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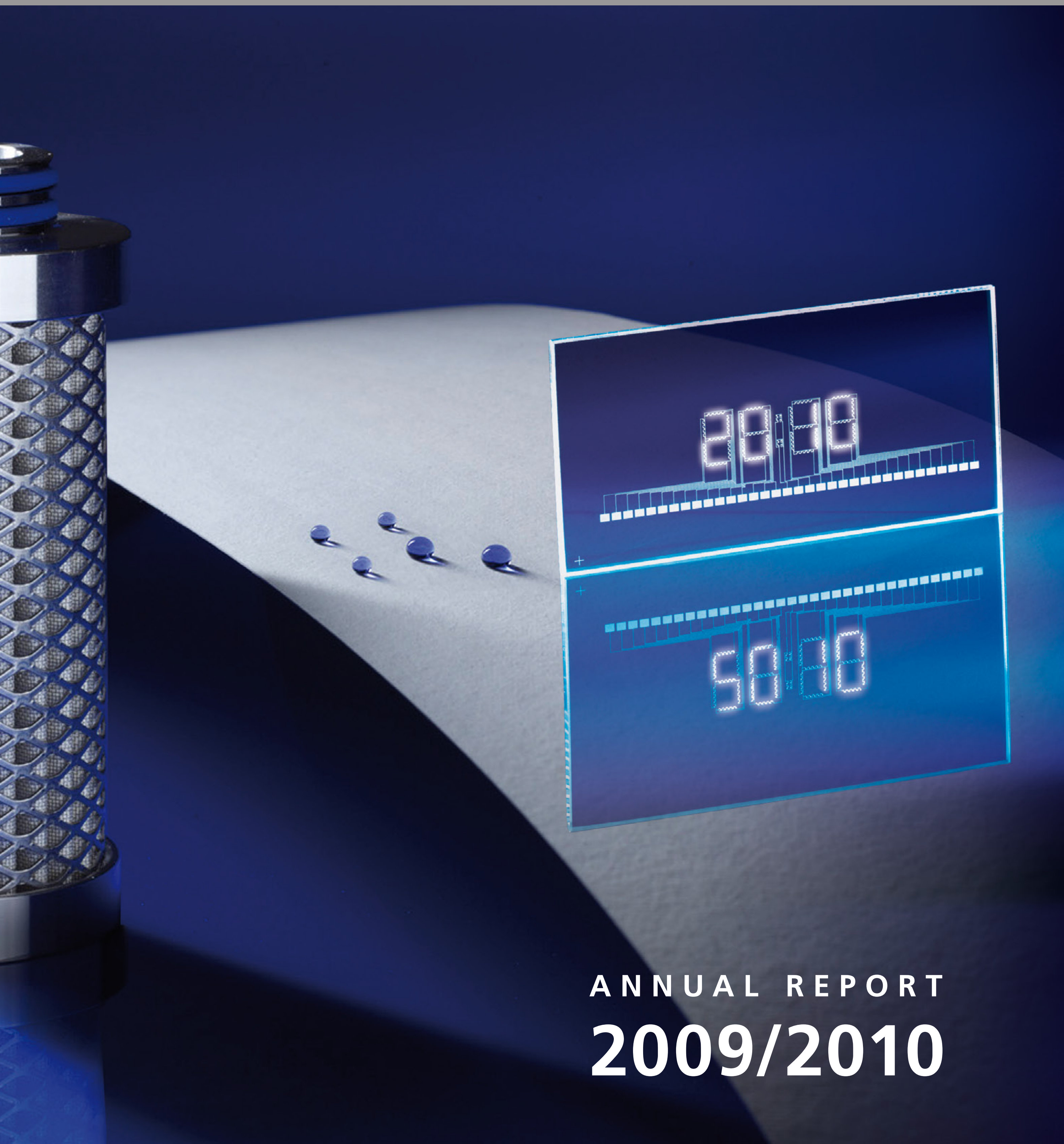
IFAM

FRAUNHOFER INSTITUTE FOR MANUFACTURING TECHNOLOGY AND ADVANCED MATERIALS IFAM



ANNUAL REPORT

2009/2010

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PREFACE

Ladies and gentlemen,
business associates and research partners,
sponsors of Fraunhofer IFAM,

Coming out of the crises stronger than before, breaking new ground, benefiting from opportunities – these were the slogans in 2009 in the context of the biggest crisis in the economy and the financial markets in decades. As a provider of research services for the industry and the public authorities, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM was not unaffected by the economic upheaval. On the contrary, the consequences were felt in many sectors. We are thus all the more pleased now to be able to show a positive balance sheet for the past business year: We have left the crisis behind us, and we are in a stronger position now. We are breaking new ground; we are seizing opportunities as they arise. Thus, 2009 was a successful year for the institute.

The strained economic situation manifested itself mainly in the fact that many companies were reluctant to invest. Consequently, the number of orders from industry declined. However, this decline was more than compensated for on another front: Fraunhofer IFAM is involved in a number of current research programs that are financed by public money. The policy strategy to increase growth and to propel modernization through the economic stimulus plans I and II also entails the strengthening of application-oriented research. At IFAM, we generate knowledge that can be quickly transformed into sustainable, competitive products. Thanks to its wide portfolio and comprehensive know-how, Fraunhofer IFAM was able to raise funds in many public tender offers. In addition to these activities, we continued to work on many projects with long-term partners, so that Fraunhofer IFAM was able to grow even in 2009.

Our growth has been continuous for many years and is a hallmark of our success. However, as a result of this development, we have once again reached the limits of our available space. We are not only temporarily renting external areas, but are also accelerating the planned construction of further sectors of the institute. Despite all of our expansion efforts, we still keep a sense of proportion when recruiting additional personnel. It is essential for us to hire people sustainably – we want to guarantee new jobs with a long-term perspective.

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Electric mobility is one of the most important issues we are working on at Fraunhofer IFAM. In many domains, the institute's department of Shaping and Functional Materials has taken the lead. Thus, for instance, in the project "Systems Research Electric Mobility", 34 Fraunhofer Institutes are working together to explore ways to align the development of all of the steps in the value added chain of electric mobility. In this process, Fraunhofer IFAM is coordinating the fabrication of prototypes and the engineering of wheel hub motors. Another focus is on projects in the "e-mobility region of NordWest Bremen/Oldenburg" – one of eight model regions selected out of 130 candidates by the federal ministry of transportation, building and urban development. The task is to build a fleet of electromobiles in the model region – from the e-bicycle to multi-seat commuter vehicles to hybrid busses. Since the beginning of January 2010, there has been an IFAM working group in Oldenburg, which is refining the performance of batteries for electro-mobiles – one of the key topics in this sector – together with partners.

All of these facts show that with electric mobility, the institute has established a new, sustainable field of activity in which Fraunhofer IFAM can fully demonstrate its know-how. The expertise of the department of Adhesive Bonding Technology and Surfaces, in particular in the field of electrochemistry, is included here. There is also a significant potential for synergistic overlaps with the already existing IFAM activity fields related to marine technology and wind energy.

Continuation of the work on the innovation cluster "Multifunctional Materials and Technologies" (MultiMaT) was another focus in 2009. Within the five pilot projects, together with enterprises from industry, we are implementing and realizing the integration of sensors and functional surfaces and are tackling problems in joining fiber composite structures in concrete applications. All of the projects progressed on schedule. Superregional partners are and will be involved to a greater extent. However, since the industrial enterprises were somewhat cautious in their investment in research, we had to put forth considerable effort to convince them to build networks and to attract additional partners in 2009.

Activities within the scope of the European aviation research program "Clean Sky" were and still are one of the outstanding tasks for Fraunhofer IFAM – in particular for the department of Adhesive Bonding Technology and Surfaces. Taking part in different projects aimed at sustainable promotion of environmental compatibility and competitiveness of European aviation led to a much higher level of interaction with this business. As a result, in addition to our close and successful cooperation with Airbus, we succeeded in establishing new – and strengthening existing – contacts with other aircraft and part manufacturers. Acquisition potential has been significantly increased by these contacts. Another success is the cooperation with partners from the wind energy sector. There is considerable overlap in this business as a result of both the cooperation with the Fraunhofer Institute for Wind Energy and Energy System Technology IWES in Bremerhaven and our comprehensive, detailed knowledge in many fields connected with building and operating on- and offshore wind turbine plants. Successful cooperation with the maritime engineering field demonstrates how we use expertise from the department of Adhesive Bonding Technologies and Surfaces in new business lines. Thus, for instance, the objective of the project "HAI-TECH" is to reduce drag resistance of ships by functional coatings.

The establishment of the Research Center CFRP North in Stade, which will open in mid 2010, is also a major milestone for the department of Adhesive Bonding Technologies and Surfaces. For the first time, large-sized components made of carbon fiber reinforced plastics for the aircraft industry can be joined, assembled, machined and tested in a non-destructive way on a 1:1 scale. In this context, the development of new production processes and equipment – even for other businesses like building means for transportation and wind turbines – are central topics. For the Research Center CFRP North in Stade, Fraunhofer IFAM has already founded its own Project Group Joining and Assembly FFM.

The IFAM department of Powder Metallurgy and Composite Materials, which is situated in Dresden, has also been growing continuously. Through the promotional program "Fraunhofer Attract", we succeeded in attracting the next generation of excellent scientists to establish a new working group. This group is, among other things, involved in research into the storage of hydrogen. This topic is relevant both for stationary and mobile applications, again bridging the gap to electric mobility.

In 2009, creative cooperation with scientific institutes in the Technology Park and at the University of Bremen continued. Interdisciplinary research on "sensorial materials" has been integrated into the newly established central scientific facility "Integrated Solutions in Sensorial Structure Engineering" (ISIS) since May 2009. Scientists from Fraunhofer IFAM are heavily involved in this activity. Total coordination of ISIS is performed in personal union by the managing director of the Fraunhofer IFAM. One of the objectives is to concentrate and develop the know-how from Bremen in this sector in such a way that more comprehensive public funding for this highly interesting future-oriented topic can be obtained.

For Fraunhofer IFAM, the future will also bring yet a stronger consolidation of the cooperation with the university, resulting from the replacement of the institute director of the department of Adhesive Bonding Technology and Surfaces in the course of 2010, which we are looking forward to. The position is also combined with a university professorship in the Production Engineering department.

Day after day, our personnel do concentrated and excellent work under tight basic conditions. In sports, sometimes, it is the readiness to go the extra step that finally helps a team to victory. Likewise in our teams, it is often admirable commitment that leads to success. Therefore we would like to express our gratitude to all our colleagues whose scientific activities are documented in all the project and trend reports in this publication.

We hope that you enjoy reading this annual report.

Matthias Busse

Andreas Hartwig

1 Director (executive)
Shaping and Functional Materials
Prof. Dr.-Ing. Matthias Busse.
2 Director
Adhesive Bonding Technology and Surfaces
Priv.-Doz. Dr. Andreas Hartwig.

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A PROFILE OF THE INSTITUTE

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM is active in research and development in the fields of

Shaping and Functional Materials

The Shaping and Functional Materials Division of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, with its facilities in Bremen and Dresden, develops innovative materials and adapts and improves existing manufacturing processes. Our R&D work ranges from material engineering, shaping and manufacturing technologies to functionalizing components and systems. We develop individual solutions for customers in various industrial sectors including automotive industry, medical technology, aviation and aerospace, mechanical, electrical and environmental engineering, as well as the electronics industry.

In the area of shaping the focus is on the cost- and resource-efficient production of increasingly complex-shaped, or miniature precision components. Using innovative manufacturing processes in both powder and casting technology, we give additional functionality to components.

Our offer includes component design and optimization, computer simulation of shaping processes as well as technical implementation in the industrial production and providing the related training for customer staff.

Our R&D activities on functional materials deal with improving the properties and processing of materials. Functional materials can either be directly integrated into components during the manufacturing process or applied later by printing or sputtering them onto the components' surfaces. They provide additional or completely new characteristics, for example electronic or sensory functions. Cellular materials have special properties that are in demand for energy absorption, noise absorption and heat exchangers. Additional research focuses on biomaterials made from metals, ceramics or polymers and their biological interaction with the environment.

Based on these two areas of expertise, we are expanding into the new application field of electric mobility, with a special focus on energy storage and electrical power trains. Analyzing, testing, evaluating and optimizing the complete system is the main objective of our work.

Adhesive Bonding Technology and Surfaces

The Department of Adhesive Bonding Technology and Surfaces provides industry with qualified products and processes in the area of adhesive bonding technology, plasma technology, and paint/lacquer technology.

The R&D services of the department are sought after by a large number of partners coming from diverse sectors of industry. At present main customers are the transport sector – manufacturers of aircraft, cars, rail vehicles, ships – as well as their suppliers, machine and plant construction, energy technology, the packaging sector, textile industry, electronics industry, microsystem engineering, and medical technology.

The work of the Adhesive Bonding Technology business unit is subdivided into Adhesives and Polymer Chemistry (synthetic materials, protein materials), Adhesive Bonding Technology (microsystem technology and medical technology, adhesives and analysis, process development and simulation, application methods), Material Science and Mechanical Engineering

(structural calculations and numerical simulation, mechanical joining technology), Joining and Assembly of large fiber reinforced plastic structures on a 1:1 scale, as well as the Certification Body of the Federal Railway Authority in accordance with DIN 6701-2.

The Surfaces business unit covers Plasma Technology (low pressure plasma technology, atmospheric pressure plasma technology, and plant technology/plant construction) and also Paint/Lacquer Technology (development of coating materials as well as application technology and process engineering).

These two business units are complemented by the Adhesion and Interface Research business unit – surface and nanostructure analysis, applied computational chemistry, electrochemistry/corrosion protection, and quality assurance of surfaces.

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

Competence network at Fraunhofer IFAM

Shaping and Functional Materials

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

Adhesive Bonding Technology and Surfaces

- Certification Body of the Federal Railway Authority in Accordance with DIN 6701-2
- Adhesion and Interface Research
- Adhesive Bonding Technology
- Adhesives and Polymer Chemistry
- Business Field Development
- Fraunhofer Project Group Joining and Assembly FFM
- Material Science and Mechanical Engiineering
- Paint/Lacquer Technology
- Plasma Technology and Surfaces PLATO
- Process Reviews
- Workforce Training and Technology Transfer

BRIEF OVERVIEW AND ORGANIGRAM

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM was founded as a working group for Applied Materials Research in 1968. In 1974, it was incorporated as an institute into the Fraunhofer-Gesellschaft. Established as an institute for contract research with new emphases on systematic extension, Fraunhofer IFAM works closely with the University of Bremen. The directors of the institute are also appointed to chairs as full professors at the university of Bremen in the Production Engineering department. The institute has locations in Bremen and Dresden.

Prof. Dr.-Ing. Matthias Busse took up his position in the institute´s management and as director of the Shaping and Functional Materials department in 2003.

From 2007 to May 2009, Dr.-Ing. Helmut Schäfer was member of the management of the institute and acted as the director of the department of Adhesive Bonding Technologies and Surfaces.

In June 2009, Priv.-Doz. Dr. Andreas Hartwig, the deputy director since 2007, became director of the department of Adhesive Bonding Technology and Surfaces, and since that time has been part of the institute management.

As a neutral and autonomous facility, the institute is recognized as one of the largest European technical facilities in the fields of Shaping and Functional Materials, as well as in Adhesive Bonding Technology and Surfaces.

In 2009, the overall IFAM budget amounted to approximately 29.5 million euros. The institute employed 422 people, among them 91 percent in the scientific-engineering sector.

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM

Shaping and Functional Materials

Prof. Dr.-Ing. Matthias Busse
Director (executive)
Shaping and Functional Materials

Dr.-Ing. Frank Petzoldt
Deputy director

Prof. Dr.-Ing. Bernd Kieback
Head of the Dresden branch

Adhesive Bonding Technology and Surfaces

Priv.-Doz. Dr. Andreas Hartwig
Director
Adhesive Bonding Technology and Surfaces

Dr. Stefan Dieckhoff
Deputy director

Dipl.-Oec. Alexander Busk
Head of Administration

THE INSTITUTE IN FIGURES

The overall budget of Fraunhofer IFAM (expenditures and investment) in 2009 is composed of the budgets of the departments of Shaping and Functional Materials, as well as the department of Adhesive Bonding Technology and Surfaces. Since Fraunhofer CWMT has been functioning as an autonomous institute since 2009 (Fraunhofer IWES), the budget of Fraunhofer IFAM is represented without CWMT's results for the first time.

Budget

The preliminary budget totaled 29.5 million euros. The individual departments achieved the results given below:

Shaping and Functional Matrials Bremen

Operating budget (BHH)	6.9 million euros
Own income	4.4 million euros
Including	
Business income	2.0 million euros
Federal/state/EU/other	2.4 million euros
Investment budget (IHH)	0.6 million euros

Shaping and Functional Materials Dresden

Operating budget (BHH)	3.8 million euros
Own income	2.8 million euros
Including	
Business income	1.0 million euros
Federal/state/EU/other	1.8 million euros
Investment budget (IHH)	0.4 million euros

Adhesive Bonding Technology and Surfaces Bremen

Operating budget (BHH)	15.7 million euros
Own income	11.5 million euros
Including	
Business income	6.5 million euros
Federal/state/EU/other	5.0 million euros
Investment budget (IHH)	2.1 million euros

INVESTMENT

During 2009, investments made by the Fraunhofer IFAM amounted to 6.1 million euros, split among the various sites as given below. The most important purchases are indicated. Due to grants from the economic stimulus plan, the investment for the department of Shaping and Functional Materials, Bremen, totaled at 1.4 million euros, and in Dresden at 1.6 million euros.

Shaping and Functional Materials Bremen
Investment budget (0.6 million euros)

- Extruder for conductive plastics
- Polystyrene foam mold (made of aluminum)
- Microinjection molds for geometric forming elements
- Mold for implant manufacturing
- Air-conditioned cabinet for long-term stability tests on printed sensor structures

Investment from the economic stimulus plan (1.4 million euros)

- Hysteresis effect scriber
- Test bench for developing electrical power trains
- Inert gas system glove box

Shaping and Functional Materials Dresden
Investment budget (0.4 million euros)

- Regeneration of a molybdenum high temperature vacuum furnace
- Universal testing machine
- Laboratory mixer

Investment from the economic stimulus plan (0.9 million euros)

- Spark Plasma sintering system
- Transistor - high frequency generator
- Measuring station based on the Seebeck effect

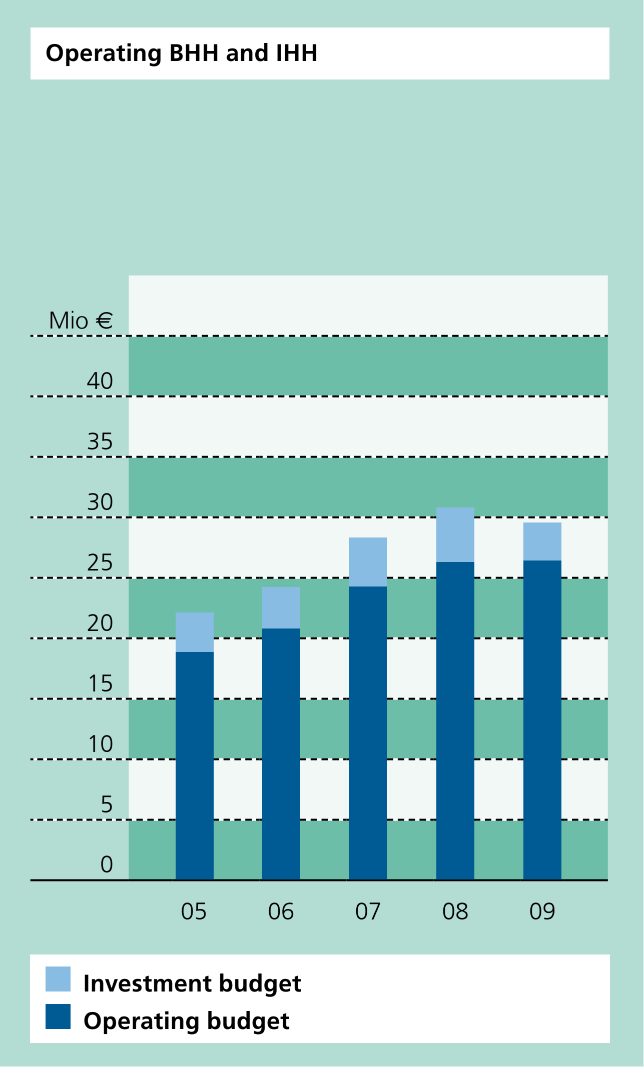
Investment from EFRE (European fund for regional development) grants of Saxony (0.7 million euros)

- Q-MACS quantum cascade laser
- Gas analysis system
- FTIR gas analyzer
- X ray diffractometer

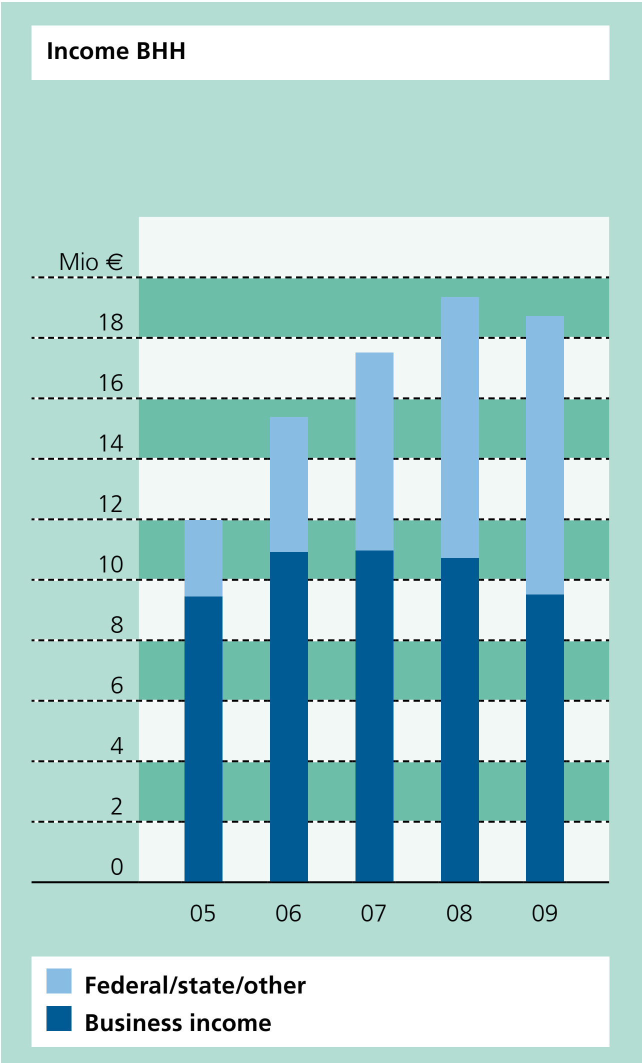
Adhesive Bonding Technology and Surfaces Bremen
Investment budget (2.1 million euros)

- Olympus OmniScan MX PA measuring device (ultrasound)
- System for plasma-enhanced layer deposition (thick layers) on web materials
- High vacuum reactor for plasma activation
- Mobile laser unit for pre-treatment of surfaces
- CO_2 snow jet system for pre-treatment of surfaces
- Confocal laser microscope
- Multiple potentiostat
- IR hand held equipment (Exoscan)

TREND IN OPERATING BUDGET AND INVESTMENT BUDGET



GROWTH IN EARNINGS OPERATING BUDGET



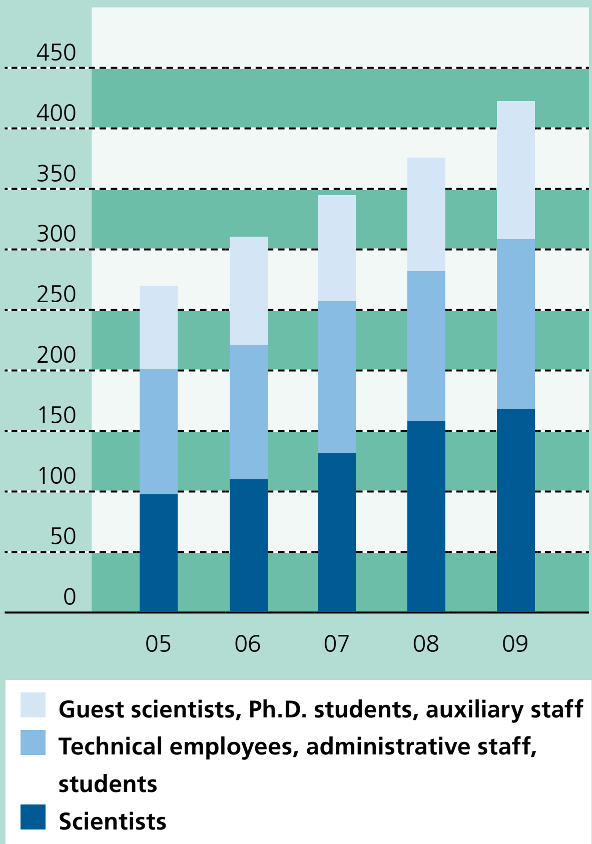
PERSONNEL DEVELOPMENT

On December 31, 2009, in total 422 people (including 91 percent in the scientific-engineering sector) were employed by Fraunhofer IFAM. In comparison with the previous year, the number of permanent employees grew by 6.6 percent.

Personnel structure 2009

Scientists	168
Technical employees	102
Administration/internal services and trainees	38
Ph.D. students, students in internships, and assitants	114
Total	422

Workforce



Remark: *Fraunhofer CWMT (now Fraunhofer IWES) has been acting autonomously since January 1, 2009. The institute was allocated with 19 employees up to December 31, 2008. The growth of 6.6 percent was calculated without taking into account the Fraunhofer CWMT. In 2009, the section FFM Stade was established, which has been registered as Fraunhofer Project Group Joining and Assembly FFM Stade since January 1, 2010.*

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RESEARCH FOR KEY TECHNOLOGIES IN STRATEGIC ALLIANCES

In 2009, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM continued its long-standing upward trend and is on a road to success that offers a pleasant change from last year's general economic development in Germany.

This extremely positive situation is the result of continuous and consistent development of research activities in all departments and an increasingly strategic orientation of the institute towards future key technologies. Recent projects in the fields of new electrical driving systems and electric mobility typify this trend. Exploration and utilization of the technologies required therein are extremely important for Germany, and it is exemplary that, as a result of the initiative and significant role of Fraunhofer IFAM, efficient and future-oriented competence clusters, which may open up essential future business areas, are being created in Northern Germany.

In terms of industry, 2009 was characterized by a strong recession in sales resulting in significant losses. Even at this stage, it became clear that sustainable competitiveness can only be ensured by intensive research and development activities, as well as by long-term strategies and investment. On the part of policy, the extent of the crisis in the economy and financial markets was recognized at an early date, which accelerated the adoption of comprehensive research programs, such as the economic stimulus plans I/II. Due to the short tendering periods, quick action was necessary on the part of the research facilities. Consequently, successful applicants were usually those who had already established subject-specific clusters with industrial firms and developed convincing concepts.

In networks with its scientific and industrial partners, Fraunhofer IFAM was successful in the acquisition of several large projects. Thus, the "Model Region NordWest", founded as one of eight German regions by the federal ministry for transportation, construction and urban development (BMVBS), was selected to explore holistic mobility concepts based on electric vehicles. This initiative, which was primarily coordinated by Fraunhofer IFAM, is an essential strategic development of the line of action, since it represents an ideal platform for transfer and tryout of those technologies, which are being investigated within the scope of "Fraunhofer Systems Research Electric Mobility", begun in 2009, in a network consisting of more than 30 Fraunhofer institutes. Within this context, another highlight of 2009 was the inauguration of the IFAM project group dealing with the development of electrical energy storages as a strategic partnership with the EWE Research Center for Energy Technology at the University of Oldenburg. This network will provide new technological impetus, which is urgently needed to implement mobility concepts based on vehicles driven by electrical motors.

As these examples demonstrate, Fraunhofer IFAM is integrating itself to a greater and greater extent as a leading institute in broader networks in order to create the preconditions for the collective development of system competences for sophisticated technologies. The main issues of research and the new strategic alliances of Fraunhofer IFAM offer optimal preconditions for a further consolidation of its strong position within the Fraunhofer-Gesellschaft and the national/international research community as a whole. As a trustee, I am convinced that the path we have opened up will lead to many other successes in 2010.

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1 *Dr. K. Dröder, Member of the Advisory Board Volkswagen AG, Wolfsburg.*

THE FRAUNHOFER-GESELLSCHAFT

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

At present, the Fraunhofer-Gesellschaft maintains more than 80 research units in Germany, including 59 Fraunhofer Institutes. The majority of the 17,000 staff are qualified scientists and engineers, who work with an annual research budget of € 1.6 billion. Of this sum, more than € 1.3 billion is generated through contract research. Two thirds of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Only one third 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 research centers and representative offices in Europe, the USA and Asia provide contact with the regions of greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

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

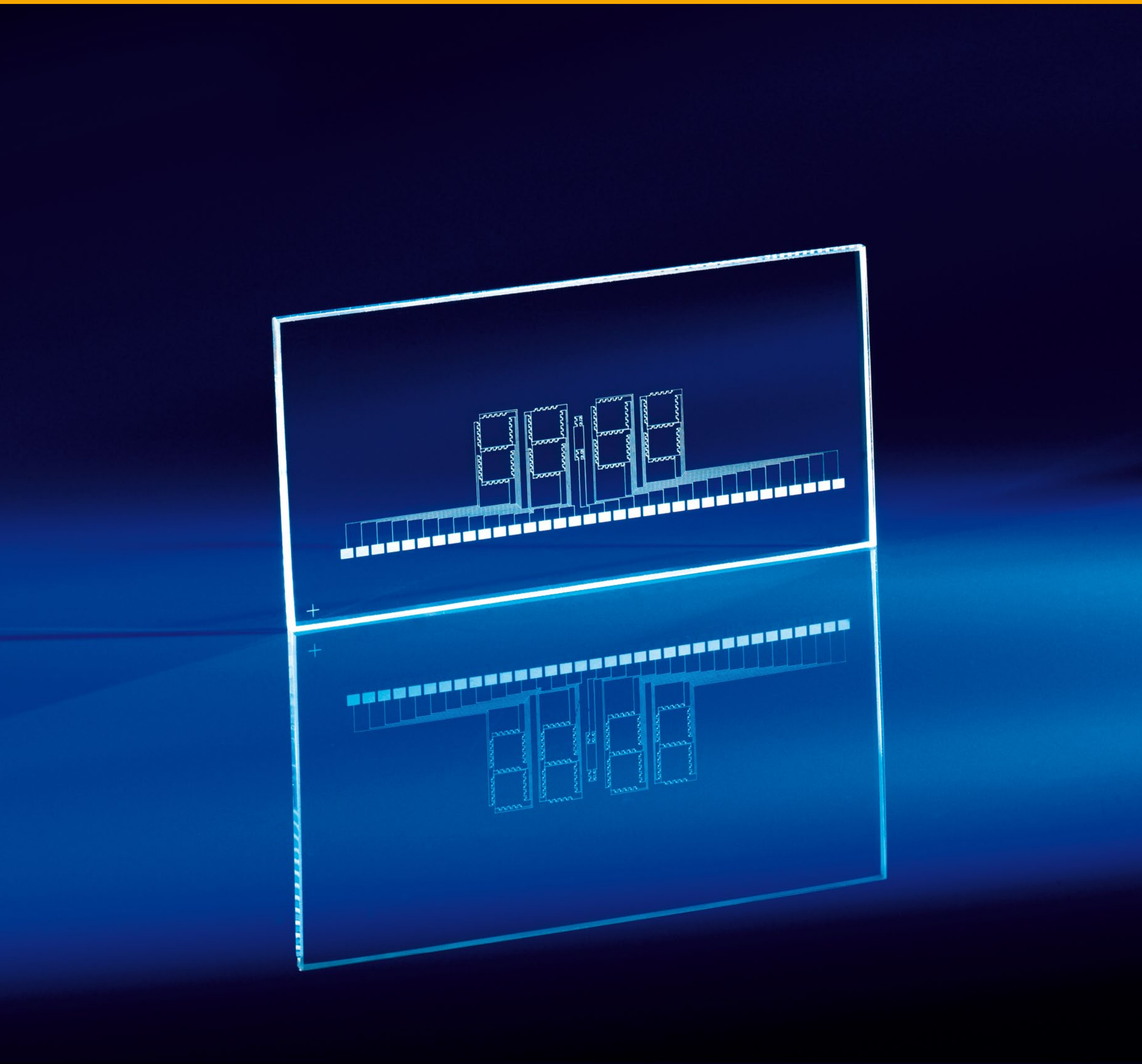
The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

1 *The Fraunhofer truck was located in the Technology Park of Bremen from September 15 to 17, 2009.*

Institutes and facilities.

Other locations.

SHAPING AND FUNCTIONAL MATERIALS



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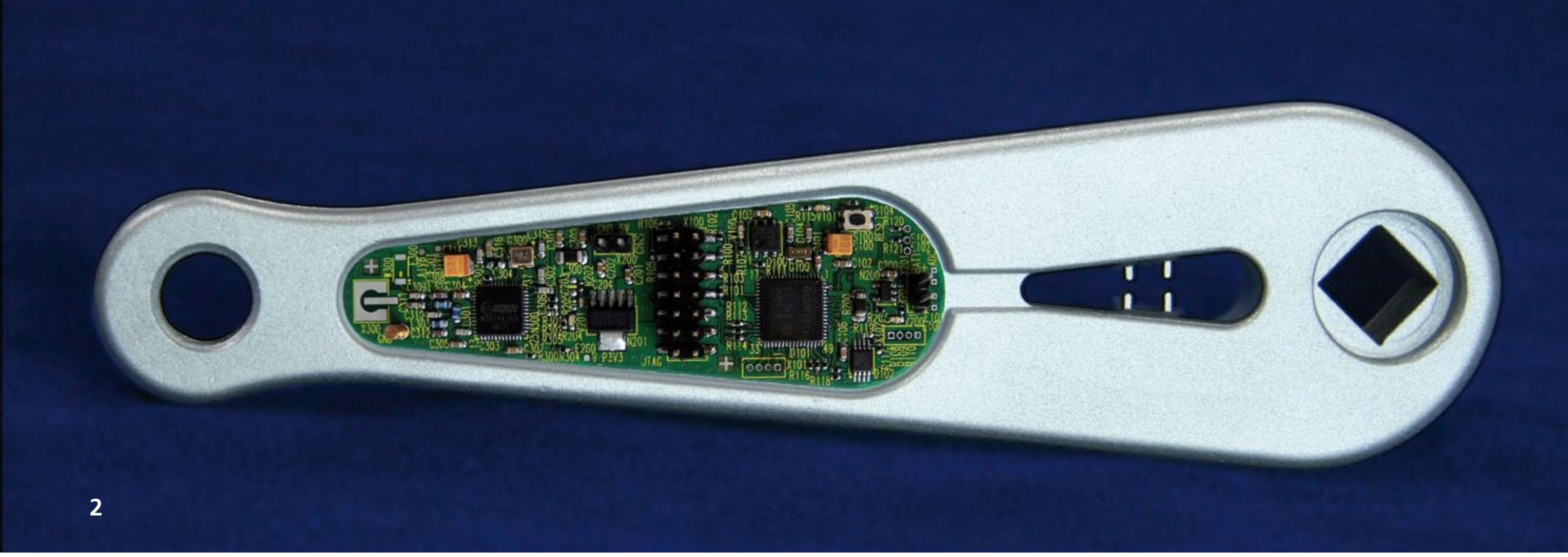

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EXPERTISE AND KNOW-HOW

When developing complex system solutions, networks of partners from industry and research facilities play an important part. In this process, especially at the interfaces between very different disciplines, methodological expertise and excellent technical knowledge are crucial. The expertise of all of the personnel at Fraunhofer IFAM, combined with our network of partners from industry and science, guarantees innovative solutions for industry.

The transfer of application-oriented fundamental research to solutions that can be implemented in production engineering or component engineering entails tasks that demand a continuous extension of the knowledge base and methodological expertise. For this reason, ongoing refinement of specific competences and know-how at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials – Shaping and Functional Materials – is of great significance.

Our research and development activities rage from application-oriented fundamental research up to the implementation in products and support during the initial stages of production.

Multifunctional components with integrated sensor functions make specific demands on the materials used. When various materials are combined in one component, it is possible to locally customize properties. A significant objective to extend this expertise involves desiging these material combinations and working with them in manufacturing processes. The scope ranges from material combinations metal–metal, metal–ceramics to combinations with carbon fiber reinforced plastics (CFRPs).

Manufacturing techniques like injection molding are presently applied in the production of geometrically demanding components made of numerous metallic alloys and ceramic materials. We now have succeeded in applying distinct materials' characteristics to specific locations on the component. Thus, for instance, it is possible to perform customized integration of material characteristics, such as hard–soft, dense–porous materials, or to integrate materials with sensory functions or even expensive and cheap materials, into components. These development trends are relevant to the manufacturing of microcomponents, where integrated manufacturing solutions make it possible to avoid microassembly.

Research into the formulation of functional inks and pastes, as well as their applications in components was done primarily to contribute to the development of "INKtelligent printing®". This technology makes it possible to equip components with sensor functions and thus, for instance, to record operational or environmental conditions.

Fraunhofer IFAM is well positioned on the market with the latest casting equipment and analytics, as well as comprehensive expertise in diecasting aluminum and magnesium alloys. In addition to the optimization of casting processes with permanent molds, expertise is continuously being extended with the Lost foam casting technology. When developing the "CAST^tronics®^ technology", we follow a procedural paradigm that enables the foundries themselves to integrate functional components immediately into the casting process.

We have achieved a high level of expertise in implementing cellular metallic materials in products. Here we find special solutions for particular markets, such as the diesel particle filter. As a result, our process knowledge is constantly increasing.

Our own portfolio of research areas is constantly adapting to the requirements of the market, resulting in new technological challenges. Here, problems pertaining to product innovation under stringent economic constraints are as important as the contribution to research results aimed at improving our quality of life and providing sustainable development in the areas of transport, energy, medicine and environment.

Materials and their manufacturing/processing in all product innovations are an essential factor in our future success. This aspect should be particularly emphasized for the primary shaping methods, since in the manufacturing process, one may simultaneously affect both materials' characteristics and the component geometry. The market arising from this is growing due to greater product complexity. Material properties and technologies for structural and functional applications are tailored to the application and identified. To do this, high-performance materials, composites, gradient and smart materials are refined, while manufacturing technologies to integrate characteristics into components are under development.

Improvement of materials and expertise in the specialized realm of functional materials, such as thermal management materials, thermoelectrical and magnetocaloric materials, as well as nanocomposites, are opening up new opportunities for product development, both with previous and new customers.

Perspectives

Simulation of the entire process chain for component manufacturing is particularly important for future process and product development or refinement. The trend is to predict component properties both for castings and components made by powder metallurgy even before their production. This makes it possible to develop robust manufacturing processes and to make component production very efficient. In the field of medical engineering and biomaterials, the topics range from the Rapid Manufacturing process chain to produce individualized metallic components to specialized micro- and nanostructuring of surfaces to control the growth of bones and tissue. Here, the materials to be applied include all of the material classes, from plastics to ceramics to metals and their compounds. Projects are focused on materials and manufacturing technologies, as well as the interface between biology and material. One significant target is the refinement of process technology and methods of characterization for bioactive and bioresorbable materials.

We are exploring and utilizing the great potential arising from the direct integration of functions into metallic and CFRP components. To do this, we rely on the steadily growing expertise obtained at Fraunhofer IFAM in the process chain from material to the intelligent components. Another important paradigm results from the integration of RFID chips into metal components by means of Rapid Manufacturing. In this area, we are exploring more and more product-specific solutions for various business lines.

Quality inspections within the production process are growing interest for cyclical manufacturing processes of metallic components. To grapple with this demanding problem, we at Fraunhofer IFAM are gathering procedural expertise in order to link self-learning systems with the corresponding manufacturing technique.

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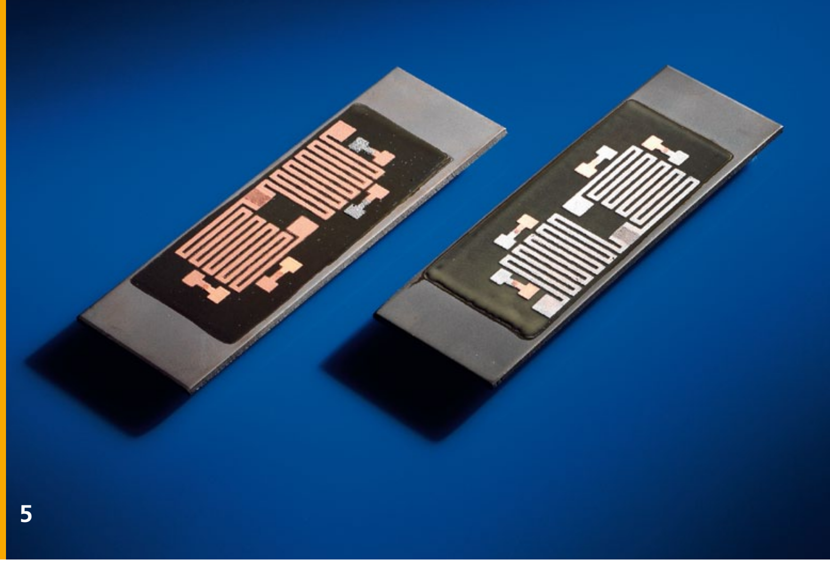

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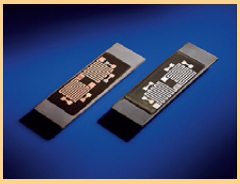
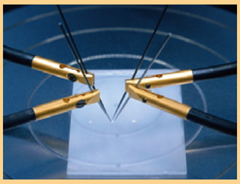
FROM MATERIAL TO RELIABLE APPLICATION

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

Competences.

A major new subject at Fraunhofer IFAM is that of electric mobility, with the central topics of energy storage, electrical drive engineering and system audit. In close cooperation with partners in the metropolitan region Nordwest, we are elaborating new battery systems. As a part of the project "Systems Research Electric Mobilty" of the Fraunhofer-Gesellschaft, the activities of the Fraunhofer IFAM are aimed at engineering magnetic materials for wheel hub motors and developing a passenger car with an electric drive. The car is intended as a prototype to integrate new components. A high performance centre to measure the complete electrical drive has already been established.

1 *Aerosol printed 7-segment display.*
2 *"CAST*TRONICS®*": Diecast pedal crank with integrated sensors and data transfer module.*
3 *Open-porous metal foams made of stainless steel 316L of 20, 45 and 60 ppi.*
4 *Interference screws, metal injection molded, used to reattach torn off cruciate ligaments in the knee.*
5 *Strain gauge made by screen printing, with thermocouples to compensate temperature (left: unsintered, right: sintered).*

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Failure analysis; examination of metallographic micrographs; powder characterization; scanning electron microscopy with EDX analysis; thermal analysis; dilatometry; trace analysis; emission spectrometry.

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EQUIPMENT/FACILITIES

Component manufacturing

- Metal injection molding units (clamping force 20 t and 40 t)
- Manufacturing cell for micro-injection molding
- Hot press (vacuum, inert gas, 1800 °C)
- Uniaxial powder presses (up to 1000 t))
- Hydraulic powder press for warm compaction (125 t)
- Extruder (5 MN)
- Rapid prototyping equipment for laser sintering of metals; conceptual models obtained via 3-D printing (also colored)
- Cold chamber diecasting machine (real time controlled, closing force 660 t)
- Warm chamber diecasting machine (real time controlled, closing force 315 t)
- Pilot plants to manufacture metal foam components
- 2-component injection molding machine
- Microwave sintering furnace
- Screen printing machine
- Modul manufacturer for Lost foam processes
- Spark plasma sintering unit (up to 300 mm part diameter)
- Styrofoam mortiser
- Hot-wire cutting unit

Micro- and nanostructuring

- Ink-jet printing technologies
- Aerosol-jet® technology
- Micromanufacturing cell
- Four-point-bend stand
- Ink test bench – drop on demand
- Sputtering technology
- Glove box system

Thermal/chemical treatment of formed pieces

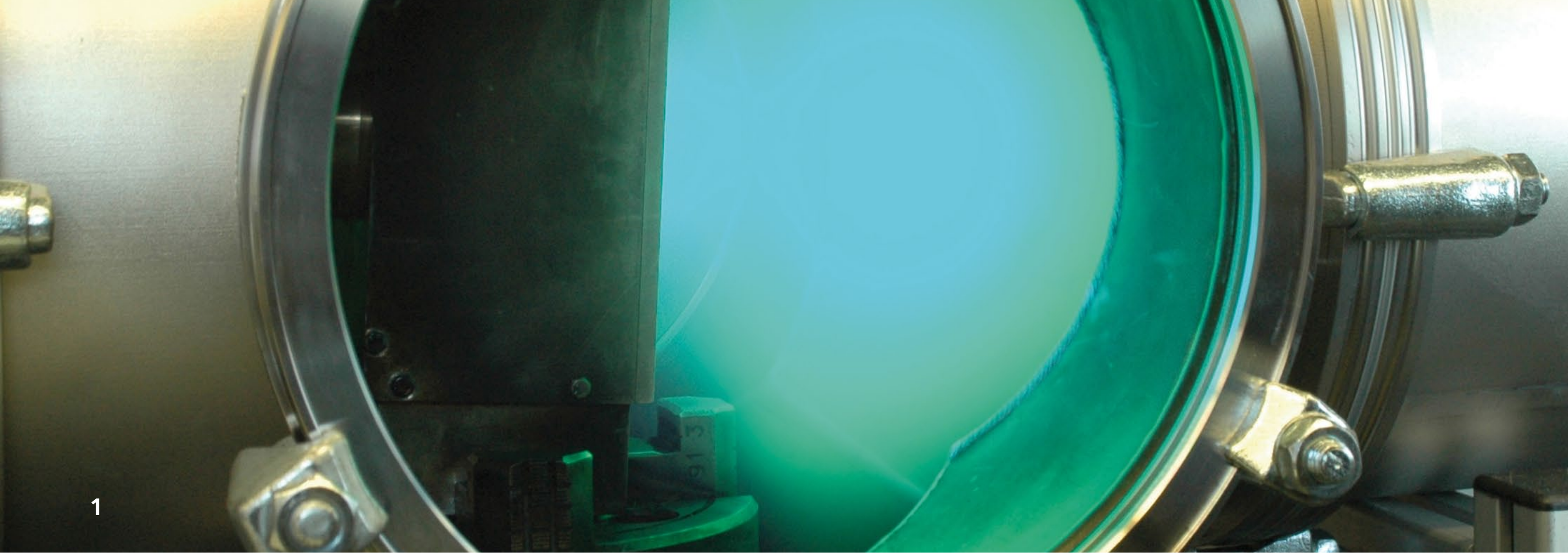
- Unit for chemical de-waxing of injection molded parts
- Various sintering furnaces (up to 2000 °C, inert gas, hydrogen, vacuum)

Material synthesis and -processing

- Systems for gradient material production (sedimentation, wet powder injection)
- Systems for metal nanopowders and nanosuspensions production
- Test bench to characterize functional inks for ink-jet printing methods
- Melt extraction unit (metal fibers)
- Centrifugal mill for high-energy milling of metal- and ceramic powders
- High-speed mixer and shear roll extruder for MIM feedstock production
- Twin-screw extruder
- Compounding unit
- Granulator

Instrumental analytics

- Rheometry
- Micro tensile testing unit
- Tensiometer
- 2-D/3-D laser surface profilometry



- Thermal conductivity measurement of molding materials
- IR laser to determine density of translucent materials
- Magnetic measuring instruments
- Electrical characterization

Certified according to DIN 9001:2008

- FE scanning electron microscope (SEM) with EDX
- X-ray absorption fine structure analysis
- Thermoanalysis with DSC, DTA, TGA
- Sinter/Alpha-dilatometer (accredited lab)
- Powder measuring equipment with BET and laser granulometry (particle size analysis)
- Trace element analysis (C, N, O, S)
- Materialography
- Emission spectrometer
- X-ray tomograph (160 kV)
- Gas permeability determination
- IR laser to determine density of translucent materials

Electric mobility

- Two engine test beds up to 100 kW
- Battery test bed up to 50 kWh

Computers

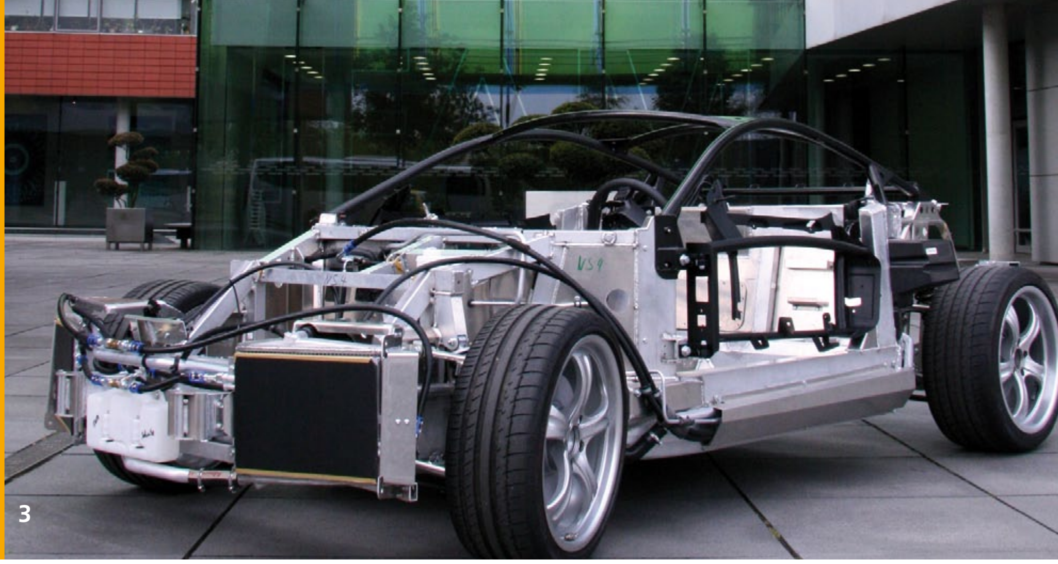
- High performance workstations with software for non-linear FE analysis, to simulate mold filling and solidification as well as component optimization

1 *Plasma of a gas flow source putter.*

SHAPING AND FUNCTIONAL MATERIALS

RESULTS FROM RESEARCH AND DEVELOPMENT

1



ELECTRIC MOBILITY MOVES

Mobilizing energies – in Germany alone, approximately one million electric cars are expected to be in use in 2020. Many crucial questions, however, remain unanswered: How can energy be generated and distributed, how can it be fed into the car and used there in an efficient manner? What materials are necessary for the batteries? How do the interfaces between the power supply system and the car function? A four pillar strategy at Fraunhofer IFAM enables a holistic approach.

Quiet and clean mobility

People need to be mobile, both to get to work and in their leisure time. We are also used to getting to our destination as fast as possible at any time, whether by motorcycle, by car or using public transportation.

The rising cost of energy and traffic in urban areas, as well as the current requirements of the modern job market will define still more extensive mobility needs for the future.

In this context, the use of electric vehicles could offer a crucial contribution to fulfilling the mobility needs, either for individuals or for public transportation. The "electric mobility" issue is highly relevant strategically for the Federal Government and was emphasized in conjunction with energy supply from sustainable sources by the Integrated Energy and Climate Programme (German abbrev. IEEAB). The task for Germany is to take a leading position in the emerging electric mobility market. Other countries, such as the USA, Japan and China, are currently working hard as well to prepare themselves for this new market.

For this reason, the Federal Government adopted the National Development Plan for Electric Mobility on August 19, 2009. This National Development Plan aims to encourage research and market preparation, as well as the launch of electric vehicles with batteries on the market. With the National Development Plan for Electric Mobility, the government is attempting to counteract our dependency on oil imports. At the same time, the vast potential that exists for electrical vehicles to reduce CO_2 and local contaminant emissions should be utilized.

Positioning in time

The predominant objectives of all endeavors in the field of electric mobility are to reduce CO_2 and local contaminant emissions, as well as to enable us to become less dependent on oil imports. Electric vehicles offer excellent potential to serve these purposes, given that widely varying driving concepts may be used. These include hybrid-, battery only and fuel cell vehicles, as well as combinations of these options, such as so-called range-extender technologies or plug-in hybrids. Even today, we can predict that this new generation of vehicles will change the look and, more to the point, the sound of our streets in the long term. But is also important to note that all of these developments are closely connected with the further extension of the use of renewable energies, in order to achieve, for example, a particularly efficient reduction of the CO_2 emission.

4

5

The special technological challenge in opening up electric mobility to a wide range of uses arises from the storage technologies suitable for automobiles (batteries) and other central components for electrical drives, such as electrical motors, power electronics and electrified auxiliary units.

In this business, a new market is emerging, and Germany needs to position itself early on, in order not to fall behind in a globalized competition. Other countries, such as the USA and Japan, as well as China have already supported their industries and research landscape with comprehensive programs aimed at electric mobility.

The four pillar strategy at Fraunhofer IFAM

1. The Model Region Electric Mobility Bremen/ Oldenburg

The new promotional emphasis on "Model Regions Electric Mobility", originated by the Federal Ministry for Transportation, Construction and Urban Development (BMVBS), is intended to promote more strongly research and development in the field of electric mobility, in the context of safeguarding employment and stability in Germany ("eco-nomic stimulus plan"). Altogether, the BMVBS has designated 8 model regions, one of which is the Bremen/Oldenburg region.

Together with the German Research Center for Artificial Intelligence (DFKI), Fraunhofer IFAM operates the regional central project headquarters for the model region. At this office, we coordinate all of the activities of the model region and act as a liaison between the ministry and the project sponsor.

The model region with its area of about 12,000 km^2 has a catchment area with distances of about 150 to 200 km. The interoperation of the metropolises of Bremen and Oldenburg, embedded in more rural surroundings, is typical for this region. This, in turn, creates a special mobility demand, arising from the traffic between the larger towns, mainly between Bremen, Bremerhaven and Oldenburg, on the one hand, and the great traffic volume resulting from commuters from the surrounding communities traveling into the towns for work, on the other hand. There is an additional increased mobility demand in the suburban areas, as well as that related to public transportation, access to the Bremen airport and the central stations offering IC/ICE connections.

Development work is aimed at sustainably generating new traffic concepts that make it possible to intelligently embed electric vehicles and connect them to available mobility services to create city and commuter traffic that is almost emission-free. This objective is intended to be implemented with consideration for maximal personal and individual mobility, to be able to offer, to the greatest extent possible, each individual either an electric vehicle or a means of public transportation.

To do this, the partners of the model region are building up the necessary infrastructure, such as electric vehicle fueling stations and service facilities. Beyond that, a versatile fleet of electric vehicles, from the E-bicycle to a four-seater commuter vehicle, will be put into use.

2. Fraunhofer Systems Research Electric Mobility

To achieve the ambitious targets of the "National Development Plan for Electric Mobility" of the Federal Government, the Fraunhofer-Gesellschaft has launched the project "Systems Research Electric Mobility". This project is intended to support the German automotive industry and its suppliers in sustainably securing a top position in the field of electric mobility. This pioneering project, in which 34 Fraunhofer institutes altogether are involved, consists of 4 main topics, within the parameters of all of which Fraunhofer IFAM has contributed its own subjects.

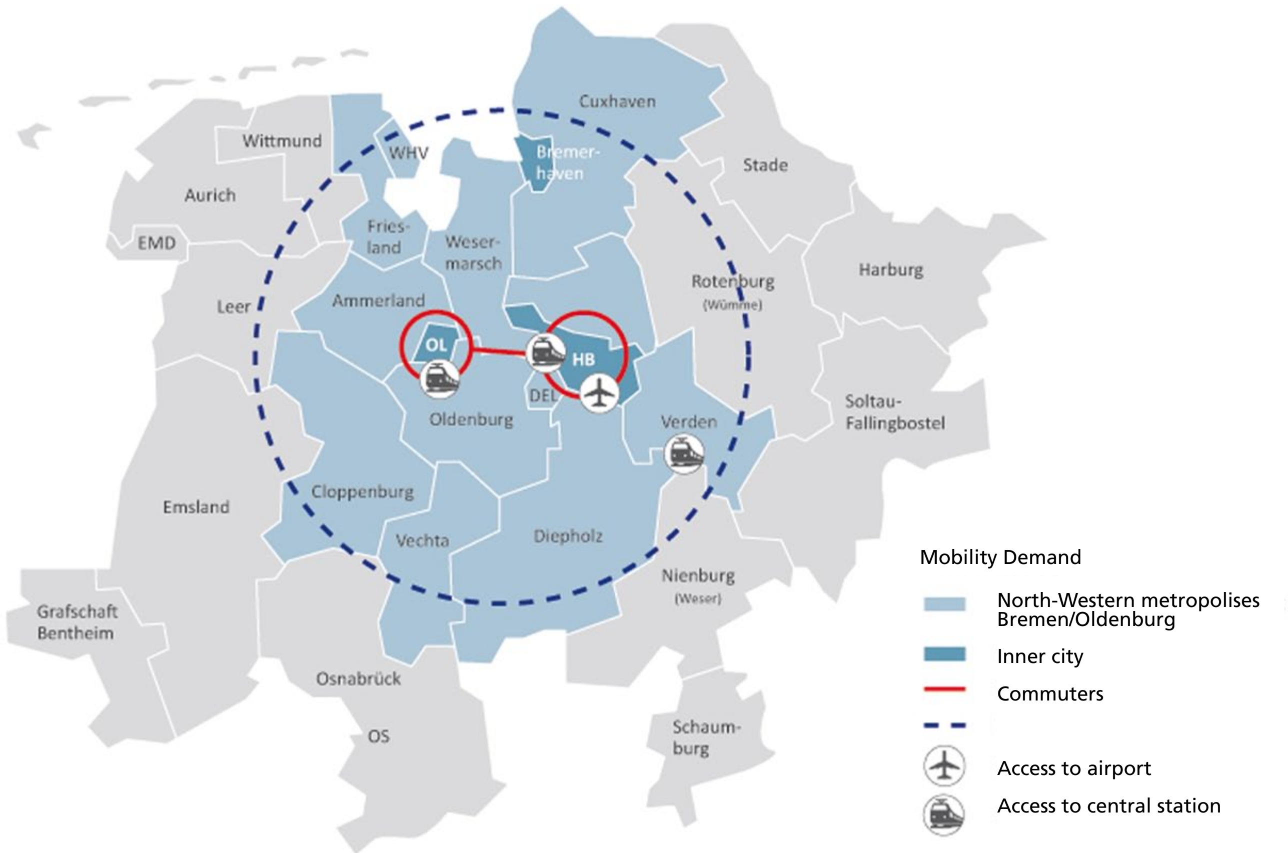


Fig. 6: The Model Region Electric Mobility Bremen/Oldenburg.

Main topic 1 – vehicle concepts

This range of subjects aims at refining existing vehicle concepts for electric vehicles and is subdivided into subprojects as follows:

- New drive concepts using wheel hub motors
- Integration of reliable and crash-resistant batteries in lightweight structures for electric vehicles
- Semi or fully automatic battery changing systems
- Establishment of a service center "Total car test stands"

The projects carried out at Fraunhofer IFAM are focused on the special field of wheel hub motors. Our endeavors focus on new design principles and modified manufacturing techniques for crankcases, increases in power density due to integrated construction principles, integration of sensors and magnet materials, and optimized heat management.

Prof. Dr.-Ing. Matthias Busse leads Main Topic 1 at Fraunhofer IFAM.

Main topic 2 – energy generation, distribution and transformation

This main subject, which includes both "Energy generation and integration into supply networks" and "Power electronics and electrical drive engineering", deals with integration into supply networks (V2G) and/or electrical drive engineering, as well as the associated power electronics. The contributions of Fraunhofer IFAM (Branch lab in Dresden) focus on increasing heat removal from the power electronics' components by using composite materials made with powder-metallurgical technologies, that is materials characterized by high thermal conductivity and a low expansion coefficient.

Main topic 3 – energy storage

The battery system is the central element of every electric vehicle. Within the scope of this main topic, we explore both material aspects at the level of the cell and new manufacturing techniques at the level of the module and battery. This work also includes standardizing the entire management of the battery. To build up optimized battery packs, Fraunhofer IFAM is engineering packaging technologies at the module and battery level and is exploring new material and process techniques for batteries of the next generation.

Main topic 4 – technical system integration and sociopolitical issues

Building up two model vehicles is regarded as an extremely important part of the work performed under the rubric of this main topic: a) a passenger car, driven electrically (Project name: "FreccO") and b) a bus-tram system for public transportation in the city (Project name: "Autotram®"). Fraunhofer IFAM took the lead in the project to build up the model car "FreccO". In this topic, the prototype-oriented developments carried out in the other main topics are integrated as components into the vehicle structure based on the sports car "Artega" and tested in their interaction with real traffic in the street.

3. Fraunhofer IFAM project group Component and Systems Design of Electrical Energy Storage

Fraunhofer IFAM intends to apply its expertise in the domains of materials science, manufacturing and process technologies in order to establish a new business line "Electrical Energy Storage". Given this background, the establishment of an Fraunhofer IFAM project group in Oldenburg, with an emphasis on "Component and Systems Design for Electrical Energy Storage" is being accelerated.

The project group activities are focused on scientific-technical services in the sector of electrochemical storage and its users. The products of the project group are scientific-technical services in the field of component and system engineering for electrical energy storage, as well as the corresponding manufacturing technologies to produce battery cells for the industry.

The major scientific-technical objectives of the project group arise from the recognized industrial need for work on the following technological issues

- Industry-oriented process and manufacturing technology for nanostructured electrodes and components, as well as analysis of their interactions;
- Modeling and simulation of electrochemical energy-storage and system dimensioning
- Tests and inspection according to selected guidelines and standards
- Development of alternative electrochemical storage concepts in the form of prototypes, incl. associated process engineering

The development projects to be performed here are subdivided into the work packages of Material Engineering, System Design, Exercisers and Modeling (Fig. 7).

The Fraunhofer IFAM project group is based on its expertise in material engineering and its industry-oriented manufacturing equipment and includes close cooperation with the University

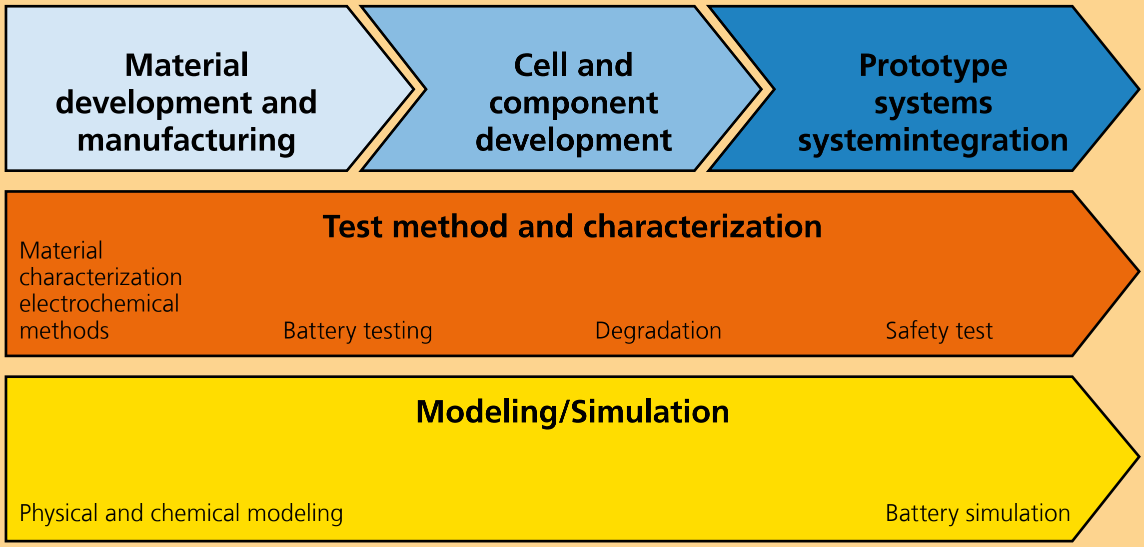


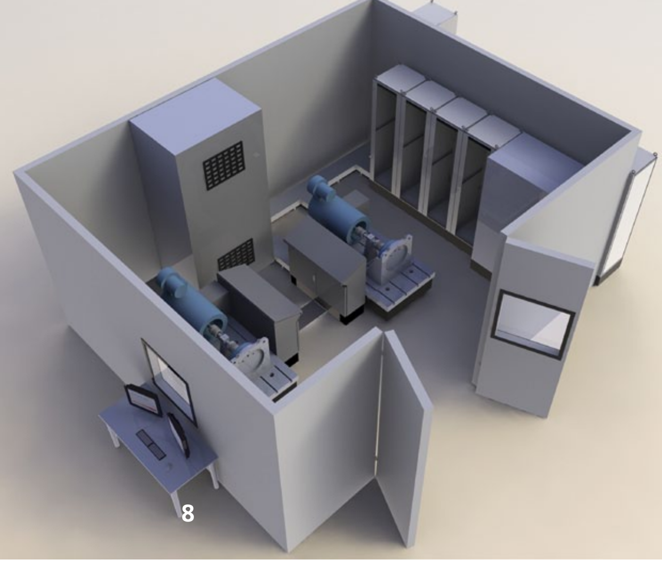
Fig. 7: Progress planning: Fraunhofer project group for component and system development of electrical energy storages.

of Oldenburg, Institute for Physics, department of Energy and Semiconductor Research, and the EWE Research Center "Next Energy". This network creates an essential component for the R&D Center "Electric Mobility NordWest", which unites the science potentials of Lower Saxony and Bremen, and provides a central contribution to strengthen the region in terms of electric mobility.

4. Fraunhofer-IFAM-test bench for an electric power train

For all activities launched at Fraunhofer IFAM in the field of electric mobility, it is absolutely necessary that the newly created components for motors and energy storage be tested on their "suitability for daily use". For this reason, we are at present establishing a corresponding test bench at the institute. With this test stand, all of the components of the electric power train (including the battery) may be tested under simulated everyday use conditions in continuous operation. The co-operation of electric motors and their power converters, the batteries with the corresponding battery management system, as well as the entire vehicle control including secondary units, is very important. At another stage, it will be possible to implement quick intermediate storage to recover the braking energy ("recuperation").

A special feature of the test bench arises from its capacity to simultaneously test two motors in parallel operation, under real time conditions. Energy supply of the specimens is realized either using a battery simulator (configurable DC voltage source) or using a "real" battery. It is possible to condition the battery via defined charging/discharging cycles in an automated mode. The battery is located in a protected environment, in which we may vary the environmental temperature, so that it may be subjected to a temperature load.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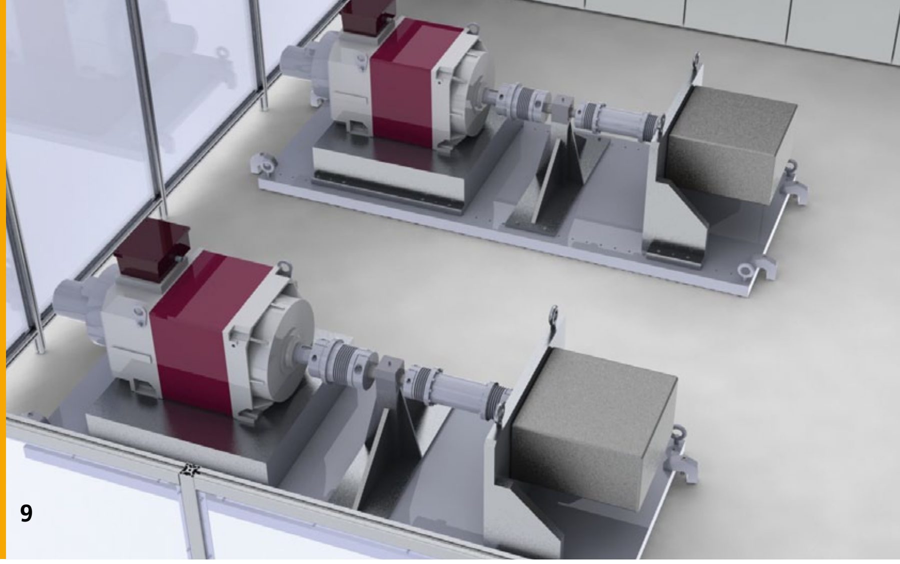
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This way, it is possible to feed standardized driving cycles into the test bench; at the same time, we can also "retrace" the driving data obtained from a real car test on the test bench. Thus, we may gather essential information about the

- Optimization of motor and car control (triggering)
- Optimization of the battery management system
- Optimization of the power converters
- Specification of the energy flows
- Data for computation of the cruising range or residual cruising range
- Aging and lifetime of batteries
- Charge management for batteries

The implementation

Energy storage in battery electric vehicles is one of the central emerging topics for Germany. The desire to become more and more independent of fossil fuel sources, in conjunction with the human drive for mobility, defines the targets of scientists in coming years and decades. Fraunhofer IFAM is ready to address these problems and create the necessary preconditions to offer a contribution to meeting these demanding goals in the future.

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

1 | 3 *Base of the Fraunhofer demonstration car "FreccO".*
2 *Electric current instead of petrol (© Getty Images).*
4 *First electric vehicles (Think City) are already in use within the scope of activities of the model region Bremen/Oldenburg.*
5 *Electric current from regenerative energy sources (© pmc).*
8 | 9 *Fraunhofer-IFAM test bench for the electric power train.*

ATTRACTING EFFECTS: CELLS GROW EXCELLENTLY ON IMPLANT MATERIAL THANKS TO SURFACE FUNCTIONALIZATION

One requirement for a high quality of life – even at an advanced age – is comprehensive medical care. These services also include readily absorbable implants for hip and knee joints that permit shorter rehabilitation periods for patients. With this target in view, new materials and special manufacturing technologies to develop low-cost and biocompatible implants are being applied.

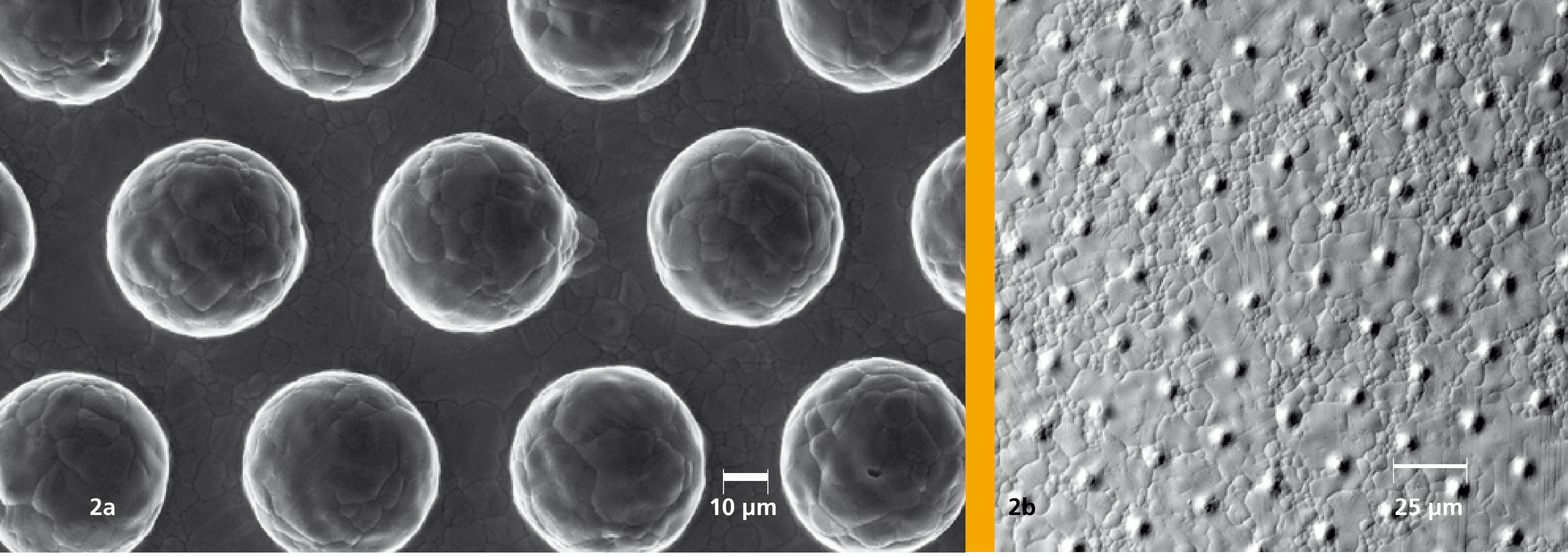
The challenge: Shaping and surface functionalization in one manufacturing procedure

For many years, we have known that surface structures support the growth of bone implants. The implant topography affects the surrounding cells, particularly their adhesion and growth characteristics. However, up to now it has not been completely clear how the interaction at the interface between implant and bone cells proceeds. Many publications demonstrate a positive effect of surface structures in the micro and nanometer region.

Currently, medical implants are made in multi-step procedures, in which surface structuring represents an additional process step. As a result of a refined Micro-Metal Injection Molding (µ-MIM) technology, we at Fraunhofer IFAM have a technique available that makes the integration of shaping and surfacestructuring possible so that further reworking steps will become unnecessary in the future.

The most important advantage of the µ-MIM procedure is the possibility to create very precise and exactly defined surface structures. With other structuring techniques, such as etching and sandblasting, only irregular surface structures can be generated.

The µ-MIM procedure enables series manufacturing of complex components of minimal size and is applicable to a high variety of biocompatible materials. The procedure consists of several manufacturing steps: First, metal powder is transformed to a molding batch that can be processed by injection molding – the so-called feedstock. To do this, the powder is blended with an organic binder under the influence of temperature. Afterwards, it can be micro-injection molded on a corresponding machine. Having shaped the component, the binder is extracted by means of a solvent and another thermal process. The following process step is sintering, whereby the component is given its final density, which is close to the theoretical density value.



The task: Development of the ideal material mix for tiny nipples on a metal surface

In the project, performed in cooperation with Empa, St. Gallen, Switzerland and promoted by the foundation Volkswagen-Stiftung, the µ-MIM procedure was refined to such an extent that it was possible to manufacture microstructured surfaces, optimized in terms of cell growth, from biocompatible stainless steel. The microstructure produced by the µ-MIM method consisted of hemispheres with diameters of 50, 30 or 5 micrometers and equidistant interspacing of 20 micrometers (Fig. 1). For our test geometry, we injection-molded rounds of 1 mm diameter, which are suitable for cell tests.

Stainless steel 316L, a biocompatible alloy used for medical implants, was selected as the material for process development. For the first tests, a pre-alloyed 316L powder of average particle size d50 = 2.8 micrometer was used. In the next step, the material was modified so that a mix of an alloy powder (CrNiMo 55-38-7) (d50 = 4.0 µm), fine iron powder (d50 = 1.4 µm) and nano iron particles (d50 = 17 nm) was applied. In the course of a diffusion processes during sintering, the 316L stainless steel is generated. With the use of the nanopowders, a desirable sub-microstructuring on the hemispheres should emerge due to the expected reduction of the grain size. Since the increased surface-volume ratio combined with smaller particle diameters made it necessary to knead the corresponding feedstock more intensively, we developed a new homogenization process. The nanoparticles were pre-mixed in an argon atmosphere with the waxes of the binder to prevent their oxidation. Afterwards, they were homogenized with the residual feedstock in a kneading machine flooded with argon.

After sintering, the manufactured samples always had a relative density of more than 95 percent. The highest density was achieved at a sintering temperature of 1200 °C, whereby the values of relative density were above 97 percent.

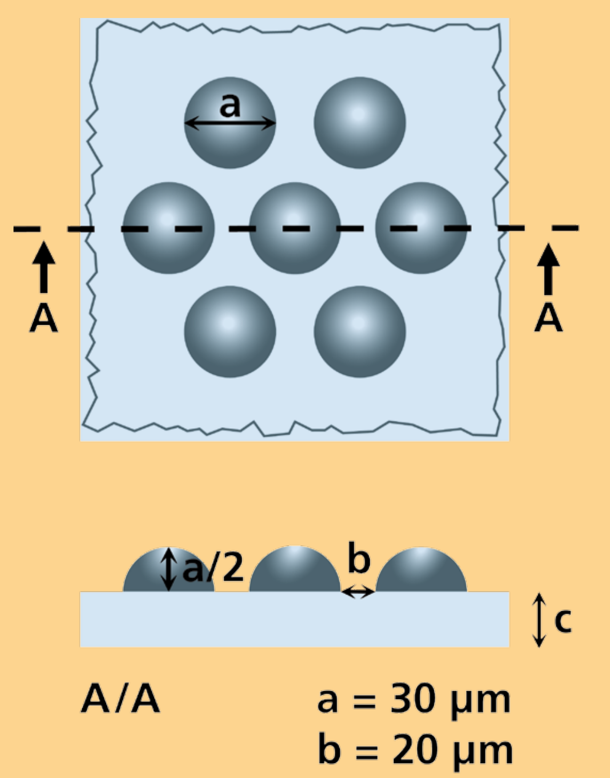


Fig. 1: Sketch of the surface structure with hexagonally arranged positive hemisphere structure.

It was clear that forming was improved by adding nanoparticles (Fig. 2a and 2b). We succeeded in clearly improving the forming of the hemisphere structures with diameters of 50 micrometers and 30 micrometers due to nanoparticles in the feedstock. Finally, a ratio of 33 percent nanoparticles made it possible to replicate even the smallest structure, with a diameter of just 5 micrometers, a result which had been impossible before using the other feedstock.

Thanks to systematic investigations of the sub-microstructure (grain structure of the metal) on the hemispheres, it was possible to relate the changes of the grain size to the nanoparticle ratio in the feedstock, as well as to various sin-

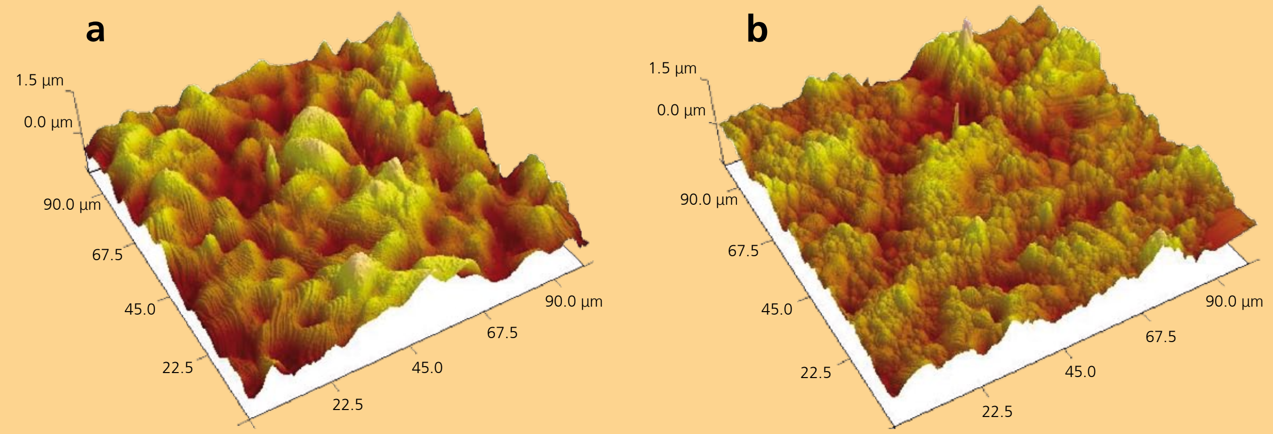


Fig. 3: Decreased grain size with increased nanopowder ratio can also be observed in images recorded with the atomic force microscope. 3a) shows a specimen without nanopowder ratio, 3b) demonstrates the surface of a sample with 33.3 % nanopowder ratio.

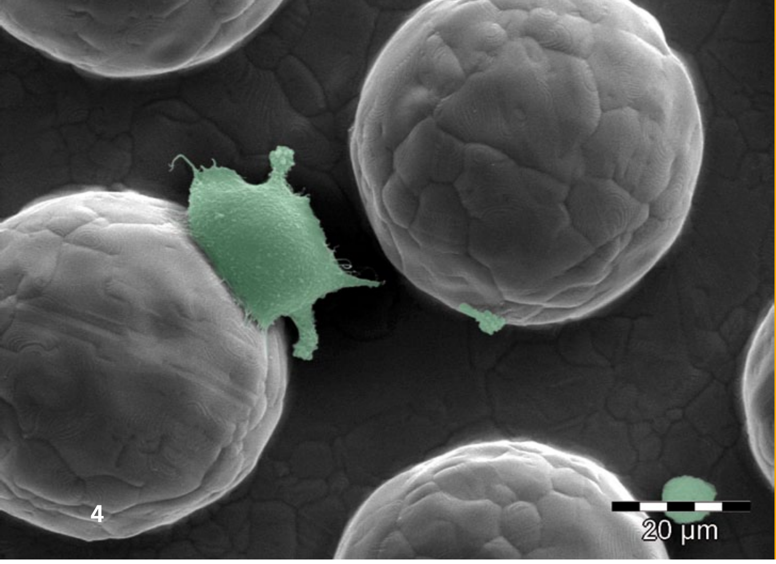
tering temperatures. With an increased number of nanoparticles, as well as low sintering temperature, we succeeded in dramatically reducing the grain size. As shown by investigations with the atomic force microscope, the grain boundaries also affect the surface topography (Fig. 3a and 3b). At the surface, the grain boundaries shape small grooves and hollows, whereby a sub-micrometer structure emerges. When using nanoparticles, these grooves appear to a greater extent, since, due to the smaller grain sizes, grain boundary density also increases.

The result: The cells adhere better to the nippled surface than to smooth metal – and the compatibility of the implant is improved

As previous investigations have shown, we may have a positive effect on the growth of bone cells by integrating a sub-microstructure in addition to the homogeneous microstructure. Initial experiments with cell cultures carried out at Empa demonstrate that the structured hemispheres have a significant effect on the adhesive attraction of human bone marrow stem cells (Fig. 4).

Systematic explorations with bone marrow stem cells have shown that the reaction of the cells to a microstructured surface is clearly different from that of the unstructured control specimens. In particular, as a result of the microstructure, we were able to positively impact cell adhesion and cell mobility. These are essential factors for strong biocompatibility. Seven days later, higher cell mobility in comparison with the unstructured control surface became obvious (Fig. 5).

Until now, we have been able to make progress in the development of the metal injection molding process and thus have been able to form feedstock with nanoparticle content and, in turn, form surface structures in the micrometer range. It was possible to significantly improve the quality and reproducibility of specimens made of biocompatible stainless steel, with various surface structures, by using a micro-injection molding machine from industry, so that for the first time surface structures of only 5 micrometer diameter could



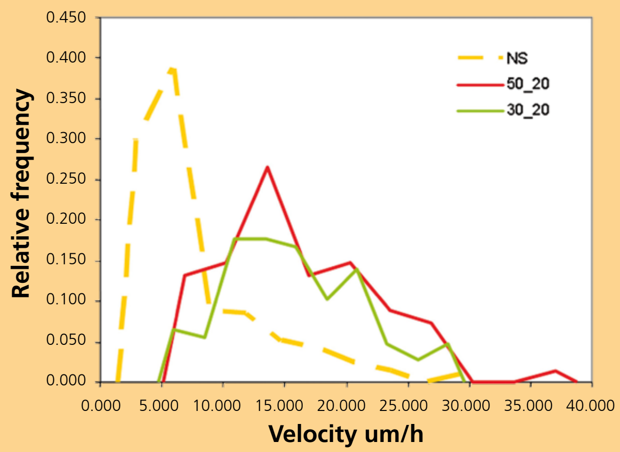


Fig. 5: Cell mobility after 7 days, on unstructured and structured specimens. Unstructured control surface (NS), microstructures with 50 micrometer diameter and interspacing of 20 micrometers (50_20) and 30 micrometers diameter (30_20).

be formed by means of µ-MIM. Additionally, it was demonstrated that we could reduce grain size as a function of increasing nanoparticle ratio. In this way, an additional surface structure was obtained in the sub-micrometer range. Further investigations verified that this sub-micrometer structure had an additional effect on roughness. It is now possible to perform targeted adjustments of the surface roughness by using the nano-MIM process. Stainless steel has primarily been used as the testing material up to now. Recently the process has also been transformed to produce microstructured titanium specimens to be used as long-term implants. Titanium is of outstanding biocompatibility and an excellent implant material.

Project funding

The project is funded by the donation Volkswagen-Stiftung within the scope of the promotional program "Innovative Methods for the Manufacturing of Multifuntional Surfaces".

Project partners

Fraunhofer IFAM and the Empa, St. Gallen, Switzerland, are project partners who maintain equal rights.

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2a | 2b *Images of structured stainless steel surface, recorded with the scanning electron microscope, formed on a micro-injection molding system for industry (Battenfeld Microsystem 50). Left: 50_20 structure, made of a feedstock with 16.67 % nanoparticles; Right: 5_20 structure, made of a feedstock with 33.3 % nanoparticles.*

4 *Cell adhesion on a microstructured surface for cell growth management on implants, surface was metal injection molded.*


1a


1b

RELIABLE PRODUCTION: QUALITY ASSURANCE FOR METAL INJECTION MOLDING (MIM)

Every enterprise can save time and money by using production methods that make efficient use of the raw materials and by minimizing scrap. High quality offers safety and promises a long life for components. For metal injection molding, we at Fraunhofer IFAM have achieved interesting new results to fulfill these demands.

On the way to zero-reject production

Today, metal injection molding, abbreviated MIM, has established itself as a mature manufacturing technology for mass producing intricate components. Here, it is very important for this industry to minimize scrap in all process steps (feedstock, injection molding, debinding/sintering). On the course towards zero-reject production, we

- determine relationships between feedstock homogeneity, rheology and feasibility of reliable simulation of the mold filling procedure to accelerate the process of making dies/molds ready for production;
- use neural networks in order to pick out defective components immediately after injection molding;
- analyze online during sintering interactions between the sintering atmosphere, the binder components and the metallic powders in order to reliably adjust the material properties and to optimize the sintering cycles.

Reliability thanks to mold filling simulation and feedstock homogeneity

In the EU project MATLAW (EU project 33006 – MATLAW "New material laws for powder filled injection molding feedstock"), we checked different paradigms to improve mold filling simulation. Our basis for this was a reliable and consistent data pool (physical and rheological data for various feedstocks, based on different binders and powders). The data pool was elaborated within the scope of MATLAW by the Institute for Plastics Processing of the Montan University of Leoben (IKV-MUL).

To quantify the phase separation of binder and powder during injection molding, we injection molded Zig-Zag specimens from different feedstocks, while widely varying the injection molding conditions, and investigated these specimens. However, neither the measurements with a Gamma densometer nor with computer tomography provided results that made possible unambiguous conclusions, whereas the X-ray image shows variations in the shades of grey due to different wall thickness values (Fig. 2).

Differences in the wall thickness, caused by temperature and pressure gradients in the component during injection molding, and a non-perfect flat-grinding procedure due to the sensitivity of the green parts superimposed the potentially available segregations.

Still, at least we were able to determine that the segregations away from the gate were so low that they are very difficult to record.

The injection molding tests with the zig-zag specimen showed up clear differences in the properties of the different injection molding feedstocks. To map these characteristics,
we introduced a rheological model for feedstocks, which assumes a yield stress and a minimal shear stress and thus forecasts the solidification of the mass at low shear rates. Figure 3 elucidates impressively that the resulting simulated filling conformed very well with the experiment. The mold filling simulation using the modified rheological model and reliable data predicts the molding reality to such a great extent that it is a very useful tool in the development of new molds and components.

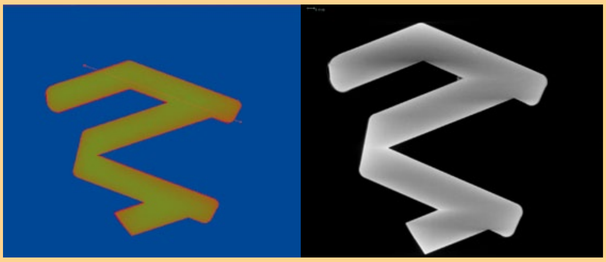

Fig. 2: CT reconstruction and X-ray image of a green part.

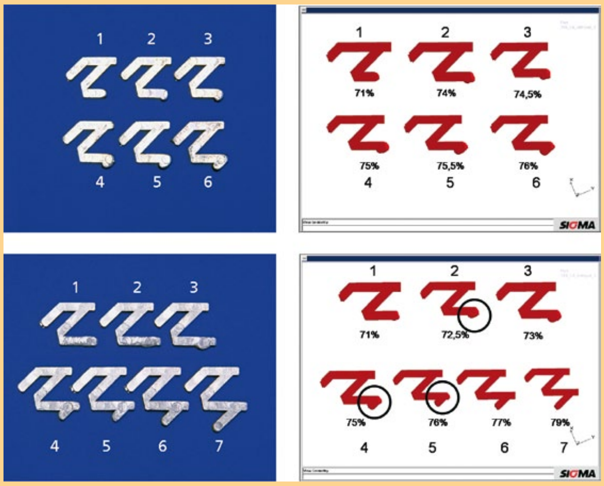

Fig. 3: Mold filling study for the zig-zag mold (left) and results of the mold filling simulation (right) for two feedstocks based on different binders.

Application of neural networks in injection molding

Dimensional accuracy and quality of the sintered component mainly depend on the choice of the process parameters in each preceding process step. Deviations in the injection molding parameters result in deviations in size and – in the worst case – in component defects, such as cracks, distortion or pores, which can only be recognized after sintering. It is a typical feature of the MIM process that all green part defects caused by injection molding errors cannot be "repaired" by subsequent process steps. The target is to obtain information about the component quality and the influence of deviating process parameters already during the injection molding procedure in order to counteract critical deviations if necessary.

One possible solution is a statement on quality given synchronously with the manufacturing cycle, with complete documentation of all relevant information. This is being developed using a neural process control systems. These systems enable to control even very complex interactions in a self-learning and self-improving system.

During the test, we collected all of the process data from the Arburg 320C injection molding machine and stored it in a database. Before using the diagnosis tool, we had to teach the system the specific process. To do this, 190 specimens with a systematic variation of the injection molding parameters were selected and weighed both as green part and as sintered part. The debinding and sintering conditions were kept constant for all components. The injection molding parameters are listed in table 1.

After having trained the neural network with the 190 specimens the system was applied to analyze the total batch of 404 specimens in order to create a weight forecast. The comparison between weight predicted by the neural network and the actual measured weight of the specimens is illustrated in figure 4. The predicted values conform well to the measured data. The correlation between the predicted weight of the green and sintered parts and the settings during injection molding is illustrated in figure 5. The correlation already observed for the training phase data is reproduced. The maximal injection pressure and the switch over pressure influence the weight of the green and sintered parts the most.

As evidenced by the results of the study, a neural network makes it possible to forecast the weight data of an already sintered MIM component, which can be affected by the machine parameters of the injection molding system. One can train the neural network to generate a mathematical model for a quality forecast with a statistical analysis of the experimental data obtained from 68 individual process parameters of each specimen and the final weight of the finished components. Correlation analysis has proven that the presented model considers strong and sophisticated interactions among the individual process parameters and the weight of the components. With this model, both online quality inspection of injection molded components and the determination of minimum deviations in the process conditions can be performed. Additional investi-

Molding pressure [bar]	800	1.000	1.200
Injection speed [mm/s]	45	85	125
Clamp pressure [bar]	400	600	800
Clamp pressure kept for [s]	0,2	0,5	1

Tab. 1: Variation of injection molding parameters.

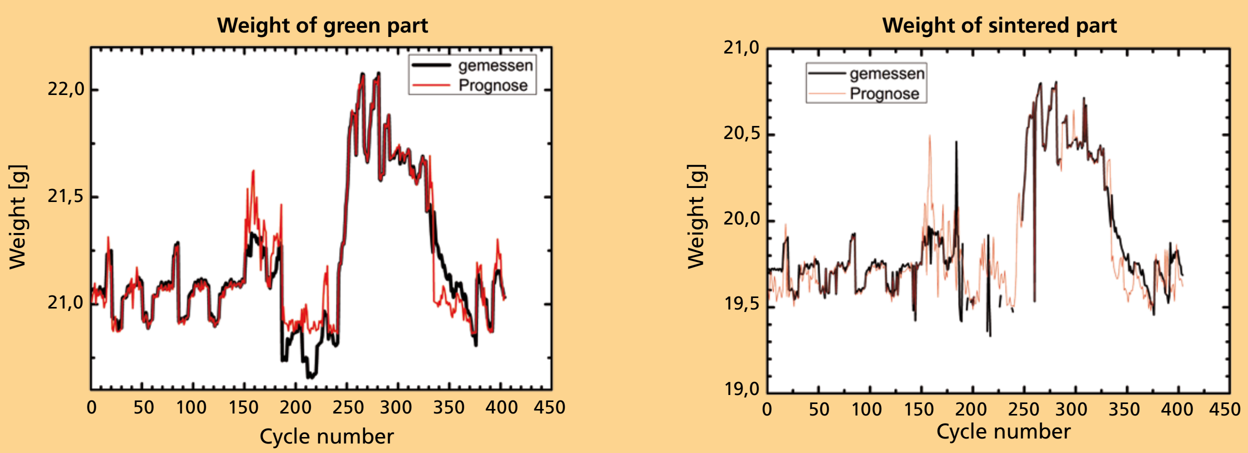

Fig. 4: Comparison of predicted and actual weights of the 404 green and sintered parts: a) Green parts, b) Sintered parts.

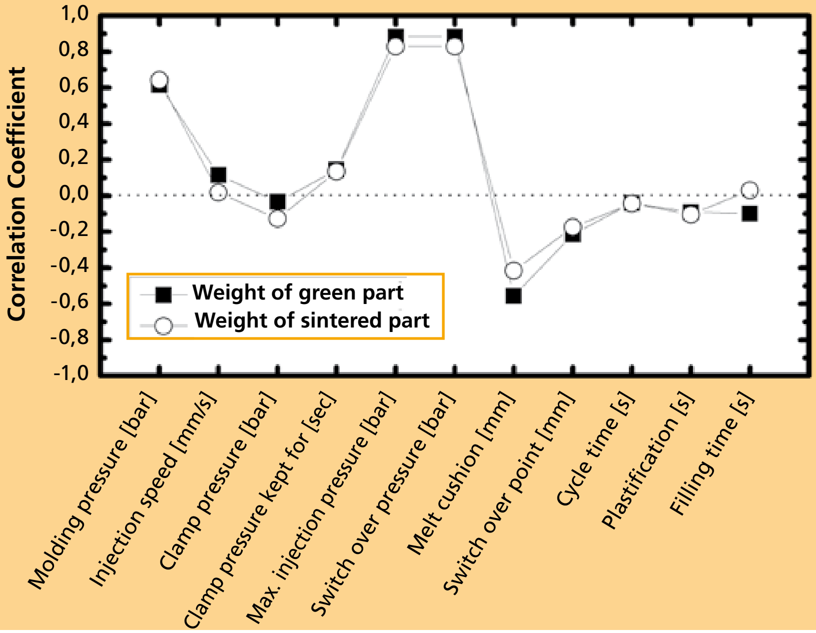

Fig. 5: Calculated correlation coefficient between the weight prediction of green and sintered parts and the injection molding parameters.

gations are necessary in order to extend the quality estimations on other component features.

Making the invisible visible: Gas analytics during sintering

The production cost and material properties of MIM components are to a great extent defined by the sintering process. Unfortunately, until now there have very limited analytical methods and sensors available to observe what is going on in the sintering furnace. However, this insight is desirable in order to analyze the influence of the temperature and atmosphere on binder and powder and thus to optimize this process step.

Several older studies already used mass spectroscopy to research aspects of sintering PM parts in laboratory experiments. Fraunhofer IFAM are the first to equip an industrial size debinding and sintering furnace with a quadrupol mass spectrometer. A gas sample is continuously extracted from the process gas directly below the furnace chamber and analyzed online in the mass spectrometer (Fig. 6).

In a series of experiments, we investigated the influence of the gas atmosphere on binder decomposition in MIM components made of Fe2Ni. For these tests, in addition to pure hydrogen and pure argon, we also used a mix of 66 per cent, 42 per cent and 24 per cent hydrogen. Figure 7 shows the evolution of methane (16 atomic mass units) as a function of time and of the gas mixture. The corresponding temperature in the furnace is plotted as well.

The very first peaks correspond to the binder decomposition. Here, peak intensity unambiguously depends on the hydrogen concentration in the furnace atmosphere. Methane is a product of the thermal degradation of the binder. If the atmosphere contains hydrogen, then the binder is degraded to a greater extent and the short chain molecules like methane are found, while under argon more long-chain decomposition products are found.

Particularly interesting is the methane formation during the holding time at 600 °C. During this stage, binder residue from carbonization of the polymer as well as carbidic carbon from the metal powder react with the hydrogen to give methane. In pure hydrogen atmosphere, this reaction is complete after half of the holding time. In lower hydrogen concentrations, this reaction is slower and remains incomplete in the given time. Through subsequent heating, the reaction is stopped before being completed. In argon, this hydriding reaction is not possible at all. This difference in carbon hydrogenation is then reflected in the carbon content of the sintered parts.

This example shows that it is appropriate to use a mass spectrometer for quality assurance during debinding and sintering. Debinding parameters can be optimized by correlating the hold times and temperatures exactly with the reaction temperatures of the desired reactions for a given gas atmosphere. This may be adapted both to the processed materials as well as to the wall thickness of components. The quality of the gas atmosphere and its influence on the components at different temperatures may be checked and adjusted.

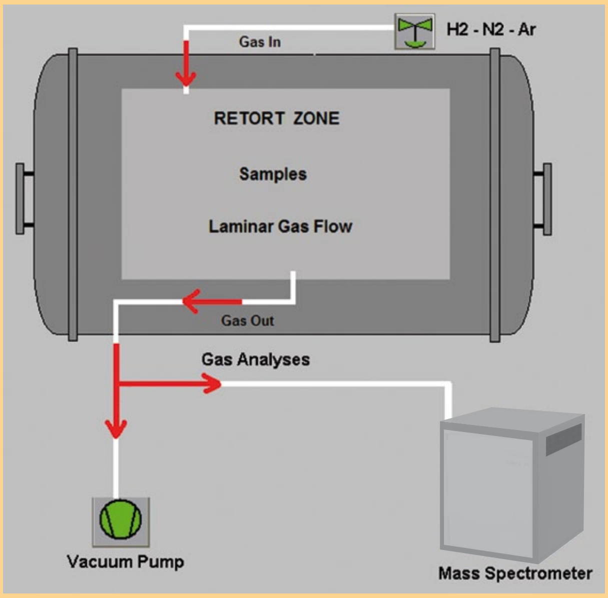

Fig. 6: Experimental scheme for gas analysis in the sintering furnace.

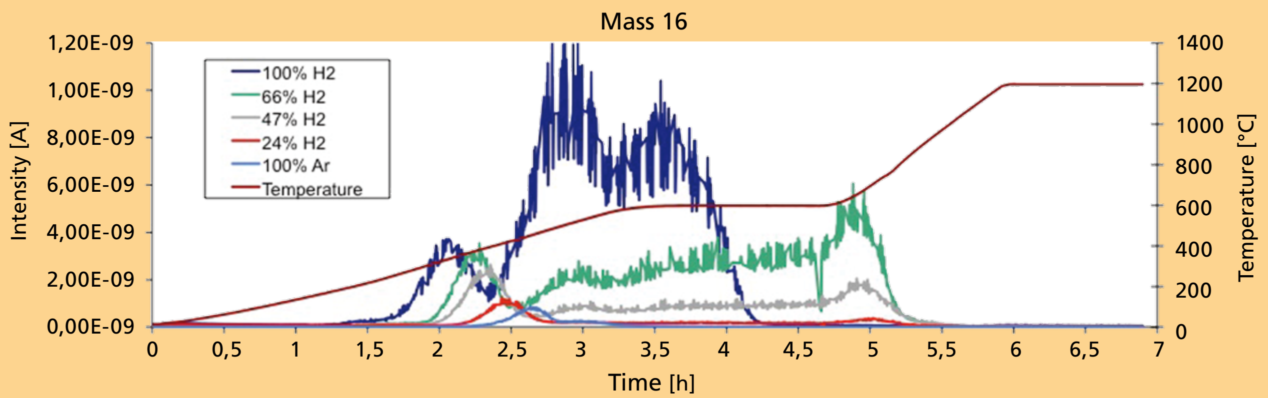

Fig. 7: Relative evolution of methane (16 atomic mass units) as a function of time and temperature for different gas compositions.

Summary

After the completion of MATLAW, several partners adopted the mold filling simulation as a useful tool for part and mold design. The problem of the segregation of powder and binder will be investigated in more depth in future cooperations in order to introduce this effect into simulation as well. The MIM expert group is testing and implementing the use of neural networks for quality assurance in powder injection molding in production. Mass spectroscopy to analyze the sintering atmosphere has attracted significant interest and is already being adopted into the design of new furnaces.

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- ITB Precisietechniek, Boxtel, The Netherlands
- MIMITALIA srl, Vado Ligure, Italy
- Alliance SA, Saint Vit, France
- Imeta GmbH, Dresden
- Inmatec Technologies GmbH, Rheinbach
- Sigma Engineering GmbH, Aachen
- Institut für Kunststoffverarbeitung, Montanuniversität Leoben, Leoben, Austria

Neural networks
- algorithmica technologies GmbH, Bremen

1a *Personnel of Fraunhofer IFAM during metal injection molding.*
1b *Employees of the Fraunhofer IFAM at the sintering furnace.*

1a

SIMULATION – VIRTUAL REALITY TO FORECAST MOLD FILLING PROCEDURES

At present, computer simulation of products and processes is decisive in all phases of the product life cycle. This method is applied in a wide variety of disciplines, from natural, economic and engineering sciences to medical and environmental research. In particular for the prediction of processes pertaining to casting technology, it is possible to use the experimental data for optimization.

Why do we use simulation programs in casting technology?

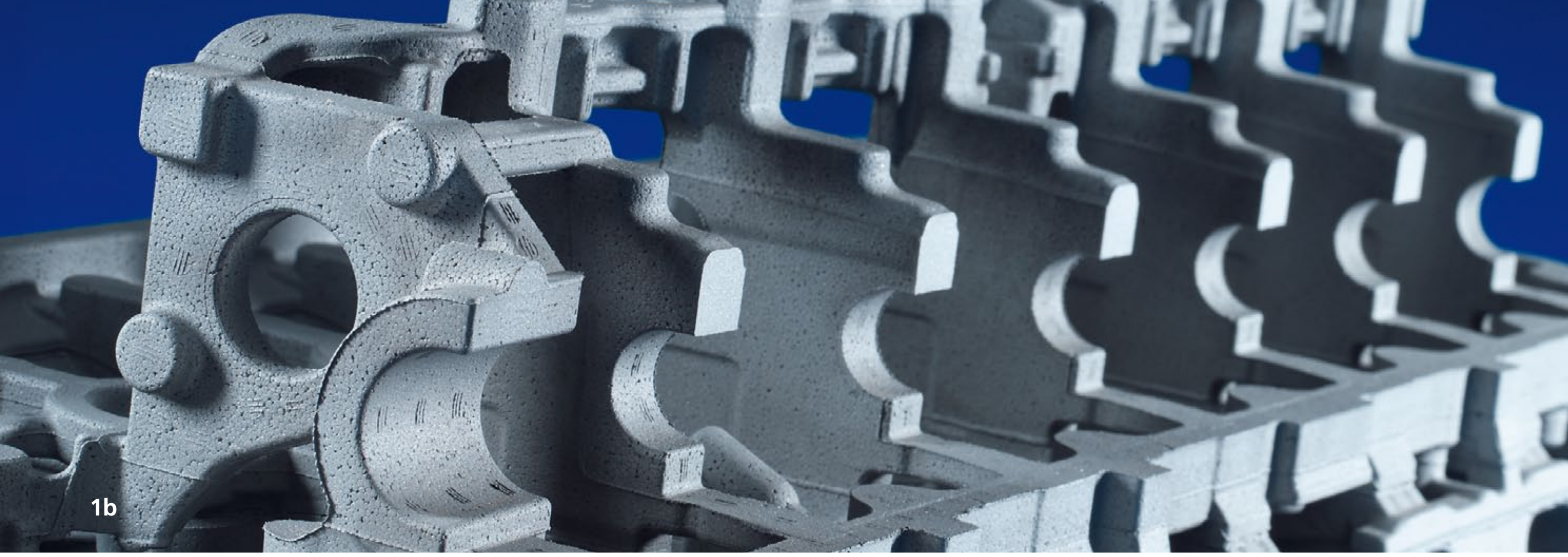
Manufacturing of casting components is always an invisible process. The liquid metal, the so-called melt, is poured into a closed mold. The melt solidifies by cooling down and we obtain a solid of fixed geometry: the casting. Using simulation programs it is possible to visualize the casting, the mold, and the pattern during mold filling and to monitor the flow and the solidification characteristics. The software supports the personnel both in engineering and production as they identify problems and find solutions for problems that are becoming more and more complex.

What casting technologies are in use?

Different casting technologies are used depending on cost efficiency and the requirements a future casting must fulfill. Diecasting and ingot casting are used for simple geometries and to produce large part quantities, whereas sand casting and the recently developed Lost foam casting technology are used for castings with complex geometries and undercuts. For a simulation of these casting processes that approximates reality it is necessary to know the material-specific parameters and thermophysical parameters, such as thermal conductivity and specific heat capacity.

The challenge: Simulation of mold filling in the Lost foam casting procedure to closely approximate reality

In Lost foam casting, the ongoing casting procedure is more complex than in the other abovementioned casting processes, because rather than pouring into an empty cavity, a polymer foam pattern (EPS – extracellular polymeric substances) is decomposed to fill the mold. The EPS pattern, which was produced in a 2-step foaming procedure before, is coated with a thin ceramic film, the coating, and embedded into the binderless sand. During the casting procedure, the heat of the melt decomposes the pattern material and fills the result-



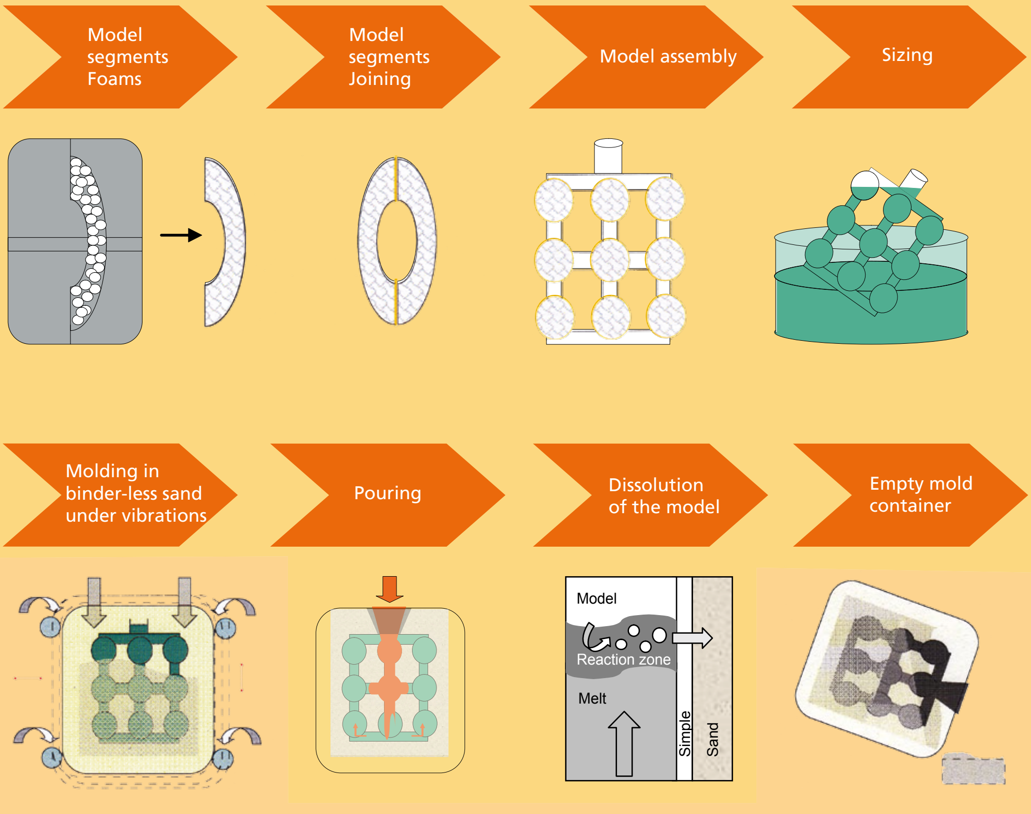
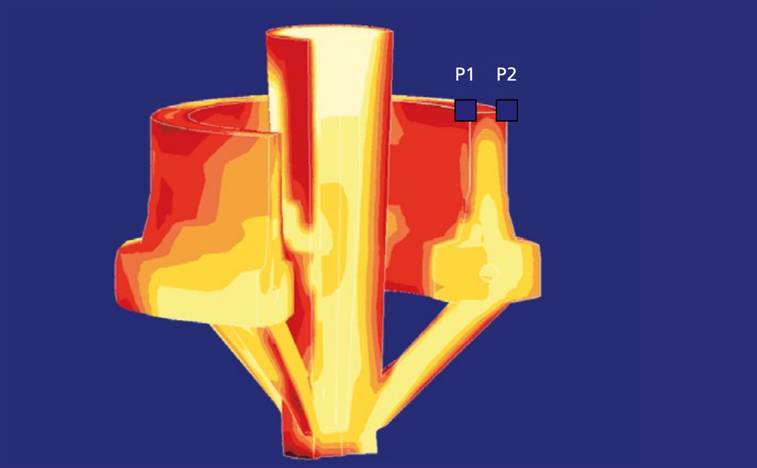


Fig. 1: Principle view of the Lost-Foam casting procedure (in steps).

ing mold cavity true to detail. In order to pyrolize the pattern completely, we need sufficient thermal energy in the melt. The gaseous and fluid products that emerge in the dissolution are emitted through the coating into the binderless sand (Fig. 1). This, in turn, assumes that the coating and sand are of sufficient permeability. It is clear that the functionality of this technique, in contrast to the conventional casting technology, is influenced by many parameters (such as model density, patternl bond, pyrolysis characteristics of the pattern material, permeability of the coating and the molding material, molding material compaction, melting temperature, etc.). In case of deviations from the limited values within the parameter range for the process, pores may appear in the casting, for instance as a result of insufficient off-gassing through the pores. These parameters and coefficients are required for the numerical simulation of the Lost foam casting process. Up to now, they are either only partially available or are not available at all. Thus, the calculations from simulations significantly differ from the real mold filling. However, simulation programs for die, ingot and sand casting have been established on the market and have been in use for a longer time.



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The task: Determination of significant material-specific coefficients to be used as input parameters for the calculation models for the Lost foam casting technology

Knowledge of the thermophysical data of all materials used (cast alloy, sand, coating, pattern material) is an essential precondition for the precision of the simulation result. The main parameters are:

- Permeability of coating and sand
- Heat conductivity of pattern material, coating and sand
- Specific heat capacities of pattern material and sand
- Melting energy required for pattern pyrolysis

We determined these thermophysical data in an empirical manner at Fraunhofer IFAM in a project sponsored by the company of Industrial Research Consortia (AiF) (AiF-No.: N14635). Since there is no suitable measuring equipment available to measure gas permeability of very thin coating layers and binder-less sand, we engineered a gas permeability test stand at Fraunhofer IFAM. This test bench determines the mass rate as a function of pressure decrease of a laminar flow element and as a function of the viscosity of the gas used. The normalized coefficient of gas permeability is calculated from the measured flow.

We developed a test stand to determine heat conductivity, upon which heat flow through the specimen may be determined and heat conductivity may be calculated again. The test setup is suitable to measure solids and bulk material. For simulation, gas permeability and heat conductivity values of coatings and sand are decisive.

For a simulation of the mold filling that approximates reality, it is necessary to know the energy required for the dissolution of the EPS pattern. We used two different methodologies to quantify this energy. First, in casting tests with EPS samples of various densities, we measured the heat losses on different sides of a test pattern during mold filling in the casting process. The energy difference obtained from that provides the sought pyrolysis enthalpy for the corresponding difference mass of the polystyrene. Secondly, we carried out calorimetric measurements (Differential Scanning Calorimetry – DSC) to determine the dissolution energy of the pattern material, as well as the specific heat capacities of sand and pattern material.

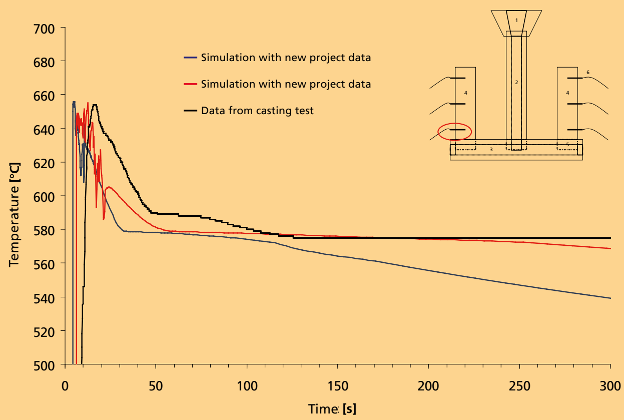
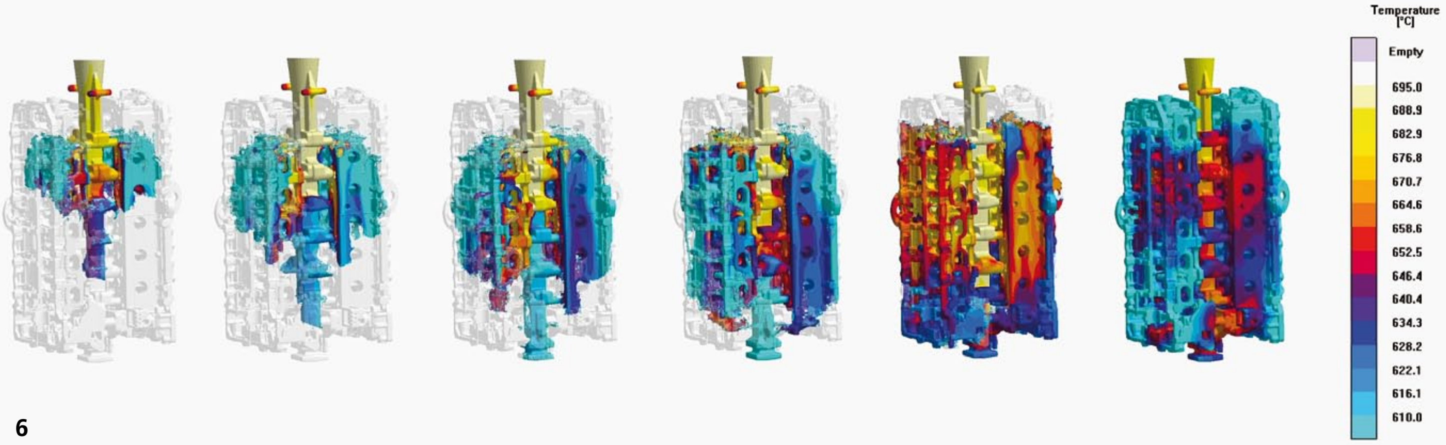


Fig. 2: Temperature – time curve of test geometry simulated with original data by the firm Magma, as well as with data determined from the project and data obtained from casting tests.

The result: New data allow more exact simulation results and improved approximation of reality

Based on the characteristics we discovered, which had already been implemented into existing simulation models, we performed simulation runs of the temperature curve of the mold filling, using test geometries as well as real cast parts. Mold filling and solidification of the specimen geometry used in the casting tests were numerically simulated both with the conventional and the newly discovered data. In figure 2, we see



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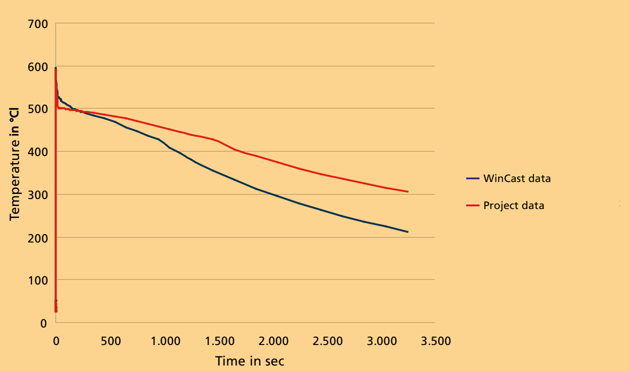

Fig. 4: Temperature- time curve for point P1.

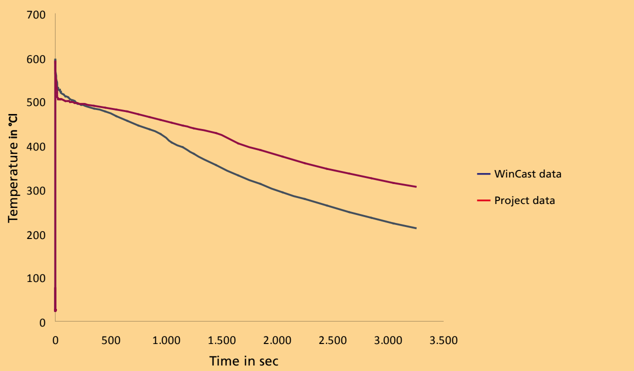

Fig. 5: Temperature- time curve for point P2.

the resulting temperature curves at a n exemplary measuring point. As can be seen, the long-term characteristics can be reproduced much more exactly by the newly obtained data (red curve), and we were able to find an improved conformity of the simulation results with the values determined in experiments in comparison with the use of the conventional data of the simulation program (blue curve).

In the short-term characteristics during mold filling, despite strong fluctuations resulting from the numerical inaccuracies in discretization in time and space, we may also obserce an approximation of the measured data in the simulated temperature curves. However, this approximation is not as close as that in the long-term curve.

The companies Magma and RWP carried out comparative simulation runs for real components, both with conventional data taken from literature and with the newly determined parameters. In these runs, comparative temperature curves were recorded at the marked locations (Fig. 3). Analogously to the results of the test geometry, these curves show differences, in particular in the long-term reaction of temperature, which can be explained by the higher measurement precision at which the values for the heat conductivities were measured (Fig. 4 and 5). Based on the investigations in this study, we were able to determine the significant thermophysical characteristics for the simulation of mold filling procedures. Thus it was possible to significantly increase the accuracy of the determined simulation results.

Equipment at Fraunhofer IFAM

At Fraunhofer IFAM in Bremen, in addition to the traditional casting technologies, we have fully integrated the entire process chain of the Lost foam casting technology on industrial scale. The equipment installed comprises steam generation for the fabrication of patterns, the foaming machines, the so-called pre-foamer and the automatic machine for finished parts, as well as the compounding table and a pouring station. It is also possible to perform casting tests and experiments for sand compaction, as well as foaming. The patterns and the castings may also be inspected in terms of quality with comprehensive metrological devices.

Project funding

The project called "Study on mathematical-physical modeling for the simulation of castings made with the Lost foam technology" was funded by the association for German casting experts, the Verein Deutsche Gießereifachleute e. V. (VDG) and the Company of Industrial Research Consortia-AiF (AiF-No.: N14635).

Project partners

- RWP Gesellschaft beratender Ingenieure für die Berechnung und rechnerunterstützte Simulation GmbH
- Magma Gießereitechnologie GmbH
- BMW AG
- Gussstahl Lienen GmbH & Co. KG
- Albert Handtmann Metallgusswerk GmbH & Co. KG
- Hellerhoff Produktentwicklung
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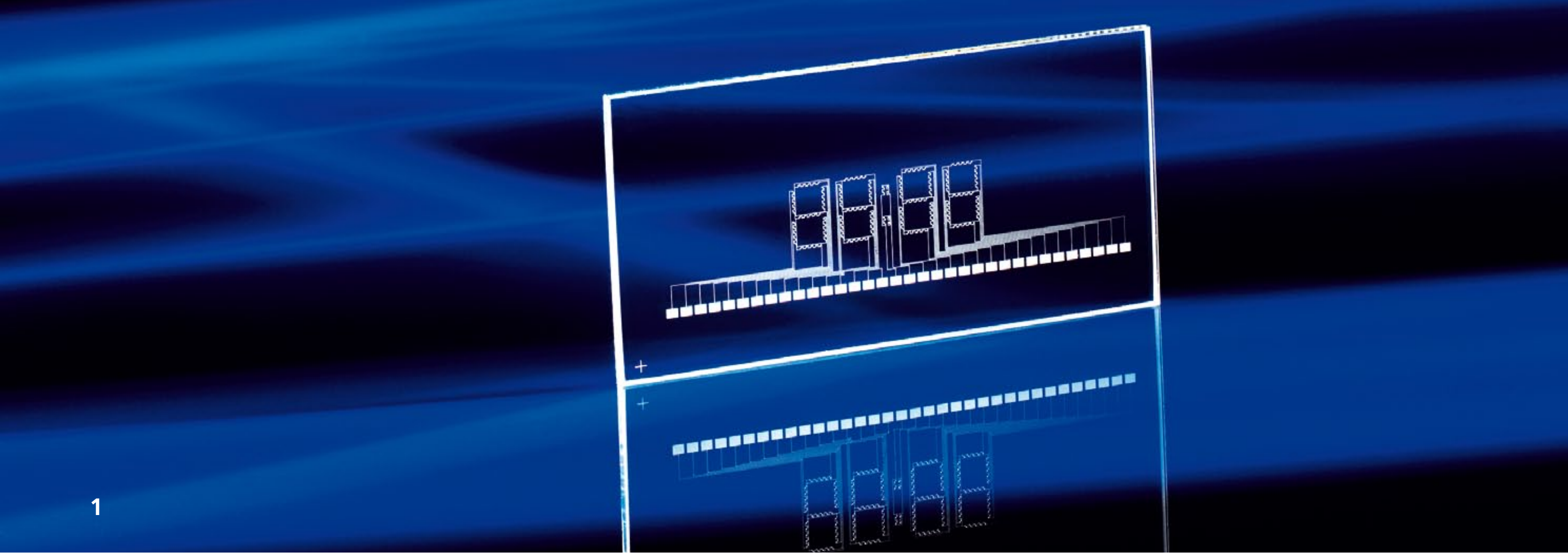
1a *Complex EPS pattern (BMW cylinder head).*
1b *Complex Lost foam casting (BMW cylinder head).*
3 *Geometry of a real component of the firm RWP.*
6 *Numerical simulation of the mold filling (BMW cylinder head).*



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STRONG LIGHT FROM THE PRINTER

The EU project MULTIPRO has set itself an ambitious goal: More efficient and lower-cost LEDs for lighting, the automotive industry and displays thanks to multifunctional materials. And the special effect: The materials are simply printed.

The challenge: Efficient multifunctional materials for LEDs

Light-emitting diodes are being applied in more and more areas, since they have some advantages over conventional light bulbs. In comparison with conventional light bulbs, LEDs are only slightly warmed during operation, they have a longer life and they are more efficient.

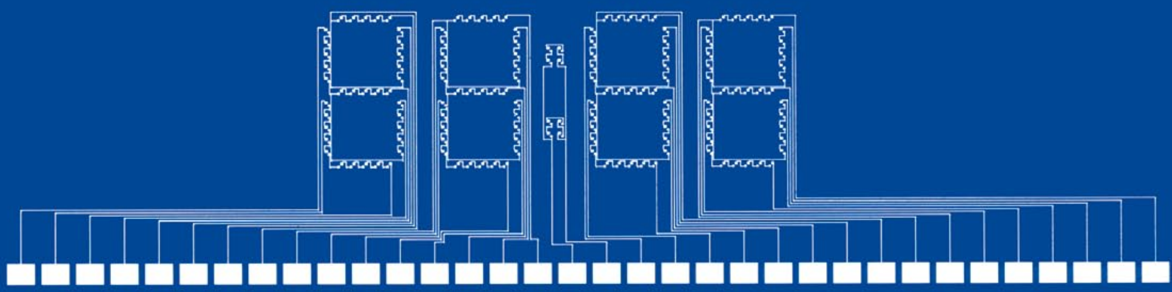
In the EU project MULTIPRO, the task is to enhance the efficiency of LEDs with multifunctional materials and to simultaneously make them more flexible and cheaper by using an innovative printing. To do this, electrically conductive materials to print conducting paths for bonding of LEDs, as well as multifunctional materials with different nanoparticles to encapsulate the LEDs are being engineered (Fig. 2). Using nanoparticles means that the refractive index of the materials can be increased, thus improving the light emission of the LEDs. At the same time, the nanoparticles ensure a wavelength modulation of the light, so that, for instance, a blue LED generates white light. The multifunctional materials are applied using a mask-less printing technology (Aerosol Jet®). In parallel to the practical work, we are also simulating the multifunctional materials' characteristics with Molecular Modeling.

Altogether, nine partners from four countries are involved in the project, and these partners have positions throughout the entire process chain, from simulation to manufacturing and application. Several universities, research facilities and small- and medium-sized companies are among the partners. Possible ranges of application for the new LEDs are the automotive industry, general lighting, and displays. In the MULTIPRO project, Fraunhofer IFAM is working on the application of multifunctional materials by means of the Aerosol-Jet®-technology.

The task: Engineering of procedural know-how and materials

The use of a mask-less printing technology makes it possible to flexibly deposit the multifunctional materials on various surfaces. To do this, the material is first sprayed in a so-called "atomizer" into an aerosol. This aerosol is transported to the printhead and focused afterwards (Fig. 3). The Aerosol-Jet®-technique allows the mask-free application of materials with minimal line widths of less than 10 micrometers. After having fully utilized the materials by printing, they are thermally activated to achieve the intended properties, such as electrical conductivity or hardening of a polymer.

For the bonding of LEDs, we need electrically conductive materials. For this purpose, different silver and silver-copper inks are designed and modified for use with the Aerosol-Jet®-



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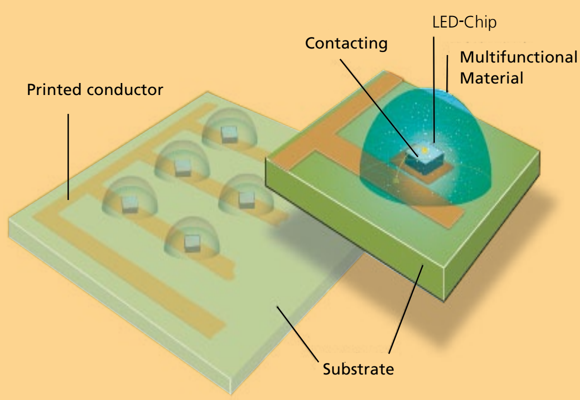

Fig. 2: Principle view of the innovative lighting technology (© Neotech Services MTP).

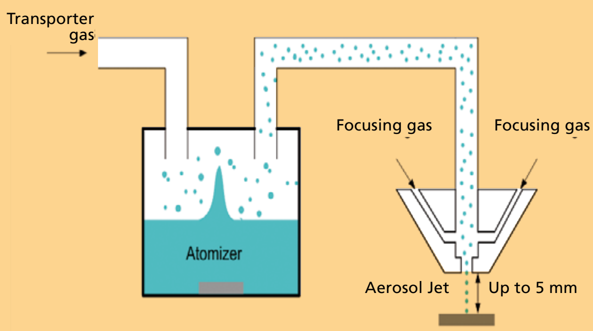

Fig. 3: Principle view of the Aerosol-Jet®-technology by Optomec Inc.

technique. The materials for the encapsulation of the LEDs consist of a hybrid polymer, in which nanoparticles are also incorporated to change the wavelength of the light.

The result: Printed 7-segment-display on transparent substrate

Within the scope of MULTIPRO, we succeeded in engineering different multifunctional materials and adapted them to the printing technology. We evaluated electrically conductive inks with different metal contents, as well as different viscosities, and printed them with the Aerosol-Jet®-technology. After the optimization of the process parameters, we were able to achieve a maximal electrical conductivity of 70 per cent in comparison with pure silver.

Based on these results, we produced a printed 7-segment-display for a digital clock on a transparent substrate (Fig. 1, 4 and 5). Furthermore, we used hybrid polymers with a high refractive index of 1.62 at 620 nanometers and applied them to encapsulate LEDs.

Project funding

The project was funded by the European Union as a part of the 6th Frame Program.

Project partners

- Centro Ricerche Plast-Optica, Italy
- Università degli Studi di Padova, Italy
- Università degli Studi di Trieste, Italy
- E. Hala Laboratory of Thermodynamics, Czech Republic
- Neotech, Germany
- Fraunhofer IFAM, Germany
- Cima Nano Tech Israel, Israel
- Sol-Gel Technologies Ltd., Israel

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1 | 4 *Aerosol printed 7-segment-display.*
5 *Printed 7-segment-display for digital clock in cooperation with Centro Ricerche Plast-Optica.*

NANOSCALED CATALYSTS AS A SUCCESSFUL PARADIGM TO REDUCE EMISSIONS FROM COMBUSTION ENGINES

The requirements for an environmentally friendly car are demanding: It has to be manufactured in a manner that conserves resources, it has to be extremely fuel-efficient and should emit a minimum of contaminants into the air. To address this last concern by reducing exhaust emission, we in the department Functional Structures have developed catalytically active materials that contribute to decreasing soot.

The automobile and the future

The future development of individual mobility is an essential topic in our lives. The phenomenon of electric mobility, which has only just begun, will help to reduce the consumption of fossil fuels and, as a corollary, the negative impact on our environment. The current initiative by the Federal Government anticipates that by 2020 approximately one million electric vehicles will be driven in our streets, making Germany the leader in this technology. However, assuming that there are around 47 million cars registered in Germany alone, it is obvious that it will probably take several more generations of vehicles with combustion engines before electric mobility is generally accepted. Consequently, in particular because of the increasing quantity of vehicles and the simultaneous shortages of fuel, it is also essential to improve combustion engines to reduce consumption and environmental impact as much as possible.

One way to improve the environmental compatibility of a combustion engine is to reduce consumption or to minimize pollutant emission. In the promotional program "WING – Materials Innovations for Industry and Society", the common project "NanoKat" was part of the lead innovation "NanoMobil". This joint project was aimed at the development, manufacturing and testing of new, nanostructured, catalytically active materials to reduce the pollutant emissions of combustion motors. These materials should allow for dramatically improved efficiency in soot reduction over a wide range of temperatures and thus contribute to environmentally compatible transportation due to the after-treatment of exhaust gas and, if necessary, treatment within the combustion engine as well. Within the scope of this project, cobalt and platinum were used as catalytically active materials, and Al_2O_3, CeO_2 and SiO_2 were investigated as carrier materials.

First target: Improvement of existing catalytic systems with nanoscaled coatings

For the actual target to further diminish the exhaust of soot particles from diesel passenger cars, we relied on the

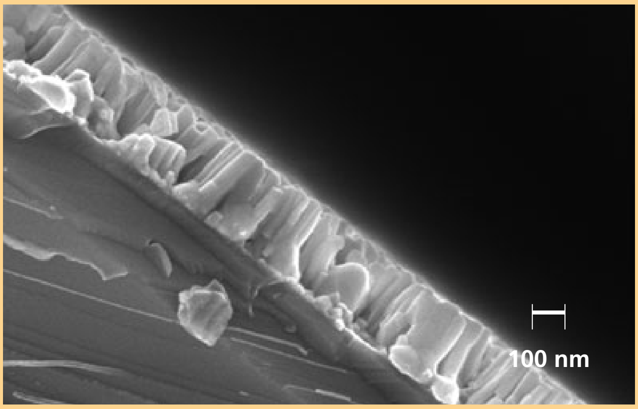

Fig. 1a: Pure nano cobalt, annealed at 400 °C for one hour in nitrogen atmosphere; considerable sintering of the coating can be observed.

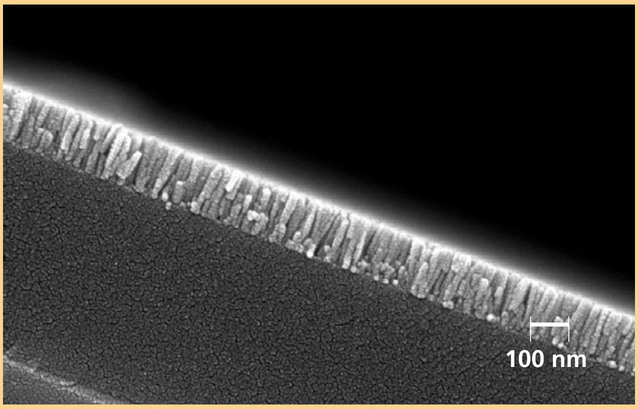

Fig. 1b: Cobalt silica composite, annealed at 400 °C for one hour in nitrogen atmosphere; no obvious effect of the temperature treatment.

already existing concept of the diesel particle filter (DPF). In this application, the task was to introduce the regeneration of the particle filters even at exhaust temperatures below 400 °C by means of a catalytically active surface. Previous systems require temperatures of about 600 °C and thus more energy, which is made available by the combustion of fuel. Regarding the soot incineration, the task was to increase the incineration rate in comparison with existing systems. Diesel particle filters made of silicon carbide were coated with nanoscaled oxidic carrier materials in combination with catalytically active, nanoscaled metals. The coating was deposited with a sol-gel procedure. Thanks to the advantages of the nanostructure, solution concepts like these promise to reduce the activation energy and thus to lower the temperatures required for optimal incineration.

Nevertheless, the catalysts have to withstand temperatures of around 400 °C. In this project, at first, pure catalyst layers were deposited and investigated under conditions similar to practical use. The layers were not able to withstand the temperatures and were sintered together, which results in a significant reduction of the specific surface and thus the catalytic activity (Fig. 1a).

This was prevented by the use of catalyst-metal oxide composites, that is compounds of platinum or cobalt with Al_2O_3, CeO_2 as well as SiO_2. The metal oxides are intended to increase the stability of the catalytic layers, since they prevent sintering of the nanoparticles. Under identical test conditions, no sintering can be observed. This means that the layers remain stable under the specified conditions (Fig. 1b).

Investigations in this project demonstrated that it is possible to significantly lower the soot incineration temperature by using the engineered material for the catalytic soot oxidation. The evaluated materials were then transferred to application-oriented demonstrator components according to diesel particle filters in current use, with which we carried out comprehensive functional inspections using engine test stands from our industrial partners.

Second target: Enhancement of the entire exhaust system

In this project, to which Fraunhofer IFAM made a major contribution, we used an innovative approach to minimize emissions. The aim is to apply thin, catalytically active films directly within the engine bay, which means on the piston floor or in the area close to the combustion chamber. By applying these layers close to the fuel combustion, it should be possible to partially reduce the contaminants formed there. This would relieve the diesel particle filter and thus further reduce fuel consumption, since regeneration would occur less frequently.

These layers have to fulfill both stringent thermal requirements and mechanical stability, since fuel is injected and combusted in direct contact with the piston floor.

With catalytic layers, in general, we aim at as large a surface as possible. However, highly porous layers like these have a relatively low mechanical stability. For this reason, they cannot be used in most technical applications. In contrast, dense layers are mechanically stable, but their specific surface for heterogeneous catalysis is too small. A good compromise is a columnar shaped layer, which has a relatively large surface and is of higher mechanical stability than a highly porous layer. Magnetron sputtering is a technique suitable for producing layers of such requirements.

The process: Manufacturing of customized catalytic layers

At Fraunhofer IFAM, we produced catalytically active materials by means of Physical Vapor Deposition through magnetron sputtering. In this procedure, argon ions are accelerated onto the material to be processed using electrical and magnetic fields. Consequently, this material is transformed into a gas and is deposited homogeneously on the substrates that are to be coated (Fig. 2).

Here, we may vary the porosity of the layers between 0 and 95 percent as a function of the sputtering parameters. This means that we may generate both dense and highly porous layers. Consequently, it is possible to modify the layers according to the applied process, customized to the corresponding

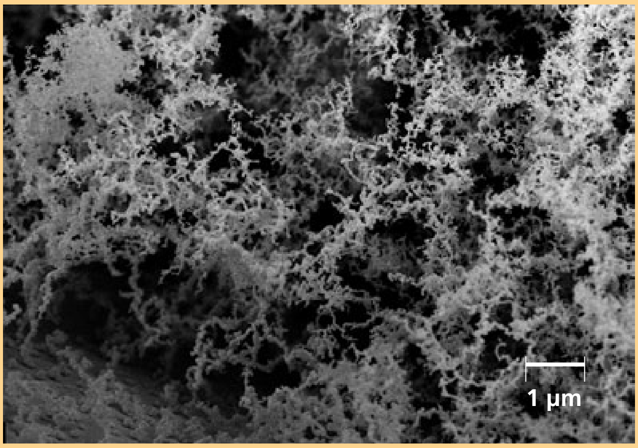

Fig. 3: Cobalt, highly porous layer growth, sputtering pressure 0.8 mbar, sputtering power 400 W, sputtering time 120 minutes.

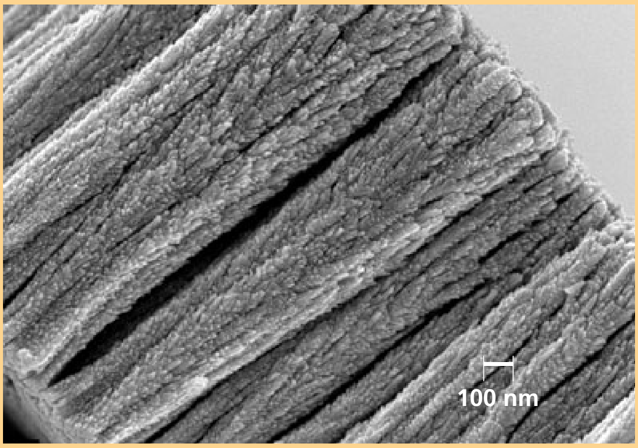

Fig. 4: Platinum, pillar-like layer growth, sputtering pressure 0.2 mbar, sputtering power 300 W, sputtering time 20 minutes.

application. The so-called co-sputtering makes it possible to generate special alloys or composites made of different materials, like those tested here in the project. This way, it is possible to incorporate sinter inhibitors into the catalytic layers, which significantly increases the thermal stability of the catalytic coatings as shown in the project.

To investigate the influence of catalytic layers on the kinetic characteristics of combustion preliminary reactions, optical measurements in a diesel combustion chamber have to be taken. Layers like these have a great potential for the application in the combustion chamber and on components close to the combustion chamber, so as to avoid carbon-containing deposits. A patent application has been filed for both the technique and the generation of these layers.

Summary

In this research project, we achieved a clear decrease in the incineration temperature while maintaining the same efficiency in the diesel particle filter (DPF). Consequently, less fuel has to be injected for regeneration, and this circumstance has a positive effect on the fuel consumption of the engines and thus their environmental impact. An additional benefit of the lower temperatures during soot incineration is the longer life of the corresponding components. A major advantage of these systems is their stability. After a number of cycles, the efficiency of the diesel particle filter remained constantly at 100 per cent. We can diminish the formation of contaminants when successfully implementing a catalyst layer in the combustion chamber. For that reason, the environmental impact due to the combustion process is reduced. Contamination of the DPF is diminished. Consequently, the intervals for regeneration become longer. Thus, with layers like these, we may further increase the efficiency of the entire exhaust system and reduce fuel consumption.

Project funding

The project was promoted by the federal ministry for economy and technology, ident FKZ 19U5028A/19U5028E.

Project partners

- Fraunhofer Institute for Surface Engineering and Thin Films IST, Braunschweig
- Volkswagen AG, Wolfsburg
- Evonik Degussa GmbH, Frankfurt am Main
- J. Eberspächer GmbH & Co. KG, Esslingen
- Saarland University, Professorship for Technical Chemistry
- Heidelberg University, Institute for Physical Chemistry

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1 *Functional thin films produced with magnetron sputtering.*
2 *Magnetron sputtering system.*

1

NEW TECHNOLOGIES FOR CELLULAR METALLIC STRUCTURES

Whether direct typed cellular structures, 3-dimensional wire structures or porous metallic papers – the variety of developments in the field of cellular metallic materials is currently being extended by innovative ideas and paradigms.

Situation

In the Dresden branch lab of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials, cellular metallic materials have been engineered for more than 10 years. In the beginning, we applied highly porous metallic fiber structures. The fine fibers required for this purpose were produced in-house with the so-called melt extraction technology. This unique technology allows us, for instance, to manufacture special fibers with a rapidly solidified structure or fiber compositions that cannot be produced with conventional methods, such as chasing or wire drawing (for instance Ni_3Al).

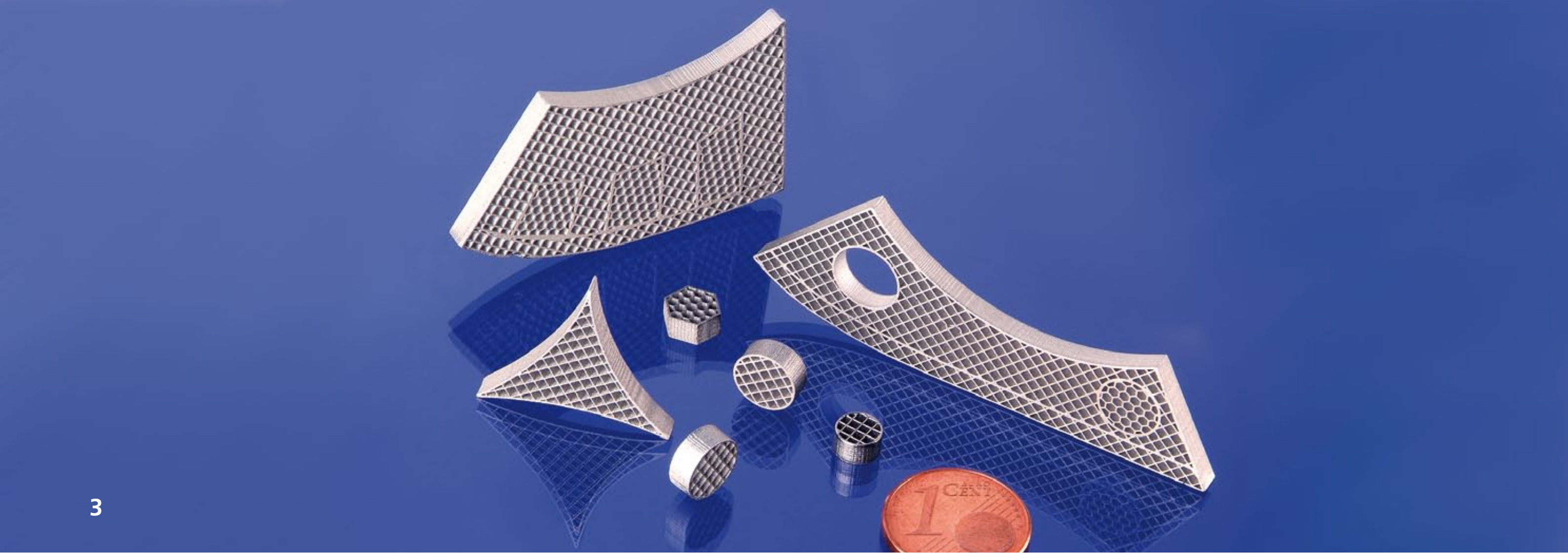
Numerous national and international research and engineering projects have investigated metallic fiber structures. In these projects, we developed and successfully tested filter plugs for hot gas filtration to be used in electric arc furnaces (EU project POMFICO) or heat exchangers for Sterling machines (growth core InnoZellMet).

In recent years, we have intensified our work on developing metallic hollow spheres and hollow sphere structures. In numerous R&D projects, both the manufacturing technology and demonstrators or prototypes made of hollow sphere structures that are relevant for applications were engineered and tested. Hollow sphere structures are particularly efficient as materials to dampen sound. Thus, for instance, sound absorbers made of hollow sphere structures were investigated for applications in passenger cars (Fig. 1). We succeeded in carrying out vehicle tests with running capacities of almost 100,000 kilometers. A major advantage also arose from a reduction of approximately 25 to 30 per cent of the total sound absorber weight.

To address the great application potential of metallic hollow sphere structures, the long-term industrial partner of the institute, the firm Glatt Systemtechnik Dresden, founded the subsidiary “hollomet”.

The most recent development projects in the field of hollow sphere structures focus on using hollow spheres filled with ceramic particles to enhance dampening of structure-borne noise (see also the project report by U. Jehring/T. Hutsch, page 66).

Over the last five years, research activities in the field of open cell powder-metallurgical foams have developed particularly successfully. Development projects on bioanalogous bone structures have received a particular impetus with titanium-based open cell foams. The challenge is to implement a technology that makes it possible to reduce the impurity content of carbon, oxygen and nitrogen well below 0.5 percent by weight. This way, we may guarantee that the mechanical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properties, particularly ductility, can meet the requirements.

In the first implantation tests carried out on an animal (sheep) at the university hospitals of the LMU Munich and Dresden (Fig. 2), both the necessary performance in terms of mechanical properties and ingrowth of natural bone tissue including the blood vessels were verified.

In recent years, we have succeeded in providing the technological foundation in the field of direct typed cellular structures. Particular emphasis is given to comprehensive investigations on the rheological characteristics of metal powder-based suspensions for the printing procedure.

With this technique and our knowledge of the fundamental technological relationships, we were able to verify that very different materials, such as pure metals, alloys and intermetallics, may be printed on to complex and highly precise structures (Fig. 3).

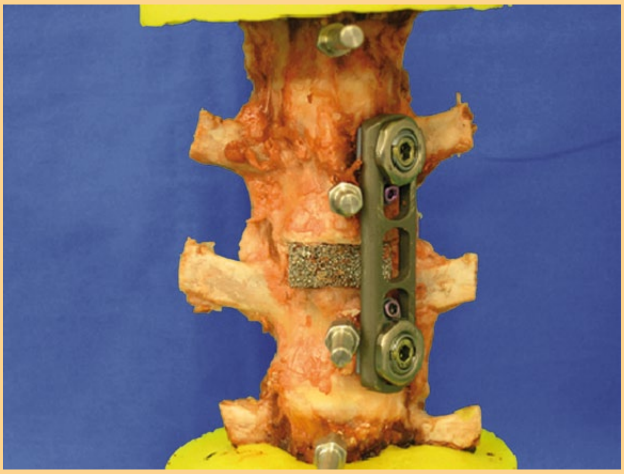
Fig. 2: Implanted open-celled Ti-foam (animal model sheep).

Research potential and current projects

Three-dimensional wire structures

Cellular materials based on three-dimensional wire structures are a new variant of cellular structures. These are periodically spatial bar structures. For large-scale industrial application, structures like these are applied as supporting structures in architecture, for example in bridges, buildings or scaffolds. In the relevant technical literature, various procedural approaches like stamping, casting, or metal forming by stretching have been described up to now. However, these techniques have not yet gone beyond the laboratory. The technological paradigm followed by an R&D joint project to manufacture 3-D wire structures is aimed at processing these wires, which are preformed in a helical shape, and using the corresponding machinery, in x-, y- and z-direction so as to create a spatial wire structure (Fig. 4).

Another variant is the textile processing of metal wires. Preliminary investigations carried out at the TU Dresden, Institute for Textile Engineering, demonstrated that only steel wires of a diameter less than 0.3 millimeter may be processed into wire structures. For this technological variant, specific requirements have to be fulfilled by the mechanical properties (tensile strength, yield strength, elongation) of the wires to be processed.

In addition to the manufacture of the spatial wire structure, in a second procedural step, it is necessary to join this structure materially to the wire contact points. The selection of the joining procedure, such as soldering or adhering, may follow subsequent requirements and ranges of application. From figure 5, we may see the significant influence of the material joining procedure, in our example, soldering, on the compressive strength of the wire structure.

Spatial wire structures are characterized by a high degree of reproducibility and, thus, homogeneity. These are calculable

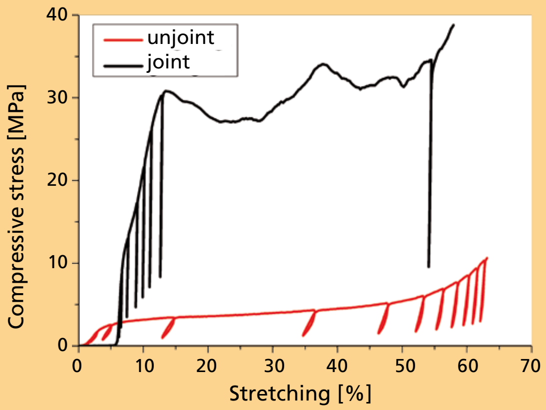

Fig. 5: Compressive strength of unjoint and joint 3D wire structures (stainless steel 1.3401).

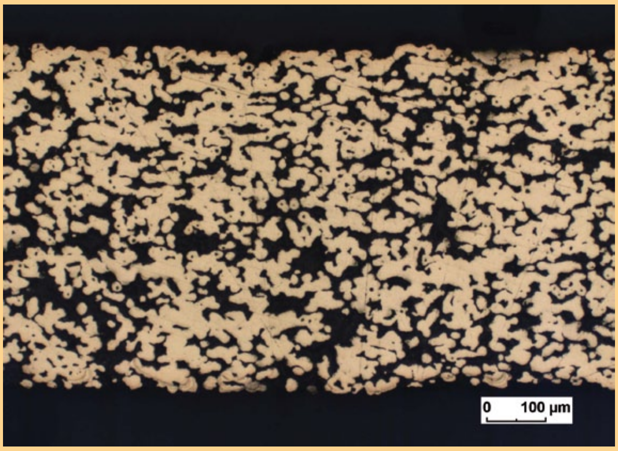

Fig. 7: Cross-section of porous sintered papers made of copper.

cellular structures. Currently, the corresponding simulation calculations are carried out based on developing models in a current project. 3-D wire structures are materials for lightweight construction that are characterized by an extremely low specific weight (for example 0.05 g/cm³), which has not been achieved with previous technologies to manufacture metallic foam materials. Promising ranges of 3-D wire structure application are permanent cores for highly loaded castings, core structures for lightweight sandwich designs or reinforcement components for polymer composite materials.

Porous sintered papers

An entirely new technological paradigm is traced with engineering so-called porous sintered papers. In this approach, paper and sintering technologies are combined. In classical papermaking, in addition to cellulose, filling materials such as kaolin, barite and other additives are added to a significant extent in order to obtain the typical properties of paper. In the case of sintered papers, the filling materials mentioned above are replaced by metal powder, with widely variable filling levels.

In 2009, in cooperation with the Papiertechnische Stiftung in Munich and Heidenau, a research initiative was begun to demonstrate the general manufacturing feasibility of sintered paper. Stainless steel powder 1.4401 and copper powder were chosen as model materials. Papers of 0.3 to 0.7 millimeter thickness, filled with metal powder, were made on a sheet forming unit, with filling levels from 75 to 88 weigh percentage.

In addition to papers filled in a 2-D manner, we also succeeded in making wavy papers. Other forming trials with papers filled with metal powder showed manufacturing opportunities similar to those for classical papers (Fig. 6). These forming options open up a great potential for future ranges of application for sintered paper. In a second step, the filled "green" papers are debindered, which means that cellulose and other additives necessary for the paper processing technology are thermally removed (300 to 500 °C). Sintering, which sets up the final properties of the sintered papers, is carried out in another technological step.

The sintered papers are open porous, so that the overall porosity may be adjusted over a wide range from about 20 to 70 percent (Fig. 7).

Porous sintered papers may be applied in a wide range of


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industries. Substantial use is expected, in particular, in the field of filtration of gases, liquids and particles. Other fields of application include sound absorption, thermal insulation, electrodes, catalyst carriers, electromagnetic yielding, heat exchangers and evaporators.

Summary and outlook

At the Dresden branch lab of Fraunhofer IFAM, numerous techniques to produce highly porous or cellular metallic materials have been developed in recent years. All of these methods are characterized by a great flexibility in material selection. Furthermore, they cover a wide range of pore sizes and morphologies, as well as overall porosity.

Besides a significant reduction in weight, the cellular metals are characterized by an additional multifunctionality (energy absorption, low thermal conductivity, sound absorption, large specific surface, etc.).

In the field of metallic hollow sphere structures, our long-term project partner, the firm Glatt Systemtechnik Dresden, founded the hollomet GmbH. In 2010, a firm specializing in open cellular titanium-based biomaterial, the company Poromes GmbH, will also be established by our long-term project partner InnoTERE GmbH Dresden.

To increase the degree of popularity of cellular metal foams, the Dresden branch lab of Fraunhofer IFAM organized and held two international symposia, entitled "Cellular Metals for Structural and Functional Applications" (CELLMET), in 2005 and 2008. The aim was to inform particularly the users from industry of the potential of cellular metallic materials and to initiate an international knowledge exchange. The next event in this series will be the CELLMAT 2010 to be held in Dresden in October 2010.

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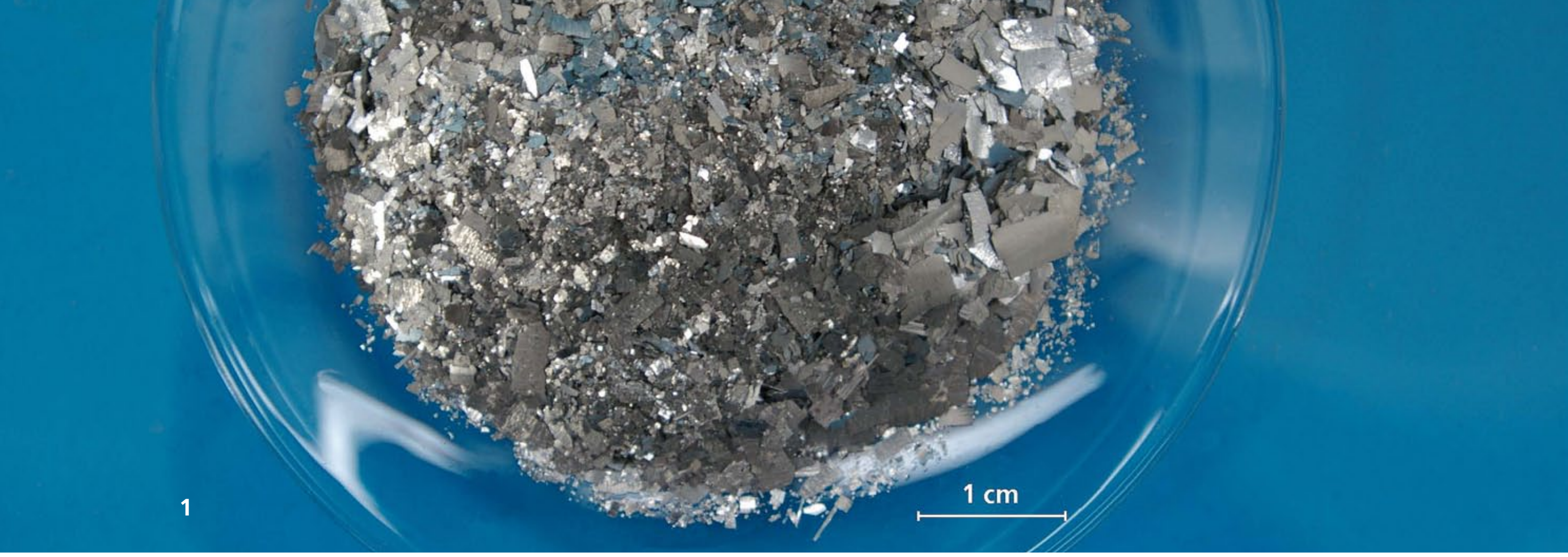
1 *Sound absorber with sintered hollow sphere structures as sound absorbing material.*
3 *Direct typed structures made of stainless steel 1.4401.*
4 *3-dimensional wire structures made of stainless steel 1.3401.*
6 *Sintered papers filled with metal powder and processed.*



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SINTERED THERMOELECTRIC MATERIALS FOR ENERGY HARVESTING

The generation and storage of energy is a highly topical problem at present. Consequently, the relevant alternative sources of energy are being explored in the domain of sintered and composite materials. Here, energy may be directly generated out of the environment, for instance by means of thermoelectric materials.

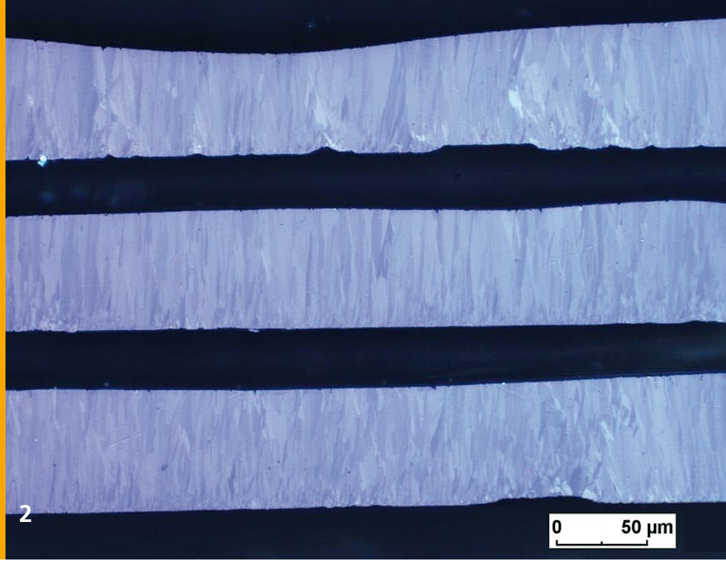
Initial situation

Energy storage in batteries or accumulators cannot be extended indefinitely, since in most applications, weight and/or volume are limited. At the same time, increasingly longer life for electrically driven systems is desired. Even external supplies are not suitable in every case due to power packs and high installation and maintenance costs. Because of the energy balance in sensor networks, many applications, such as monitoring of buildings like bridges, monuments, etc., or medical implants, are not possible at all, since the required service life lasts between a few weeks and several years. Service life is determined by energy consumption, that is, the power needed for communication among the individual sensor nodes.

Using alternative energy sources and suitable transformers, such as thermogenerators, either a percentage or the entire volume of energy required for mobile consumers may be obtained from the environment. Thermogenerators are semiconductor components made of thermoelectric materials able to convert temperature differences directly into electrical energy in a reversible manner. Such modules have been used for the current generation of satellites for many years, but are now also applied to make use of geothermal energy and industrial waste heat.

Project description

The aim of the project "Thermoelectric Nanocomposites", which went on for over three years, was to produce highly efficient, nanostructured thermoelectric materials for applications at room temperature and to establish a technology platform enabling the production of Peltier and Seebeck elements on an industrial scale. To do this, we developed a universal energy supply module to obtain energy from the environment by means of a thermogenerator. As an exemplary application, we implemented a direct power supply through integration in mobile devices (sensor nodes). The combination with the data recording and transmission module means that we can create a very flexible system with a wide variety of application options. Depending on the requirements, different sensors can be used to measure temperature, or humidity, or blood oxygen content, and to transmit these values wirelessly to the receiver. Material development, as well as material and system characterization was performed at the Fraunhofer Institute for



Physical Measurement Techniques IPM, Freiburg. The electronic components were implemented at the Fraunhofer Institute for Integrated Circuits IIS, Nuremberg.

The subproject of the Dresden branch lab of Fraunhofer IFAM dealt with manufacturing and processing of ultra-fine structured thermoelectric materials up to the semi-finished product. Commercially and specially manufactured pre-alloys based on $(Bi,Sb)_2(Se,Te)_3$, the present standard material for applications at room temperature, served as initial materials.

Results

Since one target was to produce nanostructured thermoelectrica, the entire process chain was designed from the onset of the project so that existing ultra-fine precipitations in the structure would not be destroyed.

The nanocomposites are manufactured through the targeted formation of second stages within the material. To make this process reality, the project partners engineered specific material systems and evaluated special manufacturing techniques for this purpose. To do this, we produced homogeneous melts segregated during crystallization in two stages. Since the melting particles had to be relatively small and included cracks and blowholes from cooling down, they could not be used as they were. To build up thermoelectric components with segment heights of several millimeters, it was necessary to continue processing them. To do this, they were carefully reduced in size and afterwards compacted with a short-term sintering technique – Spark Plasma Sintering (SPS).

This is a modified hot-press method, in which a pulsed DC flows through the material to be sintered and/or through the stamping die and thus directly heats up this material. With this technique, one may realize process times from a few seconds to a few minutes, thereby generally avoiding grain growth procedures.

Due to their crystal structure, the thermoelectric properties of $(Bi,Sb)_2(Se,Te)_3$ mainly depend on the direction. For this reason, sintering particles with a statistical orientation of the grains within the structure systematically show poor values. This phenomenon drastically reduces the efficiency, so that it is simply impossible to make an economical use of these materials. Consequently, it is advantageous to incorporate a preferential orientation. Since the monocrystals have a cracking direction in parallel to the thermoelectric preferential direction, their reduction in size always results in lamellae whose best thermoelectric properties are located within the lamellar plane. As the material is filled into the press mold and during the follow-up sintering procedure, most particles orient themselves so that the flat sides are situated on top of each other and perpendicular to the pressing direction.

To achieve this texture, we designed a sintering mode that both offers a sound grain-to-grain contact and causes only a few changes within the structures. Powder mixtures with special grain size distribution are sintered so that a liquid stage is temporarily formed. Whereas smaller particles completely melt, the large particles remain generally intact. Thus, a material is formed in which large grains with preferential orientation are embedded into a fine-grain matrix of random orientation of the same compound. In these sintering particles, the direction with the best thermo-electric properties lies in the disk plane. However, this phenomenon is disadvantageous to the individual segment compared to later processing, since processing starting from the end faces of the disks is much easier.

One alternative is to use lamellae as they appear in melt spinning. This quick solidification method, which is also applied to produce high-performance aluminum alloys or magnet materials, also works without the expensive step of manufacturing a pre-alloy and breaking it into pieces. In this case, the product

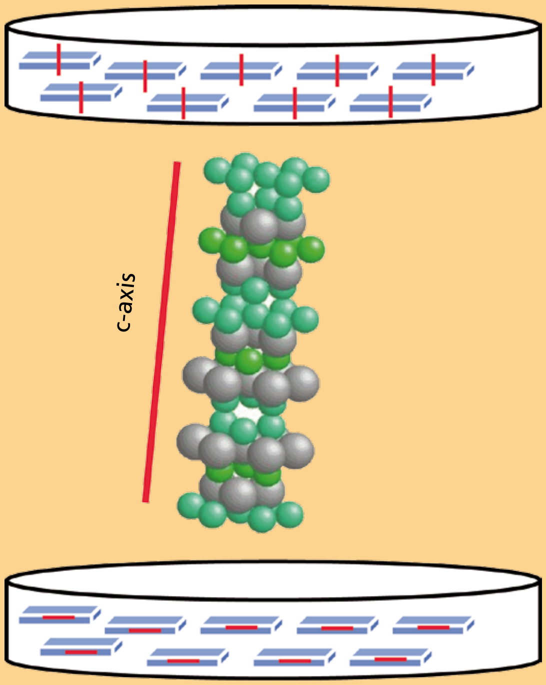


Fig. 3: Schematic view of the preferential orientation of large grains in sintering particles of directionally solidified $(Bi,Sb)_2(Se,Te)_3$ (top) and rapidly solidified $(Bi,Sb)_2(Se,Te)_3$ (bottom) in coparison with the crystal structure. The directions of the best thermoelectric properties lie perpendicular to the c axis.

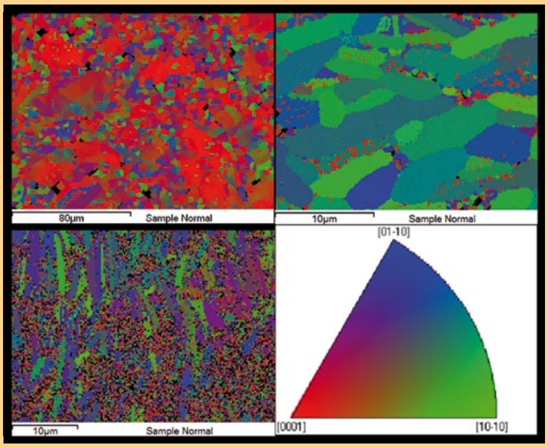
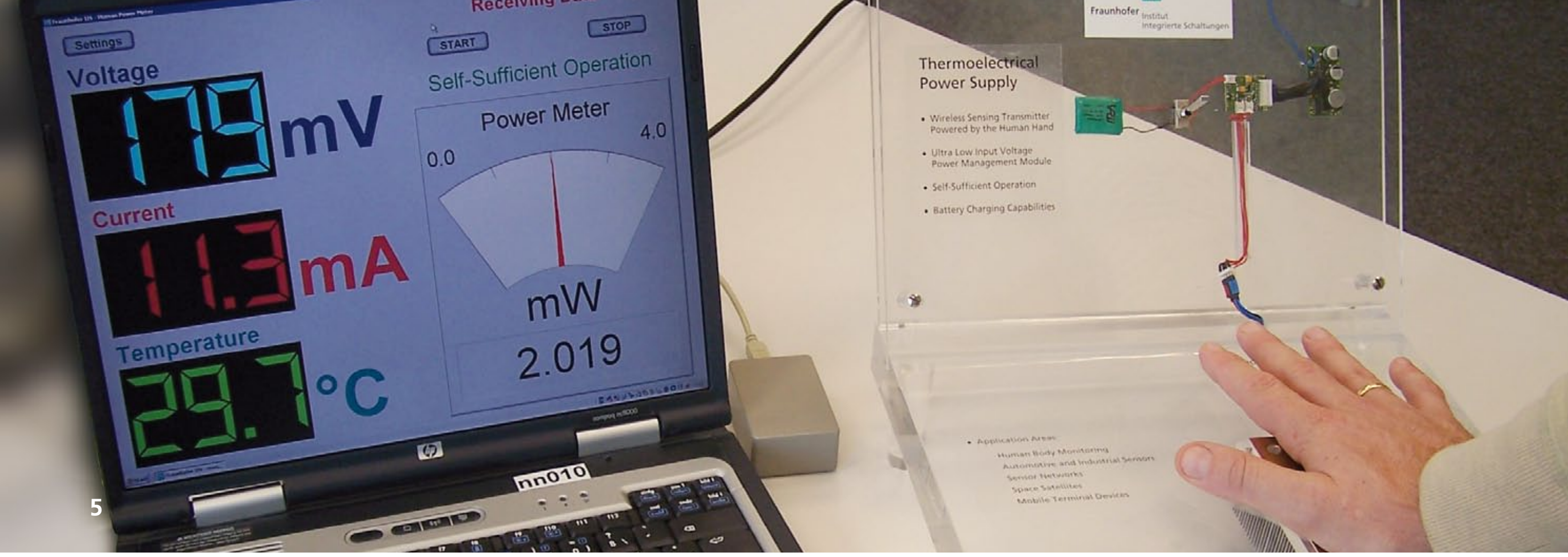


Fig. 4: Orientation map of sintered alloy based on $(Bi,Sb)_2(Se, Te)_3$ made from singlecrystalline melting particles (left top), of quickly solidified lamellae (right top) and sintering particles made of them (left bottom). The color coding of the crystallographic orientation is shown in the right bottom figure.

of melt spinning are lamellae of micrometer thickness, with edge lengths of a few millimeters. The high cooling rate results in small columnar shaped grains in the lamellae, whose best thermoelectric properties arise when lying perpendicularly to the former pouring direction (Fig. 3).

Textured sintering particles generated this way have thermoelectric properties that are, even assuming a conservative measurement, substantially better than the state of the art. In addition to this, it could be seen that the short-term sintered materials based on a $(Bi,Sb)_2(Se,Te)_3$ alloy have a relatively high mechanical stability. Since there are no marked cracking directions in the sintering particles that appear in monocrystals, bending strength is up to seven times higher. This makes it possible to produce modules of 100 micrometer thickness which could not be manufactured up to now in an economical manner using thin film technologies, and which will offer a wide application potential in the field of electronic cooling (Fig. 4).

Modules were built from these sintered materials, and the modules were successfully integrated into systems (Fig. 5).



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Perspectives

The results show that it is possible to produce highly efficient thermoelectric materials by means of short-time sintering or with the combination of quick solidification techniques and short-time sintering described above. With specific process guidance, we succeeded in generating sintering particles that take into account the thermoelectric anisotropy of the material and maintain the incorporated ultra-fine grains of the structure. With this technique, we can prepare initial materials of different shape (melting particles, powders, ribbons, flakes, etc.) and compact them in a follow-up step by means of the Spark Plasma sintering method. With this project, we have laid the cornerstone to enable processing both of thermoelectric and other functional materials with ultra-fine structures from the widest possible range of sources or synthesis lines. Semi-finished products and components can be directly integrated into existing manufacturing sequences at the customers' and users' sites.

Project funding
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1 *Rapidly solidified flakes made of (Bi, Sb)$_2$(Se, Te)$_3$ · 0.3 PbTe-alloy.*

2 *Metallographic cross section orthogonal to the basal layer of the lamellae in polarized light.*

5 *Demonstrator for a tradeshow – thermoelectric power generation from body heat. As an energy source, we are using a thermogenerator equipped with sintering materials. When a hand is placed on the copper plate, voltage is generated due to the temperature difference between body temperature and the surrounding air. The voltage is sufficient to start the electronic unit and to transfer measuring values wirelessly to the receiver.*

HIGHLY DAMPENING PM MATERIALS – THE RIGHT MATERIAL FOR EACH POSITION

At the Dresden branch lab of Fraunhofer IFAM, we are developing innovative powder-metallurgical materials that provide a variety of innovative application options, mainly for vehicle construction, and plant and mechanical engineering.

Initial situation

In recent decades, it has been confirmed that noise is not only a disturbance, but also a health hazard. The challenge is that ever more demanding requirements have to be fulfilled by manufacturing tolerances in mechanical engineering and plant design at higher manufacturing speeds. Traditionally, mostly high-density or polymer materials are used for the absorption of structure-borne sound. Polycrystalline materials mainly absorb via the thermo elastic effect, reversible dislocation motion and other reversible stress-induced effects. Polymer materials absorb to a great extent through the sliding of chain segments, ceramics through friction between the crack borders of intrinsic microcracks.

Highly dampening PM materials with great structure-borne sound absorption capacity provide new paradigms for use as passive dampening elements in a wide variety of designs.

Project description

Beginning with previous solutions for vibration damping, we traced two directions of development to enhance the dampening characteristics of materials for machines and plants. On the one hand, we engineered a material class with filled hollow sphere structures (German abbrev. GHKS) which achieves structure-borne sound absorption values that are almost independent of the temperature, like those that until now have only been observed with polymers at room temperature. This way, a high level of structure-borne sound absorption is also feasible for lightweight constructions, quickly moving machinery parts, and under extreme conditions.

On the other hand, the material class of the metal-graphite composite materials was refined so that compact components made by powder metallurgy whose graphite content is greater than 50 per cent by volume can be reproducibly manufactured. These components mostly combine very high absorption values and high stiffness with excellent thermophysical properties (heat conductivity, thermal coefficient of expansion). It is also noteworthy that the high solid lubricant content (graphite) offers an interesting starting point for tribologically stressed components or groups.

Filled hollow sphere structures

Manufacturing

Particle filled polymer spheres (carrying spheres) are coated by fluidization with a metal powder-binder suspension. Afterwards, the coated spheres are adhered with steam in a mold. In a next step, these moldings, as well as the single spheres, are subjected to heat treatment. In this way, the organic components are removed, and the metal powder film is compacted onto strong spherical shells. Inside the hollow sphere, after heat treatment, we find freely movable ceramic particles acting as vibration dampers. Sintered individual spheres may be filled into profiles and fixed there by adhesion or soldering. It is also possible to process the forming elements or individual spheres into sandwich structures or to pour in polymers or metals.

Damping mechanisms

Figure 1 shows the principle structure of a lightweight composite material with hollow spheres filled with particles. Vibrations transferred to the matrix are dampened as a function of the selected matrix material. As soon as the wave front meets the hollow shells, the sphere shell begins to vibrate. The movement of the different wall segments transforms the energy to the particles. The vibration energy is intermediately stored as the kinetic energy of the free moving particles and afterwards transformed into heat via friction and partially elastic impacts.

Properties

Filled hollow sphere structures allow for a blend of low density and high damping (Fig. 5). This combination offers interesting opportunities to be applied in designs using lightweight construction. Depending on the processing line of the filled hollow spheres to components, the stiffness of the mold solids varies between 0.5 GPa and 50 GPa, density between

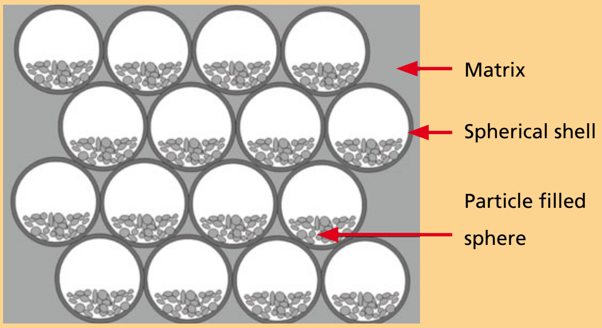


Fig.. 1: Schematic setup of a composite material with particle filled metal hollow spheres.

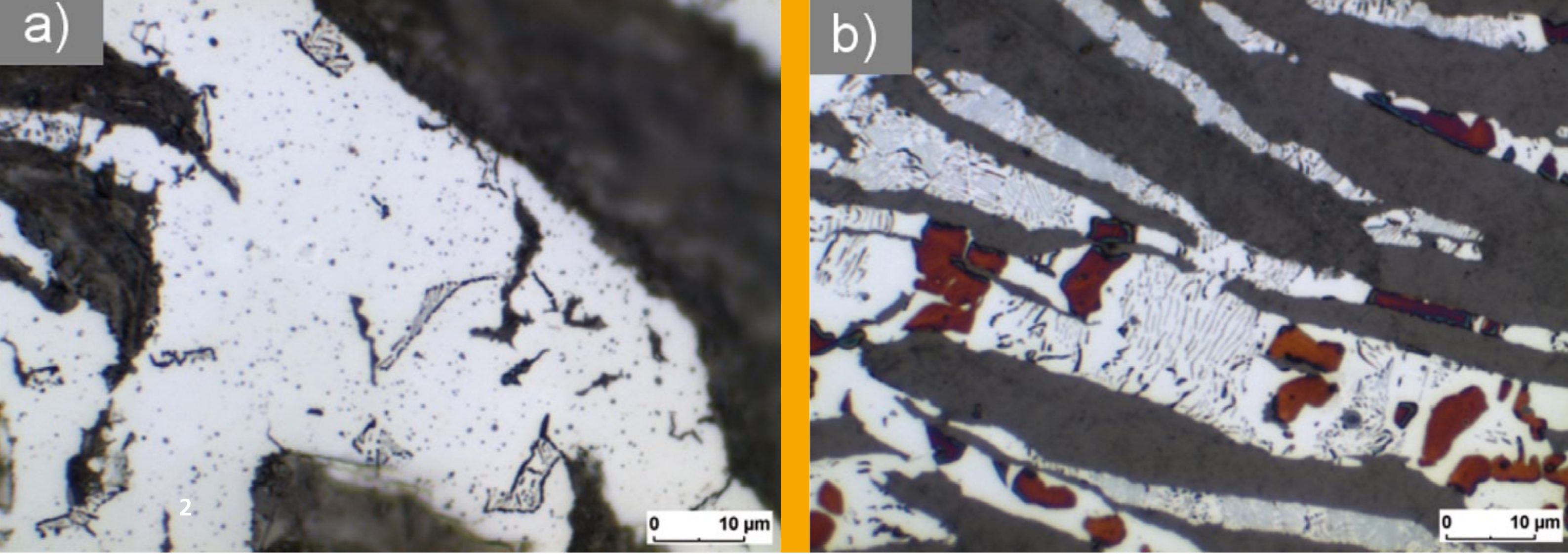
0.8 g/cm³ and 2.3 g/cm³, and damping between 0.018 and 0.18 (RFDA system 23 of the firm IMCE). At present, these values are only achieved with polymer materials at room temperature.

In contrast to slippage of carbon chains in polymer materials as a function of the temperature, vibration dampening may be performed by the particle movement in the filled hollow sphere structures, both at very low and very high temperatures.

Metal-graphite composite materials

Manufacturing

Metal-graphite composite materials are manufactured by mixing the matrix powder with graphite and afterwards using pressure-supported consolidation. The choice of the matrix metal is responsible for the various combinations that can be achieved – from the copper/graphite system which does not form carbide to the slightly carbide forming system of aluminum/graphite to highly carbide-forming systems like iron/graphite or tungsten/graphite. The carbide ratio formed due to



the reactivity between matrix and reinforcement component is set up through the sintering parameters (heating rate, sintering temperature, holding time and cooling rate). In the system iron/graphite, we may influence the structure by varying the sintering time at constant sintering temperature and thus adjust the parameters in a specific manner (Fig. 2).

With a short holding time (Fig. 2a, t=10 s), the graphite is embedded into a ferritic matrix with a very low ratio of grain boundary cementite. To extend the holding time means that more and more carbon diffuses into the matrix and forms the carbide phase (Fe_3C). The graphite is enclosed by a ferritic-perlitic matrix including partially cementite grains (Fig. 2b, t=20 min).

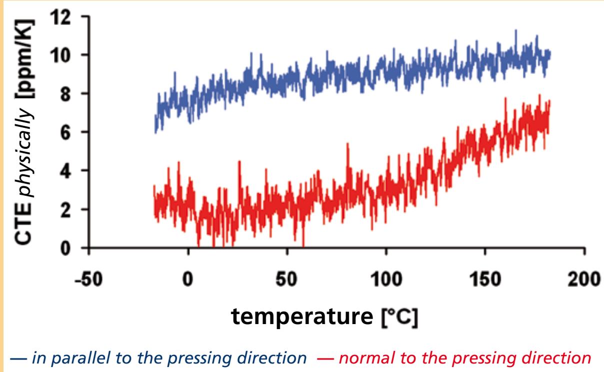


Fig. 3: Physical coefficient of thermal expansion (CTEphycical) of an Iron + 60 percentage by volume graphite composite material.

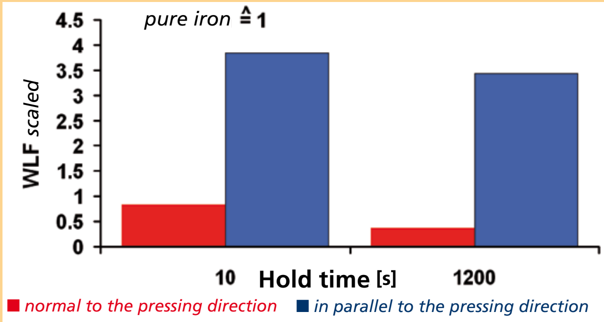


Fig. 4: Thermal conductivity (WLF) scaled to pure iron at room temperature of an iron matrix with 60 percentage by volume graphite.

Damping mechanisms

Transmitted vibrations are transformed into heat in the matrix, at the interfaces of the metal/graphite and predominantly inside the graphite. Damping increases as a function of the graphite ratio.

Properties

The metal-graphite composite materials whose density is greater than 2.2 g/cm³ not only exhibit excellent damping characteristics and great stiffness (Young's modulus greater than 150 GPa, Fig. 5), but also have extraordinary thermal expansion coefficients (Fig. 3) and heat conductivity (Fig. 4). The properties determined by application conditions or required by in mechanical engineering and plant design or for the use heat sink material may be specifically adjusted by variation of the graphite volume content.

Results and perspectives

New opportunities for passive vibration absorption arise from the new highly dampening PM materials. This is promising for applications in lightweight constructions, as well as in designs that must operate under extreme conditions (high temperature, aggressive media) in vehicle construction, plant design and mechanical engineering. There is also an opportunity to combine the damping characteristics with thermal conductivity, a reduced coefficient of thermal expansion (in comparison with metals) and stiffness.

Passive vibration dampening, high thermal conductivity, a low coefficient of thermal expansion, great stiffness and the high solid lubricant content of the metal-graphite composite

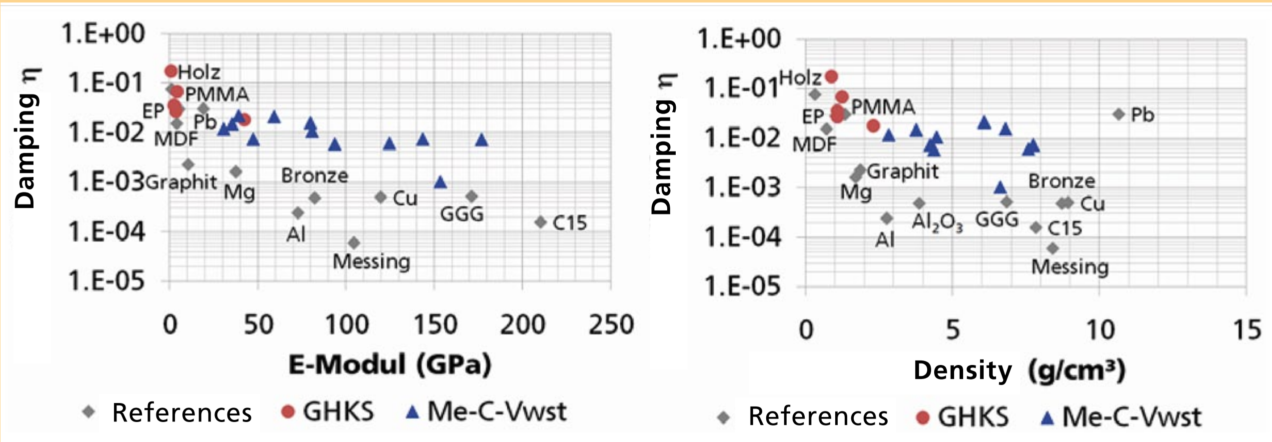


Fig. 5: Comparison of damping and stiffness of the highly damping PM materials with reference materials.

materials can be specifically considered in structures of plant design and mechanical engineering. Thus, for example, it is possible to intelligently combine the functions of heat dissipation and passive vibration dampening in the plummer block. On the other hand, for dampening of large-sized vibrations at high temperatures, sandwich design solutions consisting of filled hollow sphere structures are an alternative. They are relatively independent of temperature and have a low thermal conductivity. A hybrid structure made of filled hollow spheres and metal-graphite composite materials expands the range of applications for the designing engineer.

CONTACT

Filled Hollow Sphere Structures

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Metal-Graphite Composite Materials

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Institute

Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM,

Department of Shaping and Functional Materials, Dresden

2 *Structure formation as a function of the closing time at a sintering temperature (300 K/min, 1050 °C); a) Ferritic structure with grain boundary cementite (10 s); b) ferritic-perlitic with Fe_3C grains (20 min).*

ADHESIVE BONDING TECHNOLOGY AND SURFACES


2

EXPERTISE AND KNOW-HOW

The Department of Adhesive Bonding Technology and Surfaces at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM is the largest independent research group in Europe working in the area of industrial adhesive bonding technology and has more than 210 employees. The R&D activities focus on adhesive bonding technology, as well as plasma technology and paint/lacquer technology. The objective is to provide 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 Department of Adhesive Bonding Technology and Surfaces. Our activities range from fundamental research through to production and market introduction of new products. Industrial applications are mainly found in the car, rail vehicle, ship, and aircraft manufacturing sectors, and in the areas of plant construction, energy technology, packaging, textiles, electronics, microsystem engineering, and medical technology.

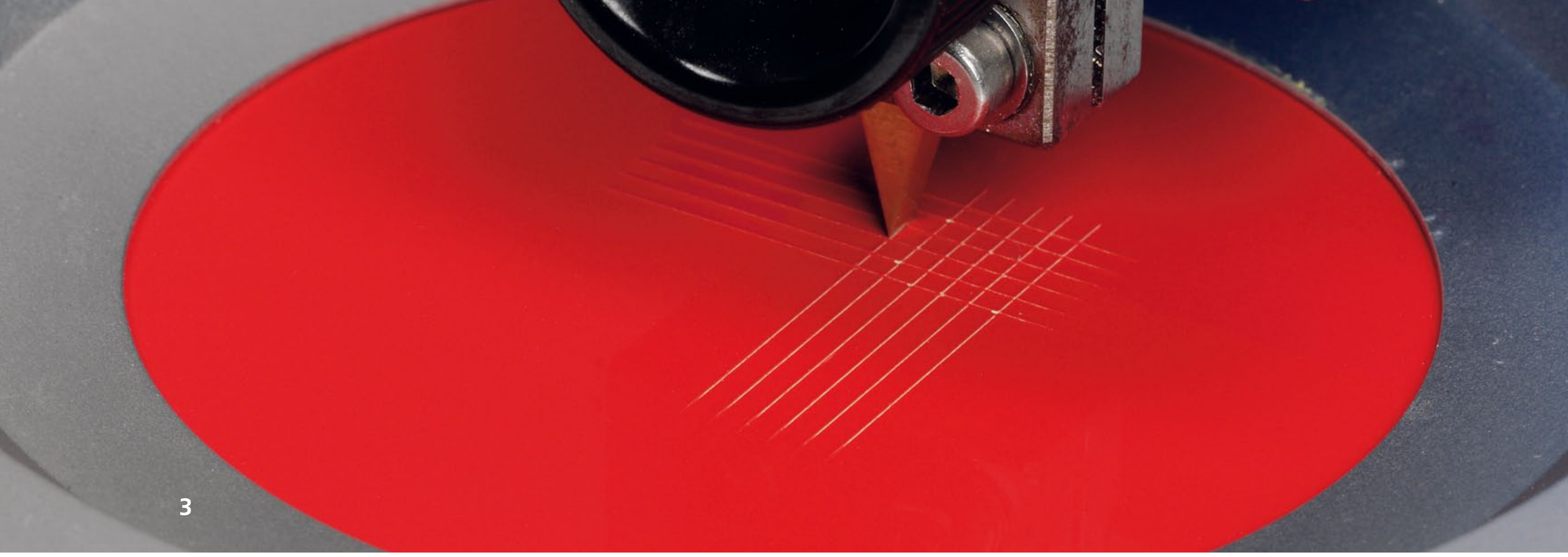
The work in the Adhesive Bonding Technology business unit involves the development and characterization of adhesives and matrix resins, the design and simulation of bonded, riveted, and hybrid joints, as well as the characterization, testing, and qualification of such joints. The planning and automation of industrial adhesive bonding applications are also undertaken. Other key activities are process reviews and providing certified training courses in adhesive bonding technology and fiber composite materials.

The work of the Surfaces business unit is subdivided into plasma technology and paint/lacquer technology. Customized surface modifications – for example surface pre-treatment prior to bonding/coating and functional coatings – considerably expand the industrial uses of many materials and in some cases are vital for using those materials.

The Adhesion and Interface Research business unit is involved, amongst other things, in the early detection of degradation phenomena, the validation of aging tests, and in-line surface monitoring. The results of this research work provide fundamental knowledge for adhesive bonding technology, for plasma technology as well as for paint/lacquer technology, and so contribute to the safety and reliability of bonded joints and coatings.

The Fraunhofer Project Group Joining and Assembly FFM of the Fraunhofer IFAM is carrying out ground-breaking work on large carbon fiber reinforced plastic (CFRP) structures and is able to carry out fully-automated assembly, joining, drilling, contour and surface milling and repairing processes, as well as non-destructive tests on large 1:1 scale CFRP structures, thus closing the gap between the laboratory/small pilot-plant scale and industrial scale in the area of CFRP technology.

The Department of Adhesive Bonding Technology and Surfaces is certified according to DIN EN ISO 9001, the Materials Testing Laboratory and the Corrosion Testing Laboratory are additionally certified according to 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 also accredited in accordance with the German quality standard for further training, AZWV.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The Plastics Competence Center is accredited in accordance with AZWV and meets the quality requirements of DIN EN ISO/IEC 17024. The Certification Body for the Manufacture of Adhesive Bonds on Rail Vehicles and Parts of Rail Vehicles is accredited by the Federal Railway Authority (FRA; Eisenbahn-Bundesamt) in accordance with DIN 6701-2 and following DIN EN ISO/IEC 17021.

Perspectives

Industry puts high demands on process reliability when introducing new technologies and modifying existing technologies. These demands are the benchmark for the R&D activities in the Department of Adhesive Bonding Technology and Surfaces. Working with customers, Fraunhofer IFAM develops innovative products which are later successfully introduced into the marketplace by the companies. In this context manufacturing technologies are playing an ever more important role, because high product quality and the reproducibility of production processes are key requirements for success in the marketplace.

Adhesive bonding technology has been used in vehicle construction for a long time, its potential has, however, not yet been fully utilized. Lightweight construction for vehicles as a means of saving resources, intentional debonding during the recycling process and 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 institute's 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.

This includes:

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

In all areas the Fraunhofer IFAM is making increasing use of computer-aided methods, for example the numerical description of flow processes in dosing pumps/valves, multiscale simulation of the 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 employed to give insight into the processes involved in the degradation and corrosion of composite materials. Using these instrumental methods and the accompanying simulations, the Fraunhofer IFAM acquires information which empirical test methods based on standardized aging and corrosion procedures cannot provide.

Other key questions for the future include the following: Where and how is adhesive bonding accomplished in nature? What can we learn from nature for industrial adhesive bonding technology? We are already studying how we can utilize bio-adhesion at a molecular level to make medical adhesives with protein components. However, the requirement to make processes and products even safer is not only limited to adhesive bonding technology. It also applies to plasma and paint/lacquer technology.

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

Key activities

- Formulation and testing of new polymers for adhesives, laminating/cast resins, including industrial implementation
- Development of additives (nanofillers, initiators, etc.) for adhesives
- Synthesis of polymers with a superstructure, and biopolymers
- Computer-aided material development using quantum-mechanical and molecular-mechanical methods
- Development and qualification of adhesive bonding production processes
- Development of innovative joining concepts, e.g. for aircraft and car manufacture (bonding, hybrid joints)
- Application of adhesives/sealants, casting compounds (mixing, dosing, application)
- Bonding in micro-production (e.g. electronics, optics, adaptronics)
- Computer-aided production planning
- Economic aspects of bonding/hybrid joining technology
- Design of bonded structures (simulation of the mechanical behavior of bonded joints and components using finite element methods, prototype construction)
- Development of industrially viable and environmentally compatible pre-treatment methods for the bonding and coating of plastics and metals
- Functional coatings using plasma and combined methods
- Testing and qualification of coating materials, raw materials, and lacquering methods
- Development of functional paints/lacquers for special applications
- Development of special test methods (e.g. icing)
- Parameter determination, fatigue strength, and alternating fatigue strength of bonded and hybrid joints
- Material models for adhesives and polymers under different strain rates (quasi static and crash)
- Evaluation of aging and degradation processes in composite materials
- Electrochemical analysis
- Evaluation and development of new anti-corrosion systems
- Analysis of development and production processes involving adhesive bonding
- Quality assurance concepts for adhesive and lacquer/paint applications via in-line analysis of component surfaces
- Internationalization of training courses:
  European Adhesive Bonder (EAB)
  European Adhesive Specialist (EAS) and
  European Adhesive Engineer (EAE)

1 Filter material with improved chemical resistance and service life due to an ultra-thin plasma-polymer coating.
2 Qualification of curing processes for adhesives – for example, rapid curing using microwaves.
3 Testing the adhesion of coatings using the cross-cut test.

FIELDS OF ACTIVITY AND CONTACT PERSONS

Institute Director

Dr.-Ing. Helmut Schäfer – up to May 31, 2009
Priv.-Doz. Dr. Andreas Hartwig – from June 1, 2009
Phone +49 421 2246-400
andreas.hartwig@ifam.fraunhofer.de

Adhesive Bonding Technology

Dipl.-Ing. Manfred Peschka
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; failure analysis; electrically/optically conductive contacts; adaptive microsystems; dosing ultra small quantities; properties of polymers in thin films; production concepts.

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

Plasma Technology and Surfaces – PLATO –

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

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

- Low pressure plasma technology
- Atmospheric pressure plasma technology
- Plant technology/Plant construction

Adhesives and Polymer Chemistry

Priv.-Doz. Dr. Andreas Hartwig
Phone +49 421 2246-470
andreas.hartwig@ifam.fraunhofer.de

Development and characterization of polymers; nanocomposites; network polymers; formulation of adhesives and functional polymers; chemical and physical analysis; peptide and protein chemistry; peptide-polymer hybrids; bonding in medicine; surfaces functionalized with peptides; marine protein adhesives.

- Synthetic materials
- Protein materials

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-repairing protective coatings, coatings with favorable flow properties; formulation optimization; raw material testing; development of guide formulations; characterization and qualification of paint/lacquer systems and raw materials; release of products; color management; optimization of coating plants; qualification of coating plants (pre-treatment, application, drying); failure analysis; application-related method development.

- Development of coating materials
- Application technology and process engineering

Adhesion and Interface Research

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

Surface, interface and film analysis; analysis of adhesion, release and degradation mechanisms; analysis of reactive interactions at material surfaces; damage analysis; quality assurance via in-line analyses of component surfaces; development of concepts for adhesive, paint/lacquer and surface applications; corrosion on metals, under coatings and in bonded joints; analysis of anodization layers; electrolytic metal deposition; accredited corrosion testing laboratory; modeling of molecular mechanisms of adhesion and degradation; structure formation at interfaces; concentration and transport processes in adhesives and coatings.

- Surface and nanostructure analysis
- Applied computational chemistry
- Electrochemistry/Corrosion protection
- Quality assurance of surfaces

Material 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 riveted 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 riveted joints.

- Structural calculations and numerical simulation
- Mechanical joining technology

Workforce Training and Technology Transfer

Prof. Dr. Andreas Groß
Phone +49 421 2246-437
andreas.gross@ifam.fraunhofer.de
www.bremen-bonding.com
www.kunststoff-in-bremen.de

Training courses for European Adhesive Bonder, European Adhesive Specialist, and European Adhesive Engineer with Europe-wide certification via DVS®/EWF; in-house courses; consultancy; qualification of production processes; studies; health, work safety and the environment; training course for Fibre Reinforced Plastic Technician.

- Center for Adhesive Bonding Technology
- Plastics Competence Center

Fraunhofer Project Group Joining and Assembly FFM

Dr. Dirk Niermann
Phone +49 421 2246-439
dirk.niermann@ifam.fraunhofer.de
Industrial, on demand semi- or fully-automated assembly involving bonding, riveting, and combinations thereof; adaptive precision machining; automated measuring and positioning processes; non-destructive tests on large fiber composite structures.

Business Field Development

Dr. Michael Wolf
Phone +49 421 2246-640
michael.wolf@ifam.fraunhofer.de
- Technology broker
- New research fields

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

Dr. Dirk Niermann
Phone +49 421 2246-439
dirk.niermann@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.

Process Reviews

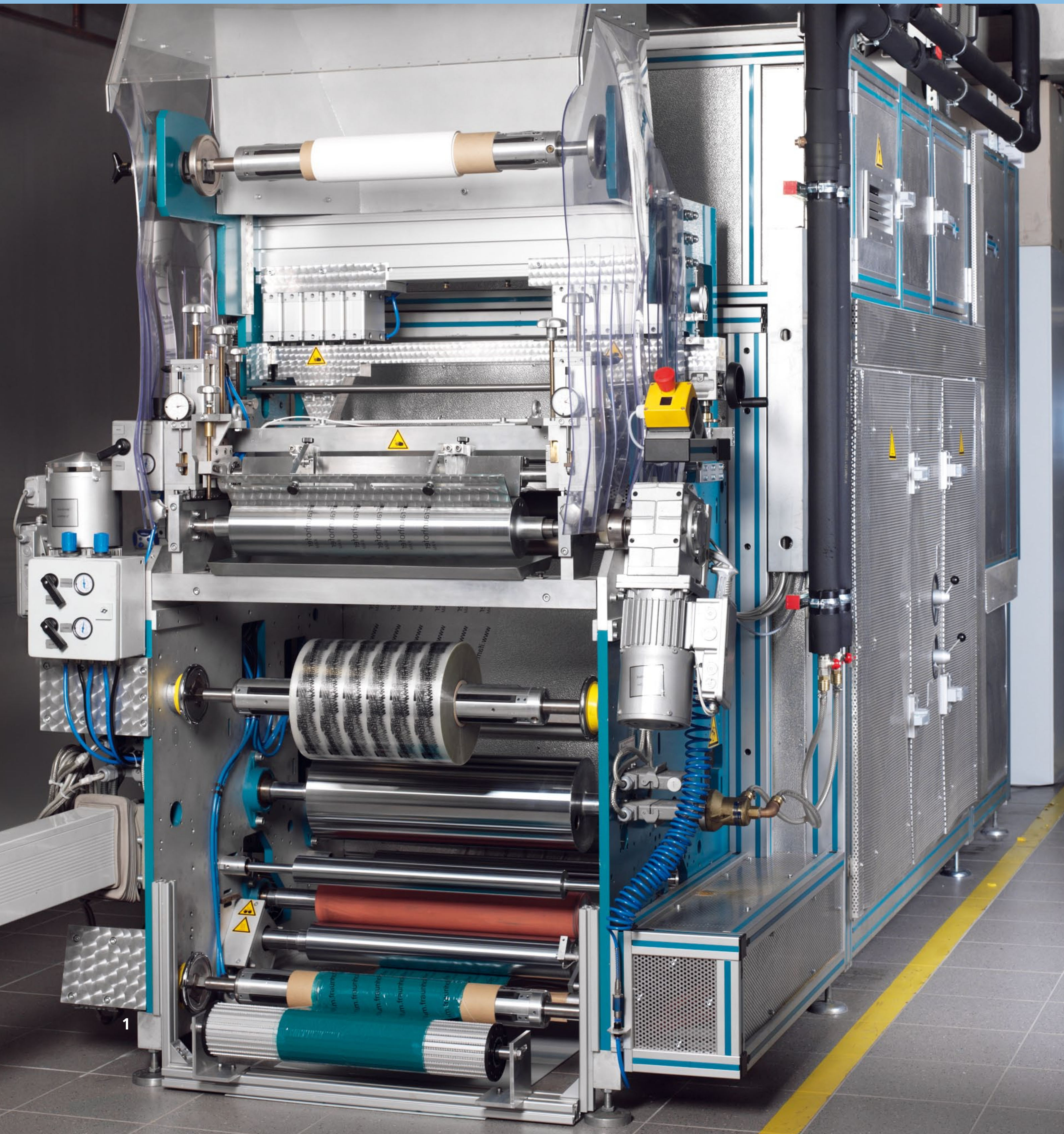
Dipl.-Ing. Manfred Peschka
Phone +49 421 2246-524
manfred.peschka@ifam.fraunhofer.de
Analysis of development and/or production processes taking into account adhesive bonding aspects and DVS® 3310; processing steps and interfaces; design; products; proof of usage safety, documentation; production environments.

EQUIPMENT/FACILITIES

Adhesive Bonding Technology and Surfaces

- Low pressure plasma plants for 3-D components, bulk products, and web materials up to 3 m³ (HF, MW)
- Atmospheric pressure plasma plants for 3-D components and web materials
- Robot-controlled atmospheric pressure plasma plant (6-axle) for laminar 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
- Laser scanner for 3-D measurement of components up to 3500 mm
- Universal testing machines up to 400 kN
- Units for testing materials and components under high rates of loading and deformation under uniaxial and multiaxial stress conditions
- All-electric laboratory 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 worEABlace monitoring
- Laboratory vacuum press with PC control for manufacturing multilayer prototypes
- 200 kV FEG transmission electron microscope with EDX, EELS, EFTEM, and 3-D tomography and cryo and heating options
- Confocal laser microscope
- Laboratory galvanizing unit
- LIF (Laser Induced Fluorescence)
- Thermography
- XRF hand unit (x-ray fluorescence analysis)
- Surface analysis systems and polymer analysis using XPS, UPS, ToF-SIMS, AES, and AFM
- Chromatography (GC-MS, headspace, thermal desorption, HPLC)
- Thermal analysis (DSC, modulated DSC, DMA, TMA, TGA, torsion pendulum)
- MALDI-ToF-MS for protein characterization
- Automatic equipment for peptide synthesis
- Light scattering for characterizing turbid dispersions
- Spectroscopic ellipsometer
- LIBS (Laser Induced Breakdown Spectroscopy)
- Small-scale pilot plant for organic syntheses
- IR, Raman and UV-VIS spectrometers
- IR-VCD spectrometer (Infrared Vibrational Dichroism)
- Rheology (Rheolyst AR 1000 N, ARES – Advanced Rheometric Expansion System)
- Equipment for measuring heat conductivity
- Dielectrometer
- Electrochemical Impedance Spectroscopy (EIS) and noise analysis (ENA)
- Twin-screw extruder (25/48D) and kneader for incorporating fillers into polymers
- Single-screw extruder (19/25D) for characterizing the processing properties of polymer composites
- 12-axle robot for manufacturing micro bonded joints
- Linux PC cluster with 64 CPUs
- Various dispersion units
- Automatic paint application equipment
- Fully conditioned spraying booth
- Paint dryer with moisture-free air
- UV curing technology
- Mechanical-technological tests
- Color measurement unit MA 68 II
- Optical testing technology
- Test equipment for anti-icing paints

ADHESIVE BONDING TECHNOLOGY AND SURFACES



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- Wave tank simulation chamber
- Test loop for measuring the loads on paints
- Miniature test loop for measuring the loads on paints
- Outdoor weathering at various locations
- Scanning Kelvin probe
- Coatema Deskcoater
- 6-axle industrial robot, 125 kg bearing load, on additional linear axis, 3000 mm
- 1-C piston dosing system SCA SYS 3000/SYS 300 Air
- 1-C/2-C geared dosing system t-s-i, can be adapted to eccentric screw pumps
- Freely configurable 1-C/2-C dosing technology, adaptable to specific tasks, with comprehensive measurement technology (own development)
- Phased-array ultrasound measuring device (Olympus OmniScan MX PA)
- Fluorescence microscope
- Bohlin Gemini 200 rheometer
- TGA Q 5000
- Climate test chamber type 3436/16

Certification and Accreditation

- The Department of Adhesive Bonding Technology and Surfaces is certified according to DIN EN ISO 9001, the Materials Testing Laboratory and the Corrosion Testing Laboratory are additionally certified 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 also accredited in accordance with the German quality standard for further training, AZWV.
- The Plastics Competence Center is accredited in accordance with AZWV and meets the quality requirements of DIN EN ISO/IEC 17024.
- The Certification Body for the Manufacture of Adhesive Bonds on Rail Vehicles and Parts of Rail Vehicles is accredited by the Federal Railway Authority (Eisenbahn-Bundesamt) in accordance with DIN 6701-2 and following DIN EN ISO/IEC 17021.

1 *Deskcoater for the laminar coating and bonding of web materials and large-area substrates on a small pilot plant scale.*

CHANGE AND CONTINUITY GO HAND IN HAND: PRIV.-DOZ. DR. ANDREAS HARTWIG SUCCEEDS DR.-ING. HELMUT SCHÄFER AS INSTITUTE DIRECTOR

That change and continuity do not have to contradict each other is something which has often been demonstrated by the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in the past, and that is also so regarding the IFAM personnel. Indeed, the change of director of the Department of Adhesive Bonding Technology and Surfaces at the Fraunhofer IFAM can be considered to be the successful symbiosis of change and continuity: On June 1, 2009 Dr.-Ing. Helmut Schäfer passed the baton to his deputy, Priv.-Doz. Dr. Andreas Hartwig.

Both Helmut Schäfer and his successor, Andreas Hartwig, played key roles in the development of this department during the era of IFAM director Prof. Dr. Otto-Diedrich Hennemann. Helmut Schäfer has been working here for more than 25 years, joining the institute back in 1984. He became deputy director in 1993 and together with Otto-Diedrich Hennemann promoted the successful development of the institute, to make it the largest independent research organization in Europe in the area of adhesive bonding technology. Following the departure of Otto-Diedrich Hennemann at the end of March 2007, Helmut Schäfer took over the reins. His experience was perfectly suited for furthering the successful development of the institute. The same now applies for the new director, Andreas Hartwig, who has been at the Fraunhofer IFAM since 1992. In his period at the institute he has utilized his chemistry background to build up the "Adhesives and Polymer Chemistry" section and was able to successfully integrate this into the scientific activities of the institute.

Helmut Schäfer at the Fraunhofer IFAM since 1984

Helmut Schäfer gained his doctorate in materials science and carried out research work at the Technische Hochschule Darmstadt and the University of Münster before moving to Bremen in 1984. He initially worked in the "Structural and Composite Materials" work group, the forerunner of today's Department of Adhesive Bonding Technology and Surfaces, under the leadership of Prof. Dr.-Ing. Walter Brockmann. His work at that time focused on the use of adhesive bonding as a joining technique. The particular task of Helmut Schäfer was to develop the use of analytical electron microscopy for studying bonded joints. Together with Otto-Diedrich Hennemann, who later took over the leadership of the adhesive bonding area from Walter Brockmann, Helmut Schäfer focused, amongst other things, on the causes of failure of bonded joints. At that time this was a considerable problem for the aircraft manu-

facturing industry. Electron microscopy became a key method for studying bond failure and became an important tool, not just for the aircraft industry, for developing bonded joints with improved long-term stability.

Although only arriving at the institute in 1984, Helmut Schäfer can be considered "a pioneer" because the character of the Fraunhofer IFAM changed significantly at the start of the 1990s with the conversion. In 1990 Otto-Diedrich Hennemann took over the helm of the Adhesive Bonding Technology department and a short time later appointed Helmut Schäfer as his deputy. This duo had the task of adapting this department to meet the growing needs and interest of numerous sectors of industry. Many of Helmut Schäfer's ideas were used for the expansion strategy for the adhesive bonding technology area. The rapid technological developments and trends towards lightweight design, miniaturization, and combinations of materials helped to establish adhesive bonding as a joining technique in those years.

Adhesive bonding technology project brought key players together

An important impulse for greater involvement and collaboration came in the latter years of the Walter Brockmann era. This concerned the Adhesive Bonding Technology project funded by the then federal ministry of research and technology (BMFT). This project brought together producers, adhesive users, and research organizations – who were competing in the marketplace with each other – to work together for the first time. The numerous new contacts and experiences gained from this project gave Otto-Diedrich Hennemann and Helmut Schäfer additional motivation for the strategic development of the institute.

Further expansion

The expansion of the institute department covering "Adhesive Bonding Technology and Surfaces" continued, with two new sections, "Plasma Technology and Surfaces" and "Materials Science and Mechanical Engineering", being set up. Other work groups soon followed. Commitment, persuasiveness, and many successes quickly gave the group in Bremen a much broader perspective of the industrial and scientific landscape. When Helmut Schäfer joined the Structural and Composite Materials work group in 1984, that group comprised only 10 employees. The adhesive bonding activities of the institute, which emanated from this, only truly became established in the 1990s. The expansion has made it necessary to move premises: From "Bremen-Lesum" via "Neuer Steindamm", Fraunhofer IFAM at last moved to the completely new institute building in the Bremen Technology Park in 1999.

A key contribution of Helmut Schäfer was to add Manufacturing Technology, which up until then had been absent, to the activities of the Fraunhofer IFAM. He pushed for the construction of small pilot plant facilities, so that industrial applications could not only be demonstrated on a laboratory scale but also under real production conditions. Last but not least, his persistence has resulted in the Fraunhofer IFAM today being able to offer most customers complete solutions.

The institute also continued to grow at the Wiener Strasse site in the Technology Park, so that today there is a need for even more space and people. In addition to his work on "Adhesive Bonding in Microproduction" and "Adhesive Bonding Technology", Helmut Schäfer assisted Otto-Diedrich Hennemann, his superior and partner, very effectively with the management of the Department of "Adhesive Bonding Technology and Surfaces", which today employs more than 200 people. During the time Helmut Schäfer was working at the Fraunhofer IFAM the number of employees in the Department of Adhesive Bonding Technology and Surfaces increased 20-fold – testimony to the success of this department.

Head of the department for more than two years

On the departure of Otto-Diedrich Hennemann it was natural that Helmut Schäfer would succeed him and he duly did so on April 1, 2007. He headed the department for more than two years until his retirement. Key development steps were taken under his leadership – the section Paint/Lacquer Technology was expanded, the section Plasma Technology and Surfaces was reorganized and there were developments in the area of wind energy and fiber composite materials:

Helmut Schäfer oversaw the development of the Fraunhofer Center for Wind Energy and Maritime Engineering (CWMT) – it was set up as a joint establishment of the Fraunhofer IFAM and Fraunhofer LBF (Fraunhofer Institute for Structural Durability and System Reliability) and later became an independent Fraunhofer institute based in Bremerhaven, the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES; as of January 1, 2009). He was also actively engaged with the involvement of the Fraunhofer IFAM in the new Research Center CFRP North in Stade. This included the setting up of the Fraunhofer Project Group Joining and Assembly FFM. This group will join, assemble, process, repair, and test large components made of CFRP materials on a 1:1 scale, in particular for the aircraft manufacturing sector.

Andreas Hartwig takes over the leadership

The work of Helmut Schäfer is finished, or more appositely said the work has been put into the hands of Andreas Hartwig. The Fraunhofer IFAM story repeats itself insofar as once again a long-term colleague of the institute director has stepped into his shoes. This occurred in June 2009 and was the best possible decision because Andreas Hartwig knows the Fraunhofer IFAM and its work well. He has worked for almost 19 years at the Fraunhofer IFAM, and was deputy to Helmut Schäfer for the past two years. In addition, Andreas Hartwig still leads the section he established so long ago – the Adhesives and Polymer Chemistry section.

Andreas Hartwig brought substantial knowledge of plasma technology and polymer chemistry with him when he joined the Fraunhofer IFAM in 1992. He studied chemistry in Cologne and gained his doctorate at the Institute for Physical Chemistry. He then gained work experience abroad at the University of Twente in the Netherlands, carrying out work in the area of surface chemistry. With that know-how, he was a valuable addition to the workforce when he joined the Fraunhofer IFAM: It was the start of the boom time for adhesive bonding technology, new strategies were needed, and they involved the basic chemical principles of adhesive manufacture and application. At the start, Andreas Hartwig focused on adhesion research and failure analysis, but new challenges soon arose. Medium-sized adhesive manufacturers sought new adhesives for special applications, and Andreas Hartwig and his section were often able to provide assistance and advice.

One of the noteworthy achievements of Andreas Hartwig was to build up an extensive network of small, medium-sized, and large companies as well as his involvement in the chemical sciences scene. Andreas Hartwig is not only a good organizer, section leader, and now institute director, he is a dedicated research scientist. He has lectured in macromolecular chemistry and vibrational spectroscopy at the University of Bremen for more than 14 years. He received his habilitation qualification in 2006, allowing him to supervise doctoral students in macromolecular chemistry in the Biology/Chemistry Faculty at the University of Bremen. The success of his work is exemplified by more than one hundred scientific publications and patents which he has to his name.

Good name attracts talented young scientists

The many contacts of Andreas Hartwig are vital for the future strategy of the Department of Adhesive Bonding Technology and Surfaces. Good contacts in the scientific community have also helped give polymer chemistry at the Fraunhofer IFAM a good name. This reputation and also the teaching activities of Andreas Hartwig – with special attention being put on the merging of theoretical knowledge and practical challenges – ensure that there is a stream of young, talented researchers wanting to join the Fraunhofer IFAM. With the new institute director, the Department of Adhesive Bonding Technology and Surfaces can thus maintain its close connections to the university, which all Fraunhofer institutes generally desire. With this, Andreas Hartwig is following another footstep of Otto-Diedrich Hennemann as the latter also taught at the University of Bremen.

The only constant is change itself

The management of the Department Adhesive Bonding Technology and Surfaces at the Fraunhofer IFAM by Andreas Hartwig ends with the appointment of a new director who will be integrated via his own professorship into the Production Engineering Faculty at the University of Bremen. This process is expected to be completed in 2010. Know-how, broad experience, networks, and in particular continuity of personnel will also be a feature of the work of the institute in the future – they are fundamental building blocks for the further development and expansion of the institute.

1 *Dr.-Ing. Helmut Schäfer.*

2 *Priv.-Doz. Dr. Andreas Hartwig.*

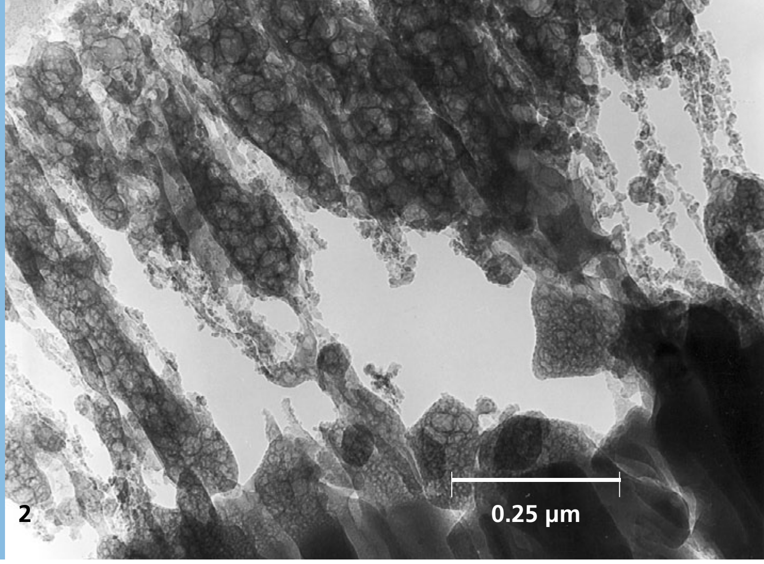
1

A SPECIAL RELATIONSHIP: FRAUNHOFER IFAM AND THE AIRCRAFT MANUFACTURING INDUSTRY

Adhesives are essential: Adhesive technology plays a key role nowadays in almost all sectors of industry. The many advantages of bonding and significant progress in R&D in the area of adhesion have allowed applications and products to be realized which until recently would have been inconceivable. Although adhesive bonding has now become a widely used joining technique, the relationship between the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM and one specific sector of industry have a special and long history. Talking here about the aircraft manufacturing industry: This sector was the driving force which helped adhesive bonding break through as a joining technique for high-tech applications. This is why the Fraunhofer IFAM has had a special relationship with this industry for more than 30 years.

Weight has played and continues to play a major role in all areas of the transport sector, and particularly so in the aviation industry. Simply put, very heavy aircraft have to get airborne and then return safely to the ground again. The lighter the plane, the easier those tasks are to accomplish, and the lower the specific fuel consumption. From the outset, optimum choice and utilization of materials have been important in the aviation industry, in order to minimize weight yet give the highest possible stability. In this context, the joining technique also played a significant part. In the early days of aviation, wood was an important construction material and specially developed adhesive bonding technology played an important role. Later, aircraft were made of metal and rivet technology, which had proven itself in other sectors of industry, came to be used. However, the pressure to develop even lighter aircraft with lower fuel consumption could not be met by using this joining technique alone, and one returned to adhesive bonding.

Everyone has experienced turbulence whilst travelling by air and silently prayed the rivets will be able to hold the aircraft together. However, they are probably oblivious to the fact that adhesives also make a key contribution to the stability of the fuselage, wings, tailfin, and inner furnishings. An ever more important role for hybrid joining is currently being considered. Aircraft manufacturers and research organizations such as the Fraunhofer IFAM are collaborating to bring together the joining techniques of riveting and adhesive bonding, with the long-term aim of significantly reducing the number of rivets and thus reducing weight.



The initial period of collaboration: Materials and processes

In the early period of collaboration between the Fraunhofer IFAM and the aviation sector there was not only close contact with the Airbus Works in Bremen but also with Fokker, the Dutch aircraft manufacturer. Up until that time, Fokker had used adhesives more widely than other companies in the sector to bond aluminum. Over a period of many years the Bremen scientists were holding discussions with Fokker engineers about materials and processes which could be used to create high performance bonded joints having good long-term stability. The development and selection of suitable adhesives and surface treatment techniques made the bonding of aluminum at Fokker a success. For example, structural adhesives were widely used on Fokker F-27 aircraft (produced from 1956 to 1986) in the area of the airfoils and fuselage. This propeller-powered aircraft was considered to be "indestructible" and is still in service today.

Over the course of time the relationship with Airbus became closer. In contrast to the established Fokker technology, the novel metal bonds used by Airbus at that time had problems with their long-term stability: The metal corroded in highly stressed regions. For the Fraunhofer IFAM this was the impulse to start working closer with Airbus on fundamental issues regarding adhesive development, processing, and the stability of bonded joints. In order, for example, to understand the failure mechanisms in corroded bonded joints, transmission electron microscope methods and other techniques were used. Along with spectroscopic methods, they made a fundamental contribution to localizing the points of failure, most of which were caused by the selected combination of surface pre-treatment/adhesive system. Electron microscopy has since then served as a key tool for failure analysis and for evaluating surface quality prior to bonding in aircraft manufacture.

Intensive evaluation of corrosion protection

The matter of preventing corrosion was at that time the focus of the activities of the Fraunhofer IFAM for the aircraft manufacturing industry. This led to an even closer collaboration between the Fraunhofer IFAM and aircraft manufacturers. Whereas up until then the collaboration had often been a rather informal exchange between engineers about materials and processes, chemical and physical matters were now being increasingly discussed. Airbus and other aircraft manufacturers recognized that in order to successfully use adhesive bonding technology in their production it made sense to involve external experts. One success of this closer collaboration between Airbus and the Fraunhofer IFAM at the start of the 1980s was the development of a tailored surface pre-treatment process for aluminum, which is used to the present day. Since then the corrosion of bonded aluminum joints at Airbus has not been an issue (Fig. 2).

The closer collaboration was also worthwhile when new materials and processes became of interest. Increasingly the bonding of titanium and carbon fiber reinforced plastics (CFRPs) was the topic of work. The focus here once again was the development of suitable pre-treatment methods. The latest examples of this series of developments is an eco-friendly chromate-free process for the corrosion protection of aluminum and an atmospheric pressure plasma process for effective pre-treatment of CFRPs.

New challenges for adhesive bonding technology

After about two decades in which materials and processes have been at the fore of the work for the aircraft manufacturing industry, new challenges were put on the Fraunhofer IFAM around the time of the millennium change. The institute is now increasingly involved with the design and dimensioning of bonded joints, and recently also hybrid bonded-riveted joints. In addition, manufacturing technology has become a greater focus. How can a joint be made which is as effective as possible under specific boundary conditions, but which is also as economical as possible to make? The experts at the Fraunhofer IFAM are devoting ever more of their time to this question. Modern computer-aided simulations are also showing how the expanded capabilities of the Fraunhofer IFAM can scale up the results from a laboratory scale to a small pilot plant scale (Fig. 3).

In order to be able to offer industrial customers ever more solutions from a single partner, the Fraunhofer IFAM has made considerable investments in space, equipment, technical and computer facilities, and employees.

Also, the aircraft industry research program initiated by the federal ministry of economic affairs brought new energy to the sector at the turn of the millennium. The Fraunhofer IFAM started more intense collaboration with structural-mechanical experts at Airbus in Hamburg to discuss and develop calculation methods for joining fiber composites. Possible applications include in the CFRP fuselage and other CFRP components such as the tailfin. The institute started working with Airbus in Bremen to develop adhesive-based repair procedures for flaps and lift systems.

Fig. 3: C-frame automatic riveting machine at Fraunhofer IFAM.

Design and production increasingly in focus

These examples typify the increasing focus on design and production in the past ten years, which accompany the continuing work on materials and processes. Decisive for this development was the boom in the use of fiber composite materials in aircraft manufacture, which puts high requirements on the design and dimensioning of adhesive bonds. Unlike with rivets, many parameters for dimensioning and other key data were not available for structural adhesive bonds – they first had to be determined in conjunction with various partners. Adhesive bonding – and hence also the Fraunhofer IFAM – is moving into a contentious area:

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Adhesive bonding is increasingly competing with riveting, an established and till now dominant joining technique for metals. If in the future, for example, the number of rivets can be reduced by up to 80 percent, because adhesive bonding technology proves to be a real alternative, this would improve the prospect of lighter aircraft. The current limitations for bonding include the size of components, which is limited by the autoclave necessary for curing. Here, the development of new adhesives which cure at lower temperature would be a step forward.

A current trend in aircraft design is towards the use of fewer rivets. The aircraft manufacturing industry is hence very interested in advanced developments which make that possible, especially for the joining of CFRPs. Projects with the Fraunhofer IFAM are already underway.

Innovation and technological progress via adhesive bonding technology

Both industry and the political world have recognized that adhesive bonding technology – with the Fraunhofer IFAM being the leading research organization in Europe in this field – is one area where Germany and Western Europe have an advantage due to the current trends in the aircraft manufacturing industry. Due to their ever growing use of adhesive bonding, it is possible for companies such as Airbus, in collaboration with the Fraunhofer IFAM, to make a key contribution to innovation and technological progress in the global marketplace. At the same time there is a need to explore all possibilities of lowering production costs, something which adhesive bonding also offers. From a political point of view, many supportive measures have been employed to combine the know-how of the research institutes in Bremen and elsewhere in Germany with that of Airbus – with the goal of improving prospects for the future as well as safeguarding jobs.

In Bremen, these measures have included the so-called AMST projects (Airbus Material & System Technology-Center Bremen), which were funded by the State of Bremen. Many projects addressed topics identified by Airbus, for example surface pre-treatment as an integral part of adhesive bonding technology and surface protection, and the advanced development of production methods. Computer simulation was also used in the projects. Besides the Fraunhofer IFAM this work also involved other research institutes in Bremen working in the material sciences and production engineering. A practical result of the collaboration between Airbus and the research institutes in Bremen is the so-called "Bremen Tandem" which is still successfully operating today. Another example was the establishment of the "Technology Broker". The aim of collaboration between the Fraunhofer IFAM, other institutes, and companies such as Airbus is to make industry more aware of the scientific know-how that is available in Bremen in the area of materials and processes and to customize development work to the needs of industry. There have been a host of activities which have led to closer interaction between R&D establishments and industry.

The latest chapter in the long relationship – more than 30 years – between the Fraunhofer IFAM and the aircraft manufacturing industry concerns the involvement of the institute in the new Forschungszentrum CFK Nord (Research Center CFRP North) in Stade, which will be up and running by mid 2010 (Fig. 4). For the first time work will be carried out on a 1:1 scale, namely bigger than the small pilot plant scale. The new facility in Stade will develop manufacturing and assembly processes for CFRP components for large structures, enabling the use of favorable cost production processes and automated plants.

Work will not only be carried out for the aircraft manufacturing industry, but also for other sectors, for example the car, rail vehicle, and ship manufacturing industries. The focus will be on topics such as joining, assembly, processing, repairing, and non-destructive testing. To carry out these tasks the

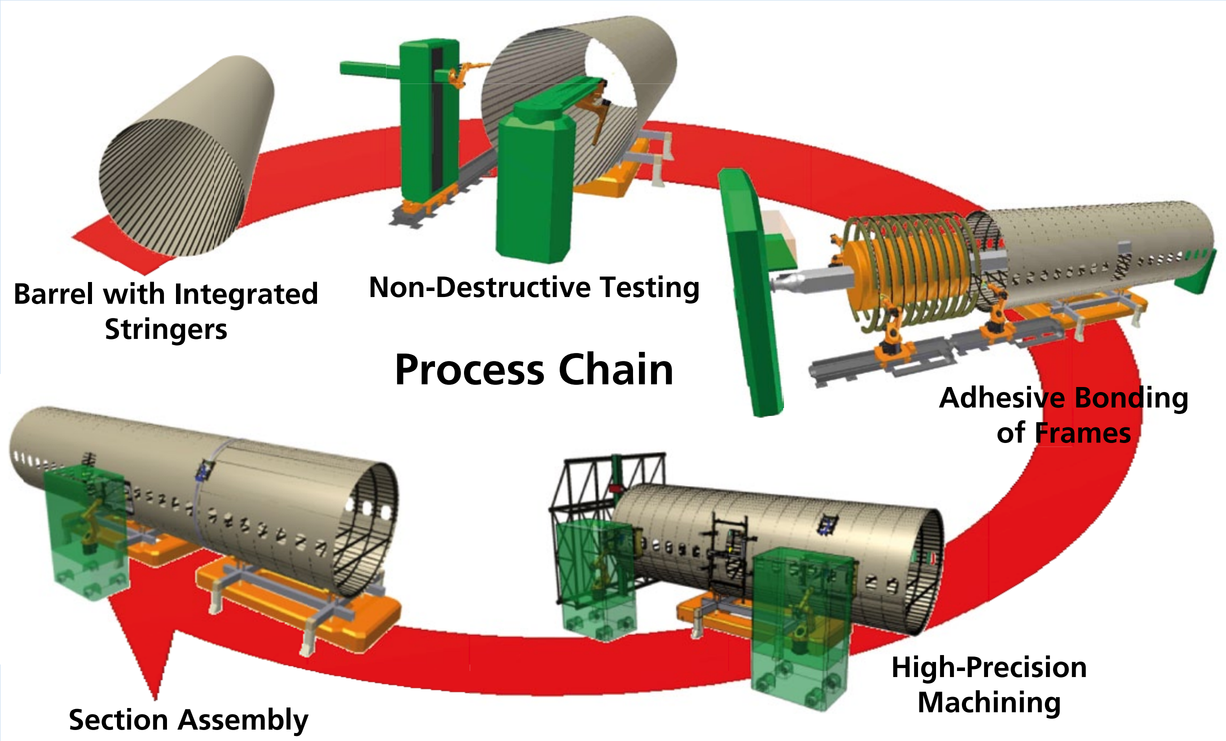
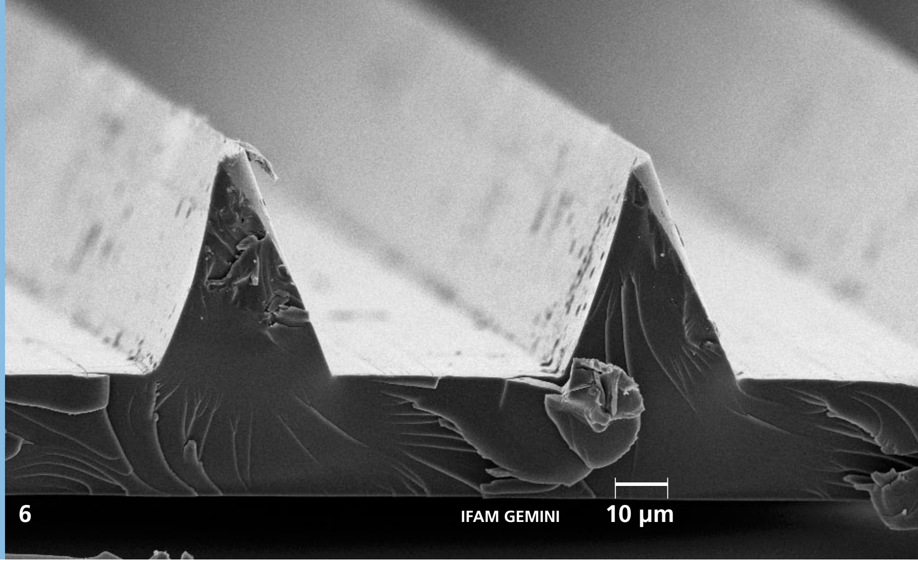


Fig. 5: Fields of activity of the Fraunhofer Project Group Joining and Assembly FFM at the Research Center CFRP North (Forschungszentrum CFK Nord) in Stade.

Fraunhofer-Gesellschaft has established the Fraunhofer Project Group Joining and Assembly FFM, which will expand the activities of the Fraunhofer IFAM (Fig. 5).

New surface functions reduce fuel consumption

Paint technology is becoming ever more important for the aviation industry and is an area where the Fraunhofer IFAM has been very successful. Over the past decade the results of many R&D projects have been able to be directly used by the aircraft manufacturing industry. Paint systems, drying processes, and sealants have been and are being tested and qualified; one main focus of the work for this sector was the use of water-based coating systems. A young but very promising field concerns functional coating systems. This involves giving the surfaces additional functions which, for example, reduce the frictional resistance of an aircraft and allow completely new aerodynamic designs. This reduces the fuel consumption – not only saving money but also protecting the environment. The activities of the Fraunhofer IFAM include anti-fouling, anti-icing, erosion-resistant, and abrasion-resistant surfaces.



In addition, so-called riblet coatings are the topic of ongoing R&D work. These coatings give surfaces a microstructure akin to sharkskin and have been demonstrated to have very favorable flow properties (Fig. 6).

Participation at the SIAE at Paris-Le Bourget for the first time

Participation in current research programs such as the European "Clean Sky" project is important. The focus of this project, which has a total budget of 1.6 billion euros, is the long-term environmental compatibility and competitiveness of the aircraft manufacturing industry in Europe. The Fraunhofer IFAM is part of a consortium of 86 partners from industry and R&D involving 16 nations which is striving over the next seven years to reduce the growing environmental pollution caused by air traffic. That the activities of the Fraunhofer IFAM for the aircraft industry are part of an ever bigger stage was demonstrated by its participation, for the first time, at the International Paris Air Show (Salon International de l'Aéronautique et de l'Espace) at Paris-Le Bourget in June 2009. The communal stand of the Fraunhofer institutes involved in the Clean Sky project and the information which were provided aroused much interest in the institute's work. When collaboration between the Fraunhofer IFAM and the aircraft industry started many years ago, no one could have envisaged the great strides we have made.

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1 *Pioneer in CFRP technology in the aviation industry – Airbus A380 (Image source: Bildagentur Hamburg, Christian Ohde).*
2 *In the past a problem: Corrosion of a bonded aluminum joint.*
4 *Research Center CFRP North (Forschungszentrum CFK Nord) in Stade.*
6 *Scanning electron micrograph of a riblet-structured coating surface developed by the Fraunhofer IFAM (cross-section).*

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THE FUTURE IN LOWER SAXONY WITH FRAUNHOFER FFM: ROBOTS ASSEMBLE AND BOND CFRP COMPONENTS FOR AIRCRAFT

Breaking new ground – Start of the construction at Forschungszentrum CFK Nord (Research Center CFRP North) in Stade with Walter Hirche, the Lower Saxony minister for economic affairs. February 4, 2009 in Stade: In the presence of Walter Hirche the first spade of soil was dug to mark the start of the construction work on the new Forschungszentrum CFK Nord. In total, investment and research projects at a value of over 100 million euros have been agreed. This funding will be available to scientists and engineers at the research center over the coming years for projects on large structures made of carbon fiber reinforced plastics (CFRPs).

CFRPs make Lower Saxony mobile

In Lower Saxony, the new R&D center will have direct contact with companies in the car, rail vehicle, and ship manufacturing sectors, and in particular with companies in the aircraft manufacturing industry. In all these sectors, CFRPs are the key materials for the future. Their light weight makes them ideal for large structures – and the weight reduction saves resources and helps protect the environment. These materials are opening up new opportunities for product design due to their high strength and rigidity, high load limit, good damping properties and excellent fatigue behavior. These characteristics also make them particularly attractive for wind turbines. With the expected increased usage of CFRP materials – for example, the use of CFRPs in large Airbus aircraft will increase from the present 20 to 50 percent in the future – the scope of the R&D work will also significantly increase.

Know-how from the Fraunhofer IFAM

The Fraunhofer IFAM can play a leading role here: The knowledge of adhesive bonding technology, one of the core areas of expertise of the institute, allows innovation in CFRP technology. The importance of bonding as a joining technique will continue to grow – and particularly so in the aircraft manufacturing industry. There are major challenges in the aircraft sector, namely a need for significantly faster assembly processes and simultaneous cost savings. These can only be achieved by a considerable automation of processes – switching from manual work steps to robot usage – and the development of adhesives having a very special combination of properties.

FFM – Fraunhofer Project Group Joining and Assembly

The Fraunhofer-Gesellschaft is represented at Forschungszentrum CFK Nord by the Fraunhofer Project Group Joining and Assembly, which is part of the Fraunhofer IFAM. The activities of the Fraunhofer Project Group FFM, headed by Dr. Dirk Niermann, are wide-ranging and cover the assembly, processing, repair, and non-destructive testing of large CFRP structures.

This Project Group also brings together the expertise of other Fraunhofer institutes that are involved with CFRPs. In addition, it has succeeded to set up an agreement with the Technical University of Hamburg-Harburg to assist with the work in Stade: Prof. Dr.-Ing. Wolfgang Hintze from the Institute for Production Management and Production Engineering is heading the "Machining" work and Dr.-Ing. habil. Jörg Wollnack of the Institute for Machine Tools, Robots and Assembly Plants is assisting the Project Group FFM in the area of 3-D geometry measurement and robot calibration.

For the Fraunhofer-Gesellschaft the center is a milestone on the way to transferring results from the R&D laboratories to a 1:1 industrial scale: The Fraunhofer IFAM has worked for many years, in close collaboration with other Fraunhofer institutes, on the development and application of CFRPs. The new objective now is to provide customers with solutions which have been proven on a production scale, and which can be transferred to industry immediately without additional cost or time impediments.

Competitiveness: regional – national – international

By bringing together the expertise of the Fraunhofer Project Group Joining and Assembly FFM of the Fraunhofer IFAM and its industrial partners (Airbus Deutschland GmbH, CFK-Valley Stade e. V., Dow Deutschland Anlagengesellschaft mbH, EADS Innovation Works, Premium Aerotec GmbH) at the Forschungszentrum CFK Nord (Research Center CFRP North) in Stade, new opportunities arise for Lower Saxony. In addition, the expansion of CFRP technology will bring about a national development push, which will strengthen and expand the competitiveness of companies in the global marketplace. That will in turn have a positive effect on regional and national employment opportunities – in particular for manufacturers of means of transport and their suppliers.

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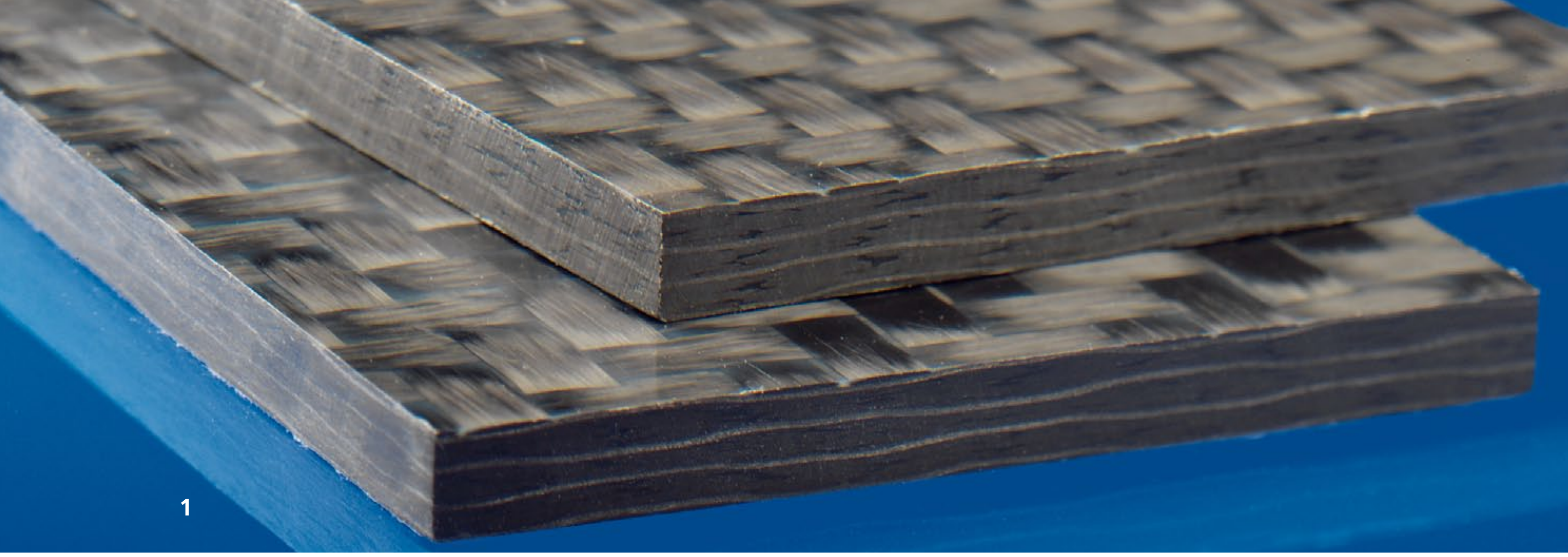
1 *The initiators at the Fraunhofer IFAM: Dr. Dirk Niermann, Head of the Fraunhofer FFM and Dr.-Ing. Helmut Schäfer, Institute Director (in the foreground from the left).*
2 *The joint start in Stade (from the left): Christian Lübbers (CFK NORD Anlagengesellschaft mbH & Co. KG), Rudolf Lamm (Dow Deutschland Anlagengesellschaft mbH), Dr. Dieter Meiners (Premium Aerotec GmbH), Prof. Dr.-Ing. Axel Herrmann (CFK-Valley Stade e. V.; R&T Manufacturing Engineering Airbus), Andreas Rieckhof (Stadt Stade), Walter Hirche (Lower Saxony ministry of economic affairs, employment and transport), Klaus Hamacher (DLR), Dr.-Ing. Helmut Schäfer (Fraunhofer IFAM), and Thomas Friedrichs (CFK NORD Anlagengesellschaft mbH & Co. KG).*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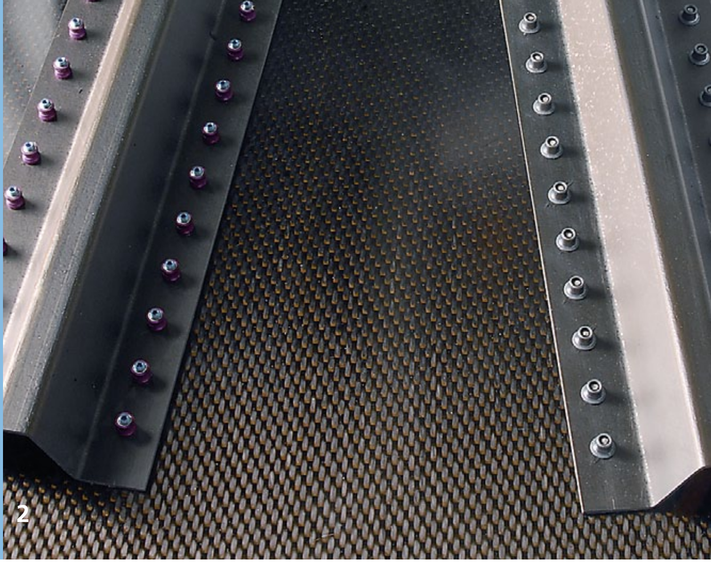
ALL EXPERTISE UNDER ONE ROOF: FRAUNHOFER IFAM HAS EXTENSIVE KNOW-HOW IN THE AREA OF FIBER REINFORCED PLASTICS

Industry favors these unique materials: Fiber composites. In general, fibers of carbon, glass, or other materials are embedded in a resin matrix. The advantage: Depending on the requirements, several layers of the fibers can be positioned on top of one another in different orientations. After curing, the resulting laminate or component has low weight but enormous strength. Light, very stable, and customizable for the relevant application: Fiber reinforced plastics (FRPs) are justifiably very popular, despite their comparatively complex manufacturing processes.

It is important to realize at the outset that fiber composites would not be possible without adhesive bonding technology. The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM has built up outstanding knowledge over many decades, ranging from the understanding of processes at the molecular level to the joining of fiber reinforced plastics on an industrial scale. The institute has actively supervised many development projects.

Both carbon fiber reinforced plastics (CFRPs; fig. 1) and glass fiber reinforced plastics (GFRPs) have become established in industry. The applications for these materials vary tremendously and range from canoes, molded from resin-soaked glass fiber mats, to the wings of the latest Airbus aircraft. Other applications include those in high-performance sports and in high-tech areas: CFRPs are used to make tennis racquets, the frames of racing cycles, and skis, while GFRPs are used in shipbuilding and wind turbines. In the aviation industry, glass fiber reinforced aluminum (GLARE®) plays an important role: Alternating layers of aluminum and glass fibers laminated together.

The sections of the Department of Adhesive Bonding Technology and Surfaces at the Fraunhofer IFAM are involved in key issues relating to the manufacture and application of fiber composites. More often than not, the transitions are seamless: Close collaboration between the individual sections guarantees comprehensive and effective project work and appraisal from different points of view.



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Dimensioning, design, and manufacture of fiber composites

The section Material Science and Mechanical Engineering is involved with the dimensioning and design of fiber composites, as well as with their manufacture, mechanical testing, and issues regarding bonding and riveting of these materials. Resin infusion and prepreg methods are preferred for the manufacture of fiber composite laminate sheeting up to a size of two square meters. Here, either dry fiber mats are placed in a mold and soaked with resin during the further processing, or – as in the prepreg method – pre-soaked mats are placed on molds and then cured in an autoclave under pressure and heat. The latter method requires extensive know-how, but gives particularly high-quality products, as required, for example, by the aviation industry.

Also important is the institute's long-time experience in testing fiber composites. The specialists at the Fraunhofer IFAM are able to determine the load limit and fatigue strength of fiber composite materials under static or alternating loads, right through to crash tests. These tests are undertaken, for example, on fiber composites used for aircraft, yacht, and wind turbine manufacture. Empirical knowledge is also important for dimensioning and designing components. This is because fiber composites can be manufactured with completely different mechanical properties, namely the layer structure and the properties of the resin can be tailored for the subsequent application.

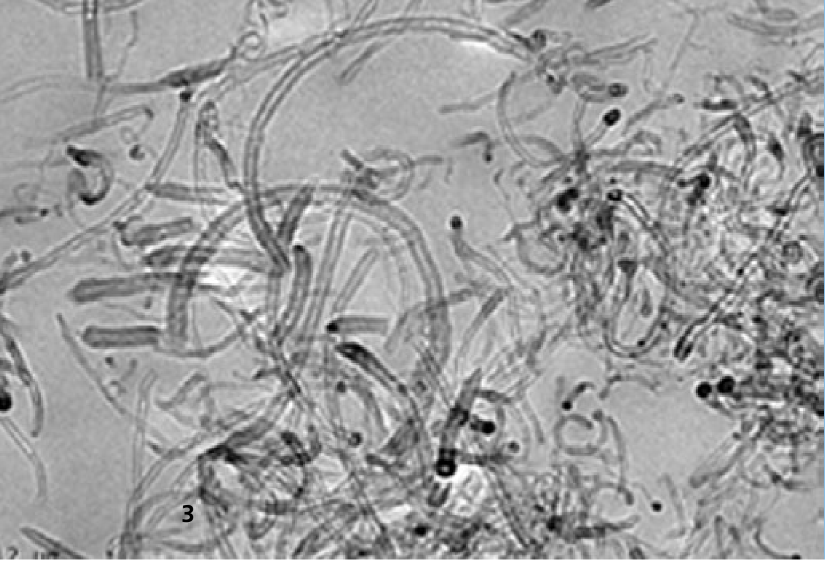
The section Material Science and Mechanical Engineering is also involved with the further processing of fiber composite components. These can be bonded, so giving thin-walled, light structures and a planar load transfer – ideal for the growing area of lightweight construction. Hybrid structures using fiber composites and other materials are also possible. In the aircraft manufacturing sector, where CFRPs are widely used, these materials are still often riveted in structural areas. The riveting of CFRPs and hybrid joining – namely the integration of adhesive bonding technology and riveting – are R&D areas in which the Fraunhofer IFAM has built up extensive knowledge and experience (Fig. 2).

Fibers and resins: The chemistry must be right

A prerequisite for optimum production and the successful use of fiber composites is precise knowledge of the relationships between the fibers and resins, including all their individual features. For example, the weight and strength depend on the composition and structure of the finished CFRP or GFRP material. The section Adhesives and Polymer Chemistry is involved with matrix resins, the optimal attachment of the fibers to the matrix, and the modification of the resins in order to optimize the property profile.

Thermosets or thermoplastics are used as the matrix resins, with the focus at the Fraunhofer IFAM being on thermosets. After curing they often have a certain brittleness which is one of the main causes of damage to fiber composite materials. Although the toughness of the materials can be improved with various additives, these often reduce the strength. Intensive work is being carried out to find ways of overcoming the current limitations. Other important points for optimization regarding the production of fiber composites are the rheological properties of the resins and the curing conditions.

Amongst the additives which are used, special attention is put on modified nanoparticles. These particles have already been proven to have positive effects in adhesive formulations. The main material being used here is silicon dioxide pretreated in various ways, but also elastomanic nanoparticles, aluminum oxide, and carbon nanotubes (CNTs; see fig. 3) are being employed.



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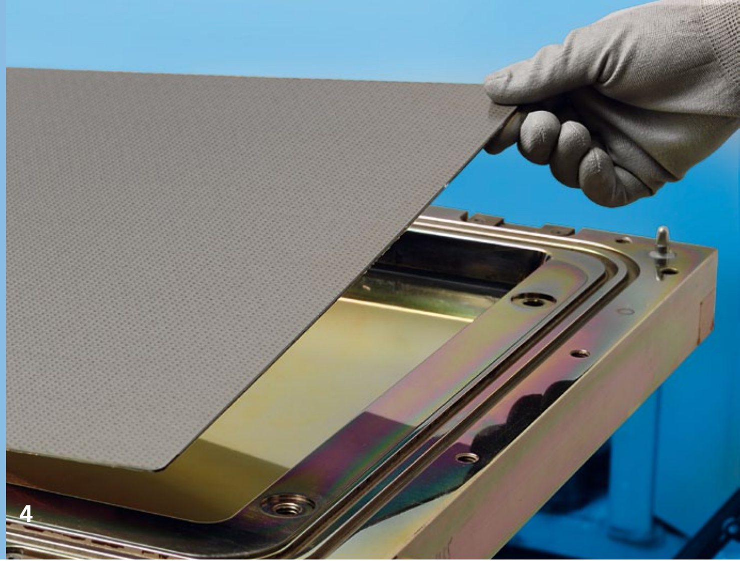

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Pre-treatment of surfaces essential

Surface pre-treatment is highly important for fiber composites. The section Plasma Technology and Surfaces – PLATO – devotes itself to this task. The pre-treatment starts with the individual carbon fibers, which may already be affected by the oxidation processes used for their industrial manufacture. The surfaces of the fibers can subsequently be further modified, depending on the particular application, for example via plasma pre-treatment or wet-chemical processes. Together with the aforementioned optimization of the matrix resins, the Fraunhofer IFAM hence creates the preconditions for manufacturing fiber composite products having the best possible properties.

During the manufacture of fiber composite components or laminates in molds, the matrix resin generally acts as an adhesive. This is why thin release layers are necessary, consisting for example of wax or silicone, to enable easy removal of the finished fiber composite parts from the molds. The residues of the release agents which remain behind on the parts are, however, a problem. They prevent effective bonding and/or coating and hence must be removed. PLATO has developed innovative surface pre-treatment methods for cleaning. These include techniques involving the removal of material such as the CO_2 snow jet or vacuum suction blasting. In addition, the surfaces are activated by plasma treatment or with high energy radiation in the vacuum ultraviolet spectral region (VUV). At a molecular level these techniques allow improved attachment of adhesives or paints/coatings.

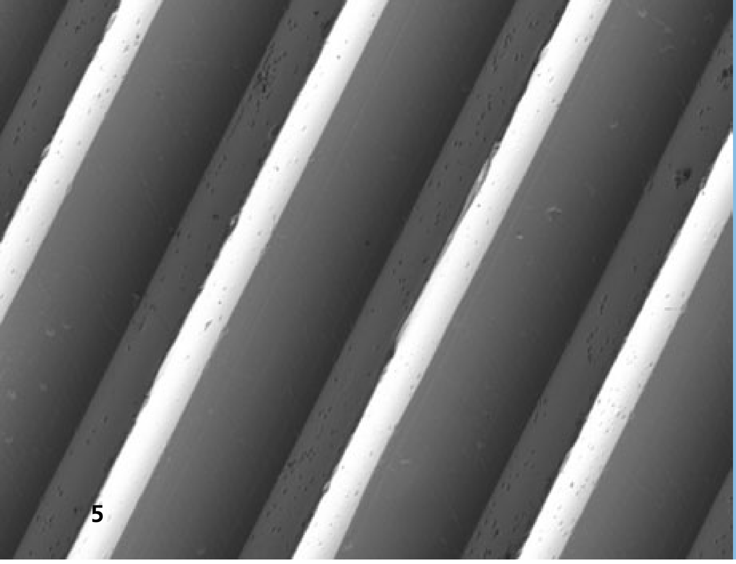
An alternative method for removing fiber composite components from molds is the coating of the molds with a permanently active release layer. In contrast to conventional release agents, the molding tool is coated with a release layer developed by PLATO. Even after many molding cycles this still has very good release properties. After being removed from the molds, the CFRP components show no presence of contaminants, meaning they are "ready-to-paint" or "ready-to-bond". Figure 4 shows a plasma-polymer coated molding tool on removal of a CFRP component.

The expertise of the section Plasma Technology and Surfaces is also relevant for other aspects of the manufacture and processing of fiber composite materials. This is particularly so regarding plasma-etching: In order to be able to monitor the intactness of carbon fiber materials during their everyday use, for example in aircraft components, glass fibers will in the future be incorporated into CFRP components as sensors to indicate the state of the component during usage (structural health monitoring: SHM). When joining such CFRP components, the individual glass fibers must be connected to each other. It is therefore necessary to expose them using a process as gentle as possible, and atmospheric plasma treatment is able to achieve this.

A further research topic of PLATO is corrosion protection when joining fiber composites with other lightweight construction materials, for example aluminum. As damage often occurs due to so-called contact corrosion, corrosion-suppressing plasma-polymer layers are applied in the joint regions.

Coating and modification of CFRPs

Surfaces are also of vital importance in the work of the section Paint/Lacquer Technology. They are investigating ways of measuring and eliminating undesired surface defects. This work concerns a variety of defects. High-quality CFRP components in particular require defect-free surfaces. A component can, however, only be as good as the mold in which it is made. If the mold has "negative" defects, then these appear on the surface of the component as "positive" defects. This gives rise, for example, to so-called voids: Pores which subsequently require extra filling and hence require additional



surface pre-treatment steps for cleaning, grinding, and activation.

If the resin and fibers expand to different extents due to temperature and humidity fluctuations, then the fiber structures – even after painting/lacquering – may be visible on the surface. The Fraunhofer IFAM is tackling issues like this in order to be able to produce acceptable paint/lacquer surfaces.

It is advantageous for the production if a component can be removed from a mold already painted/lacquered. The Fraunhofer IFAM is therefore working on developing special paints/lacquers which can be directly processed in the mold. This can, for example, be undertaken using a release film into which one of more paint/lacquer layers are integrated. Prior to manufacturing the component, the special films are deep-drawn into the mold. In conjunction with PLATO, the section Paint/Lacquer Technology is working to further improve these in-mold paints/lacquers and optimize them for applications.

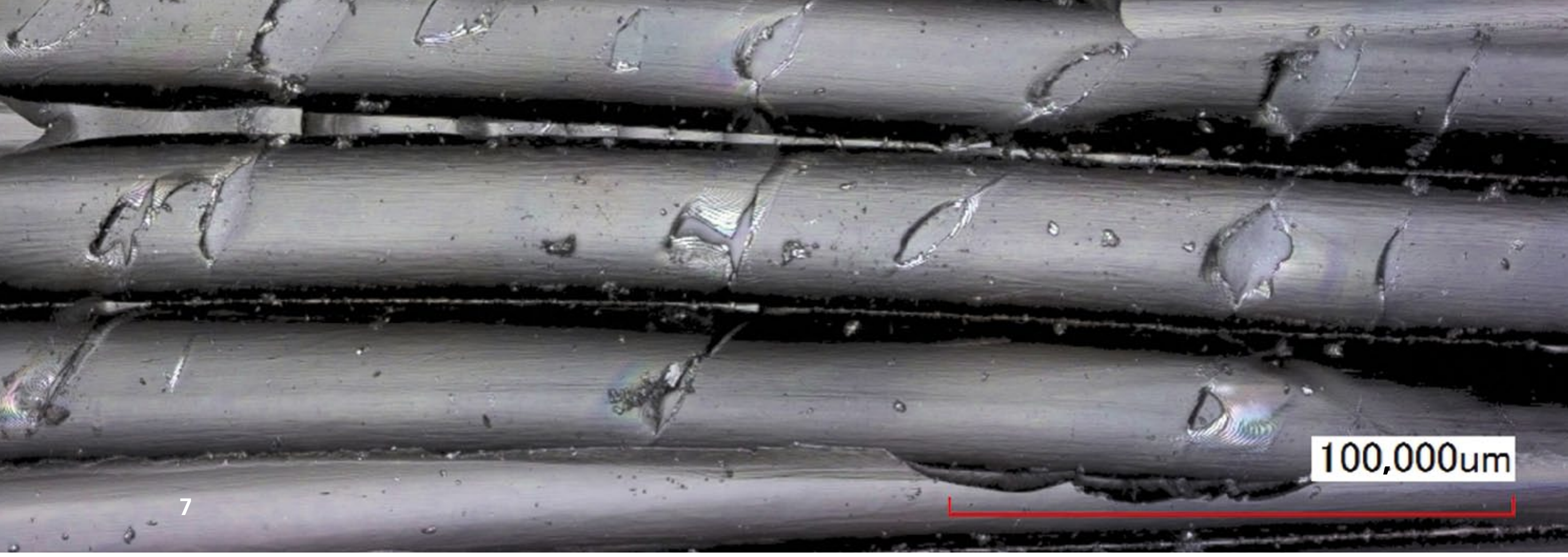
The Paint/Lacquer Technology section has extensive know-how for coating carbon fiber composites. This includes the qualification of paint and lacquer systems and also cleaning, pre-treatment, and lacquering processes. The quality of the surface can be analyzed and evaluated for its color, gloss, dust inclusions, run, and many other parameters. In addition, the functional modification of surfaces with systems such as self-repairing coatings, anti-fouling and anti-icing coatings, anti-erosion coatings, and riblet structures ("sharkskin structures"; fig. 5) are possible. The latter are particularly interesting due to the aerodynamic benefits for aviation and the wind energy industry.

The right joining technique: A lot of adhesives, with some rivets

In order to join components made of fiber composite materials to each other for a particular application such that the joints can withstand high loads, one needs an optimized and also economical joining method. This is true for both very small and very large structures: Until the day arrives when Fraunhofer IFAM can manufacture "a one-piece aircraft", wings have to be joined to the fuselage, and the tailfin to the undercarriage – ideally using adhesive bonding technology, which has always been the core competence of the Fraunhofer IFAM.

Fiber composite materials are generally joined after surface activation using film adhesives or hot curing adhesives. The bonding processes are often undertaken with the help of an autoclave in which the joints cure under the influence of pressure and heat (Fig. 6). One of the problems is that the size of the pressure vessel limits the size of the components which can be joined: There are no autoclaves which have the size of aircraft fuselages and it would not be economically viable to construct such large autoclaves. The Fraunhofer IFAM is hence developing adhesives for this purpose, which cure at lower temperatures. It is also desirable, for example, to be able to apply an adhesive to long joints with variable thickness – depending on the size of the gap between the individual substrates.

The section Adhesive Bonding Technology of the Fraunhofer IFAM is actively tackling these challenges. It is currently investigating, for example, the ideal composition of adhesives for joining fiber composites and is optimizing the flow properties and processing temperature. The section also develops complete process chains: Taking into account the relevant production environment and the given boundary conditions for the adhesives and components, the necessary personnel, machine, and space requirements are determined.



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In addition, adhesive application, namely the actually applying of the adhesive, is a focus of the work. The need for gap size dependent adhesive application and minimum overdosing is being met by a newly developed system. The components and their contours are scanned by a laser scanner and after data transformation the components are virtually assembled on the PC. The varying gap width is measured. This information can be programmed into the robot and the adhesive can be finally applied according to need.

A special challenge when joining fiber composites is the riveting of these materials. This is currently common practice in the aircraft manufacturing sector: When the wings and fuselage of an aircraft are joined, the aircraft manufacturers do not trust adhesive bonding alone, and also always require rivets. The selection of the correct types of rivets and the drilling of the holes for the rivets are areas where the Fraunhofer IFAM is actively engaged. One task is to minimize adverse effects on the properties of composite materials due to material damage. The combined use of adhesives and rivets – so-called hybrid joining – is also a key area of work of the institute.

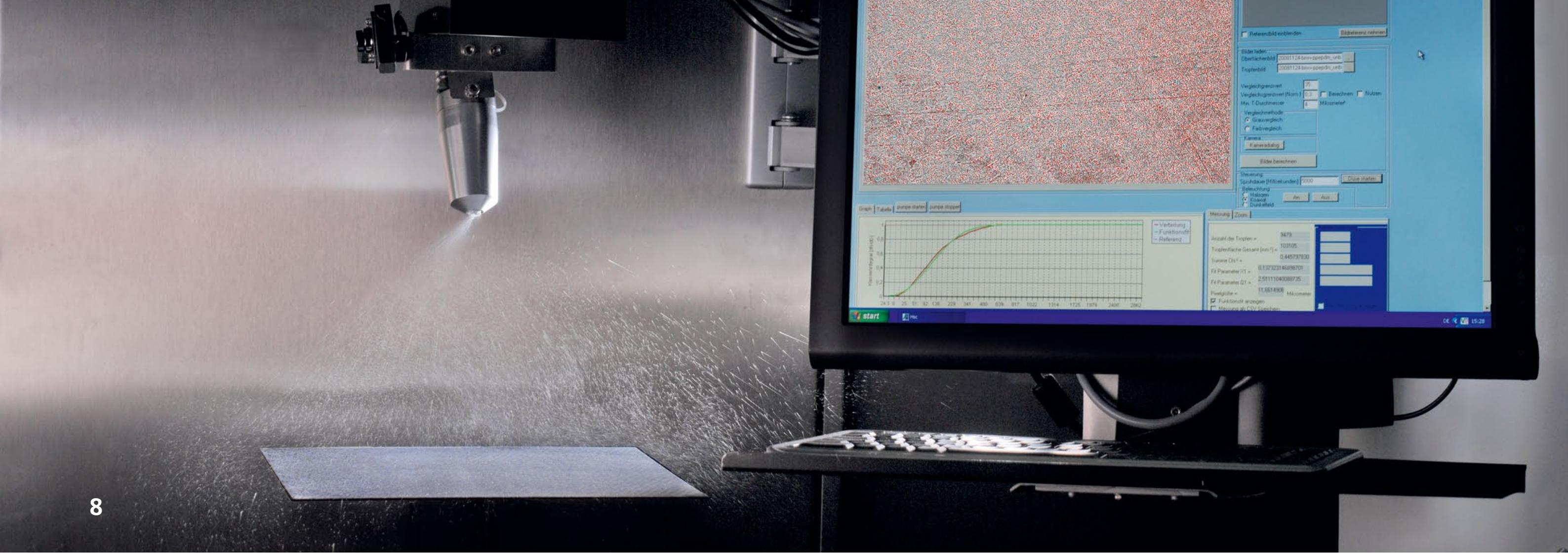
Know-how for material and process optimization: Adhesion and Interface Research

The aviation industry puts major challenges on adhesive bonding technology for the bonding of load-bearing parts, so-called structural bonding. For safety reasons it must be ensured that the bonded joint remains intact, namely does not suddenly fail. This can be tested using non-destructive test methods. Here one often encounters the problem of "kissing bonds": These material-fit joints which appear to be bonded perfectly, and yet satisfactory adhesion forces do not develop. The reason for this is a poor connection and poor interaction of the adhesive with the substrates at a molecular level.

Another means of demonstrating product safety is via process monitoring. The actual bonding process and joining process are closely monitored: Is the quality of the surface pre-treatment acceptable? Has the correct amount of the correct adhesive been applied at the correct place? Is the contact pressure acceptable and have optimum conditions such as temperature and air pressure been observed? This monitoring can also be very effectively integrated into the production process and is one of the tasks of the Adhesion and Interface Research section of the Fraunhofer IFAM. After the surface pre-treatment and before the application of the adhesive it is determined whether the surface is in an optimal state for being bonded (Fig. 8).

The surface characterization, namely analysis of the surface chemistry as well as macro- and microstructures, plays a key role regarding the adhesion of adhesives and coatings. It is hence important, prior to the surface pre-treatment, to acquire fundamental information about the microscopically thin interfacial layer in which the actual adhesion of the adhesive or coating occurs (Fig. 7).

With the help of adhesion and interface research, surface pre-treatments can be analyzed and evaluated – for example



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the use of release agents, the degree of contamination, and the effects of release agent residues on the strength of the bonded joints. At the microscopic and sub-microscopic levels tests are carried out to investigate the adhesive interactions between the carbon fibers and the matrix resins which are important for the mechanical properties of CFRP materials. These tests are carried out at the Fraunhofer IFAM using state-of-the-art analytical methods and computer-aided simulation methods.

In addition, the evaluation and optimization of concepts for preventing galvanic corrosion when joining CFRPs with light metals, including the required long-term electrical insulation of the materials, is another important task of the section, especially directed at the aircraft manufacturing industry.

From the laboratory to 1:1 scale

All the expertise of the Fraunhofer IFAM mentioned up until now regarding the manufacture and application of fiber composite materials is also very important for the manufacture of large structures, for example for aircraft manufacture. The newly established Fraunhofer Project Group Joining and Assembly FFM has started its work for the Forschungszentrum CFK Nord (Research Center CFRP North) in Stade which is currently under construction. Together with various partners from the aviation sector they will develop assembly methods for CFRP components on a 1:1 scale.

The background to this is the current drive towards weight reduction via the increased use of lightweight materials, leading to fuel savings of up to 20 percent for aircraft. Other advantages are lower service costs and longer service life of CFRP structures, excellent corrosion resistance, and easier inspection.

Examples such as the Boeing 787 (Dreamliner) or the Airbus A350 demonstrate that the use of CFRP lightweight materials is advancing rapidly. For economical series production of such aircraft it is, however, necessary to maximize the degree of mechanization and automation by a variety of parallel process steps.

As the Fraunhofer-Gesellschaft – and in particular the Fraunhofer IFAM – has expertise in the whole process chain for CFRP processing, the Project Group FFM is a vital partner for the aircraft industry. Together with Airbus, Premium Aerotec, and other suppliers the Project Group FFM will further develop the automated and parallel-machining and assembly of large CFRP structures on a scale which guarantees a seamless transfer of the newly developed production processes to industry (Fig. 9). The wide use of CFRP materials in different sectors of industry – not only in the aviation sector – will increase if the costs can be reduced via automation. The car manufacturing industry, commercial vehicle sector, rail vehicle industry, and shipbuilding industry will then use CFRP materials to an ever increasing extent.

Workforce training – an important prerequisite

No innovation will achieve a break through and exhausts all the potential of a new technology if it is incorrectly used. This is why the training and further training of the people who work with and use fiber composite materials is very important. The Fraunhofer IFAM recognized this more than 15 years ago, when adhesive bonding technology was starting to boom. The Center for Adhesive Bonding Technology of the Fraunhofer IFAM is the leading training organization in the area of adhesive bonding technology.

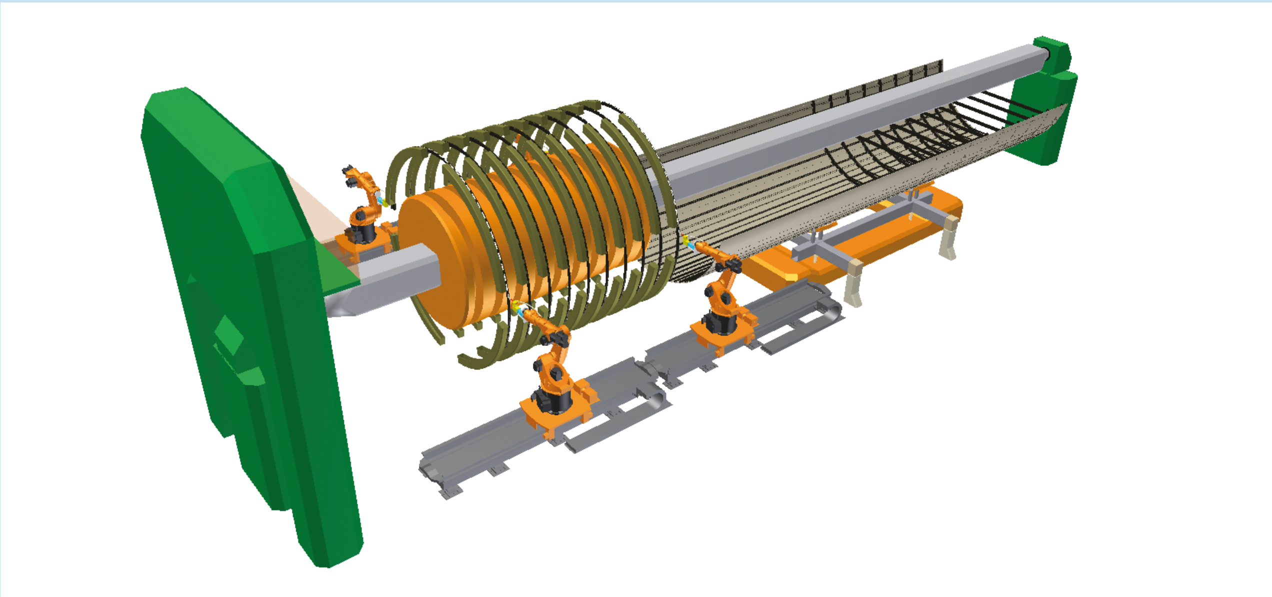

Fig. 9: Assembly plant on a 1:1 scale for bonding CFRP aircraft fuselages.

As the processing and joining of fiber composites cannot be separated from adhesive bonding, yet does have its own special features, the Fraunhofer IFAM and partners established the Plastics Competence Center. The Fiber Reinforced Plastic Technician training course is one of the activities carried out there (Fig. 10). This training course is becoming increasingly important for the plastic processing industries: The wind turbine construction industry and the shipbuilding, car manufacture, aviation and aerospace sectors require well trained employees. Such trained employees are available thanks to the Fraunhofer IFAM: To date, more than 340 people have successfully passed the Fiber Reinforced Plastic Technician training course in Bremen, Bremerhaven, and Brake.

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1 *Carbon fiber reinforced plastic (CFRP).*
2 *Hybrid joined CFRP component.*
3 *Adhesive with dispersed carbon nanotubes (CNTs).*
4 *Permanent release layer to allow molded CFRP components to be easily removed from molds.*
5 *Scanning electron micrograph of a riblet-structured paint surface developed by the Fraunhofer IFAM (top view).*
6 *Autoclave for manufacturing fiber reinforced plastics.*
7 *Laser scanning microscopy image of carbon fibers at the surface of a CFRP component manufactured by the resin transfer molding process (RTM).*
8 *Evaluation of the wetting properties of surfaces using the aerosol wetting test developed at the Fraunhofer IFAM.*
10 *Workforce training: Fiber Reinforced Plastic Technician training course at the Plastics Competence Center.*

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FROM MODERN FACADE DESIGN TO BRIDGE BUILDING: THE CONSTRUCTION INDUSTRY IS DISCOVERING ADHESIVE BONDING TECHNOLOGY

It is a common sight: the building site around the corner where homes, offices, a factory, or an architectural art object are being constructed. In the first instance such structures are associated with being made of concrete, steel, wood, and masonry, joined in conventional ways by, for example, welding or mortar. Nowadays, however, adhesives are widely used: Tiles and flooring are usually bonded, as are carpets. Adhesives are regularly used for installing insulation, for example when fitting styrofoam or for affixing vapor barrier films with air-impermeable adhesive tape. The bonding of wood has been commonly used for construction for centuries. Adhesives, as bonding agents or sealants, are also widely used for fitting windows and for roof construction. Porous concrete means that buildings can be constructed in very short time, because the lighter, large-volume blocks can be joined with a fast curing adhesive. Epoxy resins, silicones, acrylates, and polyurethanes have become well-established and important adhesives in the construction industry (Fig. 1-3).

This brief and non-exhaustive summary indicates that the use of adhesive bonding in the construction sector has a growing dynamism. And here, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM is playing a key role: There is a growing demand from adhesive users in the construction sector for the expertise and experience of the leading research institute in Europe in the area of adhesive bonding technology – and also a demand from adhesive manufacturers who wish to offer ever more products to the construction sector. The institute has responded to this and is increasing the efforts in R&D activities for this sector of industry. At the Fraunhofer IFAM, the Application Methods work group of the section Adhesive Bonding Technology is bringing together indepth know-how from different areas of adhesive bonding technology specifically for the construction industry, and is available as first contact partner.

Innovative facade membrane technology, which is being increasingly used by architects and builders and which can be used to realize complete facades, is the reason for Fraunhofer institutes establishing an industry-oriented strategic alliance (WISA) entitled "Multifunctional Membrane Cushion Construction". The Fraunhofer IFAM and five other Fraunhofer institutes combine their expertise in this alliance. The objective is to develop processes and technologies to improve practical implementation in the construction industry, for example the use of adhesive bonding technology for pneumatically assisted membrane cushion constructions (Fig. 4 and 5).

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"High-tech" – now in the construction sector

One fact above all brought the versatility of adhesive bonding to the attention of the construction industry: Namely, adhesive bonding is unique in allowing a wide range of different materials to be joined to each other. It is that which is of interest to a sector which has been relatively slow to encompass "high-tech" methods. Architecturally and technically very demanding as well as innovative building facades, such as the titanium sheet facade of the Guggenheim Museum in Bilbao or the completely glazed facade of the Hamilton House office complex in London (Fig. 6), would not have been possible without adhesive bonding technology. In the meantime, building with special materials such as alloys, plastics, ceramics, and glass has become equal to other methods. The future for construction will be various types of composite systems. That brings new challenges, because joining different materials, some more sensitive than others, has often been difficult using conventional joining techniques. Thermal methods, such as welding, change the material due to the heat input, while the use of rivets and bolts as well as screws locally weakens the materials. In addition, only point-form force transfer is possible using such joints.

The history of adhesive bonding technology has often demonstrated that this joining technique comes to the fore for high-tech applications. Applications long established in the aviation sector, car manufacturing industry, electronics sector, and microsystems technology can now also be transferred to the construction sector. Due to adhesive bonding, different materials can be bonded in a planar way, without altering the specific properties of the materials. This means that new construction methods, such as lightweight construction, can be realized. Furthermore, the use of adhesives allows additional functions to be introduced – ranging from sealing to insulation, vibration damping, barrier layers, coatings, corrosion protection, and many more functionalities. In combination with new construction materials, adhesive bonding allows architectural designs to be conceived which change the face of modern cities. Building with bonded materials such as titanium sheets, aluminum, and glass allows facades of daring geometric form to be designed, which still appear to have unity and sleekness.

A desire for light: Glass as a construction material

Many examples demonstrate the potential of adhesive bonding technology for the construction sector. Glass buildings have long been popular, and the desire for bright, naturally-lit living and office space has helped this style of construction become a success. Regardless of whether this concerns entrance halls made of glass elements, or whole office blocks, or merely a simple canopy made of glass, adhesive bonding is the only joining technique which allows sensitive glass materials to be joined without weakening them. This is because adhesive bonding allows forces to be distributed on a surface, and hence uniformly, and enable stress peaks to be absorbed via customized design of the adhesive film thickness and the mechanical properties (e.g. elasticity) of the adhesive.

Up until now, one-component and two-component silicones, epoxides, and polyurethanes have been used in the construction sector. However, other adhesive systems, for example UV or light curing acrylate systems, are conceivable, in particular for bonding glass. The special features of acrylates are their high transparency, good processing properties, and the rapid increase in strength on curing. In order to meet the high requirements of building regulations, R&D work on these adhesives is still needed before there can be widespread use.

Redevelopment and renovation of existing buildings

Adhesive bonding technology also plays an important role nowadays in the renovation and redevelopment of buildings. When, for example, very old houses in narrow streets have to be redeveloped and stabilized, it is often difficult to transport reinforcement steel to the location. Processing on site is also tricky. An alternative means of reinforcing buildings, in use for some time, is to use high-strength but light elements made of carbon fiber reinforced plastics (CFRPs). They can be processed quickly and easily and have a number of advantages – for example minimum cross-sectional increase of the reinforced component, low density, good corrosion resistance, and excellent fatigue properties. The light CFRP elements, which consist of about 70 percent carbon fiber and 30 percent epoxy resin, are delivered to building sites in rolls. They are suitable for reinforcing concrete, masonry, and wooden structures. The elements are bonded onto the base surface. In general, the base surface must be pretreated in order to get optimum bonding. The bonded CFRP reinforcing elements have a multitude of uses, for example for structural engineering and as reinforcement for large structures against earthquakes.

CFRP elements – popular for bridge building

CFRP elements have also recently become popular for bridge building (Fig. 7). Here, bonded CFRP sheets are used for reinforcing steel and prestressed concrete bridges, replacing the formerly used steel strapping. The reinforcement of bridges is very topical because of the many old bridges which can hardly bear all the traffic they now take. For the respective applications, it is very advantageous if the alignment of the individual carbon fibers can be customized in the CFRP materials. Besides carbon fibers, glass fibers and also aramide fibers are used. These fiber reinforced materials are, for example, used for reinforcing bridge columns, where they also provide additional collision protection. Carbon fibers in turn offer excellent solutions for increasing the bearing load of components due to their high rigidity. The elements or mats are generally bonded to the surface with an epoxy resin adhesive. Due to their effectiveness for increasing the tensile bending strength, CFRP systems have in the meantime become approved by building authorities in many countries.

Joining new and advanced materials by adhesive bonding

Ultra high performance concrete (UHCP) has recently become of increasing interest for the construction industry. UHCP is a fine or coarse grained concrete having a very high structural density. Its compressive strength is similar to that of steel components. In addition, the surface tensile strength of the material is six to eight N/mm^2. The use of UHCP also means that components can be joined by adhesives, instead of by the usual mechanical means. An example of this is the construction of the Gärtnerplatzbrücke in Kassel. This bridge over the River Fulda is 136 meters long and is for pedestrians and cyclists. It is the first bridge in Germany which was constructed mainly from ultra high performance concrete. A world first was the fact that the precast components here were bonded with a two-component epoxy resin adhesive to make them supporting. The pilot nature of this construction means that the construction project is being continuously monitored by the University of Kassel. It was demonstrated that adhesive bonding is an excellent method for joining UHCP components. The adhesive meets the high requirements with flying colors: Laboratory tests on the bonded joints – such as measurements of the tensile strength and tensile bending strength as well as durability tests – confirm that the adhesive used in the bridge construction met all the requirements of the Deutsches Institut für Bautechnik (DIBt) in order to receive "exceptional approval".

Even with all these positive aspects, it was still recognized that there is a need for further R&D work, as indeed it is for many applications of adhesives in the construction sector. For example, work on the aging resistance of the adhesive bonds, and on the processing of the epoxy resin adhesive. The same applies for the use of the adhesive in winter months when the moisture and temperature sensitivity of the material is currently still an issue.

Steel can also be bonded in the construction sector

Steel has played an important role in the construction industry for a long time. Due to adhesive bonding technology, completely novel opportunities are arising here, and particular so in the area of lightweight construction. High-strength steels and optimized construction methods allow steel components to be constructed having low weight and favorable production costs. Adhesive bonding is ideal for fully utilizing the properties of these often thin-walled components – for example facing for facades and cover plates for bridges. Bonded joints give effective adhesion over a large area, and there is no weakening of the base material from drilling and rivets, and failure of welded joints due to alternating loads is no longer an issue. Detailed experiments in this area have shown that the bonding on steel plates is a reliable, attractive, and equivalent alternative for the construction industry and that durable construction is possible using adhesive bonding. As so often with adhesive bonding, special attention must be given to the preparation and pre-treatment of the substrate surfaces.

Bonding terrace planking

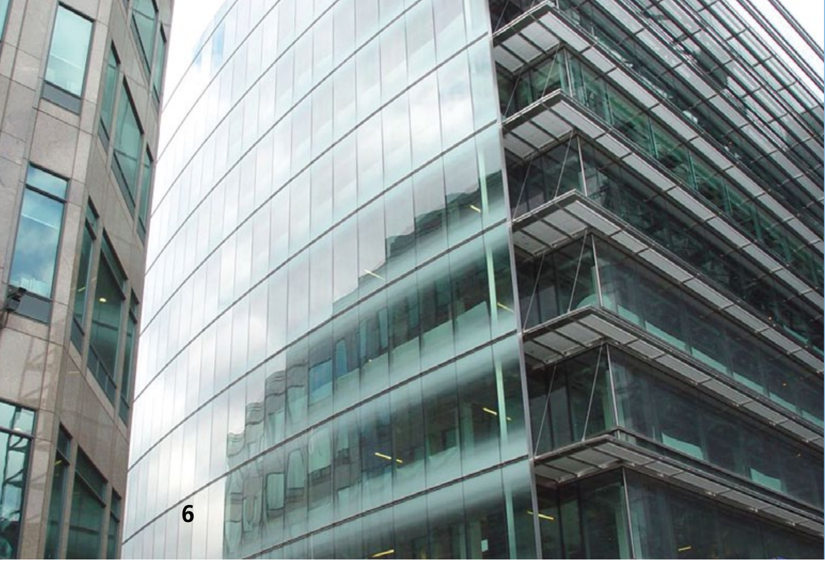
Another example application of adhesive bonding technology in the area of construction is the elastic bonding of terrace planking. In general, wooden planks are still screwed to the base construction. The result is unsightly screws and a way for moisture to penetrate into the material. In the meantime, weathering-resistant bonded joints are possible using an elastic adhesive, once again with all the associated advantages of adhesive bonding: Greater design freedom, time saving, economical due to fewer materials, and so on.

Bonding in the rail sector and in water management

Adhesive bonding has become a topic of interest for rail track and dyke construction. When building railway lines, polyurethane is used to bond the gravel in packed beds and to make the construction more durable. The principle is also of interest for dyke building. The gravel surface is only coated with a thin polyurethane film which then binds the gravel together and gives the structure considerably higher strength. All the gaps between the gravel remain in place, meaning that rain and seawater can still drain.

Adhesive bonding has come of age in the construction sector

The list of examples of adhesive bonding technology in the construction industry will continue to grow. It is clear that this joining technique has come of age in the construction sector, and in some areas is experiencing a boom. There are however still many unanswered questions and there is



hence still a great need for R&D work. Adhesive bonding technology appears ideal for many applications and for realizing completely new solutions. However, in many areas safety-related hurdles still have to be cleared with building authorities.

The Fraunhofer IFAM will certainly benefit here in the long term from its many years of experience and know-how introducing adhesive bonding to industries which were totally new to this technology. Without any doubt, the construction sector will benefit from the institute's wealth of experience and knowledge.

Regardless of whether it concerns the qualification or formulation of adhesives, adhesive selection, surface pretreatment, design and testing of bonded joints, suitable application techniques, or workforce training in adhesive bonding technology: The Fraunhofer IFAM can call on the expertise of all its specialized work groups to successfully develop adhesive bonding technology for a particular area of industry. Moreover, whenever questions arise which require the knowledge of other disciplines, the Fraunhofer IFAM has access to the vast knowledge of the entire institute network of the Fraunhofer-Gesellschaft.

In summary: The construction industry is not only an attractive area for adhesive bonding technology applications, but is also a promising market for high-tech bonding.

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1 *Bonding of chalk sandstone.*
2 *Bonding of brickwork.*
3 *Bonding of Ytong blocks.*
4 *Bonded oval-shaped membrane cushions made of ethylene-tetrafluoroethylene films (ETFE films).*
5 *Magnified image of the bonded, transparent, high-load adhesive seam.*
6 *The bonded, completely glazed facade of Hamilton House, London (Image source: Interpane).*
7 *CFRP element reinforcement under a bridge (Image source: S&P Clever reinforcement GmbH).*

HETEROGENEITY – THE KEY FOR ALL EXCELLENT PROPERTIES

Virtually all products are composed of a wide variety of components and materials. Not only is the dissimilarity of the components immediately recognizable by the naked eye, equally obvious is the fact that the individual components of the product have different functions. On moving from the macroscopic level to the microscopic level it also becomes clear that the materials themselves are virtually never homogenous: They consist, for example, of different phases, contain fillers and fibers – and that is true of all classes of materials whether it be metals, polymers, or ceramics. In particular, high-quality materials having a broad range of properties have significant heterogeneity.

Is there a "principle of heterogeneity" in the material sciences? This question arises because similar phenomena are observed in nature.

Heterogeneity – from nature to current R&D work

… in nature

Mother-of-pearl is mentioned here as an example: This is actually only calcium carbonate in aragonite form with small fractions of proteins and chitin. At first glance no one would expect this material to have excellent mechanical properties. However, examination of the fracture surface under a scanning electron microscope shows that mother-of-pearl is a heterogeneous material with a layer structure (Fig. 1). In addition, the aragonite layers themselves are interrupted. As a result of this two-phase structure, cracks are deflected such that the energy from mechanical stress is insufficient to cause a macroscopic fracture. The two phases have different functions here. The inorganic layers give high strength and the organic material in between gives toughness which

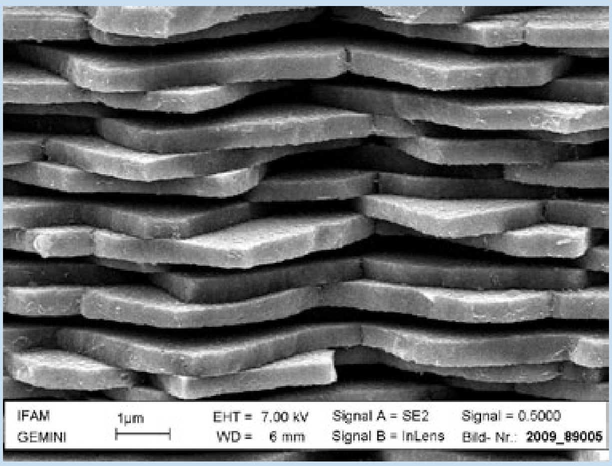
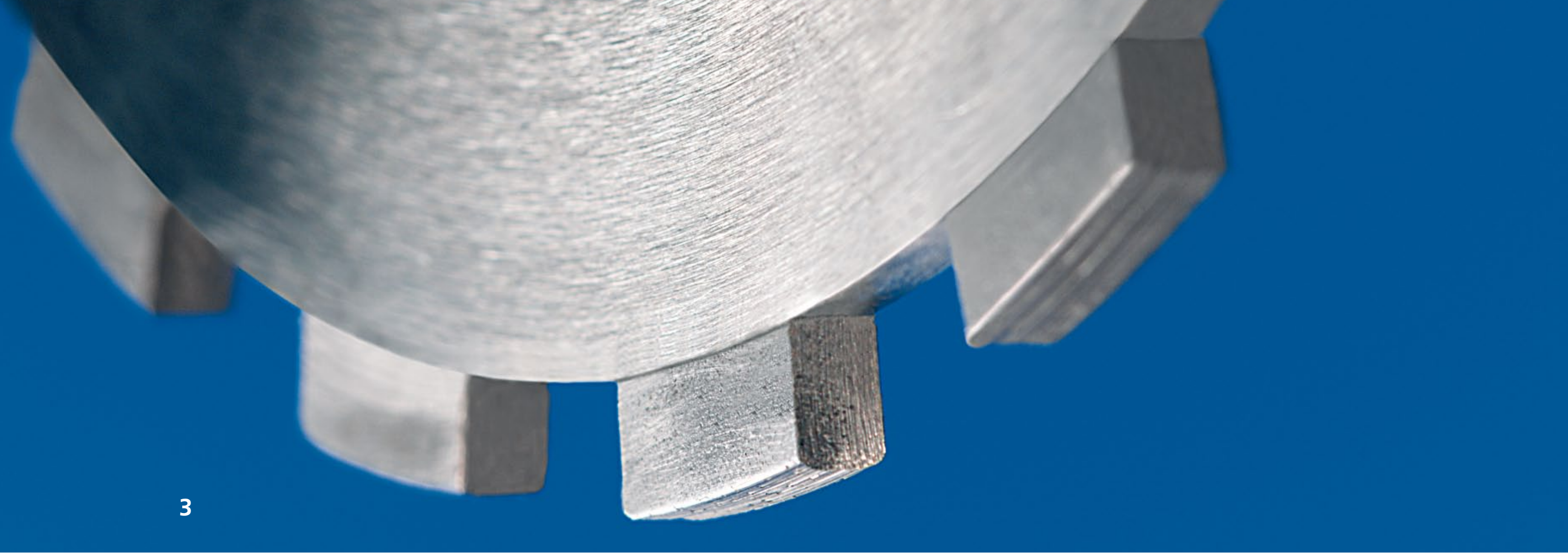


Fig. 1: Scanning electron micrograph of the fracture through mother-of-pearl from a marine snail. The layered structure of the calcium carbonate can be clearly seen, with the layers being connected by very thin layers of protein and chitin.



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prevents brittle fracture. In the case of the abalone mother-of-pearl shown in figure 1 (Haliotis tuberculata, a type of marine snail) the inorganic layers have a thickness of about 500 nanometers. In contrast, the organic "adhesive layer" in between has a thickness of only a few nanometers. Despite this, residues can easily be recognized.

Trees – another example from nature. They mainly consist of sugar and water. So how can sugar and water provide trees with good mechanical stability? On closer consideration, the typical structure of the molecules manifests itself macroscopically in the whole tree. The individual cellulose molecules, which are composed of sugar, interact with each other via hydrogen bonds and form fibers. These fibers in turn, together with the water-transporting pores, form the wood – with the detailed structure giving rise to different properties and hence specific functions for the whole tree system.

Both these examples from nature show that a "simple" chemical composition can lead to excellent properties due to ordered multiphase structures.

... in synthetic polymers

Synthetic polymers are often based on multiphase structures. Partially crystalline thermoplastics consist of amorphous and crystalline fractions, each with their own properties. This is even more apparent for plastics of heterogeneous composition. A known example is acrylonitrile-butadiene-styrene (ABS), a plastic having high strength and impact resistance – an ideal material, for example, for casings. The reason for these beneficial properties is phase separation: The hard matrix gives the high strength, but the rubber-like phase within this matrix is the reason for the toughness. These two phases are also covalently bonded to each other. If the two components were mixed at the molecular level to form a homogenous material, the hard polymer would become softer due to the rubber fraction, but not tough.

... in adhesives and bonded joints

The situation is similar for providing structural adhesives with elastic toughness: An elastomer is dissolved in the liquid epoxy resin. During the curing of the adhesive it loses its solubility while simultaneously rubber phases form having the size of a few microns. These provide the otherwise hard-brittle epoxy resin with toughness. The mixture separation which occurs on curing does however not go to completion and depends on the curing conditions. This means on the one hand that the adhesive does not become as solid as would there be a complete mixture separation, and on the other hand means that for large components the properties of the adhesive can differ from position to position. The latter depends, for example, on how quick the heating was and the temperature actually reached during the oven curing of the adhesive.

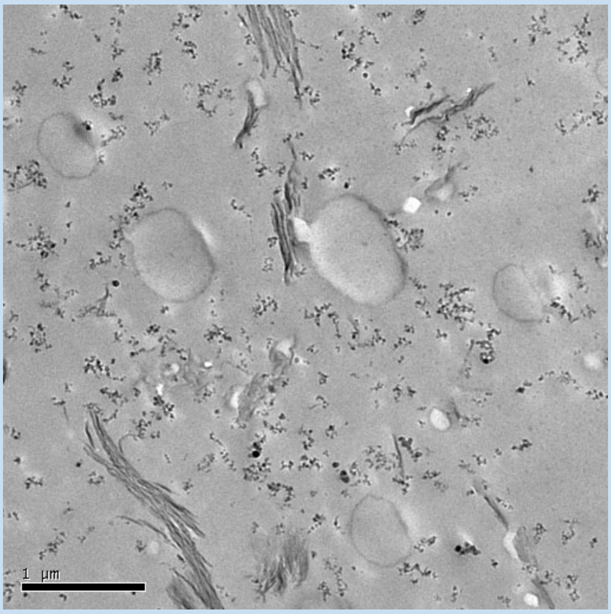
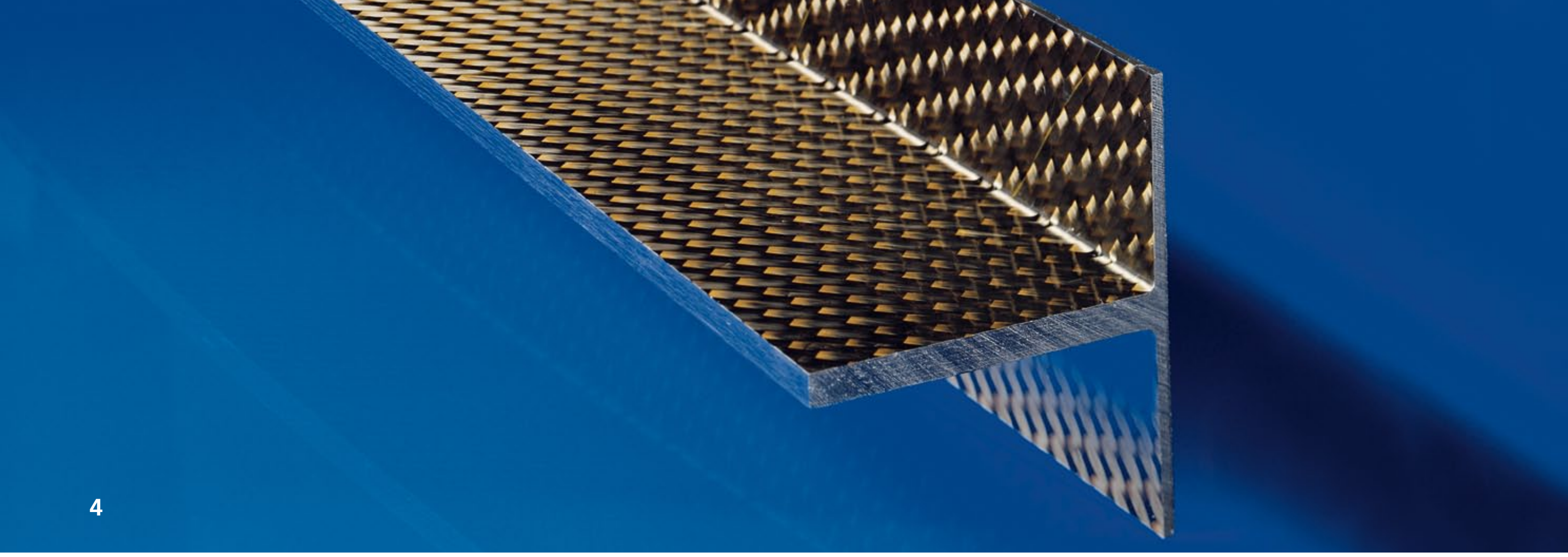


Fig. 2: Transmission electron microscopy examination of an elastic toughened epoxy resin. The virtually spherical rubber phases can be seen along with different nanofillers.



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Fillers are another component of the adhesive, already present at the formulation stage. The adhesive properties can be further modified depending on the particle size distribution and nature of the filler. For example, the strength of an adhesive can be increased by adding quartz powder. A cured epoxy resin adhesive is therefore actually a multiphase system (Fig. 2). The complex property profiles required of adhesives for technical applications are generated in this way.

At a macroscopic level, materials having different properties are also brought together – ideally using adhesive bonding. This is explained using the example of cutting discs for cutting stone (Fig. 3): If the teeth were made of the same steel as the base blade, they would wear very quickly. As such, if everything was made of a single material then the whole cutting disc would only have a limited service life. That would also be the case if the steel itself had a property-determining heterogeneous structure. A compromise regarding the material properties would be unavoidable. The solution in practice is to make the teeth for such cutting discs of another metal (hard metal) – to once again meet the principle of heterogeneity. The special point here is that the individual teeth are bonded to the base blade. The advantage of this development from the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM is that worn teeth can be replaced on site without loss of time: The worn teeth are loosened by a thermal debonding process and are replaced by bonding on new teeth – an excellent example of the effectiveness of high tech adhesive bonding.

… in fiber composite materials

Fiber composite materials intended for lightweight structures are not only heterogeneous due to the individual fibers, but the fibers also show directionally aligned structures, comparable to those of trees. An optimum alignment of the fiber structures allows very light materials having excellent mechanical properties to be produced. The components themselves can also be shaped in three directions (Fig. 4). In most cases an epoxy resin is used as the polymeric binder for the fibers. As this resin has a certain brittleness at the strength which is required, an aim of current work at the Fraunhofer IFAM is to develop a resin whose heterogeneity can be customized, so that it is less brittle but retains its original strength. This modification of the resin is being achieved by adding nanoparticles, an already preformed second phase which does not therefore first form during mixture separation processes during curing.

Heterogeneity and adhesion

Adhesion plays a key role for adhesive bonding and for heterogeneous materials. It is not only the heterogeneity itself which is decisive for the properties of materials, but how the phases are connected to each other. This is nothing else than adhesion. And this adhesion, which internally holds together a heterogeneous material, is not different from the adhesion which is responsible for macroscopic adhesion.

Heterogeneity as a goal of R&D

A future goal of the R&D work of the Fraunhofer IFAM is the improved control of the heterogeneity over many orders of magnitude – from molecules to multifunctional materials, composites, and bonded components. A fundamental understanding of mixing phenomena is necessary for this, as is an understanding of adhesion and reactions in interphases. Only in this way the institute will succeed in implementing already known strategies such that the initial properties and aging behavior can be constantly improved. The Fraunhofer IFAM has the necessary equipment and know-how for simulation und experimental work. In the future, the institute will be even more actively involved with these challenges in order to make a significant contribution to product innovation.

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3 *Cutting disc suitable for cutting granite, with bonded on hard metal teeth.*
4 *Three-dimensional fiber composite component – an example of an oriented heterogeneous structure made of carbon fibers and epoxy resin.*

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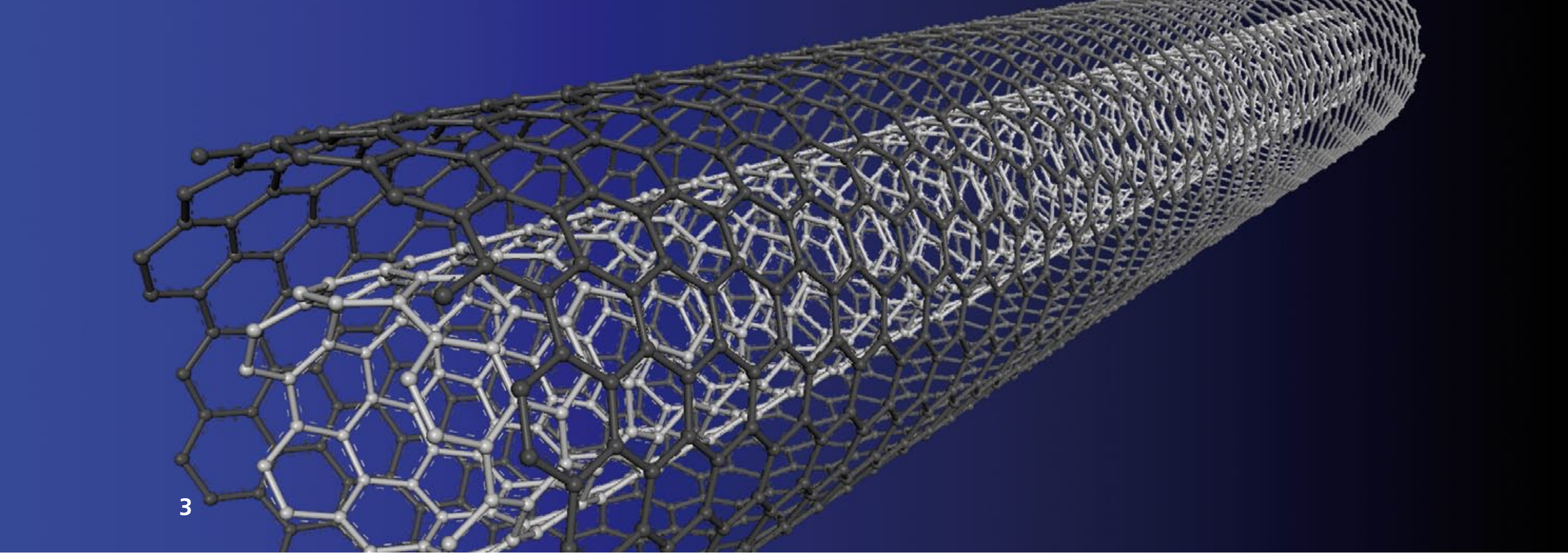
PLASMA TREATMENT OF MICROPARTICLES AND NANOPARTICLES AT ATMOSPHERIC PRESSURE PERMITS NEW MATERIALS AND APPLICATIONS

The name of the group says it all: The section Plasma Technology and Surfaces (PLATO) at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM has had many years of success in modifying surfaces by applying plasma treatment methods. Even laymen will under-stand that effective pre-treatment of surfaces is a key issue for using and optimizing materials. Of particular importance here is plasma-polymerization which can be used to generate either insulating, adhesion-promoting, or corrosion-protecting layers. Less well known is that PLATO develops these processes not only for large surfaces but also for microscopic applications: The pre-treatment of particles and their modification with adherent, dense, but also very thin layers in the order of a few nanometers has already been investigated during the last years. This approach is playing an ever more important role for novel materials, for example, in the area of electromobility.

Apart from the coating of particles, this also concerns the cleaning and pre-treatment of particles. A plasma, namely a reactive gas containing electrons, ions, and reactive molecule fragments, is able, for example, to clean surfaces: Organic contaminants can be removed. A plasma can also be used to functionalize surfaces: For example, water-repellant (hydrophobic) surfaces can be made hydrophilic, or particles which are difficult to disperse in liquids can be converted to particles that are much easier to process. The latter is achieved by using the plasma treatment to reduce the agglomeration of particles.

In plasma-polymerization, liquid or gaseous starting materials are converted into coatings that are less than a thousandth of a millimeter thick. These layers exhibit an excellent adhesion, even on very small particles, and provide them with, for example, good electrical insulation, thermal conductivity, anti-aging properties, or many other characteristics. Especially the development of atmospheric pressure plasma treatment technologies for particles has been actively improved by PLATO during the last years.



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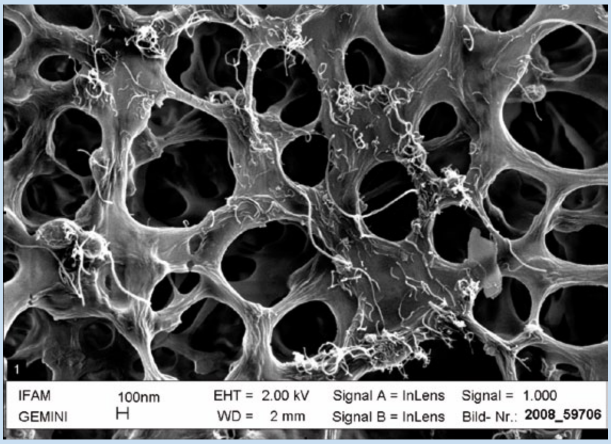

Fig. 4: Scanning electron micrograph of pretreated CNTs on filter material.

First experiences on functionalization of carbon black particles

The first experiences on the modification of particle surfaces were achieved with carbon black particles. Such particles can be produced in ovens and are a mass industrial product. The specialists at the Fraunhofer IFAM have worked with carbon black particles for a long time. This compound can be used as a filler in paints as well as for improving the mechanical and electrical properties of materials. For example, conducting paints or adhesives can be produced via the introduction of the carbon black, which alters the resistance of the polymer. Such a development can be used for lightning protection or for anti-static coatings of aircrafts (Fig. 5). For example, tailfins of aircrafts are coated with an anti-static paint so that electrical charge can be better dissipated.

Carbon black additives can, however, have undesired effects if too much is added or if there is inadequate dispersion, because they can adversely affect the stability of the coating. The PLATO section has therefore developed a method for the effective pre-treatment of carbon black particles, leading to a material that can be more effectively processed and distributed in coatings. This gives a more stable product and faster production times (Fig. 1 and 2). In addition, the use of pretreated carbon black particles allows conducting, stable adhesives to be produced.

Particle treatment – worthwhile for carbon nanotubes

Although industrial carbon black is an advanced material, there are only few niche applications for which the modification of this product using the plasma technology developed at the Fraunhofer IFAM is economically viable. The reason for this is not least the favorable price of carbon black, which only justifies the modification costs in exceptional cases. In contrast, the PLATO treatment method lends itself for high-tech novel developments – for example for carbon nanotubes (CNTs); these are microscopic tubes made of carbon (Fig. 3 and 4). Nanotubes can be used, for example, to generate highly conducting, high-strength polymers and adhesives. This is attributed to the very low electrical resistance of CNTs, meaning a current readily flows along the tubes. The addition of CNTs, however, also allows very high strength polymers to be produced, similar to the use of hollow bamboo to generate very strong structures. One application area that has already been explored for CNTs is the fabrication of special polymers for aerospace applications: In order to make materials very strong and resistant to radiation in space, nanotubes are incorporated into the materials.

In recent years the interest in carbon nanotubes has increased enormously due to their unique properties. They can be used to produce novel composite materials with extraordinary properties.


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In order to utilize these benefits, the federal ministry of education and research helped to set up the Innovation Alliance CNT (Inno.CNT; www.cnt-initiative.de). Its objective is to establish a key future market for materials technology in Germany, which can act as a worldwide leader for novel carbon nano-materials. A very large group of about 80 competent partners from industry and science have become part of Inno.CNT. This includes the Fraunhofer IFAM.

PLATO activities in the sub-project CarboFunk

The PLATO specialists at the Fraunhofer IFAM play a key role in the sub-project CarboFunk. Together with industrial and scientific institutions, work is being carried out on the customized modification of CNTs – because non-treated CNTs have only limited use for manufacturing high-performance composites. Only after surface modification it is possible, for example, to effectively incorporate CNTs in the non-agglomerated state into reactive polymers or other materials in order to mechanically strengthen these composites for lightweight structures and applications.

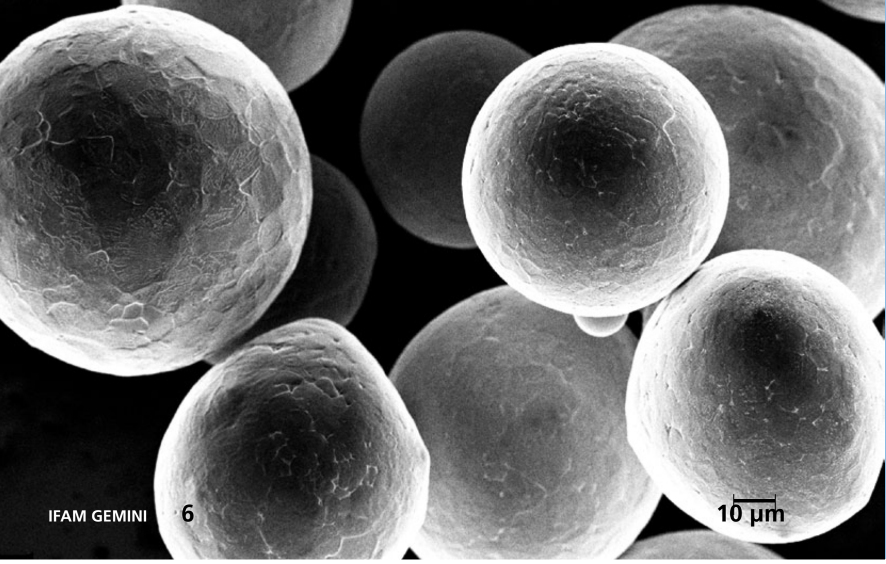
As the health risks associated with carbon nanotubes have not yet been adequately studied, processes and methods must be developed which allow harmless processing of the particles by users. One of the tasks of the CarboFunk project is hence the development of methods which allow CNTs to be safely incorporated into a solid or to be pre-dispersed in a liquid. In this context a long-term stable bond between the CNTs and matrix material is desired, as this prevents the release of CNTs during processing and handling.

Although originally developed by PLATO for the functionalization of carbon black, a low-budget product, the adapted pre-treatment method can be effectively used for CNTs, a high-end product. In the device developed at the Fraunhofer IFAM, CNTs can be functionalized in a closed system in which they are introduced as agglomerated starting products. Using ultrasound, the agglomerated CNTs are then separated from each other, mixed with a liquid, and injected into the plasma. This is carried out in a closed reactor system so that no persons come into contact with the particles. The result is a liquid suitable for further processing – for example, water or an alcohol – in which the particles are dispersed.

The advantages compared to other pre-treatment methods, which are also being studied in the CarboFunk project, include the closed process, the dispersion in a liquid, the degree of automation, and the transfer to industrial production. The PLATO method also involves no chemical baths and acids, meaning there is no chemical disposal issue. In general, nitrogen gas and water are used. The treatment process is also at atmospheric pressure, meaning that a narrow, enclosed, and environmentally-friendly apparatus can be used. This system is highly attractive to be integrated at companies into production processes.
The promising PLATO method has in the meantime been applied for a patent.

Microparticle coating process for electromobility

The experience of the PLATO section with particle treatment has also become of interest for the area of electromobility, in which the Fraunhofer-Gesellschaft created a trend-setting area of focus via the project "Fraunhofer System Research for Electromobility FSEM" (www.forum-elektromobilitaet.de). In this way, the Fraunhofer-Gesellschaft wants to assist the German car manufacturing industry to safeguard a long-term, leading position in this sector. Fraunhofer specialists are working on solutions for many aspects of electromobility – ranging from new drive system concepts to energy generation and component design. In this context, all the value-



added steps involved in electromobility must be adapted to each other. The objective is to develop fundamental building blocks for electromobility in just two years.

In this area the Fraunhofer IFAM is involved, amongst other things, in the development of new processes for making innovative polymer composites. These composites should reduce the electromagnetic losses in electrical machines. The problem here concerns eddy currents in the soft magnetic components of electrical machines, leading to losses via heat. The current solution for this problem is relatively complex and consists of a multilayered, modular structure made of electrically insulated, assembled sheets. There are numerous disadvantages – including the complicated manufacture, material losses during sheet punching, and design limitations.

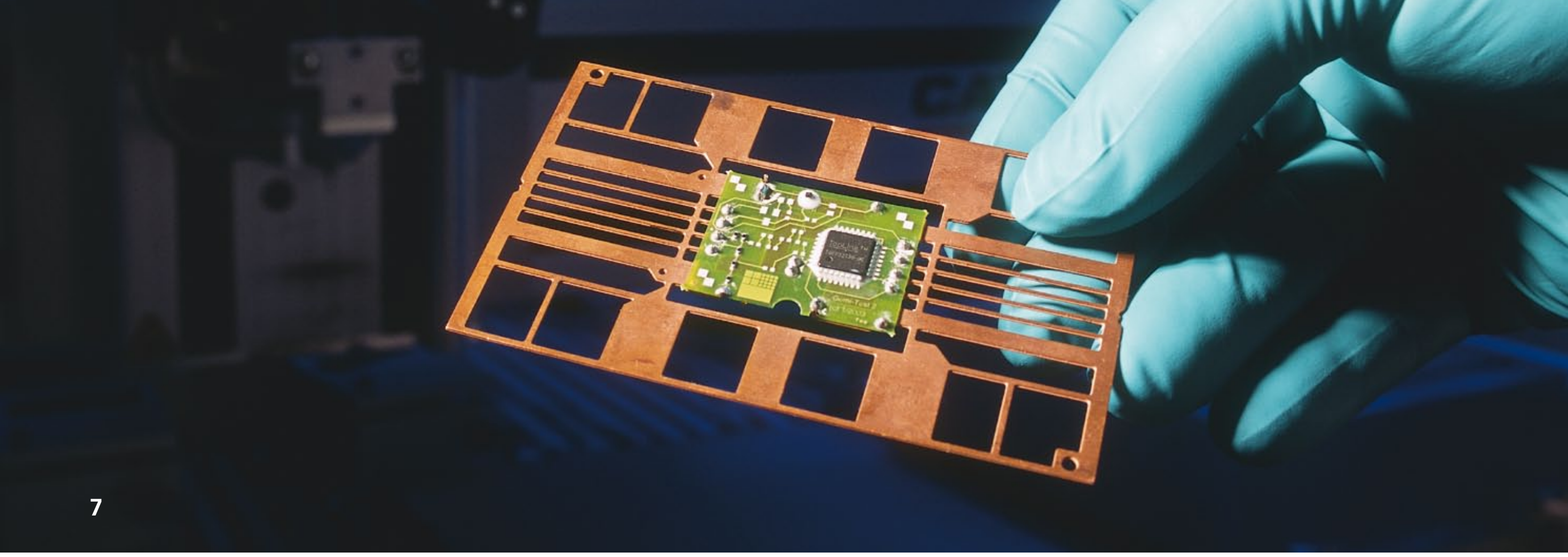
Electrical insulation of metallic fillers

The solution of the Fraunhofer IFAM: The coating of metallic fillers at the micrometer level provides mutual electrical insulation. The PLATO section can already realize this particle coating using a plasma-polymer and thereby achieving a very good electrical insulation (Fig. 6). The second main area of work of the Fraunhofer Electromobility Project is "Energy Generation, Distribution, and Conversion" and involves the further development of processes for coating soft magnetic powders. The aim is to use atmospheric pressure plasma-coating to coat soft magnetic powders having different particle size distributions. The Fraunhofer Institute for Integrated Systems and Device Technology (IISB) then performs the further processing with thermoplastic polymers or thermosets. The in-depth experience of PLATO in the area of particle coating and the close collaboration with specialists from other Fraunhofer institutes have already resulted in first successes. The polymer-bound soft magnetic materials, due to their versatile shaping properties, open up totally new opportunities for manufacturing electromagnetic components. As a result there are new technical concepts for the integration of high-performance electronics into complex-shaped spaces.

IPANEMA – new packaging materials for components

A further, promising application for plasma-polymerized micro-particles has been targeted by PLATO since autumn 2007 in the IPANEMA project (funding reference: 01RI0716B). Partners from industry and science are working together on a joint project in order to develop insulated particles for new materials in the field of electronic and electrical engineering. As innovative packaging materials – namely materials that can be used for protection against environmental influences – they should allow the manufacture of new electronic and electrical engineering products. The aim of this project is to improve the competitiveness of various sectors of industry. The unique, heat-conducting properties of these metallic particles and materials, due to the thin, insulating plasma-polymer layers, allow these products to be used as electrically insulating materials. This enables the design and construction of totally new components and systems, as current design methods have reached their limits (Fig. 7).

The background of this project is the fact that increasing miniaturization and integration of chips and assemblies is allowing ever higher power densities, with the result that operating temperatures are also constantly increasing. Other problems arise due to the fact that electronic assemblies are being used at higher ambient temperatures – for example in cars – or at higher humidity, for example, in the Asian marketplace. Where can the heat go? That is one of the key questions that has to be answered in this age of increasing miniaturization, increasing power as well as multifunctional



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technical and electronic products. Important to recognize in this context is that more than half of the failures of active components are due to excessive temperature.

The objective of the IPANEMA project is therefore to improve the thermal conductivity of the packaging materials in order to dissipate the heat as effectively as possible. This will be achieved by developing thin, electrically insulating plasma-polymer coatings for metallic particles, so that new hybrid polymers with high packing densities can be realized. In addition to aluminum and magnesium, copper particles are of growing interest due to the very high thermal conductivity of this material. The particle coating method developed by the PLATO section has also shown much promise in this project. The objective is to develop polymers containing embedded e.g. copper particles that are coated with insulating layers produced via the low temperature plasma-polymerization. These coatings dissipate the heat very effectively, but hinder electrical contact. If desired, additional functions can be given to the heat-conducting polymer layers, for example for the supplemental application as a filler or a sealant.

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1 | 2 *Plasma-pretreated colored pigments and carbon black: untreated (left), treated with different treatment intensities (center and right).*
3 *Schematic representation of a multi-walled carbon nanotube (CNT).*
5 *Conducting lacquers and adhesives for high-tech applications containing functionalized carbon nanotubes (CNTs; image source: MEV-Verlag).*
6 *Plasma-treated micro metallic powders for applications in the area of electromobility.*
7 *Heat-conducting packaging materials for innovative production concepts (Image source: MEV-Verlag).*

INCREASED SAFTEY DUE TO IMPROVED CORROSION PROTECTION FOR SHIPS – LABORATORY TESTS ON NEW TECHNOLOGIES FROM FRAUNHOFER IFAM

Increased safety standards in the shipping industry have significantly increased the requirements on corrosion protection for ships. Of particular importance are the regulations issued by the International Maritime Organization (IMO), an agency of the United Nations, concerning corrosion protection for new ships (IMO performance standard for protective coating PSPC).

From a corrosion protection perspective, the free edges are particularly critical elements. Experience shows that the degradation of coatings and corrosion is most prominent at edges (Fig. 1 and 2). A reason for this is the reduced thickness of coatings on sharp edges. In practice this problem is being combated in two ways: Firstly by post-processing of the edges and secondly by applying extra edge protection, for example primers (stripe coat application). The rounding of the edges is currently usually carried out by grinding.

The IMO regulations now demand triple edge-grinding for various regions of the ship, and an edge radius of at least two millimeters. A survey of German shipyards indicated that this work would require up to 65 percent extra time compared to current normal practice for edge rounding. However, in order to leave scope for innovation, the IMO regulations also allow the use of alternative methods.

The BeKaS project –
Development of new technologies for the production of edges on ships suitable for coating

The objective of a joint project funded by the federal ministry of economic affairs and technology entitled "Development of new technologies for the production of edges on ships suitable for coating" (BeKaS) was to replace the time-consuming methods for processing edges using thermal methods that are currently established in the shipbuilding industry. In parallel, and as a basis for approval of the thermal methods, complex laboratory tests were undertaken on the protective effect of organic coating systems (paints) on various post-processed edges.

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Laboratory tests with new technology at Fraunhofer IFAM

The laboratory tests involved scientists from the Lacquer/Paint Technology section, and from the Electrochemistry/Corrosion Protection work group of the section Adhesion and Interface Research of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM. At Muehlhan GmbH, Bremen, almost 500 test specimens (with ca. 1500 edges for testing), that had been prepared by the shipyards and rounded by the process developers, were coated with corrosion protection systems, some of which were very difficult to apply.

The specimens were then tested at the Fraunhofer IFAM using two complementary methods, employing test facilities specially developed for the project:

Wave tank simulation chamber

Following the guidelines of the IMO, a test chamber was designed and constructed which allowed simulation of the main factors affecting the ballast water tanks of ships such as waves, taking into account the different zones (spray water zone, partially immersed zone and permanently immersed zone), temperature, and salt concentration.

Its volume of 2000 liters makes it the largest of its type (Fig. 3). In Germany there is currently only one other similar test facility.

Coated edge specimens were exposed to corrosion conditions for 180 days in this wave tank simulation chamber and were then evaluated in accordance with preset criteria.

Electrochemical edge measurement cell

In addition, a special electrochemical measurement cell was designed for measuring the electrical impedance at edges (Fig. 4).

Using electrochemical impedance spectroscopy (EIS), detailed information about the degradation processes occurring in the coating system can be acquired and hence conclusions drawn about the failure mechanism. Modern devices (potentiostats) can measure barrier resistances up to a very high resistance range (tera ohm) – for example the barrier resistances of organic coatings, which counter the penetration of moisture into these layers.

Fig. 4: Electrochemical edge measurement cell for undertaking EIS measurements on coated edges.

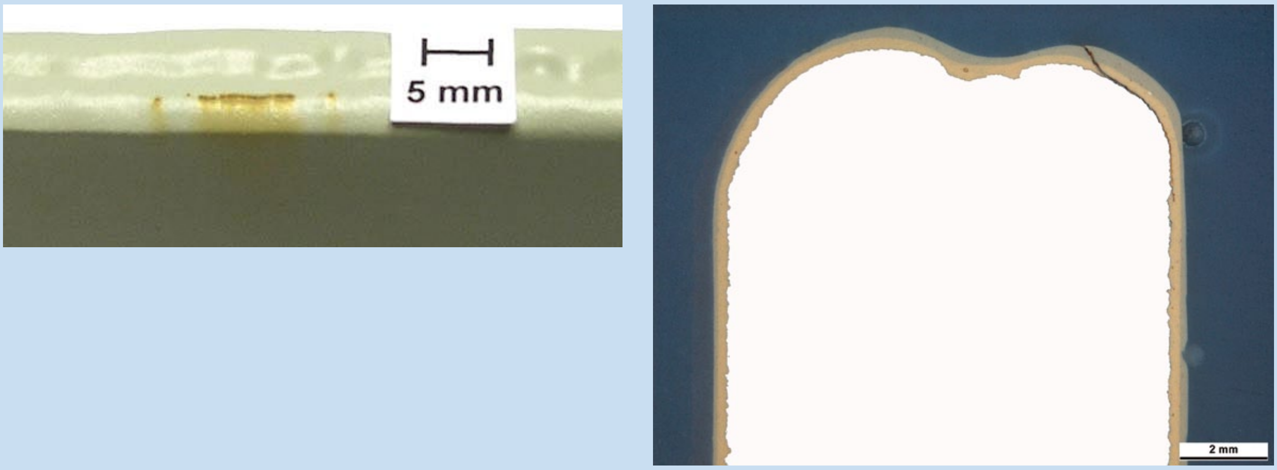

Fig. 5: Rounded edge with starting corrosion (left). The cause is crack formation in the coating (right).

Results and outlook

The tests demonstrated that mechanical stresses arise, due to swelling of the coating at the edges, which can lead to cracking (Fig. 5). These cracks represent the starting point for further corrosion.

The comparison of the two test methods allowed a unique contribution to be made to the understanding of failure at coated edges and the effect of specific parameters, for example edge geometry, layer thickness, and the coating system. Existing technical guidelines are being critically appraised based on the newly acquired findings and are being updated where necessary.

Project funding

The project was funded via Forschungszentrum Jülich GmbH (PtJ) for the federal ministry of economic affairs and technology (BMWi) under funding reference 03SX238D.

Project partners

- Center of Maritime Technologies e. V. (CMT)
- DNV Research and Innovation
- Flensburger Schiffbau-Gesellschaft mbH & Co. KG
- Fraunhofer Applications Center for Large Structures in Production Engineering of the Fraunhofer Institute for Manufacturing Engineering and Automation IPA
- Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM
- IMAWIS – Maritime Wirtschafts- und Schiffbauforschung GmbH
- Meyer Werft GmbH
- Muehlhan GmbH
- Nordic Yards, formerly Wadan Group
- Peene-Werft GmbH
- Schweißtechnische Lehr- und Versuchsanstalt Mecklenburg-Vorpommern GmbH (SLV)
- TKMS Blohm + Voss Nordseewerke GmbH

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1 | 2 *Corrosion on the sides of ballast water tanks (Image source: Muehlhan GmbH).*
3 *Open wave tank simulation chamber with test objects.*

SIMULATION OF THE VOLUME SHRINKAGE OF ADHESIVES ON CURING AND CONSEQUENCES FOR COMPONENT DESIGN

Background

Molecular modeling allows many properties of materials to be calculated. This is why it is an important tool for developing new materials and understanding physical-chemical processes. The starting point for molecular modeling is knowledge of the precise structure of the material at an atomic level. For polymer networks, for example adhesives, this is however often unknown and is difficult to determine by analytical means. In order to generate the cross-linked model structures required for molecular modeling, one often starts with the non-cross-linked polymer, namely the pure mixture of the monomers. Usually, only the cross-linking of the reactive groups based on a distance criteria is considered and the reaction kinetics of the respective groups is neglected. In many cases this results in structures which do not truly reflect real polymer networks. This is because the models are highly dependent on the often arbitrary choice of distance criteria.

A new method for generating more realistic polymer structures is to consider the macrokinetics when forming the atomic network via thermoanalytical methods. This approach was developed at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM. The network structures generated in this way by molecular modeling are then used to calculate the volume reduction due to curing shrinkage of the relevant model adhesive. For many applications, as explained below, this has a deleterious effect on the properties of the component.

Reactive adhesives change in density and volume during curing: The density increases, and the volume decreases. This phenomenon is known as curing shrinkage and is due to the fact that monomers and oligomers react to form a polymer network. In the initial state there are moving molecules which are different distances apart. These distances decrease due to reaction of the molecules with each other, and become the size of a bond length. An adhesive formulator can reduce this volume shrinkage by various measures, but it is extremely difficult to exactly predict the curing shrinkage or to fully eliminate it.

The effects of curing shrinkage on bonded components can be drastic and range from deformed substrates to substrate fractures. In optical and sensor applications, where the position of bonded components must be very precise, even small positional movement due to curing shrinkage can have a large influence on the functioning of the component. In particular, high-modulus adhesives, despite their many favorable properties, must be used with caution because they cannot absorb shrinkage-induced stress and this stress is transferred to the substrates. If the curing-related volume shrinkage was however known, this could be taken into account in the component design phase.

Fraunhofer IFAM approach to solving this problem

The starting point is determination of the adhesive composition (structure of the monomers, nature and concentration of the reactive species), and the individual reaction steps (kinetics) of the curing reaction. The kinetic constants of the individual reactions can be determined from conversion measurements. For warm and hot curing systems these measurements can be carried out using Differential Scanning Calorimetry (DSC), but other methods are also possible. Based on the kinetics, the number of available reactive groups and hence the conversion can be calculated at any point in time. These data are used in molecular modeling in order to build up realistic networks at an atomic level at different curing times. The networks are the starting point for calculating material-specific parameters such as the density. This means that for an adhesive of known composition the curing-related volume change can be calculated using a combination of appropriate methods (Fig. 1). Using finite element methods, the curing-related stress in bonded components can then be directly determined from these volume changes. The stresses can hence be taken into account and counteracted in the component design phase.

At the Fraunhofer IFAM the curing-related volume shrinkage has been determined using the example of a filled, two-component epoxy resin model adhesive. The curing-related volume shrinkage was taken into consideration in component design.

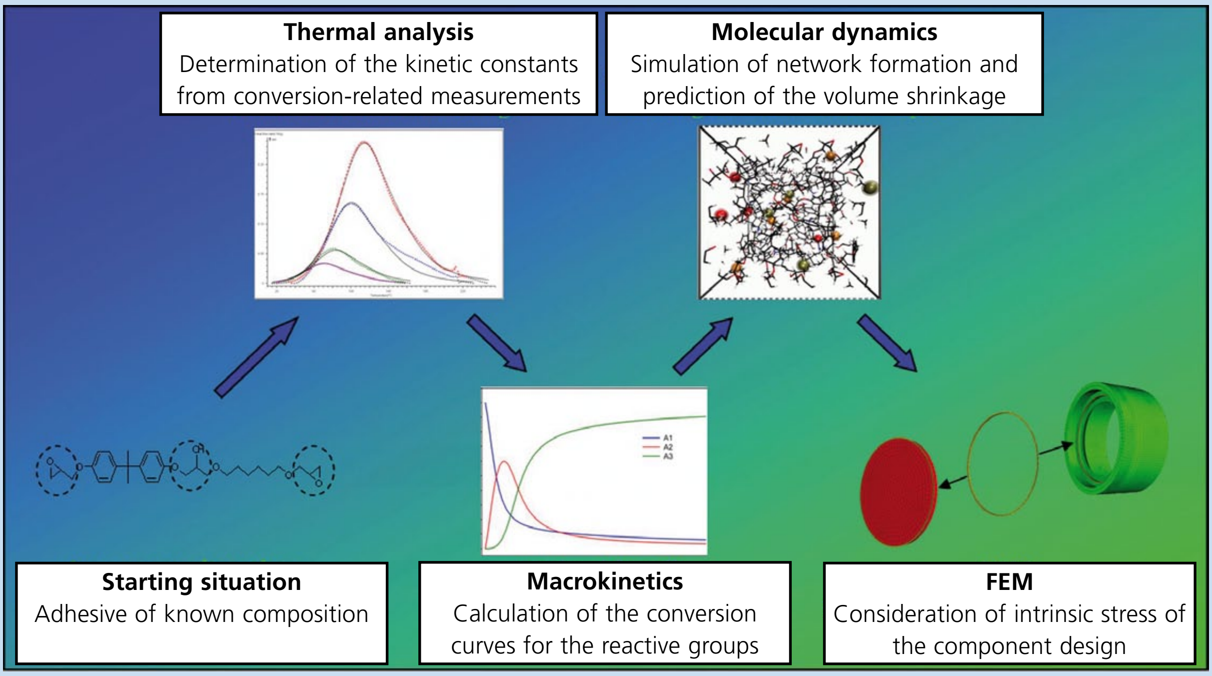

Fig. 1: Combination of individual methods for calculating and taking into account curing shrinkage in the component design phase.

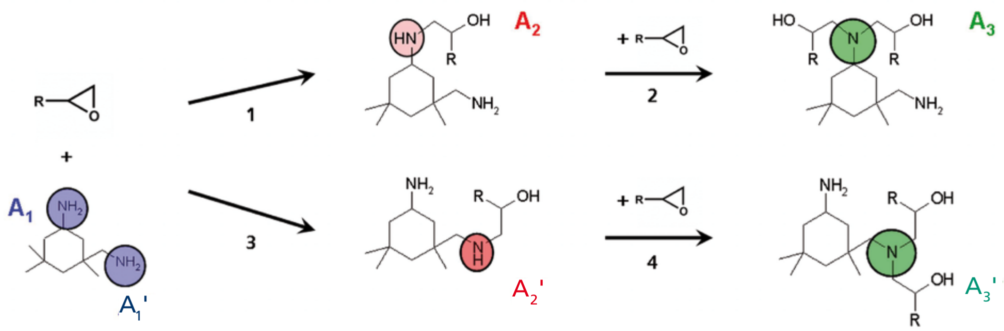

Fig. 2: Possible reactions during the curing. The primary amines A_1 and A_1' and the cross-linking species A_2 and A_2' (secondary amines) and A_3 and A_3' (tertiary amines) are highlighted.

Determination of the kinetics and conversion – thermoanalytical methods and macrokinetics

The starting point for determining the kinetic constants of the curing reaction is knowledge of the number and nature of the reactive groups. If these are unknown, these can be determined using a number of structural analysis methods. The selected model adhesive was a highly pure epoxy resin based on bisphenol A (two epoxide groups per molecule) and isophorone diamine (IPD, two amine groups per molecule). The adhesive reacts at both room temperature and at elevated temperature. Figure 2 shows the four possible reactions during the curing. Here, the reactivities of the two amino groups A_1 and A_1' can be considered to be independent of each other.

During the cross-linking reaction the two amine groups react with epoxide groups by ring-opening. Each of these reactions releases heat and this can be measured by DSC. The measured heat is proportional to the conversion. In order to analyze the reaction kinetics, heat flow curves at different heating rates were recorded using DSC. The kinetic constants of all four partial reactions were determined using the Thermokinetics program of Netzsch. In agreement with the literature, the reaction of the epoxide groups is catalyzed by hydroxyl groups which are produced in each of the four partial reactions. For

	Description	m=1	m=2	m=3	m=4
A_m [10^3/s]	*Rate constant*	13.7	6.2	16.7	65.4
E_m [kJ/mol]	*Arrhenius energy*	51	51	51	51
n	*Order of Reaction*	2	2	2	2
K_{cat}	*Catalytic constant*	15.5	12.3	44.7	0.7

Table 1: Kinetic constants for the individual reaction steps m = 1 to 4 (Figure 2).

$$v_m = A_m \cdot e^{-\frac{Em}{RT}} \cdot a_m^n \cdot \left(1 + K_{cat} \cdot X_m\right)$$

Equation 1: Autocatalytic model for the reaction rates v_m of the individual reaction steps for m = 1 to 4 (see Figure 2). a_m are the concentrations of the reactive species and X_m are the respective fractions of autocatalytic species. For other parameters see table 1.

determining the kinetic constants the autocatalytic reaction model of equation 1 therefore provides the best agreement with the measured data and a good representation of the overall reaction (Fig. 2).

The kinetic constants of all four partial reactions are summarized in Table 1. Still to be taken into account, however, is that the system vitrifies if the glass transition temperature exceeds the reaction temperature of the system. The consequence is a diffusion-controlled reaction. The time and the critical conversion beyond which the system vitrifies at room temperature and the final conversion were determined by measuring the residual reaction enthalpy via DSC for samples that had been stored for different periods at room temperature. In this way, appropriate diffusion control could be integrated into the kinetic equations, thus finally enabling the conversion curves of all reactive species in the reaction system to be calculated at any moment in time via macrokinetics (Fig. 3, upper left).

Calculation of the curing shrinkage by molecular modeling

The objective of molecular modeling is to develop realistic structures for the cross-linked adhesive and to calculate the curing shrinkage. First of all, based on the composition of

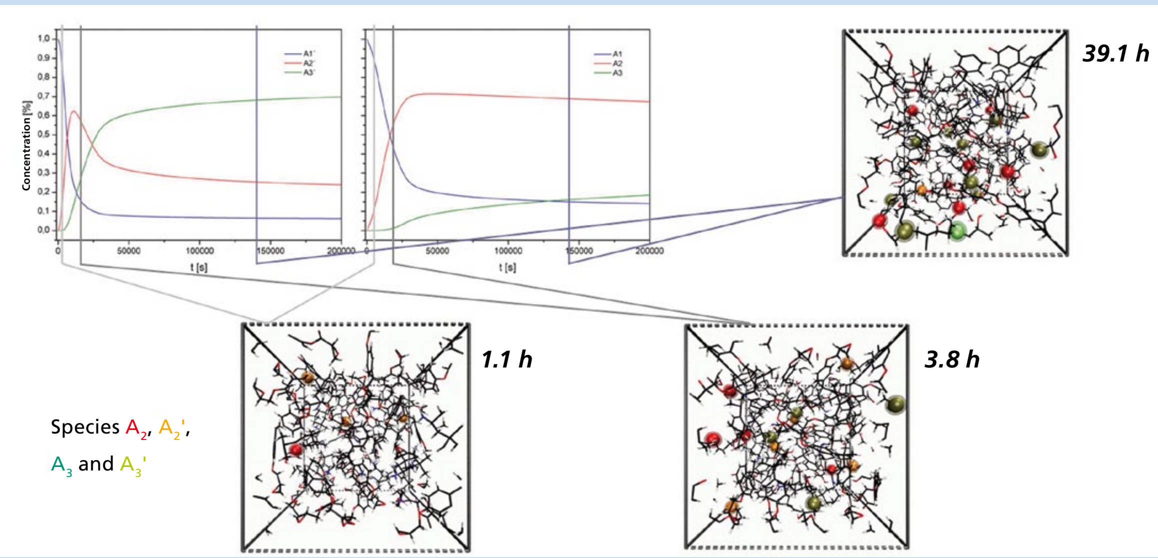

Fig. 3: Cross-linked intermediate phases generated from data from the macrokinetics (upper left) after 1.1, 3.8, and 39.1 hours. The cross-linking species A_2, A_2', A_3, and A_3' are highlighted.

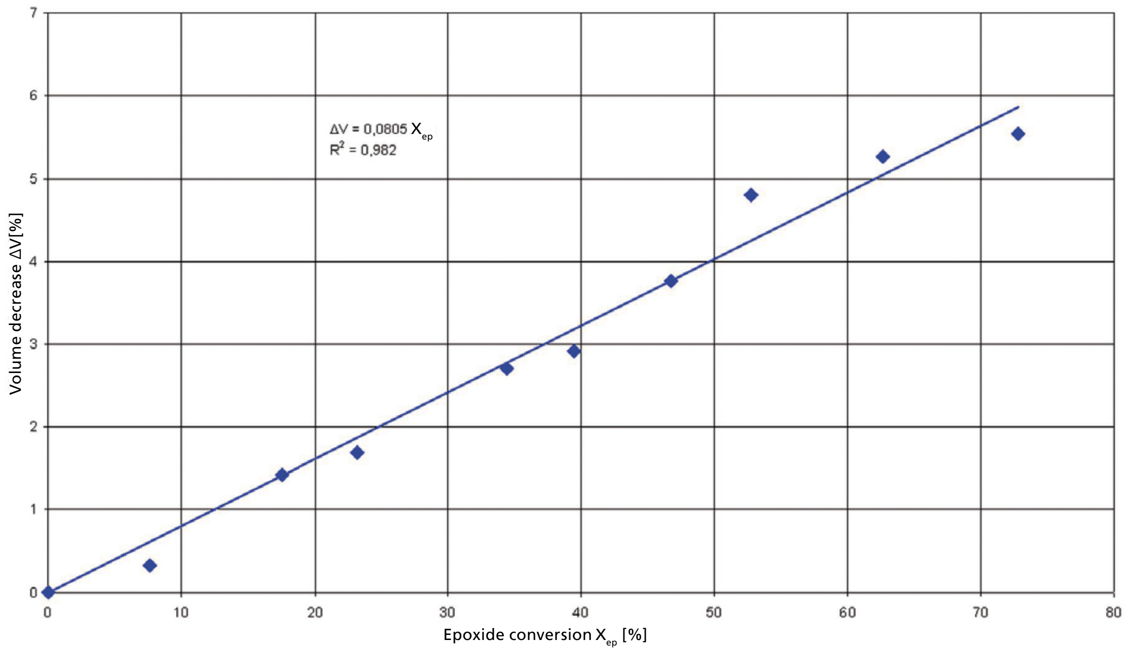

Fig. 4: Correlation of the volume shrinkage ΔV with the epoxide conversion X_{ep}.

the adhesive in its initial state, a structural model of the non-cross-linked adhesive is generated at an atomic level. This serves as the starting point for generating cross-linked models right through to the fully cured state and also as a reference system for calculating the volume change. The number of individual cross-linking species at different moments in time during the curing was calculated using macrokinetics. This involves considering the chemical reactivity of the functional groups during network formation, instead of only using a distance criterion for the cross-linking. Using a structure generator developed at the Fraunhofer IFAM which carries out the cross-linking of the atomic models based on this data, structures of the intermediate phases and the cured adhesive were generated. It was hence possible to model the whole curing period using atomic models which molecular modeling, which is normally limited to time periods of several nanoseconds, would not have been able to do alone. The optimization of these structures was undertaken using molecular dynamics techniques such as LAMMPS software (Large-scale Atomic/Molecular Massively Parallel Simulator) of Sandia National Labs. Figure 3 shows optimized model structures of the adhesive at different points of time.

The resulting model structures of the adhesive allow calculation of the densities. The volume shrinkage during the curing reaction can then be determined from the changes in density. Both the density and shrinkage increase with conversion. Figure 4 shows the volume decrease as a function of the conversion. This has been fitted to a linear function and it is clear that there is a linear relationship between the shrinkage and conversion. Based on the kinetic data, molecular modeling hence allows calculation of the volume shrinkage at any desired point of time through to the cured state. Further processing of the data using the Finite Element Method (FEM) permits the stresses induced by the shrinkage to be determined.

Component design using FEM

In bonded components, adhesive shrinkage is hindered by the adhesion to the substrates. This induces intrinsic stresses in the bonded joint which lead to deformation of the substrates. This is portrayed schematically in figure 5 for an aluminum-glass joint. It can be seen that the joint becomes compressed at the free edge, whilst the hindering of this movement by the adhering substrate results in bending of the glass.

Important for the behavior of the component is the volume decrease from the moment beyond which stresses can arise in the bonded joint. When the adhesive is still a liquid, the volume change first of all induces no stress in the component. Only when there is a network structure throughout the whole adhesive volume force transfer is possible. At the earliest this is achieved beyond the gel point, which is determined using a rheometer.

Gelling occurred after 6.8 hours for the model adhesive. At that point the conversion was 49 percent and the volume shrinkage is already about 4 percent (Fig. 4). As no force can be transferred, this 4 percent shrinkage induces no intrinsic stress. The shrinkage of about 2 percent between the gelling and the end of the reaction, namely between 49 and 75 percent conversion, manifests itself however as intrinsic stress.

The effective shrinkage determined from the molecular modeling and the material parameters for the model adhesive were used within the finite element software program ABAQUS in order to calculate the deformation due to the

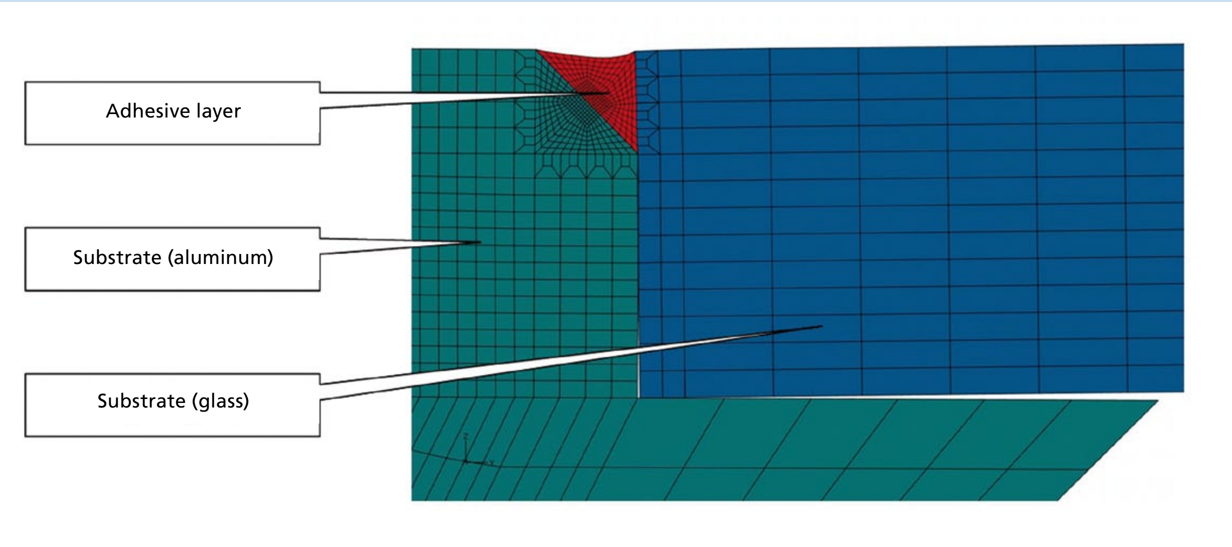

Fig. 5: Curing shrinkage induced deformation of a bonded glass sheet.

induced stress on a bonded sensor component. Figure 6 shows the range of movement due to the volume shrinkage of 2 percent. If, in contrast, one uses the shrinkage over the total reaction period of about 6 percent, obtained from density measurements before and after the reaction, this results in too high intrinsic stresses and the movement is overestimated by a considerable amount. The approach which has been described hence allows a much more accurate prediction of shrinkage-related intrinsic stresses.

Summary and outlook

The linking of experimental methods and simulation at different levels (molecular level through to bonded component) successfully allows computer-aided prediction of the curing shrinkage and can be used to solve application-related problems. The advantage of this approach is that there is direct correlation between the macroscopic intrinsic stresses and deformations in bonded components and the molecular network structure, which implicitly takes into account the effect of the real reaction kinetics.

By generating realistic network structures, molecular modeling also allows a series of material parameters to be calculated, for example the swelling properties, mechanical properties, and thermal expansion.

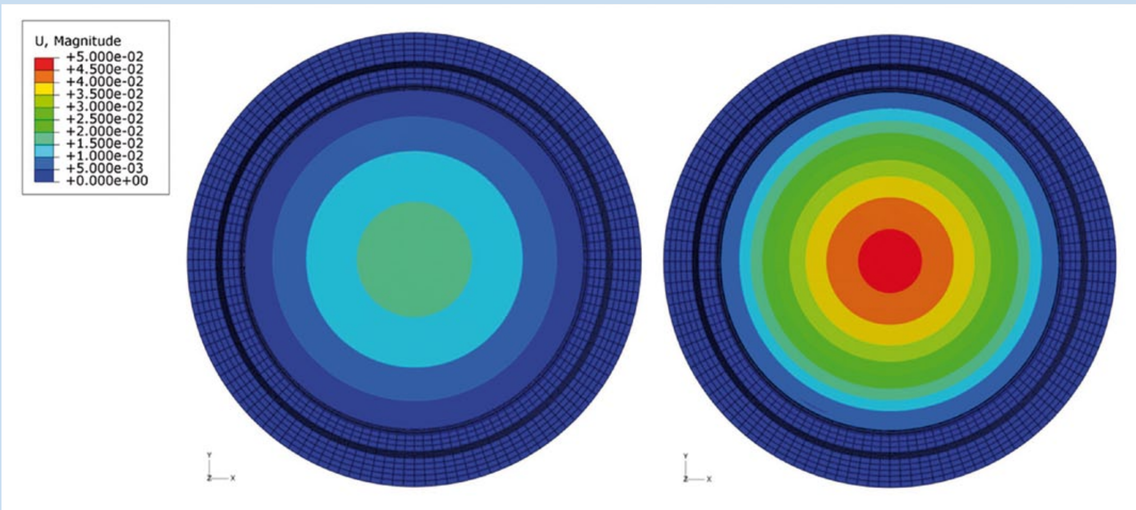

Fig. 6: Movement of a sensor component due to shrinkage of the adhesive film (in mm). Shrinkage determined by molecular modeling beyond the gel point (left) and the overall shrinkage determined from experiments (right).

Project funding

This work was undertaken as part of the project entitled "Development of a simulation tool for predicting the curing shrinkage and swelling behavior of adhesives" (reference: 03X0502D; project term: 1.4.2007 to 31.3.2010) and was funded by the federal ministry of education and research BMBF.

Project partners

Project partners in this project were Carl Zeiss Jena GmbH (Jena), Sartorius AG (Göttingen), Wellmann Technologies GmbH (Friedelsheim), and the University of Wuppertal.

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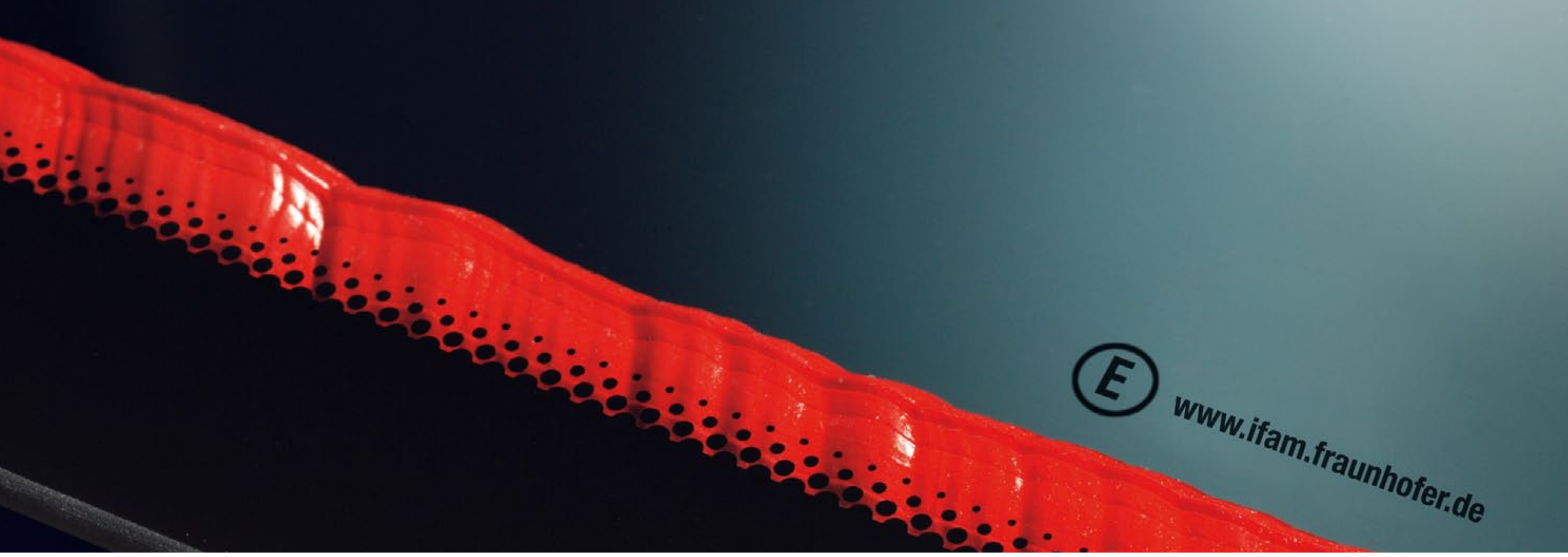

"CERTIFICATION BODY" OF THE FEDERAL RAILWAY AUTHORITY – SUCCESS STORY AND CHALLENGE

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM provides services for public organizations in many areas. This not only involves R&D, but also the definition and monitoring of quality standards. Best example: Since December 2006 the institute has acted as a "Certification Body for the manufacture of adhesive bonds on rail vehicles and parts of rail vehicles" of the Federal Railway Authority (FRA) (Fig. 1). At that time the FRA, as the national regulatory authority for all interests of rail transport, established two certification bodies in Germany. The objective was to ensure there was compliance with a new standard (DIN 6701-2) for the manufacture of adhesive bonds on rail vehicles and parts of rail vehicles. This standard was the response to the increasing importance of adhesive bonding for rail vehicle construction. The trend towards lightweight construction using an intelligent mixture of materials is also present in this sector and is resulting in a notable increase in the use of adhesives.

The DIN standard is mandatory for all companies carrying out adhesive bonding work, trading bonded products, or undertaking other services connected with designing and dimensioning bonded components. Since the start of 2007 companies have been invited to get the relevant approval and since January 1, 2010 this has been mandatory. This approval can be granted by the Fraunhofer IFAM, the larger of the two certification bodies in Germany. However, the introduction of the multi-part standard succumbed to time pressure and it was decided to initially only bring part 2 into force. This part covers the detailed description of the approval procedure for companies: What steps must be taken and what conditions fulfilled in order to be successfully accredited? The other parts – a glossary of technical terms (part 1), a description of the correct dimensions and designs of bonded joints for rail vehicle construction (part 3), and the correct application of adhesives (part 4) – were still under development when the standard came into force. The reason for the rush to enforce the standard was to give the growing use of adhesives in the sector a sound basis, not least because this involved many areas which were important for the safety of rail traffic.

DVS guideline used as an interim solution

Three of the four parts of the DIN standard would hence only be drawn up and adopted at a later date. Despite this, the Fraunhofer IFAM already had certification assignments to undertake that had to be completed on a safe legal basis. "Generally accepted engineering practice" was hence used as the basis for the certifications – and for adhesive bonding technology the long-used and proven guideline 3310 of the


Eisenbahn-Bundesamt

Zentrale

Bescheinigung über die

Anerkennung

für das

Fraunhofer Institut für Fertigungstechnik
und Angewandte Materialforschung IFAM
Bereich Klebtechnik und Oberflächen
Wiener Straße 12
28359 Bremen

als

"Anerkannte Stelle"

für das

Kleben von Schienenfahrzeugen und -fahrzeugteilen
nach DIN 6701

Identifikationsnummer: EBA - 06/6701-01

Diese Bescheinigung beruht auf der im Schreiben vom 11.12.2006 - 3.531 - 35Xfk06/6701-01 ausgesprochenen Anerkennung und den dort genannten Vorraussetzungen.

Die Anerkennung ist mit dem Vorbehalt des Widerrufs befristet bis zum 31.12.2011.

Dr.-Ing. Thomasch

Eisenbahn-Bundesamt 5 Zentrale

Bonn, 11.12.2006

Fig. 1: The Fraunhofer IFAM has been a "Certification Body for the manufacture of adhesive bonds on rail vehicles and parts of rail vehicles" of the Federal Railway Authority since 2006.

Deutscher Verband für Schweißen und verwandte Verfahren e. V. (DVS; German Association for Welding and Related Techniques) was adopted.

This guideline describes how a bonding process must be organized so that, depending on its importance, it can be effectively carried out. The guideline was hence an important basis for the Fraunhofer IFAM. In the meantime it has been incorporated into Parts 3 and 4 of the DIN standard and the latter have now also been brought into force.

A number of innovative companies in the adhesive marketplace saw an opportunity in the DIN standard to undertake further developments in order to position themselves better. They were quick to ask for an audit process and so acquire the relevant quality mark. Most companies, however, took more time to be audited. At the same time, the market grew because municipal organizations – for example tram operators – adopted the standard. The Fraunhofer IFAM had to handle the majority of the certification requests in the second half of 2009 due to the approaching deadline. This was an enormous challenge for the institute because auditors must have excellent technical knowledge and also many years of experience with adhesive bonding in rail vehicle construction. More auditors were needed: At first two Fraunhofer IFAM auditors undertook work for the Federal Railway Authority, but that number has now grown to six.

International function expanded

In parallel, the international work of the Fraunhofer IFAM in this area increased. This is because many suppliers for the German rail vehicle market are located in the Near and Far East, India, and South America. These companies, like European companies, also have to be certified. During these audits in foreign countries, which usually take several days, the IFAM auditors also have to take cultural communication differences and work practice differences into account. Most of the certified companies abroad are not involved in class A1 bonding work (highly safety-related bonding tasks), but are rather involved with classes A2 and A3 (medium and low safety requirements). This often concerns the bonding of interior components or door or control systems.

For the certification, high importance is also put on the training of the workforce. Depending on the class of bonding work that is being undertaken, there are requirements regarding the training qualifications of the people carrying out the adhesive bonding tasks. In class A1, for example, the supervisor in charge of adhesive bonding work and the equally qualified deputy must at least have a DVS®/EWF-European Adhesive Engineer (EAE) certificate. In the other classes, a DVS®/EWF-European Adhesive Specialist (EAS) or DVS®/EWF-European Adhesive Bonder (EAB) certificate suffices depending on the importance of the adhesive bonding work. Strictly separated from the work of the Certification Body, the Fraunhofer IFAM also offers these training courses (Fig. 2). The advantage here is that amended or new requirements and developments in the application of adhesive bonding in rail vehicle construction immediately become incorporated into the training course material.

Adhesive bonding training courses ever more important

The number of training courses given by the Fraunhofer IFAM continues to grow, not just due to the establishment of a Certification Body of the FRA at the Fraunhofer IFAM. A challenge here for the Center for Adhesive Bonding Technology at the Fraunhofer IFAM was also to offer the training courses to people from abroad, namely to give the courses in English. In the past, participants have often had to travel to Bremen several times to complete, for example, the various stages of the EAE training course. In the future certain training courses will be given locally in Asia, to truly meet the needs of the participants. This involves overcoming a number of organizational and logistical hurdles, because the training courses – some of which are customized for our partner Henkel Asia-Pacific & China Headquarters – have to be expanded at short notice depending on the demand.

The increasing needs of various industries have raised the importance of the Center for Adhesive Bonding Technology as a leading global center for workforce training in adhesive bonding. It is not only the rail vehicle construction sector that is asking for training. Other sectors of industry now also understand the need for adhesive users to possess the correct training qualifications.

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2 *Workforce training at the Center for Adhesive Bonding Technology at the Fraunhofer IFAM.*

THE SCIENTIFIC TALENT OF TOMORROW

The Fraunhofer IFAM attracts young scientific talent via an established and proven strategy. The Department of Adhesive Bonding Technology and Surfaces of the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM is not only involved with the Talent-School and TheoPrax® for acquiring young talent, but also with the Junior Engineer Academy: On November 5, 2009 the first Junior Engineer Academy in Lower Saxony was presented at the Fraunhofer IFAM.

Start of the first Junior Engineer Academy in Lower Saxony

Getting an insight into the training and everyday work of an engineer or scientist stimulates an interest in these careers. This is the aim of the Junior Engineer Academy, a national model project of the Deutsche Telekom Stiftung. This was set up in response to the predicted future shortage of qualified scientists and engineers. Since the start of 2009, the Fraunhofer-Gesellschaft and Deutsche Telekom Stiftung have been working together on this project, and are particularly keen to raise the number of females in "MINT" professions. MINT stands for the disciplines of Mathematics, Informatics, Natural Sciences, and Technology. The Telekom Stiftung is funding the project until 2012 with a budget of 21,000 euros. The Fraunhofer IFAM is making staff, expert knowledge, facilities, and equipment available and is getting in contact with industrial partners: This is bringing schools, R&D organizations, and industry together.

The first Academy resulting from this collaboration is starting in Lower Saxony under the leadership of the Fraunhofer IFAM: In the school year 2009/2010 interested pupils in the 9th grade of the Osterholz-Scharmbeck Secondary School will be involved with theoretical and practical aspects of physics, chemistry, and the engineering sciences for using adhesive bonding technology in areas such as car manufacture, shipbuilding, and rotor blade manufacture for wind turbines. Visits to companies will not only give them an insight into the everyday activities in these sectors but they will also get to know about the work of engineers in industry.

The school pupils will learn about application-oriented R&D in the Department of Adhesive Bonding Technology and Surfaces at the Fraunhofer IFAM: After being taught the necessary basic technical knowledge, the pupils will use the institute's equipment, under the direction of IFAM personnel, in order to then transfer the theoretical knowledge they have acquired into practical project work: The construction of a miniature wind turbine made of fiber composite structures. The school pupils also have the opportunity to learn about project management and presentation techniques in workshops. For all the activities in the Junior Engineer Academy the pupils have four extra hours of study per week during which they are supervised by their teachers or by Fraunhofer IFAM staff.

Fraunhofer-Talent-School Bremen 2009

Whilst the Junior Engineer Academy focused on school pupils in the middle grades, the Fraunhofer-Talent-School has become the forum for the next stage: Here, pupils in grades 10 to 13 with an interest in technology and engineering take part in various three-day workshops. They are engaged in topical scientific issues and have to develop solutions. Discussions with Fraunhofer managers also give them an insight into the daily work of the scientists and into science in industry at a national and international level.

In October 2009, a Fraunhofer-Talent-School took place at the Fraunhofer IFAM in Bremen for the second time. Once again this year the places had to be issued via a draw because there were many more applicants than places. In total 51 pupils in grades 10 to 13 from Bremen, Lower Saxony, Schleswig-Holstein, North Rhine-Westphalia, Rheinland-Palatinate, Saxony, and Bavaria had the opportunity to participate in five different workshops covering the areas of engineering and the natural sciences:

- Holding the world together – the chemistry and physics of adhesives
- Building blocks of life – bioanalysis of proteins
- Large equation systems – rapid solutions not a problem
- Learning from nature – how is mother-of-pearl “made”?
- Thermal treatment of steel – hard or soft – simply a matter of temperature and time

Compared to 2008, the 2009 event saw the spectrum of topics increase while the number of workshops increased from three to five. This was achieved with the assistance of the University of Bremen. The workshops were organized by scientists from the Fraunhofer IFAM, the Fraunhofer Institute for Algorithms and Scientific Computing (Fraunhofer SCAI), and the faculties of Physics/Electrical Engineering and Production Engineering at the University of Bremen.

During the evening program the school pupils had the opportunity to talk to Fraunhofer Institutes and University of Bremen staff and to learn about national as well as international scientific work and about application-oriented contract research.

TheoPrax® at the Fraunhofer IFAM

A step further: The TheoPrax® communication center at the Fraunhofer IFAM has been set up as a future-oriented mediator between potential employers and employees. Requests from companies, institutions, and public organizations are constantly welcome.

The communication center takes up contact with schools, technical colleges, and universities so that TheoPrax® projects can be started up and supervised on an ever more diverse range of topics. The special feature here is the use of the teaching and learning method TheoPrax® which was developed by the Fraunhofer Institute for Chemical Technology (Fraunhofer ICT). This combines the transfer of theoretical knowledge and practical experience in real projects. These projects are worked through by school pupils or students, from the drawing up of an offer to the preparation of the final invoice, and are supervised by the relevant TheoPrax® communication center.

Even during one’s schooling and education, regardless of whether that be at a school, technical college, or university, theory can be directly converted into practice, and science into applications. That was demonstrated by 50 pupils in the 12th grade of the Osterholz-Scharmbeck Secondary School in June 2009 at the Fraunhofer IFAM when they presented the results of their practically-oriented, eight month long TheoPrax® project works:

ADHESIVE BONDING TECHNOLOGY AND SURFACES

- Video documentation about coating processes
- Supporting information about materials for machinists
- Illustrated book: "How do young people view Osterholz-Scharmbeck?"
- Waste disposal: Waste separation or waste prevention in the medical area
- Development and testing of materials for physics teaching at middle school on the subject of climate change

Each of the commissioning parties – a metal processing company, a bookstore, a hospital, and a university – also received documentation containing viable practical solutions for solving the relevant tasks.

The school pupils were particularly motivated by the fact that the work concerned current topics of relevance for the companies. They were introduced to business thinking and commerce. They also got an insight of professional project work and learned about presentation techniques.

Besides benefiting the school pupils, the companies also profited from the TheoPrax® project work which is offered every year by the Fraunhofer IFAM. It is already evident today that in certain industries it is difficult, and will become even more difficult, to find well-qualified young talent. The Fraunhofer activities are promoting contact between employers and potential future employees.

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PEOPLE AND MOMENTS

TRAINING COURSE INNOVATION PRIZE 2009 FOR THE "FIBER REINFORCED PLASTIC TECHNICIAN"

The training concept for Fiber Reinforced Plastic Technician of the Plastics Competence Center was awarded the Training Course Innovation Prize 2009. The Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM received this award and the prize of 2500 euros. The award is presented by the Federal Institute for Vocational Education and Training (Bundesinstitut für Berufsbildung; BIBB). The Lower Saxony minister of education and arts, Elisabeth Heister-Neumann, and the President of BIBB, Manfred Kremer, presented the Innovation Prize to the Fraunhofer IFAM at the "didacta" trade fair in Hannover on February 12, 2009.

The prize is awarded for innovative training concepts, oriented at the qualification requirements of tomorrow and which stimulate the modernization of training and work areas. The BIBB prize promotes the pioneering role of training organizations and hence gives impulse for new developments and the modern design of occupational training. Under the leadership of the Fraunhofer IFAM, there has been successful development of a comprehensive, certified, supracompany workforce training system for fiber reinforced technology.

The basis: Science and industry

The jury praised the special nature of the training course provided by the Plastics Competence Center, namely that the training course is jointly designed and given by experts from R&D and industry. The Training Partnership for Plastics was set up for this purpose. Companies and organizations already involved include SGL ROTEC GmbH & Co. KG/PowerBlades GmbH, Airbus Deutschland GmbH, HAINDL Kunststoffverarbeitung GmbH, bfw – Unternehmen für Bildung und Zeit & Service Beschäftigungsfördergesellschaft mbH, Faserinstitut Bremen e. V., the Institute of Materials Science (IWT), and the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM. Theoretical and practical experts from these organizations give the training course.

This means that the training is highly application-oriented and up-to-date. It is optimally adapted to the special and practical requirements of companies and the marketplace. Car manufacture, shipbuilding, rail vehicle manufacture, aviation and aerospace, and wind turbine production benefit in particular because fiber composite materials are being increasingly used in these sectors.

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Die Weiterbildungspartnerschaft Kunststoff unter Leitung des Fraunhofer-Instituts für Fertigungstechnik und Angewandte Materialforschung (IFAM), Bremen

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Faserverbundkunststoff-Praktiker/Praktikerin

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Weiterbildungs-Innovations-Preis 2009

Das Bundesinstitut für Berufsbildung gratuliert zu dieser Auszeichnung.
Sie ist mit einem Preisgeld von 2.500 EUR verbunden.

Hannover, 12. Februar 2009

Manfred Kremer
Präsident des Bundesinstituts für Berufsbildung

The training course is open to employees of industrial companies, to short-time workers, to people threatened with unemployment, and to those without a job and seeking work. Training vouchers of the Agentur für Arbeit (employment agency) are accepted. This means that not only do technicians in the plastic processing industry receive suitable training, but also people seeking work are given an opportunity to return to the employment marketplace. In order to meet the needs of each target group, the course is given as both a four-week block and in four one-week blocks, the latter being exclusively for those already working in industry. This allows flexible integration of the training course into work schedules.

The Plastics Competence Center, which is under the auspices of the Fraunhofer IFAM, is certified in accordance with DIN EN ISO 9001 and in accordance with AZWV (German quality standard for further training) and meets the quality requirements of DIN EN ISO/IEC 17024 (www.kunststoff-in-bremen.de). The training course was established on the initiative of bremer arbeit gmbh (bag). The State of Bremen (the senator for Employment, Women, Health, Youth, and Social Affairs), the European Social Fund (ESF), and the Fraunhofer Academy of the Fraunhofer-Gesellschaft (www.academy.fraunhofer.de) are funding the further development and execution of the measures.

Number of places increased to meet the growing demand

The relevance of the training course for the aforementioned sectors is also reflected by the growing demand for places on the training course which has been offered by the Plastics Competence Center since 2007: More than 340 participants have now taken the course and become qualified Fiber Composite Technicians. Since July 2008 the training course has also been held in Bremerhaven, and in August 2009 the first training course was also held in Brake.

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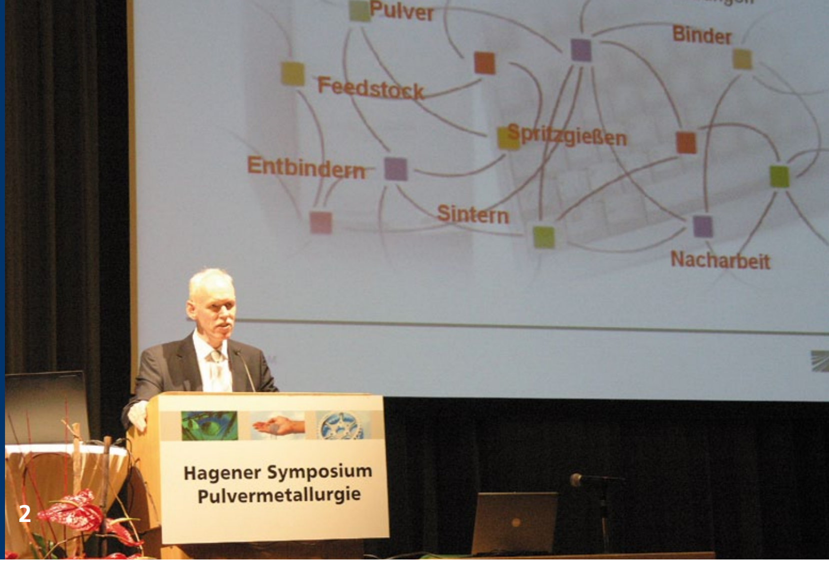

SKAUPY-AWARD 2009 PRESENTED TO DR.-ING. FRANK PETZOLDT

At the Symposium in Hagen held from November 26 and 27, 2009, the Commission of the Association of Powder Metallurgy awarded Dr.-Ing. Frank Petzoldt its highest honor: The Skaupy Award. In 1982, the Skaupy Award was presented for the first time. It is named after Prof. Dr. Franz Skaupy, board member of the Osram GmbH and powder metallurgy pioneer in Germany, who lived from 1882 to 1969. With this highest award, the association recognizes outstanding merit and technical-scientific achievements in powder metallurgy.

For more than 25 years, the physicist Frank Petzoldt has been committed in his work to powder metallurgy both in research and in practical application.

In numerous presentations and publications at the national and international level, he has reported on the wide variety of techniques and materials in powder metallurgy. In these papers, he did not only limit himself to standard applications and their refinement; rather, he and his team at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Bremen sought out special and niche applications for powder metallurgy. He emphasized early on the technique of Metal Injection Molding (MIM) in his projects. In doing so, Dr. Petzoldt was especially successful in bringing this idea from the theory and the experimental setup to industrial marketability.

He has rendered outstanding services to the field of powder metallurgy, and not only because he has established ties between science and industry again and again. He also played a prominent role in the establishment and management of the expert group "Metal Injection Molding" in the commission of the Association of Powder Metallurgy and represented this group of experts in science and industry, as well as powder metallurgy, in a very committed manner.

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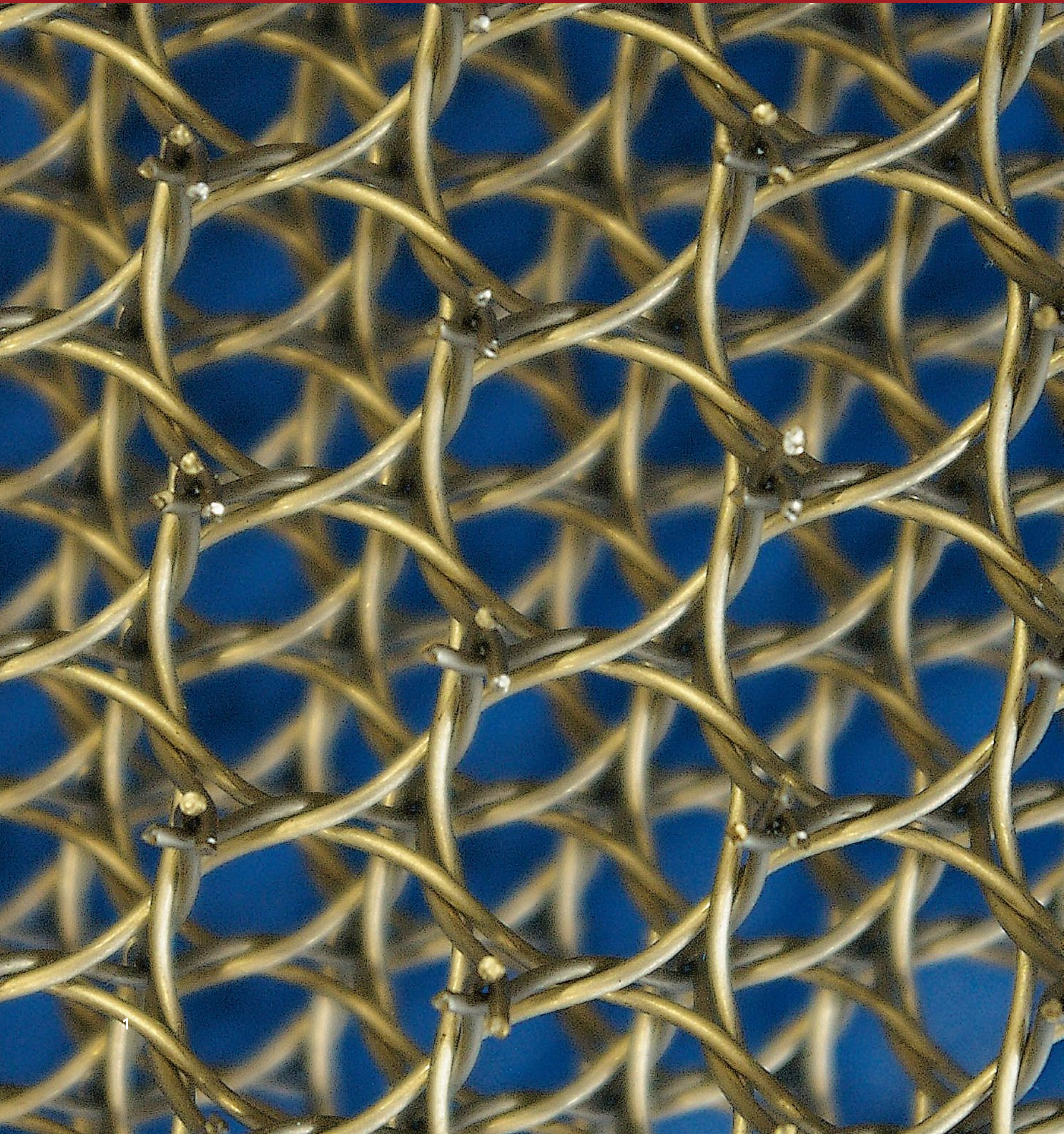
1 *The BIBB President Manfred Kremer, and the Lower Saxony minister of education and arts, Elisabeth Heister-Neumann, at the presentation of the Training Course Innovation Prize 2009 from Dr. Silke May, Dr. Daniela Harkensee and Prof. Dr. Andreas Groß Fraunhofer IFAM (from left).*

2 *Dr.-Ing. Frank Petzoldt.*

GROUPS | ALLIANCES | ACADEMY

NETWORKED AT FRAUNHOFER



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FRAUNHOFER GROUPS

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

Fraunhofer Group for Materials and Components – MATERIALS

The Fraunhofer Group for Materials and Components pools the expertise of 12 Fraunhofer Institutes that are specially concerned with materials science and also receives input from the Fraunhofer Institute for Industrial Mathematics, which is a permanent guest member of the group.

Fraunhofer materials research extends across the entire value chain, from new material development and improvement of existing materials through quasi-industrial-scale manufacturing technology to the characterization of properties and assessment of service behavior. The same research scope applies to the components made from these materials and the way they function in systems.

The Group focuses its expertise on the economically important fields of energy, health, mobility, information/communication technology and construction/living. Our aim is to achieve system innovations through targeted material and component developments. In all these fields, we rely equally on laboratory/pilot-plant studies and numerical simulation/modeling. The Fraunhofer Materials and Components Group covers the entire range of materials and their composites, including metallic, inorganic/non-metallic, polymeric and renewable materials.

www.vwb.fraunhofer.de

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

Contact Fraunhofer IFAM
Prof. Dr.-Ing. Matthias Busse
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Priv.-Doz. Dr. Andreas Hartwig
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FRAUNHOFER ALLIANCES

The Fraunhofer Alliances facilitate customer access to the services and research results of the Fraunhofer-Gesellschaft. Common points of contact for groups of institutes active in related fields provide expert advice on complex issues and coordinate the development of appropriate solutions.

Fraunhofer Adaptronics Alliance

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

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

www.adaptronik.fraunhofer.de

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

Contact Fraunhofer IFAM
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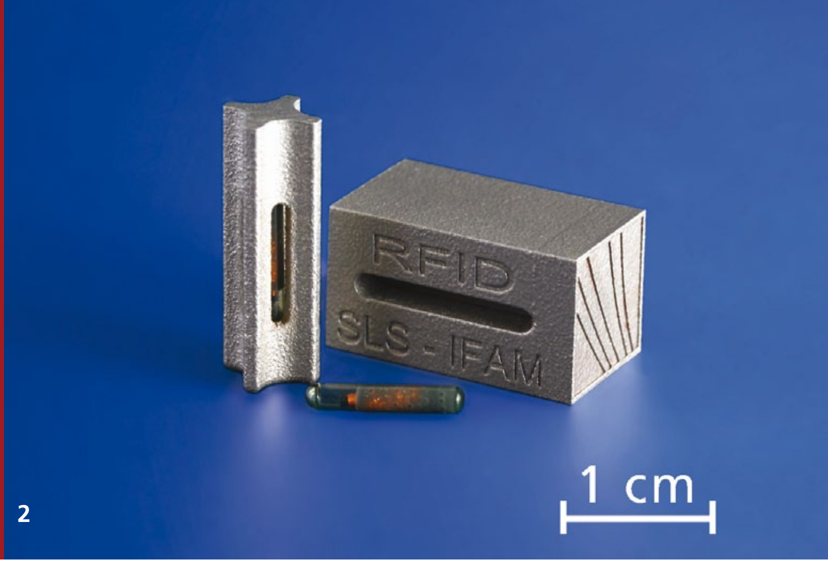

2

Fraunhofer Building Innovation Alliance

The construction industry has high potential for innovation, and it is with a view to tapping this potential that several Institutes have pooled their resources in the Fraunhofer Building Innovation Alliance. The alliance offers single-source construction expertise by means of integrated systems solutions. Its portfolio encompasses not only the systematic consideration of buildings, from materials and components to rooms, buildings and entire housing estates, but also the chronological consideration of buildings – that is, their entire life cycle from the initial idea through to final recycling. Opportunities for rationalization and potential for optimization can be found throughout the construction process chain, starting with the original construction, including building materials and systems, and extending through to the conversion and dismantling of a building.

In this era of exploding energy prices, the energy efficiency of buildings is a key issue for both residential and industrial buildings. However, the focus of the alliance goes a great deal deeper than this. It aims to assure sustainability, careful use of resources, and healthy construction methods in building and living, and to address issues such as product, system and process optimization. Construction research shares common ground with Fraunhofer expertise in the areas of energy, information and communication technology, materials and components, life sciences, production, microelectronics, and defense and security research.

www.bau.fraunhofer.de

Speaker of the Alliance
Prof. Dr.-Ing. Klaus Sedlbauer

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Dipl.-Ing. Franz-Josef Wöstmann
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Fraunhofer Additive Manufacturing Alliance

Rapid tooling and rapid manufacturing offer tremendous potential for success in terms of quickly and efficiently translating product innovations into prototypes and small production batches.

The Fraunhofer Additive Manufacturing Alliance has earned a reputation as the largest interdisciplinary European alliance of competence for high-speed processes enabling individual manufacturing of products made of metals, plastics, ceramics, and other materials.

Collaborating closely with national and international partners, the alliance develops new rapid strategies, concepts, technologies, and processes to enhance the performance and competitiveness of small and medium-sized enterprises. Its advanced rapid methods and tools enable it to support all major sectors of industry: e.g. the automotive and aerospace industries, mechanical engineering and machine tools, medicine and medical engineering.

www.generativ.fraunhofer.de

Speaker of the Alliance
Andrzej Grzesiak

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3

Fraunhofer Nanotechnology Alliance

Nanotechnology, a bundle of crosscutting new technologies for the next years to come, deals with materials, systems, and devices where something very small (below 100 nm) determines functions and applications.

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

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

www.nano.fraunhofer.de

Speaker of the Alliance
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Prof. Dr. Bernd Günther
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Fraunhofer Photocatalysis Alliance

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

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

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

www.photokatalyse.fraunhofer.de

Speaker of the Alliance
Dr. Michael Vergöhl

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Dr. Dirk Salz
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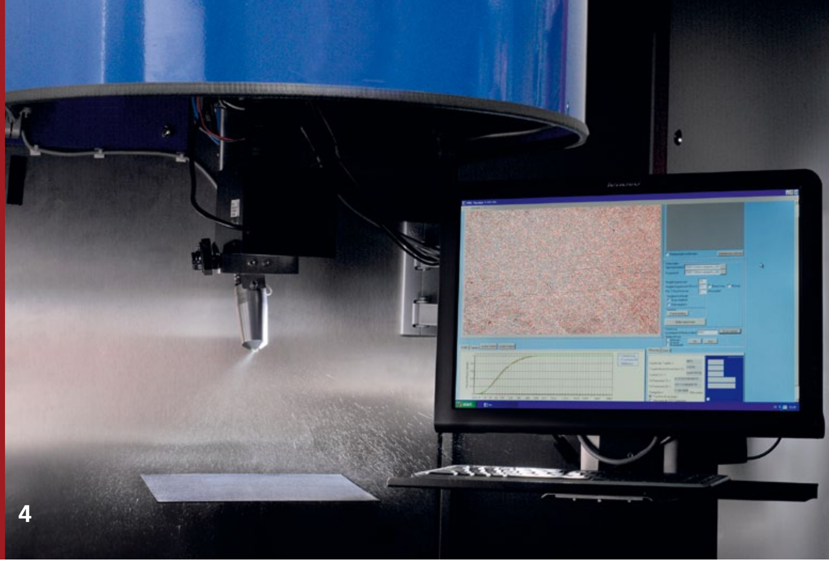
4

Fraunhofer Polymer Surfaces Alliance (POLO)

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

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

www.polo.fraunhofer.de

Speaker of the Alliance
Dr. Sabine Amberg-Schwab

Contact Fraunhofer IFAM
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Fraunhofer Cleaning Technology Alliance

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

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

www.allianz-reinigungstechnik.de

Speaker of the Alliance
Dipl.-Ing. (FH) Martin Bilz

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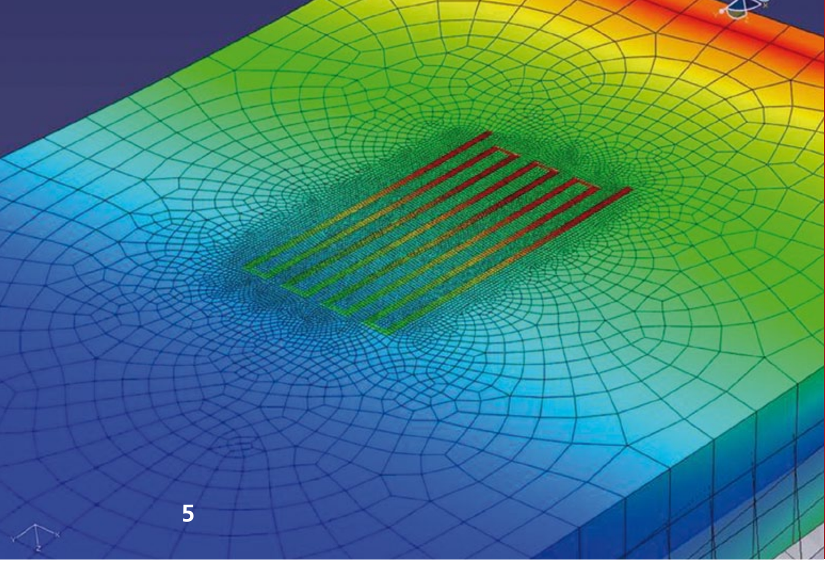

Fraunhofer Simulation Alliance

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

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

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

www.simulation.fraunhofer.de

Speaker of the Alliance
Andreas Burblies

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Andreas Burblies
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Fraunhofer Traffic and Transportation Alliance

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

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

www.verkehr.fraunhofer.de

Speaker of the Alliance
Prof. Dr.-Ing. Uwe Clausen

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Fraunhofer Academy – Research know-how for your success

The Fraunhofer Academy brings together the training courses offered by the Fraunhofer-Gesellschaft under one roof and provides excellent training opportunities for technical and management staff. The latest scientific knowledge is rapidly integrated into the training courses, meaning there is a genuine pact between research and innovation. First-class training provides the basis for a successful career – and lifelong follow-up courses are essential in order to keep expertise up-to-date.

Industrial adhesive bonding technology – Workforce training at the Center for Adhesive Bonding Technology in Bremen

Adhesive bonding technology is establishing itself as the joining technique of the 21st century. The transfer of the true potential of adhesive bonding technology into industrial applications is being promoted by the customized training courses on offer at the Center for Adhesive Bonding Technology of the Fraunhofer IFAM in Bremen.

Fiber reinforced plastic technology – Workforce training at the Plastics Competence Center

The Fiber Reinforced Plastic Technician training course, which was awarded the Training Course Innovation Prize for 2009, is directed at multifunctional products and lightweight design and is hence of particular interest for the transport sector and manufacturers of wind turbines.

www.academy.fraunhofer.de

Managing Director of the Fraunhofer Academy
Dr. Roman Götter

Contact person at the Fraunhofer IFAM
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www.bremen-bonding.com
www.kunststoff-in-bremen.de

1 *3-dimensional wire structure.*
2 *Metal components made by selective laser sintering, with integrated RFID chip and counterpart to the integrated RFID chip.*
3 *Enhanced dispersibility of nanoparticles (color particles) by plasma treatment at atmospheric pressure (plasma-treated right).*
4 *Investigation of the wetting characteristics of surfaces by means of the aerosol wetting testing method developed by Fraunhofer IFAM.*
5 *Numerical stress simulation of a strain gauge.*

NAMES | DATES | EVENTS

CONTENTS

1 *Fraunhofer IFAM*

Cooperation with international institutes

Universities and institutes

AGH University of Science and Technology
Department of Metallurgy and Materials Research Unit
Krakau, Polen
Dr. T. Pieczonka

Chonnam National University
Department of Mechanical Engineering
College of Engineering
Zellulare Metallische Werkstoffe
Gwangju, Korea
Prof. Ki-Ju Kang

Dalhousie University
Department of Physics and Atmospheric Science
Halifax, Kanada
Prof. H. J. Kreuzer

DTI Danish Technological Institute
Rapid Manufacturing and Prototyping Group
Århus, Dänemark

European Synchrotron Radiation Facility
Beam Line ROBL
Grenoble, Frankreich

Fundación Privada ASCAMM
Barcelona, Spanien

Korea Institute of Materials Science
Zellulare Metallische Werkstoffe
Changwon, Korea
Ph. D. Byoung-Kee Kim

LMSPC Laboratoire des Matériaux Surfaces et Procédés pour la Catalyse
Université de Strasbourg
Straßburg, Frankreich
Dr. V. Keller-Spitzer

Nanyang Technological University
Hochporöse Werkstoffe
Singapur, Republik Singapur
Prof. K. A. Khor

National Academy of Sciences of Belarus
State Research and Production
Powder Metallurgy Association
Minsk, Weißrussland
Prof. A. Ilyuschenko

Northwestern University
Department of Materials Science & Engineering
Zellulare Metallische Werkstoffe
Evanston, Illinois, USA
Prof. D. C. Dunand

Osaka Prefectural College of Technology
Zellulare metallische Werkstoffe
Osaka, Japan
Prof. K. Nishiyabu

Polish Academy of Sciences (IPPT)
Institute of Fundamental Technological Research
Gradientenwerkstoffe
Warschau, Polen
Prof. M. Basista

Pusan National University
Polyurethanchemie
Busan, Korea
Prof. B. K. Kim

Sharif University of Technology
Teheran, Iran
Prof. Dr. A. Simchi

Sirris
Rapid Manufacturing Department
Seraing, Belgien

Slovak Academy of Sciences
Institute of Materials & Machine Mechanics
Verbundwerkstoffe
Bratislava, Slowakei
Dr. F. Simancik

Technische Universität Wien
Verbundwerkstoffe
Wien, Österreich
Prof. H. Danninger,
Prof. C. Edtmaier

TNO The Netherlands Organisation for Applied Scientific Research
Rapid Manufacturing Department
Eindhoven, Niederlande

Universidad Carlos III de Madrid
Madrid, Spanien
Prof. J. M. Torralba

Universidade Federal de Santa Catarina
Florianópolis, Brasilien
Prof. A. Klein,
Prof. P. Wendhausen

Università degli Studi di Padova
Padua, Italien
Prof. P. Mazzoldi

Università degli Studi di Trieste
Triest, Italien
Prof. M. Fermeglia

University of Michigan
Michigan, USA
Prof. L. Thompson

University of Prague
Institute of Chemical Process Fundamentals
Prag, Tschechische Republik
Dr. M. Lisal

University of Szeged
Department of Physical Chemistry and Materials Science
Szeged, Ungarn
Prof. Dr. I. Dékány

Zhongshan University
Center for Nano-technology Research
Guangzhou, Volksrepublik China
Prof. H. Shen

International guests

AIDICO-Instituteo Tecnológico de la Construcción
Alicante, Spanien
Dr. V. J. Forrat

Guangzhou Institute of Chemistry, Chinese Academy of Science
Guangzhou, Volksrepublik China
Dan Yu

Hanyang University Alexander-von-Humboldt-Stipendiat
Ansan, Korea
Dr. Yun Sung Kang

Helwan University Faculty of Science
Helwan, Ägypten
M. Rehan

Henkel Adhesive Academy
Shanghai, China
Dr. Jingfen Zhang

North Carolina State University Department of Chemistry
Raleigh, USA
A. K. Croom

Research Internships in Science and Engineering
Prineha Narang – Philadelphia University
Chelsea Marie Tajc – Northern Arizona University

University of Ulsan DFG-KOSEF-Vereinbarung
Ulsan, Korea
Prof. Dr. Ji-Soon Kim

European network

Force Institute
Brøndby, Dänemark

GAIKER
Zamudio, Spanien

IDMEC Instituteo de Engenharia Mecânica University of Porto
Porto, Portugal

IFREMER Marine Materials Laboratory
Plouzané, Frankreich

INASMET Joining Technologies Department Centre Technologico de Materiales
San Sebastián, Spanien

ISQ R&D Training Division Instituteo de Soldadura e Qualidade
Oeiras, Portugal

IVF Institutet för Verkstadsteknisk Forskning
Mölndal, Schweden

KMM-VIN
Brüssel, Belgien

Multimaterial-Technology ETH Zürich
Swiss Federal Institute of Technology Institute for Design & Construction Methods
Zürich, Schweiz

Oxford Brookes University
Oxford, Großbritannien

SINTEF Materials Technology
Oslo, Norwegen

TNO Department of Structural Engineering
TNO Building and Construction Research
Delft, Niederlande

University of Bristol Department of Mechanical Engineering
Bristol, Großbritannien

University of Pavia
Pavia, Italien

VTT Manufacturing Technology
Lappenranta, Finnland

Adhesive bonding technology – workforce training

Chem Quest Group Inc.
Cincinnati, Ohio, USA

CRIF
Seraing (Liège), Belgien

EOLAS
Dublin, Irland

Force Institute
Brøndby, Dänemark

INASMET
San Sebastián, Spanien

ISQ (CNTP)
Oeiras, Portugal

IVF
Mölndal, Schweden

Sergem Engineering BV
Leidschendam, Niederlande

TechniFutur Assemblage
Seraing (Liège), Belgien

TWI
Cambridge, Großbritannien

Participation in committees

South Africa

Council for Scientific and Industrial Research
Materials Science and Manufacturing Unit
Research Advisory Panel
U. Lommatzsch (Member)

USA

APMI
American Powder Metallurgy International, USA (MPIF)
Metal Powder Industry Federation
Princeton, USA
B. Kieback, F. Petzoldt (Members)

International Liaison Committee of the International Journal of Powder Metallurgy
F. Petzoldt (Member)

IPCS
International Plasma Chemistry Society
U. Lommatzsch (Member)

TMS
The Minerals, Metals & Materials Society
J. Schmidt (Member)

Europe

Accelrys Inc.
Nanotechnologie Consortium
M. Amkreutz, M. Hoffmann, W. Leite Cavalcanti, P. Schiffels (Members)

AFERA
Association des Fabricants Européens de Rubans Auto-Adhésifs
U. Maurieschat (Member)

EGL
Europäische Gesellschaft für Lackier-Technik e. V.
S. Buchbach (Member)

EPMA
European Powder Metallurgy Association
B. Kieback, F. Petzoldt (Members)

European Federation for Welding, Cutting and Joining
A. Groß (German representative)

European MIM Group
F. Petzoldt (Chairman)

IISS
International Institute for Science of Sintering
B. Kieback (Member)

KMM-VIN AISBL
Virtual Institute on Knowledge-Based Multifunctional Materials
Brüssel, Belgien

Nano Mat
Netzwerk Nanomaterialien
B. Günther (Speaker)

Radnet
B. Kieback, F. Petzoldt (Members)

National

AVK
Industrievereinigung verstärkter Kunststoffe e. V.

Work committee
Umwelt und Arbeitssicherheit
S. Mai (Member)

Work committee
Personal
S. Mai (Member)

AWT
Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e. V.

Work committee
Plasmaoberflächentechnologie
U. Lommatzsch (Member)

CFK-Valley Stade

Work committee
Ausbildung
S. Mai (Member)

DECHEMA
Deutsche Gesellschaft für Chemische Technik und Biotechnologie e. V.

Technical division
Nanotechnologie und Reaktionstechnik
L. Röntzsch (Member)

Work committee
Molekulare Modellierung und Simulation für Prozess- und Produktdesign
M. Amkreutz, B. Schneider (Members)

Technical section
Klebtechnik
M. Brede, A. Groß, A. Hartwig (Members)

Technical section
Nanotechnologie
A. Hartwig, V. Zöllmer (Members)

Deutsche Gesellschaft für Biomedizinische Technik im VDE

Work committee
Biokompatible Aufbau- und Verbindungstechnik
T. Gesang (Member)

Deutsche Thermoelektrische Gesellschaft
J. Schmidt (Member)

DFG
Deutsche Forschungsgesellschaft
Fachkollegium FK 405 Werkstofftechnik
B. Kieback (Member)

DFO
Deutsche Forschungsgesellschaft für Oberflächenbehandlung e. V.

Work committee
Kunststofflackierung
V. Stenzel (Member)

Work committee
Leichtmetall
R. Wilken, S. Dieckhoff (Members)

Technical committee
Beschichtung von Kunststoffen
V. Stenzel (Member)

Technical committee
Oberflächenbehandlung von Stahl und Multisubstraten
V. Stenzel (Member)

Technical committee
Beschichtungsstoffe
V. Stenzel (Member)

DGM
Deutsche Gesellschaft für Materialkunde

Work committee
Plasmaoberflächentechnologie
A. Baalmann, U. Lommatzsch (Members)

Technical committee
Metall-Matrix-Verbundwerkstoffe
T. Schubert, T. Weißgärber (Members)

Technical committee
Biomaterialien
A. Burblies, I. Wirth,
P. Quadbeck (Members)

Technical committee
Computersimulation
A. Burblies (Member)

Technical committee
Magnesium-Anwendungen
F.-J. Wöstmann (Member)

Work group
Funktionswerkstoffe
T. Weißgärber (Member)

Work committee
Zellulare Metalle
O. Andersen, J. Baumeister
(Members)

Work committee
Werkstoffkundliche Aspekte des Verschleißes und der Zerspanung
G. Walther (Member)

Work committee
Dauerimplantate
P. Quadbeck (Member)

Work committee
Resorbierbare Implantate
P. Quadbeck (Member)

DGO
Deutsche Gesellschaft für Galvanik und Oberflächentechnik e. V.

Work committee
Plasmaoberflächenbehandlung von Polymeren
A. Baalmann (Member)

DGZfP
Deutsche Gesellschaft für zerstörungsfreie Prüfung e. V.

Technical committee
Zustandsüberwachung
G. Rausch (Member)

DIN
Deutsches Institut für Normung

Work committee 5.6
Klebtechnik im Schienenfahrzeugbau
D. Niermann (Member)

Work committee ISO/TC 119
Pulvermetallurgie
K. Kümmel (Member)

Normenausschuss Werkstofftechnologie (NWT)

Work committee NAB 14
Beschichtungsstoffe und Beschichtungen für Luft- und Raumfahrt
S. Buchbach (Member)

DIN/DVS
Gemeinschaftsausschuss

Work committee 14/
Work committee AG V 7
Thermisches Spritzen und thermisch gespritzte Schichten
F. Petzoldt (Member)

DPG
Deutsche Physikalische Gesellschaft

Section
Kondensierte Materie
L. Röntzsch (Member)

Work committee
Oberflächenphysik
S. Dieckhoff, M. Amkreutz
(Members)

Work committee
Festkörperphysik
P.-L. M. Noeske, F. Petzoldt,
B. Klöden (Members)

DVS
Deutscher Verband für Schweißen und verwandte Verfahren e. V.

Work committee
DVS-AG A 7
Fügetechnik im Schienenfahrzeugbau
M. Brede (Member)

Technical committee 8
Kleben und Kunststoffschweißen
M. Peschka (Member)

Technical committee 9
Konstruktion und Berechnung
M. Brede (Member)

Technical committee 10
Mikroverbindungstechnik
T. Gesang (Member)

Work group V 8
Klebtechnik
A. Groß (Chairman)

Work group V 8.1
Dosier- und Mischtechnik
M. Peschka (Member)

Work group
Schulung und Prüfung
A. Groß (Member)

Working committee A 3.5
Kleben im Schienenfahrzeugbau
A. Groß (Chairman)

Work group A 10
Fügen im Handwerk – Schweißen und verwandte Verfahren
V. Borst (Member)

Technical group FG 2.9
Ausbildung Karosserie
M. Peschka (Member)

Main certification committee (HZA)
Fachausschuß Kleben
A. Groß (Member)

Examination and certification committee (PZA)
Klebtechnik
A. Groß (Chairman)
M. Peschka (Member)

DWV
Deutscher Wasserstoff- und Brennstoffzellen-Verband e. V.
L. Röntzsch (Deputy)

EFDS
Europäische Forschungsgesellschaft Dünne Schichten e. V.

Work committee
Plasmaoberflächentechnologie
U. Lommatzsch (Member)

EWE – Forschungszentrum für Energietechnologie e. V.
M. Busse (Member)

FEE
Fördergesellschaft Erneuerbare Energien e. V.

Work group
Biogene Gase – Brennstoffzellen
I. Morgenthal (Member)

FhG
Fraunhofer-Gesellschaft

Alliance
Adaptronik
T. Gesang (Member)

Bibliotheks- und Informationswesen
I. Morgenthal (Member)

Work committee
Biokompatible Aufbau- und Verbindungstechnik
T. Gesang (Member)

Fachinformationsmanagement der FhG (fim)
I. Morgenthal (Member)

FTA
Fraunhofer Technology Academy
A. Groß (Deputy spokesman of the Board of Directors)

Work committee
IT-Manager
A. Burblies, G. Peter (Members)

Marketing-Netzwerk
C. Müller (Member)

Cluster
Nanoanalytik
T. Weißgärber (Steering committee)

Alliance
Nanotechnologie
B. Günther (Member),
A. Hartwig (Member of steering committee)

Alliance
Numerische Simulation von Produkten und Prozessen (NUSIM)
A. Burblies (Spokesman)

Information and Demonstration Center
Numerische Simulationstechniken zur Verfahrens- und Bauteiloptimierung (SIMTOP)
A. Burblies (Director)

Alliance
Polymere Oberflächen POLO
U. Lommatzsch (Member)

PR-Netzwerk
C. Müller (Member)

FIB
Fiber International Bremen e. V.
M. Busse (Member of the Board of Directors),
G. Rausch, O. Andersen (Expert advisory committee)

FZK/PFT
Projektträger für Produktion und Fertigungstechnologien

Industriy work committee
Strukturoptimierung
A. Burblies, N. Reichert (Members)

GDCh
Gesellschaft Deutscher Chemiker

Technical group
Anstrichstoffe und Pigmente
A. Hartwig (Member)

Technical group
Festkörperchemie und Materialforschung
P.-L. M. Noeske (Member)

Technical group
Makromolekulare Chemie
A. Hartwig, P.-L. M. Noeske (Members)

Ortsverband Bremen
A. Hartwig (Chairman)

GDM
Gesamtverband Deutscher Metallgießereien e. V.

Initiative Zink
F.-J. Wöstmann (Member)

GEFTA
Gesellschaft für Thermische Analyse
J. Kolbe (Member)

Gemeinschaftsausschuss Pulvermetallurgie
(Trägergesellschaften DGM, DKG, VDEH, VDI)

Work committee
B. Kieback (Member)

Expert group
Sintern
B. Kieback, G. Veltl (Members)
J. Schmidt (Chairman)

Expert group
Aluminium
T. Weißgärber (Chairman)
T. Schubert (Member)

Expert group
Metallpulverspritzguss
F. Petzoldt (Chairman)
T. Hartwig (Deputy chairman and secretary)

Expert group
Metallpulvererzeugung
B. Günther (Member)

Expert group
Sintern
J. Schmidt (Chairman)
B. Kieback, G. Veltl (Members)

Work committee
Sinterstähle
G. Veltl (Member)

GfKORR
Gesellschaft für Korrosionsschutz e. V.

Work committee
Korrosionsschutz bei erhöhten Temperaturen
B. Klöden (Member)

Work committee
Korrosionsschutz durch Beschichtungen
P. Plagemann

Work committee
Prüf- und Untersuchungsverfahren/Corrosion Monitoring
O. Yezerska

Work committee
Korrosion von Polymerwerkstoffen
P.-L. M. Noeske

Work committee
Korrosionsschutz in der Elektronik und Mikrosystemtechnik
T. Fladung

GfT
Gesellschaft für Tribologie
G. Walther (Member)

GTS
Gemeinschaft Thermisches Spritzen e. V.
C. Aumund-Kopp (Member)

i–Kon e. V.
Ingenieur-Kompetenzzentrum Oberflächentechnik Norddeutschland
IFAM (Founding member)
V. Stenzel (Member of the Board of Directors)

IVAM
Fachverband für Mikrotechnik
P. Imgrund, T. Studnitzky (Members)

IVK
Industrieverband Klebstoffe

Technischer Ausschuss (TA)
A. Groß (Member)

Work committee
Strukturelles Kleben und Dichten (SKD)
A. Groß (Member)

Technical committee
Strukturelles Kleben und Dichten (SKD)
A. Groß (Member)

Work committee
Industrieklebstoffe
A. Groß (Member)

Lost Foam Council e. V.
F.-J. Wöstmann (Director)
M. Busse (2nd Chairman)

MULTIFAS
Multifunktionale Faser-systeme
V. Zöllmer (Member)

VDG
Verein Deutscher Gießerei-fachleute

Technical committee
Ingenieurausbildung
M. Busse, F.-J. Wöstmann (Members)

Technical committee
Druckguss
T. Müller, F.-J. Wöstmann (Members)

Technical committee
Leichtmetallguss
F.-J. Wöstmann (Member)

Work committee
Zinkdruckguss
F.-J. Wöstmann (Member)

Regional

Brennstoffzellen Initiative Sachsen e. V.
L. Röntzsch

EMB
Embedded Microsystems Bremen
V. Zöllmer (Member)

Fakultätsrat Maschinen-wesen der TU Dresden
B. Kieback (Member)

GfT
Gesellschaft für Tribologie

Work committee
Sachsen
G. Walther (Member)

ISIS
Sensorial Materials Scientific Centre
ZWE Universität Bremen
M. Busse (Speaker of the board)

Konzil der TU Dresden
B. Kieback (Member)

Materialforschungsverbund Dresden e. V.

Work group
Öffentlichkeitsarbeit
C. Müller (Member)

Work committee
Materialforschungsver-bund Dresden
B. Kieback (Member)

MCB Microsystems Center Bremen
M. Busse (Member)

Personal Mobility Center (pmc)
Modellregion NordWest Bremen/Oldenburg für Elektromobilität
M. Busse (Spokesman and coordinator)

Rapid Prototyping Zentrum e. V.
C. Aumund-Kopp (Secretary)

Silicon Saxony
T. Weißgärber (Member)

VDI
Verein Deutscher Ingenieure
Bremer Bezirksverein

VDI Bremer Bezirksverein
F. Petzoldt (Member)

Work committee
Kunststofftechnik
S. Buchbach, G. Pauly (Work committeel)

Work committee
Werkstofftechnik
D. Lehmhus (Chairman)

VDI
Verein Deutscher Ingenieure
Dresdner Bezirksverein

Work committee
Werkstofftechnik
O. Andersen (Work commit-tee)

Growth core
inno.zellmet
O. Andersen (Member of the management)

Technical journals

International Journal of Powder Metallurgy
F. Petzoldt
International Liaison Committee

PIM International
F. Petzoldt
Consulting Editor

Qualification in the Center for Adhesive Bonding Technology 2009

Course and examination for
European Adhesive Bonder – EAB
in accordance with guidelines DVS®/EWF 3305
one-week module inclusive examination

Date EAB 1	26.–30.1.2009
Date EAB 2	2.–6.3.2009
Date EAB 3	11.–15.5.2009
Date EAB 4	7.–11.9.2009
Date EAB 5	12.–16.10.2009
Date EAB 6	16.–20.11.2009
Date EAB 7	23.–27.3.2009
Date EAB 8	30.11.–4.12.2009
Date EAB 9	26.–30.10.2009

External Courses

Alstom, Salzgitter	2.–6.2.2009
Alstom, Salzgitter	23.–27.2.2009
Delo, Windach	16.–20.3.2009
Handwerkskammer, Hamburg	20.–24.4.2009
Bombardier, Kassel	31.8.–4.9.2009
Bombardier, Kassel	19.–23.10.2009
Handwerkskammer, Hamburg	28.9.–2.10.2009
Deutsche Bahn, Eberswalde	2.–6.11.2009
Deutsche Bahn, Dortmund	16.–20.11.2009
Deutsche Bahn, Dortmund	23.–27.11.2009
Alstom, Salzgitter	30.11.–2.12.2009
Alstom, Salzgitter	7.–11.12.2009

Course and examination for
European Adhesive Specialist – EAS
in accordance with guidelines DVS®/EWF 3301
three one-week modules inclusive examination

EAS Part I:
Principles of Adhesive Bonding

Date EAS GL 1	19.–23.1.2009
Date EAS GL 2	30.3.–3.4.2009
Date EAS GL 3	31.8.–4.9.2009
Date EAS GL 4	28.9.–2.10.2009

EAS Part II:
Adhesive bonding of metals and other materials

Date EAS MK 1	16.–20.2.2009
Date EAS MK 2	4.–8.5.2009
Date EAS MK 3	5.–9.10.2009
Date EAS MK 4	26.–30.10.2009

EAS Part III:
Adhesive bonding of plastics and other materials

Date EAS KK 1	16.–20.3.2009
Date EAS KK 2	15.–19.6.2009
Date EAS KK 3	2.–6.11.2009
Date EAS KK 4	7.–11.12.2009

EAS – Examination:

Date EAS P 1	20.3.2009
Date EAS P 2	19.6.2009
Date EAS P 3	6.11.2009
Date EAS P 4	11.12.2009

Courses in English language

Date EAS Week 1	3.–7.8.2009
Date EAS Week 2	31.8.–4.9.2009
Date EAS Week 3	28.9.–2.10.2009
Examination	2.10.2009

Course and examination for
European Adhesive Engineer – EAE
in accordance with guidelines DVS®/EWF 3309
eight one-week modules including examination

Date EAE Week 1	12.–16.1.2009
Date EAE Week 2	9.–13.2.2009
Date EAE Week 3	9.–13.3.2009
Date EAE Week 4	20.–24.4.2009
Date EAE Week 5	25.–29.9.2009
Date EAE Week 6	21.–25.9.2009
Date EAE Week 7	19.–23.10.2009
Date EAE Week 8	23.–27.11.2009
Examination	27.11.2009

Date EAE Week 1	4.–8.5.2009
Date EAE Week 2	15.–19.6.2009
Date EAE Week 3	14.–18.9.2009
Date EAE Week 4	12.–16.10.2009
Date EAE Week 5	9.–13.11.2009
Date EAE Week 6	11.–15.1.2010
Date EAE Week 7	8.–12.2.2010
Date EAE Week 8	15.–19.3.2010
Examination	19.3.2010

Qualification in the Plastics Competence Center 2009

Fiber Reinforced Plastics Technician
(FRP Technician)
Offered by the Weiterbildungsgemeinschaft
Kunststoff in the Plastics Competence Center:
AZWV certified courses of several weeks,
inclusive examination

Bremen-Nord

Block course

Date FRP 1	9.3.–3.4.2009
Date FRP 2	28.5.–25.6.2009
Date FRP 3	3.8.–25.9.2009

Module course

Date FRP 1	26.–30.1.2009
Date FRP 2	20.–24.4.2009
Date FRP 3	5.–9.10.2009
Date FRP 4	7.–11.12.2009

Bremerhaven

Date FRP 1	12.1.–6.3.2009
Date FRP 2	13.2.–9.4.2009
Date FRP 3	23.3.–20.5.2009
Date FRP 4	20.4.–18.6.2009
Date FRP 5	25.5.–17.7.2009
Date FRP 6	31.8.–23.10.2009
Date FRP 7	28.9.–20.11.2009
Date FRP 8	26.10.–18.12.2009

Brake

Date FRP 1	17.8.–9.10.2009
Date FRP 2	23.11.2009–29.1.2010

Conferences | Workshops | Fairs

Conferences and workshops

Work committee meeting
DGM-Work committee Dauerimplantate
Dresden
14.1.2009

Conference
3rd International Symposium Hydrogen & Energy
Braunwald, Schweiz
25.–30.1.2009

Workshop
Klebfachkraft Refresher
Bremen
3.–5.2.2009

9. Colloquium
Gemeinsame Forschung in der Klebtechnik
DECHEMA-Haus
Frankfurt am Main
10./11.2.2009

Workshop
AIF-Brennstoffzellenallianz
Duisburg
17.2.2009

Colloquium
4. Landshuter Leichtbau-Colloquium
Landshut
26./27.2.2009

Workshop
Nanotechnology in Polymer Composites
Clausthal-Zellerfeld
2.–4.3.2009

Work committee IVAM
Energie und Effizienz
Hattingen
17.3.2009

General meeting
IVAM-Members-versammlung
Hattingen
17.3.2009

Conference
One-on-One Cooperation Event von Bayern Innovativ
MedTech–Pharma–Biotech
Garching
17.3.2009

Conference
9. Internationaler Deutscher Druckgusstag
Nürnberg
18.3.2009

Workshop
Klebtechnische Fertigung
Fraunhofer IFAM
Bremen
24./25.3.2009

Conference
17. Symposium "Verbundwerkstoffe und Werkstoffverbunde"
Bayreuth
1.–3.4.2009

Workshop
2. Fraunhofer-Allianz-Adaptronik-Workshop
Hannover-Messe
Hannover
22.4.2009

Forum
Werkstoff-Forum
Hannover-Messe
Hannover
22.4.2009

Conference
2. Wissenschaftliches Symposium SFB/TR 39 PT-PIESA
Fraunhofer IWU
Chemnitz
27./28.4.2009

Conference
Aalener Gießerei-Colloquium 2009
Aalen
7.5.2009

Seminar
DGM-Fortbildungsseminar Pulvermetallurgie
Dresden
13.–15.5.2009

Workshop
Deutsche Forschungsgesellschaft für Oberflächenbehandlung e. V.
Nachhaltige Oberflächentechnik – Selbstheilende Schichten
Fraunhofer IFAM
Bremen
28.5.2009

Work committee meeting
Arbeitssitzung der Fördergesellschaft Erneuerbare Energien e. V. – Work group "Vergasung von Biomasse"
Dresden
8.6.2009

Lange Nacht der Wissenschaften
Dresden
19.6.2009

Workshop
8. Bremer Klebtage
Klebtechnische Fortbildung im Rahmen der DVS®/EWF-Personalqualifizierung
Fraunhofer IFAM
Bremen
23./24.6.2009

VDI-Evening
Gemeinschaftsveranstaltung des AK Werkstofftechnik des VDI Dresdner Bezirksvereins und des DGZfP-Arbeitskreises Dresden
"Entwicklung maßgeschneiderter pulvermetallurgischer Werkstoffe, Technologien und Charakterisierung"
Dresden
24.6.2009

Conference
International Conference on Thermoelectrics ICT 2009
Freiburg
26.–30.7.2009

Conference
THERMEC 2009
Berlin
26.8.2009

Innovationstage Fa. Hennig und Richter
Hermsdorf
26.8.2009

Conference
International Conference on Metal Foams – Metfoam 2009
Bratislava, Slowakei
1.–4.9.2009

Congress
Euromat 2009
Glasgow, Schottland
7.–10.9.2009

Conference
ProcessNet – JahresConference der DECHEMA
Mannheim
8.–10.9.2009

Symposium
Leichtbau-Symposium 2009
Chemnitz
9.9.2009

Conference
Biomaterial-Colloquium
Friedrichroda
17.9.2009

Conference
Tribologie-FachConference 2009
Göttingen
21.–23.9.2009

EFDS-Workshop
Schichten aus Nanopartikeln – Abscheidung aus Dispersionen, Flammen und Plasmen
Dresden
29.9.2009

Colloquium
12. Werkstofftechnisches Colloquium
Chemnitz
1.10.2009

Conference
Magdeburger Maschinenbautage 2009
Magdeburg
1.10.2009

Industrietage Fa. Umwelt- und Lufttechnik
Löbau
2.10.2009

Talent-School Bremen
5.–7.10.2009

Conference
BDG-Fachtagung
"Gussteilkennzeichnung – Methoden und Datenmanagement – Praxisberichte"
Essen
7.10.2009

Conference
GEFTA-Jahrestagung 2009
Gießen
7.–9.10.2009

Conference
European Powder Metallurgy Conference – Euro PM 2009
Kopenhagen, Dänemark
12.–14.10.2009

Conference
Mikrosystemtechnik-Congress 2009
Berlin
12.–14.10.2009

Conference
DFG-NSF Research Conference – Sustainable Use of Nanomaterials for Novel Engineering Solutions
New York City, USA
14.–17.10.2009

Workshop
Designers Day
Bremen
20.10.2009

Conference
Lost Foam 2009
Bremen
20./21.10.2009

Workshop
IMPRESS Final Plenary Meeting
Budapest, Ungarn
21.–23.10.2009

Conference
JahresConference der Gesellschaft für Korrosionsschutz (GfKORR)
Frankfurt am Main
3./4.11.2009

Workshop
23. Workshop mikrotechnische Produktion
Dresden
4./5.11.2009

Conference
Synergien mit Stahl
Eisenhüttenstadt
5.11.2009

Conference
16. Energie-Symposium der FH Stralsund
Stralsund
5.–7.11.2009

Workshop
Bruker AXS Workshop: Anwendertreffen XRF und XRD
Dresden
9.–13.11.2009

Innovationstag
"Elektromobilität" Veranstaltung der swb AG Elektromobilität in der Modellregion NordWest
Bremen
11.11.2009

2. FrauenBerufsMarkt
Bremen
12.11.2009

Work committee meeting
9. Sitzung des Exprtenkreises Sintern des Fachverbandes Pulvermetallurgie
Dresden
12.11.2009

Conference
28. Hagener Symposium Pulvermetallurgie
Hagen
26./27.11.2009

Conference
DGM-Forum Werkstoffe
(EuroMold 2009)
Frankfurt am Main
2./3.12.2009

Seminar
Statusseminar des InnoNet-Projektes TiFoam "Metallschäume als bioanaloge Knochenersatzstoffe"
Dresden
3.12.2009

Forum
Kooperations-Forum "Moderne Beschichtungen"
Köln
9.12.2009

Fairs

KarriereStart 2009
Dresden
23.–25.1.2009

Didacta – Die Bildungsmesse
Hannover
10.–14.2.2009

intec 2009
12. Fachmesse für Fertigungstechnik, Werkzeugmaschinen- und Sondermaschinenbau
Materialforschungsverbund Dresden
Leipzig
24.–27.2.2009

MEDTEC 2009
Messe und Conference für den technischen Zulieferbedarf von Medizinproduktherstellern
Stuttgart
3.–5.3.2009

Jobbörse Bremerhaven
Bremerhaven
19.3.2009

European Coatings Show
Leitmesse für die internationale Lack- und Farbenindustrie
Nürnberg
31.3.–2.4.2009

Hannover-Messe 2009
Gemeinschaftsstand Innovationszentrum Ingenieurwerkstoffe
Hannover
20.–24.4.2009

Hannover-Messe 2009
Gemeinschaftsstand Wasserstoff im Rahmen der sächsischen Brennstoffzelleninitiative
Hannover
20.–24.4.2009

Hannover-Messe 2009
MICRO-Technologie
IVAM-Gemeinschaftsstand
Hannover
20.–24.4.2009

Hannover-Messe 2009
Simulation in der Produkt- und Prozessentwicklung
Hannover
20.–24.4.2009

Hannover-Messe 2009
Fraunhofer-Allianz Adaptronik
Hannover
20.–24.4.2009

Hannover-Messe 2009
Surface Technology
Produkte und Anwendungen der Plasmaoberflächentechnik
Hannover
20.–24.4.2009

Aerospace Testing, Design and Manufacturing
Leitmesse für Konstruktion und Entwicklung in der Luft- und Raumfahrtindustrie
München
21.–23.4.2009

InterPart
Karlsruhe
4.–6.5.2009

SMT/HYBRID/PACKAGING 2009
Europas größte Spezialmesse für Systemintegration in der Mikroelektronik
Nürnberg
5.–7.5.2009

Achema
Leitveranstaltung der chemischen Technik und Prozessindustrie
Frankfurt am Main
12.5.2009

Sensor und Test 2009
16. Internationale Fachmesse für Sensorik, Mess- und Prüftechnik mit begleitenden Kongressen
Nürnberg
26.–28.5.2009

CFK-Valley Stade Convention 2009
Neueste Entwicklungen bei Verfahren, Prozessen und Bauweisen von Faserverbundwerkstoffen in Forschung und Praxis
Stade
10./11.6.2009

Paris Air Show 2009
Internationale Luft- und Raumfahrt-Schau
Paris, Le Bourget, Frankreich
15.–21.6.2009

EuroLITE
3. Internationale Messe für Leichtbaukonstruktionen (NEMO-Netzwerk)
Salzburg, Österreich
23.–25.6.2009

Schweißen & Schneiden
Weltmesse für Fügen, Trennen, Beschichten
Essen
14.–19.9.2009

Bondexpo
Fachmesse für Industrielle Klebtechnologie
Stuttgart
21.–24.9.2009

EcoExperience 2009
Wissenschaft und Praxis im Bereich nachhaltige Mobilität
Oldenburg
12.10.2009

Euro PM 2009
Kopenhagen, Dänemark
12.–14.10.2009

Materialica
12. Internationale Fachmesse für Werkstoffanwendungen, Oberflächen und Product Engineering
Materialforschungsverbund Dresden
München
13.–15.10.2009

testXpo
Ulm
20.–22.10.2009

parts2clean
Internationale Leitmesse für Reinigung in Produktion und Instandhaltung
Stuttgart
20.–22.10.2009

Composites Europe
4. Europäische Fachmesse und Forum für Verbundwerkstoffe, Technologie und Anwendungen
Stuttgart
27.–29.10.2009

Wissenswerte
Bremer Forum für Wissenschaftsjournalismus
Bremen
9.–11.11.2009

Productronica 2009
19. Weltleitmesse für innovative Elektronikfertigung
München
10.–13.11.2009

Compamed
Fachmesse High tech solutions for medical technology
Düsseldorf
18.–20.11.2009

28. Hagener Symposium
Pulvermetallurgie mit Fachausstellung
Hagen
26./27.11.2009

EuroMold 2009
Weltmesse für Werkzeug- und Formenbau, Design und Produktentwicklung
Frankfurt am Main
2.–5.12.2009

EuroMold 2009
Weltmesse für Werkzeug- und Formenbau, Design und Produktentwicklung
Sonderschau Werkstoffe
Frankfurt am Main
2.–5.12.2009

Scientific publications

PhD theses

J.-E. Damke
Studien zur Synthese von Chlorinen mit invertiertem Stickstoff
Universität Bremen

Experts:
Prof. Dr. F.-P. Montforts
Prof. Dr. W.-D. Stohrer
Examiners:
Priv.-Doz. Dr. A. Hartwig
Dr. M. Osmers
Dipl.-Chem. M. Erbacher
C. Beck (student observer)
Public colloquium: 27.7.2009

Lectures

A. Burblies
Finite-Elemente-Methode
Hochschule Bremerhaven
SS 2009

A. Burblies
Werkstoffe und Simulation
Hochschule Bremerhaven
WS 2009/2010

M. Busse
Forschung und Entwicklung im Automobilbau
Universität Bremen
Fachbereich Produktionstechnik
SS 2009

M. Busse
Leadership im Automobilbau
Universität Bremen
Fachbereich Produktionstechnik
WS 2009/2010

S. Dieckhoff
Oberflächentechnik
Fachhochschule Bremerhaven
SS 2009

H. Fricke
Simultaneous Engineering and Rapid Prototyping
Studiengang Master of Computer Based Mechanical Engineering
Hochschule Bremen
(CMBE) – Fachbereich 5
WS 2009/2010

B. Günther, M. Busse
Funktionswerkstoffe im Automobilbau – Funktionalisierung von Oberflächen
Universität Bremen
Fachbereich Produktionstechnik
SS 2009

A. Hartwig
Moderne Schwingungsspektroskopie – mehr als der Nachweis von Carbonylgruppen
Universität Bremen
WS 2009/2010

A. Hartwig
Makromolekulare Chemie – Grundlagen
Universität Bremen
SS 2009

A. Hartwig
Werkstofftechnik – Polymere
Universität Bremen
WS 2009/2010

B. Kieback
Pulvermetallurgie und Sinterwerkstoffe II
Technische Universität Dresden, Institut für Werkstoffwissenschaft
SS 2009

B. Kieback
Festkörperchemie II
Technische Universität Dresden, Institut für Werkstoffwissenschaft
SS 2009

B. Kieback
Verbundwerkstoffe
Technische Universität Dresden, Institut für Werkstoffwissenschaft
SS 2009

B. Kieback
Festkörperchemie I
Technische Universität Dresden, Institut für Werkstoffwissenschaft
WS 2009/2010

B. Kieback, R. Leuschner
Technologien zur Werkstoffherstellung und -verarbeitung I
Technische Universität Dresden, Institut für Werkstoffwissenschaft
WS 2009/2010

B. Kieback, T. Weißgärber
Pulvermetallurgie und Sinterwerkstoffe I
Technische Universität Dresden, Institut für Werkstoffwissenschaft
WS 2009/2010

U. Lommatzsch
Oberflächentechnik
Hochschule Bremerhaven
SS 2009

U. Meyer
Grundlagen der Mathematik
Hochschule Bremen
WS 2009/2010

U. Meyer
Festigkeitslehre I
Hochschule Bremen
WS 2009/2010

F. Petzoldt, M. Busse
Endformnahe Fertigungstechnologien 2
Universität Bremen
Fachbereich Produktionstechnik
SS 2009

F. Petzoldt, M. Busse
Endformnahe Fertigungstechnologien 1
Universität Bremen
Fachbereich Produktionstechnik
WS 2009/2010

F. Petzoldt
Produktionsorientierte medizinische Prozessketten
Hochschule Bremerhaven
Studiengang Medizintechnik
SS 2009

P. Plagemann
Kleben und Hybridfügen
Universität Bremen
SS 2009

P. Plagemann
Korrosion
Hochschule Bremerhaven
WS 2009/2010

H.-E. Rikeit
Konstruktionssystematik / Produktentwicklung
Universität Bremen
WS 2009/2010

J. Weise
Modul Werkstoffwissenschaften (WKME) für Internationalen Studiengang Wirtschaftsingenieurwesen B.Eng.
Hochschule Bremen
WS 2009/2010

R. Woltmann, M. Busse
Bauteilentwicklung für automobile Gusskomponenten
Universität Bremen
Fachbereich Produktionstechnik
SS 2009

R. Woltmann, M. Busse
Leichtmetallgießen im Automobilbau
Universität Bremen
Fachbereich Produktionstechnik
WS 2009/2010

Publications

O. Andersen, U. Jehring, J. Hohlfeld, R. Thümmler
Hochdämpfende Sandwiches mit zellularem Stahlkern für die Anwendung im Maschinenbau
Tagungsband Magdeburger Maschinenbautage 2009

O. Andersen, J. Meinert
Heat Transfer and Fluid Flow in Sintered Metallic Fiber Structures
Proceedings THERMEC 2009,1884–1889

O. Andersen, T. Studnitzky
Development and properties of sandwich with open-cell sintered short fiber core and comparison with other types of sandwich material
Proceedings of MetFoam 2009

C. Aumund-Kopp, F. Petzoldt, T. Schäfter
Extrusion and In-line Calibration of Hollow Profiles Based on MIM Feedstocks
Proceedings Euro PM 2009, Kopenhagen, Dänemark, 12.–14.10.2009, 111–116

M. Avalle, D. Lehmhus, L. Peroni, H. Pleteit, P. Schmiechen, G. Belingardi, M. Busse
AlSi7 metallic foams, aspects of material modeling for crash analysis
International Journal of Crashworthiness, Vol. 14, No. 3, 6.2009, 269–285

J. Baumeister
Methods for Filling Hollow Structures with Aluminium Foam Materials
Science Forum, Vols. 638–642 (2010), 61 doi:10.4028/www.scientific.net/MSF.638-642.61

T. Bindemann, R. Foest, R. Ihrke, U. Lommatzsch, A. Ohl, J. Schäfer, K.-D. Weltmann
Plasma-assisted removal of organic contaminants inside cavities
Vacuum 83 (2009), 779–785

E. Boschi, L. Mark, B. Claise
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Jena
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Bremen
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Bremen
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Bremen

Internal experts

12.1.2009
C. Regula
Schichtbildung von Plasmapolymeren mittels Atmosphärendruckplasma

9.2.2009
G. B. Dutra
Simulation 2K-MIM

9.2.2009
D. Kolacyak
Funktionalisierung von Kohlenstoffnanoröhrchen mit Atmosphärendruckplasmatechnik

2.3.2009
C. Pille
Funktionsintegrierte Gussbauteile

2.3.2009
Y. Dan
Composites of Epoxy with Low Melting Glasses for Improvement of Retardancy

20.4.2009
M. Rehan
Fixation of carrier molecule materials to different textile materials by means of plasma-processes

4.5.2009
M. Müller
Funktionale nanoskalige Suspensionen für Druckverfahren

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S. Nouri Shirazi
Nasschemische Oberflächenmodifizierung von der Titanlegierung TiAl6V4 und deren Auswirkung auf die resultierenden Adhäsionseigenschaften

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M. Maiwald
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J. Felker
Alterungsbeständigkeit von Kupferpartikeln in Epoxiden

10.8.2009
R. Muller Schröder
Gas atmosphere analyses during debinding and sintering of powder injection molding components

14.9.2009
T. Seemann
In-situ-Erfassung und -Bewertung von PVD-Prozessparametern

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Untersuchung der chemischen und physikalischen Eigenschaften von Faser/Matrix-Interphasen in CFK-Verbundwerkstoffen

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C. Werner
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Untersuchungen des Alterungsverhaltens von Klebverbindungen mittels elektrochemischer Impedanzspektroskopie

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A. Hartwig
Einführung in das wissenschaftliche Arbeiten

7.12.2009
C. Merten
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External experts

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G. Diaconu
Institute for Polymer Materials POLYMAT and Chemical Engineering Group
Faculty of Chemistry University of the Basque Country San Sebastian, Spanien
Waterborne polymer/clay nanocomposites

30.6.2009
V. Sergo
University of Trieste, Italien
Applications of Raman Spectroscopy in the Biomedical Field

5.8.2009
A. Avelino Pasa
Departmento de Fisica – Universidade Federal de Santa Catarina Florianópolis, Brasilien
Electrodeposition of Metals and Oxides on Semiconductors

Dresden

Internal experts

15.1.2009
J. Schmidt
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S. Prasse
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Von gefüllten Hohlkugeln zu Leichtbauverbundwerkstoffen für die Körperschalldämpfung

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External experts

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Bundesinstitut für Berufsbildung (BIBB)
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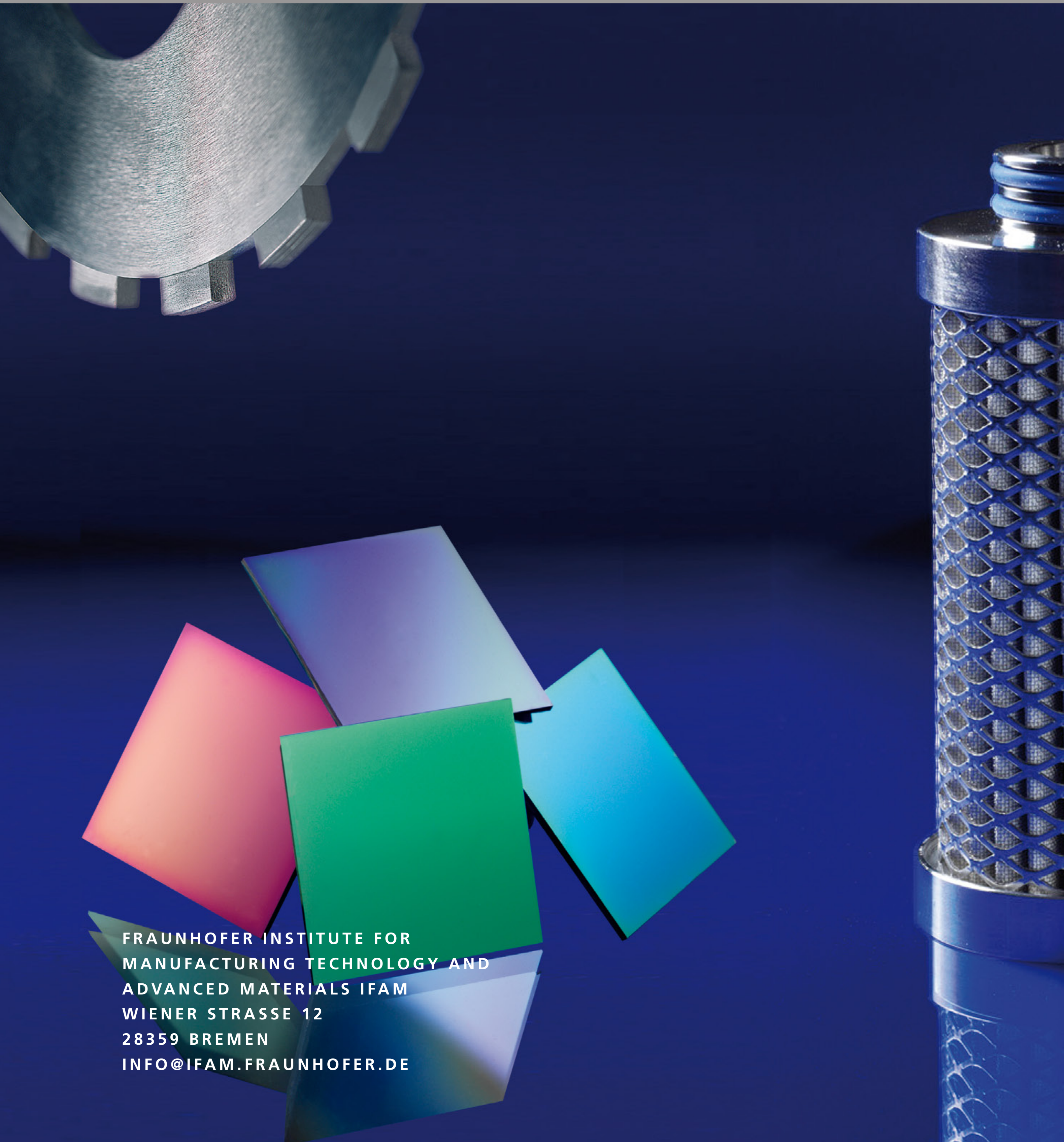

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