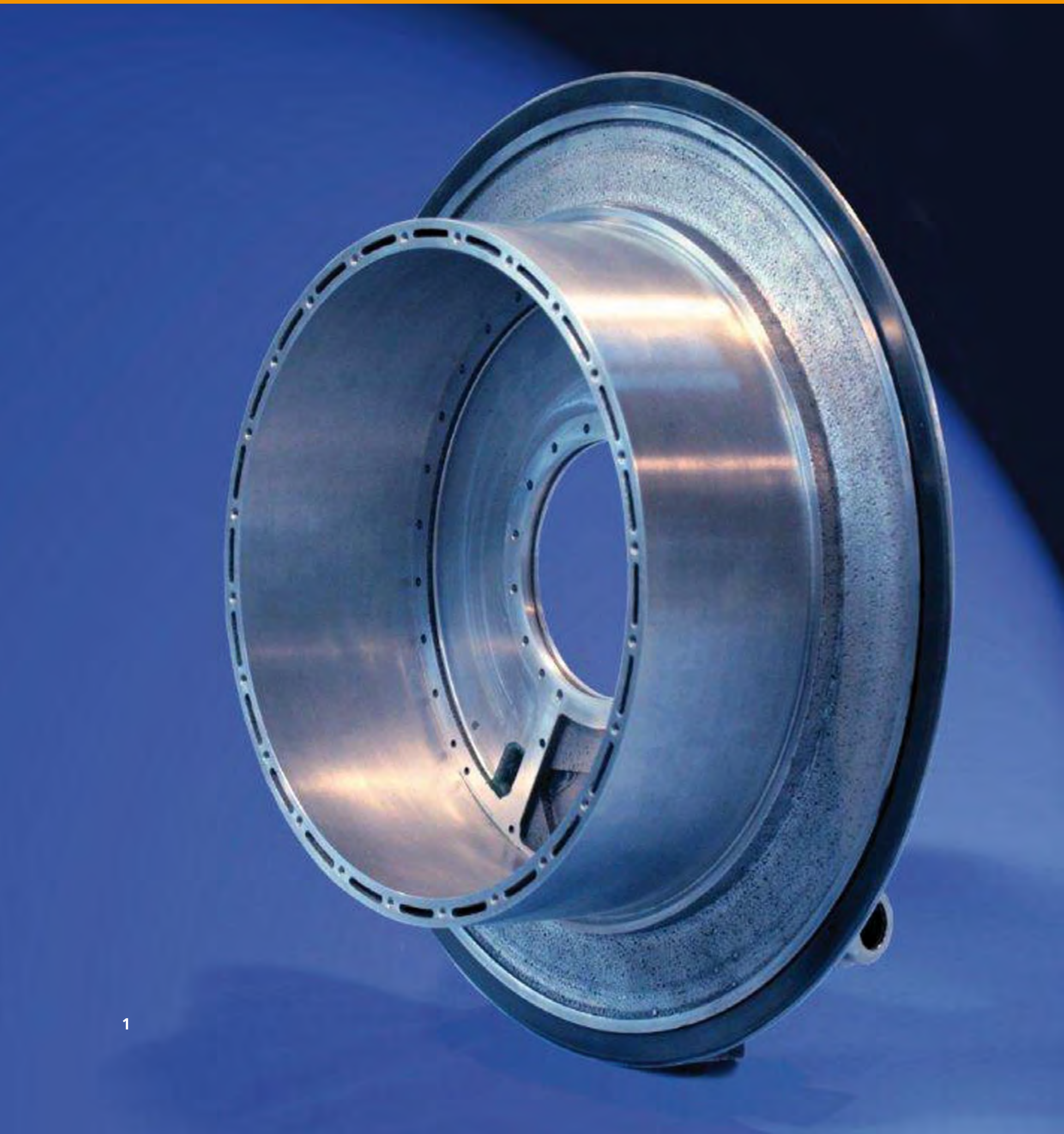
Dipl.-Wi.-Ing. Christian Werner
Functional Structures
Phone +49 421 2246-142
christian.werner@ifam.fraunhofer.de

Dr. Volker Zöllmer
Functional Structures
Phone +49 421 2246-114
volker.zoellmer@ifam.fraunhofer.de

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

2 *Printed circuit boards: Customized combination of thermoelectric and metallic materials allows structures to be printed as thermoelectric generators.*

CASTING TECHNOLOGY



1

CORE COMPETENCE CASTING TECHNOLOGY

Casting technology has many established applications in a range of industries. Fraunhofer IFAM supports industrial customers in the area of casting technology, from the initial idea to the final product. A variety of casting processes and materials are used for different applications.

Fraunhofer IFAM has built up in-depth know-how and has an extensive range of facilities for die casting, investment casting, and lost foam casting, the three most important casting methods.

Die casting is the most productive of the three methods and still today has enormous potential for enhancing value creation. Key current research areas include lost (salt) cores, cast structural components, and hybrid joining of FRPs with casting materials, in particular CFRP and aluminum.

Investment casting is useful for complex and delicate structures with fine surfaces. Here, a wax model of desired geometry is prepared, embedded in molding material, and then heated. The resulting hollow space is then filled with melt in the investment casting plant.

Lost foam technology is used for casting large and small parts of high complexity directly as near net shaped parts. The method allows uniquely complex components to be manufactured with any design of channels and undercuts – without demolding grooves or burrs. Fraunhofer IFAM is a leader in lost foam technology and works closely with industry via the Verbund des Lost Foam Council e. V..

The casting materials used include aluminum, magnesium, zinc, copper, steel, and customer-specific special alloys. In addition, special materials such as metal-matrix composites are developed and improved, opening up new applications for casting and cast components.

The function-integrated cast components being developed at Fraunhofer IFAM are a growing area of work. The integration of electronic components involves function-integration during the casting process. CAST$^{\text{TRONICS®}}$ technology allows advanced electronic, sensor, and actuator functionalization of cast components, for example RFID component identification and sensors for load detection. Numerical simulation of casting processes and extensive analytical facilities are also available at Fraunhofer IFAM.

Furthermore, there is the unique opportunity for customers to also benefit from the expertise of other related research groups at Fraunhofer IFAM, for example in the area of corrosion protection, surface coatings, and adhesive bonding.

1 *Cast housing with integrated water jacket and cooling ducts for an electric motor, manufactured using the lost foam process.*

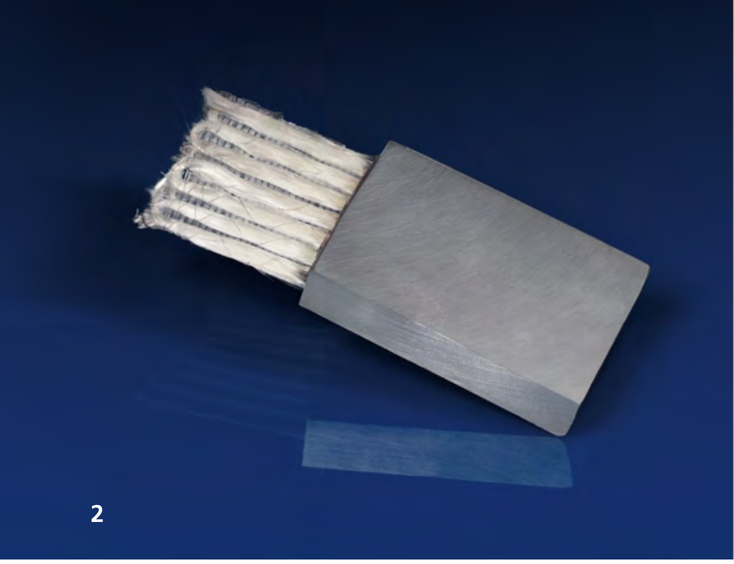
JOINED VIA CASTING: HYBRID CFRP-ALUMINUM MATERIALS FOR LIGHTWEIGHT STRUCTURES

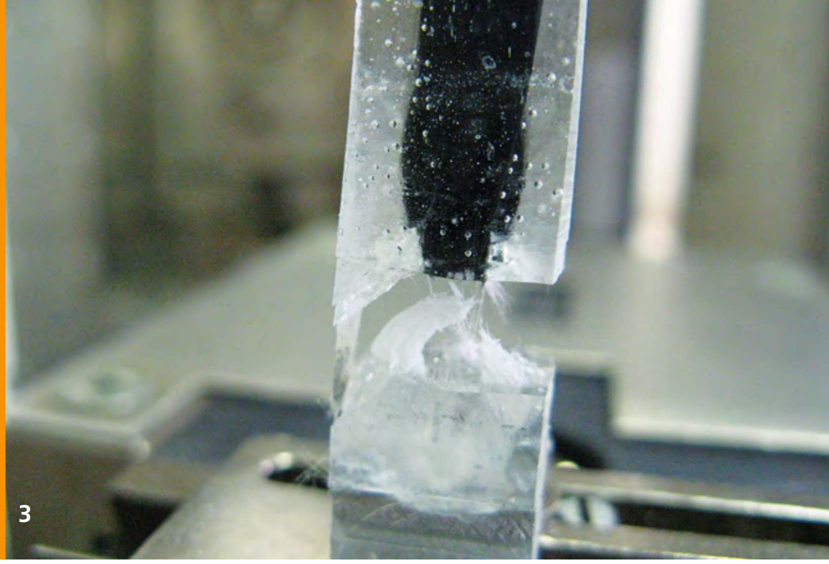
Lightweight design is a key technology. Fiber composites come into their own wherever low weight and load-bearing functionality are required. Experts are unanimous that carbon fiber and glass fiber reinforced materials hold great promise for new products. However, metals are also sometimes required. One method that unites the best properties of different materials is the so-called hybrid construction, for example the joining of light aluminum with strong CFRP. These materials are currently joined with adhesives or mechanical fasteners. New construction and joining methods are required here to optimize the weight and mechanical properties of these hybrid materials.

Joining substrates using transition members made of titanium wire or glass fiber

Hybrid aluminum / CFRP structures have potential benefits for a wide range of industries: lower weight, lower spatial requirements, and fewer production steps. There is already much demand for these materials. The aviation industry uses these materials, and they are also being increasingly used in wind turbines and for machine construction in general. For modern automobile production, wholly CFRP chassis are already been used. The vehicle frame, which is made as a separate component, is made of aluminum. To assemble these components, a joining technique is required and this is usually a combination of bolts/rivets and adhesive bonding.

The DFG research group „Schwarz-Silber" was set up at the University of Bremen in order to develop novel joining concepts. A number of joining concepts have been tested and the resulting mechanical properties have been evaluated. All the approaches that were tested utilize a so-called transition member between the aluminum and CFRP. This design is optimized for fiber materials and takes account of the lower space requirements and weight compared to conventional joining techniques. The transition member that is introduced leads to electrochemical decoupling of the materials and so prevents corrosion of the aluminum-CFRP composite. A particular advantage of these transition members, which can be made of heat-resistant glass fibers or titanium wire, is their simple direct integration into aluminum components via aluminum casting. This is being studied by the Casting Technology group at Fraunhofer IFAM and is being assisted by the Plasma Technology and Surfaces (PLATO) group. The latter is investigating surface modification of the transition members to improve the mechanical and anti-corrosion properties of the joints.





Firmly joined via die casting

Besides die casting, the project also studied the integration of transition members using lost foam casting. This process allows components with almost any desired complex geometry to be manufactured. Firstly, special cast inserts made of suitable materials were manufactured. These are inserted into the mold before the actual casting process. Part of the transition member is covered so that there is no infiltration with melt. This part – an either titanium wire noose, glass fiber noose, or glass fiber fabric – protrudes from the aluminum component after the casting process and forms the attachment point to the carbon fibers in the next production step.

The challenge in such a joining technique is positioning the transition members in the mold or pattern, depending on the casting method. This positioning step is necessary so that the members are not carried or forced away as the aluminum melt flows in. Suitable holders have been developed and tested. However, the casting process parameters must be chosen to allow as full an infiltration of the transition members as possible. Depending on the material used for the transition member, a key parameter is its thermal stability.

The current project work, which will last a total of 3 years, is studying the feasibility of manufacturing such joints. The tensile strength of such joints will be compared to the strength of traditional joints.

Results up until now indicate that such joints can be manufactured using both die casting and lost foam casting. In addition, initial tensile tests have been carried out on the whole joint system comprising aluminum - transition member - CFRP. The results indicate the latter have a similar strength to conventional bolted/rivet connections, although this new type of joint has considerably lower weight.

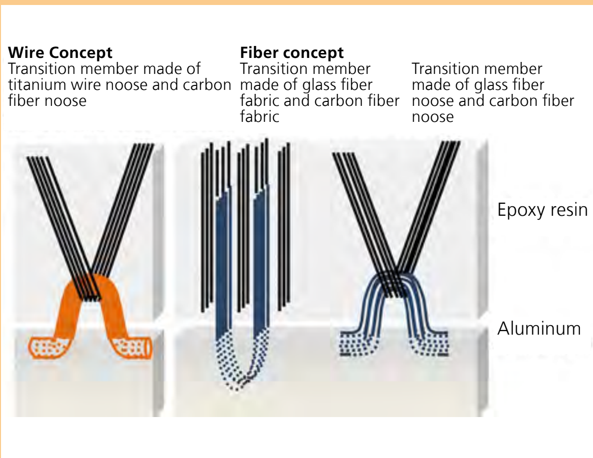


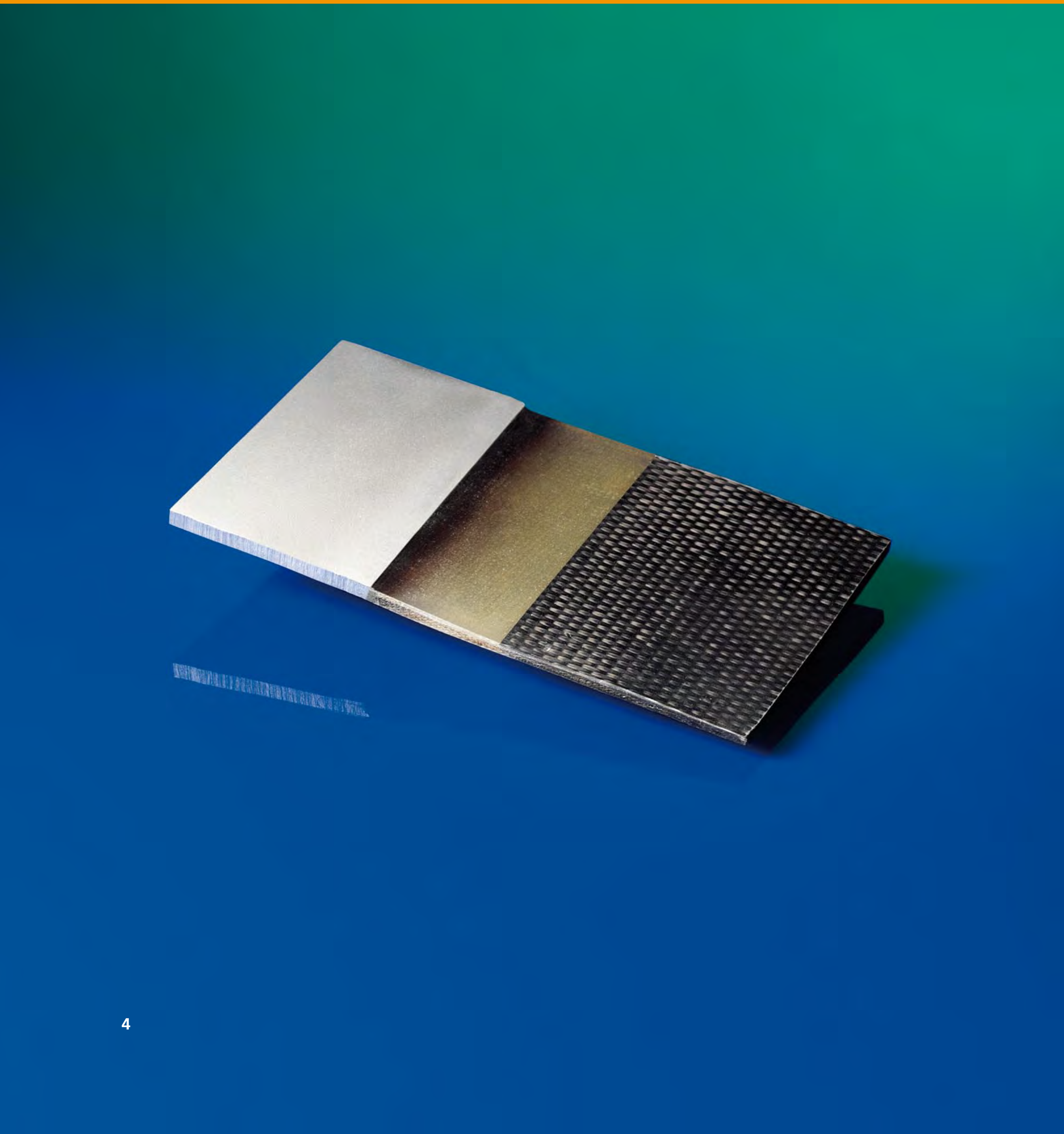
Fig. 1: Schematic representation of the joining concepts being developed at Fraunhofer IFAM.

Development potential: Automated joining

IIn future work the mechanical properties of joints manufactured using selected joining techniques will be tested and compared. Further concepts will also be developed at Fraunhofer IFAM to integrate the cast joint manufacture into existing production processes. The manufacture of large quantities of casting inserts for the novel joining techniques will be evaluated. Also, the automated insertion of the casting inserts into the die casting mold will be studied and evaluated.

2 *Fiber concept: Glass fiber noose partially infiltrated in the die cast aluminum.*

3 *Tensile test on an aluminum-CFRP joint with glass fiber noose transition member (© Stiftung Institut für Werkstofftechnik (IWT), Bremen).*




5

Project funding

Deutsche Forschungsgemeinschaft

Project partners

- University of Bremen
- Faserinstitut Bremen e. V. (FIBRE), Bremen
- Bremer Institut für angewandte Strahltechnik GmbH (BIAS), Bremen
- Bremer Institut für Strukturmechanik und Produktions-anlagen (BIME), Bremen
- Bremen University of Applied Sciences
- Stiftung Institut für Werkstofftechnik (IWT), Bremen

CONTACT

Dipl.-Ing. Jan Clausen
Casting Technology and Component Development
Phone +49 421 2246-273
jan.clausen@ifam.fraunhofer.de

Dipl.-Phys. Uwe Specht
Plasma Technology and Surfaces PLATO
Phone +49 421 2246-272
uwe.specht@ifam.fraunhofer.de

Dipl.-Wi.-Ing. Christoph Pille
Casting Technology and Component Development
Phone +49 421 2246-227
christoph.pille@ifam.fraunhofer.de

Institute
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen

4 *Hybrid CFRP-aluminum joint with glass fiber web (incorporated via casting) as the transition member.*

5 *Hybrid pipe joint between a die cast aluminum component and CFRP, with a titanium wire noose as the transition member.*

1

CORE COMPETENCE ADHESIVE BONDING TECHNOLOGY

Adhesive bonding refers to a manufacturing method, belonging to the group of joint processes, that involves the joining of substrates using an adhesive to form a material-fit joint. Over recent decades, adhesive bonding has become ever more widely used by a host of industries. The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM realized the potential of adhesive bonding technology at an early stage and developed this as a core competence. Fraunhofer IFAM is internationally recognized in this field and is the largest independent research organization in Europe working in this area.

The core competence adhesive bonding technology at Fraunhofer IFAM involves development and characterization of materials, development and usage of various application techniques, design and validation of structures, as well as in-depth quality assurance.

The institute has a wealth of experience regarding the modification of polymer systems as well as the development of adhesives and sealants. Challenges such as adhesion promotion and protection against aging form part of the portfolio as do the development and use of biomimetic adhesives. For characterizing adhesives and bonded joints a wide spectrum of chemical, physical, and mechanical test methods is utilized. The aging behavior and service life of bonded joints are often key aspects.

The integration of adhesive bonding technology into industrial production requires an application method adapted to the specific utilization. To achieve high-quality bonded joints it is often necessary to pre-treat the substrate surfaces. The substrates are cleaned and activated or modified to enable the adhesives to adhere to the substrates with good long-term stability. Process automation, including tolerance-specific production methods, is important in many industries. Also important are the design of bonded joints and the dimensioning of bonded structures. This is based on experimental parameters for materials, joints, and components determined in an accredited test laboratory, taking into account the specific boundary conditions of the application.

The institute provides consultancy on all matters relating to adhesive bonding technology. Optical methods, in-line analyses, and a wide variety of destructive and non-destructive test methods are used for quality assurance purposes. An established and comprehensive portfolio of training courses in adhesive bonding technology is also offered. The certificates of the courses which are given worldwide are accredited and recognized in all of Europe. These courses are a further key aspect of the quality assurance concept for adhesive bonding technology.

Fraunhofer IFAM also acts as a Certification Body of the Federal Railway Authority for auditing and approving companies that carry out or subcontract adhesive bonding work, sell bonded products, or offer services regarding the designing and dimensioning of bonded components for rail vehicle construction.

1 *Pre-applicable PASA® adhesive on metallic fasteners.*

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3

GUIDELINES "ADHESIVE BONDING – THE RIGHT WAY"

Adhesives are nowadays used for a wide variety of applications. Adhesive manufacturers are therefore not able to provide detailed information about the different and often very specific applications on data sheets. If users of adhesives do not have a good basic knowledge of the special aspects of adhesive bonding, the result is often failure of the bonded joint and product damage. To prevent this, the Center for Adhesive Bonding Technology of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen, in collaboration with the Industrieverband Klebstoffe e. V. (IVK; German Adhesive Association) has prepared guidelines entitled "Adhesive bonding – the right way".

Frequently the complexity of an adhesive bonding process is underestimated and simple basic rules go unheeded, such as:

- No knowledge about the fundamental mechanism of adhesion.
- When selecting the adhesive, only the substrate material is considered.
- The ban on silicones and silicone oils being used in production areas where adhesive bonding work is undertaken is often ignored.
- Users are familiar with assembly adhesives, universal adhesives, glues, and superglues, but not the differences in properties between these and other adhesives.

As adhesive users work from their subjective point of view to the best of their knowledge and so believe they are doing everything correctly, the cause of any failure of bonded joints is often put down to the adhesive or bonding technology. Age-old and false prejudices such as "it was only bonded", "adhesive bonds cannot hold for long", and "had it been welded/screwed/bolted" are often heard.

This line of thought has a negative effect on adhesive manufacturers and on the image of adhesive bonding technology for potential adhesive users.

The guidelines prepared by Fraunhofer IFAM in conjunction with the Industrieverband Klebstoffe e. V., "Adhesive bonding – the right way", will make a huge contribution to improving the trust in adhesive bonding technology and raising its image (Fig. 1). If the number of application errors – indeed even just the biggest errors – is reduced and the number of effective bonded joints increases, then the project will have made a contribution to qualified market development (QMD) of adhesive bonding technology.

Objective

The objective of the project was to prepare general guidelines for adhesive application and quality assurance, from the initial planning phase for a product through to repair respectively disposal of the bonded product. "Adhesive bonding – the right way" will primarily allow adhesive users to identify options for quality assurance for their applications and to select suitable methods.

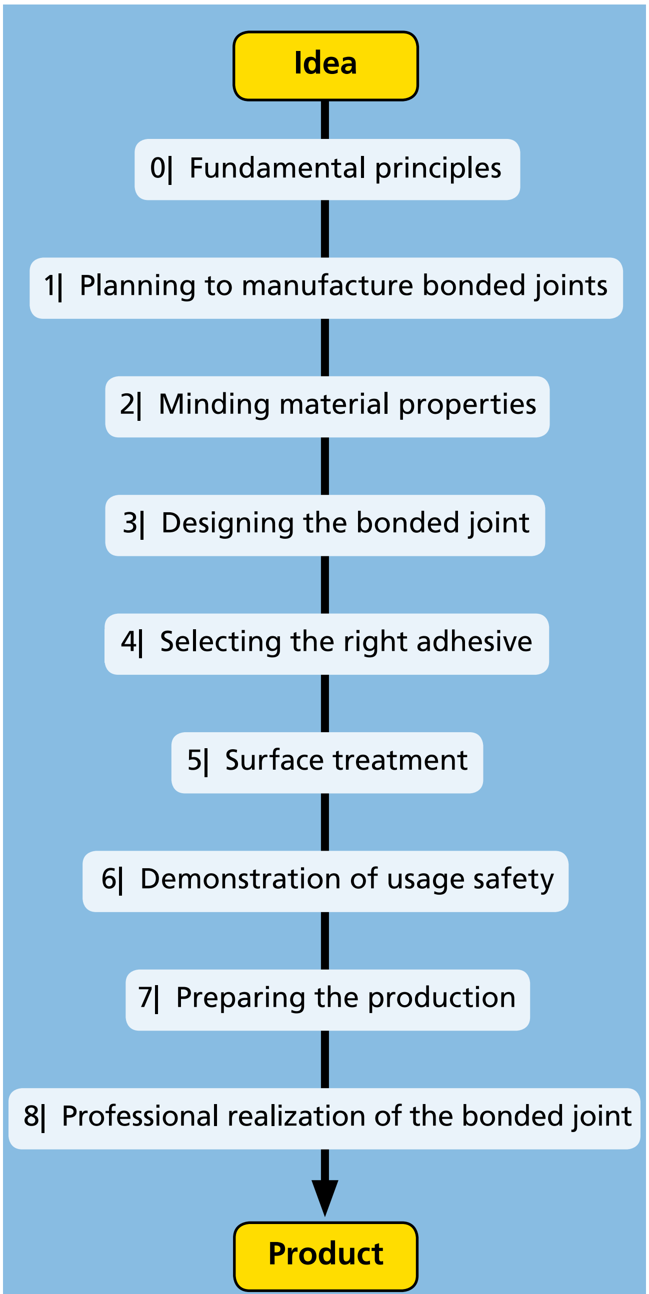


Fig. 2: Quality management concept: Subdivision of the whole bonding process – from the planning phase right through to the production phase – into different process steps.

In addition, the guidelines will make adhesive users aware of the key special features of adhesive bonding and so help them avoid major errors when selecting and using adhesives. The guidelines perfectly complement the supracompany training courses in adhesive bonding technology, the advice given to users by adhesive manufacturers, and product training.

The target group includes existing users of adhesives and also prospective users who require information about how to avoid pitfalls when using adhesives. "Adhesive bonding – the right way" was developed for both adhesive manufacturers as well as users, has general validity, and is relevant for all industries. The guidelines are available in both German and English.

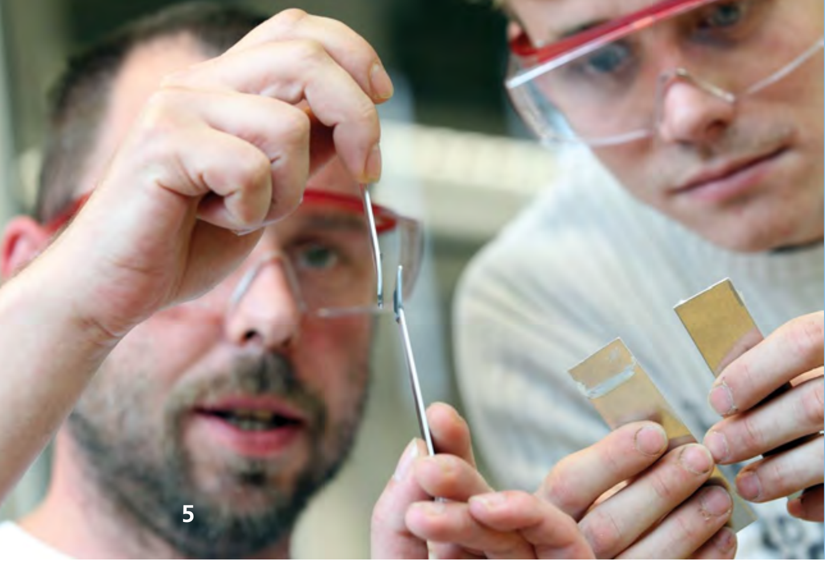
Contents

The guidelines are relevant for simple examples of industrial structural bonding as well as for more special bonding applications, e. g. for the packaging sector, the installing of parquet floor, the shoe manufacturing industry and the building industry. They are based on the proven principles of the comprehensive quality management (QM) concept that was developed at Fraunhofer IFAM (Fig. 2).

The most significant features of the QM concept are:

- the holistic view of the bonding process and
- differentiation between the bonding process and measures for quality assurance.

1 *Adhesive bonding technology – a reliable joining method.*
3 *Cleaning and activation of complex component surfaces using atmospheric pressure plasma.*
4 *Manual application of a moisture-curing polyurethane adhesive from a cartridge.*



First of all the bonding process is subdivided into the planning, conception, design, elaboration, production, and usage phases. For each of these phases there is further subdivision into the individual process steps (Fig. 3 + 4). This means that, for the first time, users have available a complete and logical sequence that describes the course of the process. Practical experience shows that simply keeping to the correct sequence respectively iteration of process steps results in major errors being avoided, so saving not only time but also money. The positive effect here is essentially due to the timely and complete procurement, elevation and consideration of data.

"Adhesive bonding – the right way" also contains information about how to correctly carry out the processing steps. Whilst this information can in principle be obtained from books on joint design, design catalogs, technical data sheets, text books on adhesive bonding technology, and standards, there is often no time during the industrial working day to carry out time-consuming fact-finding from different text sources. The inclusion and the equitable allocation of this information in a logical way in the guidelines is an added benefit.

The main intention and innovative aspect of the guidelines is, however, to inform users about quality assurance. The arrangement and guidance of the information are carried out by the process steps. This means, for each individual step all known options and methods are described to allow quality assurance of each single process step (Fig. 5).

Conclusion

The guidelines provide users with information about the bonding process at three different levels. Firstly, a proven sequence respectively iteration of process steps is recommended to the user. Secondly, users are provided with information about how to effectively carry out each step. Thirdly, options and methods for the quality assurance of each process step are given.

A holistic view of the bonding process combined with the linking of information in the described way, which provides quick and intuitive knowledge for relatively inexperienced users of adhesives whilst sparing them from the complexity and sheer amount of information available, has not existed up until now. The guidelines "Adhesive bonding – the right way" now remedy what was seen by many users as a major shortcoming.

http://leitfaden.klebstoffe.com/

CONTACT

Dr. Tanja Warratz
Workforce Training and Technology Transfer
Phone +49 421 2246-616
tanja.warratz@ifam.fraunhofer.de

Institute
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen

5 *Assessment of lap shear specimens after testing.*

ADHESIVE BONDING FOR TIMBER ENGINEERING

Low costs, solid design, sustainability, and a responsible attitude to the environment are becoming ever more important in the construction sector. Research and development on timber construction is being intensified to tackle the few shortcomings of wood – such as its poor resistance to weathering if not protected, lower strength if compared to other structural materials, and the direction-dependent mechanical properties such as rigidity and strength (orthotropy) – and create suitable conditions for efficient usage of this resource.

Joining methods for wood construction

Structures made of wood are normally joined by pin-shaped fasteners. These have the decisive disadvantage that they cut through the fibers and hence significantly weaken the cross-sections. These fasteners usually also require relatively high deformation to achieve the connection force. As a result, the connections are "weak" and the assembled structures exhibit lower rigidity.

The introduction of fiber reinforced materials such as glass fiber and carbon fiber reinforced plastics (GFRPs, CFRPs), for example, for aircraft and car manufacture, has seen industry face similar challenges for many years. Acknowledging this, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen, has been working intensively on the development, design, and testing of effective load-bearing solutions using adhesives and their implementation in industrial production. Based on this expertise, know-how is being transferred to wooden structures and will be developed further.

Successful research projects on bonding wood have highlighted the potential of adhesive bonding technology to give new impulses to this area. Bonded joints allow higher loads and have considerably less deformation. Also, wood can be joined much more easily and particularly more appropriately for the material involved via force-fit joints to form hybrid structures with other materials, such as steel, glass, GFRP, or CFRP.

Adhesive bonding – the joining technique for creating hybrid and multifunctional structures

Wood shows all its qualities when combined with other materials – in form of adhesively bonded hybrid structures – with loads being effectively distributed over the different materials. Optimally designed hybrid components or structures bring together relatively low-cost materials with higher performance materials and so contribute to affordable design. Fraunhofer IFAM has expertise in surface technology, joint design using a wide range of substrate materials, adhesive selection, modification, and development, as well as optimized application technologies and is hence an ideal partner for developing wood-based hybrid structures.

If the concept of hybrid structures is thought through to a logical end, the result is hybrid multifunctional structures whose different materials play not only a static but also a functional role. The shape and function are considered together in the design phase and duplication is avoided. A typical example is glass panels used to provide static rigidity to a structure but simultaneously acting as the building envelope. Here, even more than for hybrid structures, effective bonded joint design is very important. In order to guarantee the adequate load-bearing capacity, it must also be ensured that the adhesively bonded joint preserves the functional integrity of the structure.

Wood-glass bridge

In order to illustrate the potential of adhesively bonded joints for wood structures, Fraunhofer IFAM, working in collaboration with architects, has designed a hybrid multifunctional pedestrian bridge made of wood and glass. The static principle is relatively simple: The bridge deck, a cross-bonded wooden board, was bonded on its side force-fit via glass panels to a series of upper laminated timber trusses. Overall, the bridge shown in Figure 1 acts as a box girder in which the glass largely serves to carry the shear forces. The bridge spans a freeway of 58 meters width via four supports. It is a hybrid structure because the glass and wood act statically in the overall structure. It is also multifunctional because the glass also acts as the structure envelope. Due to the avoidance of duplication, features as transparency and lightness distinguish the design.

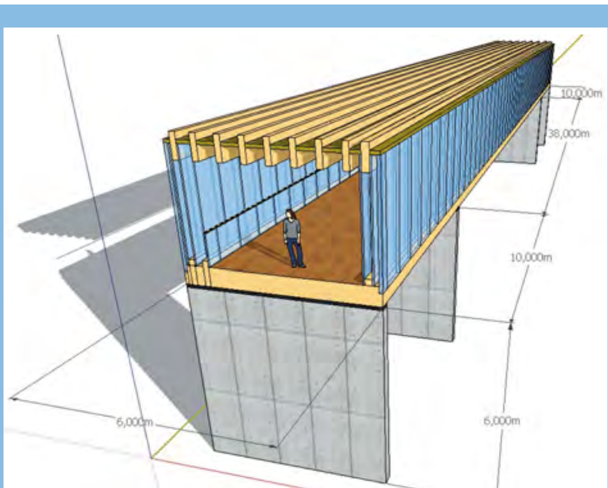


Fig. 1: The prototype pedestrian bridge is from a static viewpoint a girder with a box cross-section. The top and bottom members are made of wood and are connected force-fit to each other via the bonded glass panels.

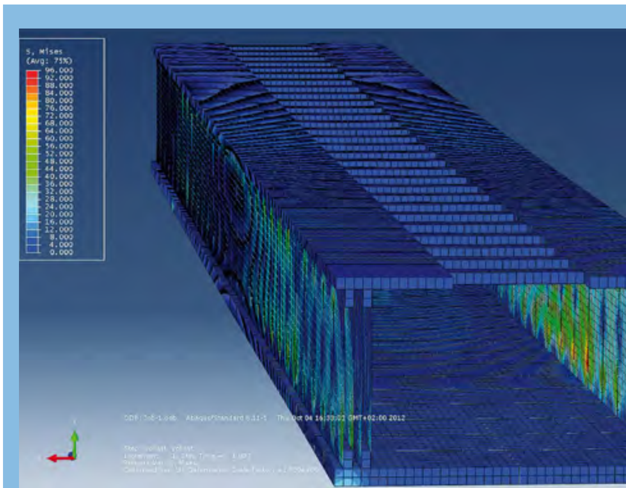


Fig. 2: The computation of hybrid structures, in particular the sizing of the adhesively bonded joints, is undertaken using FEM. Experimental tests on relevant wood and glass connections provide the necessary parameters.

Based on the expertise of Fraunhofer IFAM in adhesive bonding technology and the experimental characterization of bonded structures, all the joints were sized for the expected loads using the Finite Element Method (FEM; Fig. 2). Due to the generously sized bonding areas, the forces to be transferred resulted in relatively low stresses.

Outlook

Adhesively bonded joints are still viewed skeptically by some practitioners, not only for wooden structures but indeed in combination with all materials. An effective bonded solution is nowadays available for virtually all applications, e. g., meeting the required strength and able to withstand particular climatic conditions. Nevertheless, adhesive bonding technology for structural bonding must meet special requirements:

- Adhesives that are used on the building site must be able to be processed under the conditions prevalent there, for example, under fluctuating temperature and humidity. Complex pre-treatment of substrate surfaces is not possible here.
- A "healthy work" environment requires adhesives which are harmless from a health and environmental point of view and which can be used inside buildings.
- Dismountable adhesively bonded joints are of particular interest in civil engineering for facilitating the replacement of damaged elements or guaranteeing material-pure separation of the adhesive and structural elements for subsequent recycling.

The Adhesive Bonding Technology and Surfaces division of Fraunhofer IFAM is an ideal partner for research and development on practical solutions for structural bonding applications in the timber construction. Expert knowledge, optimum facilities, and decades of experience working closely with almost every industry in the area of surface technology, the design of bonded joints, product and application specific adhesive development, adhesive dosing and application, implementation of bonding processes in production optimized for the customers, as well as process automation provide a very solid basis for this.

CONTACT

Dr. Till Vallée
Adhesive Bonding Technology
Phone +49 421 2246-474
till.vallee@ifam.fraunhofer.de

Dipl.-Ing. Cordula Grunwald
Adhesive Bonding Technology
Phone +49 421 2246-7359
cordula.grunwald@ifam.fraunhofer.de

Institute
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen

FATIGUE STRENGTH OF ADHESIVELY BONDED STEEL COMPONENTS FOR CARS UNDER LOADS OF VARIABLE AMPLITUDE

The structural bonding of high-strength steel sheets is becoming increasingly important in the automobile industry. Simulation and modeling methods for designing adhesively bonded lightweight structures are indispensable for new developments. This concerns in particular considerations regarding the fatigue strength and fatigue life.

A joint project undertaken by the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen, the Institute of Mechanics (IfM) of the University of Kassel, as well as the System Reliability and Machine Acoustics (SzM) department at the Technical University of Darmstadt has studied two different approaches for estimating the fatigue life assuming that the adhesively bonded joints fail solely due to cohesion failure in the adhesive.

Two approaches for estimating the fatigue life of structural adhesively bonded joints

Scientists at Fraunhofer IFAM and University of Darmstadt are collaborating on the first approach for estimating the fatigue life of structural adhesively bonded joints. It is based on local stress states in highly stressed regions of the adhesive layer. These are being quantified using the Finite Element Method (FEM) assuming the material has linear elastic properties. The fatigue life is estimated using post-processing software which maps a local stress state onto a fatigue life based on experimental stress-number (S-N) curves. Adhesively bonded joints were tested under cyclic loads of variable and constant load amplitude.

The second approach being evaluated by the University of Kassel totals the damage caused by each oscillation due to creep loads and cyclic loads.

Both approaches were based on the same experimental data. The first approach allows rapid calculation but requires experience and detailed experiments for calibrating and ensuring the reliability of the service life estimation. The second approach requires very long calculation times.

Effect of hydrostatic stress states on the fatigue life – an innovative contribution of Fraunhofer IFAM to the joint project

The first approach is based on the geometric stress concept, whereby the fatigue life, based on a static stress calculation, is estimated from the S-N curve of adhesives or adhesively bonded joints. The calculated fatigue life depends, amongst other things, on the equivalent stress by which the stress tensor is expressed as a scalar quantity.

Due to the complex behavior of adhesives and bonded joints there is in practice a lot of experimental work required to adequately characterize the failure behavior and average stress dependence. Despite the high amount of work involved, the procedure is still an approximate method that is based on certain assumptions and a limited set of experiments.

In this context, we have been successful in explicitly considering multiaxial stress states in adhesive layers. An equivalent stress was chosen which links the hydrostatic stress component – that leads to a volume change – to the deviatoric stress component – which leads to shape change in the adhesive.

The necessary cyclic tests and S-N curves were undertaken on specimens which in each case had a different ratio of the hydrostatic stress (p) to deviatoric (q) stress (multiaxial ratio). The specimens were lap shear, bevel, and butt joint specimens (Fig. 1), in each case with solid steel substrates in order to have the stress distribution as homogenously as possible in the adhesive layer.

A graph was developed (Fig. 2) correlating the measured fatigue life N with the calculated stress components p and q. For this the p and q values for a stress state were entered for the same fatigue life N (N = 1000, 10,000 etc.) for the differ-

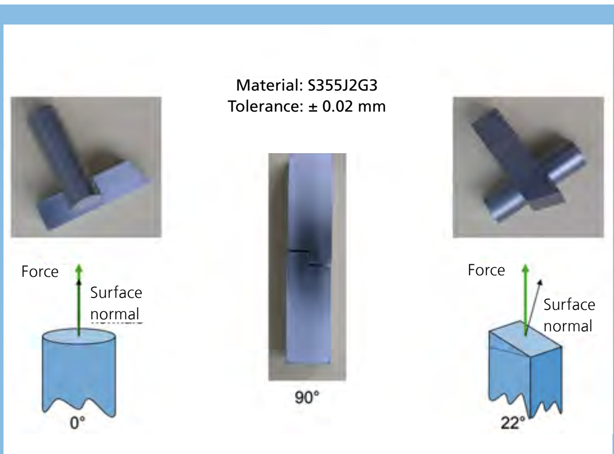


Fig. 1: The angle between the surface normal and the direction of load determines the multiaxial stress state in the adhesive layer of the tested specimen types – lap shear joint, bevel joint, and butt joint (from left to right).

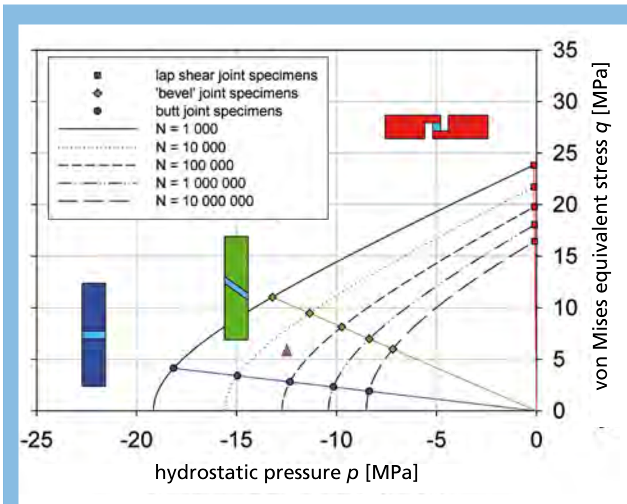


Fig. 2: Fatigue life diagram for multiaxial stress states.

ent test specimens (lap shear, bevel, and butt joint specimens). The calculation of the stress components p and q for a specific fatigue life N was carried out using the Finite Element program ABAQUS based on suitable models.

Such a graph can be used to assign a fatigue life to any critical stress state (p, q) in the adhesive layer. The fatigue life of a specimen with stress components p and q, indicated in Figure 2 by "▲", lies between 10,000 and 100,000 load cycles, namely it is about 50,000 load cycles. The crude graphical determination of the fatigue life in this way is simple. The calculation procedure is very complex and uses tables of experimentally determined relationships.

Results of the fatigue life estimation

For laboratory and simple test objects (Fig. 3) the fatigue life can be estimated with good accuracy, namely a deviation of factor 2 to 8. The accuracy of the prediction depends on the element definition and extension of the areas for which a value pair (p, q) is determined.

Conclusion

The quality of the fatigue life estimation of adhesively bonded steel components using the developed multiaxial approach is within the accuracy required by industry (deviation factors

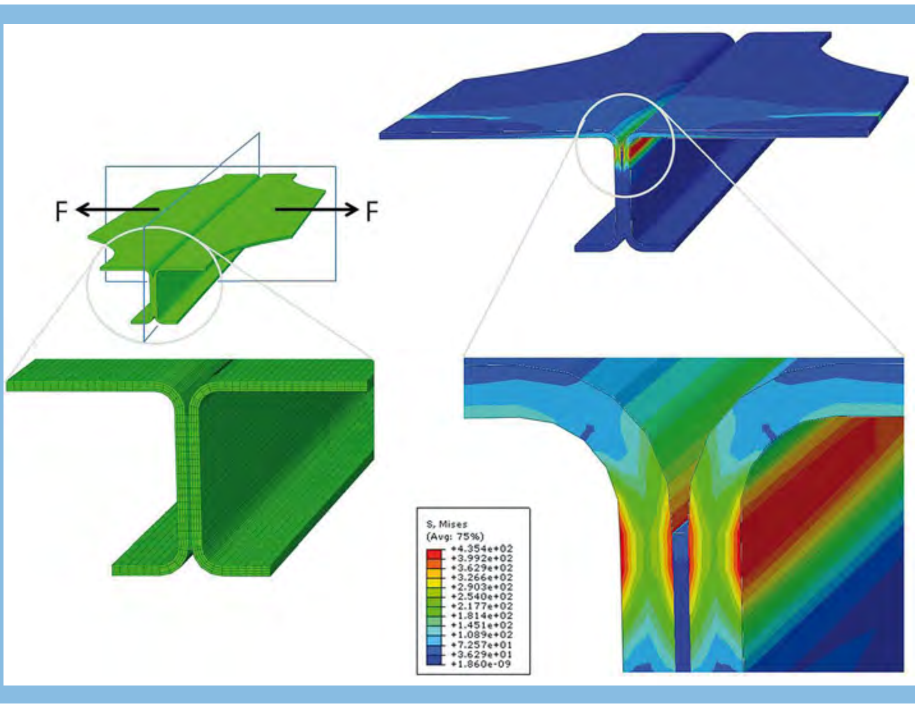


Fig. 3: Fatigue life estimation for the example of a simple adhesively bonded component (F = load).

below 10). In the case of the toughened adhesive considered here the fatigue life estimation can be used for the design of components.

Experiments with a non-toughened adhesive highlighted that the primary database necessarily required to estimate the fatigue life depends on the type of adhesive.

Outlook

Up until now the multiaxial approach has only been used for cyclic loading with tensile mean. Tests under reversed cyclic loading are planned. A joint project is ongoing to determine the fatigue life of adhesively bonded specimens under the effect of temperature [IGF project 428 ZN].

Project funding and partners

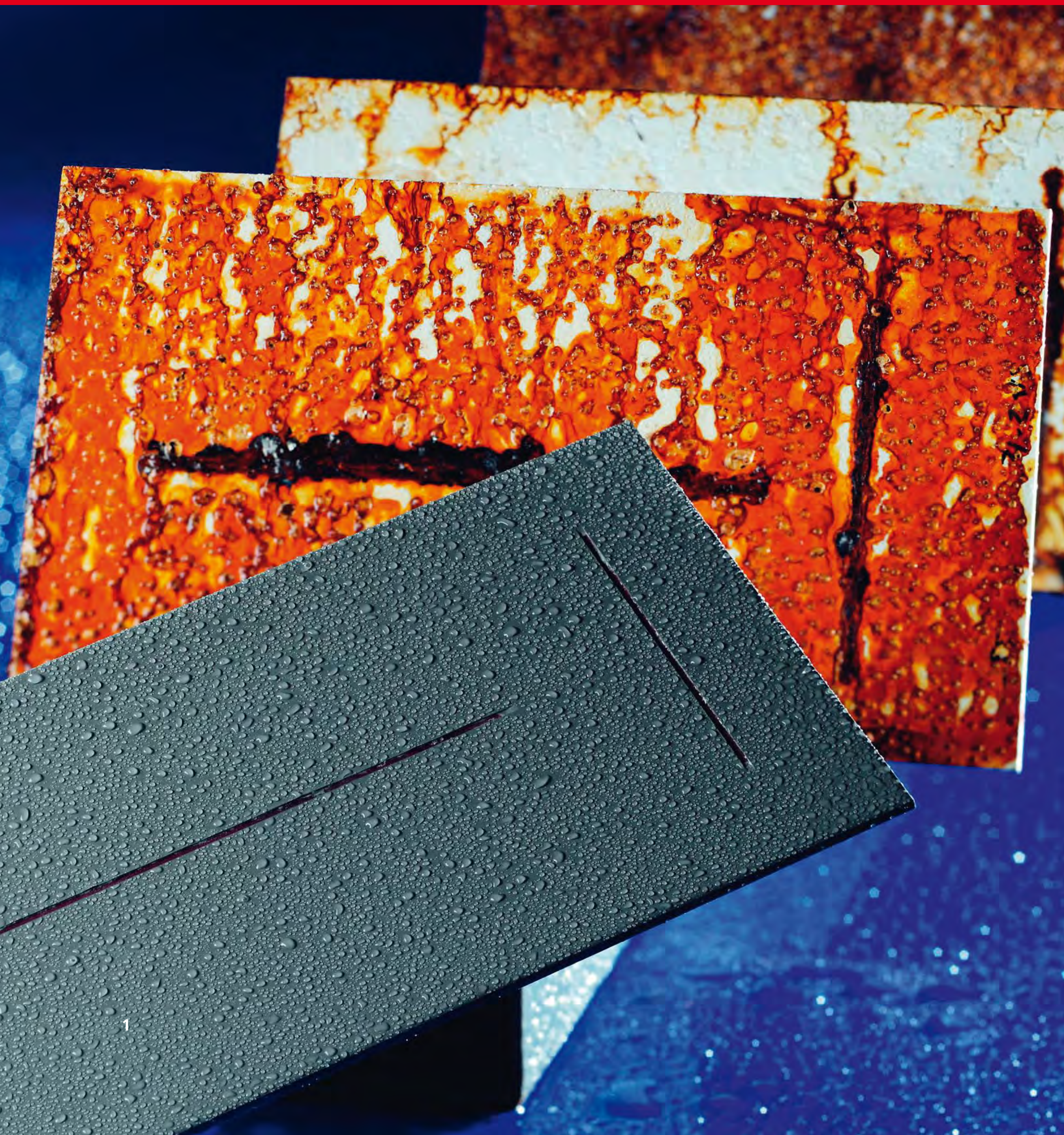
The IGF project 307 ZN of FOSTA – Forschungsvereinigung Stahlanwendung e. V., Düsseldorf, was carried out by the Institute of Mechanics (IfM) of the University of Kassel, the System Reliability and Machine Acoustics (SzM) department of the Technical University of Darmstadt, and the Fraunhofer IFAM. The project was funded via the AiF under the program for funding joint industrial R&D (IGF) of the Federal Ministry of Economics and Technology (BMWi) due to a decision by the German Bundestag.

CONTACT

Dr. Markus Brede
Materials Science and Mechanical Engineering
Phone +49 421 2246-476
markus.brede@ifam.fraunhofer.de

Dr.-Ing. Bernhard Schneider
Materials Science and Mechanical Engineering
Phone +49 421 2246-422
bernhard.schneider@ifam.fraunhofer.de

Institute
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen



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CORE COMPETENCE SURFACE TECHNOLOGY

New materials often drive innovation and end up in key technologies of everyday life. The industrial range of uses of many materials can be considerably expanded by customized modification of their surfaces. The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM has long-standing and in-depth expertise in surface technology, acquired in projects with partners from a range of industries and involving many innovative products and processes.

In general, materials are designed to meet predefined property requirements, such as strength, elasticity, and heat resistance, or to meet the requirements of a production process. If components have to suit certain additional needs, this is often only possible using special surface technologies. Intelligent surface technologies such as pre-treatments and coatings are able to improve the properties of materials and components or provide them with additional functions.

The expertise of Fraunhofer IFAM covers the whole process chain of surface technology from materials' development to the characterization and evaluation of surfaces, their functionalization and modification, and on to various application methods. The development of processes – such as dry and wet chemical pre-treatment, coating processes, printing processes, as well as thin/thick film technologies – and also quality assurance are key areas of the work. The characterization and evaluation of surfaces using chemical, electrochemical, and structural analysis is an important aspect of the institute's work, as is the application of various simulation methods.

The experts at Fraunhofer IFAM have a comprehensive knowledge of customized surface modification and functionalization. This includes the cleaning as well as the activation of surfaces and suitable pre-treatment prior to coating or bonding. The functional attributes of surfaces are very varied and depend on the respective application. Surfaces can be customized with low-drag, anti-icing, dirt-repellent, antifouling, antibacterial, and biocompatible properties. Specific tribological or optical requirements as well as sensor functions can also be provided. In addition, a very wide spectrum of application methods can be used, ranging from the laboratory scale to pilot plants as far as upscaling for (large) series production.

Quality assurance is an important aspect of surface technology. In-line quality assurance concepts and test methods, which allow constant process monitoring, are developed at Fraunhofer IFAM. The institute possesses accredited test facilities, which are also utilized for failure analysis. Finally, special training courses are given and there is a regular transfer of surface technologies to industrial practice.

1 *Testing corrosion resistance: Coated test specimens after exposure in the salt-spray chamber of Fraunhofer IFAM.*

1

ENHANCED RANGE AND CO_2 SAVING OF PASSENGER CARS BY REDUCING FRICTION AND WEAR

Experts of Plasma Technology and Surfaces – PLATO – at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen, are developing surface functionalities and coatings. Their work ranges from fundamental research to pre-series and series production readiness. Currently, regarding the energy saving of automobiles, plasmapolymeric coatings on elastomeric substrates ("rubber") are being investigated concerning the effect of friction and wear reduction. In the power train of cars kinetic energy is getting lost due to friction and wear. A certain amount of the energy loss is contributed by dynamic seals that are necessary for holding back lubricating oil. PLATO has succeeded in applying a plasmapolymeric coating strongly on the flexible, viscoelastic elastomer material (Fig. 1).

Reduced friction and wear via plasmapolymeric coatings ...

The selected coating system reduces friction and wear at dry and also lubricated friction contact. For a dry running ball-on-disc contact, the friction value decreases from 1.24 for the uncoated base material to about 0.17 with the plasmapolymeric coating. Accordingly, the coating lowers the dry friction by 86 percent (Fig. 2). This is of special interest for applications with high level of purity where no lubricants are allowed. Lubricated running is of interest, for example, for dynamic seals in cars. Using a model experiment test rig with representative pin-on-disc contact a reduction of friction was also found due to the coating. At lubricated contact, model oils revealed friction reductions of 55 percent and commercialized oils with a full complement of additives showed a friction reduction of 23 percent (Fig. 3). Applying commercialized greases with full additive complement, as, for example, used for cassette seals in wheel bearings in series, the coating lowers the coefficient of friction by up to 71 percent (Fig. 3).

The transfer of this technology to components has already been successful: Using a component test rig, industrially produced seals coated at Fraunhofer IFAM have shown friction reduction of almost 20 percent for grease and oil lubrication.

1 *Radial shaft sealing rings coated with plasmapolymeric layer on the sealing edge.*

… obtains enhanced range and less carbon dioxide emissions

The reduced friction saves drive energy, lowers CO_2 emissions, and increases the range for a constant energy reserve, for example, gasoline or battery energy. In addition, even for dry running the wear is drastically decreased using the coating in comparison to uncoated base material. This significantly increases the service life of a seal and means longer intervals between seal changes. Figure 4 highlights the high wear resistance and load capacity of the plasmapolymeric coating. During the tribological testing with a steel ball, the specimen was indented by about 50 micrometers. The 1 micrometer thin layer even withstood long-term loading without problems. A compression set is all that can be seen in the elastomer base material.

Customized coatings

In order to optimize the reduction in friction and wear for the special case of elastomer friction of a seal, the coating was varied regarding the processing parameters, such as the gas mixing ratio and applied power.

For the characterization of coatings a high-quality test system for measuring friction, wear, and lubrication is being used: This new tribometer at Fraunhofer IFAM allows, with oscillating and rotating motion, the determination of friction and wear in dry and lubricated states at a defined temperature.

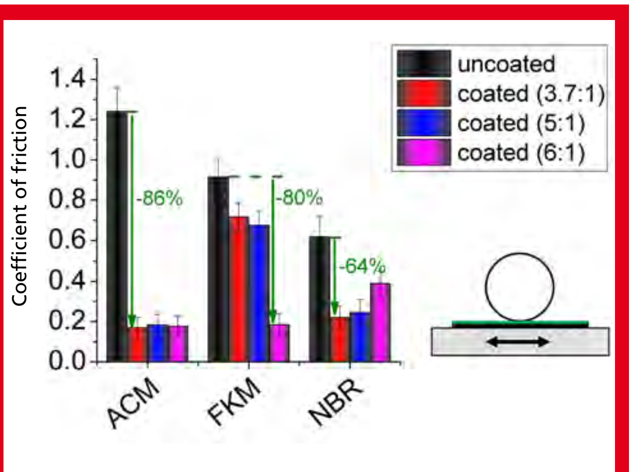


Fig. 2: Dry coefficient of friction and friction reduction of uncoated and coated elastomers. The O_2:HMDSO mixing ratio was varied in the coating process. Dry running, 1.5 MPa initial Hertzian contact pressure.

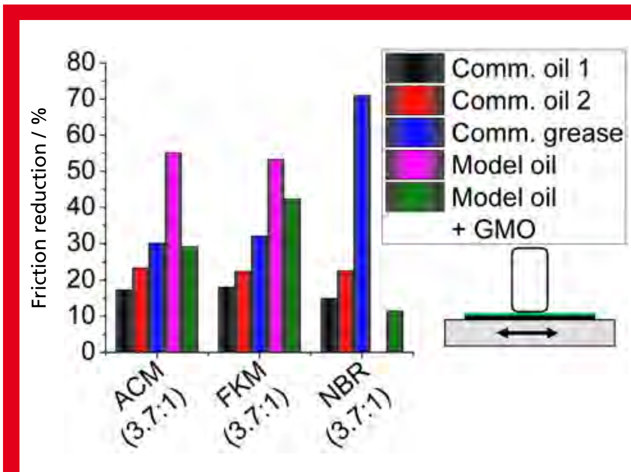


Fig. 3: Friction reduction in the lubricated system using the coating variant with an O_2:HMDSO mixing ratio of 3.7:1 on various types of elastomers. Lubricated running, 0.5 MPa initial contact pressure.

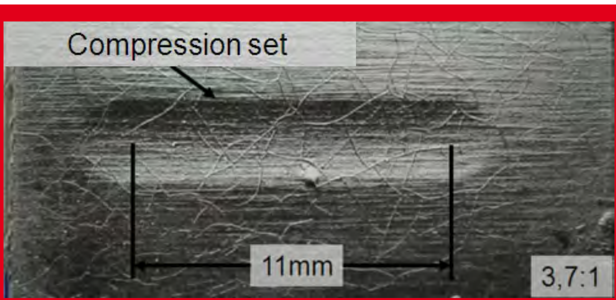


Fig. 4: Coated elastomer sample lubricated with commercialized oil after endurance testing (1.5 MPa initial Hertzian contact pressure) for approximately 785,000 cycles (ca. 17.3 km distance with oscillating motion): no wear is visible.

In order to reduce friction and wear, it is being found that the entirety of interactions between elastomer base material, coating, as well as lubricant must be considered. In the case of elastomers, not only, e. g. the hardness but also the damping behavior, tensile strength, elasticity, texture, and surface roughness, optimized for the relevant application, are important parameters. A particular demand on the coating and the relevant test method is the flexible elastomer base material with its viscoelastic deformation behavior. The coating must not be too rigid otherwise it will break and result in scales contributing to the friction contact – with the risk of enhanced wear. In addition, using a hard coating can have an adverse effect on the sealing function at corresponding application.

The experts of PLATO, with their expertise of coating release films and flexible anti-scratch layers etc., are able to apply coatings to meet the special requirements, on the one hand necessary following the movements of the elastomer and on the other hand resulting in lower friction and wear than would be the case for the uncoated base material. The coating also chemically interacts with the used lubricants and its various additives. Based on existing knowledge of the coating composition (Fig. 5–7), the coatings can be tailored for specific applications.

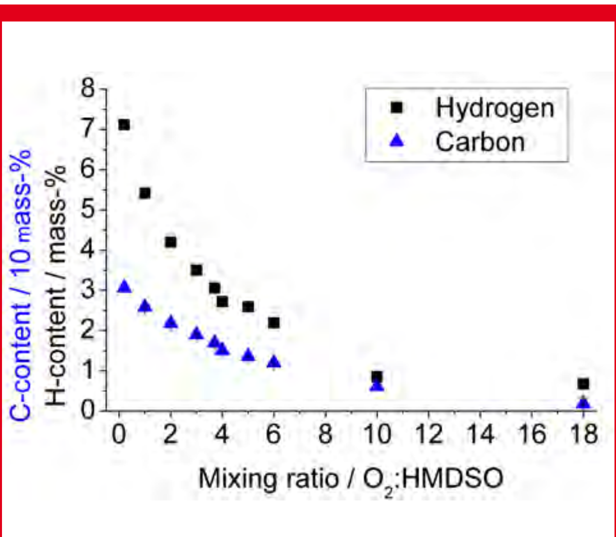


Fig. 5: Carbon and hydrogen content of the plasmapolymeric coating varying the gas mixing ratio. Fixed power of 1500 W.

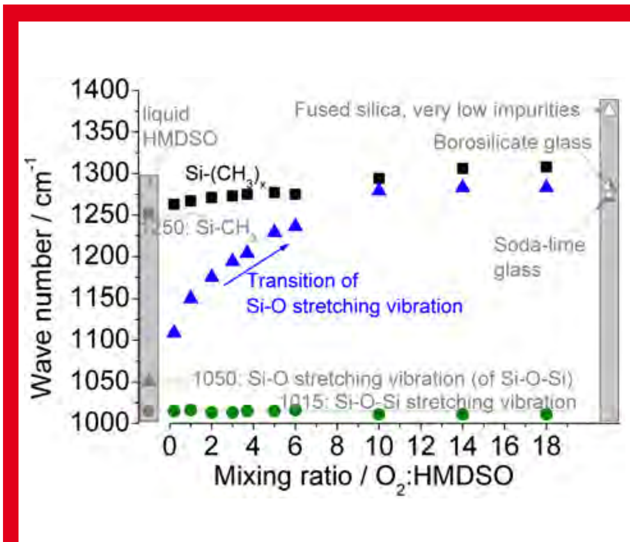


Fig. 6: Peak shifts in the IR spectrum of the plasmapolymeric coating varying the gas mixing ratio. Fixed power of 1500 W.

The newly acquired nanoindentation testing equipment at Fraunhofer IFAM allows measurement of the Young's modulus as well as nanohardness of the pure coating. The determined results show that these mechanical properties can be tailored via varying the process parameters (Fig. 7) according to requirements. Higher hardness can result in enhanced wear resistance.

Outlook

The PLATO scientists have already shown that the coating of radial shaft sealing rings can be realized for favorable-cost production. Current development work by PLATO is focusing on scaling up the coating process to the required piece numbers. The production costs applying the coating, due to the deposition method involved, are only a fraction of the component cost. Regarding comprehensive R&D work, the optimal layer composition is able to be selected for the specific component and application. This layer composition will be homogeneously applied on a large scale across the production series.

Acknowledgement

The project is being funded by the Federal Ministry of Economics and Technology (BMWI) and many project partners under the funding program "Progressive gain of energy efficiency in power trains by coatings and lubricants" (PEGASUS). The funding reference is 0327494A.

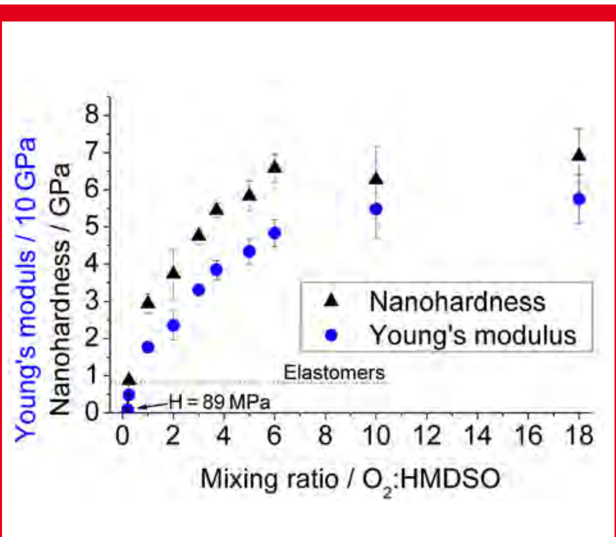


Fig. 7: Young's modulus and nanohardness of plasmapolymeric coatings varying the gas mixing ratio. Fixed power of 1500 W.

CONTACT

Dr. Dominik Paulkowski
Plasma Technology and Surfaces PLATO
Phone +49 421 2246-677
dominik.paulkowski@ifam.fraunhofer.de

Dr.-Ing. Klaus Vissing
Plasma Technology and Surfaces PLATO
Phone +49 421 2246-428
klaus.vissing@ifam.fraunhofer.de

Institute
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen

CUSTOMIZED UV COATINGS BY FRAUNHOFER IFAM

High-quality plastic components are used in a wide range of industries including the automotive industry, rail vehicle manufacturing industry, aviation, and the consumer electronics sector. Coating of such components is often very demanding and energy-intensive. A faster and more resource-friendly coating process is highly desirable. UV technology could offer a solution here: In the automotive industry, for example, UV curing clearcoat systems could be used because they allow the generation of hard, scratch-resistant surfaces which also show good long-term resistance to chemicals, heat, and UV radiation. A requirement for this is a corresponding network structure and a high degree of crosslinking, because these two factors are directly linked to the hardness and resistance of the coating. Within the framework of the BMBF (Federal Ministry for Education and Research) funded ENSIKOM project, the experts of Paint/Lacquer Technology as well as Adhesion and Interface Research at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen, have developed a method for evaluating the suitability of UV clearcoats for specific applications and their resulting properties in advance merely from their formulations.

Effect of the network structure on the mechanical properties

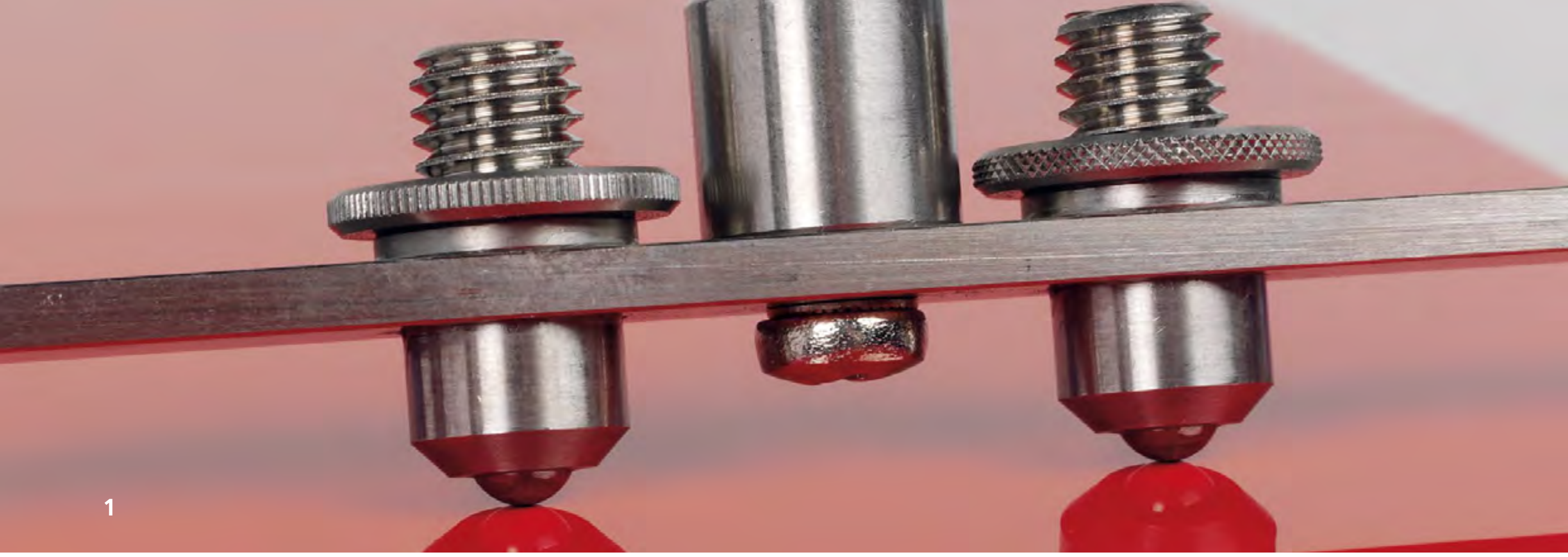
The degree of crosslinking is determined by the contributions of the different reactive groups which all add differently to the network structure. Coating systems having the same degree of crosslinking can therefore have very different properties. Analytical techniques such as dynamic mechanical analysis (DMA), infrared spectroscopy (IR), and inverse gas chromatography (iGC) only provide information about the overall degree of crosslinking.

By simulating the curing process, all the contributions to the network are taken into account and predictions can be made about the resulting properties of the coating. Carrying out such a screening procedure prior to development of a coating allows formulations for a particular application to be evaluated in advance and to shorten coating development times. The objective of the project was to develop such a simulation method.

Characterization of the UV clearcoat systems

In collaboration with BASF SE, the experts at Fraunhofer IFAM selected two UV clearcoats with different ratios of urethane acrylate to reactive diluent (system 1: 7 to 3 and system 2: 1 to 1). The crosslinking reactions and resulting properties were studied.

The curing of the clearcoats was carried out under a CO_2 atmosphere and the conversion of the double bonds at different curing times was monitored using IR spectroscopy. In addition,



the scientists measured the pendulum damping according to König (Fig. 1) and the scratch resistance using a Crockmeter.

At the end of the curing time, about 93 percent of the double bonds had reacted in system 2 whilst only a conversion of about 80 percent was measured for system 1 with the higher acrylate functionality. The pendulum damping tests showed that curing under an inert atmosphere produced sufficiently hard films. System 2 showed the higher hardness. The same results were found for the Crockmeter measurements. Consequently system 2 proved to be the better coating.

Simulation of the curing reaction

Two things are required to simulate the curing: A reaction scheme covering the reactions that take place during curing plus their relevant probabilities and a starting structure model which describes the coating system and its components immediately after mixing – namely before the curing.

First of all the individual steps of the curing reaction were identified and a suitable reaction scheme under inert conditions was established. The starting point for this was the formulation of the clearcoat systems (binder, reactive diluent, and two photo initiators).

For the reactions, molecular modeling was used to calculate the relevant educts and products. By comparing the energy differences between the highest occupied molecular orbital of the radical and the lowest unoccupied orbital of the relevant monomer for the respective reaction, in combination with activation energy data, the relevant reaction probabilities can be calculated. This resulted in two competing reactions each (Fig. 2).

The formulations of the coating systems also allowed the individual components and their number respectively ratio to

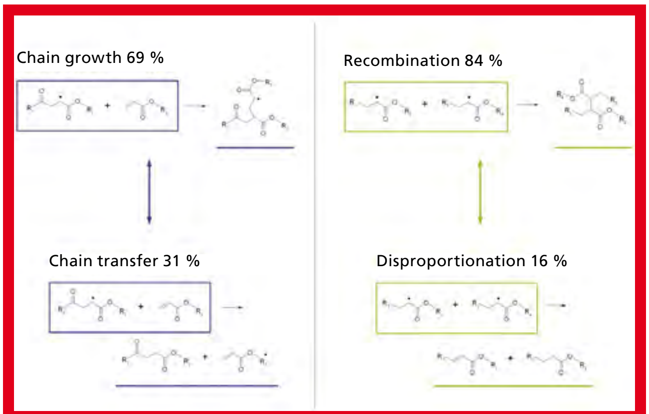


Fig. 2: Probabilities of the four curing reactions.

be determined – a prerequisite for preparing structure models for the non-cured coatings. By applying the reaction scheme, structure models for the cured coating systems could be generated via molecular dynamics simulation of the crosslinking process (simulation of the movement of the atoms at a given pressure and temperature). The calculated conversion of C=C double bonds agreed well with the time-dependent conversion of C=C double bonds measured by IR (Fig. 3).

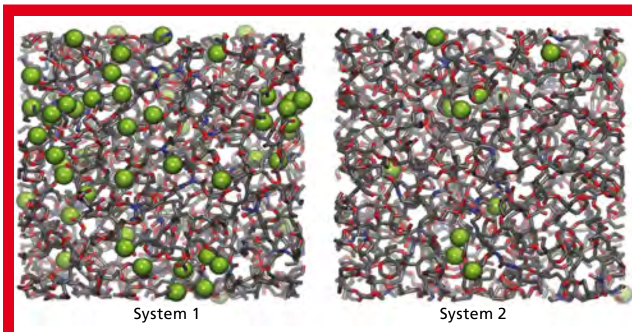


Fig. 3: Structure models of the two clearcoats. The remaining non-crosslinked double bonds are indicated as green spheres.

1 *Pendulum damping test according to König at Fraunhofer IFAM.*

Evaluation of the formulations

The characteristic structural properties were now evaluated using these structure models. It was shown that system 2 had a greater crosslinking density – more crosslinks per volume – and a lower "defect density", i. e., considerably fewer non-crosslinked double bonds per volume (Fig. 4).

There was also a more efficient and more homogeneous crosslinking observed for system 2 since it showed a higher average number of crosslinks per reactive group and considerably smaller standard deviations (Fig. 5). System 2 also had a more efficient topology: Due to the greater fraction and more efficient incorporation of the reactive diluent it possesses a higher hardness for the same elasticity. Hence system 2 – as in the experiments – was classified as the better coating.

Conclusion

The simulation method developed by Fraunhofer IFAM allows the properties of new UV coatings to be predicted based solely on the formulation and allows different formulations to be compared in advance of actual development work. This leads to significantly lower development cycles for new coatings.

Furthermore, it is possible to derive statements about the resistance to chemicals, volume shrinkage, and elasticity of the coatings. The method can be easily applied to other formulations and systems, for example, adhesives cured via thermally initiated polymerization.

Project funding

Federal Ministry for Education and Research (BMBF)
Project ENSIKOM – "Development, simulation and effective implementation of more environmentally friendly and more

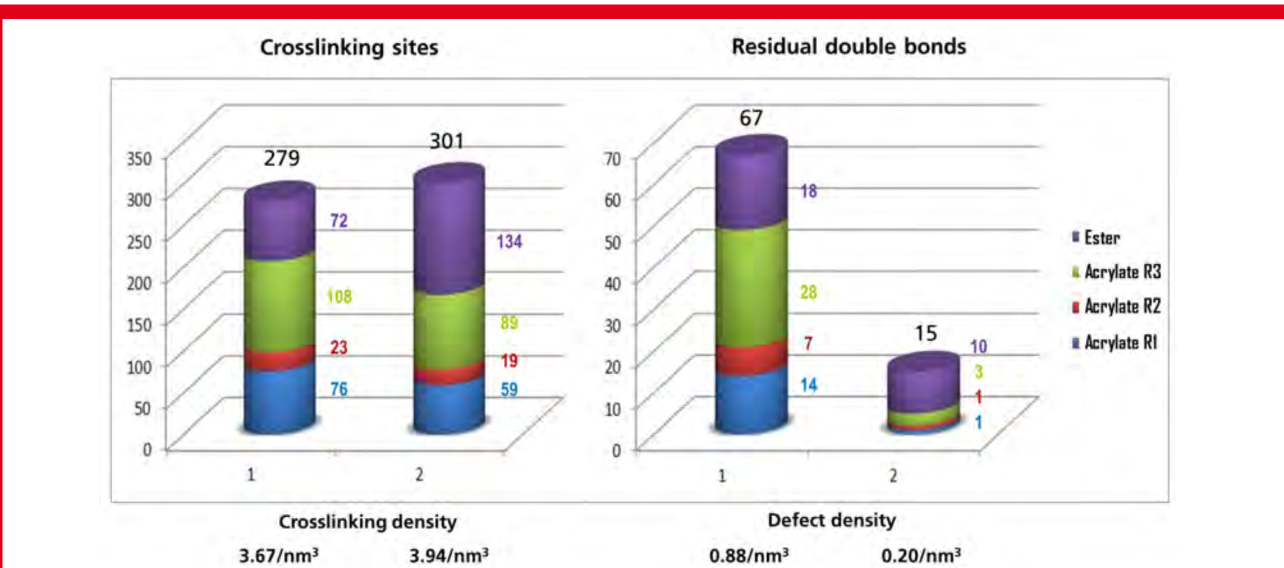


Fig. 4: *Comparison of the crosslinking density and "defect density" of the two clearcoats.*

cost-effective coating of complex plastic components", funding reference 033R030, November 1, 2009 – October 31, 2012.

Project partners

- JKL Kunststoff Lackierung GmbH
- BASF SE
- Mercedes-Benz Cars
- KARL WÖRWAG GmbH & Co. KG
- EISENMANN Anlagenbau GmbH & Co. KG
- Fusion UV Systems GmbH
- Linde AG
- tesa AG
- iLF Forschungs- und Entwicklungsgesellschaft Lacke und Farben mbH
- LCS Life Cycle Simulation GmbH
- Fraunhofer-Institut für Produktionstechnik und Automatisierung IPA
- Deutsche Forschungsgesellschaft für Oberflächenbehandlung e. V.

CONTACT

Dr. Marc Amkreutz
Adhesion and Interface Research
Phone +49 421 2246-647
marc.amkreutz@ifam.fraunhofer.de

Dipl.-Ing. (FH) Yvonne Wilke
Paint/Lacquer Technology
Phone +49 421 2246-613
yvonne.wilke@ifam.fraunhofer.de

Institute

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen

6 *High performance computer cluster of the Applied Computational Chemistry department at Fraunhofer IFAM for the calculation of structural properties of UV clearcoats.*

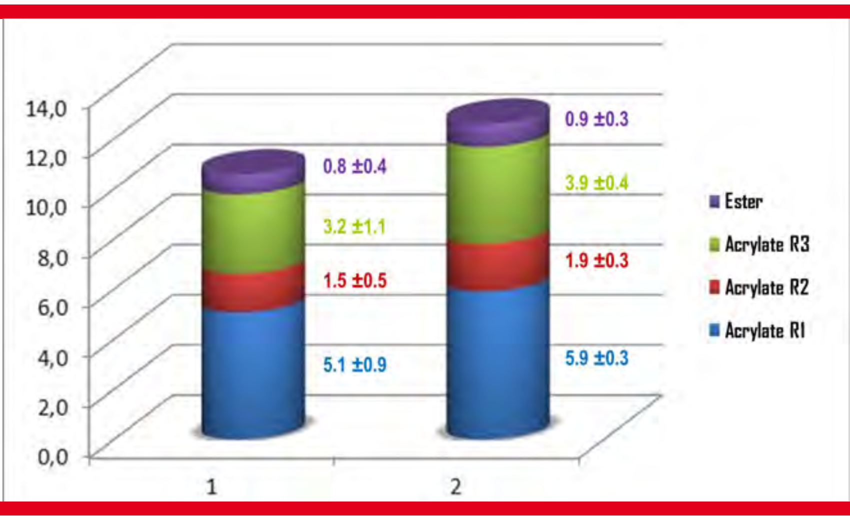


Fig. 5: Average number of crosslinks per reactive group and standard deviation of the two clearcoats in comparison.

DEVELOPMENT OF NOVEL POLYMERIC CORROSION INHIBITORS FOR ALUMINUM AND STEEL APPLICATIONS

Users are increasingly demanding innovative materials and particularly coatings to fulfill a variety of functions. Fundamentally, coatings and paints have to effectively protect the surfaces and interfaces of all materials, including those still in development. Modern surface technology, which combines empirical know-how and knowledge of materials with computer based algorithms based on physical-chemical principles, provides a forward-looking or, if necessary, fast-reacting platform for studying this. The bilateral project involving Straetmans High TAC GmbH and the Adhesion and Interface Research as well as Paint/Lacquer Technology departments of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen, demonstrates how the concept of molecule adsorption, namely the concentration of molecules at interfaces, can provide the basis for the development of both temporary protective systems and additives for long-life coatings.

Background

With regard to the future selection of adsorbing molecules, scientists not only have to consider the chemical and material-related requirements and economical aspects but also have to comply with statutory boundary conditions as laid down, for example, by the REACH Regulation. For the sustainable development of new coatings, two main design options will probably be of interest: intelligent formulations which do not demand the synthesis of new substances, and the path followed in this project via polymers which are usually not very hazardous.

Tasks – Project description – Procedure

In nature, surface-active molecules play an important protective role in cell membranes. Such amphiphiles are chemically non-reactive and use the concept of self-organization to form closed layers. In order to develop novel amphiphilic polymers, it saves time and is helpful to use computer-aided modeling to study the organization of molecules of differing structure in liquid media and on substrate surfaces. In the presence of a liquid application medium, such polymers form submicroscopic micelles and at interfaces with solid substrates there is a uniform layer of adsorbed molecules whose thickness is uniform and may be tailored based on the molecular weight. Figure 1 shows, for instance, intermediate steps for different

polymer molecules when establishing the association behavior in a polar solvent and the adsorption behavior on a hydrophilic substrate surface. The structures that form from the polymer molecules are shown in green.

The objective of the project was to transfer this amphiphile-based concept to chemical synthesis with reactive and structural base elements that can form head, tail, or spacing units in the resulting polymer molecules. Based on the simulation results, their relative arrangement in the molecules can be attuned to be suitable for distinct liquid media. The chemical reactivity of the resulting molecules can be customized by partial or full incorporation of virtually non-reactive molecular end-groups. This means that neither the desired coating formulations nor the substrate surfaces are altered by chemical reactions with inhibitor molecules in a hardly predictable way.

The developed polymer molecules form thin and closed layers on immersion of the metal substrates in inhibitor solutions or dispersions. Particularly effective molecule layers have a corrosion-inhibiting effect and can – when applied in this way – provide temporary corrosion protection. Surface analysis of sheets of AA 2024 aluminum alloy by x-ray photoelectron spectroscopy, energy-dispersive x-ray analysis, and scanning electron microscopy show that about a 0.01 micrometer thick protective layer forms and that, following a salt-spray test, there is only a slight increase in the thickness of the aluminum oxide layer on the substrate. As Figure 2 illustrates, coated sheets exposed to the salt-spray test for 250 hours show no signs of corrosion (bottom image), unlike sheets not protected with inhibitor polymers (salt-spray test for 24 hours, top image).

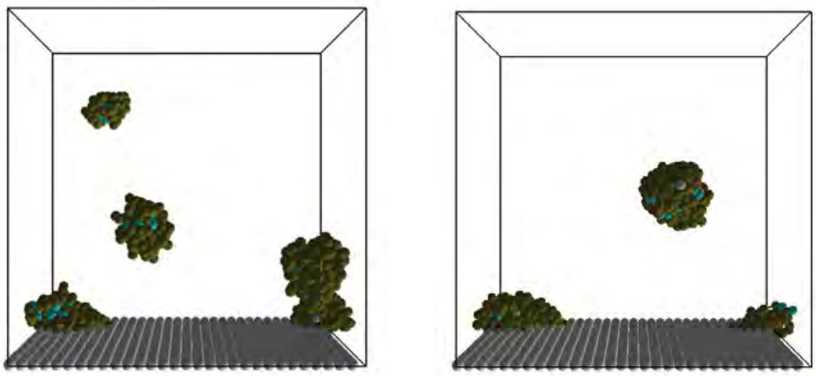


Fig. 1: Simulation of the early phases of association and adsorption of polymer molecules.

2 *Corrosion protection effect of a polymer inhibitor layer on aluminum developed in collaboration with Fraunhofer IFAM (top: uncoated, bottom: coated).*

The fact that a corrosion-inhibiting effect was achieved on sheets of steel with one and the same polymer formulation confirms that the physical concept of layer formation modeled in the simulation work is effective.

If the inhibiting effect of the amphiphilic polymers is also retained in cured coating systems, it can be synchronized with the action of other corrosion protection systems in the coating. The test studied novel coating systems with polymeric corrosion inhibitor additives on AA 2024 sheets compared to coatings without corrosion inhibitor additives. The layer disbonding in the salt-spray test and thread growth in the filiform corrosion test were measured. The test results are summarized in Table 1. It can be seen that several chemically different formulations of the novel coating systems have advantageous properties.

Results and perspective

The medium-sized project partner benefited from the interdisciplinary procedure. The development time for marketable products is reduced compared to a purely empirical material development strategy. Polymeric agents, which based on physical principles introduce additional functionalities into coatings and crosslinking polymers, contribute to sustainability and the efficient use of resources.

	Infiltration in the salt-spray test after 1008 hours		Thread length in the filiform test after 504 hours	
Coating system	Without inhibitor	With 2 % inhibitor	Without inhibitor	With 2 % inhibitor
Water-based 2-C epoxide coating	6 mm	2 mm	9 mm	3 mm
Solvent-based 2-C epoxide coating	7 mm	2 mm	12 mm	3 mm
Alkyd resin coating	12 mm	4 mm	26 mm	7 mm
Alkyd-melamine coating	After 240 h: Break	After 480 h: 2 mm	After 168 h: Break	After 240 h: 5 mm

Tab. 1: Test results on aged coating systems.

Project funding

German Federal Ministry of Economics and Technology (BMWi)
Central Innovation Program for Medium-sized Companies – ZIM
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Project partner

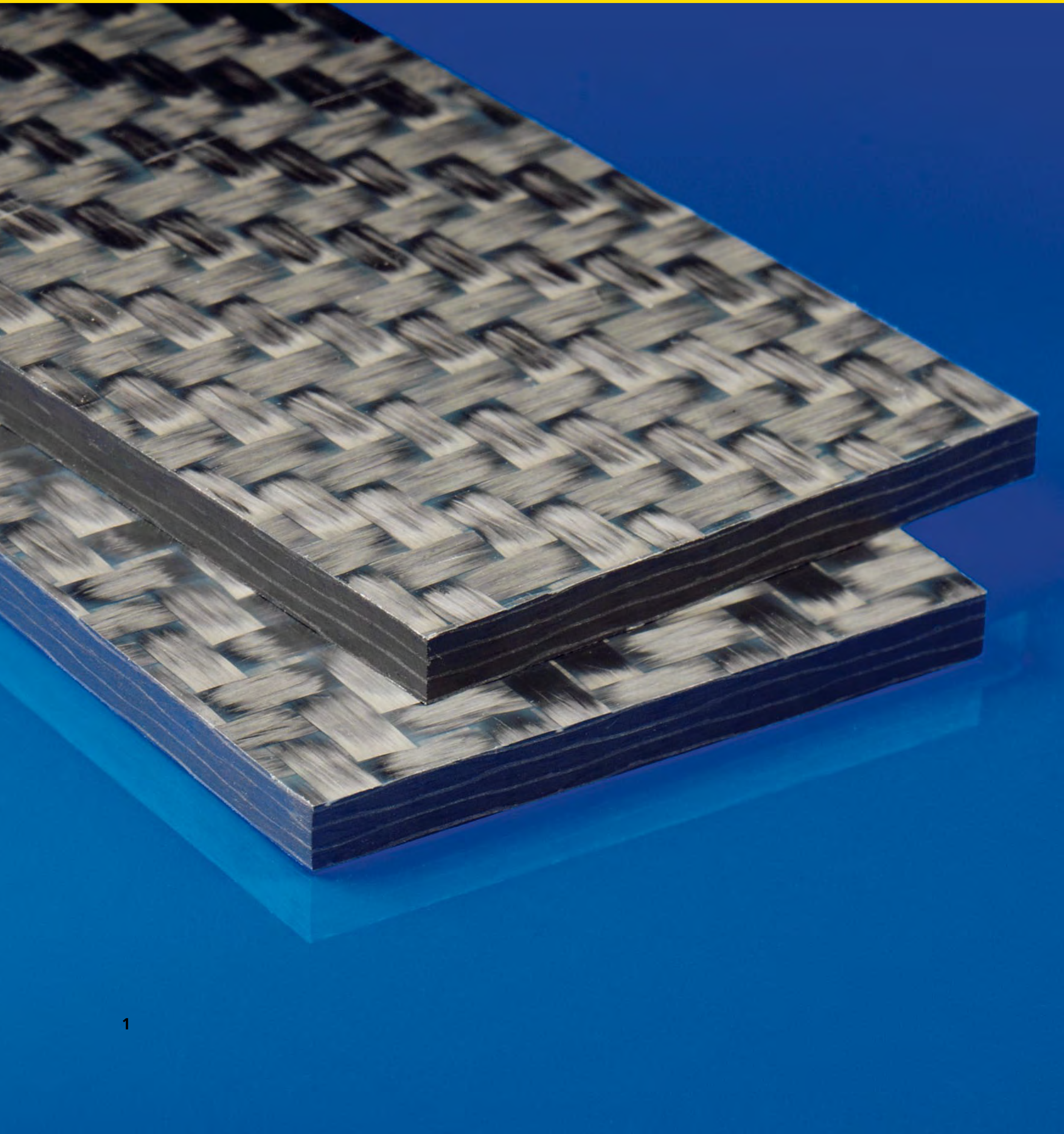
- Straetmans High TAC GmbH, Hamburg

CONTACT

Dr. Welchy Leite Cavalcanti
Adhesion and Interface Research
Phone +49 421 2246-487
welchy.leite.cavalcanti@ifam.fraunhofer.de

Dipl.-Ing. (FH) Sascha Buchbach
Paint/Lacquer Technology
Phone +49 421 2246-497
sascha.buchbach@ifam.fraunhofer.de

Institute
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen



1

CORE COMPETENCE FIBER REINFORCED COMPOSITES

Fiber reinforced plastics (FRPs) refer to materials that consist of a matrix with embedded fibers. Thermosets are used as matrix materials at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM. The advantages of FRPs are their high stiffness in the direction of the fibers combined with the ability of the matrix to be shaped. These advantages, along with their low specific weight, mean FRPs are ideal for lightweight components such as those used for aircraft and car manufacture.

In all areas of transport – cars, rail vehicles, ships, and aircraft – new materials and lightweight design are resulting in lower fuel consumption, reduced CO_2 emissions, and hence resource friendly and environmentally friendly mobility. In the area of renewable energy, and in particular wind energy, FRPs are opening up energy-efficient construction methods and are improving the profitability of wind turbines. Lightweight design at Fraunhofer IFAM is particulary concerned with fiber reinforced plastics containing glass, carbon, and natural fibers. The expertise ranges from resin development, design, component manufacture, and surface modification to automated assembly as well as joining technologies.

The first task is the selection or development of suitable resin systems to meet the specific requirements of the manufacturing process such as low curing shrinkage and rapid curing. Challenges such as electrical conductivity, lightening protection, and impact resistance are also addressed. Only by customization of the interfacial properties between the fibers and matrix resin can an optimal material system be used. This is achieved using a range of surface techniques, including plasma treatment of fiber surfaces. Surface modification is also vital for the manufacture and further processing of the components. Techniques worthy of mention at this juncture are cleaning, activation, coating, and the application of functional layers.

The growing industrial use of FRPs necessitates increased automation of assembly and joining technologies – this is a further field of expertise of Fraunhofer IFAM. With the help of optical measurement techniques, shape and positional adjustments can be made to both small and large components to enable precision machining using robots.

Quality assurance is an absolute must in all phases – namely during the manufacture, assembly, and repair of FRP components. This is aided by Fraunhofer IFAM's comprehensive range of training courses. The training courses are a means of technology transfer, whereby technological findings and methods are passed on to industry.

1 *Ideal material for lightweight design – carbon fiber reinforced plastic (CFRP).*

AUTOMATED ASSEMBLY OF LARGE FRP STRUCTURES – FRAUNHOFER FFM DEVELOPS ESSENTIAL PROCESSES AND PLANTS

At the Forschungszentrum CFK NORD (Research Center CFRP North), Stade, the Fraunhofer Project Group Joining and Assembly FFM, which is part of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, is currently successfully completing its first major projects. These involve assembly and machining processes for the aircraft manufacturing industry and also large plants for automated series production of XXL structures made of fiber reinforced plastics (FRPs) – such as carbon fiber reinforced plastic (CFRP) and glass fiber reinforced plastic (GFRP). Three major projects have been initially undertaken to develop the necessary processes as well as components and to undertake initial qualification for industrial production. Work in Stade is currently focusing on the aircraft manufacturing industry – although in principle the results can also be transferred to other industries where large FRP structures are used.

The introduction of new materials and combinations of materials for a product or the integration of new technologies is often only economical once processes are available for favorable-cost mass production. This also applies for "black gold", as carbon fiber reinforced plastics are sometimes called. These relatively young materials have a number of advantages over steel. Most importantly: They are light and can bear extremely high loads. These are the reasons for their ever growing popularity for aircraft manufacture. Indeed, some aircraft being built today consist of more than 50 percent CFRPs and this percentage is still increasing. The manufacture and assembly of such components still, however, involve a great deal of manual work. A key goal in the aircraft manufacturing industry, as in the automobile industry, is to automatically process, join, and seal high numbers of work pieces in a shorter time with high precision, not least in order to meet the growing demand for lower weight aircraft.

Within this context, the Forschungszentrum CFK NORD in Stade, outstanding in all of Europe, was officially opened in September 2010 (Fig. 1). It is an investment for the industrial future of Lower Saxony and will strengthen Germany's position in the global marketplace. Since the opening, a start has been made on automating the production of large CFRP structures on a 1:1 scale for the aircraft industry. As this technology is vitally important for industry in Lower Saxony, this state invested 19.7 million euros just to build the research center.

1 *Forschungszentrum CFK NORD in Stade.*

In addition, the Fraunhofer Project Group Joining and Assembly FFM has to date also received 11.5 million euros from Lower Saxony to partially fund its work. Fraunhofer FFM is one of the two main lessees of the large development hall at the CFK NORD, which has an area of about 8000 square meters and a height of 24 meters. In collaboration with industrial and academic partners as well as experts of Fraunhofer IFAM, Bremen, the researchers in Stade have for the past three years been developing innovative solutions which will soon enable the aircraft industry to process large CFRP components with a high degree of automation. The R&D results will, however, be also to be utilized in other industries where large FRP structures are used such as the wind energy industry, commercial vehicle manufacture, and rail vehicle manufacture.

Challenges of automation

Automation in the aircraft manufacturing industry is nothing new. Up until now though, this has mainly concerned special machines for a particular processing step on a particular component. These machines are often designed as so-called portal machines, moving on gantries above the large structures – for example, aircraft fuselages or wings – and are used for automatic bolting or milling. As these machines are usually heavy, expensive, and highly specialized, there is a considerable demand for reasonably priced, versatile solutions that can be rapidly configured from manageable modules. The aim is in the near future to provide a shortly available more universal automation technology that can be easily adapted to other components and assembly situations or even simultaneously undertake tasks that have hitherto been carried out sequentially.

In the automobile industry, for example, the necessary processing steps are precisely set to a fraction of millimeter prior to the start of production. Robots then travel continuously the same paths to carry out their work. For smaller components with minimal size deviations this is an excellent automation solution. Some processes that are standard in the automobile industry are, however, a major challenge for aircraft manufacture: The much greater size of aircraft components, and production-related distortion, means that they differ significantly in geometry – each component is unique. Were an industrial robot with rigid programming to drill bolt holes in these large components, then the holes would be in a different place each time and that would be unacceptable.

Thus, the processing and joining of large structures involves individual adaptation of the process to the actual shape and position of the actual component that is in the plant. The high precision with which a robot can repeat a motion is not useful in this situation. In order to guide a robot over each contour deviation on a large component, its absolute positional accuracy, which is much lower than its repeat accuracy, must be increased to the required measure: Only during the ongoing process is the control system told the exact path the tool must travel. As the robot has not learned the optimal positions of its arms in advance, it cannot simply repeat these. It can therefore not take account of individual deviations at gear boxes and axles, leading to relatively high inaccuracy. It is thus necessary to modify plants and robots in such a way that they always guarantee the optimal path regardless of the different size and position of a component.

Objective: Series production using industrial robots

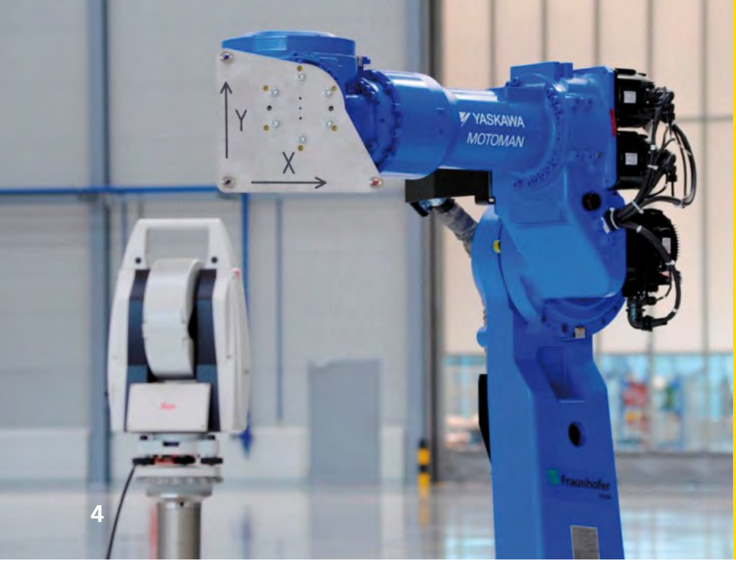
Challenges such as this are at the fore of the R&D activities of Fraunhofer FFM. More than 25 experts, including production and automation engineers, mechanical engineers, aeronautical engineers, material scientists, software programmers, electrical engineers, chemists, and specialists in the development of processes and plant components, are working on the processing and assembly of large FRP structures to cover the whole process chain. The objective is effective automatic processing of large components in series production using conventional industrial robots. To this end, there is close collaboration in the area of machining, robotics, and measurement technology with the Institute for Production Management and Technology (IPMT) of the Technical University of Hamburg-Harburg. In addition, Fraunhofer FFM expertise is complemented by that of its neighbor at Forschungszentrum CFK NORD, the Center for Lightweight Manufacturing Technology (Zentrum für Leichtbauproduktionstechnologie, ZLP) of the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e. V., DLR), who is working on automated component manufacture for the upstream section of the process chain.

One of the key approaches of FFM researchers is self-adaptation of robot-based processes to different component geometries and positions. Very precise guidance must be guaranteed in spite of this additional flexibilty. On the one hand, there must hence be precise measurement of the size of the component down to a few hundredths of a millimeter. On the other hand, there is the requirement of the robot control software to adapt, for constantly differing component dimensions, the angles of the five, six, or seven axes of the robot and so largely compensate accuracy-lowering effects.

For this purpose, a development platform for adaptive assembly and machining processes has been built as part of the project entitled "Adaptive CFRP manufacturing and assembly cell" (CFK-AFMO FFM). This has also enabled novel component pick-up systems, grippers, measurement methods, and software to be tested and optimized (Fig. 2). A special feature of the platform is the very versatile jig: Six hexapods – robots with six parallel drive elements – apply suction to the component using vacuum grippers and hold it firmly. The individual adjustment of each hexapod and gripper means that the cell can pick up very different large structures with various geometries, without any change in equipment being required (Fig. 3). Also, the large components can be moved in position, tilted, or rotated, and even deformed within permissible limits in order to optimally adapt them to joining partners and assembly processes and so accelerate tolerance management. Sensors in the vacuum grippers constantly measure the forces and torques applied to the component and so prevent any excess loads and allow management as well as documentation of loads during the assembly. This is the first time that a test platform has been available for load-monitored assembly of original components, promising a significant simplification of the complex process of tolerance management. The test platform was developed by the Fraunhofer Project Group Joining and Assembly FFM in collaboration with the Institute for Production Management and Technology (IPMT) of the Technical University of Hamburg-Harburg, preceded by intensive tests and attempts.

2 *Development platform CFK-AFMO FFM.*

3 *Vacuum gripper on hexapod.*



Precision by measuring and calibrating

A prerequisite for robot-based processing of large structures in series production is exact measurement. This is essential not only for the large component itself, but also for the robots used here. To start with, selected positions of the robot arm are measured highly accurately using lasers in order to determine the precision-lowering influence of production tolerances (Fig. 4). The method developed by Fraunhofer FFM and IPMT experts yields specific correction parameters for any robot – regardless of the manufacturer, type, and control system – which allows it to be calibrated via its control software. In this way, the absolute positioning accuracy required for large structure assembly can be achieved rapidly and without complex equipment changes.

At the same time, exact size measurement of the individual component is necessary. An aircraft fuselage section can be up to 20 meters long. While measuring such large structures is today still often carried out in a very time-consuming way using touch probes, the contactless laser method used by Fraunhofer FFM in the manufacturing and assembly cell is rapid and accurate (Fig. 5). The measurement data allow the virtual description of the component from the design to be adapted by alignment with the real parameters. In order to keep the measuring process as short as possible, the base component dimensions from the CAD model are used. The laser method is then used to make new measurements on only those areas that are of importance for the subsequent processing. The measured values allow the absolute spatial coordinates to be calculated. The control software converts these into commands for the individual positions of the robot axes.

Preplanning in virtual environment

When designing a CFRP series production, it is standard practice to preplan the whole size measurement, processing, and assembly steps for large structures in a virtual environment. Only if there are differences between the highly accurate measurements in the real process and the programmed "offline" model are the parameters of the actual component in the production cell modified. This procedure means the process can adapt to each component, if "adjustment" is required. A key task, among others, of Fraunhofer FFM is to program the software for the envisaged solutions.

The technologies developed for use in the CFRP manufacturing and assembly cell CFK-AFMO FFM form the basis for all further processing steps. Regardless of whether the large structures have to be drilled, milled, cut by high pressure water-jet, or joined: It is always vital to precisely calibrate the robot and accurately measure the large structures with the described tools.

4 *Calibrating a robot with a laser tracker.*

5 *Measuring a component with the laser radar on the CFK-AFMO FFM platform.*

Processing large structures – the same work in half the time

The realization of high-precision series production of large CFRP structures with rapid adaptation to different components and geometrical deviations involves a number of challenges. The portal machines that are currently used are inadequate for a versatile, highly productive processing plant: they are expensive, very heavy, and too slow in their measuring and processing functionality. Also, there is generally no integrated process monitoring. Processing errors can lead to irreparable damage to the large structure, causing delivery delays and costs for rejects amounting to up to several hundred thousand euros per component. The project entitled "Efficient, highly productive, precision machining of large CFRP structures" (ProsihP) being undertaken by Fraunhofer FFM is developing technology for the processing of large components using several robots simultaneously. This parallelization of the processing allows processing times to be reduced by a half compared to current processing technology. Other objectives are fully automatic measuring processes and the development of continuous process monitoring systems which do not detect errors belatedly but act in a timely way in the process when there is an increased risk of error.

When processing a large CFRP structure, many parameters have to be continuously monitored. A mere incorrect setting or an "unnoticed" irregularity on the tool can make the expensive component unusable. In-line monitoring systems are therefore being developed by the scientists for characteristic process parameters. The monitoring of these parameters in real time guarantees that the processing meets the required quality. One example is the detection and monitoring of protruding carbon fibers which can arise on milling. If these "edges" remain unnoticed, the result can be high repair costs and in some cases even rejection of the component. An optical monitoring system was realized in the ProsihP project to detect any errors directly during the milling process. The plant responds by immediately stopping or adjusting the processing parameters to better adapt tool and component to each other.

The machining process must take into account that each single CFRP component can differ in size and material structure. Unlike metals, which are more homogeneous, the rigid carbon fibers embedded in the flexible resin matrix in different directions can lead to considerable direction-dependent variation of the material properties – thus each component behaves individually because it is optimized in form and structure for the respective application (fuselage, wing, tailfin, etc.). For a fully automated parallel processing system suitable for various large components, major parameters, such as the processing strategy, tool type, tool diameter, speed, and advance, are important. For each CFRP component, the correct combination of these parameters must be chosen. For example, in order to determine the correct speed and advance when drilling or milling, it is also necessary to monitor the processing forces. An optimized processing strategy is also important – is the component finished directly or are two or more processing steps more sensible? Fraunhofer FFM has achieved very good results dividing the work into preprocessing and finishing: Rough preprocessing followed by a finishing step allows, for example, to considerably reduce the milled edge temperature. This in turn minimizes possible sources of error and significantly improves the edge quality.

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7

Multifaceted optimization potential for dust extraction

Fraunhofer FFM recognized the urgent need to optimize dust extraction when machining large components. The milling or drilling of CFRPs lead to considerable dust production. Virtually all fine particles need to be removed in order to ensure there are no effects on people, machinery, components, or on joining processes. Up until now, dust has been extracted during CFRP processing with concomitant consumption of very high amounts of energy. A production hall extraction system would be uneconomical for future series production. Instead, the scientists developed an automated adaptive dust removal system which adapts to the relevant component and current processing step. Milling dust can thus be completely extracted before getting into the surroundings. The challenge was for the extraction system to register interfering contours – for example, stringers and spars – and to adjust to them (Fig. 6).

In order to develop and test various realistic solutions for future application in industrial production, FFM constructed a large test plant at Forschungszentrum CFK NORD for machining using robots, as part of the ProsihP project. It enables components up to 13 meter length and 6 meter diameter to be processed. This utilizes all the described machining, monitoring, and extraction technologies. Using three robots simultaneously the results achieved to date on large volume CFRP structures are being optimized and know-how is continuously being enhanced (Fig. 7). In upcoming projects the focus will be on improved management of undesirable influences, such as vibrations when simultaneously carrying out processing work at several places on the same component.

Water-jet cutting – an alternative to machining with blades

Fraunhofer FFM is also further developing a promising technology for processing FRPs: Water-jet cutting. Unlike conventional machining, the cutting tool in this case, namely a water-jet, does not wear out. The jet can be at a pressure of up to 6000 bar and can be either pure water or water mixed with an abrasive cutting agent. It cuts the material in a highly precise and quality assured way. The advantages are numerous: It is a cold cutting process and so there is no thermal damage. The cut edges are also less prone to delamination. Fragile shell components can be cut vibration-free due to the low cutting forces, however, the technology does also allow very thick components (up to 40 centimeters) to be cut. Regardless of whether cutting soft or hard materials or combinations of materials with contrasting mechanical properties, water-jet cutting is often the cutting method of choice.

Fraunhofer FFM is developing this technology in parallel with milling in order to be able to offer customers the best processing method for their particular task. The objective of the R&D work is to develop the cutting process for large structures using robots, with the focus on clean edges, high precision, high processing speed, as well as long service life of the periphery. The processing technology is being developed and tested in Stade with a state-of-the-art, 3D high pressure water-jet cutting system for components of up to 3 meters in length, 2 meters in width, and 50 centimeters in depth (Fig. 8).

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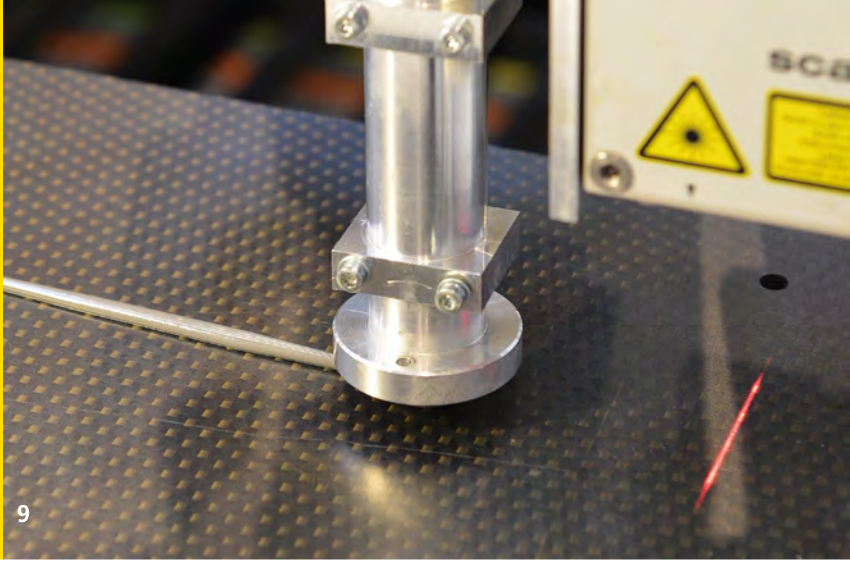


9

One-step-assembly: Rapid and precise joining

The automated assembly of large FRP components using precise, fast, and favorable-cost processes should soon be possible. Before attempting to join CFRP shells to each other to form aircraft sections or before attempting to automatically join complete fuselage sections with each other, Fraunhofer FFM is first of all optimizing the joining of smaller components to large components in an automated process.

The precision joining of small components to a large structure requires minor defects or irregularities on the joining areas to be smoothed out using a gap filler material – the so-called shim. This is the case, for example, when spars are attached to the fuselage using what aircraft manufactures call a “clip”. The clips are first of all joined, and the spars are attached to these in a further step. In series production the application of the optimum amount of shim material – usually a two-component adhesive – must be carried out automatically in order to smooth out the slight unevenness on the inner skin of the aircraft (Fig. 9).

Joining the clips is currently very time-consuming and costly. The small components are initially temporarily joined for manual determination of the relevant gap size. The two components to be joined are then separated again and the shim is applied together with a release film. Another temporary joint is made to determine whether the correct amount of shim material is present. If necessary, further corrections are made. Only prior to the final joining process is the release film removed, enabling the components to be joined. Aircraft manufacturers have long wanted to simplify and streamline this long, complex, and costly process.

FFM experts are now engaged in a project entitled “Fuselage – Development of New Optimized Components“ (RENO) to reduce the multiple steps to a ”one-step-assembly”. The key objective of the innovative, automatic processes for assembling the described clips and also the attachment of cable holders is ”one-step-assembly” (Fig. 10). What previously was carried out manually by ”trial and error” is now carried out much faster by computer: The new developed processes allow not only accurate measurement of the surface topology at the joining position on the aircraft skin but also allow the joining surface of the clip to be accurately surveyed. Software virtually calculates the gap size from the measurement data, obviating the need for any temporary joining and manual measurements (Fig. 11). Important control parameters for the robot and adhesive dosing module can be derived from the result: For each clip to be bonded, the amount of adhesive that needs to be applied at what position to completely fill the gap is known. Furthermore, a little adhesive must emerge from the edges to allow optical monitoring of the degree of gap filling.

The automatic adhesive bonding of cable holders has lower precision requirements because deviations of a few millimeters are acceptable. This concerns, however, several thousand holders that need to be positioned at the correct places on an aircraft fuselage. The current joining process is also still manual: The employees determine the positions and press on the holders. The latter are then secured for several hours with a self-adhesive plastic bridge until the bonded joint has cured.

6 *Adaptive dust removal during CFRP machining with a robot.*

7 *Test stand for machining using robots.*

8 *3D high pressure water-jet cutting unit of Fraunhofer FFM in the Forschungszentrum CFK NORD.*

9 *Application of the shim to a CFRP surface using a robot.*

10

The Fraunhofer FFM team is developing a fully automatic process for this as part of the RENO project. Here it must be ensured that the correct amount of adhesive is initially applied to the holders before the robot travels to join and secure them in the correct positions on the fuselage. The main task is guaranteeing the efficient gripping, moving, and joining of the holders using a multifunctional tool attached to the robot head. After determination of the correct joining position via the integrated sensors, a pressure check is carried out to ensure that the holders have adequate surface contact at the relevant position. A fixing aid is still currently necessary to hold the holders in position during the adhesive curing process which lasts several hours. The experts of Fraunhofer FFM are already working on a module that cures the adhesive sufficiently in a few minutes via input of an energy burst. The adhesive itself then acts as the fixing agent for the holder, and the holder can be released from the robot gripper after a short time. The adhesive, a two component system, then cures fully at room temperature.

New deep-drawable film revolutionizes the manufacture of large structures

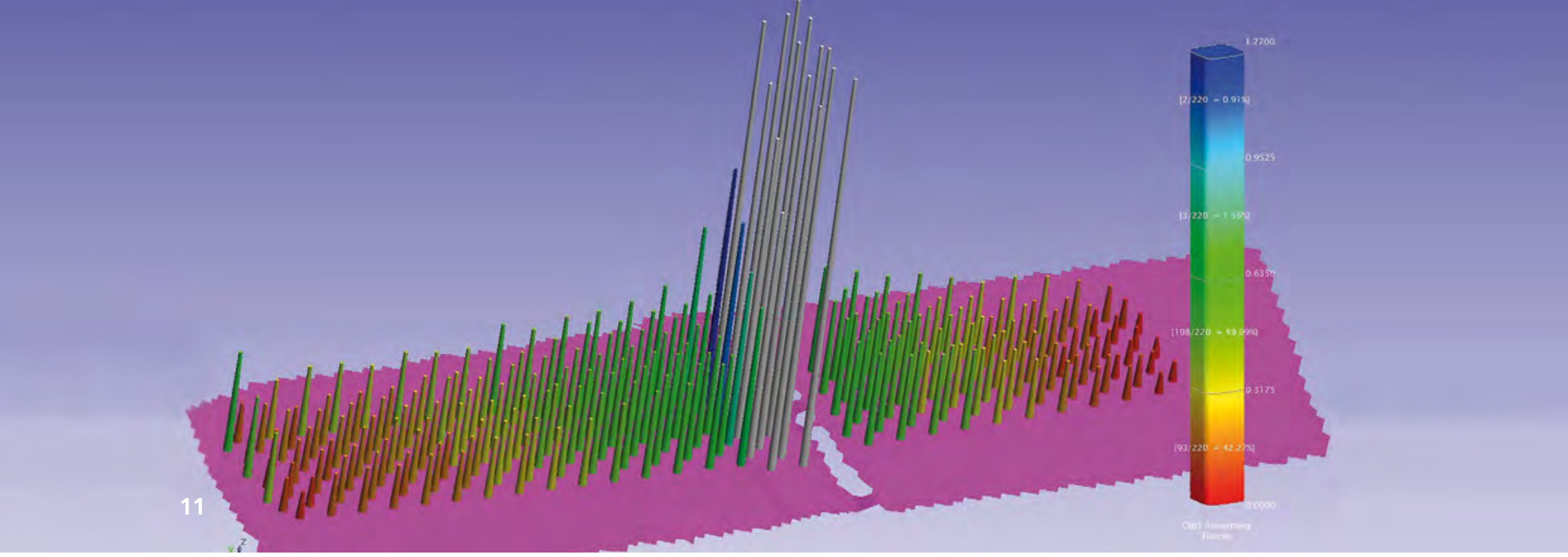
Deep-drawable Flex$^{PLAS®}$ release film: A successful development of Fraunhofer FFM in Stade together with Plasma Technology and Surfaces PLATO of Fraunhofer IFAM in Bremen represents a major breakthrough for the manufacture and processing of large FRP components. The film allows the manufacture of large FRP structures without the use of release agents – a major benefit over existing technologies. Up until now a release agent has always been required to prevent adhesion of the component to the mold during component manufacture.

The new deep-drawable Flex$^{PLAS®}$ release film is an elastic polymer film. It is coated with a thin plasma-polymer release layer having a thickness of less than 0.3 microns. This layer is extremely flexible. The film can readily be applied to complex molds, enables easy demolding, and leaves behind no residues on the component surface. It can also be applied to curved or structured molds without fold formation and is therefore particularly suitable for large FRP components. This new release film has already allowed large CFRP structures to be produced in autoclaves using the prepreg method at 180 degrees Celsius. The innovative Flex$^{PLAS®}$ release film is not only suitable for use with prepreg technology but can also be used for other manufacturing processes such as the (vacuum) infusion process or the hand lamination process.

Another major advantage is that components made using the release film can be immediately coated after removal of the release film – without further pre-treatment. The new method also allows in-mold coating of FRP components. A further advantage: The release film can, if desired, remain on the component until delivery to the end customer in order to provide protection (see Page 107: "Pioneering development: Flex$^{PLAS®}$ allows large FRP components to be manufactured without the use of release agents", and Page 124: "AVK Innovation Prize 2012 for Flex$^{PLAS®}$ release film awarded to Dr.-Ing. Gregor Graßl and Dr. Matthias Ott").

Outlook

The project results achieved to date in Stade and the large plants that have been commissioned provide Fraunhofer IFAM and its Project Group FFM with the opportunity to develop customized processes for even more complex structures and processes that put even higher requirements on automated systems in order to meet the specific requirements of customers in the aircraft manufacturing industry and other sectors. Topics being covered by ongoing projects include the automated assembly of CFRP tailfin structures or the joining of large CFRP fuselage components.



CONTACT

Dr. Dirk Niermann
Fraunhofer Project Group Joining and Assembly FFM
Head of FFM
Phone +49 4141 78707-101
dirk.niermann@ifam.fraunhofer.de

Dipl.-Ing. Tim Brencher
Fraunhofer Project Group Joining and Assembly FFM
Measurement Technology | Robotics
Phone +49 4141 78707-252
tim.brencher@ifam.fraunhofer.de

Dipl.-Ing. Karsten Gensicke
Fraunhofer Project Group Joining and Assembly FFM
Assembly and Plant Technology
Phone +49 4141 78707-221
karsten.gensicke@ifam.fraunhofer.de

Dr.-Ing. Gregor Graßl
Fraunhofer Project Group Joining and Assembly FFM
Joining Technologies |
Release Agent Free Component Manufacture
Phone +49 4141 78707-222
gregor.grassl@ifam.fraunhofer.de

Dipl.-Ing. Simon-Markus Kothe
Fraunhofer Project Group Joining and Assembly FFM
Processing Technology
Phone +49 4141 78707-272
simon-markus.kothe@ifam.fraunhofer.de

Prof. Dr.-Ing. Wolfgang Hintze
Technical University of Hamburg-Harburg
Phone +49 40 42878-3051
w.hintze@tu-harburg.de

Priv.-Doz. Dr.-Ing. habil. Dipl.-Ing. Dipl.-Ing. Jörg Wollnack
Technical University of Hamburg-Harburg
Phone +49 40 42878-3494
wollnack@tu-harburg.de

Institute
Fraunhofer Institute for Manufacturing Technology and
Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Stade

10 *"One-step-assembly" test plant with stations for holder and clip assembly.*

11 *Optical representation of the calculated adhesive gap geometry.*

PIONEERING DEVELOPMENT: FLEX$^{PLAS®}$ ALLOWS LARGE FRP COMPONENTS TO BE MANUFACTURED WITHOUT THE USE OF RELEASE AGENTS

Flex$^{PLAS®}$ is the name of a new release film which obviates the need to use conventional release agents when manufacturing large components made of fiber reinforced plastics (FRPs). The film, which was developed by Fraunhofer IFAM experts of Plasma Technology and Surfaces PLATO, Bremen, and Fraunhofer Project Group Joining and Assembly FFM, Stade, has a number of key advantages. Indeed, it is attracting attention in many sectors of industry, because it has considerable time and cost saving implications for product manufacture.

It concerns a process that is repeated thousands of times a day on a small scale: A component is manufactured using a mold and thereafter the mold is removed. To prevent sticking to the mold, a release agent is sprayed onto the surface of the mold. This then enables the component to be easily demolded after the curing step – just like removing a cake from a greased tin after being baked in the kitchen oven. Scientists from the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM have developed a pioneering technology which also allows large FRP components to be manufactured faster and at more favorable cost. Many sectors of industry are using ever more carbon fiber reinforced plastic (CFRP) materials and this new release film technology paves the way for efficient series production of these components. The Flex$^{PLAS®}$ film is an extremely elastic polymer film that is coated with a flexible plasma-polymer release layer. It allows easy removal of components from molds, even when stretched by 300 percent.

Large FRP components are being increasingly used for, amongst other things, manufacturing aircraft or wind turbines. Materials such as CFRPs are of great interest for these industries: They are light, can bear extremely high loads, and can be readily customized to meet specific requirements. The molding process hitherto was very complex, because conventional release agents left residues on both the component and mold. Cleaning and, in some cases, sanding down of the surfaces of components were arduous and crucial processes, not only with a risk of damaging the component but also requiring costly downtime during the manufacturing process.

The concept of the deep-drawable Flex$^{PLAS®}$ release film had its origins during Fraunhofer IFAM work developing molds coated with a non-stick coating applied using a low pressure plasma process. Here, the molds were treated in a reactor at low pressure by introducing special gases into a plasma. Highly reactive fragments of silicon or carbon molecules in the plasma lead to layers that have excellent adhesion to the mold. A mold modified in this way can be used up to 1000 times before a new coating has to be applied. This was a quantum leap compared to the then current method using sprayed on release agents. The release technology has been developed over a number of years by PLATO.

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Film coating in a plasma reactor

As plasma reactors are limited in size and so are unsuitable for manufacturing large components, the technology had to be further developed. The solution: Not the mold is coated in the plasma reactor, but rather an elastic, tear-resistant, plastic film. The plastic film is less than 0.1 millimeters thick and the plasma-polymer coating, which leaves no residues at all on the component surface, is only 0.3 microns thick. The film rolls pass into the reactor on a carriage (Fig. 1) – the film is unwound and then wound up again in the plasma. The PLATO experts optimized the plasma process: The molecule segments within the layer align themselves so that there are no longer any chemically reactive groups on the surface – so the coating allows perfect separation of the component from the mold.

Due to the fact that the film can be stretched by up to 300 percent, it can be readily applied to curved or structured molds without folds forming. It is hence ideal for the series production of very large FRP components (Fig. 2). A goal of Fraunhofer FFM at the Forschungszentrum CFK NORD (Research Center CFRP North) in Stade is to further develop this technology for industries such as the aircraft manufacturing industry or wind energy sector. Working together with PLATO, the Flex$^{PLAS®}$ release film technology has been optimized for industrial applications: Large full-sized CFRP components have successfully been manufactured using the prepreg method at 180 degrees Celsius in an autoclave.

Immediate coating possible

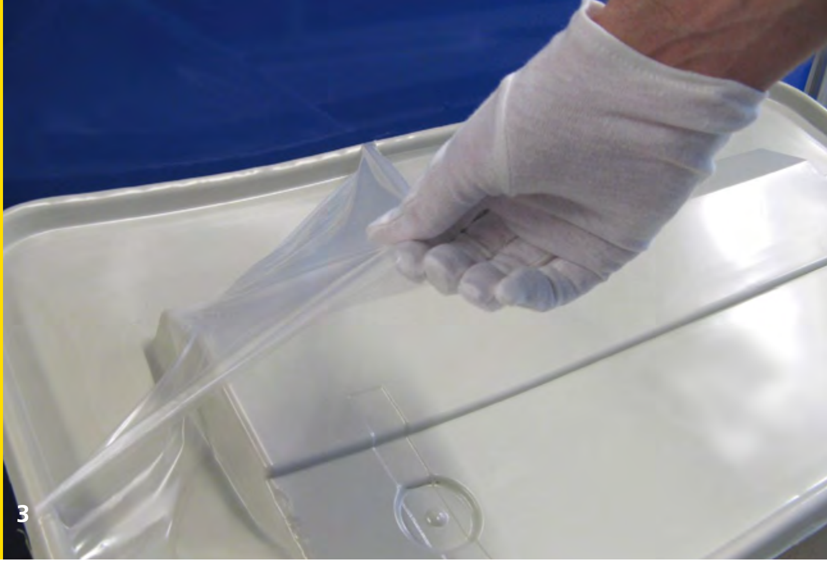
Tray-shaped molds made of special steel are used for this method. The Flex$^{PLAS®}$ release film is first placed in the mold. Vacuum pumps then extract the air between the mold and film – leaving no folds. The CFRP sheets can then be placed in the mold in the desired thickness; after “baking” in the autoclave and cooling, the component can be demolded without any release agent residues. The release film can be easily removed but if desired can also remain on the component to provide protection during transport.

As the component surface is free of contamination and release agent residues after removing the film, it can be coated immediately without further pre-treatment. The new method also allows in-mold coating of FRP components. For this a gelcoat is applied with comparatively low effort to the Flex$^{PLAS®}$ film in the mold. The production of the FRP component then takes place on the coating. The in-mold coating and the FRP component are cured together and the coated component with the release film is then removed from the mold (Fig. 3).

These developments have created huge interest and there have been numerous enquiries from industry.

1 *The low pressure plasma reactor is used to coat and functionalize the film for the Flex$^{PLAS®}$ release film.*

2 *Checking the deep-drawn, fold-free Flex$^{PLAS®}$ release film in the mold for a CFRP fuselage shell.*



The Industrievereinigung Verstärkte Kunststoffe e. V. (AVK; Federation of Reinforced Plastics) awarded Dr. Matthias Ott – PLATO – and Dr.-Ing. Gregor Graßl – Fraunhofer FFM – the AVK Innovation Prize 2012 for their scientific work on Flex$^{PLAS®}$ release film. The award was presented at the Composites Europe 2012 fair. The Fraunhofer IFAM scientists won the first prize in the category "Innovative processes and methods" (see Page 124: "AVK Innovation Prize 2012 for Flex$^{PLAS®}$ release film awarded to Dr.-Ing. Gregor Graßl and Dr. Matthias Ott").

Outlook

A key objective of the development work is to utilize the advantages of release agent free FRP component manufacture for a wide array of applications in the future. Besides processes involving preimpregnated fibers, the focus will also be put on infusion methods where liquid resin flows around dry fibers in closed molds. A further challenge is the manufacture of glossy CFRP surfaces that require no complex grinding and polishing processes.

CONTACT

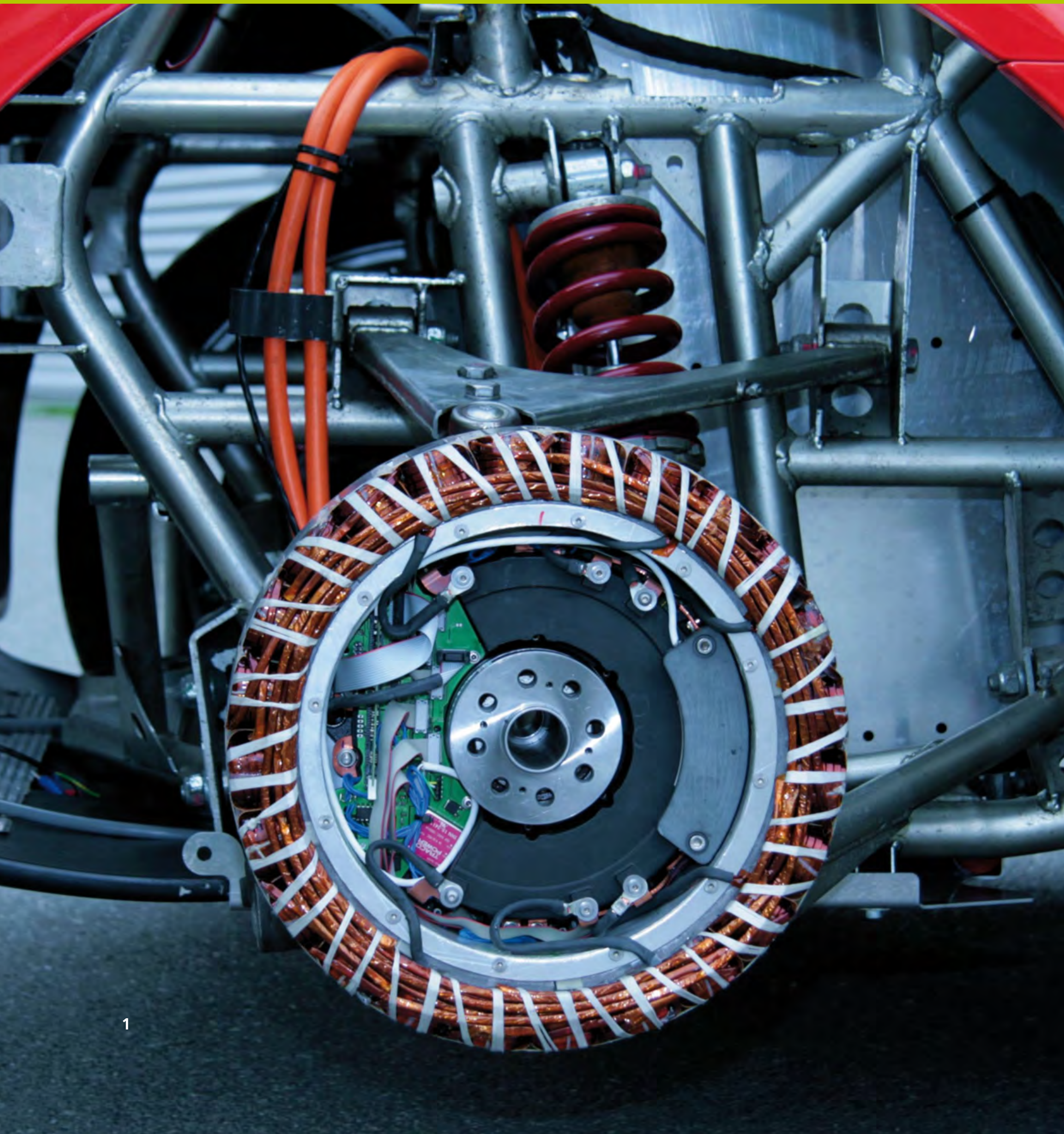
Dr.-Ing. Gregor Graßl
Fraunhofer Project Group Joining and Assembly FFM
Phone +49 4141 78707-222
gregor.grassl@ifam.fraunhofer.de

Dr. Matthias Ott
Plasma Technology and Surfaces PLATO
Phone +49 421 2246-495
matthias.ott@ifam.fraunhofer.de

Institute
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen and Stade

3 *Removing the Flex$^{PLAS®}$ release film, developed at Fraunhofer IFAM, from a FRP component which was coated with a gel-coat in the mold.*

ELECTRICAL COMPONENTS AND SYSTEMS



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CORE COMPETENCE ELECTRICAL COMPONENTS AND SYSTEMS

The core competence "Electrical components and systems" is a relatively new area for Fraunhofer IFAM. Our expertise in this area has significantly expanded over recent years and we collaborate closely with other areas of expertise at the institute.

Fraunhofer IFAM adopts a system research approach in this area, whereby individual technologies and components are always considered and developed in relation to the whole system, for example an electric car.

At a component level the scientists are developing novel metal-air batteries, with the synthesis and processing of new active materials being particularly at the fore. In addition, thermochemical energy storage systems are being developed based on innovative hydrogenatable metal alloys. Electrical drive technology is focusing on the development, control, assembly, and testing of electrical machines, in particular for drive applications. Adhesive bonding technology, surface technology, and coatings extend the expertise for matters such as the joining, contacting, insulation, and protection of electrically conducing materials.

As many electrical components are being developed for cars, an understanding of systems for electric cars and electromobility is vital. Our know-how in this area includes the design, control, assembly, and testing of vehicles and concept vehicles, as well as their components, especially with electric and hybrid drive systems. In order to improve operating reliability, individual components such as the electric drive shaft are being qualified by "hardware in the loop" simulations of operating performance on a test stand. Here, experience is utilized from the fleet of electric vehicles operated in the Bremen/Oldenburg model electromobility region. We pass on our know-how by giving training courses in electromobility. These courses are specifically targeting Germany and China.

An example of the multidisciplinary approach of Fraunhofer IFAM is the cast coil. This innovative product, originally developed at Fraunhofer IFAM, involves know-how in casting technology and electric drive technology plus the development of special insulating coatings.

Over the coming years, Fraunhofer IFAM will continue to expand its R&D activities on electrical components and systems. At the fore will be thematic networking and collaboration within the institute and also with other partners in the Fraunhofer-Gesellschaft. An example of this is the "Fraunhofer System Research Electromobility project – FSEM".

1 *Stator of the wheel hub motor mounted on the "Fraunhofer electric concept car".*

CAST COILS FOR ELECTRICAL MACHINES

Cast coils offer huge potential for improving the performance and torque of electrical machines. A process developed at Fraunhofer IFAM is used to manufacture these innovative components. Special features are the much improved utilization of the available space and the resulting improvement in torque density and efficiency. The array of expertise available at Fraunhofer IFAM allows a holistic approach, from the initial design right through to the production of the electrical machines.

Casting instead of winding

About 40 percent of global electricity is consumed by electrical motors [1]. These electrical machines are used for a wide range of different tasks and cover the power range of more than 15 orders of magnitude, from a few µW to the GW range. The efficiency and performance of all electrical machines are largely determined by the magnetic field generating coils. The main production process for manufacturing such coils involves the winding of enameled copper wire around the poles of the stator and in some cases also the poles of the rotor. Due to limitations in the manufacturing process and also economic reasons, up to a half of the available space is typically filled with electromagnetically active conductor material (see Fig. 2). This has led to electrical machines becoming larger and heavier than they actually need be. The air space between the conductors, which arises due to the winding technology, adversely affects heat dissipation from the coils, which limits the power rating.

The idea of Fraunhofer scientists to use cast coils aims to alleviate this problem. The geometric freedom of design offered by casting technology enables customized design of the coils and optimal adaptation to the available space. Key here is the so-called slot fill factor, namely the summed cross-sectional areas of all conductors as a fraction of the available space in the slot. The slot is the intermediate space between the so-called teeth of the laminated core which together with the teeth and yoke forms the electromagnetically active

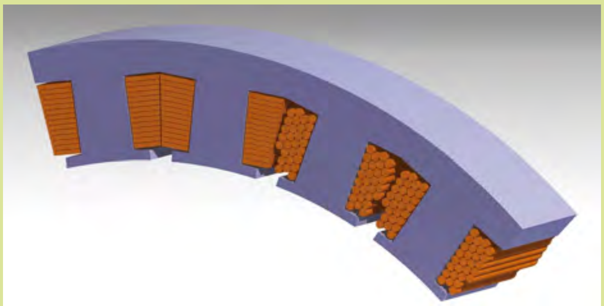

Fig. 2: Cross-section of cast coils (left) compared to wound coils (right).

1 *Cast copper coil.*

[1] P. Plötz, W. Eichhammer: „Zukunftsmarkt Effiziente Elektromotoren", P. 5, Table 1. Case study of Fraunhofer ISI, FKZ 03KSW016A/B. Karlsruhe, 10/2011.

4

part of the machine. In principle, the electrical resistance of the winding and hence electric heat losses decrease with increasing slot fill factor. Casting technology allows slot fill factors of up to 90 percent to be achieved. The part not filled with conductor material is required for the electrical insulation (Fig. 1 and 2).

Compared to conventionally manufactured coils, the use of cast coils opens up a number of directions for development work (Fig. 3). On the one hand, the larger cross-sectional area of the conductor in the same space allows notable increase in the torque density (volumetric as well as gravimetric). This leads to improved electromagnetic utilization of the laminated core. On the other hand, the current density in the conductor can be reduced for the same power, leading to lower losses and hence an increase in efficiency. Furthermore, the use of alternative conductor materials to copper, such as aluminum alloys, is also possible because the poorer

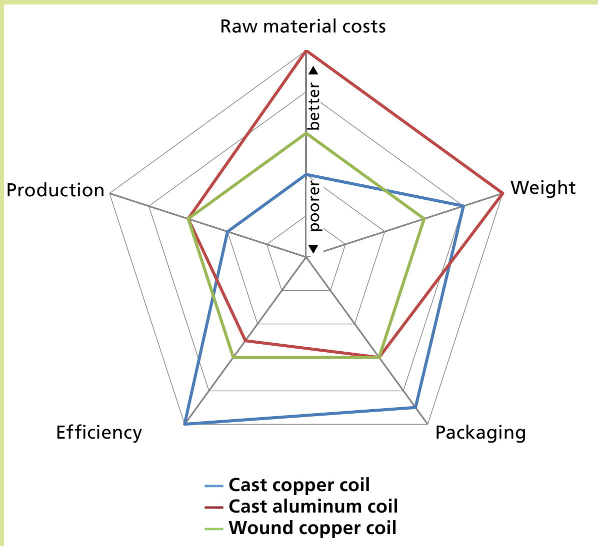

Fig. 3: Different approaches for optimizing cast coils compared to conventionally wound coils.

conductivity of these materials compared to conventionally wound copper coils can be compensated for at the same power.

Customized production by investment casting

Fraunhofer IFAM has expertise that covers the whole process chain for the construction, manufacture, and coating of cast coils for electrical machines via investment casting. The holistic approach and optimization of the whole process taking into account design, electromagnetic, production, and cost requirements leads to electrical machines customized for the relevant application and the specific operating points in the torque-speed diagram. The combined Fraunhofer IFAM expertise in the design and simulation of electrical machines, the manufacture of models via wax injection molding, production of cast coils via investment casting, and the development and qualification of innovative surface pretreatment technologies and insulating coatings means that all key aspects are covered and allows customized solutions to be offered to customers (Fig. 4).

The properties of these coils were studied via electromagnetic simulations and conductivity measurements on cast coils made of different conductor materials. In summary the key advantages are as follows:

- The significant increase in the slot fill factor considerably increases the torque density and efficiency of electrical machines.
- Automation of the casting process allows cast coils to be manufactured at favorable cost.

4 *Cast aluminum coil with insulating coating.*

- There are further possible cost-saving opportunities from reduced usage of active materials (electrical steel sheet and permanent magnets) and using aluminum as the conductor material.
- Due to the flat conductor layout, current displacement effects at high stator current frequencies are much reduced.
- The thermal properties of the machines can be significantly improved by specific heat dissipation measures and the better overall heat conductivity of the coils.
- For the same machine geometry, the high fill ratio allows equivalent replacement of copper by aluminum and so considerable weight and cost savings.

Application scenarios

Important application fields for cast coils can be found in traction drives, where high requirements are put on the torque density due to the usually limited space. In direct drives, such as wheel hub motors, the advantages of cast coils can also be readily utilized. For wheel hub motors, the use of a cast coil made of aluminum alloy may also be attractive due to the lower cost and much lower weight.

For industrial drives in the power range up to 375 kW, manufacturers are oblidged to improve the efficiency on account of requirements under EU Regulation No. 640/2009 on environmentally friendly product design and the requirement to comply with efficiency class IE3 from 2015 [2]. The three-phase asynchronous machines that have hitherto dominated this market segment can either no longer meet these efficiency requirements or only at high expense, meaning that permanent magnet excited machines are being increasingly used by industry. Cast coils are highly suitable for these types of machines and can considerably raise the efficiency. This opens up enormous opportunities for energy-saving, meaning a secure future market for the R&D services of Fraunhofer IFAM.

For wind turbines, cast coils allow heat dissipation from hotspots during operation via customized design of the stator winding and in some case the energizer winding. The design freedom of lost foam technology, a technology with which Fraunhofer IFAM has much experience, can be utilized here to produce larger coils with suitable heat exchange surfaces at favorable cost and of variable design.

[2] See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:191:0026:0034:DE:PDF

Outlook

In the next development phase the work will focus on the assembly and testing of a Fraunhofer wheel hub motor with cast coil for detailed comparison with the performance of a conventional coil. The detailed measurement of the operating performance will allow precise electrical and thermal characterization of the cast coils. This will also highlight further opportunities for process improvement and cost reduction.

Priority here will be put on the development of novel conductor materials that can be readily cast and have very good electrical conductivity. These materials will then be qualified in real use in a suitable electrical machine.

CONTACT

Dipl.-Ing. Felix Horch
Casting Technology and Component Development
Phone +49 421 2246-171
felix.horch@ifam.fraunhofer.de

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

ELECTROMOBILITY – HEADSTART IN KNOWLEGE DUE TO TECHNICAL TRAINING

Our understanding of mobility will change fundamentally in the years ahead due to the emergence of electric vehicles. A start has been made: There have been promising developments regarding infrastructure and many new vehicle technologies and concepts are being tested by industry. These changes require new training courses for specialists in this area. Fraunhofer IFAM has recognized this and responded accordingly. From August 2013 an "Electromobility Specialist" training seminar is being organized in collaboration with TÜV Rheinland Akademie.

Training courses in electromobility

Participants will be given an overview of key topics, including standards and safety, energy storage, powertrain technology, and vehicle concepts. Besides basic theoretical knowledge, there will be practical assignments on real components in order to further participants' knowledge about the functioning of key vehicle components. For example, the participants will test the charging and discharging of batteries and the properties of various electrical drives on the motor test stand. They will also survey various electrical vehicles on the road and subsequently analyze the energy consumption. This will give the participants a real feel for electromobility.

Overarching topics are also highly relevant for electromobility, for example the networking and management of electricity generators, electricity storage systems, and consumers – and hence also the integration of electromobility into overall energy concepts and plans. It has been identified that there is a need for a practically-oriented training course covering all these topics.

Electromobility specialist

This training seminar is directed at people with a technical/commercial background in the supply industry, managers in production and development areas, and consultants.

The five-day course will be given by experts and has a modular structure (A to E) (Fig. 2). On successful completion of the course, participants will receive a PersCert certificate for "Electromobility specialist". The participants will then be accredited under BGI/GUV-I 8686 and authorized to independently carry out work on high-voltage intrinsically safe vehicles.

In addition, further optional courses will also be offered. These will cover, for example, systematic troubleshooting on electric vehicles and future mobility concepts.

1 *Schematic representation of a hybrid vehicle (© iStockphoto).*

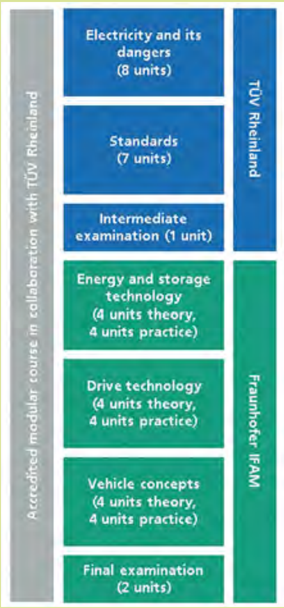

Fig. 2: Overview of the electromobility training course.

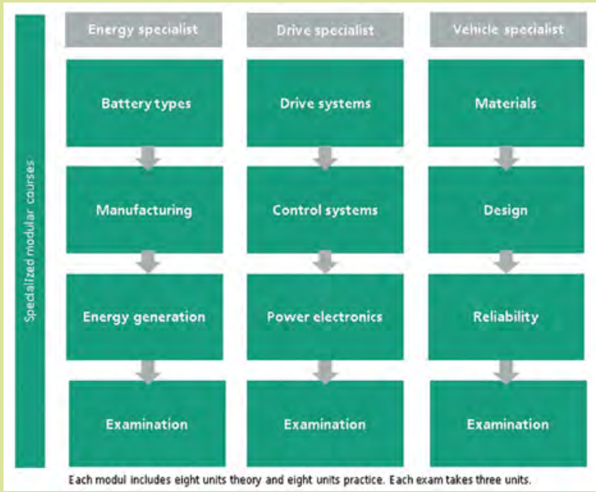

Fig. 3: Further optional training courses in electromobility for more in depth knowledge.

Expert courses – for more in-depth knowledge

For more in-depth knowledge of electromobility, expert courses are planned for 2014 (Fig. 3). These will expand on the basic course, but will be more detailed and comprise more practical sessions. To start with, three expert courses on energy technology, vehicle concepts, and powertrain technology are planned. The target groups are employees with a supervisory/management role and engineers working in R&D in electromobility.

Further information about the "Electromobility specialist" training seminar and about the application procedure can be found online at www.ifam.fraunhofer.de/fachkraft-emobility.

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CONTACT

Dr.-Ing. Marcus Maiwald
Technical Training in Electromobility
Phone +49 421 2246-124
marcus.maiwald@ifam.fraunhofer.de

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

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INTERNATIONALIZATION – BRAZIL AND CHINA IN FOCUS

The Fraunhofer-Gesellschaft strongly expanded its international activities over recent years. Fraunhofer IFAM follows the same direction, aiming to increase international cooperation with excellent research partners based abroad. The contacts and cooperation are increasing also to outside Europe: in 2012 significant progress was performed in collaboration with Chinese and in particular with Brazilian partners.

Closer collaboration with Brazil

A considerable step for closer contact with universities and industrial partners in Brazil came from research-oriented political decision-making bodies in Germany and Brazil. This manifested itself in 2010/11 in the German-Brazilian Year of Science, Technology, and Innovation (DBWTI). Since then researchers at Fraunhofer IFAM have being setting up network structures and cooperating in joint projects.

The network and activities are based on three main pillars: university education and research, applied research, and industrial applications. International visibility on both sides of the Atlantic is a prerequisite for acquiring future partners and becoming familiar with regulatory frameworks for collaboration. Intense collaboration with Brazilian universities, their staff and especially their students provided a strong and successful platform for scientific research cooperation, in particular due to the focus of Fraunhofer institutes on applied research.

Also attractive for industrial research partners in Brazil is the high quality of German R&D. A highlight was the invitation of Fraunhofer IFAM researchers and Brazilian students undertaking practical training at Fraunhofer IFAM to a meeting with the Brazilian President, Dilma Rousseff, and the Brazilian Minister for Research, Technology, and Innovation, Dr. Marco Antonio Raupp. At the meeting in March 2012 in Hannover, the conception and first experiences implementing the Brazilian initiative "Science without borders" (CsF - Ciência Sem Fronteiras) and the setting up of the Brazilian Research and Industrial Innovation Company (Embrapii: Empresa Brasileira de Pesquisa e Inovação Industrial) and its collaboration with the Fraunhofer-Gesellschaft were discussed in detail.

Eight Brazilian CsF fellowship holders, who undertook one year of internship at Fraunhofer IFAM in 2012 under this CsF initiative, together with bilateral exchange students from the Federal University of Santa Catarina (UFSC) currently represent the largest group of international students working at Fraunhofer IFAM. The visit of the President of the Brazilian Association of Rectors of State and Municipal Universities (ABRUEM) and rector of the University of Ponta Grossa (UEPG), Prof. João Carlos Gomes, to Fraunhofer IFAM in June 2012 emphasized the importance of this collaboration from the Brazilian side.

The German Academic Exchange Service (DAAD) provides further opportunities for international collaboration. Following

2

a successful application for funding, the DAAD supported a summer school organized in September/ October 2012 in Florianópolis by TU Dresden (Dr. Jan-Ole Joswig) and Fraunhofer IFAM (Dr. Welchy Leite Cavalcanti) entitled "Nanotechnology for the design of functional materials: theory, experiment, and developments". Selected Brazilian master and PhD students from throughout the country keenly learned about current and future research work via activities and lectures performed by the organizers Dr. Jan-Ole Joswig and Dr. Welchy Leite Cavalcanti , and by Prof. Dr. Florian Müller-Plathe (TU Darmstadt), Prof. Dr. Michael Springborg (University of Saarland), Dr. Michael Noeske and Dr. Klaus Rischka (both Fraunhofer IFAM), and the hosts at Federal University of Santa Catarina (UFSC) Prof. Dr. André Avelino Pasa, Prof. Dr. Mauricio Girardi, and Prof. Dr. Aloisio Nelmo Klein.

The main areas of research at Fraunhofer IFAM were presented in a plenary lecture by Prof. Dr. Bernd Mayer in Florianópolis on the occasion of the annual meeting of the Brazilian Materials Research Society (SBPMat) in September 2012. Within the SBPMat 2012 a new symposium entitled "Joining Technology – Adhesion in Research and Development" was organized by Dr. Welchy Leite Cavalcanti of Fraunhofer IFAM and SBPMat local organizers. The symposium enabled the research results of the Brazilian students working at Fraunhofer IFAM to be presented. In addition, there was the opportunity to strengthen the cooperation with the President of the Brazilian Society for Adhesives and Adhesion (ABAA), Prof. Dr. Silvio Barros, to couple the symposium topics to the first Brazilian-Portuguese conference on adhesives and adhesion taking place in Rio de Janeiro in November 2012. The Brazilian students working at Fraunhofer IFAM were also able to present research work within this ABAA conference.

Electromobility driving the collaboration with China

In July 2011, an agreement was made between the Federal Ministry of Transport, Building and Urban Development (BMVBS) in Germany and the Ministry of Science and Technology (MOST) in China on closer collaboration in the area of alternative drive systems and electromobility. This collaboration in particular involves wide-ranging exchange between six German and Chinese model cities or regions.

One of the selected partnerships is between Bremen/Oldenburg in Germany and Dalian in North China, which will extend the existing twinning of the cities of Bremen and Dalian that has existed since 1985. In April 2012, a delegation of 23 people from Dalian, led by Liu Yan, Assistant Mayor and Director of Dalian Economic and Information Technology Committee, visited Bremen for the first exchange on the subject of electromobility. The return visit was in May 2012 when federal councillor Heiner Heseler went to Dalian with a delegation from Bremen.

Further German-Chinese workshops are currently being planned. They will address the topics of urban development and electromobility using the example of gated areas (e. g. Überseestadt Bremen), port logistics, battery/electric buses in the public transport network, taxis based on electric vehicles and hybrids, and the charging infrastructure.

1 *Prof. Dr. João Carlos Gomes, with Brazilian students working under the Brazilian study program "Science without frontiers" and Fraunhofer IFAM researchers, during his visit to Bremen.*

2 *Visit of the delegation from Dalian (China) to Fraunhofer IFAM in Bremen.*

Besides collaboration between the model regions, there are worthwhile opportunities for training in the area of electromobility. In 2012, Fraunhofer IFAM, working with a German vehicle manufacturer, started developing suitable training courses for China. Important contacts for this have been established with research organizations (universities and institutes), in particular in Shanghai.

CONTACT

Dr. Welchy Leite Cavalcanti
Adhesion and Interface Research
Phone +49 421 2246-487
welchy.leite.cavalcanti@ifam.fraunhofer.de

Prof. Dr.-Ing. Horst-Erich Rikeit
Business Development
Phone +49 421 2246-674
horst-erich.rikeit@ifam.fraunhofer.de

Institute
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen

Dr.-Ing. Gerald Rausch
Electrical Systems
Phone +49 421 2246-242
gerald.rausch@ifam.fraunhofer.de

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

PEOPLE AND MOMENTS

DEPUTY DIRECTOR ANDREAS HARTWIG APPOINTED PROFESSOR AT THE UNIVERSITY OF BREMEN

On October 18, 2012 the University of Bremen appointed Priv.-Doz. Dr. rer. nat. Andreas Hartwig as a professor. The deputy director of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, who also heads the Adhesives and Polymer Chemistry section, teaches Macromolecular Chemistry in the Chemistry/Biology Department (Department 2) at the University of Bremen.

As well as teaching the fundamentals of macromolecular chemistry, Professor Andreas Hartwig will now expand the master's course in chemistry at the University of Bremen with detailed practical and theoretical modules, in close collaboration with Fraunhofer IFAM. Not only will the full scope of polymer chemistry be in focus, but also its linking with engineering aspects. The main research areas of Andreas Hartwig are crosslinked polymers and heterogeneous polymer systems, which are typically required for adhesives, matrix resins for fiber composites, and coating systems.

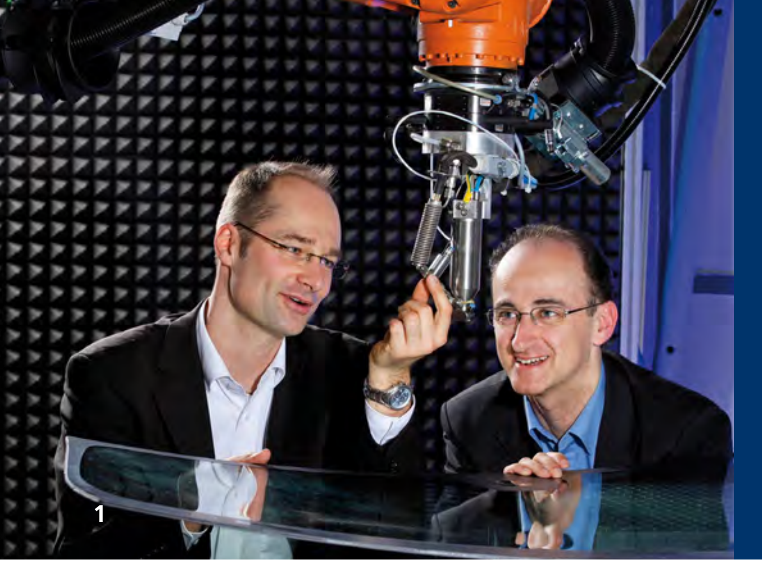
These disciplines not only put high requirements on the synthesis and characterization of materials but are at the same time of huge commercial importance in virtually all branches. Even so, they are rarely taught and researched at European universities. This challenge – and in particular also the acquisition of new scientific talent with knowledge of crosslinked polymers – is being addressed by the activities of Professor Andreas Hartwig at the University of Bremen and motivated by the excellence of the university.

CONTACT

Institute

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen

1 *The deputy institute director of Fraunhofer IFAM, Prof. Dr. Andreas Hartwig, is responsible for teaching Macromolecular Chemistry in the Chemistry/Biology Department at the University of Bremen.*



JOSEPH VON FRAUNHOFER PRIZE TO DR. JÖRG IHDE AND DR. UWE LOMMATZSCH FOR FUNCTIONAL PLASMA COATINGS

At the annual meeting of the Fraunhofer-Gesellschaft on May 8, 2012 in Stuttgart, which was this year held under the motto "Living and working in the city of the future", Dr. Jörg Ihde and Dr. Uwe Lommatzsch were awarded the Joseph von Fraunhofer Prize for their novel, atmospheric pressure plasma coating process. A special honor since the prize was for the last time presented by the outgoing President of the Fraunhofer-Gesellschaft, Prof. Dr. Hans-Jörg Bullinger.

Nano coatings can provide protection against rust, scratches, and moisture or modify the adhesion: The new plasma process allows these nano-coatings to be applied more easily, faster, and at lower cost – on an industrial scale.

The innovative process developed by the team of Jörg Ihde and Uwe Lommatzsch, from the Plasma Technology and Surfaces PLATO department at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, in collaboration with Plasmatreat GmbH, is based on an atmospheric pressure plasma nozzle in which the outflowing plasma is relaxed in a controlled way. For layer deposition, a polymerizable material is introduced into the relaxing plasma. The special nozzle design means that very high deposition rates and excellent layer qualities are achieved. Customized surface properties can be set. For example, layers for corrosion protection, adhesion promotion, or anti-stick properties are deposited.

Features of the process are its eco-friendliness, low investment costs, and production efficient usage of resources. It may be readily integrated into production lines, can be automated – thus is controlled using robots – and further involves low chemical usage. High processing rates also lower the costs. The technology is already being successfully used in industrial production – for example, in the car manufacturing industry and energy technology sector – and provides amongst other things protection against corrosion and aging.

CONTACT

Institute

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Adhesive Bonding Technology and Surfaces, Bremen

1 *Dr. Jörg Ihde and Dr. Uwe Lommatzsch (left to right) developed a new resource-efficient method for the high-rate deposition of functional nano coatings using atmospheric pressure plasma technology.*

AVK INNOVATION PRIZE 2012 FOR FLEX$^{PLAS®}$ RELEASE FILM AWARDED TO DR.-ING. GREGOR GRASSL AND DR. MATTHIAS OTT

The Industrievereinigung Verstärkte Kunststoffe e. V. (AVK; Federation of Reinforced Plastics) awarded the AVK Innovation Prize 2012 to Dr. Matthias Ott – Plasma Technology and Surfaces PLATO – and Dr.-Ing. Gregor Graßl – Fraunhofer Project Group Joining and Assembly FFM – for their outstanding development work on release agent free FRP component manufacture using an innovative film technology. The two scientists of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen and Stade, were presented with the first prize in the category "Innovative processes" at Composites Europe, the European trade fair for composites, technology, and applications, on October 8, 2012 in Düsseldorf.

The newly developed Flex$^{PLAS®}$ release film allows release agent free production of large fiber reinforced plastic (FRP) components such as those used, for example, in the manufacture of aircraft or wind turbines. The new films not only result in higher manufacturing productivity for FRP components but also have advantages for subsequent coating and for protection during transport. All these attributes are of much interest to industry, as reflected in the large demand (see page 107; "Pioneering development: Flex$^{PLAS®}$ allows FRP components to be manufactured without the use of release agents").

The Flex$^{PLAS®}$ release film is a thin, firmly adhering plasma-polymer release layer of less than 0.3 micrometers thickness. It allows easy demolding and leaves behind no residues at all on the component surface. The film can be applied using a special deep-drawing process without alteration of the process design, and is suitable for both female and male molds. It is also very durable and elastic. It can even withstand extreme elongation up to 300 percent without functional impairment. This allows it to also be applied to curved and structured molds without fold formation.

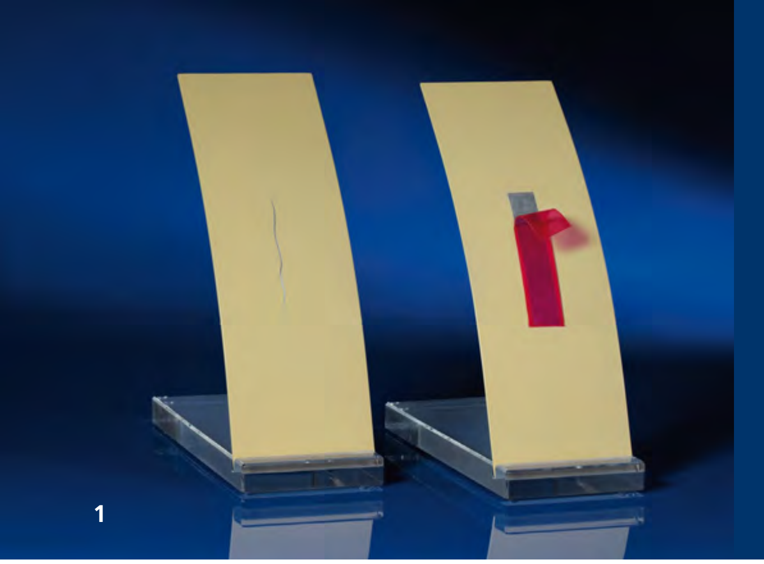
Following the production, the components can be coated without further pre-treatment because there are no residues on the components. The new technology also allows in-mold coating: Here, the component is coated integrally by applying a gel-coat to the film.

CONTACT

Institute

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen and Stade

1 *AVK board members Dr. Gerd Eßwein (left) and Dr. Rudolf Kleinholz (right) presented Dr. Matthias Ott and Dr.-Ing. Gregor Graßl (center) with the AVK Innovation Prize 2012 (© AVK/Foto Behrendt & Rausch).*



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SURFAIR AWARD FOR INNOVATION TO DR. MALTE BURCHARDT AND DR. MALTE KLEEMEIER FOR ADHESIVE PICKLING TAPES FOR THE LOCAL PRE-TREATMENT OF ALUMINUM

At the 19th International Conference on Surface Treatment in the Aeronautics and Aerospace Industries – SURFAIR in Biarritz, France, the SURFAIR Award for Innovation was presented to the research project "Adhesive pickling tapes for the local pre-treatment of aluminum". The award was presented on June 1, 2012. Linda Duschl, Senior Manager at Boeing Research & Technology, presented Dr. Malte Burchardt with the award, representing the development team at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen.

Appropriate pre-treatment is vital for durable bonding and coating of aluminum. An established pre-treatment method for aluminum is pickling in acid or alkaline baths. Some of these processes involve multiple steps. These bath processes do, however, have drawbacks if only local pre-treatment of certain places on a component is required for repairs or touch-up work and when large components need to be treated.

The experts at Fraunhofer IFAM have developed a solution for this. The work was carried out by Dr. Malte Burchardt, Dr. Stefan Dieckhoff, Philippe Vulliet, and Dr. Ralph Wilken from the Adhesion and Interface Research department as well as by Dr. Malte Kleemeier and Katharina Teczyk from the Adhesives and Polymer Chemistry department. The functional adhesive tape allows selective pickling of metal surfaces prior to bonding and coating. The adhesive pickling tape is applied like standard adhesive tape and is simply stuck to the area to be treated. All the required chemicals are contained in the pickling tape. In contrast to pickling pastes, no subsequent rinsing is necessary. A simple wiping of the surface is all that is required – contaminated wastewater is avoided. The tapes are easy to handle, safe, and environmentally friendly.

In practical tests the adhesive pickling tape has proved as effective as conventional bath methods for treating aluminum before bonding or coating. Thus, adhesion is considerably increased – in particular in corrosive environments. Applications include local touch-up work in production processes, repairs, and partial pre-treatment in bonding areas of large components, in instances where bath treatment is uneconomical.

CONTACT

Institute

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen

1 *SURFAIR Award for Innovation 2012 for the adhesive pickling tapes developed at Fraunhofer IFAM.*

1

Dr. Klaus Seppeler Stiftung

URKUNDE

Auf Beschluss des Vorstands der

GfKORR - Gesellschaft für Korrosionsschutz e.V.

Frankfurt am Main

wird

Herrn Dipl.-Ing. (FH) Andreas Brinkmann

für seine vorbildliche Masterarbeit im Studiengang Corrosion Protection Technology

an der Fachhochschule Südwestfalen, Fachbereich Informatik und Naturwissenschaften

„Untersuchungen zum Korrosionsschutz von Beschichtungen auf Polypyrrol-Basis

für unlegierten Stahl als Alternative zu Phosphatschichten"

der Dr. Klaus Seppeler Stiftungspreis verliehen.

Frankfurt am Main, den 6. November 2012

GfKORR - Gesellschaft für Korrosionsschutz e.V.

Prof. Dr.-Ing. Bernd Isecke
Vorsitzender der
GfKORR - Gesellschaft für Korrosionsschutz e.V.

Dr. Klaus Seppeler Stiftung

Kai Seppeler

EFFICIENT CORROSION PROTECTION – ANDREAS BRINKMANN RECEIVES THE DR. KLAUS SEPPELER ENDOWMENT

Andreas Brinkmann has been awarded the Dr. Klaus Seppeler Endowment 2012 for his master's thesis entitled "Studies on the corrosion protection of polypyrrole-based coatings for non-alloyed steel as an alternative to phosphate layers". The award was presented at the annual meeting of the GfKORR Gesellschaft für Korrosionsschutz e. V. (Society for Corrosion Protection) on November 6 in Frankfurt/Main. The endowment supports young scientists working in the area of corrosion and corrosion protection. It was presented by GfKORR chairman, Prof. Dr.-Ing. Bernd Isecke, and the managing director of the Seppeler Group, Kai Seppeler.

In his master's thesis, which formed part of the Corrosion Protection Technology master's course, Chemical Engineer Andreas Brinkmann describes the manufacture and characterization of differently doped polypyrroles for intelligent corrosion protection. The purposeful incorporation of anions (doping), which have a corrosion inhibiting effect on steel, into polypyrrole results in effective corrosion protection: Anions are only released on corrosion of the steel substrate, so there is customized inhibitor dosing. This means more sustainable, more resource-efficient, and more environmentally friendly corrosion protection.

The effectiveness of the corrosion protection layers based on polypyrrole was studied using electrochemical methods and was compared on non-alloyed steel to commercial phosphate layers which are used as standard in the car manufacturing industry. It was demonstrated that the corrosion-initiated inhibitor release mechanism is effective. In addition, the polypyrrole layers had a corrosion protection effect that not only exceeded that of phosphate layers but in particular also effectively suppressed infiltration caused by damage to the layer.

The results achieved by Andreas Brinkmann, working together with experts of Paint/Lacquer Technology and Electrochemistry/Corrosion Protection at Fraunhofer IFAM in Bremen, form the basis for promising further development of resource-efficient, eco-friendly corrosion protection systems.

CONTACT

Institute

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,
Adhesive Bonding Technology and Surfaces, Bremen

1 *Andreas Brinkmann (left) receiving the Dr. Klaus Seppeler Endowment from Kai Seppeler, the managing director of the Seppeler Group (© Kaczykowski, DECHEMA).*

FABIAN PETERS WINS THE DRIVE-E STUDENT AWARD

With 62 applicants from 16 universities of applied sciences and 12 other universities throughout Germany, interest in the DRIVE-E Award has never been so high. In Aachen on March 14, 2012, the Federal Ministry for Education and Research (BMBF) and Fraunhofer-Gesellschaft presented awards for excellent student work in the area of electromobility. Fabian Peters of Fraunhofer IFAM was one of the awardees. The awards are part of the DRIVE-E program that was initiated in 2009 by the BMBF and Fraunhofer-Gesellschaft to promote student involvement with electromobility.

Fabian Peters studied Production Technology at the University of Bremen. In his Master's thesis entitled „Preparation and characterization of high capacity silicon-based anodes for the next generation lithium-ion batteries" he identified factors that limit the energy density and service life of lithium ion batteries. His master's research was performed at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Bremen.

Many factors have a major effect on the energy density of the battery. An in-depth understanding of the physical and chemical processes in a battery cell is thus vital in order to optimize the whole system. The award-winning work systematically examined at the processes that limit the energy density and service life of lithium ion batteries with silicon anodes. An in-depth understanding of these processes helps to minimize these limitations and hence extend the travel distances compared to currently favored battery types. The study work of Fabian Peters was supervised by Professor Matthias Busse and the Electrical Energy Storage project group at Fraunhofer IFAM.

CONTACT

Institute

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

1 *Fabian Peters next to the system for testing materials for electrical energy storage (© Christian Schmid).*

NAMES | DATES | EVENTS

Fraunhofer IFAM is a research institute based in material sciences and manufacturing technologies. In addition to its strong focus on applied research documented in projects with partners from various industries, scientific excellence is a core guideline for the institute.

Cooperation with universities and colleges

Close cooperation and the network with local universities and colleges plays an important role for Fraunhofer IFAM at all of its locations. In particular, this is valid for Bremen University and the Dresden University of Technology both of which were awarded within the German federal government's Excellence Initiative in 2012.

In 2012, six Fraunhofer IFAM scientists received a Ph.D. degree from the University of Bremen. Over the summer term 2012 and the winter term 2012/2013, Fraunhofer IFAM scientists held over 30 courses between the University of Bremen, Dresden University of Technology, Bremen University of Applied Sciences, Bremerhaven University of Applied Sciences, and the International University Dresden.

Publications and Presentations

Well over 100 publications in the scientific arena document research results achieved at Fraunhofer IFAM, confirming the strong position the institute holds within the academic community. Honors and awards for individual scientists underscore this.

With regard to conferences, congresses, and workshops, Fraunhofer IFAM scientists were very active again in 2012. The majority of the more than 170 active contributions (as papers or posters) was in Germany. Yet with more than every fourth contribution made at an event abroad, from Europe to Asia to the Americas, the strong international network of the institute is evident. Besides actively participating at events organized by others, Fraunhofer IFAM regularly organizes scientific events itself. In 2012, scientific conferences, congresses, or workshops organized by Fraunhofer IFAM averaged to more than once a month.

Patents

Patents document the innovative capability of an organization. With ten patents registered in 2012, Fraunhofer IFAM is holding up the high level from previous years.

The detailed listing of

- conferences, congresses, and workshops
- scientific publications,
- patents as well as
- awards and prizes

can be found online at **www.ifam.fraunhofer.de/nde**

1 *Fraunhofer IFAM, Dresden.*

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PATENTS

Applications 155

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1 *Fraunhofer IFAM, Bremen.*

Conferences | Congresses | Workshops

Workshop
Innovative Fertigungstechnologien für medizinische Instrumente und Implantate
Fraunhofer IFAM, Bremen
1./2.2.2012

Industry day
Herstellung von Wärmespeicher-Modulen auf Basis von Al-Fasern
International Congress Center, Dresden
8.6.2012

Workshop
Tagung des Arbeitskreises »Mechanisches Fügen der Europäischen Forschungsgesellschaft für Blechverarbeitung e. V.«
Fraunhofer IFAM, Bremen
12.6.2012

Congress
4. Deutscher Elektro-Mobil Kongress
Fraunhofer Academy Elektromobilität
Bundesverband Solare Mobilität, Essen
14./15.6.2012

Workshop
11. Bremer Klebtage
Klebtechnische Fortbildung im Rahmen der DVS®/EWF-Personalqualifizierung
Fraunhofer IFAM, Bremen
19./20.6.2012 and
28./29.11.2012

Expert conference
7. Rapid Prototyping-Fachtag »Vom Objekt zum Bauteil«
Fraunhofer IFAM, Bremen
21.6.2012

Conference
1. Internationales VDI-Forum Lost Foam
(with VDI and LFC)
Swissôtel, Bremen
26./27.6.2012

Symposium
Prozess- und Werkstoffinnovationen in der Pulvermetallurgie
International Congress Center, Dresden
5.7.2012

Workshop
1. Dresdner VDI Werkstoffabend
International Congress Center, Dresden
17.9.2012

OTTI-Seminar
Funktionale Implantatoberflächen
Hotel COURTYARD by Marriott, Regensburg
17./18.9.2012

Workshop
Polymerverguss in Elektrik und Elektronik
SKZ Weiterbildungszentrum, Würzburg
7./8.11.2012

Conference
CELLMAT 2012
Fraunhofer-Institutszentrum, Dresden
7.–9.11.2012

Workshop
EAB-Refresher
Fortbildung für DVS®/ EWF-Klebpraktiker
Fraunhofer IFAM, Bremen
14./15.11.2012

SCIENTIFIC PUBLICATIONS

Ph.D. theses

M. F. Rehan
Immobilization of Active Compounds on Polymer Surfaces after Plasma Activation
Universität Bremen

Experts:
Priv.-Doz. Dr. Andreas Hartwig
Prof. Dr. Dieter Wöhrle
Thesis defense:
18.7.2012

K. Richter
Peptidbasierte Materialentwicklung
Universität Bremen

Experts:
Priv.-Doz. Dr. Andreas Hartwig
Prof. Dr. Franz-Peter Montforts
Thesis defense:
26.7.2012

G. Patzelt
Untersuchung des Vernetzungs- und Alterungsverhaltens von Klebstoffen mittels elektrochemischer Impedanzspektroskopie
Universität Bremen

Experts:
Priv.-Doz. Dr. Andreas Hartwig
Prof. Dr. Marcus Bäumer
Thesis defense:
9.11.2012

S. Vasić
Herstellung und in-situ-Charakterisierung von Katalysator-Sputterschichten sowie deren elektrochemische Leistungsfähigkeit in Polymer-Elektrolytmembran-Brennstoffzellen
Universität Bremen

Experts:
Prof. Dr.-Ing. M. Busse
Prof. Dr.-Ing. J. Thöming
Thesis defense:
23.11.2012

S. Lösch
Agglomeration von Nickel-Nanopartikeln in einem thermisch erzeugten Nickel-Aerosol unter Gravitation und Mikrogravitation
Universität Bremen

Experts:
Prof. Dr.-Ing. M. Busse
Prof. Dr. C. Lämmerzahl
Thesis defense:
7.12.2012

G. Graßl
Entwicklung und Bewertung plasmapolymerer Trennschichten für die Entformung von CFK-Bauteilen im Flugzeugbau
Universität Bremen

Experts:
Prof. Dr. Bernd Mayer
Prof. Dr.-Ing. Wolfgang Hintze
Thesis defense:
14.12.2012

Lectures

M. Busse, B. H. Günther
Funktionswerkstoffe im Automobilbau
Universität Bremen
Summer 2012

S. Dieckhoff, M. Noeske, U. Lommatzsch, T. Fladung, M. Burchardt
Oberflächentechnik
Hochschule Bremerhaven
Summer 2012

H. Fricke
Simultaneous Engineering and Rapid Prototyping
Hochschule Bremen
Winter 2012/2013

I. Grunwald
Proteomics in Practice
Universität Bremen
Summer 2012

I. Grunwald, R. Dringen
Bioorganic Chemistry
Universität Bremen
Winter 2012/2013

A. Hartwig
Makromolekulare Chemie – Grundlagen
Universität Bremen
Summer 2012

A. Hartwig
Makromolekulare Chemie und supramolekulare Chemie der Polymere für Fortgeschrittene
Universität Bremen
Summer 2012

A. Hartwig
Mitarbeiterseminar Oberflächen und Polymere
Universität Bremen
Summer 2012

A. Hartwig
Vertiefungspraktikum Makromolekulare Chemie
Universität Bremen
Summer 2012

A. Hartwig
Chemisches Kolloquium
Universität Bremen
Winter 2012/2013

A. Hartwig
Mitarbeiterseminar Oberflächen und Polymere
Universität Bremen
Winter 2012/2013

A. Hartwig, M. Bäumer, P. Swiderek, T. M. Gesing, W. Dreher
Festkörper- und Oberflächenanalytik
Universität Bremen
Winter 2012/2013

A. Hartwig, P. Spiteller, J. Beckmann, F.-P. Montforts
Integriertes Syntesepraktikum
Universität Bremen
Winter 2012/2013

B. Kieback
Pulvermetallurgie und Sinterwerkstoffe II
Technische Universität Dresden
Summer 2012

B. Kieback
Festkörperchemie II
Technische Universität Dresden
Summer 2012

B. Kieback
Technologien zur Werkstoffherstellung und -verarbeitung
Technische Universität Dresden
Winter 2012/2013

B. Kieback
Festkörperchemie I
Technische Universität Dresden
Winter 2012/2013

B. Kieback
Pulvermetallurgie und Sinterwerkstoffe I
Technische Universität Dresden
Winter 2012/2013

B. Kieback, T. Schubert
Verbundwerkstoffe
Technische Universität Dresden
Summer 2012

S. Lösch
Technische Mechanik
Hochschule Bremen
Winter 2012/2013

B. Mayer
Blockpraktikum Polymere
Universität Bremen
Summer 2012

B. Mayer
Kleben und Hybridfügen
Universität Bremen
Summer 2012

B. Mayer
Werkstofftechnik – Polymere
Universität Bremen
Winter 2012/2013

J. Meinert
Technische Thermodynamik
Dresden International University
Summer 2012

U. Meyer
Angewandte Mathematik
Hochschule Bremen
Summer 2012

U. Meyer
Festigkeitslehre II
Hochschule Bremen
Summer 2012

U. Meyer
Festigkeitslehre I
Hochschule Bremen
Winter 2012/2013

U. Meyer
Grundlagen der Mathematik
Hochschule Bremen
Winter 2012/2013

F. Petzoldt
Produktionsorientierte medizinische Prozessketten
Hochschule Bremerhaven
Winter 2012/2013

F. Petzoldt, M. Busse
Endformnahe Fertigungstechnologien II
Universität Bremen
Summer 2012

F. Petzoldt, M. Busse
Endformnahe Fertigungstechnologien I
Universität Bremen
Winter 2012/2013

P. Plagemann
Elektrochemie
Universität Bremen
Summer 2012

P. Plagemann
Korrosion
Hochschule Bremerhaven
Summer 2012

M. Popp, M. Noeske
Strukturelles Kleben
Hochschule Bremerhaven
Summer 2012

J. Weise, S. Lösch
Werkstoffwissenschaft/
Mechanik
Hochschule Bremen
Winter 2012/2013

T. Weißgärber, B. Kieback
Werkstoffe der Energie-
technik II
Technische Universität
Dresden
Winter 2012/2013

Publications

M. Amkreutz, Y. Wilke, M. Hoffmann
Simulierte Vernetzung – Vorhersage des Einflusses der Netzwerkstruktur auf die mechanischen Eigenschaften von UV-Lacken
Farbe & Lack 5, 2012, 28–33

O. Andersen, S. Kaina, T. Studnitzky, G. Stephani, C. Saame, J. Münchhoff, R. Mayer, B. Kieback
Multi-material brake disc concept utilising 3D wire structures for weight savings and improved venting behaviour
Proceedings EuroBrake 2012, Dresden, 16.–18.4.2012

O. Andersen, C. Liebert, C. Kostmann, G. Stephani
Manufacturing and joining of advanced metallic filter media for demanding environments
Proceedings 11th World Filtration Congress Graz, Graz, Austria, 16.–20.4.2012

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EDITORIAL NOTES

Directors

Prof. Dr.-Ing. Matthias Busse
Shaping and Functional Materials
Phone +49 421 2246-100
Fax +49 421 2246-300
info@ifam.fraunhofer.de

Prof. Dr. rer. nat. Bernd Mayer
Adhesive Bonding Technology and Surfaces
Phone +49 421 2246-419
Fax +49 421 2246-430
ktinfo@ifam.fraunhofer.de

Bremen

Fraunhofer Institute for Manufacturing Technology and
Advanced Materials IFAM
Wiener Strasse 12
28359 Bremen / Germany
Phone +49 421 2246-0
www.ifam.fraunhofer.de

Dresden Branch

Fraunhofer Institute for Manufacturing Technology and
Advanced Materials IFAM
Winterbergstrasse 28
01277 Dresden/Germany
Phone +49 351 2537-300
www.ifam-dd.fraunhofer.de

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Editorial team

Anne-Grete Becker
Jennifer Dillon
Karsten Hülsemann
Cornelia Müller
Martina Ohle
Stephanie Uhlich

External service providers

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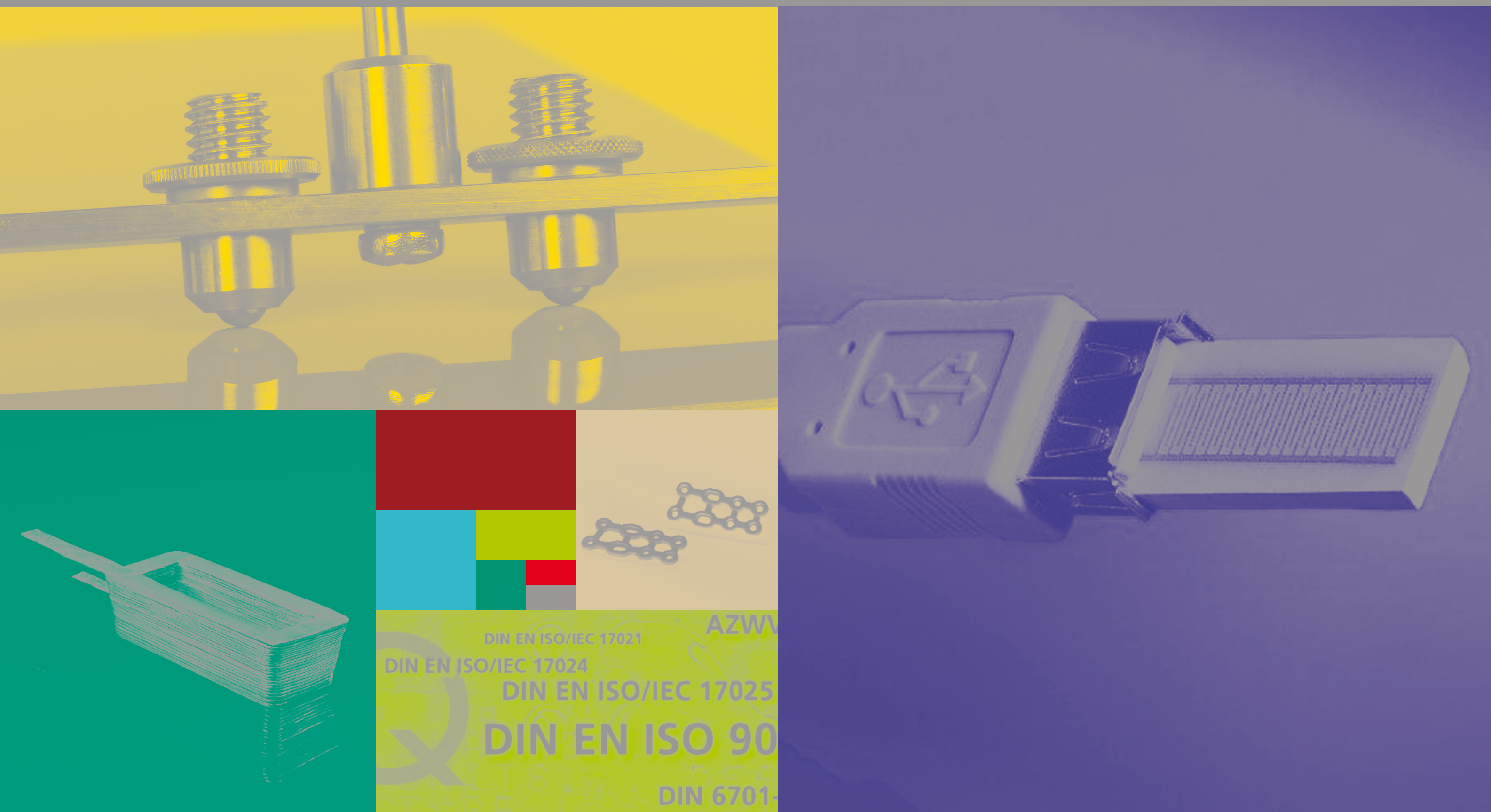

Fraunhofer Institute for
Manufacturing Technology and
Advanced Materials IFAM
Wiener Strasse 12
28359 Bremen | Germany
info@ifam.fraunhofer.de