Fraunhofer

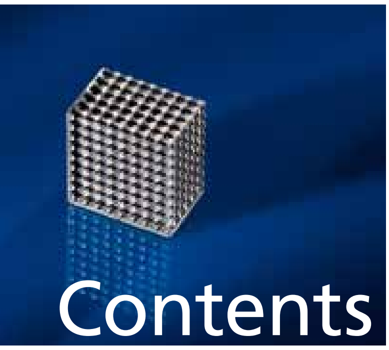
IFAM

FRAUNHOFER INSTITUTE FOR MANUFACTURING TECHNOLOGY AND APPLIED MATERIALS RESEARCH IFAM

ANNUAL REPORT 2008/2009

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research IFAM

Annual Report 2008/2009



Contents

A Profile of the Institute

Department of Shaping and Functional Materials

Department of Adhesive Bonding Technology and Surfaces

People and Moments

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

Head of the institute: Prof. Dr.-Ing. Matthias Busse (left), Dr.-Ing. Helmut Schäfer.

the year 2008 was not only our institute's 40th anniversary, – it was also another successful business year. We were able to continue our trend towards growth: Both the budget and the number of the institute's employees increased by ten per cent. In spite of the characteristic deficit in natural scientists and engineers on the job market, in 2008, Fraunhofer IFAM succeeded again in recruiting committed employees. Our positive development continues to initiate new projects throughout the institute – which, in turn, results in a lack of space. Consequently, we are already planning further building measures.

Inside the Fraunhofer-Gesellschaft FhG, the institute is among the largest facilities. The institute plays a major role even in the Fraunhofer Materials and Components Group. Bremen established itself as an important Northern location within the FhG, which is actually still expanding. We are very proud of the fact that the Fraunhofer Institute for Wind Energy and Energy System Technology IWES, which is located nearby in Bremerhaven, began its activities on January 1st, 2009. This facility goes back to an initiative by the Fraunhofer Institutes IFAM and LBF (Institute for Structural Durability and System Reliability, Darmstadt) that resulted in the creation of the Fraunhofer Center for Wind Energy and Maritime Engineering CWMT. Only a few hundred meters away from IFAM, the Fraunhofer Institute for Medical Image Computing MEVIS began its work at the same time. Here, personal contacts have already been established which may become the basis for a future cooperation. IFAM explores many issues resulting from biology and biomedicine, whereas MEVIS is focussed on information science and software engineering applied in the medical domain. Synergy effects are to be expected from this interaction.

The new Bremen Innovation Cluster "Multifunctional Materials and Technologies" (MultiMaT) has been operating at its full capacity since the beginning of 2008. In agreement with the enterprises involved and its scientific partners, the group succeeded not only in defining the targets of the five pilot projects, but also in achieving initial results. Their tasks also indicated the need to intensely build up the innovation cluster network, which will also include supraregional firms and facilities whose experience will be in line with the topics investigated at "MultiMaT". However, taking part in the European research program "Clean Sky" is equally important for the institute. The project, which has a total budget of 1.6 billion euros, is focussed on sustainable improvement in the environmental compatibility and competitiveness of European aviation. Fraunhofer IFAM is a member of a consortium embracing 86 industrial and research partners from 16 countries, whose intent is to diminish the emissions resulting from increased air transport in the next seven years.

In 2008, the department of Shaping and Functional Materials was able to convince Professor Kurosch Rezwan, University of Bremen, an expert in the field of ceramic materials with the focus on bioceramics, to take the lead of the newly established range of competency: biomaterials technology. Numerous points of contacts arose between the scientists from this domain at the university and the activities of IFAM at the interface between biological cells and technical materials. We are confident that the combination of fundamental research and development driven by applications in this field will soon bear fruit. This department is also turning more and more to the important issue of electromobility. In the future, increasing value will be attached to engineering of reduced-emission or even emission-free vehicles.

IFAM is involved in the strategic exploration of this issue on behalf of the FhG and is performing research in essential subdomains, such as the optimized storage of electrical energy in batteries of the future or the creation of highly efficient drives, based on its materials science orientation.

The IFAM department of Powder Metallurgy and Composite Materials, which is situated in Dresden, is well on its way to success. A cooperative creative relationship has been developed among the various working groups despite the great distance between sites, and this collaboration will be extended step by step.

The Department of Adhesive Bonding Technology and Surfaces continued its close cooperation with its first customer, the aircraft manufacturer Airbus Deutschland GmbH, in the tandem constellation ("Bremer Tandem") in 2008. The department is being extended through the establishment of a project group in the new Research Center CFK Nord in Stade near Bremen. This group is concerned with the assembly of large CFK structure parts, refining the results obtained by IFAM to make these products fit for series production. These structures are intended for the aircraft industry, as well as vehicle and rail vehicle manufacturers. Research in the seminal domain of protein-based materials was intensified. Investigation of biopolymers and their interaction with technical surfaces is a topic of growing importance. The target is to decode the working principles of adhesion in nature on a biological basis. Once the interrelations are understood, adhesive bonding processes should be made possible in domains such as medical engineering, in which the combination of organic and inorganic materials has encountered great difficulties up to now. In this segment, computer-based simulation to investigate the complex procedures down to the molecular level plays an important role.

IFAM is the leading institute in Bremen activities within the Excellence Initiative of the Federation and the States. In 2007, two applications oriented towards materials science were deemed to be of outstanding quality, but they narrowly missed receiving subsidies. IFAM's interdisciplinary cooperation with other scientific institutes in the technology park and at the University of Bremen was further expanded with the filing of the application in 2008, which ultimately resulted in the foundation of a Scientific Centre ISIS at the university. Under the name ISIS "Integrated solutions sensorial structure engineering", a suitable platform was created to prepare a new application for the next series of requests made by the Excellence Initiative in the domain of sensor materials for innovative use.

Signs that the global economic situation is undergoing a sustainable change in many business lines began to appear in the last third of 2008. For IFAM, this means carefully following the development trends and reacting flexibly to them in its own business activities. Due to the fact that the institute has established a wider portfolio of activities and consequently, with its future-oriented research and development, is always finding new research objectives, it became an important contact partner and provider of ideas even in a problematic economic climate.

But no development, research or project may be done without highly motivated and committed people. For this reason, we are especially grateful to our employees who render outstanding achievements to the Fraunhofer IFAM every day. Our employees are the drivers of our success, which is described in the trend and project reports that follow.

We hope that you enjoy reading this annual report.

Matthias Busse

Helmut Schäfer

40th Year Anniversary of Fraunhofer IFAM: "Our employees are the key to our success"

Opening of the celebratory colloquium by Prof. Dr.-Ing. Matthias Busse.

Senator Renate Jürgens-Pieper.

Let's take a long look at the past and then focus on the future: If a 40th birthday is imminent, it is worthwhile to think with satisfaction over our achievements, as well as take an optimistic outlook to the future. This was the essence of the celebratory colloquium of the Fraunhofer IFAM on the occasion of its 40th anniversary on 3rd June 2008. Current and former employees and partners from industry and economy, as well as representatives from policy and science met in the institute's building in Bremen to celebrate the "IFAM's history of success" together. The speeches gave insight into four successful decades of applied research and into 40 years of in-depth cooperation between science and economy. Anecdotes and remarkable stories from the institute's history were given new significance in light of the current and future activities of IFAM. People seized the opportunity to exchange information during the breaks and also in the evening, at the celebratory event in the Chocoladium and in the Universum Science Center.

At the opening, Professor Matthias Busse, the head of the institute, yielded the center stage to those who have made possible the success of IFAM: "It is always the people – our employees – who are the impetus behind the manifold achievements of the institute". In this context, Busse especially highlighted two individuals: the former head of the institute, Professor Hans-Dieter Kunze, and Professor Otto-Diedrich Hennemann, who are both closely connected with the institute's history. "40 years of IFAM marks a period longer than that of a single professional career. This is why there is no one now employed at IFAM who began working in the year of foundation in 1968", stated Matthias Busse. However, former employees who had joined at the start of the "Working Group for Applied Materials Research" (AfaM), headed by the materials scientist Professor Alexander Matting in Bremen-Lesum, also took part in the celebratory colloquium.

Prof. Busse succeeded in vividly summarizing the momentous history and development of IFAM. First of all, the move into the technology park and thus into the neighbourhood of the university was decisive – for "IFAM would not exist in its present structure without the support of the University of Bremen since the middle of the 1990s", Busse affirmed. The fact that IFAM has always been promoted by policy was also worth remembering: "We have an excellent cooperation with the senatorial authorities".

Recognition from Bremen and Munich

These laudatory words were music to the ears of Renate Jürgens-Pieper, the Senator for Education and Science in Bremen. Although she had only been a senator for a year at the time of the celebratory colloquium, she had already been involved in many activities with the Fraunhofer Institute Bremen – and all for good reasons. The

Prof. Dr. Ulrich Buller.

Prof. Dr. Jürgen Klenner.

senator went through the records: "The increase in third-party funds and the total budget of the institute are remarkable", Jürgens-Pieper outlines. The senator also paid tribute to the increase in personnel over this period. "IFAM has always succeeded in orienting itself toward forward-looking subjects and fulfilling both economic and scientific demands", Renate Jürgens-Pieper states. "The container village on the institute site and the development in Bremerhaven, where the Fraunhofer Center for Wind Energy and Maritime Engineering is making excellent progress, demonstrate that the institute is following the right path – not to mention the Fraunhofer Innovation Cluster 'MultiMaT', which is central to the Bremen scientific segment of materials science"!

"Success through Change" was the keyword for Professor Ulrich Buller, the Executive Manager for Research Planning at Fraunhofer. He has been with IFAM for 24 of its 40 years, and these years have been full of action: "I don't know any other Fraunhofer institute that has met change with such commitment". When he first came, in 1984, the institute was focusing on "stun bullets". Later, the institute moved from being a service provider for the Ministry of Defence to an order-based research institute for private industry. Buller spoke about the pioneering work of Professors Hennemann and Kunze, which required projects and offices in Dresden, Teltow, Delaware and – for a short time – also in Clausthal. "Continuous advancement is typical for IFAM – despite the strong competition, even inside the Fraunhofer-Gesellschaft". A special highlight in the history of the FhG was the successful approach to using continuing education in the adhesive bonding sector as a means of integrating high-tech innovation as widely as possible into the economy – thereby shaping a model project from which the entire Fraunhofer Gesellschaft benefits to this day".

A Successful Tandem: IFAM and Airbus

When we consider the successful cooperation of science and business, the team of the "Bremer Tandem" formed by IFAM and Airbus is often given as an example. IFAM board of trustees member Professor Jürgen Klenner (Airbus Toulouse), who has been working with IFAM in Bremen for many years, reported on the creative partnership between the institute and the aircraft manufacturer in research and development. "We have been partners from the beginning and have supported IFAM from then until today", Klenner remembered, recalling when Airbus was known as VfW, VfW Fokker, DASA or MBB. He also recollected difficult periods – for instance the "adhesive bonding disaster" in the aircraft industry, resulting at the end of the 1970s in significant damage due to delaminations. "Efforts to work together to cope with this crisis by IFAM, Airbus and the adhesive manufacturers led to great progress in research and really leveraged adhesive bonding as a technology in the aircraft industry",

Dr. Dietrich Zeyfang.

Prof. Dr. Rolf Drechsler.

Klenner added. Thanks, among other things, to the excellent cooperation that began at that time, they were able to ensure the establishment of the segment of "Material and Processes" within the Airbus group at the Bremen location.

Fraunhofer IFAM and the University in Flux

The longtime chairman of the IFAM board of trustees and former head of the Mercedes-Benz plant in Bremen, Dr. Dietrich Zeyfang, remembered the special relationship between industry and science in Bremen in the 1970s: "The AfaM, later renamed IFAM, at that time was closely affiliated with the so-called 'military-industrial complex'. When I applied to the 'leftist University of Bremen' in 1978, they threw me out"! The conversion of IFAM on the one hand, and changes at the university, on the other – in particular due to the foundation of the Department of Production Engineering, in which IFAM employees also teach today – gave science and industry a gradual understanding of each other. The positive trend increased with the move to the Wiener Strasse: Whether we are talking about the tripling of the budget, the enormous increase in personnel or the intensive, result-driven cooperation with other facilities and institutes: The scientific position of Bremen today is unimaginable without IFAM.

Professor Rolf Dressler, Deputy Head for Research at the University of Bremen, could only confirm this statement. Dressler affirmed that the cooperation between IFAM and the university is "full of life". Because of this successful collaboration, it has been found that when applications for the Excellence Initiative are filed, alliances of this type are given still higher priority: "In the Excellence Initiative, only universities that work together in clusters with large institutes like IFAM were successful". The fact that the institute encountered a distinguished research environment in physics, chemistry, electrical- and production engineering at the university after its move into the technology park was clearly important for the development of IFAM. Also the integration of the heads of the institutes into the university structure as professors is regarded as essential. The trend towards still closer cooperation is almost mandatory – many joint measures are planned in anticipation of the next round of the Excellence Initiative in 2011.

40 Years of Adhesive Bonding in Bremen

"Knowledge of our origins is the basis for the path we want to follow in the future", Dr.-Ing. Helmut Schäfer, head of the Department of Adhesive Bonding Technology and Surfaces, said with certainty. He had available photos and information from the earliest years of the institute's history – and discovered one constant issue through the years: "As long as IFAM has existed, there has always been a lack of space, and so

Dr.-Ing. Helmut Schäfer.

they are always building something". Once, 1500 square meters were available for research purposes. Today, that area is more than ten times larger, and IFAM is constantly growing. Schäfer mentioned the locations Bremen-Lesum and Neuer Steindamm, discussed military research, adhesive bonding of metals and the beginnings of the qualification in adhesive bonding. He closed with the latest challenges to be met, such as the combination of adhesive bonding and mechanical joining procedures, adhesive bonding of fibre composites, and new challenges for surface technology, among other things. His conclusion was: "From its modest beginnings, the Department of Adhesive Bonding Technology and Surfaces has become the largest independent research institute in Europe in the field – financially strong and with close connections to industry"!

The Future: Intelligent and Lightweight Components

The head of the institute, Matthias Busse, is responsible for looking into the future. "We devote a lot of time to thinking about current trends. Our future development tends towards issues that affect all of us: Energy, safety, environment, health, communication and mobility". Busse used examples from the automobile industry to demonstrate how the complexity of products has increased. The trend is towards lightweight, intelligent systems – in cars, for instance, the emphasis is on "safe and clean". This can be implemented using "multi-material design", i.e. joining differentiated materials; integrating functionalities may also result in a kind of "intelligence". The future belongs to "sensitive components that can signal technical disturbances" – for example, in offshore wind turbines. Its integration in efficient networks makes IFAM well prepared for the future. Busse sees new connections and areas for development at the margins of the traditional scientific disciplines; in cooperation with universities and other institutes, Fraunhofer IFAM will move along this direction. However, the most essential factor of success – and here the circle of the celebratory colloquium is closed – is once again the individual: "Also in future will we need many committed and motivated employees"!

MultiMaT Opening Ceremony in the City Hall of Bremen – Celebrating with Joy, Information and Optimism

Prof. Dr.-Ing. Matthias Busse.

The opening of the Innovation Cluster "Multifunctional Materials and Technologies" (MultiMaT) will remain a vivid memory for the many people involved: In the festive ambience of the city hall of Bremen, more than 200 representatives from science, industry, policy and society met on 22nd April 2008 to inaugurate the cluster. It was an event which went well beyond the welcoming addresses. It also offered precise information about the subjects and objectives to be investigated and achieved in the Innovation Cluster in the coming years. Representatives from the most important participants spoke at the successful celebratory colloquium in the Upper City Hall. They not only expressed their joy in the establishment of the Innovation Cluster, but also gave a clear view of the future cooperation of science and industry through presentations and a moderated expert round table session.

Whether at the celebratory event or the press conference that immediately preceded it, in which the general public was given information about the Innovation Cluster MultiMaT and its targets, all of the speeches, – emphasized the benefit to science and industry in Bremen and the metropolitan region of Bremen – Oldenburg. Last but not least, on this day, with MultiMaT, the first and only Northern German Innovation Cluster in a total of 14 facilities of this type in Germany was started. The cost of 8.1 million euros for the first four years will be divided among the Fraunhofer-Gesellschaft, the companies involved and the state of Bremen. Jens Böhrnsen, the mayor, sees the financial contribution of the state, which was funded by the European Funds for regional development (German abbreviation: EFRE) in the spheres of industry and education/science, as a good investment: "The innovation cluster is excellently suited to our strategy to make Bremen and Bremerhaven one of the leading areas for technology in Germany. According to our ranking, we are at the moment in 11th place nationwide. With "MultiMaT", we should definitely crack the Top Ten"!

"Making the Strong Stronger" with MultiMaT

Renate Jürgens-Pieper, Senator for Education and Science, expressed her pleasure in the excellent cooperation of all involved "in making this a reality". To have one of the 14 clusters in her own state makes her proud – and it fits perfectly into her own strategy, as well as that of the industry, of "making the strong stronger" in the land of Bremen. Jürgens-Pieper was delighted that the establishment of the innovation cluster also means an award for IFAM – "since it is an excellent institute"! On behalf of the Senator of Commerce, Ralf Nagel, State Council Dr. Heiner Heseler appeared very pleased about the establishment of MultiMaT, recognizing that well known institutions such as the firms joining the cluster – Airbus, Daimler, Hella Fahrzeugkomponenten, Thyssen Krupp Krause, OHB System and many others - have been successfully working with research institutes in Bremen and Bremerhaven for a long time. These cooperations in everyday life paved the way for an innovation cluster such as MultiMaT in the "Capital of Materials Science".

As Executive Manager of Research Planning of the Fraunhofer-Gesellschaft responsible for innovation clusters, Professor Ulrich Buller, began by explaining why they had agitated in the "Pact for Research and Innovation" with the Federal government, among other topics, to establish these facilities in 2005. "People know Black Forest clocks or lace from Plauen. For centuries, there have been regions with very special strengths. We are picking up on this idea with the innovation clusters and are refining it". Since Bremen, on the one hand, has typical strengths in the car-, aeronautics, aircraft-, ship- and wind turbine plant industries and their associated suppliers, and, on the other hand, is also very experienced in materials and processes at universities and research facilities, a materials science innovation cluster is clearly sustainable. Professor Buller was very happy that IFAM is coordinating MultiMaT: "This will be another success for the institute, which has developed so brilliantly in this very place"!

A Clear Example: The Human Tooth

The head of IFAM, Professor Matthias Busse, did not see any reason to contradict this appraisal. He also gave an example that was easy for laypersons to follow to describe the content of MultiMaT: the human tooth. It is subject to enormous mechanical loads and should be much larger to withstand the constant strain put on it – but its sensitivity enables it to send an "alarm" signal in the event of a disturbance, so it can do its job for decades despite being small and slight. The target of MultiMaT is to make technical components similarly "sensitive": "The defective gearwheel or the cracked rotor blade of an offshore wind turbine autonomously sends a signal via integrated sensors". Professor Busse showed five pilot projects in a demonstrative presentation. In these projects, partners from science and industry work together closely.

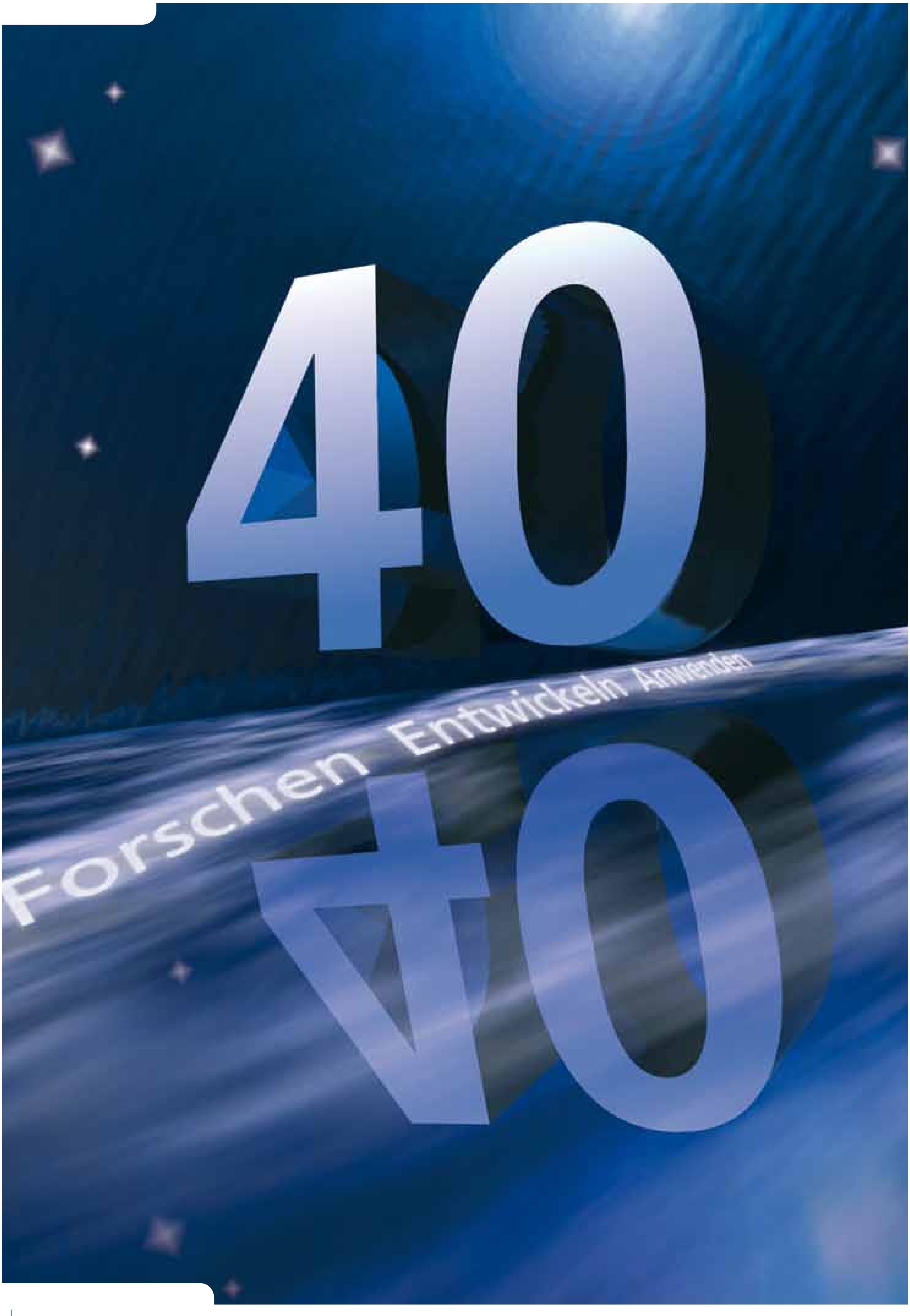
Dr. Matthias Fonger, Chief Executive of the Chamber of Commerce, was optimistic in his outlook for the industry because of the coming years of collaboration. "Cooperation like this improves the site in the long term. The cutting edge technology in Bremen also inspires the potential for economic growth". The initiative coincides with a period, in which, thanks to a favorable macroeconomic situation, many enterprises have money to invest in research and development. Shared financing of the innovation clusters elucidates the "Team spirit of the cooperation" on site – an essential basis for the success of this demanding project, in which the latest scientific results will be quickly implemented in actual products.

Informative Round Table – Fascinated Audience

The ideas and subjects to be dealt with in detail, as well as the way that interaction functions both among the scientists and among the cooperating firms, was clarified by the informative round table discussion directed by Dr. Matthias Fonger in the Upper City Hall. In a casual discussion with Dr.-Ing. Helmut Schäfer, the head of the IFAM Department of Adhesive Bonding Technology and Surfaces, Dr. André Walter (manager of the company Metalltechnologie Airbus Deutschland) and the managing directors Klaus Müller (WeserWind GmbH Offshore Construction Georgsmarienhütte) and Manfred Meise (Hella Fahrzeugkomponenten GmbH) gave insight into the content that makes MultiMaT what it is. The fascination of the audience proved that this kind of discussion was a good choice.

Mayor Jens Böhrnsen.

From left to right: Dr. Matthias Fonger, Prof. Dr. Ulrich Buller, Mayor Jens Böhrnsen, Prof. Dr.-Ing. Matthias Busse.


40
Forschen Entwickeln Anwenden

A Profile of the Institute

40 years Fraunhofer IFAM in Bremen.

The Institute's Profile

The Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM carries out research and development work in the areas of Shaping and Functional Materials and Adhesive Bonding Technology and Surfaces.

The Department of Shaping and Functional Materials has facilities in Bremen and Dresden and develops customized materials using innovative manufacturing methods and processes. The R&D work focuses on Material – Shaping – Component interaction. Other areas of expertise include surface microstructuring and the integration of functions into components. The individual solutions we develop are for customers in different industrial sectors, including the car manufacturing industry, medical technology, aviation and aerospace, mechanical engineering and plant construction as well as the electronics industry.

In the area of shaping, the focus is on the efficient and resource-friendly production of highly complex precision components, including miniaturized components. R&D activities include simulation of shaping processes as well as technical implementation in the production and providing the relevant training for company personnel. Processes for the microstructuring of sufaces are being used in a host of industries extending from medical technology to the energy sector. Innovative casting processes, involving the direct integration of functional electronic elements, are giving rise to new multifunctional components for a wide range of industrial applications.

The R&D activities in the area of materials development are centered on improving the properties and processing of existing materials. Other main work areas are special functional materials and the integration of sensory properties into components. Functional coatings can be directly generated on structured surfaces and on a wide range of materials. The special properties of cellular materials are in demand for energy absorption, noise absorption, heat exchangers, and material transport. Biomaterials made of metals, ceramics, and polymers are at the fore of developments in environmental and medical technology.

The Adhesive Bonding Technology and Surfaces department at IFAM offers industry-qualified development projects in adhesive bonding technology, plasma technology and paint/lacquer technology.

The services provided by this IFAM department are in demand from many partners in a wide range of industries. Currently our most important customers come from vehicle construction – aircraft, road vehicles, rail vehicles, ships – as well as their suppliers, mechanical- and equipment engineering, the electrical industry and electronics, appliance industry, medical engineering, and information and communications technology.

Certified training in the Adhesive Bonding Technology department is a service that complements the R&D activities and is used by all of these business lines. Having successfully implemented the certified training concept in German-speaking countries in the field of bonding technology and having performed qualification courses in other European states, the training is now also being offered in the USA for multinational companies.

The subject area of Adhesive Bonding Technology is subdivided into the following work groups: Adhesives and polymer chemistry, biomolecular surface- and material design, application technology, manufacturing engineering, bonding in micromachining, construction types.

Plasma technology, which comprises low-pressure plasma-, atmospheric plasma- and the paint/lacquer technologies is combined in the domain of Surfaces. The two business fields are complemented by the Adhesion- and Interface Research businesses, which consist of work groups in applied surfaces and layer analysis, electrochemistry and molecular modelling.

The Adhesive Bonding Technology and Surfaces department, in conjunction with the Fraunhofer Institute for Structural Durability and System Reliability, operates the Fraunhofer Center for Wind Energy and Maritime Engineering CWMT.

Brief Overview and Organigram

Founded in 1968 as a working group for applied materials research, the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM was incorporated as an institute into the Fraunhofer-Gesellschaft in 1974. Established as an institute for contract research with new emphases and systematic extension, IFAM works closely with the University of Bremen. The directors of the institute are also appointed to chairs in the Production Engineering department of the University of Bremen.

The institute has sites in Bremen, Bremerhaven and Dresden.

Prof. Dr. Matthias Busse took up his position in the institute's management and as head of the Shaping and Functional Materials department in 2003.

Dr.-Ing. Helmut Schäfer entered the institute's management in 2007 and since then has been the head of Adhesive Bonding Technology and Surface department.

As a neutral and autonomous facility, IFAM has been established as one of the largest European technical facilities in the fields of shaping and functional materials, as well as adhesive bonding technology and surfaces.

IFAM belongs to the association of 57 institutes which make up the non-profit organisation Fraunhofer-Gesellschaft. At present, the organisation maintains about 80 research facilities throughout Germany. A staff of approximately 15,000 employees, most of whom are highly qualified scientists and engineers, generate an annual research volume of more than 1.4 billion euros. Of this amount, more than 1.2 billion euros is derived from contract research. Research orders from industry and publicly financed projects generate approximately two thirds of the Fraunhofer-Gesellschaft's contract revenue.

In 2008 the overall IFAM budget amounted to approximately 31.3 million euros. The workforce comprised some 379 employees, 89 % of them among the scientific engineering staff.

Professor Dr.-Ing. Matthias Busse
(executive)
Managing director Shaping and Functional Materials

Deputy director: Dr.-Ing. Frank Petzoldt

Professor Dr.-Ing. Bernd Kieback
Managing director of IFAM Dresden

Dr.-Ing. Helmut Schäfer
Managing director Adhesive Bonding Technology and Surfaces

Deputy director: Priv.-Doz. Dr. habil. Andreas Hartwig

Dr. habil. Hans-Gerd Busmann
Managing director of CWMT Bremerhaven

Andreas Heller
Head of administration

The Institute in Figures

Budget

The total IFAM budget (expenditure and investment) in 2008 comprised the budgets of the two departments of Shaping and Functional Materials and the Department of Adhesive Bonding Technology and Surfaces.

The provisional budget result was in total 31.3 million euros. The results for the individual departments are shown below.

Shaping and Functional Materials Bremen

Operating budget	6.8 million euros
Own income	4.1 million euros
Including	
Business income	2.1 million euros
Federal/state/EU/other	2.0 million euros
Investment budget	0.8 million euros

Shaping and Functional Materials Dresden

Operating budget	3.5 million euros
Own income	2.6 million euros
Including	
Business income	1.7 million euros
Federal/state/EU/other	0.9 million euros
Investment budget	0.3 million euros

Adhesive Bonding Technology and Surfaces Bremen

Operating budget	13.1 million euros
Own income	9.9 million euros
Including	
Business income	7.0 million euros
Federal/state/EU/other	2.9 million euros
Investment budget	1.3 million euros

Fraunhofer-Center for Wind Energy and Maritime Engineering (CWMT) Bremerhaven

Operating budget	2.8 million euros
Own income	2.5 million euros
Including	
Business income	0.2 million euros
Federal/state/EU/other	2.3 million euros
Investment budget	2.7 million euros

Investments

During 2008, IFAM investments amounted to 5.1 million euros, split among the several departments as given below. The most important purchases are indicated.

Shaping and Functional Materials Bremen (0.8 million euros)
- Laboratory planetary mixer PMS 0.2
- Application technology for conductive polymers
- Mini-VERL
- Mass spectrometer GAM 200
- Vertical vibratory conveyor for bulk material
- Induction furnace

Shaping and Functional Materials Dresden (0.3 million euros)
- HF-generator
- Modular high-performance rheometer

Adhesive Bonding Technology and Surfaces (1.3 million euros)
- C-Frame riveting machine
- Conditioning cabinet WK3-180/70-UKA
- Coating machinery
- Coatema deskcoater
- Atmospheric pressure plasma polymerisation device for local chemical vapour deposition

Fraunhofer-Center for Wind Energy and Maritime Engineering (CWMT) Bremerhaven (2.7 million euros)
- Two beam test benches
- Coupon test bench
- Measurement achiving system for the 90 m rotor blade test bench

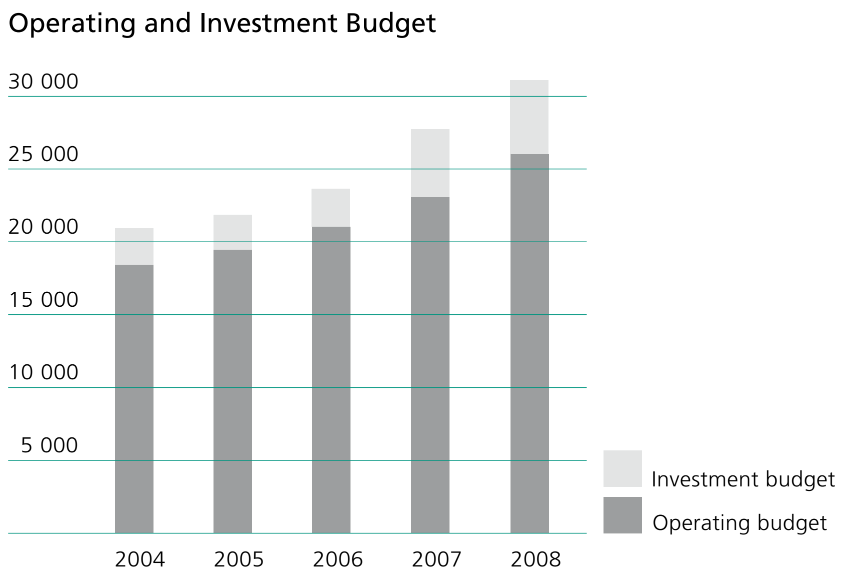


Fig. 1: Total expenditure of IFAM (BHH and IHH).

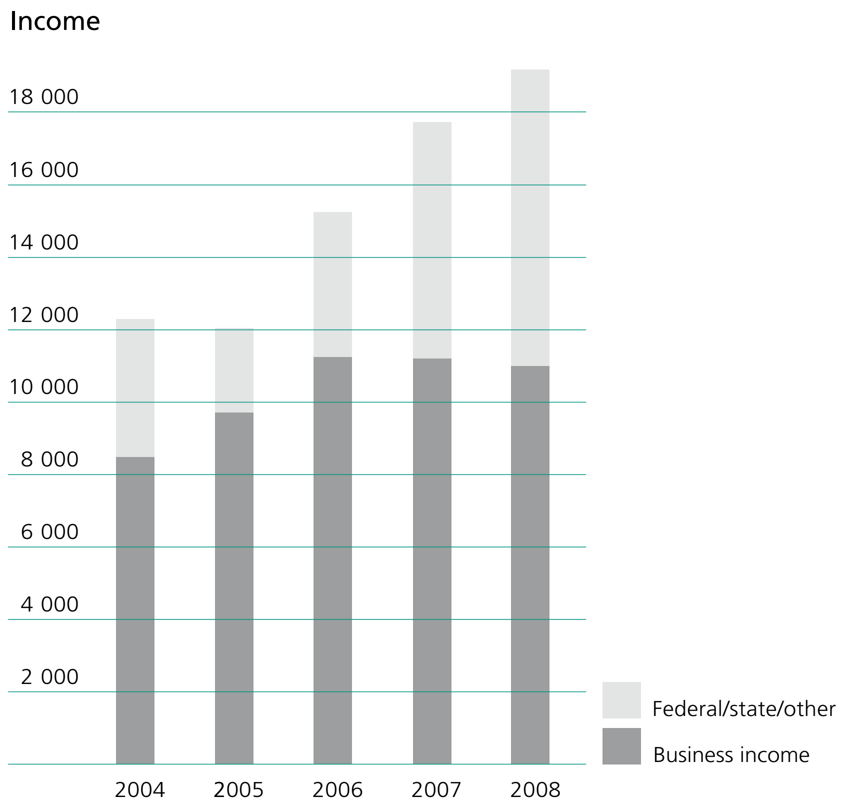


Fig. 2: Total income (BHH) of IFAM.

Workforce

On December 31th, 2008 IFAM employed a total of 379 people (89 percent of which in scientific/ technical areas).
Compared to the previous year, the number of permanent employees rose by 9 percent.

Workforce Structure 2008

Scientists	161
Technical employees	87
Administration/internal services and trainees	41
Ph.D. students, interns and auxiliary staff	90

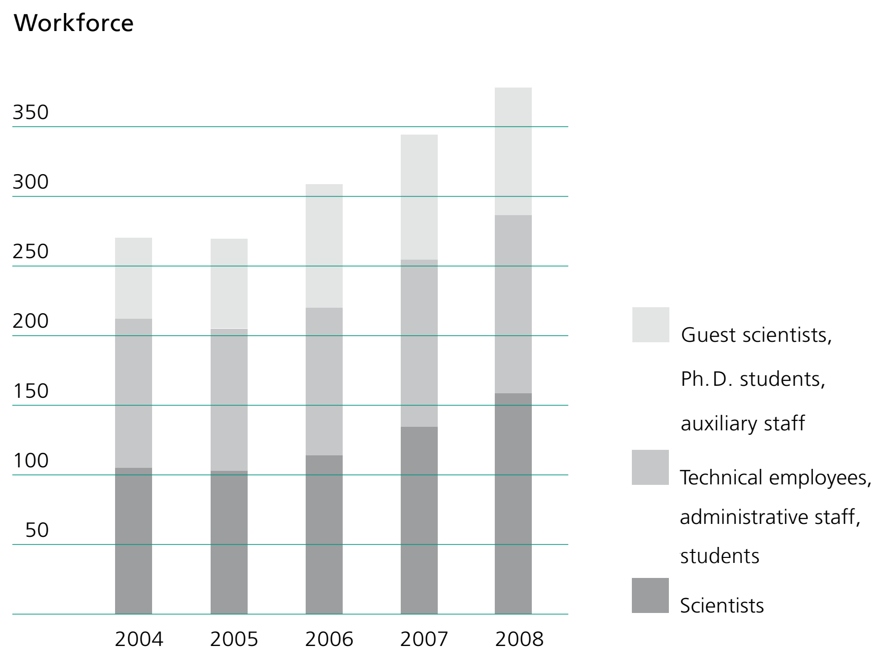


Fig. 3: Total number of employees at IFAM.

The IFAM Advisory Board

Members

A. Picker (until end of June 2008)
Chairman
Henkel Adhesives Technologies
Japan, Tokyo

Prof. Dr. J. Klenner (starting June 2008)
Chairman
Airbus S.A.S.
Toulouse, Frankreich

Dr. R. Bacardit
Henkel AG & Co. KGaA
Düsseldorf

K. Dröder
Volkswagen AG
Wolfsburg

Prof. Dr. M. Dröscher
EVONIK Degussa GmbH
Essen

Prof. Dr. O. R. Fischer (until end of July 2008)
Deutsche Forschungsgemeinschaft
Bonn

Prof. Dr. R. X. Fischer
University of Bremen
Bremen

M. Grau
Mankiewicz Gebr. & Co.
Hamburg

Dr. S. Kienzle
Daimler AG
Ulm

Dr. J. Kurth
KUKA Roboter GmbH
Augsburg

R. Nowak
Glatt GmbH
Binzen

Staatsrat C. Othmer
Senator of Science and Education
of the Hanseatic City of Bremen
Bremen

Dr. R.-J. Peters
VDI-Technologiezentrum GmbH
Düsseldorf

Dr. R. Rauh
Airbus Deutschland GmbH
Bremen

J. Tengzelius M. Sc.
Höganäs AB
Höganäs, Schweden

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

Dr. G. Wolf
VDG Verein Deutscher Gießereifachleute
Düsseldorf

MinRat Dr. R. Zimmermann
Saxon State Ministry
of Science and Arts
Dresden

Research in Turbulent Times

The Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM again looks back on a very successful year – despite the fact that times have obviously become more complicated. The excellent achievements of all the departments and the success in the Department of Shaping and Functional Materials result from the outstanding commitment of the employees and the top management. IFAM is in a tip top shape and can thus meet the challenge of the future well-prepared.

In the coming years, the basic conditions will become more disadvantageous. After a long phase of steady growth, the crisis in the financial sector has resulted in a critical situation. We can only hope that these turbulent times do not encroach to much upon the economy and industrial sector as well as the closely related applied research. Consequences like the freezing of manufacturing rates or even the temporary interruption of production have just been put on the agenda. Politicians are attempting to counterbalance the negative trends in order to keep them from worsening. But at the moment, it is of primary importance that the decision makers in the economic sphere – despite the negative circumstances – look forward and prepare for "the period after". In these endeavours, research and development should be given special attention.

The crisis in finance is repeating the lessons of the environmental and globalisation crises: It is absolutely necessary to enhance technologies through research in order to cope with the requirements of the future. In this field, we cannot hide in a "virtual" world. Here, in reality, many creative ideas and disciplined work show measurable results that protect the environment and preserve resources, yield higher earnings, improve safety and convenience, and enhance competitiveness. Here, IFAM makes – and will continue to make – an essential contribution to the future. Progress in technological development cannot be obtained for nothing; rather, this process is very expensive.

Responsible managers in policy and industry can have a great impact by making the necessary R&D investment in economically difficult times. Only investment in this sector will guarantee the future for all of us. In this field, it is fairly easy to convince customers to invest in application-oriented and order-based research characterized by a relatively rapid "return on investment". It is more difficult to interest customers in longer-term research, and, still more critical, in the required education and development of the scientists and engineers of the future. But this is exactly what is needed to create the preconditions for successful development in the long term.

As a trustee, I am confident that IFAM will be flying through this "patch of bad weather" and will emerge from the situation that lies ahead even stronger than it was before.

Prof. Dr. J. Klenner
Chairman Advisory
Board Airbus S.A.S.
Toulouse, France.

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 promotes 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 57 Fraunhofer Institutes. The majority of the 15,000 staff are qualified scientists and engineers, who work with an annual research budget of € 1.4 billion. Of this sum, more than € 1.2 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.

Fraunhofer Materials and Components Group

Material research within the Fraunhofer-Gesellschaft covers the entire value chain, from the development of new materials and the enhancement of existing ones, to industrial-scale manufacturing technology, characterization of material properties and evaluation of material behavior when employed in components and systems.

The group concentrates its expertise primarily on fields of activity that are important to the national economy: energy, health, mobility, information and communication technology, construction and housing. It promotes the use of novel, customized materials and components as a means of implementing innovative systems.

Core competencies

- Materials – design and characterization
- Modeling and simulation
- Technological development (production, processing and test methods)
- Assessment of the materials, components and systems characteristics of use

Business areas

- Energy
- Health
- Mobility
- Information and communication technology
- Construction and housing

Contact persons

Chairman of the Group:
Prof. Dr.-Ing. Holger Hanselka
Fraunhofer Institute for Structural Durability and System Reliability LBF
Bartningstrasse 47
64289 Darmstadt

Deputy Chairman:
Prof. Dr.-Ing. Peter Elsner
Fraunhofer Institute for Chemical Technology ICT
Joseph-von-Fraunhofer-Strasse 7
76327 Pfinztal

Central Office:
Dr. phil. nat. Ursula Eul
Phone: +49 6151 705-262
ursula.eul@lbf.fraunhofer.de
Fraunhofer Institute for Structural Durability and System Reliability LBF
Bartningstrasse 47
64289 Darmstadt

www.werkstoffe-bauteile.de

Members
Fraunhofer-Institutes: EMI, IAP, IBP, ICT, IFAM, IKTS, ISC, ISE, ITWM (guest), IWM, IZFP, LBF, WKI

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.

Business areas

- Materials and components
- Numerical and experimental methods
- Electronics and control engineering
- Systems

Contact persons

Spokesman of the Alliance:
Prof. Dr.-Ing. Holger Hanselka
Director of the Fraunhofer Institute for
Structural Durability and System Reliability LBF
Bartningstrasse 47
64289 Darmstadt

Managing director:
Dr.-Ing. Tobias Melz
Phone: +49 6151 705-236
Fax: +49 6151 705-214
info@adaptronik.fraunhofer.de
Fraunhofer Institute for Structural Durability
and System Reliability LBF
Bartningstraße 47
64289 Darmstadt

Members
Fraunhofer-Institutes EMI, IAIS, IIS, IKTS, IFAM, ISC, IST, ITWM, IWM, IWU, IZFP, LBF

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, while ultra-thin coatings are an important element in data storage media. The technology is already in use for a wide variety of applications across all sectors of industry, generating a worldwide sales volume of 80 to 100 billion euros.

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

Business areas (crosscutting technologies)

- Nanomaterials/nanochemistry
- Nano optics/electronics
- Nanobiotechnology
- Modeling/simulation
- Manufacturing technologies, handling

Contact persons

Spokesman of the Alliance and head of central office:
Dr. Karl-Heinz Haas
Phone: +49 931 4100-500
Fax: +49 931 4100-559
karl-heinz.haas@isc.fraunhofer.de
Fraunhofer Institute for Silicate Research ISC
Neunerplatz 2
97082 Würzburg

Deputy Spokesman of the Alliance
Priv.-Doz. Dr. Günter Tovar
Phone: +49 711 970-4109
Fax: +49 711 970-4200
Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
Nobelstrasse 12
70569 Stuttgart

Members
Fraunhofer-Institutes IAO, IAP, ICT, IFAM, IFF, IGB, IISB, IKTS, IOF, IPA, ISC, ISE, ITEM, IWM, IWS, IZFP, IZM, LBF, TEG, UMSICHT

Fraunhofer Polymer Surfaces Alliance (POLO)

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

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

Business areas

- Coatings acting as barriers against gases and vapors
- Surfaces affording mechanical protection
- Composites with oxygen indicators and oxygen scavengers
- Antistatic coatings
- Surfaces with antimicrobial properties

Contact person

Spokeswoman of the Alliance and head of the central office:
Dr. Sabine Amberg-Schwab
Phone: +49 931 4100-620
Fax: +49 931 4100-698
sabine.ambergschwab@isc.fraunhofer.de
Fraunhofer Polymer Surfaces Alliance
Neunerplatz 2
97082 Würzburg

Members
Fraunhofer-Institutes FEP, IAP, IFAM, IGB, IPA, ISC, IVV

Fraunhofer Photocatalysis Alliance

Photocatalytic active coating systems with self-cleaning, anti-bacterial, 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.

Business areas

- Switchable coatings
- Coatings for indoor applications
- Coatings on glass and ceramics
- Coatings on plastics
- Analytical techniques and activity measurement
- Biocompatibility testing and environmental impact assessment

Contact persons

Spokesman for the Alliance:
Dr. Michael Vergöhl
Phone: +49 531 2155-640
Fax: +49 531 2155-900
michael.vergoehl@ist.fraunhofer.de
Fraunhofer Institute for Surface Engineering and Thin-Films IST
Bienroder Weg 54 E
38108 Braunschweig

Public Relations and Marketing:
Dr. Simone Kondruweit
Phone: +49 531 2155-535
Fax: +49 531 2155-900
simone.kondruweit@ist.fraunhofer.de
Fraunhofer Institute for Surface Engineering and Thin Films IST
Bienroder Weg 54 E
38108 Braunschweig

Members
Fraunhofer-Institutes FEP, ICT, IFAM, IGB, IME, ISC,ISE, IST

Fraunhofer Numerical Simulation of Products, Processes Alliance

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

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

The object of the alliance is to address institute-overarching issues and to represent the interests of the member institutes as a central point of contact with the 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.

Business areas

- Numerical methods and software engineering
- Materials modeling and component simulation
- Simulation of manufacturing methods and production processes
- Simulation in surface engineering, photonics and microelectronics

Contact person

Spokesman of the Alliance and head of the central office:
Andreas Burblies
Phone: +49 421 2246-183
Fax: +49 421 2246-77183
andreas.burblies@ifam.fraunhofer.de
Fraunhofer Institute for Manufacturing Engineering and Applied Materials Research IFAM
Wiener Strasse 12
28359 Bremen

Members

Fraunhofer-Institutes EMI, FIRST, IFAM , IGD, IIS-EAS, IKTS , ILT , IPA , IPK , IPT , ISC , IST , ITMW, IWM, IWS, IWU, IZFP, LBF, SCAI, UMSICHT

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.

Business lines

- Cleaning of buildings
- Cleaning in hygiene-relevant areas
- Cleaning in microsystems engineering
- Surface cleaning before coating
- Cleaning of components

Contact person

Spokesman of the Alliance:
Dipl.-Ing. Mark Krieg
Phone: +49 30 39006-159
Fax: +49 30 3911037
mark.krieg@ipk.fraunhofer.de
Fraunhofer Institute for Production Systems and Design Technology IPK
PascalStrasse 8-9
10587 Berlin

Members

Fraunhofer-Institutes FEP, ICT, IFAM, IFF, IGB, ILT, IPA, IPK, IST, IVV, IWS

Fraunhofer Construction Alliance

The institutes united in the Fraunhofer Construction Alliance want to make us of the great innovation potential of the building industry. The Fraunhofer Construction Alliance offers experience in single source responsibility in the form of integral system solutions. The Alliance's portfolio not only covers a methodological consideration of buildings – from material , component, space, building up to the settlement – , but also a chronological analysis of a building's entire life cycle, from its first conception up to its recycling.

Beginning with the building process chain via construction materials and systems all the way to the conversion and destruction of buildings, there are also opportunities available for rationalization and optimization potentials.

In an era of exploding energy prices, energy efficiency of buildings, both for private and industrial use, is an important issue. However, the technical focus of the Construction Alliance clearly goes beyond just that. The task is to guarantee sustainability, conservation of resources and health compatibility both of construction and of habitation, and to find solutions for product-, system- and process optimization. Research in the construction domain has interfaces with Fraunhofer know-how in the research domains of Energy, Information- and Communication technologies, Materials and Components, Life Sciences, Production, Microelectronics, as well as research for Defence and Safety.

Subject areas

- Product development
- Components, construction systems, buildings as holistic systems
- Software
- Construction flow, construction planning, logistics, construction plant, life cycle consideration of a building
- International projects, construction in other climate zones

Targets of the Fraunhofer Construction Alliance

Recent customers from the construction industry have made greater demands in terms of convenience, energy efficiency, power support and sustainability. The Fraunhofer Construction Alliance creates synergies between the institutes involved that enable customers to equip their products with value added services. The Fraunhofer scientists work in teams to develop new and innovative technologies pertaining to "Construction". Thus, the Fraunhofer specialists support building companies in any problems, from the selection of the suitable planning software to recycling of building materials.

Contact persons

Spokesman for the alliance:
Prof. Dr. Klaus Sedlbauer
Phone: +49 8024 643-243
Fax: +49 8024 643-366
klaus.sedlbauer@ibp.fraunhofer.de
Fraunhofer Institute for Building Physics IBP
Fraunhoferstrasse 10
83626 Valley/Oberlaindern (Holzkirchen)

Deputy Spokesman for the alliance:
Prof. Dr. Peter Elsner
Phone: +49 721 4640-401
peter.elsner@ict.fraunhofer.de
Fraunhofer-Institute for Chemical Technology ICT
Joseph-von-Fraunhofer-Strasse 7
76327 Pfinztal

Central Office:
Andreas Kaufmann
Phone: +49 8024 643-240
Fax: +49 8024 643-366
andreas.kaufmann@ibp.fraunhofer.de
Fraunhofer Institute for Building Physics IBP
Fraunhoferstrasse 10
83626 Valley/Oberlaindern (Holzkirchen)

Members
Fraunhofer-Institutes: IBP, EMI, AO, ICT, IFAM, IGB, IMS, IRB, ISC, ISE, LBF, UMSICHT, WKI

Fraunhofer Rapid Prototyping 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 Rapid Prototyping 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.

Competencies

- Engineering
  - Design and development
  - Integration and reduction
  - Simulation

- Technologies
  - Printing techniques
  - Laser-based procedure
  - Process chains and series production

- Materials
  - Metals
  - Ceramics
  - Polymers

- Quality
  - Process quality
  - Product quality
  - Quality management systems

Business areas

- Rapid for Design / Design for Rapid
- Rapid Engineering
- 3-D Digitizing and Reverse Engineering
- Virtual Reality and Simulation
- Rapid Prototyping
- Rapid Tooling
- Rapid Manufacturing
- Rapid Repairing
- Rapid Testing und Quality Management

Contact person

Spokesman of the alliance:
Andrzej Grzesiak
Phone: +49 711 970-1746
Fax: +49 711 970-1004
info@rapidprototyping.fraunhofer.de
Fraunhofer Alliance Rapid Prototyping
Nobelstrasse 12
70569 Stuttgart

Members

Fraunhofer-Institutes: IFF;IFAM, IKTS, ILT, IPA, IPT, UMSICHT; IWM, IZM

Fraunhofer Technology Academy

The Fraunhofer-Gesellschaft is the leading organization for application-oriented research in Europe and is driving innovation for industry. To promote the successful implementation of innovations in industry, the Fraunhofer-Gesellschaft systematically relies on order-oriented research for industry, spin-offs of companies and transfer of personnel. Now the Fraunhofer Technology Academy is extending this range by offering professional qualification for specialists and managers.

The perfect interaction between management and the use of innovative technologies is the key to success today. At the Fraunhofer Technology Academy, we offer qualified candidates the opportunity to learn the fundamental tools necessary to work in a world characterized by innovation. In cooperation with excellent partners from university, participants may acquire recognized certificates and diplomas – from certificates of qualification to various master's degrees.

The Fraunhofer-Gesellschaft contributes to creating a new German culture of innovation with this qualification service. The goal is to qualify specialists and managers so that they can develop new, refined, unique products, as well as innovative techniques and services.

The Fraunhofer Technology Academy makes available knowledge from innovative fields of technology, know-how that will be relevant in future markets. The close connection between research and practice and the constant feedback from market development make the courses optimally tailored to the participants. Here, the Fraunhofer Technology Academy is concentrating on the areas of technological knowledge and technology management.

Cooperation partners

University of St. Gallen and the Rhenish-Westfalian polytechnical institute (RWTH) Aachen

Contact person

Fraunhofer-Gesellschaft
Dr. Roman Götter
Phone: +49 89 1205-1116
roman.goetter@zv.fraunhofer.de
Hansastrasse 27C
80686 München

Members
Involved institutes: Center for Adhesive Bonding Technology at the IFAM, IML, IWS, UMSICHT

Fraunhofer Network for Wind Energy

Finding a sustainable energy supply through renewable energy resources is regarded as the 21st century's major task for the future. From a quantitative energy economy perspective, wind energy is globally important for network-bound large turbines. Even today, wind energy is economically competitive and has created a significant market for itself.

The Fraunhofer Network for Wind Energy is the entry into this market. As the greatest organization for applied research in Europe, the Fraunhofer-Gesellschaft has made it its business to strengthen the innovative potential of wind energy. The Fraunhofer institutes present a unique variety of cutting edge research and services – from feeding wind energy into the European integrated network up to the management of individual wind power stations in the local energy system, via equipment simulation, – control and maintenance up to the development and testing of materials and components.

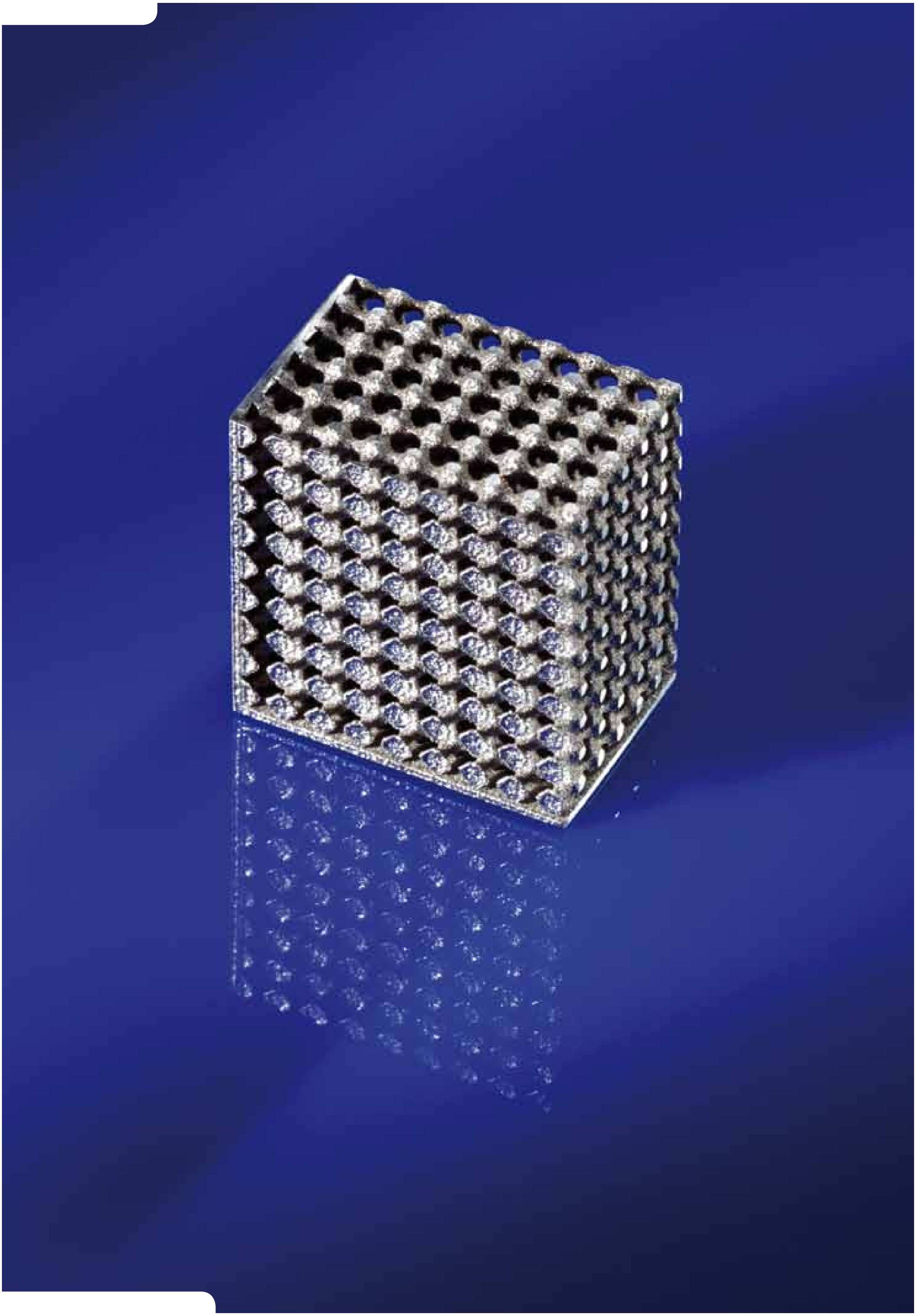
The engineering and management of wind power stations, as well as their integration into the power supply system, are sophisticated tasks. For this reason, the Fraunhofer Energy Alliance created the Fraunhofer network for wind energy in cooperation with six other Fraunhofer institutes from materials research, operational safety, simulation and power electronics. Altogether, ten institutes provide an integrated range of services and competencies to dimension and operate energy systems with coupled wind turbines.

In the field of research and development, the provided services include not only wind energy forecasts on various time scales, load management methods and techniques for dimensioning the supply system, but also algorithms for master control- and communication systems and simulation tools, as well as non-destructive testing techniques for machinery components.

Contact person

Coordination Fraunhofer Network for Wind Energy:
Dr. Mario Ragwitz
Phone: +49 721 6809-157
info@windenergie.fraunhofer.de
Fraunhofer-Institute for Systems and
Innovation Research ISI
Breslauer Strasse 48
76139 Karlsruhe

Members
Fraunhofer-Center for Wind Energy and Maritime Engineering CWMT, Fraunhofer-Application Center Systemtechnology IITB/AST, Fraunhofer-Institutes IFF, IIS/EAS, ISE, ISI, ITWM, IZFP



Department of Shaping and Functional Materials

Results Applications Perspectives

Laser design structures made of stainless steel.

Expertise and Know-how

Transferring application-oriented fundamental research into solutions that are to be implemented in production engineering or projects focussed on component engineering is a task demanding a constantly expanding knowledge base and procedural competency. For this reason, the continuous expansion of IFAM-specific experiences and know-how at the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research's Department of Shaping and Functional Materials is a top priority. Based on our core competencies, such as powder – and sintering technologies, casting- and light metal technology, as well as micro- and nanotechnologies, we develop innovative and profitable solutions for our customers.

Networks of partners from industry and research facilities are playing a more and more important role in finding complex system solutions. Above all, procedural expertise and excellent technical knowledge are required at the interfaces of various disciplines. The expertise of the IFAM employees and their networking activities with partners from industry and science guarantee that innovative solutions for industry can be generated.

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

Multifunctional components fitted with integrated sensor functions make special demands on the materials used. Compounds of various materials in one component make it possible to optimize properties according to the customers' needs. To expand expertise, designing these material combinations and dealing with them in manufacturing processes is a major task. Possible combinations range from metal-metal to metal-ceramic all the way to combinations with CRFP.

Manufacturing techniques such as injection moulding are currently used 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 it is possible to integrate materials' characteristics, such as hard-soft, dense-porous materials, or to integrate materials with sensory capabilities or even high-cost and low-cost materials into components in a manner tailored to a specific purpose. This development is of particular importance in the manufacturing of microcomponents, where integrated manufacturing solutions like these make microassembly unnecessary.

Formulations for functional inks and pastes, as well as knowledge of their application to components, were re-determined in order to develop an intelligent printing technology under the trademark of "INKtelligent printing®". Thus, we are able to equip components with sensors, and, in turn, e.g. to record operational or environmental conditions.

IFAM has established itself in this market with state-of-the-art foundry equipment and analysis, as well as comprehensive know-how in processing aluminum and magnesium alloys with die casting. We not only optimize casting processes using a permanent mould, but are also constantly refining our expertise in the Lost Foam casting procedure. Our latest development, called "CAST$^{tronics®}$", follows a technological approach that enables the foundries to autonomously integrate functional components directly during the casting procedure.

We have achieved a high level of expertise in implementing cellular metallic materials in products. Here we find special solutions for specific markets, such as the Diesel particle filter. Consequently, our process knowledge is always increasing.

Perspectives

Our own portfolio of research topics 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 the environment.
Materials and their manufacturing/ processing in all product innovations are an essential factor in our future success. This aspect is to be particularly emphasized for the primary shaping methods, since in the manufacturing process, one

may simultaneously affect both the 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, and manufacturing technologies to integrate characteristics into the components are developed. Improvement in materials and expertise in the specialised realm of functional materials, such as thermal management materials, thermoelectrical and magnetocaloric materials, as well as nanocomposites, open up new opportunities for product development, both with previous and new customers.

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 future, the area of medical engineering and biomaterials will be further explored. Here we are establishing close relationships within the network of partners from institutions with complementary expertise, as well as business enterprises and hospitals. Subjects being investigated range from the Rapid Manufacturing process chain and the production of one-of-a-kind metallic components to targeted surface structuring of surfaces for cell growth management. Here, the materials to be applied include all material classes, from plastics to ceramics, up to metals and their compounds. New projects are focussed on materials- and manufacturing technologies, as well as the interface between biology and material.

The broad potential for direct integration of functions into metallic components, as well as CFRP components, is being made accessible due to steadily expanding know-how at IFAM, within the process chain from material to the intelligent component. To continue this, product-specific solutions for different business lines must also be developed. Quality inspections within the production process are of growing interest for cyclical manufacturing of metallic components. To grapple with this demanding problem, we at IFAM are gathering procedural expertise in order to link self-learning systems with the corresponding manufacturing technique.

Composite material as granulate and rods.

A major new subject investigated at Fraunhofer IFAM is that of electrical drive engineering, with both energy storage and system audit. In close cooperation with partners from the metropolitan region Nordwest, we are elaborating new battery systems and building up an experimental infrastructure for complete electrical driving concepts.

Fields of Activity and Contact Partners
Managing director Prof. Dr.-Ing. Matthias Busse

Bremen

Powder Technology
Powder-metallurgical shaping; warm compaction for manufacturing highly dense sintered components; metal powder injection moulding; 2-component injection moulding; process and material development; rapid manufacturing; laser sintering; screen-printing; simulation.
Dr.-Ing. Frank Petzoldt
Phone: +49 421 2246-134
frank.petzoldt@ifam.fraunhofer.de

Functional Structures
Nanocomposites; nanosuspensions; nanoporous layers; functional integration; INKtelligent printing®: ink-jet-printing, aerosol-printing (M³D®); specialty equipment.
Dr. rer. nat. Volker Zöllmer
Phone: +49 421 2246-114
volker.zoellmer@ifam.fraunhofer.de

Micro Engineering
Micro injection moulding for metals and plastics; nanocomposites; micro-structuring; series production of miniature components; 2-component injection moulding for micro components; microreaction technology; microfluidics.
Dr.-Ing. Frank Petzoldt
Phone: +49 421 2246-134
frank.petzoldt@ifam.fraunhofer.de

Lightweight Structures and Analysis
Cellular lightweight components; functional, open-porous metal foam structures; aluminum foam sandwich structures; production processes for metal foam components.
Dr.-Ing. Gerald Rausch
Phone: +49 421 2246-242
gerald.rausch@ifam.fraunhofer.de

Casting Technology
Zinc, aluminum and magnesium pressure diecasting; functional integrated casting components (CAST^tronics®); thixocasting; pressure diecasting moulds; lost-foam processes; sand casting; simulation; rapid prototyping.
Dipl.-Ing. Franz-Josef Wöstmann
Phone: +49 421 2246-225
franz-josef.woestmann@ifam.fraunhofer.de

Biomaterials Technology
Processing and characterization of biomaterials; injection moulding; extrusion and micro-structuring; metals, bioceramics, polymers and nanocomposites.
Prof. Dr.-Ing. Kurosch Rezwan
Dr.-Ing. Philipp Imgrund
Phone: +49 421 2246-216
philipp.imgrund@ifam.fraunhofer.de

Service centers and contact persons

Application Center for Metal Powder Injection Moulding
Dipl.-Ing. Lutz Kramer
Phone: +49 421 2246-217
forming@ifam.fraunhofer.de

Application Center for Functional Printing
Dr.-Ing. Dirk Godlinski
Phone: +49 421 2246-230
printing@ifam.fraunhofer.de

Application Center for Rapid Prototyping
Dipl.-Ing. Claus Aumund-Kopp
Phone: +49 421 2246-226
rapid@ifam.fraunhofer.de

Application Center for Function-Integrated Cast Components
Dr.-Ing. Jörg Weise
Phone: +49 421 2246-125
casting@ifam.fraunhofer.de

Service Center for Materialography and Analysis
Jürgen Rickel (until 31.12.2008)
Dr.-Ing. Andrea Berg (starting 1.1.2009)
Phone: +49 421 2246-146
andrea.berg@ifam.fraunhofer.de

Demonstration Center SIMTOP
Numerical Simulation Techniques for Process and Component Optimization.
Andreas Burblies
Phone: +49 421 2246-183
info@simtop.de

Dresden

Powder Metallurgy and Composite Materials
Prof. Dr.-Ing. Bernd Kieback
Phone: +49 351 2537-300
Fax: +49 351 2537-399
Address: Winterbergstrasse 28
01277 Dresden
www.ifam-dd.fraunhofer.de

Cellular Metallic Materials
Fibre metallurgy; high porosity structures; metallic hollow sphere structures; open cell PM foams; screen-print structures; applications for e. g. lightweight structures; crash-absorbers; heat exchangers; catalyst support materials.
Dr.-Ing. Günter Stephani
Phone: +49 351 2537-301
guenter.stephani@ifam-dd.fraunhofer.de

Sinter and Composite Materials
High temperature materials; aluminides (NiAl-foam); nano-crystalline materials; materials for tribological exposure; sputter targets; modification of powders; materials for hydrogen storage.
Dr.-Ing. Thomas Weißgärber
Phone: +49 351 2537-305
thomas.weissgaerber@ifam-dd.fraunhofer.de

Service center and contact person

Demonstration Center for Cellular Materials
Dr.-Ing. Günter Stephani
Phone: +49 351 2537-301
guenter.stephani@ifam-dd.fraunhofer.de

Equipment/Facilities

Component Manufacturing

- Metal powder injection moulding units (clamping force 20 tons and 40 tons)
- Manufacturing cell for micro injection moulding
- Hot press (vacuum, inert gas, 1800 °C)
- Uniaxial powder presses (up to 1000 tons)
- Powder press for heat compaction (125 t)
- Extruder (5 MN)
- Rapid prototyping systems for laser sintering, and 3-D printing
- Cold chamber die casting machine (real-time control, closing force 660 tons);
- Hot chamber die casting machine (real-time control, closing force 315 tons)
- Pilot plants to manufacture metal foam components
- 2-component injection moulding machine
- Microwave sintering furnace
- Screen printing machine
- Model manufacturer for lost foam processes
- Spark Plasma Sintering unit (up to 300 mm part diameter)
- Styrofoam mortiser
- Hot wire cutting machine

Micro- and Nanostructuring

- Ink-Jet-Printing-Technologies
- Aerosol jet printing-technology (Maskless Mesoscale Material Deposition M³D®)
- Micromanufacturing cell
- Four-point-bend stand
- Ink test stand – Drop on demand
- Sputtering technology

Heat/Chemical Treatment of Mouldings

- Unit for chemical de-waxing of injection moulded parts
- Several sintering furnaces (up to 2400 °C, inert gas, hydrogen, vacuum)

Material Synthesis and -processing

- Systems for gradient material production (sedimentation, wetpowder injection)
- Systems for metal nanopowder and nanosuspension production
- Test stand to characterize functional inks for inkjet printing methods
- Melt extraction unit (metal fibres)
- 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

Twin screw extruder.

Instrumental Analytics

- FE scanning electron microscope with EDX
- X-ray fine structure analysis
- Insulation resistance
- Thermonanalysis DSC, DTA, TGA
- Sintering-/ Alpha dilatometry (accredited lab)
- Powder measuring equipment with BET surface and laser granulometry device
- Rheometry
- Analysis of trace elements (C, N, O, S)
- Materialography
- Emission spectrometer for elemental analysis of Al, Mg and Zn alloys
- Micro tensile testing equipment
- X-ray tomograph (160 kV)
- Tensiometer
- Analysis of particle size
- 2-D/3-D laser surface profilometry
- Thermal conductivity measurement of moulding materials
- Determination of moulding materials' permeability to gas
- IR laser to determine density of translucent materials

Computers

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

Biomaterials Technology – a New Range of Expertise at Fraunhofer IFAM

Motivation

In recent years, biomaterials have gained significant importance in many technical applications. Biological interactions between materials and their biological environment have increasingly moved into the foreground in medical technology and a number of further application areas, such as environmental engineering, micro technology and energy management. The need for new materials, processes and technical systems that take into account biological functions will grow further, driven by the variety of requirements arising in the 21st century. The materials to be applied include all material classes – from polymers to ceramics, metals, and alloys. Based on the existing experience of the Department of Micro Engineering, the Biomaterials Technology department will focus on the development of materials, manufacturing techniques and system concepts in the biomaterials field. In the department's new orientation, the basic competencies in manufacturing metal and polymer micro parts and micro structured surfaces by micro injection moulding will be strengthened through close cooperation with the Bioceramics group at the University of Bremen. The latter contributes broad expertise in processing and use of ceramic materials in medical and environmental engineering. The close cooperation and, in turn, further strengthening of the team in the department of Biomaterials Technology comprehensively expands the existing manufacturing know-how towards understanding the interactions between materials and their biological environment.

Current Projects

The new focus towards Biomaterials Technology is based on a broad experience in materials and manufacturing technology gained through various projects in the field of medical and environmental engineering. To exemplify, two current projects are described in the following, which reflect the new orientation to future work areas.

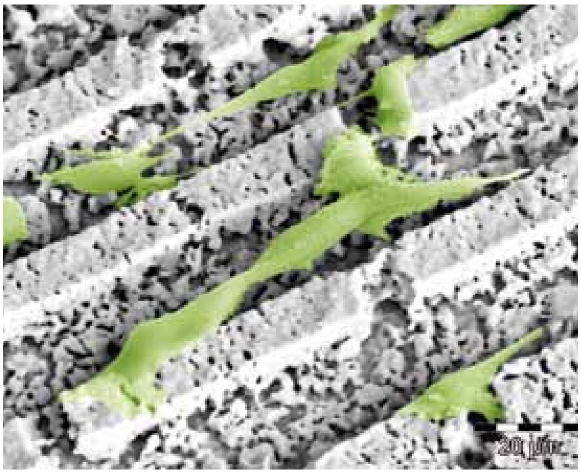


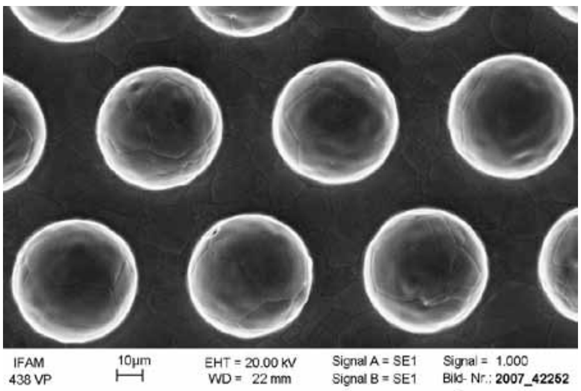
Fig. 1: Bone cells in ceramic micro channels - image taken with a scanning electron microscope – to investigate innovative bone substitute materials (Research group of bioceramics, University of Bremen).

Functionalizing Implant Surfaces by Combined Micro- and Nanostructuring

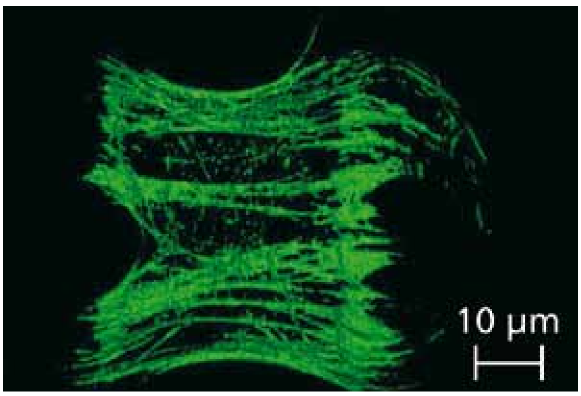
The project entitled "Nano Metal Injection Moulding for the Functionalization of Metal Surfaces" is aimed at developing an innovative technique to manufacture functional micro- and nano structured surfaces in an integrated manner. The new process is based on the metal injection moulding technique (MIM); additionally, it comprises the use of nano powders as well as defined new sintering strategies for biocompatible materials with respect to their application as implants. Thus, a new and low-cost production process for bioactive metallic implants is to be developed. Bioactivity is to be realized by a combined method of surface micro- and nano structuring. For micro structuring of the sample surfaces, a hexagonal layout of hemispheres with diameters from 5 to 50 micrometers, as well as an interhemisphere distance of 20 micrometers, was chosen (Fig. 2a). Biocompatible stainless steel 316L and titanium were chosen as materials for the process development. In the first year of the project duration, a processing method was developed to manufacture the corresponding feedstock under an inert atmosphere in order to minimize material contaminations. The technique allows for the preparation of feedstock that can be injection moulded with a nano powder share of 33 %. With an iron powder, it was possible to show that the preparation of feedstock with 100 % nano powder is feasible. Due to the need for complete filling of the micro structures in the moulding process and with regard to the higher percentages of the nano powder, the injection moulding procedure was optimized for the novel material by applying higher injection temperatures and injection pressures. In sintering, density values greater than 98 % of the theoretical density were achieved. The positive effect of the nano powder on the formation of the intended structure was confirmed by scanning electron microscope (SEM) and atomic force microscope (AFM) analyses. With an increasing share of nano powder in the feedstock, it was possible to reduce the sintering temperatures while obtaining sub-micrometer scale grain structures on the material surfaces. Our project partner, EMPA Materials Science and Technology in St. Gallen, checked a first batch of samples with regard to biocompatibility and bioactivity. In this check, biocompatibility as well as preferential adhesion of human bone marrow cells to the hemisphere micro structures was confirmed (Fig. 2b).

Development of Powder Injection Moulding for Nickel-Titanium

High-performance intermetallics are expected to play an increasingly important role as smart materials in future applications. The most popular representative of this material class, nickel-titanium (NiTi), may be available as a superelastic or shape memory material depending on its composition and pre-treatment. NiTi is commercially used in various actuator applications in form of wires, tubes or thin sheets. In the project "Nickel-Titanium for Biomedical and Transport applications (NiTiBiT)", powder metallurgical manufacturing processes are investigated with regard to their suitability for low cost and near-net-shape production of small-sized complex components. The project is part of the European Network of Excellence "Knowledge-based multicomponent materials for durable and safe performance (KMM)" whose consortium involves 37 international partners. Within this project, IFAM adapted the Micro-Metal Injection Moulding (µ-MIM) process to manufacturing small and complex Nickel-Titanium components. To achieve this, the entire process chain had to be adjusted to the material requirements. This involved proper selection of the powder and preparation of feedstock, setting of suitable injection moulding, debinding and sintering parameters and last but not least the appropriate characterization of the physical and mechanical properties. An essential challenge was to set the phase transition temperature from martensite to austenite, which controls the superelastic or shape memory effect in a reproducible manner. During



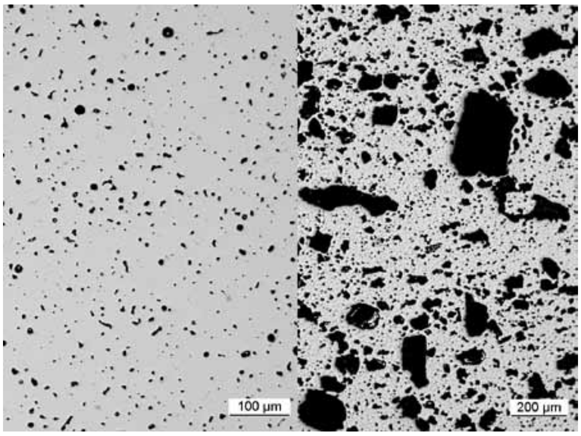
a)



b)

Fig. 2: **a)** SEM image of the micro structured surface made of stainless steel to develop new implants; **b)** Adhesion of human bone marrow at the hemispheres, Courtesy: EMPA.

a)



b)

Fig. 3: Superelastic nickel-titanium components by MIM:
a) Micro tensile test specimens and demonstrators for sealing devices, which were sintered to maximize density
b) Micrographs of fully dense and highly porous sample in comparison.

the project, the developments carried out at IFAM led to a demonstrator, which may be used as a sealing device in automotive applications (Fig. 3a). In parallel, a procedure based on space-holder methods to manufacture porous NiTi parts by MIM was defined. Figure 3b illustrates an example for a comparison of a densely sintered and porous structure. The option to manufacture components of complex shape with high porosity opens up the chance to adjust the material properties to the mechanical characteristics of human bone. This may lead to future use of Nickel-Titanium as bone replacement material. The corresponding development needs, such as setting up reproducible porosities, engineering and application of coatings, as well as the optimization and characterization of biocompatibility, are objectives that go beyond the scope of this project, but which will be addressed in future research work.

New Ranges of Application

With its scope, the Biomaterials Technology department will work within the many ranges of application in which biological functions implemented by materials and components and their technological aspects are crucial. Thus, for instance, because of demographic changes in industrialized countries, there is an urgent need for the development of innovative materials and manufacturing techniques for medical and implant technology. The new scope of the Biomaterials Technology group opens up new possibilities not only regarding the development of innovative biomaterials and related processes, but also for the characterization of biological features such as biocompatibility and cell performance of engineered components.

In the manufacturing domain, miniaturization of components and micro structuring of surfaces will remain a central topic. These can be produced at low cost through innovative material and process developments of, for example, micro fluidic systems, which are necessary for diagnostics or lab-on-a-chip systems. Concerning applications in environmental engineering and energy management, it is necessary to address manifold topics in terms of the design of interfaces between sensor or filter materials and their biological surrounding, such as cell cultures or ocean water, in order to develop more efficient systems. In environmental engineering, the so-called biofouling (contamination of material surfaces by biological molecules or organisms) is an essential industrial challenge.

With the close connection between the department of Bioceramics of the University of Bremen and the application-oriented research at IFAM, the new department of Biomaterials Technology offers its customers innovative material, process and system developments based on a solid scientific foundation. Thus, the Biomaterials Technology group is an ideal partner to quickly and skilfully carry out engineering projects in direct cooperation with industry. The strong networks among the employees, ranging from institute internal cooperations to international networks, give rise to optimal preconditions for long-term strategic joint projects with research- and industrial partners.

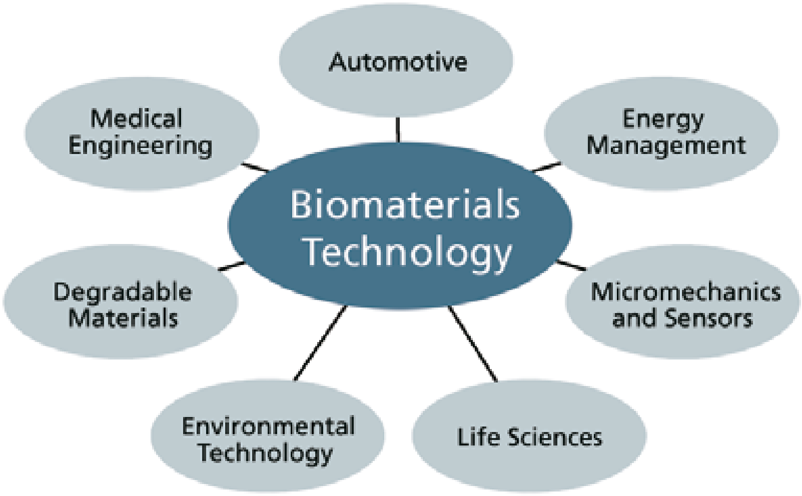


Fig. 4: Biomaterials technology - ranges of applications.

Contact persons

Prof. Dr.-Ing. Kurosch Rezwan
Phone: +49 421 218-4507
kurosch.rezwan@ifam.fraunhofer.de

Dr.-Ing. Philipp Imgrund
Phone: +49 421 2246-216
philipp.imgrund@ifam.fraunhofer.de

Institute

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

Bioprinting – Precise Printing of Biological Materials

Fig. 1: Fraunhofer IFAM employee printing biological materials.

Situation

In Genome research, it is now state of the art to put a whole laboratory on a small chip. But complex systems like these are also in demand in medical diagnostics. To use them, small detector systems, among other things, are necessary. But the sensor field can only be miniaturized if one succeeds in precisely applying biological materials to surfaces. This accurate application of biological materials is also a central prerequisite to the manufacture of small biochips. As a rule, as many experiments as possible should be carried out quickly using the minimum of space and personnel. Here we imagine anything from several hundred to thousands of biochemical reactions. Under such conditions, these characterizations on the molecular level demand sensor fields with a high spot density. To achieve this, various application methods are used, which more or less fulfil the requirements. Contactless maskless application methods offer a great potential to cope with these requirements.

The Challenge

When manufacturing biochips, biosensors or even biocompatible and bioactive implants, precise surface functionalization is significant. In addition to ongoing miniaturization, which is a central issue also in this department, surface structuring is additionally faced with greater demands. Conventional application methods have reached their limits. For this reason, we are currently exploring the inkjet printing and aerosol printing M^{3}D® technologies (Maskless Mesoscale Materials Deposition), since these techniques make it technically possible to quickly and precisely apply small structures on a wide variety of surfaces in a structured manner.

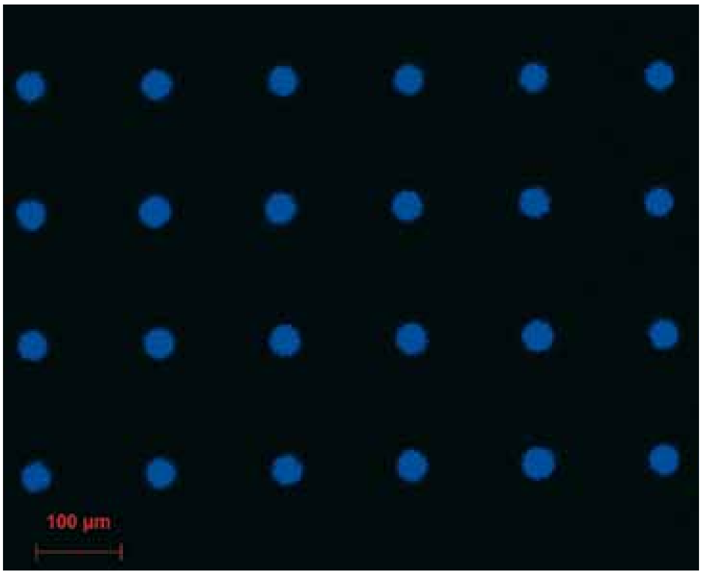


Fig. 2: Printed DNA microarray.

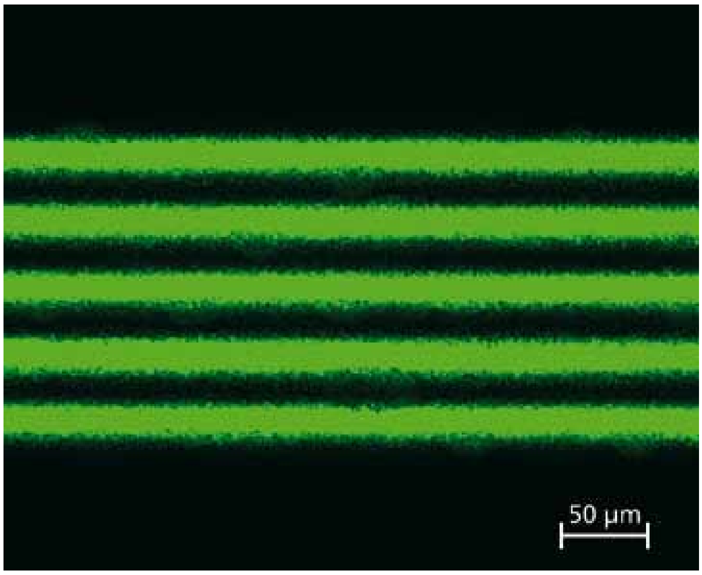


Fig. 3: Structure of linear DNA printed by means of M³D®.

In general, it is thus possible to apply biological materials, such as proteins or DNA, onto surfaces in a non-destructive way.

During inkjet printing, low volumes of the material to be printed are pressed by short pulses out of the nozzles, whereupon individual drops are formed. With an appropriate choice of the pressure parameters, one may minimise the shearing forces that appear, so that even biological materials may be printed in individual drops without any destruction. Drop size can be varied by choosing an adequate print head (for instance 1 picolitre or 10 picolitres drop size).

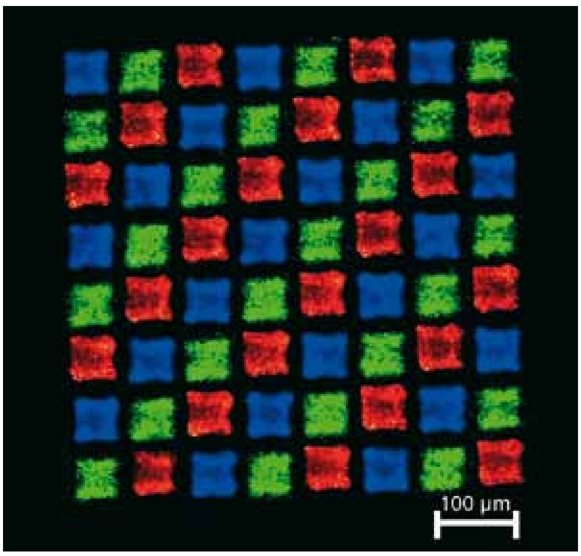


Fig. 4: Printed structure of fluorescence marked proteins.

The aerosol printing technology M³D® is also regarded as a maskless non-contacting pressing technique. In the M³D® technology, biological materials are applied on substrate surfaces with an aerosol jet. Depending on the type of aerosol generation, in this technique, shearing forces sometimes have less effect on the biological materials than in inkjet printing. Since the volume of the individual droplets – about 60 femtolitres - in the aerosol jet is very small, the M³D® technology is able to achieve a fine surface structuring of less than 10 micrometers structural width.

Research Potential

A major advantage of inkjet printing, and, above all, the M³D® technology, results from the fact that almost any material can be precisely applied on a wide variety of surfaces. The enormous variety of materials used for printing ranges from metallic to biological suspensions. Due to the demand concerning the biological surface functionalization, it is primarily the potential of the

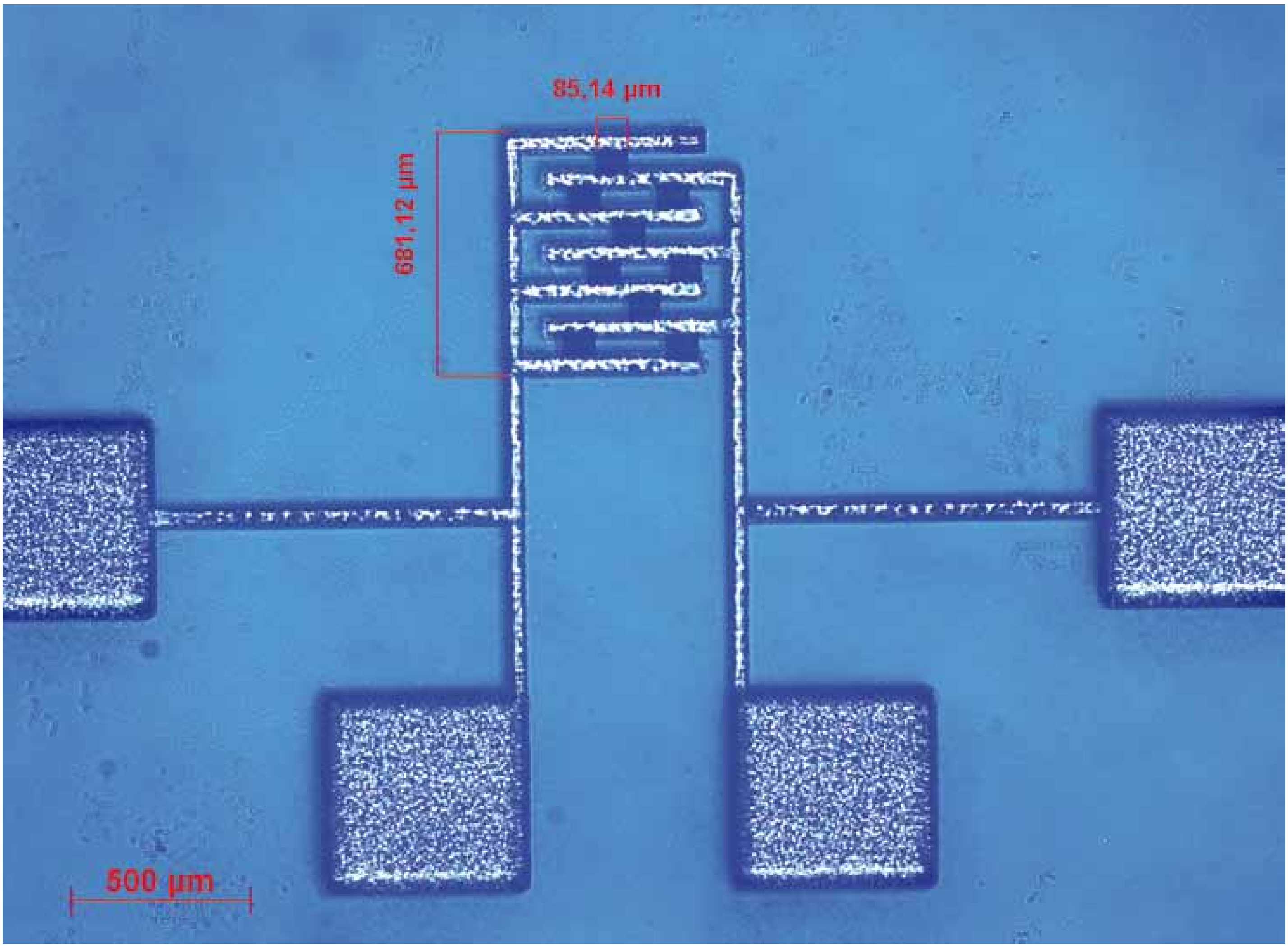


Fig. 5: Functionalized sensor structure.

M^{3}D®- and inkjet technologies in terms of their applicability for DNA-, peptide- and protein suspensions that is relevant.

Current Projects

We explored in detail both the inkjet printing- and the M^{3}D® technology with respect to possible applications in biosensors. When doing this, first the DNA and proteins were printed with printing methods. To get a better assessment of the applied structures, the proteins to be printed were marked with three different fluorescent colorants. As shown by the investigations, it was possible to target the proteins by means of M^{3}D® on the substrate surfaces without any destruction.

Furthermore, current projects demonstrate in a reproducible way that we may print DNA in a dimensional range from 100 to 10,000 alkali couples without any destruction by means of inkjet printing. We also succeeded in applying DNA printed with M^{3}D®, which was transferred into an aerosol with a pneumatic atomizer, onto the substrate surface in a non-destructive manner.

With the inkjet technology, it is possible to apply 27,700 spots per square centimetres when using a 10 picolitres printing head. With a 1 picolitre printing head, we were able to achieve spot densities of max. 40,000 spots per square centimetres. In contrast, conventional spotters frequently only achieve spot densities of less than 1,000 spots per square centimetres. With the M^{3}D® technology, even higher spot densities than in inkjet printing can be achieved.

The M^3D® technology was used for targeted sensor functionalization. To do this, first finger structures with silver- or gold ink were applied on the glass object holder. Next, small regions between the finger structures with the enzyme were overprinted with horseradish peroxidase. We were thereby able to demonstrate that the enzymes could not only survive the application by means of M^3D®, but also higher temperatures during the printing procedure without any denaturation.

Outlook

In the future, miniaturization will be used to a wider extent also to manufacture biochips and biosensors. For this reason, technologies for surface functionalization and -structurization will be used more and more; these technologies make it possible to apply biological materials on diverse surfaces in a quick, precise and low-cost manner and with a fine structure, which is necessary for the smallest biological sensors. The results gained up to now demonstrate that both the M^3D® - and the inkjet technologies are suitable for the structured application of biological materials. Both technologies have the potential to cope with the requirements, mainly concerning the quick and low-cost production of biosensors and microarrays, which are particular to diagnostics. Thus, the printing techniques introduced make it possible to apply the sensor itself immediately on various surfaces and to print the required sensor molecules.

Contact persons

Dr. Ingo Wirth
Phone: +49 421 2246-232
ingo.wirth@ifam.fraunhofer.de

Dr. Ingo Grunwald
Phone: +49 421 2246-630
ingo.grunwald@ifam.frauhofer.de

Institute

Fraunhofer Institute for
Manufacturing Technology
and Applied Materials Research IFAM,
Department of Shaping and Functional Materials,
Department of Adhesive Bonding Technology
and Surfaces,
Bremen

Design and Manufacturing of Biomimetic Materials

Fig. 1: Proximal femur (human thigh bone) with graduated bone foam structure (cancellous bone); (courtesy: Fraunhofer ILT).

Initial Situation

Material structures that follow the model of the bone foam are called biomimetic materials. Since 1981, so-called cancellous bone metals with cell sizes from 0,5 to 5 millimetres and a surface opening level of max. 70 percent, have been available on the market. They were used, for example, in hip implants. These cancellous bone metals were made by casting; in contrast to natural bone foam, they had no graduation (Fig. 1).

The living bone passes through a permanent composition- and decomposition process, which is called "Remodelling". In a healthy bone, both tendencies are in a dynamic equilibrium, so that the bone mass remains constant. This is managed by special cells in the bone: Osteoclasts for bone decomposition and osteoblasts for bone formation. The process is controlled by mechanical loads affecting the bone structure. In the last years, at Fraunhofer IFAM, a computer-based numerical optimization method (MPTO = Multi Phase Topology Optimization) was developed, which is able to simulate "Bone Remodelling" with sufficient accuracy. In this approach, materials with different density values are allocated in a space, so that maximum stiffness will appear when a predefined mechanical load impacts it. Material concentrations and -masses remain constant.

With this new numerical method, one may determine graduated cellular structures according to each load case. These cellular structures may result in a new generation of cancellous bone metals, if it proves to be technologically feasible.

Motivation and Targets

Today, rapid manufacturing techniques are able to produce components whose microstructure has previously been exactly calculated, with web widths in the submillimeter region. Starting with the three-dimensional CAD model of the intended component, we create a layer model including the necessary support structures, which is to be transferred to the manufacturing system. During the fabrication process, metallic powder is locally molten by SLM (Selective Laser Melting), using a focussed laser beam, and solidifies afterwards. We remove components of almost 100 % density without any subsequent sintering procedure. On the current market, laser melting is the process most widely in use for generative metal powder processing.

The component generated from the titanium-based light metal alloy Ti6Al4V (Fig. 2) is an example of a product with a complex inner geometry. In the implant study shown, the inner geometry contributed to weight savings while at the same time maintaining mechanical strength. Other options for the use of these inner geometries are to insert internal geometry, replicating the human bone structure, or to build reservoirs for a long-term medication. The mean-term target is to produce computer-generated cancellous bone structures that are optimized for predefined mechanical loads from the outside, by means of rapid manufacturing procedures. They are used for permanent implants and lightweight structures.

Current Projects

The MPTO method developed at Fraunhofer IFAM distributes materials of different density, initially randomly, on the two- or three-dimensional geometry of a mechanically loaded part, for example, on a femur during walking (Fig. 3). Afterwards, a Finite Element Analysis is carried out to calculate the energy density distribution of the elastic internal energy. Based on the results, the materials are repositioned, analogously to "Bone Remodelling". Materials with high density values are transmitted to regions of high energies, and materials of low density are correspondingly transported to regions of low energies. This technique leads to a reduction of the total inner energy and thus an increase in stiffness (general lightweight principle). Afterwards, the procedure is repeated as long as convergence appears. As shown in Figure 3, having passed 24 iterations, we obtain a bone density distribution in the cancellous bone that more or less precisely approximates the tension- and pressure fibre bundles appearing in real bones.

Subsequently, the density distribution is converted in a graduated trabecula grid in the computer. This procedure is demonstrated in Figure 4, showing a human lower jaw bone, subjected to asymmetric bite load. The network consists of

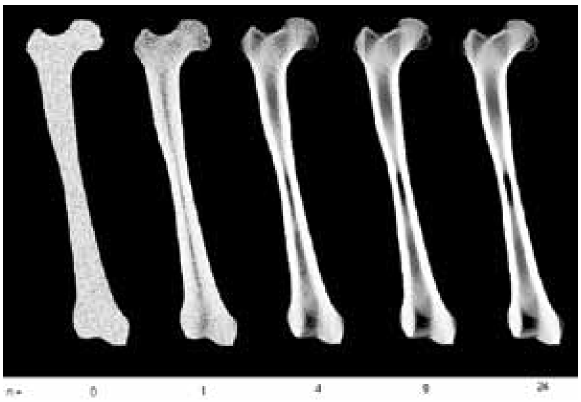
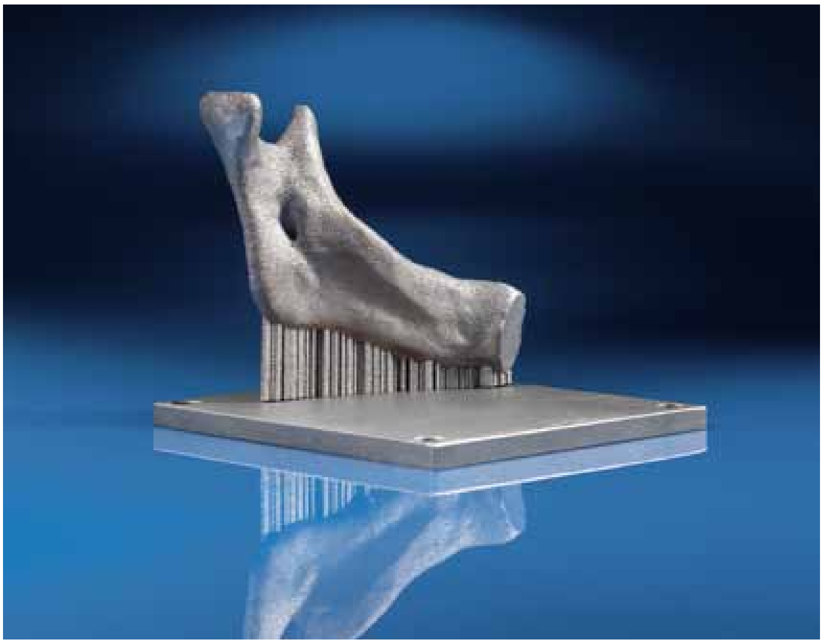


Fig. 3: 2-D simulation of the "Bone Remodelling" procedure in a human femur while the person is standing on one leg. After 24 iterations, we obtain a bone density distribution in close compliance with an X-ray image of a real bone.



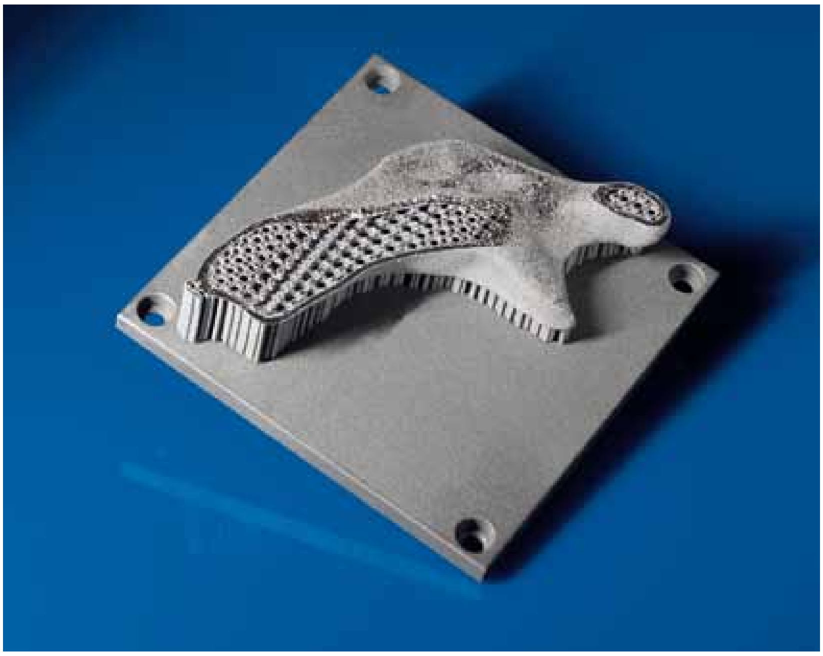
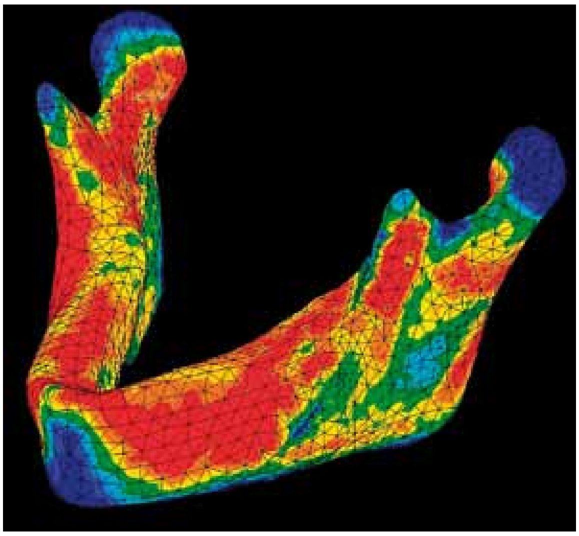


Fig. 2: Part of a human jaw bone (top: with support structure on the fabrication platform, bottom: open, with visible complex inner structure (material: TiAl6V4; generated on an EOS-M270 system).



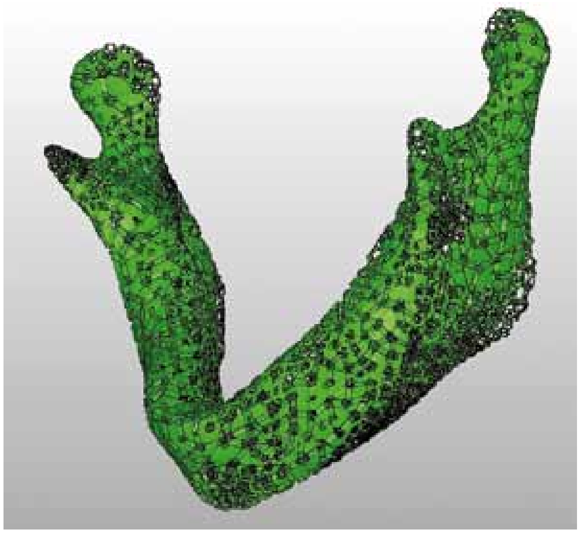


Fig. 4: 3-D simulation of the "Bone Remodelling" procedure in a human jaw, for an asymmetric central bite (left: Bone density distribution according to load, right: Density distribution graph on a graduated cellular structure).

Fig. 5: Human lower jaw with biomimetically graduated cellular structure, made by SLM (metallic bone foam).

tetrahedra of various sizes, which are adapted to the density distribution. The side faces are connected with the side faces of their nearest neighbours using "Trabeculae". In the next step, the trabecula structure is transferred via triangulation in a format (STL) that can be processed by generative manufacturing systems.

Implementation and Outlook

As shown by the first tests, the trabecula structures described may be manufactured, for example, by means of SLM (Fig. 5). However, the tetrahedron basic structure is less strong than structures with a high coordination number (hexahedral, octahedral, dodecahedral). Consequently, future projects are focussed on the geometric part decomposition, using polyhedra with a higher number of side faces. We are also striving to enhance the technological quality, in particular, of the trabecula diameter, below 0.5 millimetres.

A special challenge results from the robustness of the manufacturing process when varying the manufacturing direction, since it affects the quality of the trabeculae. Future applications of this method are to be found in the field of permanent implants, in particular to replace reconstruction plates in the jaw region, for example, if greater bone parts are destroyed due to a tumor. Here, the use of biomimetic cancellous bone materials would be a significant improvement for the patient (Fig. 6).

However, new ideas for lightweight components are also imaginable in the automotive- and aircraft industries.

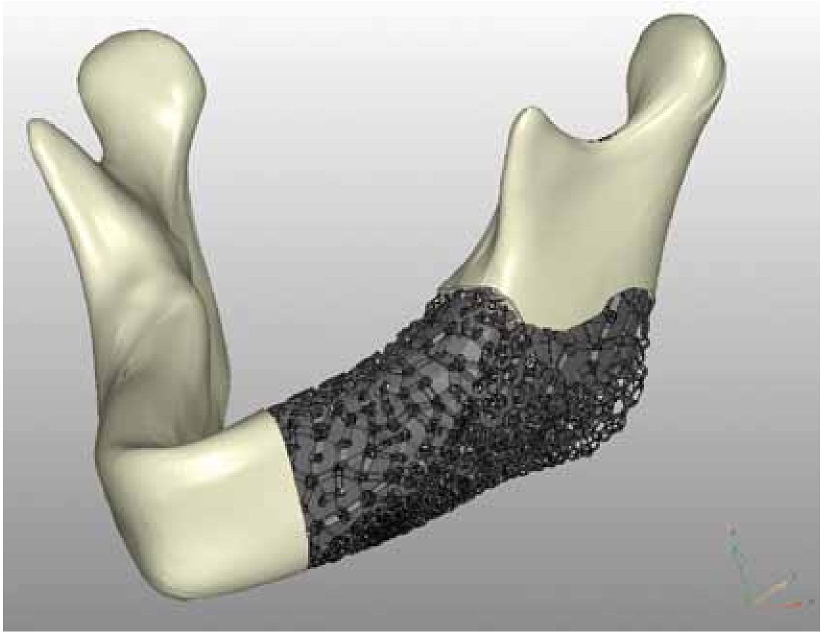


Fig. 6: Metallic biomimetic implant as a replacement for the reconstruction plates in mouth-jaw surgery.

Contact persons

Andreas Burblies
Phone: +49 421 2246-183
andreas.burblies@ifam.fraunhofer.de

Dipl.-Ing. Claus Aumund-Kopp
Phone: +49 421 2246-226
claus.aumund-kopp@ifam.fraunhofer.de

Institute

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

CellForce: Development of a Single Cell-based Biosensor for Sub-cellular Online Detection of the Cell Characteristics in Diagnostics and Healthcare

Initial Situation

Biosensors have become more and more important in a wide variety of everyday life applications. Thus, more and more lab-on-a-chip systems (LoC systems) are under development, which are used in medical engineering, diagnostics or biotechnology and the life-science domain [1]. The development of a biological sensor to measure cell forces is introduced in this joint project funded within the scope of the 6th Frame Program of the European Union (project acronym: CellForce). The functional principle of the sensor mainly depends on the manufacturing aspect of the biosensor and the necessary surface structuring.

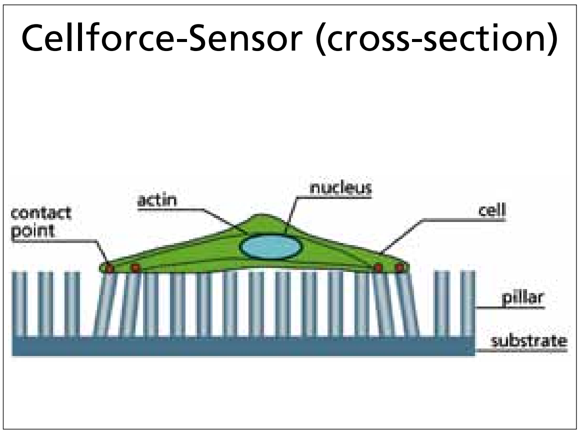


Fig. 1: Schematic side view of the CellForce-Biosensor.

To detect the cell forces, we need a grid of pillars (pillar carpet) to which the cells adhere. When doing this, the pillars are bent by the applied cell force. From this deflection of the pillar from the centre, one may directly conclude the applied force of the corresponding cell. The principle of the cell force sensor is shown in Figure 1. Pillar carpets are currently produced with costly foundry equipment, which makes it impossible to produce more than a few components per day. For this reason, the project is aimed at manufacturing the biosensor at a low cost and in great quantities, using the batch production technology of micro-injection moulding. The challenge of this method is to shape components with surface structures in the micrometer region in a reproducible manner. A matrix is needed for such a CellForce sensor in order to detect cell forces. Depending on material stiffness and pillar diameter, this matrix makes it possible to exactly shape several hundred thousands of identical pillars with a defined diameter of 2 to 5 micrometers and a pillar length of maximum 30 micrometers.

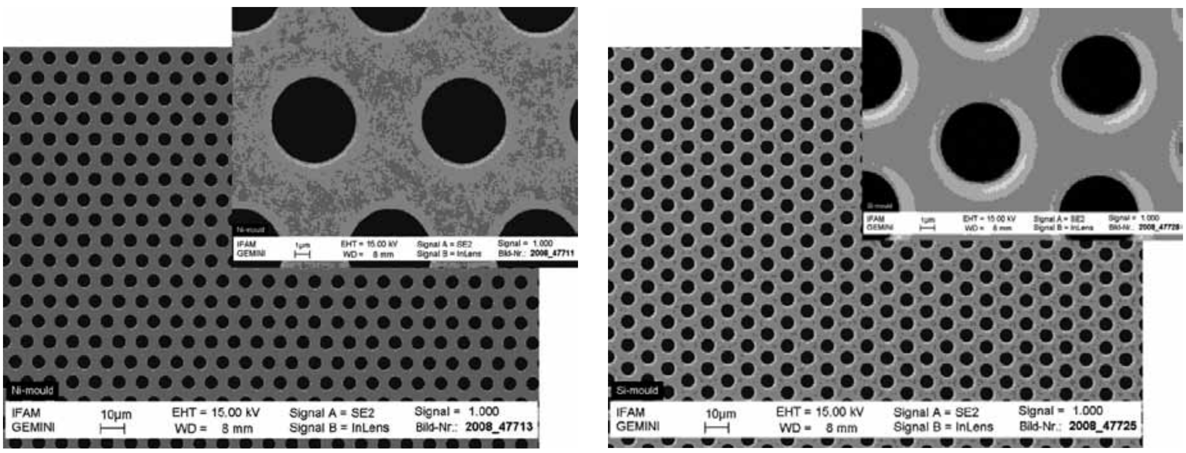


Fig. 2: Structured inserts for micro injection moulding.

Current Projects

Microinjection moulding is a technique in which thermoplastics are made free-flowing under the influence of a certain temperature and are injected into a structured mould. The plastic solidifies and represents the die's negative structure. In this project, the technological challenge comes from the task of implementing the pillar dimensions and distances in the sizes required for the functioning of the biosensor. Figure 2 illustrates a detail of the die insert with 250,000 cavities, with a diameter of 5 micrometers and a depth of 25 micrometers. As a die insert, an etched silicon wafer (Si) and a nickel form insert structured with UV-LIGA [2] were used.

The mould inserts were integrated into a microinjection moulding die (Fig. 3) and shaped on an injection moulding machine of the type Microsystem 50 by Battenfeld. The machine is characterized by its ability to produce microcomponents and microstructured surfaces with the highest precision, and also offers the option of automatic quality inspection and part removal. The smaller and more filigree the components to be realized are, the more important the advantages resulting from the equipment. In addition, the Microsystem 50 enables a variothermal temperature guidance, which is necessary for the manufacture of the pillar carpets.

Before microinjection moulding, we had to find an appropriate thermoplastic polymer that is both sufficiently elastic (Young's modulus < 17 MPa) and biocompatible. After initial biocompatibility tests of several materials under consideration for their processability and usability as a biosensor, we selected the thermoplastic polyurethane Elastollan® with a Young's modulus of 11.4 Megapascal as our basic material. Figure 4 shows that the cells "feel comfortable" on the Elastollan® material and form their typical cell morphology.
To shape the filigree microstructures necessary for the CellForce sensor, it is imperative to dimension and control the microinjection moulding procedure in an optimal manner.

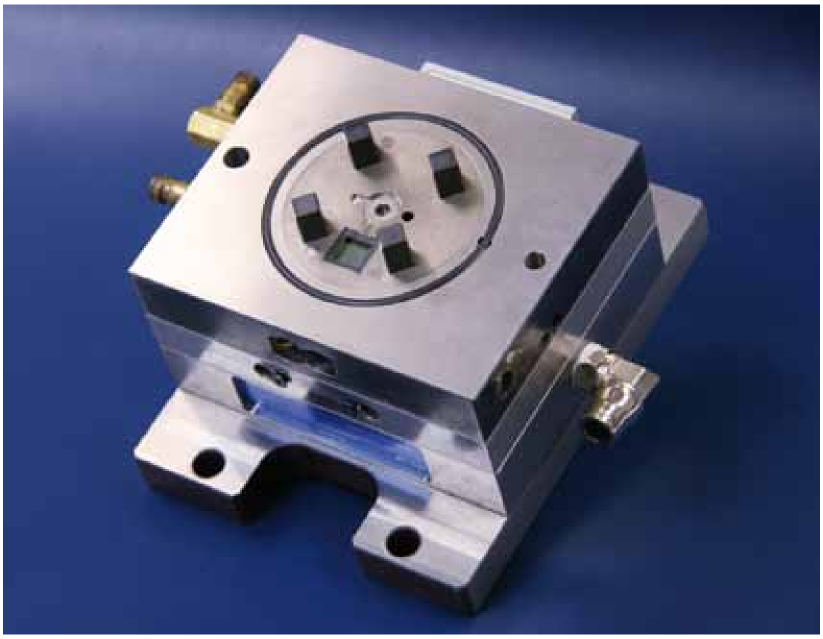


Fig. 3: Micro injection moulding tool for the injection moulding machine Microsystem 50 of Battenfeld.

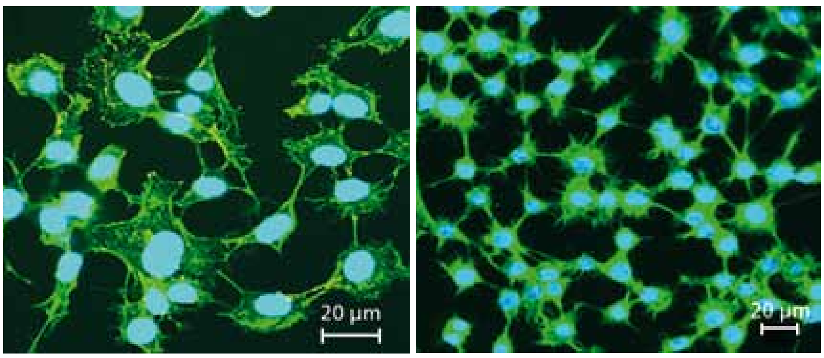


Fig. 4: Biocompatibility of Elastollan® in diagram. Left: Mouse fibroblasts on Elastollan® with typical formation of the cell morphology, right: Mouse fibroblasts on polystyrene, with altered cell morphology. The actinium fibres of the cell are colored green, the cytoblasts in blue, Bar: 20 micrometers.

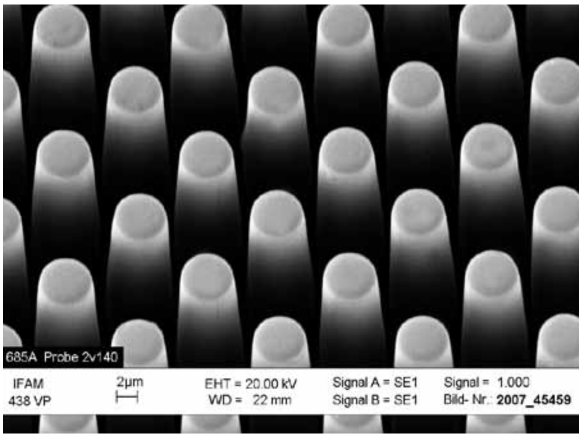


Fig. 5: Vertical pillar structure, diameter 5 micrometers, 25 micrometers height, made of Elastollan®.

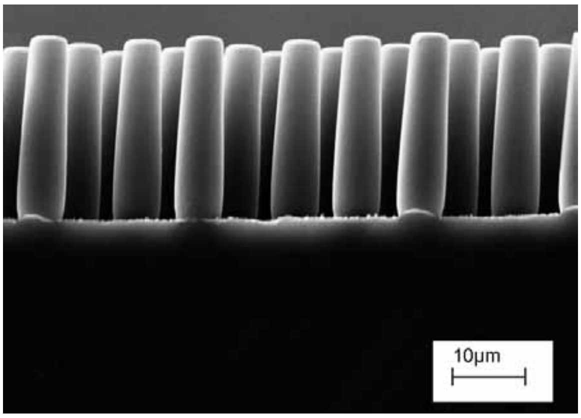


Fig. 6: SEM image showing tilted pillars in the sample's marginal region.

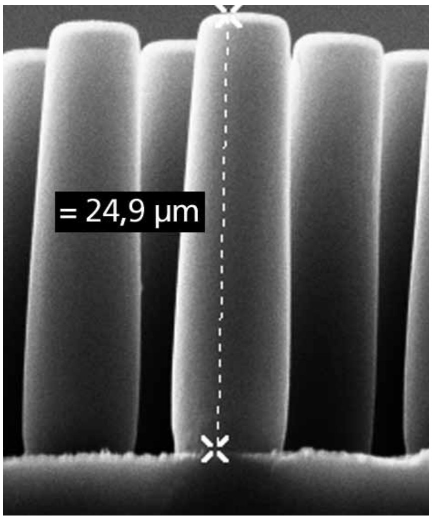


Fig. 7: Measurement of pillar height by means of SEM.

Thus, in particular for the manufacture of the biosensor, we implemented a variothermal process. Here, the die is heated before injection moulding to provide maximum flowability into the micro cavities. Immediately after injecting the material, the die is cooled by about 30 °C in order to remove the biosensor from the mould without tilting the pillars. For easier removal from the mould, the mould insert used was coated with a hydrophobic plasma polymer cover. Only this innovative optimization of the microinjection moulding procedure made it possible to achieve a consistent formability of the pillar structure (Fig. 5). The pillars may be sporadically bent or tilted only in the marginal region
(Fig. 6). We were able to implement a pillar height of 25 micrometers at a pillar diameter of 5 micrometers (Fig. 7).

Results and Prospects

With the microinjection moulding of thermoplastic Elastollan®, we were able to manufacture 250,000 micropillars of 5 micrometers diameter, 25 micrometers height and a pillar distance of 5 micrometers. Structuring of the polymer is an important step in the development of biosensors in general. The pillar carpets made using microinjection moulding are now being tested for their usability as a cell force sensor and will if necessary, be further modified. In parallel, we are engineering an optical measuring system, which is able to record the ejection of the pillars. Only this interdisciplinary cooperation between micromanufacturing, biology and optics can make it possible to use biological sensors not only to measure cell forces, but also for other ranges of application in medicine, biotechnology and the life science domains.

References

[1] Padinger, M., Sonnleitner, M., Schnelle Analyse mit "Lab-on-a-Chip", Elektronik Praxis 2007
[2] Brück, R., Rizvi, N., Schmidt, A., Angewandte Mikrotechnik – LIGA-Laser-Feinwerktechnik, Hanser Verlag, München 2001

Customer

EU-Brüssel, Sixth Framework Programme. IST-NMP-2 Biosensor for Diagnosis and Healthcare, Contract No.: FP6-016626

Project partner

Swiss Federal Laboratories for Materials Testing and Research (EMPA), Switzerland
Faculty of Material Science and Engineering (FMSE), Poland
University Coimbra, Department Engineering Quimica, Portugal
Fraunhofer Institute for Shaping and Functional Materials IFAM,
Germany
Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Germany

Project duration

November 1st, 2005 until June 30th, 2009

Contact person

Dr. Natalie Salk
Phone: +49 421 2246-175
natalie.salk@ifam.fraunhofer.de

Institute

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

Metallic Nano-inks for Printed Electronics in Microsystems Engineering

Initial Situation

Microsystems engineering includes the design, manufacture and application of assemblies with integrated functions in the micrometer range. In many cases, miniaturization of individual, isolated sensor/ actuator systems, which is a necessary prerequisite for integration, is insufficient; in fact, structural- and bonding technologies will be decisive in the future. Microsystems, which have been installed in electronic housings up to now, will increasingly be directly embedded in various materials in the future, which will result in a fundamentally higher integration density. To do this, it is first of all necessary to integrate nanomaterials by means of maskless printing technologies.

For this purpose, the process chain INKtelligent printing® developed at Fraunhofer IFAM is a promising option for embedding sensors and contacting. Here, non-contacting, maskless printing methods like aerosol- or ink-jet printing are applied for functional microstructures of less than one micrometer thickness and structure widths of max. 10 micrometers. One of several prerequisites is that printable inks of new or enhanced functionality have to be generated based on nano-scaled metallic materials.

Project Description

The qualification of such innovative inks in connection with the aerosol printing method in an entire microsystems engineering process (INKtelligent printing®) is demonstrated in cooperation with the project partner Microsystems Center Bremen (MCB).

The essential tasks are to create pure, printable metallic inks without adding media for dispersion, to print microstructures with strong conductivity using thermal activation, to determine the crucial electrical properties by means of the test structures, and to find the design rules. The bonding of an embedded thermoelectrical flow sensor developed by MCB was chosen as the demonstrator for the use of the whole INKtelligent printing® chain.

The VERL process (Vacuum Evaporation on Running Liquids) engineered by Fraunhofer IFAM is the cornerstone for the manufacture of printable inks. In this technique, based on the physical sputtering technology, a very high purity of particles may be achieved. It is possible to set up particle sizes from a few to 50 nanometers. This range corresponds to the sizes of commercial, chemically precipitated nanoparticles.

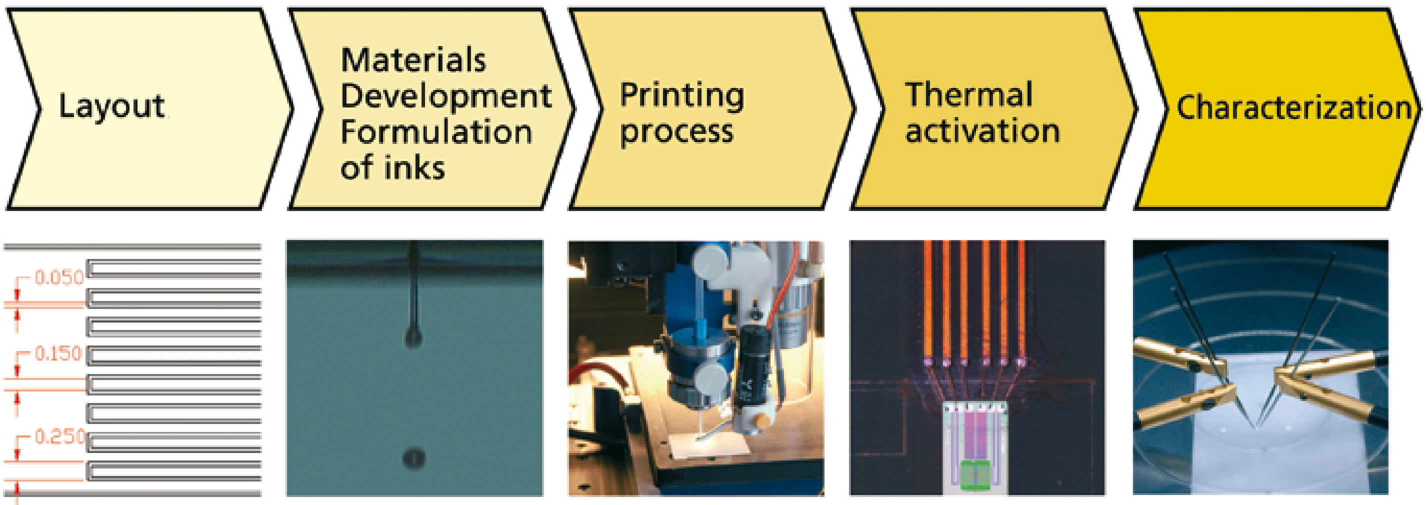


Fig. 1: INKtelligent printing® - process chain.

In contrast to these, however, the VERL nanosuspensions are very pure and, having no surface-active substances are well suited for dispersion. They are correspondingly reconcentrated for the printing processes and adjusted in terms of viscosity and surface tension. In ink formulation, the wider process window of the continuous aerosol printing technique demands less effort concerning the viscosity and stability of the material to be printed than would be necessary for the known ink-jet printing techniques.

Activation or functionalization – as well as set up of the desired conductivity – is performed by thermal processes. Sintering in the furnace is disadvantageous, since the complete chip with superstructures has to be subjected to a temperature range from 150 to 250 °C, to sinter the printed structure. However, in laser sintering, only the printed structure is subjected to a local thermal load, which may be an advantage, in particular in case of substrates sensitive to temperature.

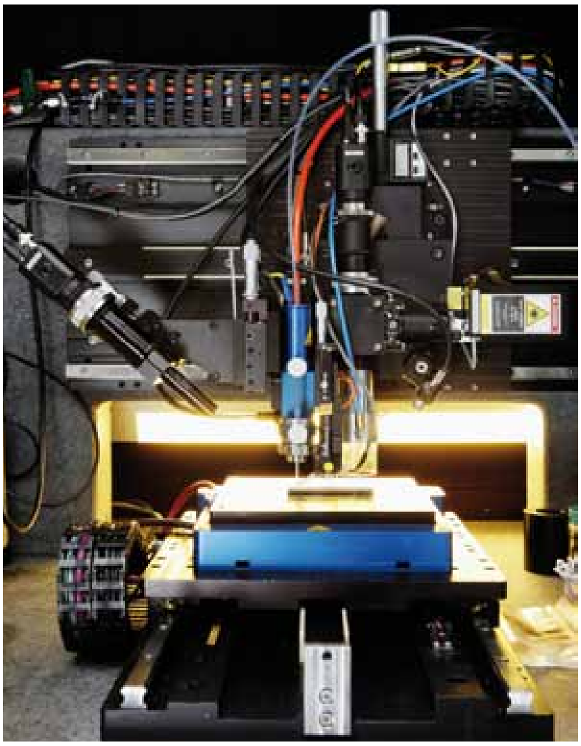


Fig. 2: Insight into the core of the aerosol printer for fine structures.

Results

By bonding a thermoelectrical flow sensor, we were able to demonstrate in the project that INKtelligent printing® is potentially suitable to bond embedded systems in microsystems engineering. Conventional bonding techniques with wire bonds are hardly suitable to bond microsystems engineering flow sensors, since they strongly affect the flow characteristics in the sensor's environment due to their size.

After characterization, the expected benefits were confirmed: Due to the very low height of the printed conducting paths of about 0.5 to 3 micrometers, they also only marginally affect the sensor's flow characteristics.

Contact resistance with respect to gold- or platinum bond pads is very low, and the bonding is relatively insensitive to mechanical influences. Due to oxide layers on the surface, it has been impossible to reliably reproduce the bonding resistance to sputtered aluminum or copper pads up to now. The resistance of the printed bondings is higher than those of bond wires. This phenomenon mainly results from the fundamentally thinner cross-sections of the printed microstructures. Depending on material, conductivity values of up to ¼ of the value in literature were reachable. Furthermore, we were able to demonstrate that the bondings have a great adhesive strength on many printed circuit materials, as well as high long-term stability (in the climatic chamber at 85 °C and 85 % of rel. humidity).

At the present state of development, bonding of micro-systems engineering sensors by means of INKtelligent printing® is more complex than bonding with wire bonds. On the one hand, this results from the topographic requirements that must be fulfilled by the substrates to be printed. Whereas it is possible to print sculptured or obtuse-angled stepped surfaces up to a few millimetres of height difference without any problem, spaces in the printed conducting path may occur as a result of low 90° steps or undercuts. The corresponding inclined positioning of the substrate or the printing head may provide an easy procedural solution.

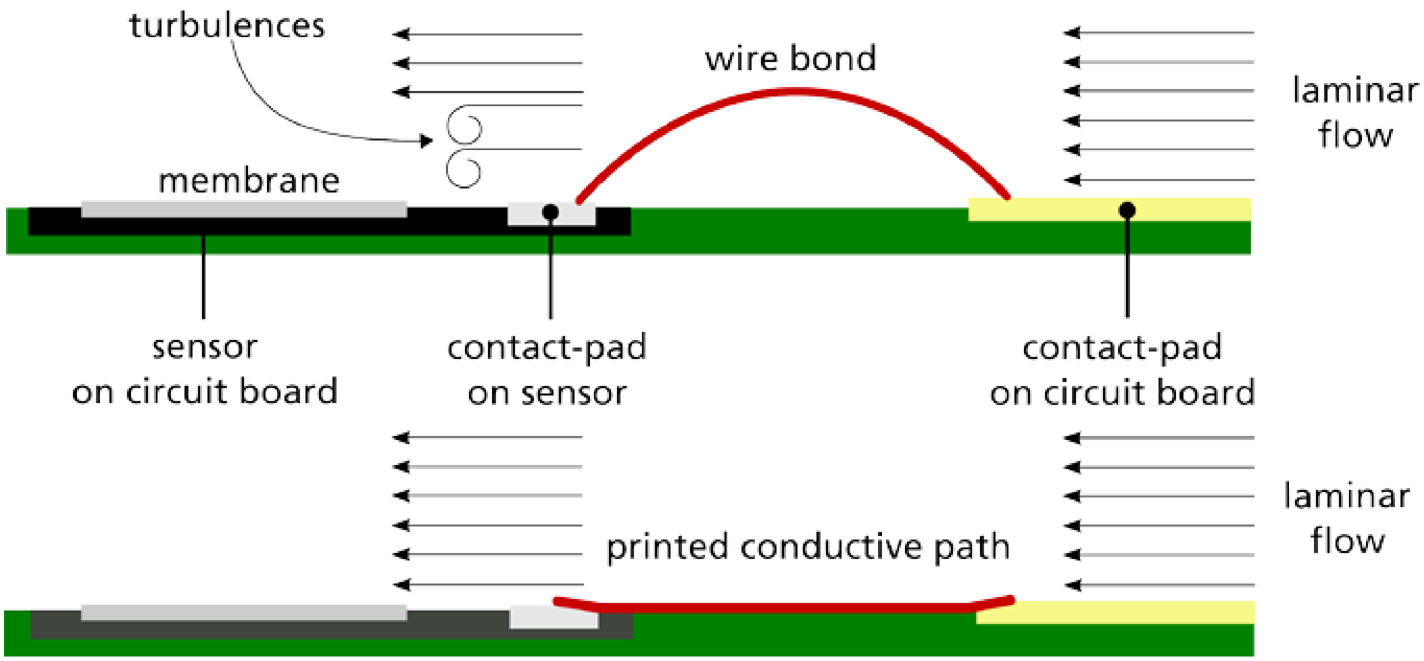


Fig. 3: Flow conditions – wire bonded flow sensor in comparison with printed bonding.

Because of the necessary thermal activation, stresses or even cracks of the printed conducting paths may appear at the material transitions as a result of different coefficients of thermal expansion of the materials sensor/ potting compound/ circuit board. In the application example, this challenge was met by using special high-temperature-resistant circuit boards and potting compounds with modified coefficients of thermal expansion, as well as silver-nanoinks, which are processable at 150 °C.

Prospects

In addition to bonding of thermoelectrical flow sensors for combustion engines or microfluidics described here, aerosol printing with metallic nano-inks is economically interesting, in particular, to repair conducting paths on printed boards or to manufacture prototypic, even multi-layer printed circuits in small-batch production. To do this, in addition to the silver-inks, further printable nano-scaled functional materials are currently being developed, such as Cu- or special alloyed inks, both in projects with public funding or projects with industrial partners. The latter are not only important for printing of resistors or heaters, but also for printed sensors like strain gauges or thermocouples.

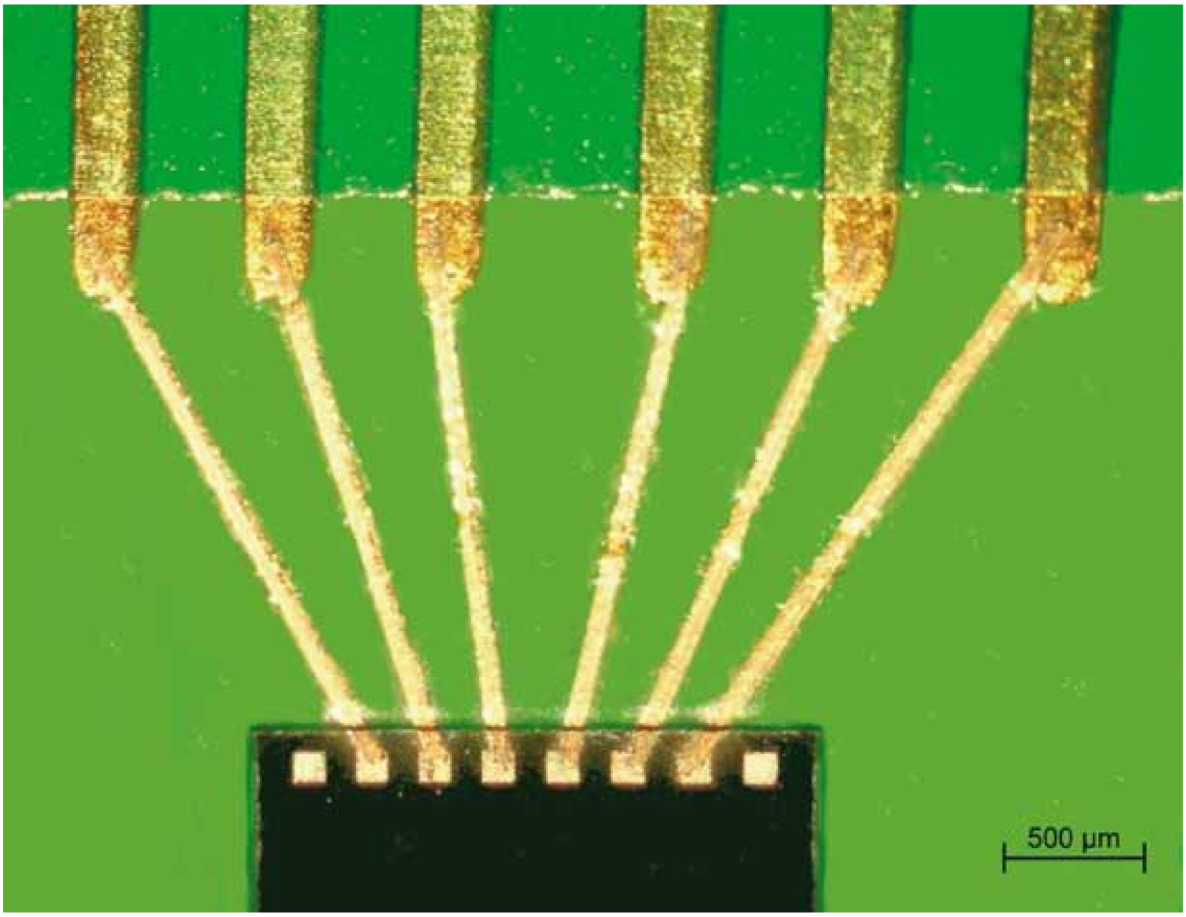


Fig. 4: Bonding of an embedded flow sensor from chip to printed circuit board by means of INKtelligent printing®.

Customer

The project was funded under the title "Nanomaterials for multi-scale Structural- and Bonding Technology", dated from April 2007 to March 2008 within the Frame Program "Microsystems 2004–2009" of the Federal Ministry for Education and Research (BMBF) under the technical focus "Micro-Nano-Integration for Microsystems Engineering".

The Microsystems Center Bremen (MCB) of the University of Bremen is the project partner in the subproject "Nanoinks".

Contact persons

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

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

Institute

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

Hot Gas Corrosion Resistant Aluminide Layers through Sintering of Powder-filled Pastes

Initial Situation

Components that are exposed to high temperatures in an oxidizing, corrosive atmosphere have to be made of highly alloyed, very expensive steels or superalloys in order to fulfil their functions. These are components applied in fuel technology, in the exhaust systems of vehicle motors, as well as in thermal and chemical process engineering. The best performance can be achieved by using alumina layers whose basic material contains sufficient aluminum content. These layers also have a kind of an "innate recuperative power", since aluminum diffuses to the surface, and the layer is rebuilt by reacting with the atmosphere.

Project Description

The project is aimed at making commercially available stainless steels applied in apparatus engineering and tank construction more resistant to corrosion in oxidizing atmospheres by modifying the surface. This way, the range of application for conventional stainless steels can be extended, and low-cost solutions offered to end users.

The approach involves the application of aluminum-containing layers, which locally improve the hot gas corrosion characteristics, on the surface of the steel. These layers are to be made of so-called aluminides. These are intermetallic compounds of transition metals with aluminum that have high melting points and the potential to form dense alumina top layers. These aluminides should be formed in situ as a result of the reaction of the base material with pure aluminum.

A ferritic stainless steel (410L, material no. 1.4000) and an austenitic stainless steel (316L, material no. 1.4404) were each used as initial material. Both stainless steels were analyzed in the form of rolled sheets and as a powder metallurgical pellet. The aluminum paste was made of two powders of different particle size (< 80 µm and < 4 µm). We used a commercially available product by the company Zschimmer&Schwarz (Decoflux) as binder for the pastes. The paste consisting of the powders was stirred together with the binder and was viscous enough for screen printing. In general, wide ranges of viscosity can be achieved by changing the powder-binder ratio, so that other coating techniques, such as plunging, spraying or a simple application with a brush are also feasible. In the investigations here, the pastes were applied to the sheets or pellets in stencils. The thickness of the paste film was 80 micrometers; it was determined by the thickness of the stencil, from which the paste was stripped away with a squeegee made of steel. The pastes were dried at 80 °C in an air-circulating furnace and afterwards heated in a sintering cycle under nitrogen or argon to temperatures up to 1250 °C.

During this heat treatment, the aluminum powder was sintered and molten. The aluminides, which correspond to the local composition, formed very quickly, particularly in the fused state. Due to diffusion at high temperatures, the concentrations balance one another, and we obtain two adjacent states that are almost in equilibrium. This is especially true for the very high sintering temperature of the stainless steel at 1250 °C, which is inherently too high for stainless steel sheets and results in the formation of coarse grains.

The layers were subjected to metallographical analysis and tested for hot gas corrosion resistance in annealing tests under air. For these processes, the uncoated sections of the samples were used as reference material. We determined the phase composition of the layers after the reaction annealing procedures and the annealing tests by means of X-ray diffraction.

Results

The metallographic microsections in Figures 1a and 1b illustrate aluminide layers on the powder metallurgical steels 410L and 316L. As can be seen, the layers are highly porous, independent of the initial size of the aluminum powder particles. The reason for this is the obstruction of aluminum sintering and wetting of steel by carbon residuals of the binder. For the sheet (Fig. 1c), the wetting ratio is much better, since the binder residuals have only to vaporize through the thin aluminum layer. On the sheet, one may clearly recognize the deep diffusion zone of the aluminum, in which aluminum nitrides were separated, in dark colour. However, it is also possible to influence wetting,

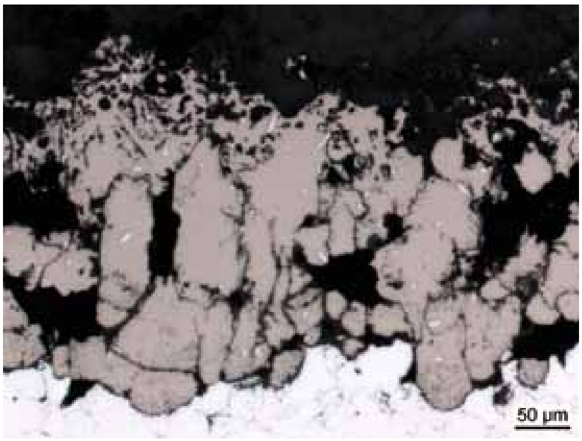


Fig. 1a: Powder metallurgical pressed steel 410L, coated with coarse aluminum powder.

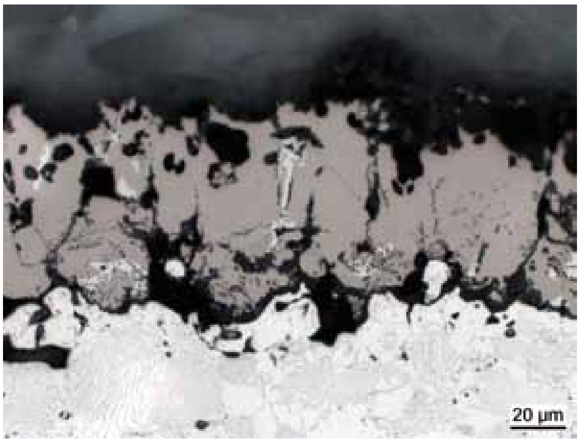


Fig. 1b: Powder metallurgical pressed steel 316L, coated with fine aluminum powder.

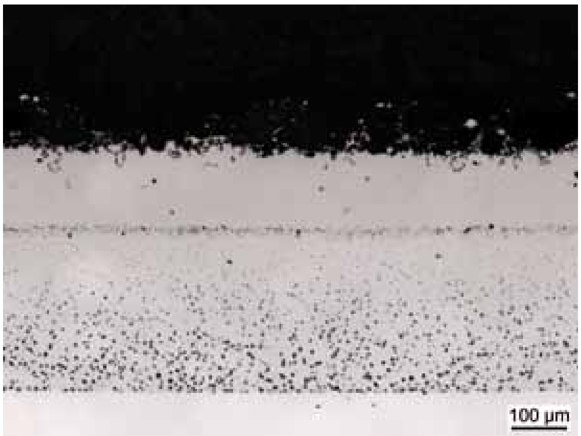


Fig. 1c: Sheet made of 316L, coated with coarse aluminum powder.

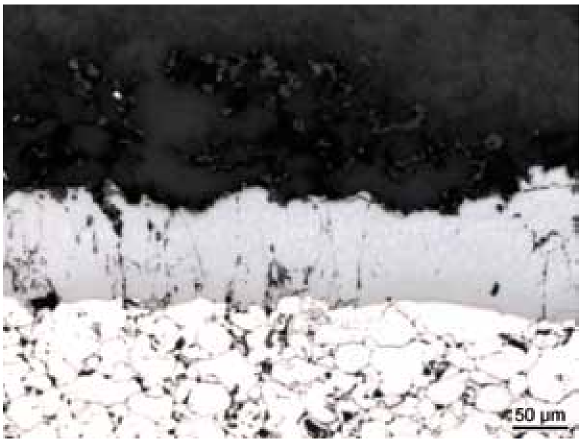


Fig. 1d: Powder metallurgical pressed steel 316L, coated with copper-alloyed aluminum-powder.

as well as sintering characteristics and temperature by means of the alloyed components. Figure 1d shows an aluminum layer alloyed with copper, which densely and homogeneously covers the sintered powder pellet. As shown, the low copper content (< 5 %) does not affect the corrosion characteristics of the material. In Figure 2a, a sheet coated with the paste, an annealed sheet with a reaction coating, and a sheet after the test are illustrated side by side. It is clear how the paste abreacts to gray aluminide during sintering. After the corrosion test, the free steel surface is strongly affected.

As the detail shows (Fig. 2b), the aluminide layer – in contrast to the basic material – was barely affected. During annealing, the sheet became thinner by a few tenths of a millimetre over a period of 10 hours at 850 °C.

The comparison between the corroded sheet specimen and the specimen made by powder metallurgy (Fig. 3a and 3b) is noteworthy, too.

The powder metallurgical steel 316L shows almost no damage, even in the uncoated regions. This phenomenon results from the predominant corrosion mechanism. The oxide of the stainless steel occupies a greater volume than the uncorroded metal.

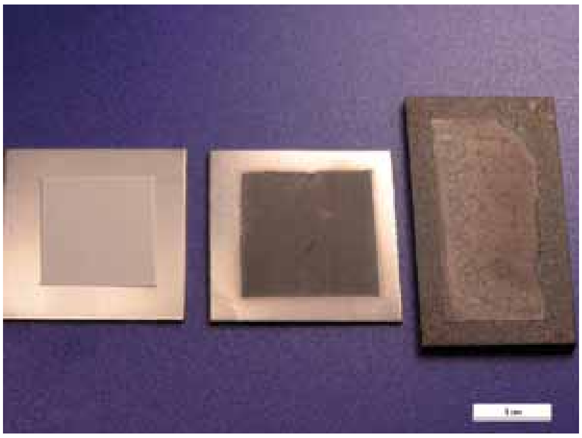


Fig. 2a: From the left: Sheet with aluminum paste, sheet after reaction sintering, after annealing test over 10 hours at 850 °C.

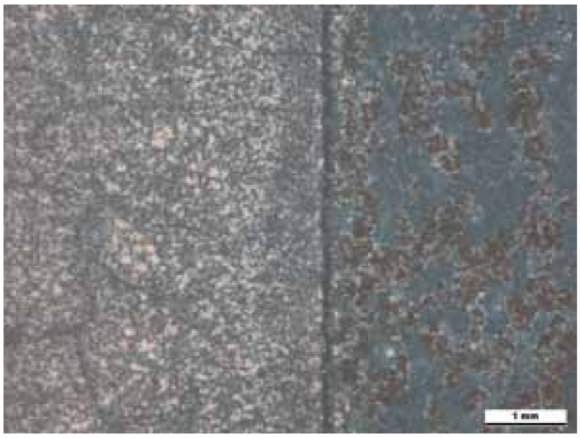


Fig. 2b: Detail view: left – aluminide layer, right – uncoated steel sheet after corrosion test.

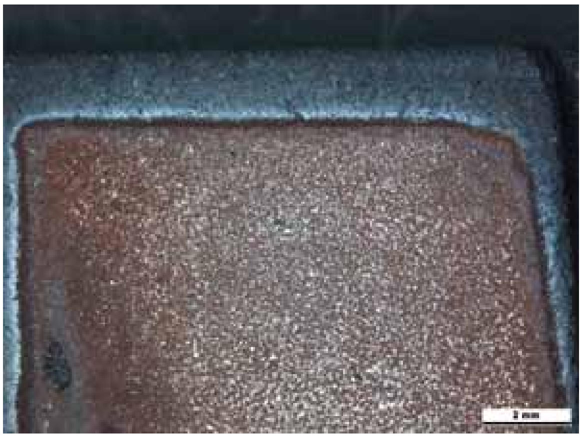


Fig. 3a: Aluminide layer on powder metallurgical steel 316L after corrosion test. A little scale at the unprocessed margin.

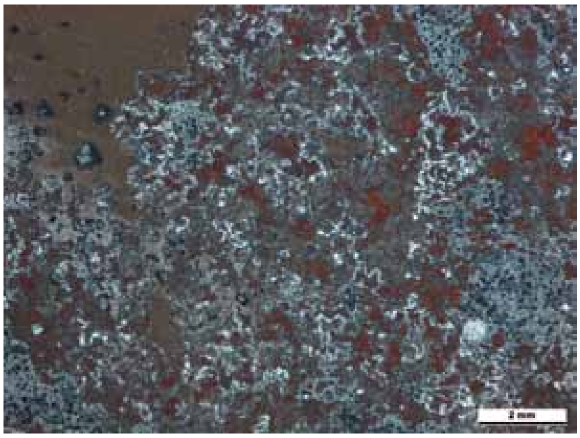


Fig. 3b: Sheet specimen made of 316L, with strong crater formation.

Since the oxide is very brittle, the oxidized layers flake off the base material. This is obviously the speed-determining step of the hot gas corrosion. In the case of the powder metallurgical material, the existing pores make it possible to compensate for stresses and allow free growth of the oxide in the pore regions.

This way, few to no stresses are formed in the oxide, and the oxide continues to adhere to the base material. In this case, powder metallurgical material with pores has an advantage over the bulk material. After sintering and the corrosion tests, the layers were investigated by x-ray di-fraction in terms of their phase compositions.

The X-ray diffraction spectrum after sintering (lower, black curve) shows the characteristic reflexes of the phases FeAl and, to some degree, Fe_3Al. In addition, we find peaks of aluminum nitride, to be seen as black inclusions in the microsections of Figure 1c. The diffraction spectrum of the layer after the annealing test in air (upper, red curve) additionally outlines small reflexes of the alumina Al_2O_3, that evidence the formation of a protecting scale.

Prospects

The tests demonstrate the applicability of the procedure described above to make stainless steel resistant to corrosion for high-temperature applications. A suitable alloying technology significantly contributed to improving the microstructure of the coating and adhesion. We also succeeded in lowering the sintering temperature. Sinter-fusing and abreacting of the aluminum pastes to form aluminides made it possible to generate dense layers that adhered well. As demonstrated by the comparison of rolled sheets and specimens made by powder metallurgy, the latter material has the overall advantage, since the corrosion mechanism is weakened by porosity. A goal of further investigations is to inspect the thermal shock resistance of the layer and its consistency at various temperatures over longer periods. The objective is to further reduce the reaction temperatures through ongoing modification of the alloy, so that the process can be much better integrated into existing manufacturing processes by customers and users.

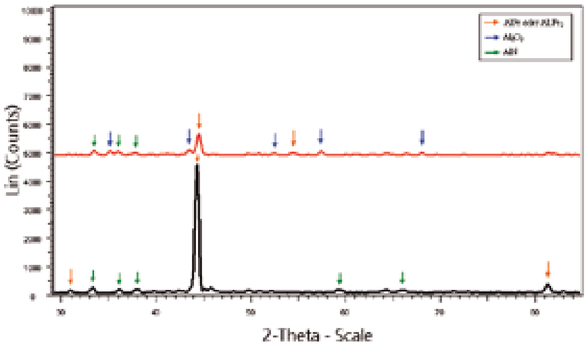


Fig. 4: X-ray diffraction spectrum after sintering (lower, black curve) and after the annealing test (upper, red curve).

Contact persons

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

Dipl.-Phys. Claudia Drescher
Phone: +49 421 2246-104
claudia.drescher@ifam.fraunhofer.de

Institute

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

Powder-Metallurgical Technologies for the Production of Nanostructured Materials

Situation

For a consistent use of the potential of nanostructured materials, it is necessary to develop efficient and thus low-cost manufacturing technologies. In this endeavour, powder metallurgy and, in particular, the combination of nanotechnology and powder metallurgy offer a great potential for innovation. The nanocrystalline structure of materials means that the mechanical characteristics at room temperature and elevated temperatures, the wear properties, and also the physical properties can be significantly improved and modified for each application because of the options arising from structural design. To enable the powder metallurgical production of nanostructured materials, it is first of all necessary to pay special attention to the mechanisms for retardation of grain growth and efficient compression techniques. Consequently, design and production are fundamental goals in the development of suitable nanocrystalline materials. Furthermore, it is important to study the retention of the nanostructure coarsening during component production by means of new procedural variants.

Chance

Whether intended for use in the direct transformation of thermal into electrical energy or to obtain a more efficient electrochemical reaction during electrolysis of water for hydrogen production or for highly temperature-resistant lightweight parts, the demand for superfine-crystalline or partially amorphous materials is growing. It is an interesting approach to generate the smallest possible structures, sometimes only a few nanometers in size, resulting in properties that are clearly superior to those of conventional structures. Numerous combinations of alloying elements or the production of nanocomposites may open up a variety of ranges of application for superfine crystalline materials:

- Aluminum high-performance materials with enhanced mechanical properties, both at room temperature and higher temperatures (< 400 °C).
- Sintered, very fine crystalline thermoelectric materials efficiently transform residual- or waste energy, for instance in the exhaust system of a combustion engine, immediately into electrical energy (the Seebeck effect; thermoelectrical quality coefficient: ZT > 1).
- Due to the very high "internal surface" (grain boundaries, dislocations) of nanostructured materials, solid-state storage systems for hydrogen based on magnesium alloys are regarded as a promising alternative to conventional compressed hydrogen gas storage.
- Cathodes, anodes and catalysts made from nanostructured materials help to increase process efficiencies in various chemical or electrochemical reactions.

Potential Research Topics and Current Projects

Fine-crystalline or amorphous structures in materials may be generated by the corresponding choice of alloys in combination with a rapid extraction of heat, a quasi freezing of the molten mass. In particular, when designing nanostructured materials, "Melt Spinning" (high-speed solidification) provides the best precondition for a rapid solidification of molten metallic materials. Here, a molten metallic mass is poured onto a water-cooled rotating roller, generating flakes or continuous ribbons of a few micrometres in thickness. In this procedure, the material solidifies with a maximum cooling rate of up to one million Kelvin per second. The new melt-spinning device at Fraunhofer IFAM allows us to process melting masses from 100 to 2000 g (volume related to aluminum) at temperatures of maximally 1700 °C and in various atmospheres, such as vacuum (10-5 mbar), inert gas or air (Fig. 1).

Fig. 1: Melt spinner to produce metallic materials of homogeneous characteristics.

Fig. 2: Bolts compacted by means of Spark Plasma Sintering (SPS), made of an atomised aluminum alloy (Ø 75 mm, height 85 mm, almost 100 % of calculated density).

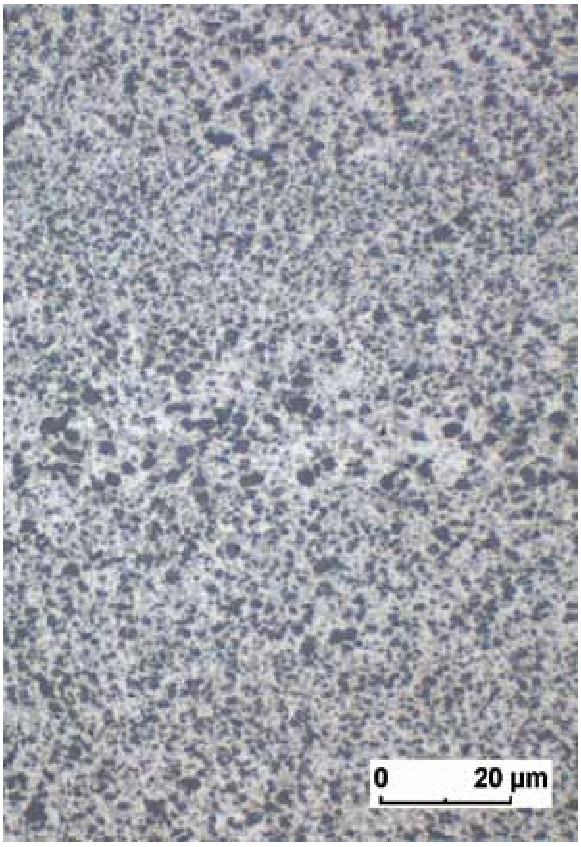


Fig. 3: Structure of AlSi20FeNiMgCu after Spark Plasma Sintering (SPS) and subsequent hot forming.

In the next step, the ribbons or flakes are usually compressed with high pressures and temperatures, whereby the microstructures may be lost due to grain growth. To limit coarsening, Spark Plasma Sintering (SPS, a compacting technique) offers important features: Direct heating with high-current pulses combined with a pressing force. As a result, the material is pressed in a very short time, thereby maintaining the desired very fine microstructure. The high speed of this procedure makes it necessary to choose and optimize the relevant technological parameters carefully and for each material individually.

In joint projects, funded by the Federal Ministry for Education and Research (BMBF) or the Company of Industrial Research Consortia (AiF), refinement of Spark Plasma Sintering of Al high-performance materials was successful both in terms of the equipment and the procedure. Thus, it was possible to press simple geometries with almost the full density, thereby maintaining homogenous and superfine crystalline structures (Fig. 2 and 3). To make comprehensive use of the material properties, we have to execute additional forming steps; however, advantages may be expected due to a reduction in the number of processing steps. We follow a similar technological approach in the production of highly efficient thermoelectric materials. In rapidly solidified alloys based on $(Bi,Sb)_2(Te,Se)_3$, superfine segregations which reduce thermal conductivity and thereby maintain electrical conductivity, are generated. After short-term sintering by means of the SPS technique, we can use these materials to produce thermogenerators that transform the exhaust heat immediately into electricity. In the WISA project "Thermoelectric Nanocomposite" founded by the Fraunhofer-Gesellschaft, we succeeded in developing a market-ready version of the material basis with the associated manufacturing technology and the necessary electronics use.

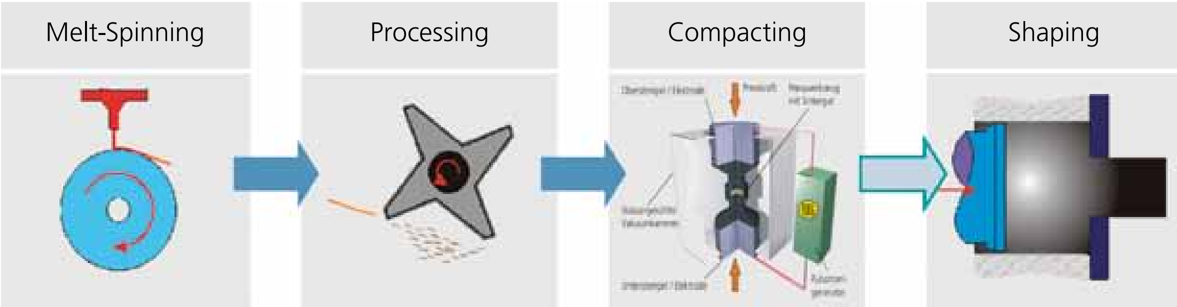


Fig. 4: Process chain for compact semi-finished products or components of superfine crystalline structure at Fraunhofer IFAM.

In current R&D projects, the melt spinning technique is also applied for the synthesis of nanocrystalline light metal alloys, which are developed as reversible and reliable solid-state storage systems for hydrogen (light-weight metal hydrides). Here, the superfine crystalline structure has a strong positive effect on the kinetics of the hydrogen sorption reactions due to the clearly enlarged "internal surface". Interesting hydride-forming light metal alloys (primarily magnesium-based), with which one may achieve gravimetric hydrogen storage densities of greater than 6 percent by weight, can be produced profitably and reliably by means of the melt spinning technique. In comparison with the widely used technology of mechanical alloying of metal powders via high-energy grinding processes, the melt spinning technique provides clear advantages in terms of the material yield rate, homogeneity of the element distribution and process costs, as well as up-scaling. The importance of these development projects becomes obvious in view of the required implementation of a hydrogen-based energy cycle, especially for mobile applications.

Implementation and Outlook

At Fraunhofer IFAM, we have built up a technological chain to produce superfine or nanostructured materials, from the ribbon/ flake fabrication to the compression by means of short-term sintering and possible subsequent hot forming (Fig. 4). In addition to "classical" mechanical procedures of powder production and modification, melt spinning allows us to produce nanostructured or amorphous materials on the scale of kilograms. Due to the micrometer size of the powder particles, they are easier to handle than metallic nanopowders. The spark plasma sintering technique is a variant to transfer the nanostructure generated within the powder particles into the compact component as well. The project is focussed on up-scaling to sizes relevant for components of up to 300 millimetres diameter. The technological chain is currently applied for aluminum materials and thermoelectrica. In future developments, further material groups, such as those used for hydrogen storage or metals with high melting points, will be important.

Contact person

Dr.-Ing. Thomas Weißgärber
Phone: +49 351 237-305
thomas.weissgaerber@ifam-dd.fraunhofer.de

Institute

Fraunhofer Institute for
Manufacturing Technology
and Applied Materials Research IFAM,
Department of Shaping and Functional Materials,
Dresden

New Biomaterials Based on Cellular Metallic Materials

Initial Situation

Bone- and bone/ cartilage defects are a major problem in medicine. Localized cartilage lesions, in which underlying bones are involved, are considered a serious issue not only in sports injuries among younger people, but also in the emergence of arthrosis in older people. However, defects that cannot be compensated for spontaneously in the body also appear in traumatology or as a result of operations on bone tumours or metastases of other virulent tumours in the bone. These lesions have to be replaced in a stable manner, until the bone produced naturally in the body is able to regain its mechanical function autonomously. Typically, defects like these are at present replaced with bone produced naturally in the body or with solid bone replacement materials. The former calls for additional invasive operations, which carry risks, while the latter are disadvantageous due to their great stiffness. These implants greatly exceed the stiffness of the surrounding bone and assume the load at this point, which affects the corresponding part of the body. Since bone regeneration follows load distribution, solid implants tend towards premature loosening.

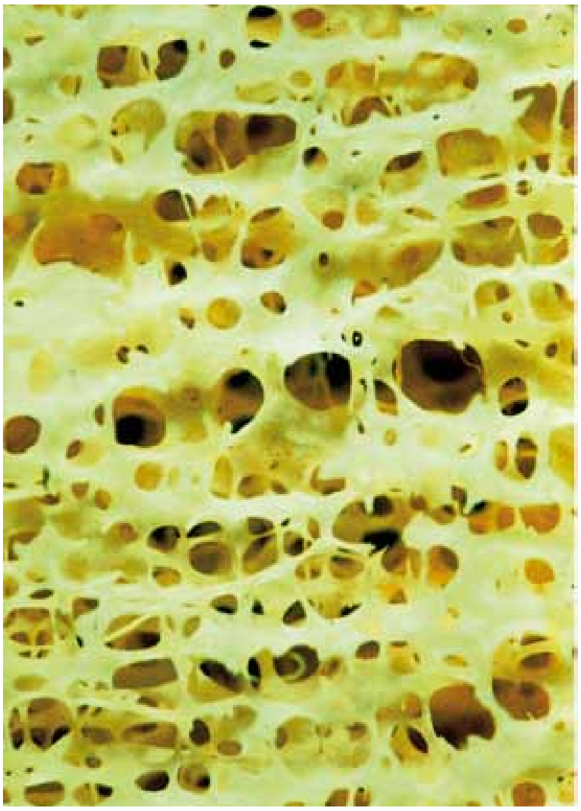


Fig. 1: Structure of a healthy spongy bone (by courtesy of the rs media GmbH)

Cellular metallic materials are less stiff due to their porous structure. This value typically falls within the stiffness range of a cancellous bone. The bone of an adult human being is histologically composed of two bone types – the substantia corticalis and the cancellous bone (Fig. 1). Cancellous bone is understood as the juxtaarticular (situated in the vicinity of a joint), highly porous structure of the bone at the bone's end, which is frequently subjected to a damage fracture, in particular in osteoporosis patients. Open-porous metals enable bone cells and blood vessels, which are absolutely necessary for bone growth, to be incorporated. Moreover, the strength of these materials may also be compared with that of bones. The great interest of medical research in such materials arises from these properties.

Project Description

Open-porous metals are under development at the Fraunhofer Institute Center IZD in Dresden, in a cooperative effort between the Fraunhofer institutes IFAM and IKTS. These developments are focussed on implants made of steel or titanium. These materials are produced by means of a powder metallurgical replication technology, in which reticulated polyurethane foams are impregnated with a metal powder-binder suspension. In the next step, the organic material is removed thermally, and the powder skeleton is sintered. In this process, very homogeneous foam-like structures with a density of ~ 1 g/cm³ (Fig. 2) are formed. The mechanical properties of the bone replacement material may be specially adapted to the corresponding values of the bone through a targeted manipulation of the material's density and structure. This may be done, for instance, by setting up the desired coating thickness or by selecting a particular basic material. Specifically, this technology makes possible an individual adaptation to the state of the surrounding bone material. This way, the material may be adjusted to fit either into an adolescent bone or an older, osteoporotic bone.

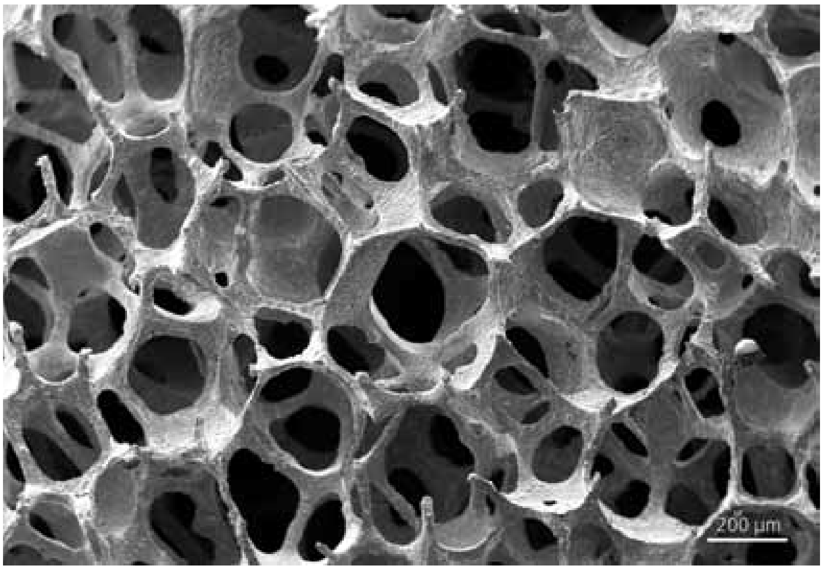


Fig. 2: SEM image showing open-porous metal foam. The structure is very similar to the spongy bone structure.

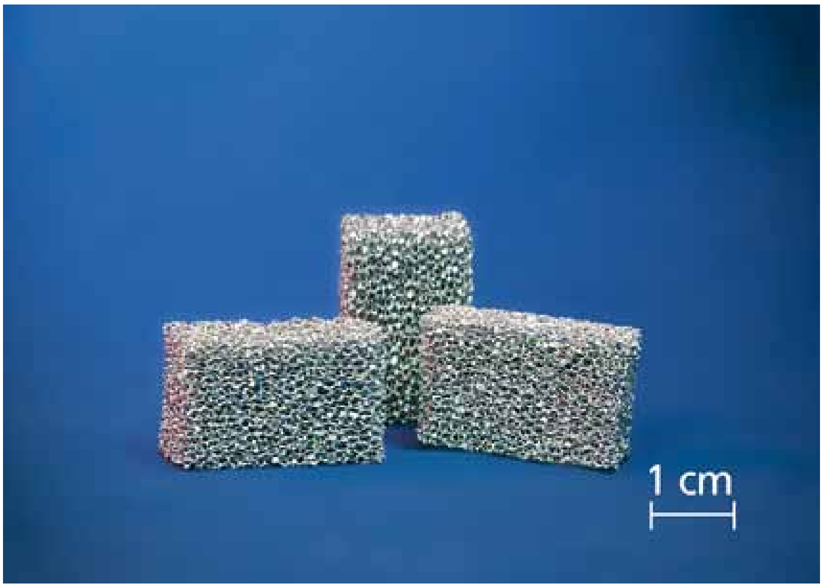


Fig. 3: Open-porous metal foam made of the titanium alloy Ti6Al4V.

This innovative material with its fascinating properties is analyzed in interdisciplinary projects; the Fraunhofer institutes cooperate with their industrial partners and clinics to explore the various materials, biological and medical aspects of engineering up to the application in the animal model.

Permanent Implants

Initially, the new implant material was conceived as a permanent implant. In other words, after the operation, the implant remains in the human body forever. For implants like these, titanium has been established as the material of choice. This is mainly because of its low density and extraordinarily strong biocompatibility, coupled with an excellent corrosion resistance. For unabsorbable bone replacement materials, this means contact with the bone that is free of connective tissue and inflammation. The good osteoconductivity of titanium also argues in favour of its use as an endoprosthesis. For this reason, among metallic replacement materials, titanium and its alloy Ti6Al4V enjoy the highest acceptance on the market. Thus, it seems reasonable to design a bone replacement material based on titanium. This is the subject of the joint project TiFoam funded by the Federal Ministry for Science (BMWi).

The challenge in implementing the concept with the material titanium comes mainly from the extraordinary affinity of titanium for the elements of oxygen, carbon, nitrogen, which, when they appear as oxides, carbides or nitrides, result in embrittlement of the material even at very low volumes. Here, we succeeded thanks to process optimization in producing open-porous titanium foams with the intended ductile characteristics (Fig. 3). From the perspective of medicine, the focus is on checking the applicability of the designed material. These tests are executed by the Dresden university hospital. The new implant material is incorporated as a replacement for vertebral bodies in sheep. The first tests with permanent implants demonstrated an outstanding in-growth of bone cells into the material.

Absorbable Implants

The development of biodegradable materials also follows another concept. At the beginning of the healing process, an ideal implant at first takes on the function of the full stabilization. As bone regeneration increases, the absorption of the implant materials introduces an augmented load transmission to the bone. In this ideal case, progressive osteointegration (in-growth of the bone) on the one hand, and degradation of the implant on the other guarantee an optimal adaptation to the corresponding strength state at any time (Fig. 4).

Magnesium has been discussed as an alternative bone material for some time. Although this material is highly biocompatible, it corrodes at such a speed that, as a rule, the newly established bone is not yet able to carry the load necessary. An alternative is to use iron as a biomaterial. Degradable iron implants were also tested in experiments in cardiovascular surgery. The implanted stents were completely absorbed and left no pronounced inflammation reactions. However, implants made of degradable iron have received far less consideration in bone surgery. Nevertheless, they are very interesting, since iron corrodes much more slowly than magnesium. Furthermore, iron is mechanically more stable.

At Fraunhofer IFAM, open-porous metal foams are developed on a base of unalloyed and low-alloyed steel. Here, even the influence of low-volume alloy additives is checked. Generally only alloy elements naturally produced with a high rate of biocompatibility in the body are under consideration. Thus, for instance, even a slight addition of phosphor < 1 % leads to a significant increase in the strength of metal foams. The degradation rate of the foam is the first interesting aspect. In-vitro investigations of this material carried out by the partner InnoTERE GmbH showed that degradation occurs within about two years. At present, the absorption of this implant material is being verified in an animal model at the university hospital Großhadern.

Prospects

Previous projects have proved that open-porous metal foams are suitable for use as a synthetic bone replacement, both as a permanent implant and a degradable implant. The crucial criterion is now to confirm the in-vivo results using the animal model. In the meantime, the focus is on the implementation of results, in particular on greater production of titanium implants and ongoing optimization efforts. Economically speaking, we need to determine whether the project results may also be used for the design of bone implants for various clinical ranges of application.

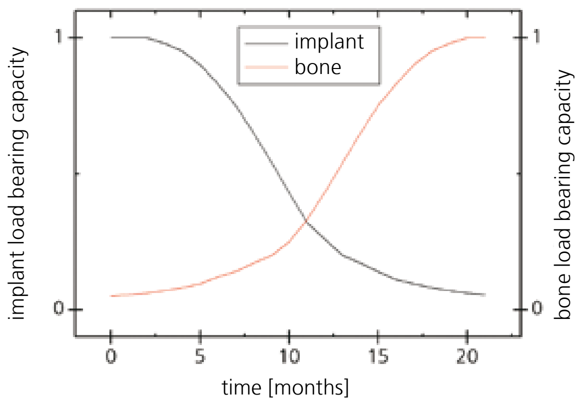


Fig. 4: Ideal healing and load transmission of an absorbable bone implant and the in-growing bone.

Contact persons

Dr. Peter Quadbeck
Phone: +49 351 2537-372
peter.quadbeck@ifam-dd.fraunhofer.de

Institute

Fraunhofer Institute for
Manufacturing Technology
and Applied Materials Research IFAM,
Department of Shaping and Functional Materials,
Dresden

Aluminum-fibre Sandwich Structures for Applications in Heat Exchangers

Initial Situation

Adsorption chillers generate useful cooling energy through water vaporizing out of a reservoir (vaporizer), from which the vapour is extracted by adsorption on a zeolite (in the so-called adsorber) (Fig. 1). To make use of this principle even in mobile applications, we need a power density that is a multiple of the state-of-the-art value. To achieve this, it must be possible to feed to and deduce large heat flows from a zeolite with poor thermal conductivity in a small space, so that conventional design types based on bulk no longer can be used for the adsorber.

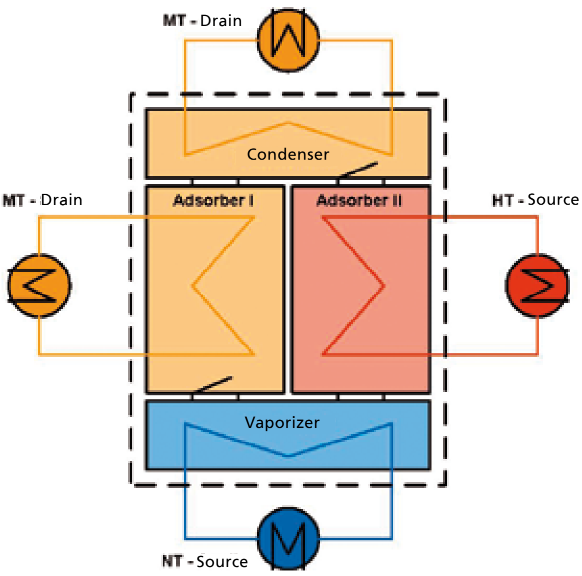


Fig. 1: Adsorption chillers – functional principle.

Paradigm

One feasible solution consists of thin zeolite layers deposited on a material with excellent thermal conductivity. However, the material as a whole should be kept open-porous, so that the steam will be unobstructed. For this reason, within the scope of a project carried out autonomously by Fraunhofer, THOKA (thermally driven high-performance cooling techniques), we developed aluminum fibre structures with a large specific surface in order to yield the highest possible volume of zeolite.

Results and Prospects

We succeeded in finding an aluminum alloy capable of liquid sintering of bulk commodities (loose fibres) with thermodynamic calculations. To produce the fibres out of the designated special alloys, the Fraunhofer IFAM's melt extraction procedure was applied (Fig. 2). Liquid state sintering also makes it possible to form a connection to sheets (Fig. 3).

Fig. 2: Melt extraction system.

Fig. 3: Aluminum fibre sandwich.

Thus, we were able to manufacture aluminum-fibre structures with specific surfaces of maximum 15,000 m^2/m^3 with a porosity of 65 percent. Mutual sintering of the fibres affords a significant increase in thermal conductivity to 15 W/(m K).

Such structures were successfully coated with zeolites by an industrial partner. The Fraunhofer Institute for Industrial Mathemathics (ITWM) acted as project partner and analyzed tomographic structure images (Fig. 4) to deduce (abstract) calculation models to dimension the adsorber. With the new structures, it was possible to obtain a clear increase in power density up to more than 300 W/l, as proven by kinetic tests carried out by the Fraunhofer Institute for Solar Energy Systems (ISE) (Fig. 5). This way, we were able to achieve power densities at which the application of adsorption cooling processes becomes feasible. Other projects are aimed at optimizing manufacturing processes and further increasing power densities to make the process as economical as possible.

Project Partner

WISA THOKA
Fraunhofer Institute for Solar Energy Systems (ISE)
Fraunhofer Institute for Industrial Mathemathics (ITWM)
Fraunhofer Institute for Process Engineering and Packaging IVV
Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM in Bremen

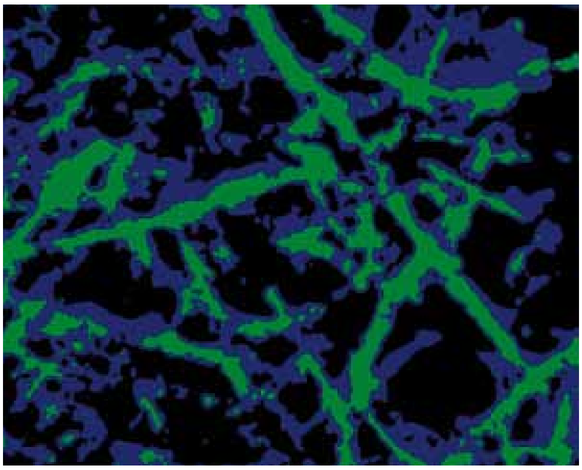


Fig. 4: Tomographic pseudocolour image of the fibre structure coated with zeolite. Green: Aluminum fibres, blue: Zeolite coating.

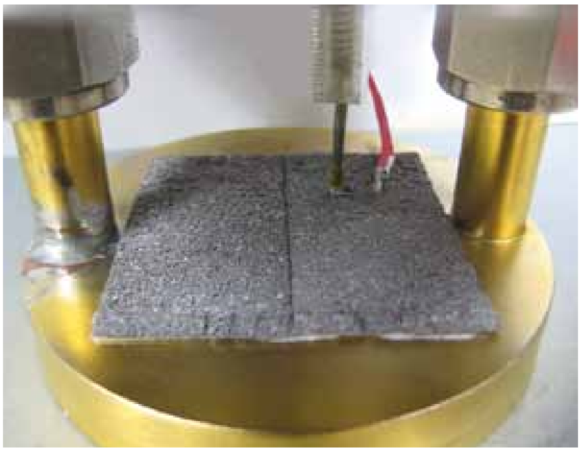


Fig. 5: Zeolite-coated aluminum-fibre structure in the kinetics test bench of Fraunhofer ISE.

Contact persons

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

Institute

Fraunhofer Institute for
Manufacturing Technology
and Applied Materials Research IFAM,
Department of Shaping and Functional Materials,
Dresden

Department of Adhesive Bonding Technology and Surfaces

Results Applications Perspectives

VUV excimer plant of the Fraunhofer IFAM for activating and coating surfaces.

Expertise and Know-how

The Department of Adhesive Bonding Technology and Surfaces at the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research is the largest independent research group in Europe working in the area of industrial adhesive bonding technology. More than 170 employees carry out industry-oriented R&D activities in the fields of bonding and surface technology. The activities range from fundamental research to technical implementation and market introduction of new products. Industrial applications are mainly in car manufacture and plant construction, energy technology with a focus on wind and solar energy, micro-production, packaging and the electronics industry.

The work in the area of adhesive bonding technology involves the development and characterization of adhesives, the design and simulation of bonded and hybrid joints, as well as the characterization, testing and qualification of such joints. Planning and automation of industrial adhesive bonding applications is also undertaken. Other key activities are process reviews and certified training courses in adhesive bonding technology and fiber composite materials.

The work in the area of surfaces is subdivided into plasma technology and paint/lacquer technology. Customized surface modifications – for example surface pretreatment prior to bonding/coating and anti-corrosion coatings – expand the industrial uses of many materials.

Both these work areas involve surface and interface analysis. The knowledge acquired here makes a significant contribution to improving the safety and reliability of bonded joints and coatings.

The Department of Adhesive Bonding Technology and Surfaces is certified according to DIN EN ISO 9001, and the Materials Testing Laboratory and the Corrosion Testing Laboratory are also 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. The Plastics Competence Center is accredited in accordance with the German quality standard for further training, AZWV. The Certification Body for the Manufacture of Adhesive Bonds on Rail Vehicles and Parts of Rail Vehicles is accredited by the Federal Railway Authority (EBA) in accordance with DIN 6701-2 and in part in accordance with DIN EN 45012.

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 our customers, we develop innovative products which are later successfully introduced to the marketplace by the companies. Manufacturing technologies are playing an increasingly important role here, because high product quality and the reproducibility of production processes are key requirements for success in the marketplace.

Adhesive bonding technology has been employed for vehicle construction for a long time, however, its potential has not yet been fully utilized. Lightweight construction for vehicles as a means of saving resources, recycling, intentional debonding 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 our activities is: Make the bonding process and the bonded product even safer!

We can only achieve this objective 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 pretreatment 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 production of products
- Training courses in fiber composite technology for production staff

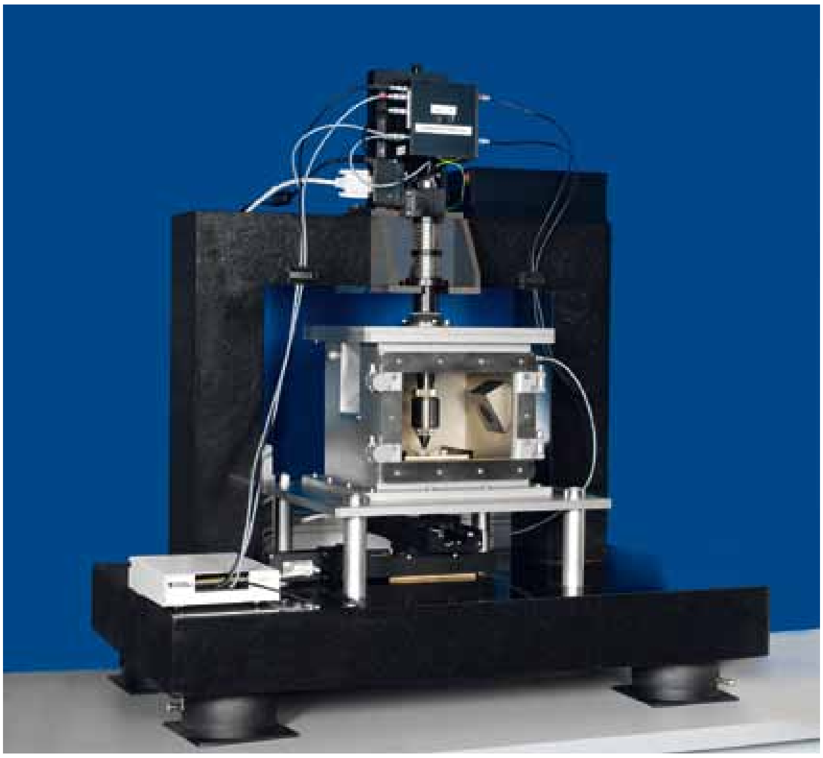
In all areas, the Fraunhofer IFAM is making increasing use of computer-aided methodologies, for example the numerical description of flow processes in dosing pumps/valves, multiscale simulation of the molecular dynamics at a molecular level and macroscopic finite element methods for the numerical description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

A variety of spectroscopic, microscopic and electrochemical methods are 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 ageing and corrosion tests cannot provide.

Other key questions for the future include the following: Where and how is 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 surface technology.

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



Contact-free potential measurement for corrosion testing using a scanning Kelvin probe.

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 superlattice, and biopolymers
- Computer-aided material development using quantum-mechanical and molecular-mechanical methods
- Internationalization of training courses: Adhesive Bonder, Adhesive Specialist and European Adhesive Engineer
- 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 pretreatment 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 life-time-estimation of bonded and hybrid joints
- Material models for adhesives and polymers (quasi-static and crash states)
- Evaluation of ageing 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

Icing chamber.

Fields of Activity and Contact Partners
Managing Director Dr.-Ing. Helmut Schäfer

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, qualification of adhesives, sealants and coatings; damage analysis; electrical/optical conductivity contacts; adaptive microsystems; dosing ultra small quantities; properties of polymers in thin films; production concepts.

Adhesives and Analysis
Dr. Jana Kolbe
Phone: +49 421 2246-446
jana.kolbe@ifam.fraunhofer.de

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

Processes and Automation
Dr. Holger Fricke
Phone: +49 421 2246-637
holger.fricke@ifam.fraunhofer.de

Microsystem and Medical Technology
Dr. Thomas Gesang
Phone: +49 421 2246-474
thomas.gesang@ifam.fraunhofer.de

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 construction.

Low Pressure Plasma Technology
Dr.-Ing. Klaus Vissing
Phone: +49 421 2246-428
klaus.vissing@ifam.fraunhofer.de

Atmospheric Pressure Plasma Technology
Dr. Jörg Ihde
Phone: +49 421 2246-427
joerg.ihde@ifam.fraunhofer.de

Plant Technology/Plant Construction
Dr. Alfred Baalmann
Phone: +49 421 2246-473
alfred.baalmann@ifam.fraunhofer.de

Adhesives and Polymer Chemistry

Priv.-Doz. Dr. habil. 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; surface functionalized with peptides; marine protein adhesives.

Biomolecular Surface and Material Design
Dr. Klaus Rischka
Phone: +49 421 2246-482
klaus.rischka@ifam.fraunhofer.de

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 (pretreatment, application, drying); damage analysis; application-related method development.

Development of Coating Materials
Dipl.-Ing. (FH) Yvonne Wilke
Phone: +49 421 2246-613
yvonne.wilke@ifam.fraunhofer.de

Application Technology and Process Engineering
Dipl.-Ing. (FH) Sascha Buchbach
Phone: +49 421 2246-497
sascha.buchbach@ifam.fraunhofer.de

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
Dr. Thorsten Fladung
Phone: +49 421 2246-451
thorsten.fladung@ifam.fraunhofer.de

In-line Surface Analysis
Dr.-Ing. Susanne Markus
Phone: +49 421 2246-612
susanne.markus@ifam.fraunhofer.de

Electrochemistry/Corrosion Protection
Dr.-Ing. Peter Plagemann
Phone: +49 421 2246-530
peter.plagemann@ifam.fraunhofer.de

Applied Computational Chemistry
Dr. Peter Schiffels
Phone: +49 421 2246-567
peter.schiffels@ifam.fraunhofer.de

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; 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
Dr. Christof Nagel
Phone: +49 421 2246-477
christof.nagel@ifam.fraunhofer.de

Mechanical Joining Technology
Dr.-Ing. Oliver Klapp
Phone: +49 421 2246-479
oliver.klapp@ifam.fraunhofer.de

Center Adhesive Bonding Technology/Training Courses

Prof. Dr. Andreas Groß
Phone: +49 421 2246-437
andreas.gross@ifam.fraunhofer.de
www.kleben-in-bremen.de
Training courses for Adhesive Bonder, Adhesive Specialist and European Adhesive Engineer with Europe-wide certification via DVS®-EWF; In-house courses; consultancy; qualification of production processes; studies; health, safety and the environment; training course for Fiber Composite Technician.

Plastics Competence Center Bremen and Bremerhaven
Dr. Silke Mai
Phone: +49 421 2246-625
silke.mai@ifam.fraunhofer.de
www.kunststoff-in-bremen.de

Fraunhofer Project Group Joining and Assembly FFM

Dr. Dirk Niermann
Phone: +49 421 2246-439
dirk.niermann@ifam.fraunhofer.de
Assembly involving bonding, riveting and combinations thereof – suitable for industrialization; adaptive precision machining; automated measuring and positioning processes; non-destructive tests for large CFRP structures.

Business Field Development

Dr.-Ing. Helmut Schäfer
Phone: +49 421 2246-401
helmut.schaefer@ifam.fraunhofer.de

Technology Broker
Dr. Michael Wolf
Phone: +49 421 2246-640
michael.wolf@ifam.fraunhofer.de

New Research Fields
Dr. Uwe Lommatzsch
Phone: +49 421 2246-456
uwe.lommatzsch@ifam.fraunhofer.de

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

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.

Other Contact Person
Dr. Markus Brede
Phone: +49 421 2246-476
markus.brede@ifam.fraunhofer.de

Process Reviews

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.

Dr. Dirk Niermann
Phone: +49 421 2246-439
dirk.niermann@ifam.fraunhofer.de

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

Equipment/Facilities

Department of Adhesive Bonding Technology and Surfaces

- Low pressure plasma plants for 3-D components, bulk products and web materials up to 3 m³ width (HF, MW)
- Atmospheric pressure plasma plants for 3-D components and web materials
- Robot 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
- 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 and high speed workplace monitoring
- Laboratory vacuum press with PC control for manufacturing multilayer prototypes
- 300 kV and 200 kV transmission electron microscopes EDX, EELS and 3-D tomograph
- 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)

IMO test chamber for measuring corrosion for applications on ballast water tanks.

- 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
- Testing technology for anti-icing coatings
- IMO test 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)
- Fluorescence microscope

Moving out of the Laboratory: The Fraunhofer IFAM soon to be Working with Large CFRP Structures

A flashy car which raises the heartbeat: the Porsche Carrera GT. Sports car fans will be amazed by the top speed of 334 km/h and the incredible acceleration which takes the 450,000 euro car up to 200 km/h in less than 10 seconds. Materials engineers are, however, more interested in the Carrera GT for another reason – it is the first series production car in which the chassis and the door modules are completely made from carbon fiber reinforced plastic (CFRP). The car is an example of the growing trend to use CFRP components for automobile manufacture.

The Fraunhofer IFAM is involved in these developments: The institute has been working for some 20 years on the joining of CFRP materials and has supported developments in this sector with important research results. The knowledge is generally acquired in the laboratory and then transferred to large scale applications. The Fraunhofer IFAM is now extending its services: The recently established Fraunhofer Project Group Joining and Assembly FFM will soon also be involved with the joining of large CRFP structures, including the associated tests, in the future Research Center CFK Nord.

In CFRP materials, carbon fibers are embedded as reinforcing layers in a plastic matrix – for example an epoxy resin (Fig. 1). In particular for components which are exposed to high loads, the optimal orientation of the fibers can be calculated using computers. This allows very high strength and stiffness to be achieved. There is a further advantage: CFRP is light. And light and strong materials are just what are required to build the aircraft, cars, trains and ships of the future. With energy costs ever increasing, lower weight structures mean lower fuel consumption and in some cases higher speeds can also be achieved. In addition, these CFRP materials have favorable fatigue properties under alternating loads, good damping properties and many other advantages which make them very interesting for all means of transport as well as for wind turbines.

The cost of carbon fibers and the matrix resins are, like energy costs, determined by the market and are difficult to influence. For that reason, opportunities for cost-saving in manufacturing and assembly processes are becoming ever more

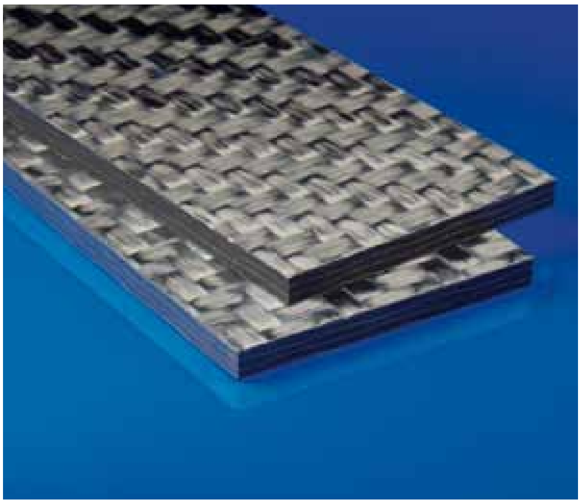


Fig. 1: Carbon fiber reinforced plastic (CFRP material).

important. The latter, in particular, is the focus of work at the Fraunhofer IFAM: For example, automated adhesive bonding and riveting processes in the assembly of CFRP structures for aircraft manufacture is vital for meeting future requirements regarding productivity and production costs. Optimized non-destructive testing and inspection methods for quality assurance are also part of this.

The Fraunhofer IFAM has already made many contributions to the safe and reliable bonding of CFRP components, ranging from various pretreatment techniques to application and testing methods: Using the know-how available in-house or in collaboration with other Fraunhofer institutes, many problems have already been solved regarding the application and advanced development of CFRP materials. However, customers were not always able to directly transfer the solutions developed in the laboratory to large-scale applications, and in some cases this necessitated time and cost intensive use of their own resources. For this reason, the Fraunhofer IFAM decided to extend its R&D services in the CFRP area to a 1:1 scale. The growing number of fiber reinforced components being used in large structures – for example in the new wide-bodied Airbus aircraft this is currently 20 % but will increase to 50 % – enforces the importance of this future-oriented step. The use of the technology in general industry will be anticipated by the institute in such a way that companies can concentrate on their actual design/production tasks and operations.

Fig. 2: Assembly of the Airbus A380 in Hamburg (source: Airbus Deutschland).

New Scale – New Challenges

For the experts at the Fraunhofer IFAM, the step up to real dimensions brings a series of new challenges. The design of the parts to be joined and also the nature of the joining processes must be agreed in close collaboration with the customers. One example from the aircraft manufacturing sector: Here there are a variety of specifications regarding the shape and appearance of a component – for aerodynamic reasons or for resource-friendly assembly (Fig. 2). There are also requirements regarding joining technologies for large CFRP structures. Are the thickness of the adhesive films and the overlaps of the components sufficient to give a reliable bonded joint? How can meter-long bonded joints be tested by non-destructive means and automatically? What forces act and what deformation occurs at the joints? How do they cope with external influences such as water, acids and UV radiation? Matters which in the meantime are routine and easy to answer on a small scale must now be reconsidered to take into account the large scale.

The organization of the abovementioned matters on a 1:1 scale brings new challenges for the Fraunhofer IFAM. The core expertise of the institute is the design of structures with optimum probability of remaining intact. The new large-scale work, however, changes the basic conditions. Things that function smoothly on a laboratory scale are confronted with totally different tolerance requirements on a large scale. It must be clarified what deviations from the optimum, uniform layer thickness of adhesive – used for laboratory scale work – still allows the extended mechanical requirements to be met. This requires, for example, efficient "tolerance management" in order to ensure that an uneven joint in the production – for example when joining large fuselage sections of several meters diameter for aircraft manufacture – or an adhesive is so designed that the safety requirements are 100 % fulfilled.

A further task of the Fraunhofer IFAM is to transfer lab-proven methods to a large scale. Surface pretreatment and adhesive application must also be able to be carried out on large surfaces in a reproducible way with uniform quality. That is only possible on large structures using robots. For adhesive application, exact quantities of adhesive must be applied at the correct places. The curing must also be able to be optimally incorporated

Fig. 3: Autoclave for manufacturing fiber reinforced plastics.

into the production process. The Fraunhofer IFAM aims to find the best solution for the respective application – even if that means developing new adhesives. Following successful assembly, reliable quality tests must be carried out on a large scale. This is also a significantly more demanding task than on a small laboratory scale. The evaluation of the comprehensive test results across several hundred meters of bonded joint per day can no longer simply be carried out by people but requires the assistance of relevant software.

In summary, the abovementioned aspects mean that in order to continue the success story of CFRP technology, more efficient production, assembly, inspection and repair processes will be required in the future. In order to bring this to fruition, close collaboration of industry with R&D service providers such as the Fraunhofer IFAM is indispensible. There is, however, also a further point which must not be neglected under any circumstances: The bonding of the CFRP structures must be undertaken by trained technical personnel at the user companies and they must possess all the special knowledge required for their area of work.

Training Course: Fiber Reinforced Plastic Technician

There is no training which covers fiber composite materials along with production methods. Qualified personnel in this area are being urgently sought in many branches of industry.

The Fraunhofer IFAM has also taken measures here: In conjunction with industrial partners the Fraunhofer IFAM has established a fiber reinforced plastic (FRP technician) training course at the Plastics Competence Center Bremen and Bremerhaven

INFO

Fraunhofer FFM and Research Center CFK Nord in Stade

On December 23, 2008 the government of Lower Saxony made available the funds for building the Research Center CFK Nord in Stade. Completion is planned for mid 2010.

The objective of the new research center is to promote industrial-related advanced development of production and assembly processes for large CFRP components. The focus will be on aircraft manufacture, and also on other forms of transport, wind turbines and large structures. The total process chain will be represented on a 1:1 scale: from the manufacturing processes – under the leadership of the German Center for Aviation and Aerospace (Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR)) – through to assembly, involving joining, processing, repair and non-destructive testing which will be carried out by the newly founded Fraunhofer Project Group Joining and Assembly FFM.

The FFM project group, as a department of the Fraunhofer IFAM in the area of CFRP technology, will fill the gap between the laboratory/small pilot plant scale and industrial scale in the range of services provided by the Fraunhofer-Gesellschaft.

which also includes CFRP materials. The 4-week course over 160 hours is accredited by the AZWV. It covers both theoretical and practical work (Fig. 3). Since May 2007 more than 180 participants have taken the course – from industry as well as people seeking work. More than 80 % of the latter subsequently found a permanent job.

In 2009, the course will for the first time be held in four 1-week blocks, aimed at those currently in work, thus allowing optimum combination of the course with normal work activities. As the content of the training course is jointly designed and given by people from the worlds of science and industry, it is optimally adapted to the special practical requirements of companies and the commercial market – an important prerequisite for promoting the use of CFRP materials.

Contact persons

Fraunhofer Project Group Joining and Assembly FFM
Dr. Dirk Niermann
Phone: +49 421 2246-439
dirk.niermann@ifam.fraunhofer.de

Plastics Competence Center Bremen and Bremerhaven
Dr. Silke Mai
Phone: +49 421 2246-625
silke.mai@ifam.fraunhofer.de

Institute

Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM, Department of Adhesive Bonding Technology and Surfaces, Bremen

Hybrid Joints: Combining Riveting and Adhesive Bonding

Fig. 1: Hybrid CFRP joint.

Scientists in the Materials Science and Mechanical Engineering section at the Fraunhofer IFAM have being working for a number of years on combining two joining techniques, namely riveting and adhesive bonding, which optimally complement one another for the construction of aircraft, road and rail vehicles, and ships (Fig. 1). The scientists are convinced that their solutions, particularly for aircraft manufacture, will see a renaissance in adhesive bonding – with many benefits for the customers. In the aircraft manufacturing industry increasing use is being made of advanced, lightweight materials made of metals and carbon fiber reinforced plastics (CFRPs). In particular, adhesive bonding is the ideal joining technique for "black plate", as CFRP is commonly known amongst experts because of its deep black color. This is because adhesive bonding does not weaken the material to any extent – in contrast to riveting, which needs holes to be drilled in the components being joined. Effective and reliable adhesive bonding should hence help reduce the number of rivet holes when joining CFRP components. The aircraft manufacturing industry is very interested in these hybrid joining techniques and is currently carrying out the first projects with specialists at the Fraunhofer IFAM.

A look into the past shows that the use of adhesive bonding for aircraft manufacture is not new, but has quite a history. The importance of this joining technique has however fluctuated over the years. In the middle of the last century, bonded wooden structures were successfully used in aircraft manufacture. Even back then, there was a move towards "lighter – faster – cheaper", and this soon pushed aluminum to the center of attention. Aluminum could also be effectively joined using the proven adhesives used for wood. As aircraft became ever larger and ever more complex, other joining techniques – such as riveting and welding – increasingly came into play, particularly since many adhesives were toxic and they had to be cured at high temperatures and pressure. Substitute adhesives which were developed proved not be effective enough, and there were particular shortcomings with regard to the corrosion resistance. The consequence: Besides having undisputed benefits for aircraft manufacture, adhesive bonding was put aside and up until today riveting has been the preferred joining technology.

That was not least due to the fact that so-called *fail-safe* requirements have been placed on connections in the aircraft manufacturing sector: The failure of a riveted joint in an aircraft may not be spontaneous or have catastrophic consequences. For example, cracks can be identified during an inspection and repairs carried out. Adhesive bonds, in contrast, must however be appraised by *safe-life* considerations: They can remain intact for a long time, but sometimes there is no warning of impending failure – unlike the warning given by the visible fine cracks around riveted joints. Scientists at the Fraunhofer IFAM are actively working on finding a way of determining the active state of adhesive bonds in order to be able to predict possible failure in advance. At present this is still futuristic, but great strides have been made in recent years in the area of non-destructive testing technology. For safety reasons, therefore, the aircraft manufacturing industry is at present only considering using adhesive bonding in combination with riveting (forming so-called hybrid joints) for joining primary CFRP structures.

Riveting is a proven technology for joining metallic structures, for example aluminum and titanium. The demands of the aircraft manufacturing sector for ever greater weight-saving – at equivalent or even higher loads on the structures – has in recent years brought new, ultra-modern materials into the spotlight. Carbon fiber reinforced plastics (CFRPs) are ideal, because they not only have high strength and stiffness but under alternating loads are also highly resistant to fatigue and have good damping properties (see also the trend report "Moving out of the laboratory: The Fraunhofer IFAM soon to be working with large CFRP structures" on Page 78). At present 20 % of the new large-bodied Airbus A380 comprises CFRP components, and this will rise to 50 % in the future A350.

Riveting CFRPs Takes away Many of the Benefits of these Materials

Given the high fraction of fiber composite materials in aircraft, what is the most suitable joining technology to use? The abovementioned reasons indicate that although rivets are indispensible, their use removes many of the benefits of CFRP materials. These materials have high strength, because during the manufacture of the components the fibers align themselves optimally in the direction of the stress. The load flow can be calculated using computer simulation methods and gives information about how the fibers must be aligned in order to ideally absorb and dissipate the forces. Rivet holes interrupt the force flow: From a long-term perspective, riveting is therefore a disadvantageous joining technique, because when rivets are employed the full potential of modern CFRP materials cannot be fully utilized.

As adhesive bonding is a material-fit joining technique and does not require holes being drilled in the substrate structures, it is the optimal joining technique. However, in some areas this technology has not yet reached sufficient process maturity to allow unreserved use.

Against this background, the Fraunhofer IFAM has for some time been undertaking advanced R&D work in collaboration with Airbus Deutschland GmbH on the hybrid joining of both metallic structures and CFRP components. It is being investigated, for example, whether combining these two joining techniques allows elimination of one of the three rows of rivets on a longitudinal seam on the aircraft fuselage. If the sealant which has been required up until now for sealing and corrosion protection was replaced by a suitable adhesive, the load capacity of the joint could be considerably increased, despite the fact that there are fewer rivets. This would also shorten the production time. Aspects to be examined include the best way to apply the adhesive and interaction with the riveting process.

The aim here is not to make rivets overall superfluous. Rivets are used for fastening large structures which are being bonded at selected points. They hold the components together during the curing process. However, in the medium term the currently practiced transfer of riveting technology from the production of metallic structures to CFRP structures must be reconsidered. This is because ultimately this leads to the fiber composite materials not being optimally joined.

Fig. 2: C-frame automatic riveting machine of the Fraunhofer IFAM.

Accurate Recording of All Process Data – The C-frame Automatic Riveting Machine of the Fraunhofer IFAM

In order to further the R&D work on the described hybrid technology under industrial conditions, the Fraunhofer IFAM brought an ultra modern C-frame riveting machine into operation (Fig. 2 and 3) in 2008. The machine represents the very latest technology and has been optimized for riveting CFRP materials. The objective of the work is to combine riveting and adhesive bonding optimally and to utilize the resulting synergies to produce improved, more resistant joints in an easier and more favorable way. This will be achieved by utilizing the benefits of the two individual joining techniques.

In contrast to older, hydraulic riveting machines, the automatic riveting machine of the Fraunhofer IFAM is electrically driven. This makes it possible to record all process data continuously and with high accuracy. That is necessary, amongst other things, because the Materials Science and Mechanical Engineering section at the Fraunhofer IFAM is also actively working on simulating the mechanical behavior of riveted joints using the Finite Element Method (FEM). The aim here is to predict the strength of riveted joints and hybrid joints based on simulations. The load limit of such joints depends not only on the external loads which are acting but also considerably on the internal stress which acts inside the joints. The internal stresses largely arise due to the installation process for the rivets, and these must also be accurately simulated: starting with the positioning of the rivet parts, via the drilling and on to fitting the rivet. The same simulation procedure will be carried out for bonding or hybrid joining with application and curing of the 'adhesive' joining element. By comparing the simulation results with the empirical data from, for example, the riveting machine, the simulation results can be validated and the prediction accuracy considerably improved.

The control system of the C-frame riveting machine records for example upsetting forces, upsetting paths, locking forces, drill advance and drilling torque. A high-speed camera monitors the whole process in the work zone and shows, for example, the critical start of the drilling of CFRP materials and the drill removal from the materials, how the closing head formation takes place and much more. This information in turn also allows the simulation results to be validated and the quality of the simulations to be further improved. This procedure not only deepens our understanding of the process. The medium term aim is also to use the combination of experimental results and simulated results to be able to evaluate the process parameters in such a way that statements can be made about the stability and load limit of hybrid joints.

This does not, however, fully describe all the applications of the C-frame riveting machine. The Fraunhofer IFAM also offers the machine for qualifying fasteners for the aircraft industry. One-part and two-part fasteners can be fitted under industry-relevant conditions.

Another service provided by the Fraunhofer IFAM is the subsequent mechanical testing of the joints, using an array of test methods under defined climatic conditions. This work is undertaken in the institute's own testing laboratory. The results give the customers clear statements about whether the fasteners are suitable or not for their production.

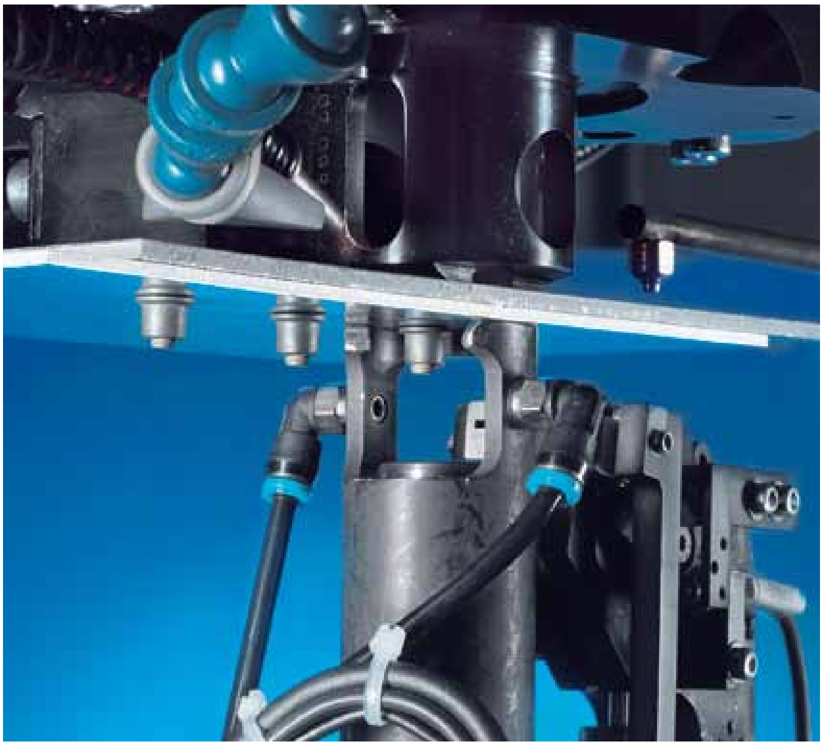


Fig. 3: Automatic lower die lock bolt.

Contact person

Dr.-Ing. Oliver Klapp
Phone: +49 421 2246-479
oliver.klapp@ifam.fraunhofer.de

Institute

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research IFAM,
Department of Adhesive Bonding Technology and
Surfaces,
Bremen

New Approaches for Plasma Technology and Surfaces: Multifunctional Coatings in Only a Single Processing Step

The Fraunhofer IFAM has been involved in adhesive bonding technology for more than 40 years – and hence has also been involved with the surfaces of materials which are bonded or coated. For these surfaces and their properties play a key role: indeed, many materials require customized pretreatment and modification to give the additional functionality which provides the component with its usage value. The section Plasma Technology and Surfaces (PLATO) at the Fraunhofer IFAM was founded at the start of the 1990s and has been involved in many important developments in this sector right through to market introduction. These are used today in virtually all sectors of industry – including the electronics industry, car manufacturing sector, medical technology sector, and packaging industry.

Materials are cleaned and activated using a wide range of techniques. This allows adhesives, sealants and paints to adhere better to these materials. They are then coated to give the materials new functions: scratch resistance, anti-soiling properties, water-repellant properties, corrosion resistance and dehesive (namely non-adhesive) properties. The PLATO section has many ongoing partnerships with industrial companies, but constantly seeks new fields and areas of application to form new customer circles and open up new markets. Due to future-oriented development work and promising results from R&D projects, new strategies for functionalizing materials or products via suitable surface pretreatment constantly arise. Special attention at the moment is being put on the development of methods which allow multifunctional coatings to be generated in a single processing step. The bringing together of hitherto separate functionalization steps should shorten production processes and allow layer combinations which up until now have involved considerably higher processing complexity.

Surface Technology is a Cross-sector Technology

New developments in one area always have implications for other areas. Functional surfaces are required everywhere – in the aviation and aerospace sectors, in the car manufacturing industry, in electronics and production engineering, in machine construction, and the consumer goods' industry. The low pressure plasma technology of the Fraunhofer IFAM is a proven and recognized technology. It was used, for example, to develop the PermaCLEAN$^{PLAS®}$ coating – an ultra-thin plasma-polymer anti-adhesion coating. Lacquers and paints only adhere very weakly to its surface. In the lacquering industry, gratings are coated with this coating. It is resistant to cleaning with extremely high water pressure. Due to PermaCLEAN$^{PLAS®}$ it is considerably easier to free the gratings of paint residues.

Fig. 1: Antimicrobial coating of catheters via plasma technology.

There are various dehesive films with a similar effect, for example the patented anti-soiling surface DryCLEAN$^{PLAS®}$ or the release layers BestSkin$^{PLAS®}$ and ACMOS Coverel®. The coatings are generated via plasma-assisted deposition and grease, dirt particles, and even adhesives hardly adhere to them. Components coated in this way – for example for molding processes – mean that for example the plastic components can be more easily removed from the molds. Traditional release agents are not required for processing the plastic components and hence cleaner plastic components can be manufactured. Other successful work of the PLATO section ranges from adhesion promotion to reliable corrosion protection right through to anti-bacterial coatings for biological-medical systems (Fig. 1)

Advantages of Combining PVD and CVD Coating

The developments and experience of the PLATO group provide the basis for new challenges in new areas. Particularly interesting is the generation of multifunctional films in a single processing step by utilizing synergies. In general up until now, there has been a process for each specific surface functionalization. The PLATO scientists are now working to adapt similar processes to each other so that in the future they can be carried out in a single step process. An example of the principle is combining PVD (Physical Vapor Deposition) and CVD (Chemical Vapor Deposition) for transparent polycarbonate plastics. These are used for vehicle headlights, helicopter domes and helmet visors (Fig. 2). Both processes run under vacuum, with layers being applied to a substrate by either physical deposition or chemical reaction. Due to the treatments, the polycarbonate plastics have scratch protection and protection against ultraviolet radiation. Up until now two process steps were necessary. The PLATO scientists now want to combine these in one application and even improve the quality of the coating. The addition of an anti-soiling or water-repellant layer is also possible, facilitating the cleaning the components. Future users not only have cost benefits due to the shorter process times but also profit from the high-quality multifunctional coatings.

Combining Processes at Atmospheric Pressure

The linking of several processing steps is not only being undertaken for vacuum applications but is also being attempted for atmospheric pressure processes. An example of this is combining aerosol processes and atmospheric pressure plasmas (AP plasmas). AP plasmas already allow very good corrosion protection to be achieved via plasma-polymerization: The layers provide a barrier to water, electrolytes and oxygen (Fig. 3). If the coating is mechanically damaged, the substrate can corrode locally to a limited extent at those spots.

Scientists at the Fraunhofer IFAM are currently working on an active corrosion protection layer in which chemical inhibitors are embedded. They are released on there being damage to the layer and

Fig. 2: Transparent scratch protection for plastic surfaces.

protect the material at the damaged spot via an inhibition effect.

Via suitable feeding, particles can be specifically treated in the AP plasma. These can be fed dry or also in the form of an aerosol into the reactive

Fig. 3: Corrosion protection for aluminum pressure-die casting components using atmospheric pressure plasma technology (AP plasma technology).

zone of the discharge. This is interesting, for example, for the functionalization of carbon nanotubes (CNT). When used in plastics or coating materials the new fillers can, for example, increase the strength or conductivity. Due to the functionalization of their surfaces and their increased chemical reactivity, the carbon nanotubes can be more uniformly dispersed in the coating material, and in higher quantities, and this increases the efficiency.

In addition, new ways of particle feeding and particle treatment in the reactive discharge zone are being investigated. The aim is to adapt the plant and processing conditions to achieve as high as possible treatment efficiency, without adversely affecting the desired properties of CNTs.

VUV Irridation and Aerosol Treatment in a Single Step

Another approach is to provide materials with functional coatings via a combination of aerosol application and vacuum ultraviolet radiation (VUV). The technology of VUV radiation is still a new field for the PLATO group. Due to the excellent equipment which includes an ultra modern VUV excimer plant (Fig. 4 and 5), PLATO is able to realize different process steps under various atmospheres.

Interesting for the medical sector is the goal of the Fraunhofer IFAM to generate customized surface functionalities via radicals. This involves reactive atoms or molecules which are excited via VUV radiation or via a plasma. They are used to generate specific biocompatible layers – important, for example, for implants to prevent rejection by the body. These biological systems are also interesting for the areas of adhesion promotion and the functionalization of textiles.

Fig. 4: VUV excimer plant of the Fraunhofer IFAM for activating and coating surfaces.

Fig. 5: Internal view of the VUV excimer plant.

Selective surface functionalization via low pressure plasma (LP plasma) and wet-chemical post-treatment is similar: A surface provided with many functionalities after activation with LP plasma is made so uniform that only the functionality desired for the planned application remains on the surface. This allows, for example, the specific requirements of biocompatible materials – for example a heart valve made of special steel or implants made of titanium – to be met.

Contact person

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

Institute

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research IFAM,
Department of Adhesive Bonding Technology and Surfaces,
Bremen

Synthetic Peptides and Functionalized Nanoparticles as the Basis for Medical Adhesives of the Future

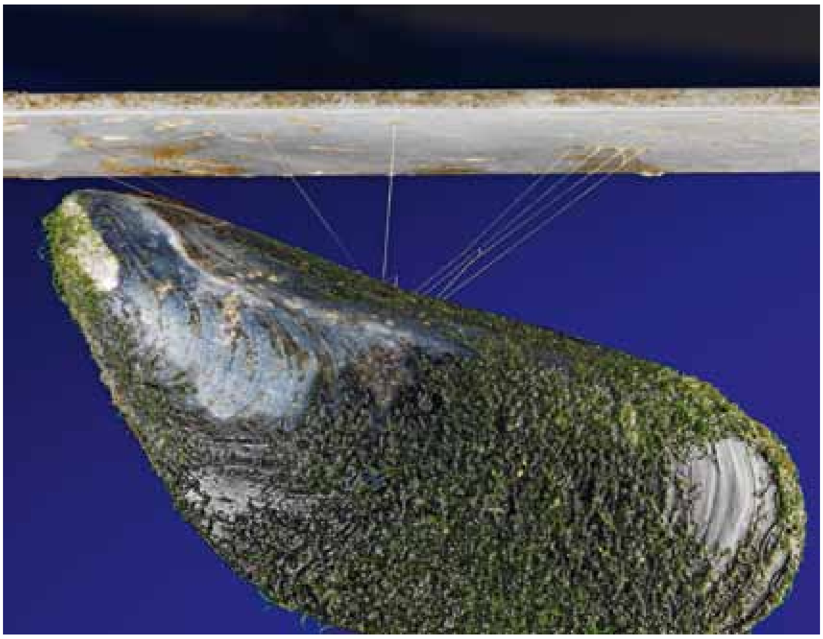


Fig. 1: Common mussel Mytilus edulis.

The Biomolecular Surface and Material Design (BIOM) and Applied Computational Chemistry (ACC) work groups at the Fraunhofer IFAM are currently working with partners on a collaborative, multidisciplinary, three-year research project on new approaches for synthesizing adhesives for medical applications. The project partners are the Surface and Material Technology work group of the Institute for Materials Science and Technology at the Friedrich-Schiller-University of Jena and the research group in the Materials Laboratory of Dental Clinic 1 at the University Hospital Erlangen.

The objective of the project, which is being sponsored by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG), is to develop a biologically based hybrid adhesive system. The project is entitled "Peptide-based nanohybrids as adhesive systems for medical applications" and involves researching the interactions between peptides, polymers and oxidic ceramics.

Important aspects here are the search for suitable adhesive peptide structures, investigation of the bonding processes to biogenic connective tissue and proteins and customized nanoparticle functionalization. The results of these fundamental studies will provide the foundation for future development of high-performance adhesives for applications in dentistry and orthopedics.

An example from dentistry will clarify the background of the research work. The securing of ceramic replacement teeth, after manufacture and shaping, is generally carried out with a special adhesive. The adhesive is cured immediately with a UV lamp. Over the course of time, however, the adhesive bond can lose its strength, because the replacement tooth is subjected to extreme loads – firstly due to the high forces which act on the tooth during chewing and secondly due to the aggressive conditions in the mouth. Water, sugar and acids strongly attack the bonded joint over the course of time. The dentist undertakes steps to guarantee optimum securing of the tooth: The tooth surface is first of all etched and demineralized by an acid treatment in order to expose the organic components underneath. Further treatment steps guarantee optimum chemical and micromechanical bonding of the filler materials. Here, the adhesive should penetrate as deep as possible into the so-called hybrid layer. The hybrid layer is extremely sensitive to moisture and is the critical point for securing the replacement tooth. Minute traces of moisture reduce the adhesion strength, as does too strong drying of the dentine.

Key to Improved Adhesion: The Common Mussel

In order to solve the problem, help was sought from a creature in nature – the common mussel *Mytilus edulis* (Fig. 1). It is able to bond to stones, rocks, ships' fuselages and harbor installations, even under the most severe conditions in aggressive saline seawater.

The BIOM work group at the Fraunhofer IFAM has been studying the mechanisms of adhesion of common mussels for a number of years. In particular, the group is investigating the interactions at the interfaces between synthetic materials (such as metal, ceramics, plastic and glass) and the organic biomatter. In the past the work group has been successful in synthesizing parts of the protein-based adhesive material of the mussels. In ongoing DFG-funded research projects the work is focusing on a specific component of the protein Mefp-1 (*Mytilus edulis* foot protein 1).

This common mussel protein is composed of repeating peptide sequences, the so-called decapeptides. The peptides in turn are composed of amino acids. A key amino acid for the bonding of the common mussel is dihydroxyphenylalanine (dopa). Other amino acids in a specific sequence are also necessary to guarantee optimal adhesion.

The researchers working on the DFG project are investigating which specific sequence of amino acids have to be present in the adhesive to optimally bond the ceramic surface of the replacement tooth and also ideally to bond the organic collagen fibers of the tooth. For these studies, the interactions of the decapeptide in the protein Mefp-1 with these two types of surfaces must be investigated in detail. One of the many questions to be answered is, for example, how the key amino acids required for bonding optimally bond with the tooth material. The liquid adhesive currently used in practice is drawn by capillary forces into the extremely fine channels of the dentine which are exposed by demineralization. As a result, the adhesive is able to undergo micromechanical bonding with the dentine. The objective of the work is to create strong chemical bonds in addition to this physical bonding. The amino acids must bond as strongly as possible to the collagen fibers in the dentine and hence develop a high-strength bond with the organic material.

Search for the Best Peptide Modifications

The powerful capabilities of solid phase peptide synthesis which IFAM possesses are an important basis for this work: At the Fraunhofer IFAM, peptides can be synthesized, modified, adapted and dyed. Using the synthesized Mefp1-decapeptide variants it can now be determined which peptides give an optimum bond with both the ceramic material and the collagen. This involves a large number of experiments, changing the peptide structure each time. The interactions between the respective peptides and the oxidic ceramics are being studied using Fourier Transformation Infrared Spectroscopy (FT-IR), Vibrational Circular Dichroism Spectroscopy (VCD), and by Molecular Modeling. The results of this work allow the most suitable modified peptides to be selected. Synthesized decapeptides with fluorescent labels are being employed in turn to study the interactions between the peptides and collagen. Laser Scanning Microscopy (LSM) then allows determination of whether the peptides have penetrated into the collagen lattice (Fig. 2).

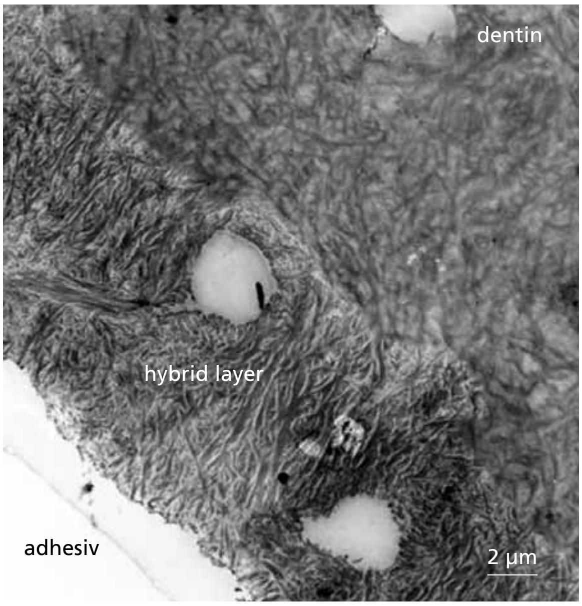


Fig. 2: Laser scanning microscopy image of the adhesive-dentine boundary layer in order to investigate the depth of penetration of the peptides into the collagen lattice: The hybrid layer region (diagonal collagen fibers running from top left to bottom right) is clearly penetrated by the adhesive applied to the tooth (adhesive, light region on the bottom left (source: University Hospital Erlangen).

This work is being carried out in close collaboration with Dental Clinic 1 of the University Hospital Erlangen. The interactions between the peptides and ceramics are being studied in collaboration with the Institute for Materials Science and Technology at the Friedrich-Schiller-University of Jena. For analysis of the adhesion mechanisms to ceramic materials and collagen, and for identifying the amino acids involved therein, computer-aided simulations (molecular modeling) play an important role. Microscopy provides information about whether a peptide is anchored to the material, but does not tell which amino acids play the key role. VCD spectroscopy gives a spectrum composed of different frequencies. Overlapping peaks, however, make it difficult to precisely assign the individual components of the spectrum to participating structural units.

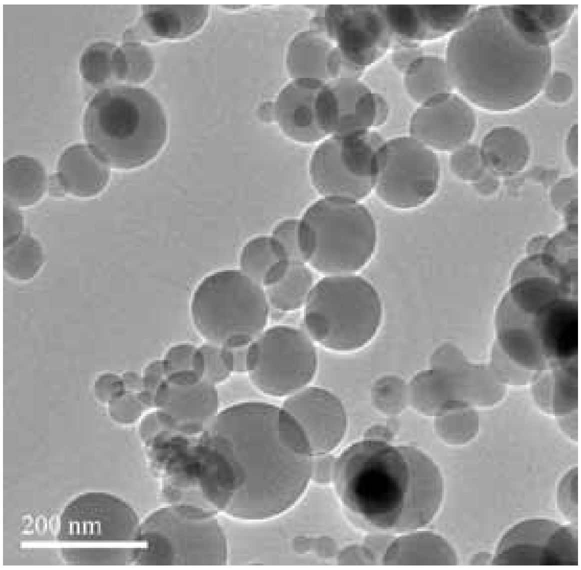


Fig. 3: Nanoparticles of calcium phosphate for modifying adhesives, manufactured by laser evaporation (source: Friedrich-Schiller-University of Jena).

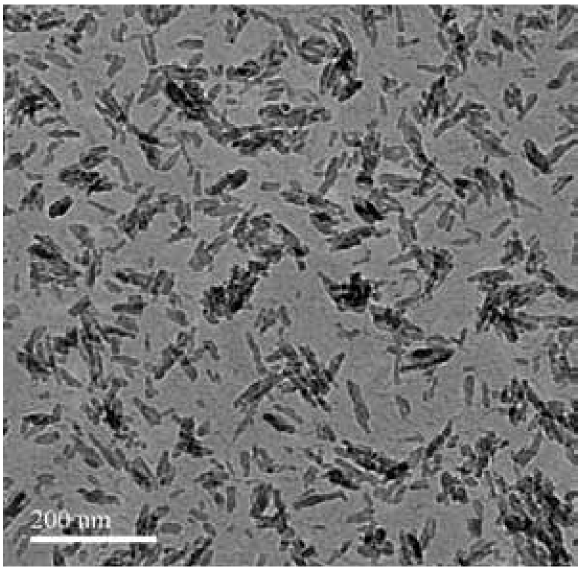


Fig. 4: Nanoparticles of calcium phosphate, manufactured by wet-chemical precipitation (source: Friedrich-Schiller-University of Jena).

For this reason, the adhesive being investigated in the practical laboratory tests is simultaneously simulated on the computer with the relevant sequence of amino acids. This gives an optimized model at the atomic level which, being self-built, contains all relevant information about the structural units: The structure of the peptide – and hence the sequence of the amino acids – is already known and is inputted into the model. A VCD spectrum is then calculated. This allows the structural units of the model to be precisely assigned to the individual components of the spectrum.

The calculated spectrum can now be compared with the experimentally determined spectrum until there is agreement. It can then be ascertained what portions of the experimental spectrum belong to which structural units. Comparison of the spectra also allows conclusions to be drawn about which amino acids have reacted with the surface – and which are therefore vital for the adhesion (Fig. 3 and 4).

In this way, computer simulation can also provide information about as yet "unsynthesized" peptides in order to ultimately find a model of an adhesive which gives optimum adhesion. For example, researchers learn which sites of the peptide have to be altered during synthesis in order to come as close as possible to the calculated ideal adhesive.

The simulation work shortens the R&D time considerably and is an important tool for realizing viable results. Parallel to the experimental tests, tensile tests are also being undertaken at Dental Clinic 1 in Erlangen to measure the adhesion strength of the adhesive systems.

For all the R&D activities, the BIOM and ACC work groups not only have ready access to all the knowledge available at the Fraunhofer IFAM but also benefit from the excellent equipment and facilities at the institute: For the synthesis, work up and analysis of the peptides and proteins, the equipment available includes a High Pressure Liquid Chromatograph (HPLC), a Matrix-Associated-Laser-Desorption-Ionization Time-of-Flight Mass Spectrometer (MALDI-ToF MS), FT-IR spectrometer, VCD spectrometer, and optical and fluorescence microscopes. For simulation of the structures and the VCD spectra, the Fraunhofer IFAM possesses two high performance computer clusters with a total of 128 processors and a wide range of commercially available and self-developed simulation methods.

The expertises of all the project partners are essential for the success of the project.

Project partners

University Hospital Erlangen,
Dental Clinic 1 – Operative Dentistry and Parodontology
Priv.-Doz. Dr.-Ing. Ulrich Lohbauer

Friedrich-Schiller-University of Jena,
Institute for Materials Science and Technology
Prof. Dr.-Ing. Frank Müller

Contact persons

ACC work group
Dr. Marc Amkreutz
Phone: +49 421 2246-647
marc.amkreutz@ifam.fraunhofer.de

BIOM work group
Dr. Klaus Rischka
Phone: +49 421 2246-482
klaus.rischka@ifam.fraunhofer.de

Institute

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research IFAM,
Department of Adhesive Bonding Technology and
Surfaces,
Bremen

Silicones – Surprisingly Good Adhesives

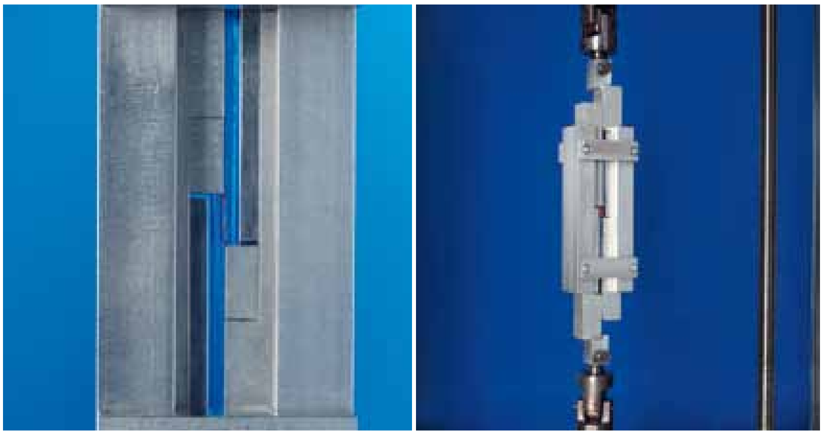


Fig. 1a and 1b: Shear test under compressive load on a glass test specimen bonded with silicone.

Introduction

Silicones are commonly used as release agents because there is very little adhesion to them – for example silicone paper for labels. Otherwise, silicone-based sealants are also widely used and are known for their good adhesion. This is particularly so for types of silicones which cure via a condensation reaction involving moisture-induced cleavage of acetic acid. The properties of the adhesives can be customized by careful selection of the base structure of the silicone and the adhesive formulation.

Typical properties are as follows:

- Shore A hardness 25 to 80
- Fracture strength 0.3 to 7.0 MPa
- Elongation at fracture 100 to 800 %
- Lap shear strength 1 to 13 MPa
- Temperature range for usage -100 °C to +200 °C (special types up to +300 °C)

Another group of silicone adhesives cure via platinum catalyzed addition of silicones which have Si-H groups to those having vinyl groups. The reactivity of the catalyst can be adjusted by adding retarders. It is, however, difficult to manufacture one-component silicones having adequate storage stability which cure via this mechanism. Also, there are many poisons for the platinum catalyst and after contact with such poisons curing is no longer possible. The best known catalyst poison is sulfur in virtually any chemical form, for example sulfur compounds in rubber materials.

A third curing variant is the peroxide vulcanization of silicones having high molecular weight and viscosity at high temperature. For silicones having suitably low viscosity for processing as adhesives, this reaction has up until now not been utilized.

The biggest advantage of silicones is their high heat resistance, in combination with high elasticity down to low temperatures.

Typical applications for silicone-based adhesives are electronics, medical instruments, aviation and aerospace, and the car manufacturing industry – in particular the engine electronics. Silicones are also often used for bonding glass. In order avoid glass fracture during mechanical tests, a modified shear test under compressive loads has been developed at the Fraunhofer IFAM (Fig. 1a and 1b).

Reinforcing Silicones

Silicones are commonly reinforced with hydrophobic-modified fumed silica. As soon as a certain amount of added silica is exceeded, there is a marked increase in the viscosity. However, this is not the case when individual silica nanoparticles (Nanocone®, produced by Hanse Chemie) are added.

The same applies when reinforcing silicones

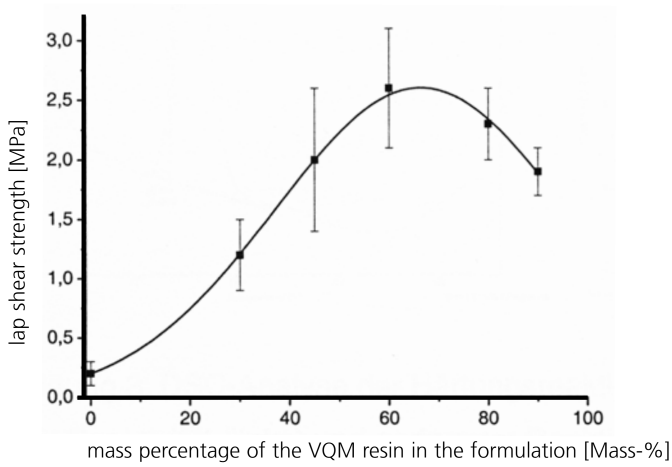


Fig. 2: Effect of the quantity of the VQM preparation on the lap shear strength of bonds prepared with peroxide cured silicone adhesives.

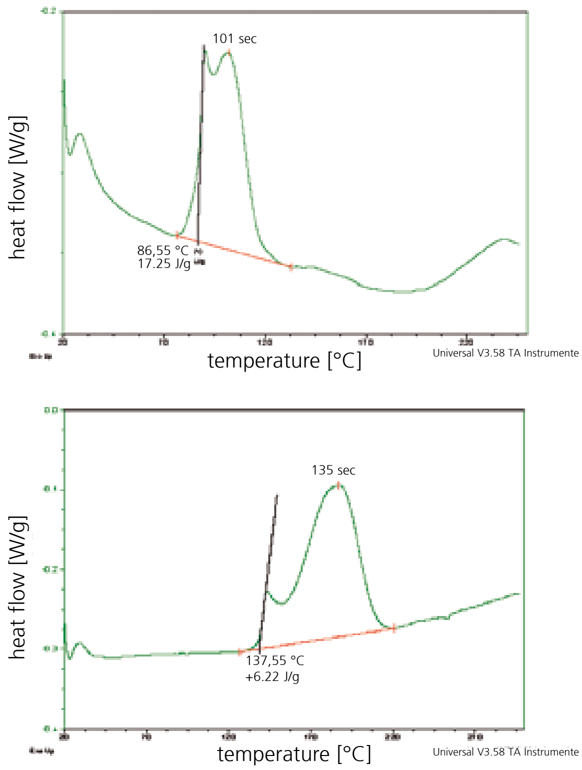


Fig. 3: DSC curves of the curing reaction with 1.5 mass percent peroxide, with high reactivity (top) and low reactivity (bottom).

with VQM resins. These materials have a certain similarity to POSS® – but their structures are not as orderly or free of defects – and contain reactive vinyl groups. Via the vinyl groups, the VQM is incorporated into the crosslinked silicone during curing. During the crosslinking reaction the Si-H groups of the crosslinking agent react with the vinyl groups of the base silicone and those of the VQM resin. In contrast to POSS®, VQM resins have good solubility in the silicones.

Figure 2 shows the effect of the amount of VQM on the lap shear strength of the bonded polyester substrates. A linear polydimethylsiloxane with vinyl end-groups and a silicone with Si-H groups were used as the base formulation. The amount of the VQM resin was varied and the amount of crosslinking agent so adjusted that there were equimolar amounts of Si-H and vinyl groups. The VQM resin which was used was a formulation of base silicone and 45 percent VQM resin. To initiate the curing reaction, 1.5 percent of peroxide was used. The curing was carried out at 170 °C over a period of 30 minutes. With increasing amount of VQM resin the modulus of the adhesive increased and for higher quantities a tough-elastic material formed. The figure shows that the adhesion strength increases with increasing amount of the VQM resin, but decreases again when the resin content is too high. The maximum, at circa 60 mass percent VQM, represents an optimum of strength and required elasticity.

Curing Reactions

For the addition reaction between the silicones containing Si-H and vinyl groups, traces of platinum are normally used as the catalyst.
The catalyst is destroyed if the surfaces of the substrates being bonded are contaminated, for example with traces of sulfur, tin or nitrogen. In addition, it causes either the whole silicone or a thin phase boundary layer not to cure: That is one of the biggest disadvantages of curing using platinum as a catalyst. This can however be overcome by employing peroxides as catalysts. Depending on the peroxide used, the curing can be carried out at different temperatures. Figure 3 illustrates this. The DSC curves (differential scanning calorimetry) for the curing reactions of the adhesive preparations – as described in the previous paragraph – show peaks at 100 °C and 180 °C depending on the reactivity of the selected peroxide. The adhesives are one-component systems with good adhesion properties which can be stored under outside temperatures. There was no evidence of poor curing on surfaces which contained catalyst poisons when using these adhesives.

Silicones as Additives

Due to their low surface energy, silicones are able to wet most surfaces, improve the distribution of fillers and prevent foam or blister formation. For these reasons, a great many additives used in adhesives, paints and grouting materials contain organosilicon portions in the molecules. The properties can be widely varied by selecting the chemical structure. This also applies to the effect on the adhesion. Besides the well-known dehesive properties of silicones, it is possible to use these

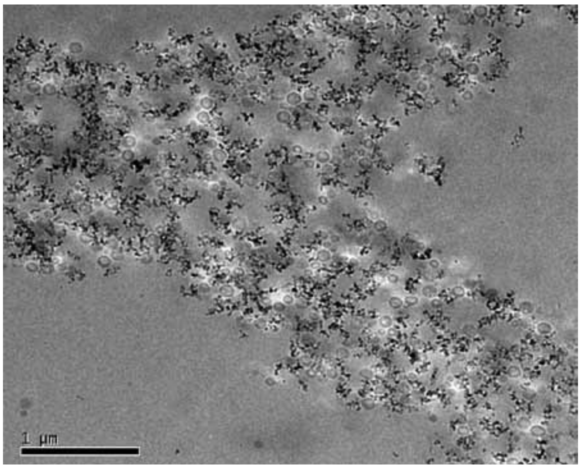


Fig. 4: Development of a microscale superstructure comprising silicone and silica nanoparticles.

as the base materials for adhesion promoters. In order to modify the cohesive properties of adhesives, silicones which become incorporated into the polymer network can be employed. For example, silicones with acrylate groups are incorporated into acrylate adhesives and those with epoxy groups into epoxy adhesives.

Silicones for Introducing Tough-elastic Properties

Just like other elastomers, silicones can also be used for making, for example, epoxy resins tough-elastic. As the use of conventional silicones often adversely affects the adhesion, it is recommended here to use crosslinked silicone particles. Silicone nanoparticles, modified on the surface, are particularly effective.

The combination of such particles with modified silica nanoparticles gave, for example, significantly increased lap shear strength and peel strength in an epoxy-based adhesive.

Interestingly, the two different nanoparticles form a microscale superstructure. This can be seen in the TEM image in Figure 4. Whether there is a causal relationship between the superstructure development and the marked synergistic effect of the particles must be investigated in future work.

Conclusions and Outlook

Silicones are suitable adhesives for applications requiring heat resistance combined with elasticity. Recently, individual silica particles and VQM resins have become available for reinforcement of the silicones. These complement the traditionally used hydrophobic fumed silicas. The curing of silicone adhesives is mostly carried out with a platinum catalyst. The reaction can also be undertaken with peroxides, if suitable catalysts are available. With the new variants, catalyst poisoning by traces of contaminants no longer has to be feared. In addition, many additives are based on silicones – and silicones are suitable for giving adhesives and other resins tough-elastic properties.

This summary shows that silicones have a wide range of applications in adhesive bonding technology and are slowly losing their inferior image. Ongoing and future project work at the Fraunhofer IFAM on the synthesis of new silicones and silicone-based polymers for special applications, the formulation of silicones and the use of silicone-based raw materials in other formulations will further emphasize this.

Contact person

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

Institute

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research IFAM,
Department of Adhesive Bonding Technology and
Surfaces,
Bremen

Automotive Quality Saar (AQS) – Development Center for Car Manufacturers and Suppliers

Adhesive Bonding Technology in Lightweight Automotive Construction

Modern lightweight design has revolutionized automotive construction in recent years and has led to notable improvements in weight, safety and comfort. At the same time, cost savings can be achieved. This is possible due, amongst other things, to the use of modern materials such as fiber reinforced composites or Tailored Blanks. Another factor in the progress that has been made is the use of modern joining techniques such as adhesive bonding and laser beam welding.

Adhesive bonding technology, in particular, allows the efficient production of hitherto difficult to manufacture material combinations, for example the joining of different metals to each other and the combining of metals with glass or fiber composite materials. The adhesives also allow additional functions to be introduced, for example vibration damping, electrical insulation and corrosion protection. This extremely versatile joining technique also improves the rigidity of vehicles. Bonded joints can nowadays meet the highest requirements and can also be very successfully used in combination with mechanical methods – such as clinching or riveting – and spot welding to form so-called hybrid joints.

Supplier Industry Undergoing Change

Following these changes in production technology, the automotive industry is faced with making radical changes to its production infrastructure. Over the coming years, there will be a considerable shift in the value-creation from the manufacturers to the suppliers. The latter will be far more responsible over the whole development phase for the production and supply of ready-to-install modules and complete systems. This development represents an enormous challenge for the sector and requires further extension of the production know-how and quality management of the suppliers.

Fraunhofer Competence for Innovation – AQS

The Fraunhofer Innovation Cluster AQS, Automotive Quality Saar, was established in 2007 as a technology development center to improve the efficiency of the supplier industry (Fig. 1). In the initial phase it is being funded in equal portions by the Saarland government, the European Union and the Fraunhofer-Gesellschaft. The total funding amounts to more than 27 million euros. Following this initial phase the center will be self-funding.

The Innovation Cluster consists of three Fraunhofer institutes: IZFP (Non-Destructive Testing) in Saarbrücken, LBF (Structural Durability and System Reliability) in Darmstadt and IFAM (Manufacturing Technology and Applied Materials Research) in Bremen. Their joint goal is to offer an attractive, need-based portfolio via the synergistic linking of available expertise and the further extension of expertise oriented to requirements of the automotive industry.

Fig. 1: Planned building complex of the AQS in Saarbrücken (source: Fraunhofer IZFP).

The Saarbrücken based innovation cluster AQS is involved with the following areas:

- Materials and construction
- Processing, production and joining technology
- Safety, reliability and service life

In collaboration with other partners, a machine park is set up where new technologies required by the automotive industry are being prepared, developed and qualified. The focus here is on the quality assurance compliant and innovative production, processing and utilization of, in particular, modern materials for hybrid and lightweight construction, plus the related joining and testing techniques.

AQS and the participating parent institutes cover the whole value-creation chain – from the raw materials via the tested component through to recycling and reuse of the final product.

Based on this knowledge, simulation tools and experimental devices for the design, structural evaluation and optimization of automotive components can be further developed or created.

Know-how from the Fraunhofer IFAM

The core expertise brought by the Fraunhofer IFAM into the innovation cluster AQS comprises:

- Low-heat joining techniques (adhesive bonding, mechanical joining, hybrid joining)
- Surface pretreatment
- Surface coating

The know-how of the Fraunhofer IFAM covers the complete process chain of adhesive bonding for the automotive industry, including related hybrid processes. The Fraunhofer IFAM is hence in a position to assist its customers during all phases of the production process (Fig. 2).

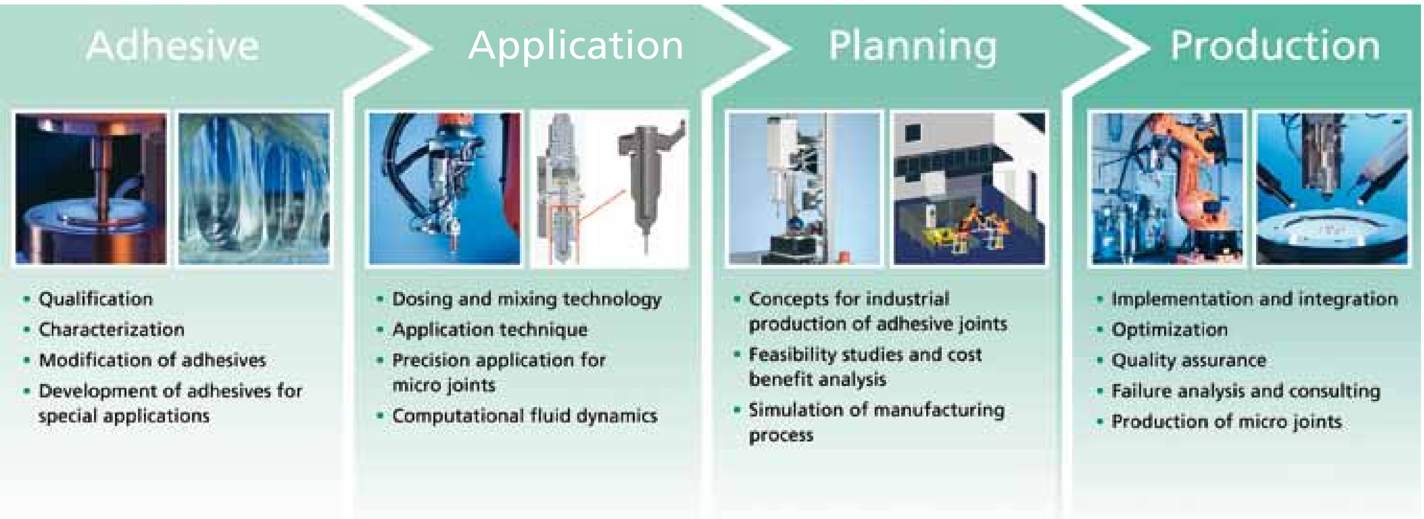


Fig. 2: Subject areas relating to adhesive bonding technology at the Fraunhofer IFAM.

The process chain comprises:

- Adhesive selection, modification and qualification
- Thermal analysis and rheology
- Adhesive bonding technology including micro-production, hybrid joining and adhesive coatings
- Bonding-related construction, process design and automation
- Process simulation (e.g. flow simulation)
- Destructive testing and service life characterization
- Quality management
- Economic considerations

The surface pretreatment and surface coating activities at the Fraunhofer IFAM provide the materials with additional properties which make them suitable for further applications. Surfaces are cleaned and activated so that lacquers, paints and adhesives adhere better to them. They are coated to realize new functions. The coatings provide, for instance, scratch resistance, anti-soiling, anti-tarnishing and corrosion resistance properties. Some examples of applied processes are fluorination, low pressure and atmospheric pressure plasma technology as well as coatings applied via plasma-polymer deposition. These technologies allow optimization of existing production processes and introduction of new surface properties which are often essential for the usability of materials.

Quality Management

The quality assurance of innovative products, new materials and technical services is based on national and international regulations and standards. Certification of testing laboratories and testing personnel is prescribed. The AQS hence qualifies the developed products and technologies in accordance with internationally recognized standards and guidelines of the automotive industry and makes its services available in the accredited laboratories of the participating Fraunhofer institutes.

The Adhesive Bonding Technology and Surfaces Department of the Fraunhofer IFAM is accredited in accordance with DIN EN ISO 9001. The Materials and Corrosion Testing Laboratories are also accredited in accordance with DIN EN IS0/IEC 17025. The Center for Adhesive Bonding Technology at the Fraunhofer IFAM has been certified via DVS-PersZert® in accordance with DIN EN ISO/IEC 17024 as an accredited and internationally recognized staff training organization for providing training courses in adhesive bonding technology.

Contact persons

Fraunhofer Innovation Cluster AQS, Saarbrücken
Administration
Dipl.-Ing. Siegfried Kraus
Dr.-Ing. Bernd Valeske

Fraunhofer Innovation Cluster AQS
at the Fraunhofer IFAM, Bremen
Dr. Jochen Skupin
Phone: +49 421 2246-465
jochen.skupin@ifam.fraunhofer.de

Institute

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research IFAM,
Department of Adhesive Bonding Technology and Surfaces,
Bremen

Calculation of High-Strength Bonded Steel Joints for Car Design under Crash Loads – More Rapid Product Development Using Numerical Simulation

Background

The competitiveness of the car industry can be improved by making greater use of computer simulation tools because the speed at which new products can be developed is increased. A contribution to this is made by simulations and relevant experiments for determining material parameters which allow the calculation of bonded joints in cars under crash loads.

For simulating the behavior of bonded joints, the dimension ratios of the bonded joints and the relatively complex material behavior represent a challenge. A bonded joint is long, but thin and narrow, meaning that a simulation with Finite Elements (FE) requires a great many elements which in turn means a long calculation time. The material behavior is elastic-plastic depending on the time and rate of loading, with plastic deformation not solely occurring under shear.

Description of the Project

Eight institutes, including the Fraunhofer IFAM, were involved in the project. The research expertise of these partners was in mechanics, numerical methods, adhesive bonding, and material/component behavior under high rates of loading.

The elastic-plastic and viscoplastic behavior as well as progress of damage and failure were to be studied. For this the necessary material, failure and substitute models were developed and efforts undertaken to improve the analytical methods for parameter determination under high rates of loading. In addition, the available FE tools were extended, modified and, after implementation, validated. The pursued solutions were first of all validated on simple test joints and then later on more complex component-like specimens.

Results and Perspectives

Material models and simulation methods were developed and implemented which for the first time allow computer simulation of the failure behavior of the bonded joints in the event of a crash. Two routes were explored: continuum-mechanical

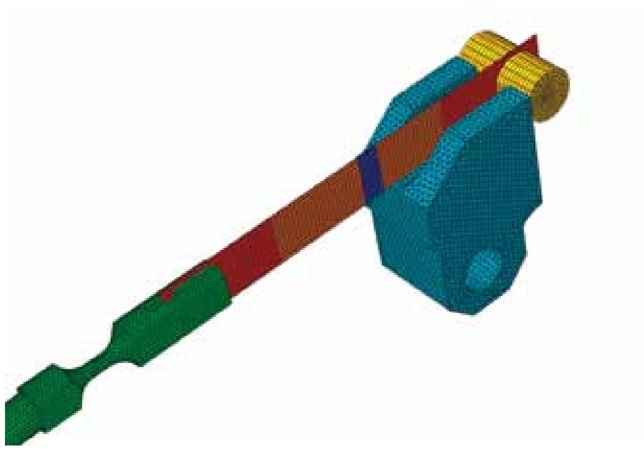


Fig. 1: Numerical simulation: FE model for dynamic test of a lap shear specimen.

models provide the basis for local consideration of the bonded joint, whilst simplified substitute models facilitate timely implementation in the industrial application.

For continuum-mechanical based approaches, both physically based formulations and also combinations with empirical approaches are available for the dependence of the plastic flow and failure on the rate of loading. The FE modeling requires several elements across the thickness of the adhesive layer. For the substitute models, special interface elements or simplified representations of the joint with a volume element across the thickness of the adhesive layer were chosen. The simplest approximation used was a bilinear substitute model with fracture-mechanical based failure.

Crash experiments on simpler test specimens – KSII-specimen, T-joint – as well as on modified components from car manufacture – B-column, inside door stiffener – were successfully modeled with the developed simulation methods. The progress in simulation technology which was achieved in the project also allowed deeper understanding of the tests at high rates of loading for determining parameters (Fig. 1, 2 and 3). In contrast to slow tests, during dynamic tests inertia effects can strongly influence the measurement signals. In some cases, improvements in testing technology were made during the project based on the simulation results.

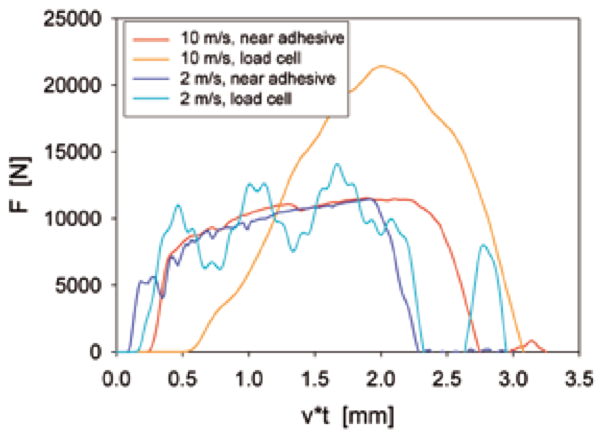


Fig. 2: Calculated forces from the simulation of the test of the lap shear specimen. F = force, v = velocity, t = time.

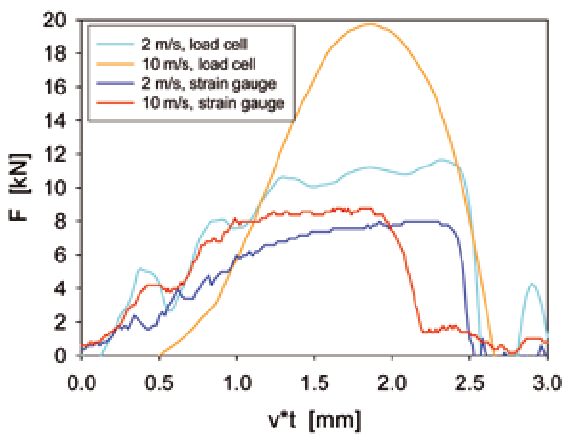


Fig. 3: The measurement results show good agreement with the results from the simulation (see Figure 2). F = force, v = velocity, t = time.

Currently the Fraunhofer IFAM and other project partners are implementing the new simulation methods into industrial practice at companies in the car manufacturing sector. In parallel, a further joint project is being planned to determine the robustness and reliability of the calculation methods. Based on quantification of all uncertainties, it is planned to optimize experiments, parameter identification methods and models.

Fraunhofer-Gesellschaft – Fraunhofer Institute for Mechanics of Materials IWM, Fraunhofer Institute for High-Speed Dynamics EMI (Ernst-Mach-Institute) and the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM.

Commissioning Parties

ThyssenKrupp Steel AG, Henkel KGaA, Daimler AG, Volkswagen AG, 3M Germany, DYNAmore GmbH, CADFEM GmbH, Dr.-Ing. h. c. F. Porsche AG, Sika Technology AG, Wilhelm Karmann GmbH, Adam Opel GmbH, DOW Automotive AG, Brose Fahrzeugteile GmbH & Co. KG, ESI GmbH, Arcelor Commercial FCSE, Ford-Werke GmbH, BMW AG with technical assistance and financial support from FOSTA – Forschungsvereinigung Stahlanwendung e. V., Düsseldorf, from funds of the Stiftung Stahlanwendungsforschung, Essen.

Project Partners

University of Kassel – Institute for Materials Technology and Institute for Mechanics
University of Paderborn – Chair of Technical Mechanics and the Laboratory for Material and Joining Technology
Technical University of Braunschweig – Institute for Joining and Welding Technology

Contact person and project coordinator

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

Institute

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research IFAM,
Department of Adhesive Bonding Technology and
Surfaces,
Bremen

Resource-friendly Miniature Loop Developed by the Fraunhofer IFAM – New Analytical Method for Characterizing the Shear Behavior of Polymeric Liquids

Fig. 1: Test loop at the Fraunhofer IFAM.

Challenges for Paint Loop Systems in Industrial Practice

For the industrial painting of cars, rail vehicles, aircraft, machinery and other large objects, the paint is usually supplied via paint circulation systems, so-called "loops". The paint is subject to considerable shear forces in the valves, pumps and mixer units.

As a consequence, there is a risk of:

- Redispersion of the pigments
- Damage to effect-pigments
- Damage to the dispersion film-formers in water-based paints (sticking together, "breaking" of the dispersion droplets, destruction of the polymer matrix)
- Changes in the viscosity (adverse effects on the technical-application properties)

For the development and release of a new paint it must be ensured that the paint loop systems can adequately withstand the forces. Otherwise, the paints cannot be used for industrial applications.

Traditional Test Loops

Up until now the testing of polymeric liquids for their suitability for use in loop systems has been carried out in test loops which mimic real industrial application plants. Due to the size of the test plants (volume capacity about 100 liters), there are very high costs, time requirements and environmental effects associated with procuring the test results. In particular, the cleaning of the test loop has a considerable environmental impact.

Polyshear – Development of a Miniature Loop

The objective of the Polyshear project at the Fraunhofer IFAM is to develop a miniature test chamber having a volume capacity of about 1 liter in which the flow and shear behavior of a conventional test loop can be mimicked.

The approach we adopted was to quantify the shear behavior of existing test loops in advance both experimentally and via numerical simulation in order to be able to subsequently transfer this knowledge to a miniature test chamber. By analyzing the conventional test loop it can be determined what potential stresses – in particular temperature, pressure and shear – on the paint must be borne by the individual components of a test loop (for example pumps, fittings, reductions, bends in pipes). The 20 meter long test loop at the Fraunhofer IFAM was used here as a model for large industrial plants (Fig. 1).

Numerical Simulation

Numerical simulation of the flow using Computational Fluid Dynamics (CFD) allows the shear force of the flow to be quantified.

The starting point for simulating the flow is precise specification of the geometries of all the components in the test loop via 3-D models or technical drawings. These data were transferred to a CAD program and processed. The region passed through by the liquid was extracted as the flow channel and was saved as the base model for the simulation.

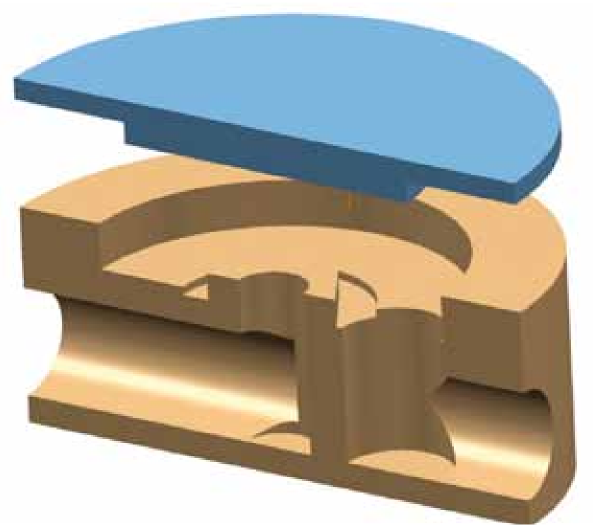


Fig. 2: CAD drawing of a pressure-reducer.

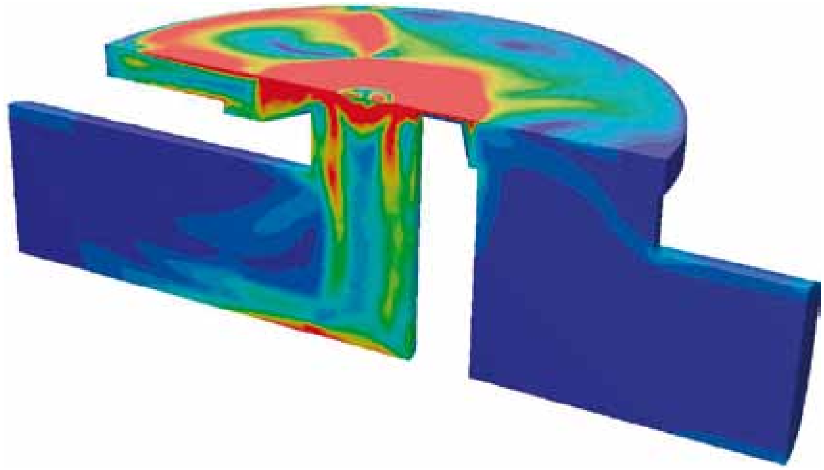


Fig. 3: Representation of the regions of the pressure-reducer subject to increased stress using computer simulation (CFD).

The kinematics of the moving components of pumps and valves are taken into account and incorporated into the simulation. The plant operating parameters such as temperature, pressure and feed quantity were incorporated as boundary conditions. In addition to modeling the geometry and process, determination of the material properties of the paint is also necessary. The simulation program also allows the shear forces in conventional size plants to be mimicked (Fig. 2 and 3).

During the course of the project it has been demonstrated that computer simulation is a very effective tool for determining the parameters of loop systems and that the acquired knowledge can be transferred.

Determination of the Shear Behavior of Paints

From computer simulation of the flow profiles and the determination of the shear behavior and stresses in the loop test, the shear rates experienced by an individual volume element during the course of the loop test can be calculated. Using these data, a test was carried out on the rheometer and a sample was subjected to shear (Fig. 4).

Both the experimental results on the test loop and the results of the flow simulations indicate that the pressure-reducer in the loop is the element on which the paint puts most stress.

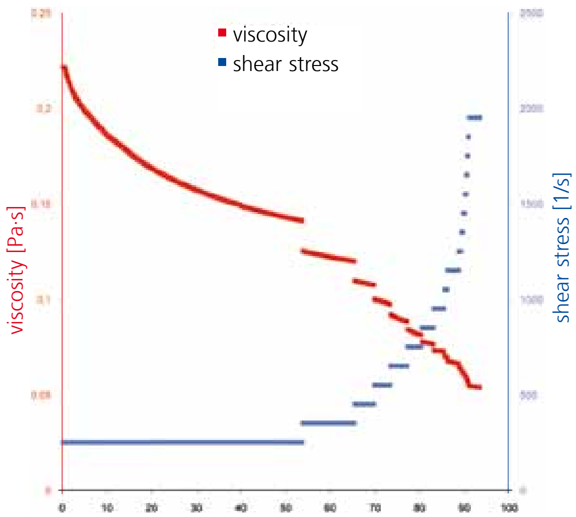


Fig. 4: Mimicking the shear stress on paint in a loop using a rotation-viscometer. The viscosity change is due to the change in the paint sample.

Fig. 5: Miniature loop at the Fraunhofer IFAM.

Development of the Miniature Loop at the Fraunhofer IFAM

Once the shear behavior has been quantified, the data can be transferred to the "one liter test chamber": The precondition for the concept of a compact test chamber with miniature loop has been met.

The miniature plant consists of a container having a volume capacity of 1 liter, a membrane pump and a pressure control valve which are connected to each other by a single line. To quantify the stress caused by the paint, the pressure before and after the pressure-reducer and the flow are measured and displayed. The total volume of paint in the system is about 0.6 liters.

In the miniature loop, the key point is that the paint, despite the short path, is just as highly stressed as it is in industrial operations. This test loop at the Fraunhofer IFAM not only allows the paint system to be operated continuously but also intermittently, namely in one feed direction (Fig. 5 and 6).

Resource-friendly Test Method for Paint Manufacturers and Paint Users

For paint manufacturers and users – in, for example, the car, rail vehicle and aircraft manufacturing industries as well as the machine construction sector – the development of the miniature loop by the Fraunhofer IFAM and its project partner the Fraunhofer UMSICHT means that there is now a resource-friendly test method for characterizing the shear behavior of polymeric liquids for paints and coating materials.

It is possible to heat the loop up to 40 °C. During the tests, the temperature, pressure, flow rate and shear rate are measured inline at different places and documented. This allows, for example, viscosity changes due to a new batch of paint or due to too long circulation in the loop to be directly measured. The miniature test loop can be operated at low pressure or at high pressure.

All components which subject the paint to high stress are integrated into the miniature test loop at the Fraunhofer IFAM. Other lines and hoses which cause little stress to the paint have been omitted. Instead of 50 to 100 liters of paint which are required in a conventional test loop, a maximum of 1 to 2 liters suffice in the miniature loop.

The project involved the planning, sizing, construction and operation of a favorable-cost miniature loop which allows paints to be characterized under favorable conditions. It therefore, in particular, offers small and medium-sized companies the opportunity to test and qualify newly developed products at considerably lower cost than has hitherto been possible.

Fig. 6: Miniature loop.

Project partner

Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT

Contact persons

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

Dr. Holger Fricke
Phone: +49 421 2246-637
holger.fricke@ifam.fraunhofer.de

Institute

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research IFAM,
Department of Adhesive Bonding Technology and
Surfaces,
Bremen

Fraunhofer-Talent-School Bremen 2008 – School Pupils Experience the World of Science

Practically-oriented Talent-School 2008 at the Fraunhofer IFAM.

Under the motto "Fraunhofer-Talent-School Bremen 2008", four workshops were held between October 13 and 15, 2008 at the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research. Almost 50 talented school pupils with ages ranging from 15 to 19 took part in the 3-day science program.

With there likely to be a shortage of qualified scientists in the future, the headquarters of the Fraunhofer-Gesellschaft in Munich initiated the idea of the Talent-School in 2006. The idea was to interest more school pupils in a scientific career at an early stage, to motivate them to study science and engineering at college and university, and ultimately to promote the Fraunhofer-Gesellschaft as a potential employer of young talented scientists.

From June 2008 onwards, the school pupils were allowed to apply for a place in one of the workshops of the Fraunhofer-Talent-School Bremen 2008. The condition for application was either a recommendation by a teacher at their school or demonstration of special knowledge and skills in the subject area of the relevant workshop. Interest in the workshops was enormous, with over 70 applicants for the 30 places in the 3 workshops. To allow more people to participate, the number of places per workshop was increased from 10 to 12 and the workshop on adhesives was held in duplicate, meaning that almost 50 workshop places in total could be offered. Most of the participants were from Lower Saxony and Bremen, but some also came from Berlin, Hamburg, Schleswig-Holstein and North Rhine-Westphalia to take part in the 3-day long program. The program covered the following topics:

Scientists chatting with school pupils.

Holding the World Together - The Chemistry and Physics of Adhesives

This workshop, which was held in duplicate, covered the fundamental principles of adhesive bonding – adhesion and cohesion. The tutors of the Center for Adhesive Bonding Technology at the Fraunhofer IFAM gave the participants a broad insight into the world of adhesives. The theory was complemented by practical work in which the properties of adhesives were modified and tested.

Building Blocks of Life - Bioanalysis of Proteins

The participants were informed about the structure and function of proteins. Also, protein-based bioadhesion and the mechanisms involved in this were discussed.

In order to gain improved understanding of the functions of proteins, the structure of proteins was dealt with at some length. The tutors at the Fraunhofer IFAM introduced the participants to modern biochemical methods of protein analysis – SDS gel electrophoresis, dye methods, protein digestion and MALDI-ToF MS – and mentioned the importance of database searches.

Large Equations – Rapid solutions

Scientific and technical problems are often described by differential equations. Via "discretization" these are transformed into large equation systems. The resulting equation systems have specific characteristic properties which are of importance for efficiently solving them. The workshop first of all covered a few mathematical principles. In the second part of the workshop the participants, under the guidance of a tutor from the Fraunhofer Institute for Algorithms and Scientific Computing (SCAI) in Sankt Augustin, put the acquired mathematical knowledge to practical use: Working in teams, a variety of efficient methods for solving large equation systems were programmed and used to solve a model problem.

Expanding the Participants' Insight

After the first day of the workshop program, the participants were led on an evening action program organized by a team of students. The program took the form of a city rally, which not only allowed the school pupils to get to know each other better but also allowed them to see Bremen and its sights. The evening program on the second evening was a get-together with the institute management and scientists at the Fraunhofer IFAM which allowed questions to be asked about careers and the work at Fraunhofer institutes as well as a detailed impression to be gained of scientific work and more specifically of the everyday work of a Fraunhofer employee.

Positive Experiences of 2008 – Prelude for the Fraunhofer-Talent-School Bremen 2009

At the end of the 3 days at the Fraunhofer IFAM the school pupils were asked to give their feedback by completing a form. Overall there was very positive feedback about the Talent-School and in particular the evening get-together with the IFAM employees: The school pupils gained new and positive experiences and are in a better position to make decisions about their future careers.

The participants were particularly positive about the pleasant working atmosphere at the institute and the fact that during the three days they were treated as researchers and were taken seriously. A large contribution here was made by the high practical content and the laboratory activities. The school pupils were able to work in the institute's laboratories under the guidance of their supervisors and so gain new experience: Due to a lack of equipment at schools, such work and opportunities were hitherto unknown to the school pupils.

The tutors were also very positive about working with the school pupils – it was a challenging yet rewarding experience with knowledge-hungry and highly motivated young people: The Fraunhofer-Talent-School Bremen will be held again at the Fraunhofer IFAM in the autumn school holidays of 2009.

Contact person

Beate Brede
Phone: +49 421 2246-421
beate.brede@ifam.fraunhofer.de

Institute

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research IFAM,
Department of Adhesive Bonding Technology and
Surfaces,
Bremen

Fraunhofer Center for Wind Energy and Maritime Engineering CWMT (up to 31.12.2008) – Fraunhofer Institute for Wind Energy and Energy System Technology IWES (from 1.1.2009)

Up until the end of 2008 the Fraunhofer CWMT in Bremerhaven carried out industry-related R&D work on the utilization of wind energy. The work covered the testing of materials, surfaces, joints and production technologies as well as the structural durability and system reliability of plants. The Fraunhofer CWMT was jointly operated by the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM in Bremen and the Fraunhofer Institute for Structural Durability and System Reliability LBF in Darmstadt. A workforce of about 380 people and an infrastructure comprising laboratories and analytical facilities covering an area of more than 20,000 square meters were available.

The main task of the Fraunhofer CWMT was to focus the expertise of the Fraunhofer IFAM and LBF on wind energy utilization and maritime engineering as well as specific project work in close collaboration with the wind energy and offshore industry. The services offered ranged from fundamental research work right through to market introduction of products. The work covered the use of new materials, surface protection systems, joining technologies, integrated sensors and actuators plus relevant processing and production technologies. For example, work was carried out to optimize the design of offshore structures for weight, production costs and technical availability.

The activities of the Fraunhofer CWMT were split between two areas. In the area of System Reliability, numerical tools and analytical methods were developed and adapted for specific tasks. The aim was to increase the quality of service life predictions and at the same time reduce the necessary experimental testing work. In the area of Rotor Blade Testing, rotor blades and their components for the current and next generation of turbines were statically and dynamically tested on ultra-modern test stands. By combining experimental and numerical methods, new test methods were developed, new designs were tested and service life tests were carried out.

With this successful foundation, a new Fraunhofer Institute was established on January 1, 2009: The Fraunhofer Institute for Wind Energy and Energy System Technology IWES (see also the report on Page 113: From CWMT to IWES).

Like the Fraunhofer CWMT, the Fraunhofer IWES is funded by the Land Bremen and federal funds.

Land Bremen
Senator for the Environment, Construction, Transport and Europe
Senator for Industry and Ports
Senator for Education and Science
BIS Bremerhavener Gesellschaft für Investitionsförderung und Stadtentwicklung mbH

Federal government
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)
Federal Ministry of Education and Research (BMBF)
With co-financing from the European Fund for Regional Development (EFRE)

Bremerhaven Bremen
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
Das Fraunhofer CWMT wird aus Mitteln des Europäischen Fonds für regionale Entwicklung (EFRE) und aus Forschungsmitteln des BMU kofinanziert.

Fraunhofer Institute for Wind Energy and Energy System Technology IWES
Am Seedeich 45
27572 Bremerhaven
www.iwes.fraunhofer.de

Management
Priv.-Doz. Dr. habil. Hans-Gerd Busmann
Phone: +49 471 902629-10
hans-gerd.busmann@iwes.fraunhofer.de

Offshore Structures and Systems
Dr. Holger Huhn
Phone: +49 471 902629-21
holger.huhn@iwes.fraunhofer.de

Rotor Blade Testing
Dr. Arno van Wingerde
Phone: +49 471 902629-23
arno.van.wingerde@iwes.fraunhofer.de

Wind Energy at Sea: Fresh Breeze for Germany's Electricity Generation

Regenerative energy will experience unprecedented growth in the coming years and decades – and not only in Germany. Politicians expect the greatest contribution in this area to be made by wind energy. The Fraunhofer IWES in Bremerhaven is working on improving the efficiency and technical reliability of offshore wind turbines. The Fraunhofer IWES was established on January 1, 2009 from the former Fraunhofer Center for Wind Energy and Maritime Engineering CWMT. Up until December 31, 2008 the Fraunhofer CWMT was jointly operated by the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM in Bremen and the Fraunhofer Institute for Structural Durability and System Reliability LBF in Darmstadt.

The recent exorbitant increase in the price of crude oil and gas, an end to which cannot be predicted, has once again put renewable energy in the spotlight of the climate and energy debate. The federal government has set a goal of reducing the emission of greenhouse gases by 40 % by 2020. To achieve this it will increase the fraction of regenerative energies for electricity generation from the current 12 percent to 25 - 30 percent by 2020 and to 45 percent by 2030. Responsible for 42 % of the regenerative energy used for electricity generation, wind energy in Germany is the most important source of regenerative energy. By 2020 this fraction will grow to two-thirds.

From a commercial point of view, wind energy will also play an ever more important role:

- German producers and suppliers represented 37 % of the total global turnover of 15.4 billion euros. Germany is hence market leader in this sector.
- The value-creation of the German wind energy sector increased in 2007 by 21 % to a record level of 6.1 billion euros.
- For the year 2020, the German economy in the area of regenerative energy forecasts a turnover of 24 to 30 billion euros. Considering the envisaged two-thirds fraction for wind energy, this would correspond to 16 to 20 billion euros for wind energy.

In view of the rapidly growing market, global competition is increasing, forcing the manufacturers of wind turbines to be ever more innovative in order to remain competitive in the marketplace.

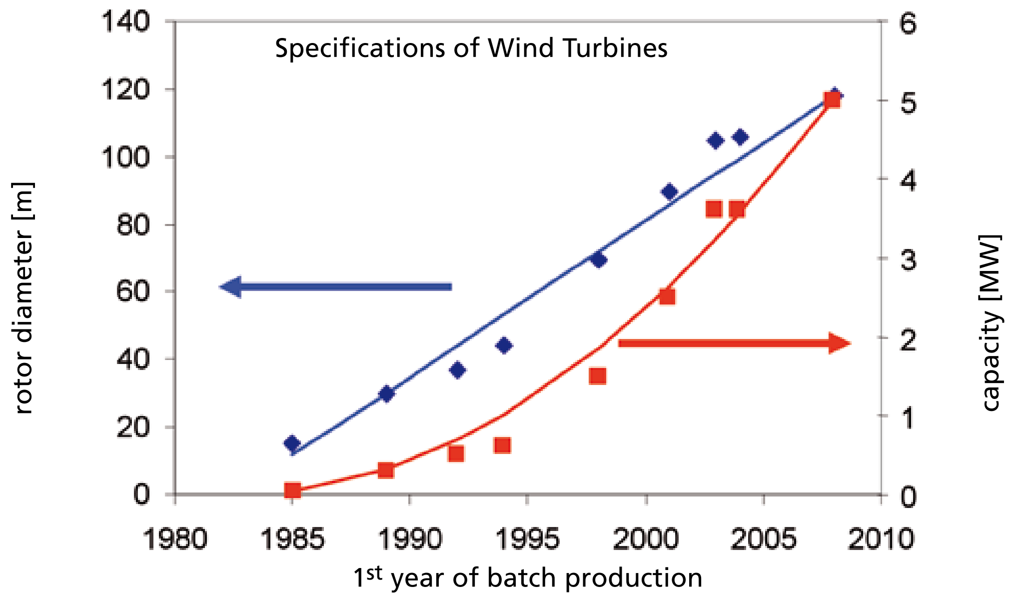


Fig. 1: Rotor diameter and power of wind turbines from 1985 to today: the turbine data is from the time of the first series production. The drawn lines represent a linear function (diameter) and quadratic function (turbine power). The data up to 2004 originate from H. Seifert, DEWI, Wilhelmshaven. The 2008 data are average values for the M5000 (Multibrid), 5M (Repower) and E112 (Enercon).

Objectives: Greater Reliability and Greater Power

Wind turbine developers currently have two main objectives: to increase the technical availability on the grid over an operating period of up to 20 years, and to develop more powerful wind turbines. Whilst the power generated by a wind turbine in 1985 was about 50 kilowatts, it is now 100-fold higher at 5 megawatts (Fig. 1).

In order to be able to determine the commercial viability of planned wind turbines, the costs of the power relative to the construction costs are calculated. For onshore turbines today, the guide cost is a million euros per megawatt. For offshore turbines, the cost is considerably more than two million euros per megawatt. As the costs for installation work, cable connections and maintenance increase much less with higher turbine power, it is more favorable, for example, to erect 10 turbines of 5 megawatts than 20 turbines of 2.5 megawatts.

The growing global competition supports this trend towards larger, more economical turbines. With larger turbines, the requirements on materials, design and production also increase. The supporting base of turbines – the substructure – for deep water application usually consists of a so-called resolved structure. This involves, for example, foundations with a tripod or finer strut structure (jacket). In order to maintain the necessary tolerances in the production, the dimensions and weights of the components represent an enormous challenge - because a steel foundation weighing several hundred tons having a deviation of a few centimeters can quickly destroy lightweight savings. For the rotor blades, a design with single or double shear web beam and aerodynamic skin is used, analogous to aircraft manufacture.

Using current technology, it will in future not be possible to built new generations of turbines that are even larger and more powerful than their predecessors. A reason for this is that the turbines will have virtually already reached their highest possible theoretical efficiency. Also, they cannot be made ever larger because their components – such as the rotor blades – would at a certain point break under the load of their own weight. Major increases in power will therefore in the future only be possible with new technological innovations. In particular, lightweight construction with new materials such as high-strength steel, light metals, carbon fibers and polymers as well as new designs and new production methods offer enormous potential.

Aeroelastic Simulations Increase the Technical Availability

Prior to testing new materials and designs, it is necessary to analyze and quantify the forces from the wind, water and ground which act on the wind turbines. The results allow the engineers at the Fraunhofer IWES to optimize the design. A wind turbine which is better able to withstand external forces has a longer technical availability. Optimization is carried out nowadays in the laboratory and on the computer. Here the researchers monitor the interplay between the aerodynamic and mechanical forces acting on the wind turbine, and also the operational management. Under these acting forces, the components – bearing structure and machinery with rotor and nacelle (including drive train) – must demonstrate their functional reliability. For offshore applications, a total simulation also takes into account other forces such as waves, drifting ice and earthquakes as well as the interaction between the foundation and the ground. Consideration of the spatial and time-related interplay of wind and waves also provides a means of optimizing offshore wind turbines (Fig. 2).

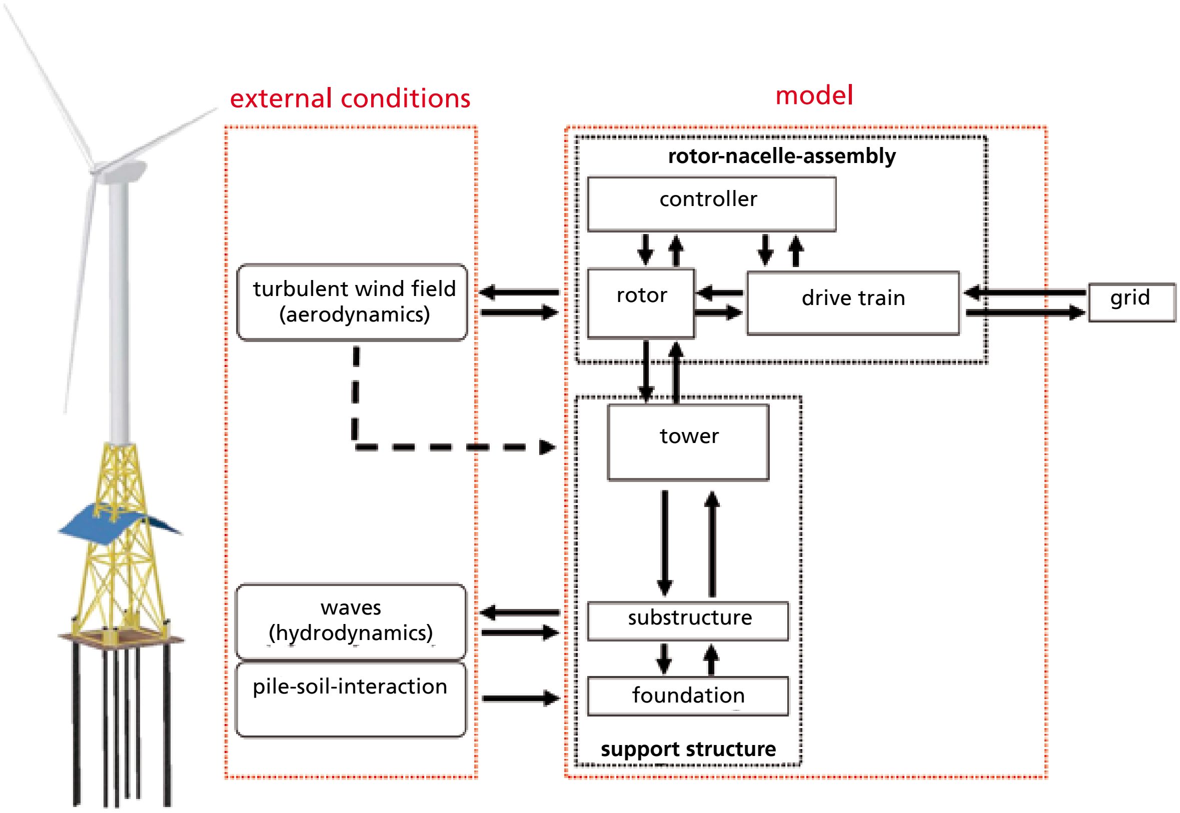


Fig. 2: Representation of the interactions of an offshore wind turbine with forces from wind, water and ground: The elastic simulation takes into account the movement of the individual turbine components as a function of the operational management. Specifically for offshore applications, forces such as periodic waves, drifting ice and earthquakes as well as interactions of the foundation with the ground were integrated into the overall simulation.

Lightweight Construction Provides Power Increases

Whilst lightweight construction is already contributing to increasing the technical availability of wind turbines, it is unavoidable for developing turbines with higher powers than the current megawatt types. Otherwise, offshore turbines would reach weights which would make transport and erection both technically and financially impossible.

Further improvements to turbines are being studied using aeroelastic-hydrodynamic simulations. This allows, for example, the efficiency of passive and active damping elements in the bearing structure to be evaluated. Such elements reduce the loads as well as the extent of vibration of the individual components and hence also reduce the total weight. Examples of this are passive and active vibration dampers in the foundation, as used in bridges and high buildings, as well as intelligent control and regulating systems for, for example, the rotors.

With the high quality of the current simulation programs, the researchers at the Fraunhofer IWES can individually alter the actuators to the actual load situation. The scientists hope, for example, to one day be able to damp natural vibrations of a foundation in a timely way with opposing forces generated by adjusting a rotor blade. However, it is not only the simulation programs which are becoming more advanced, but also the test methods. The latter are yielding faster and more meaningful results. Such developments at the Fraunhofer IWES offer, for example, component tests, scaling and numerical methods for simulating rotor blades, as already used for aircraft manufacture. Despite all the progress, it will in the future remain imperative in preparation for series production to test the actual loads on components using prototypes under real conditions.

Overall, the aeroelastic-hydrodynamic simulations and also lightweight construction offer enormous potential to further increase both the efficiency and technical reliability of wind turbines. They are hence making a key contribution to solving our climate and energy problems.

INFO

From CWMT to IWES

The Fraunhofer senate made the decision to found the Fraunhofer Institute for Wind Energy and Energy System Technology IWES. It will be formed from the Fraunhofer Center for Wind Energy and Maritime Engineering CWMT in Bremerhaven and the Institute for Solar Energy Generation Technology ISET in Kassel. It will collaborate closely with universities in Hanover, Kassel, Oldenburg and Bremen. The CWMT switched to being an institute on January 1, 2009 while the incorporation of ISET will take place during the course of 2009.

With their investment of 85 million euros for the establishment of the Fraunhofer IWES, the federal ministries and the three Federal States – Bremen, Hesse and Lower Saxony – wish to secure a leading position in Germany in wind energy technology. The institute will serve as a partner for plant manufacturers, plant operators and energy suppliers.

CWMT and ISET complement each other ideally: ISET focuses on electrical and control engineering including grid integration, whilst CWMT concentrates on the development and stress testing of wind turbines and offshore parks. The Fraunhofer IWES covers other locations, because part of the plan is close collaboration with the North German universities of Hanover, Bremen and Oldenburg.

Contact person

Priv.-Doz. Dr. habil. Hans-Gerd Busmann
Phone: +49 471 902629-10
hans-gerd.busmann@iwes.fraunhofer.de

Institute

Fraunhofer Institute for Wind Energy and Energy System Technology IWES
Am Seedeich 45
27572 Bremerhaven

TheoPrax Awards 2008 at the Fraunhofer IFAM in Bremen – Awarding School Pupils and Students for Practically-Relevant Project Work

The Bremen Senator for Education and Science, Renate Jürgens-Pieper, with TheoPrax award winners at the Fraunhofer IFAM.

From theory to practice.

The Bremen Senator for Education and Science, Renate Jürgens-Pieper, acted as patron on November 6, 2008 and presented the TheoPrax awards 2008 from the TheoPrax Foundation to school pupils and students for their excellent, practically-relevant project work. The presentations took place at the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research. The motto for the national 2008 award was "The aim of education is knowledge and action".

The enthusiastic applicants from schools, technical colleges and universities throughout Germany not only developed practically-relevant solutions for companies and communities but proved at the same time during the training that theory can be directly converted into practice and science into applications.

There were awards in three categories (school, technical college and university). The school pupils and students presented their practical solutions on a wide range of subjects:

- Development of an information and marketing platform for engineers
- Development of a sportive mobilization for long learning programs
- Optimization of drinking water purification
- Design and construction of a water fountain
- Separation of plant seeds in organic farming
- Development of a bible reading for Latin teaching, with Internet presentation
- Firewood processing with associated direct marketing

The last-mentioned project, undertaken by a school for children with learning difficulties, not only took the spotlight because of the practical demonstration at the award presentation in Bremen, but also in particular because it led to the school pupils founding their own company.

In this seventh year of presenting the TheoPrax awards, it was again demonstrated how project work with specific objectives can motivate school pupils and students to learn: Business-oriented thought and action can be practiced and learned at any early age. The school pupils and students converted theoretical knowledge into practice and became familiar with professional project work and the working methods of science and everyday life.

The Fraunhofer IFAM, as a TheoPrax communication center, endeavors to introduce young people to subjects and working methods which are usually not covered at school and to discover talented individuals and give them an insight into the work of an R&D institute.

Just how stimulating, interesting and relevant to everyday life science can be became evident after the presentation of the projects in an experimental presentation by Prof. Dr. Manfred Euler of the Leibniz Institute for Science Education (IPN) at the University of Kiel on "The Fascination of Physics" – he captivated all those present right up to the last minute of the event and left behind a lasting impression.

The good mood of the TheoPrax award winners is increased by the practical implementation of the sportive mobilization.

Project partner

TheoPrax Center at the Fraunhofer Institute for Chemical Technology ICT, Pfinztal

Contact person

TheoPrax Communication Center at the
Fraunhofer IFAM
Beate Brede
Phone: +49 421 2246-421
beate.brede@ifam.fraunhofer.de

Institute

Fraunhofer Institute for
Manufacturing Technology
and Applied Materials Research IFAM,
Department of Adhesive Bonding Technology and Surfaces,
Bremen

Award to Promote Science and Research

From left: Prof. Dr. Kunze, Prof. Dr. Busse, Hr. Schütze, Dr. Stöbener, Dr. Rausch, Dr. Lehmhus, Dr. Berg, Hr. Baumeister, Hr. Wichmann, Hr. Baarß.

Towards Success with Breezy Metal Spheres

June 3rd, 2008 was a happy day for the whole working group of Lightweight Materials at Fraunhofer IFAM. The award to promote science and research was granted for the development and manufacture of metallic foam spheres. This award on behalf of the state of Bremen was funded by the Peter Franz Neelmeyer Foundation.

This distinction was a big surprise, since a powder metallurgical procedure to manufacture metal foams had already been engineered at Fraunhofer IFAM in Bremen by the physicist Joachim Baumeister in the early 1990s. Here, aluminum powder is mixed homogeneously with a foaming agent and afterwards compressed densely. This semi-finished material may be expanded into metal foam by heating it above the melting point. During heating, the foaming agent starts to set free gas, which cannot escape out of the solid and gas-proof material. As soon as the metal starts to melt at about 600 °C, the stored gas forms a host of expanding bubbles. "The foaming agent makes the metal foam paste expand like the yeast during baking bread", Baumeister explains. Quick cooling down below the metal melting temperature means that the initially liquid foam may be transformed into a solid state.

But what do the many pores in the metal cause? Given the same component volume, metal foam is obviously lighter than a part made of non-porous material. In addition to this, the foam has many other advantages. In contrast to the dense metal, the cellular structure offers a far greater dampening of sound and vibrations. But the foam can do more. Embedded in a carbody, it strongly enhances passive safety without significantly increasing the car's weight.

The jury was particularly convinced by the continuous refinement of technology. Many new ideas were drawn from the demands of the industry and were developed into applicable products. The latest approach is the APM variant, which Dr. Karsten Stöbener gave a strong impetus to with his dissertation. Stöbener highlights the advantages as follows: "Here, many small coated aluminum foam spheres may be poured in a component of complex geometry, and afterwards glued together at low temperatures".

The award was presented to the entire foaming team, since this achievement is the result of many diligent hands working together with patience and motivation.

Contact person

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

Institute

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

Competition for Innovations for the German Car Industry

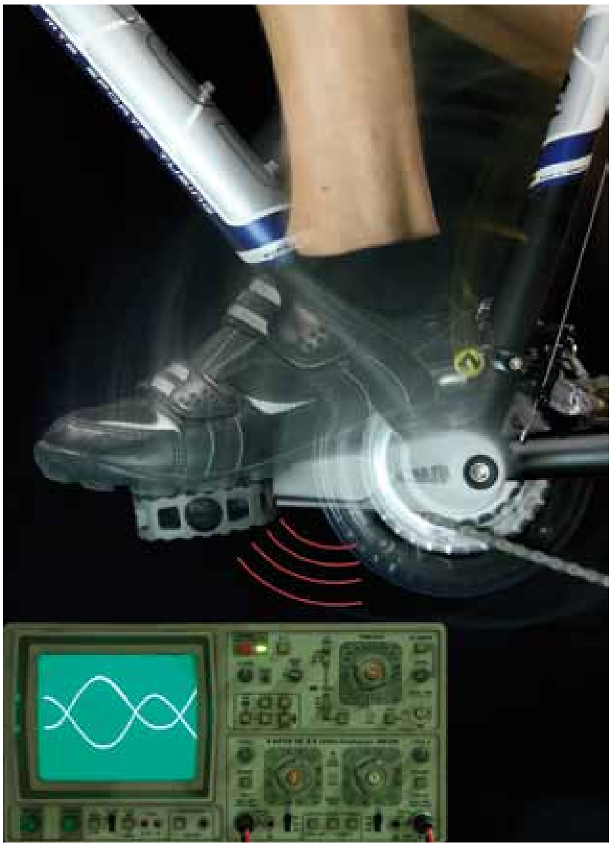
Successful Search for New Ideas – Fraunhofer IFAM was Awarded as TOP-30 Laureate

Researchers in IFAM's foundry department received awards during the Competition for Innovation of the Network of Automotive Excellence (NoAE) of the German car industry. In the NoAE network, car manufacturers, suppliers, development partners and research facilities cooperate to find ways to meet the challenges of the automotive industry and to engineer solutions together. 30 out of a total of 170 innovations presented by Germany, Austria and Switzerland succeeded in winning awards at the NoAE Innovation Vernissage held during the automotive summit Würzburger Automobil Gipfel 2008.

The TOP-30 laureates selected, including the head of the foundry Franz-Josef Wöstmann and project engineer Christoph Pille, presented their achievement to a top-class jury. The jury included innovation managers from enterprises like Audi, BMW, Daimler, Ford, MAN, Mazda, Opel, Porsche and Volkswagen. The jury was joined by external technical experts.

Fraunhofer IFAM took part with the topic "Functionally integrated cast components". Research is aimed at the direct integration of electronic functional elements into the casting. Function generators may be piezoceramics, such as a sensor for load measurement in highly stressed safety components, actuators for dampening of vibrations and RFID transponders to identify components and product labels. The combination with a memory module will also make it possible to record the life story of the component. By integrating various functional groups, each component is allocated an individual identity and function.

The outstanding achievement of the IFAM engineers results from the direct integration of the sensitive components into the casting process, so that a follow-up manufacturing step to combine the casting component with the electronic unit becomes unnecessary. Based on a targeted layout of functional elements in the component, the specific stress can be precisely measured pointwise, and thus provides detailed data for future new solutions designed for stress in light weight construction.



Die-cast pedal with integrated piezosensors to measure compressive and tensile forces.

According to the estimations of the NoAE experts, the majority of the innovations demonstrated have an excellent chance of being implemented in the near future.

Contact person

Dipl.-Ing. Franz-Josef Wöstmann
Phone: +49 421 2246-225
franz-josef.woestmann@ifam.fraunhofer.de

Institute

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

Visit by the EU Commissioner Prof. Dr. Danuta Hübner – First Milestones of the Innovation Cluster "MultiMat" were Presented

Prof. Dr. Danuta Hübner and Dr.-Ing. Dirk Godlinski during their visit to the project "Smart materials for miniaturized sensors".

From left to right: Senator Renate Jürgens-Pieper, Prof. Dr. Danuta Hübner, Dr. Ralph Wilken, Dr. Madeleine Mahovsky and Stefanie Kaprolat inspecting the project "Long-term resistant functional surfaces and their manufacturing technology based on quality assurance".

On September 4th, Professor Danuta Hübner, EU commissioner for regional policy, visited the site to ascertain whether the money spent in Bremen by the European Fund for Regional Development (EFRE) had been invested well. The Innovation Cluster of Multifunctional Materials and Technologies "MultiMaT" is sponsored by the state of Bremen with funding from the EFRE, the Fraunhofer-Gesellschaft and an industrial consortium.

In view of the joint scientific-technological requirements of the enterprises involved in the innovation cluster, they are exploring and designing innovative concepts for materials with new properties which have not yet been realized, as well as sensor functionalities, and the necessary manufacturing processes. The main focus is on application and integration of sensors, functional surfaces and joining of fibre composite structures. The research domains of "MultiMaT" are subdivided into five projects. Danuta Hübner inspected two of them very closely. "Smart materials for miniaturized sensors" is aimed at engineering materials with special sensor functions to produce an intelligent component at the end of the manufacturing chain. In the second project, on "Long-term resistant functional surfaces and their manufacturing technology based on quality assurance", materials and processes that result in surfaces with innovative functions or outstanding qualities and long-term resistance are being explored.

The EU commissioner gave the explanations of the scientists at Fraunhofer IFAM her undivided attention. IFAM had reached the first milestones, so that praise was also forthcoming. "We are very pleased with the cooperation. Bremen is a good example for others", Danuta Hübner was pleased to confirm.

Contact person

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

Institute

Fraunhofer Institute for
Manufacturing Technology
and Applied Materials Research IFAM,
Bremen

International Symposium on the Application of Cellular Metallic Materials in Dresden – CELLMET2008

From October 8^{th} to 10^{th}, 2008, the Second International Symposium on the Application of Cellular Metals was held at the Dresden Institute's department of the Fraunhofer-Gesellschaft. About 120 participants from 20 countries, approximately 40 percent of them from industry, came to Dresden in order to discuss results obtained in using cellular metallic materials and to exchange information. In total, 35 papers and 40 posters were presented, which involved applications such as heat exchangers, sound absorbers, thermal insulations, flame protection, filters, catalysts, machine tools, explosion protection, and also biomaterials. It was clear that, in comparison with the CELLMET2005, there was a substantial increase in the number of studies relevant to applications, and the first applications are already in industrial use (crash absorbers, mechanical engineering components, and filters).

During CELLMET2008, two CELLMET awards were presented, which recognize outstanding achievements in the field of applications. The firm Bekaert (Zwevegem/ Belgium) received the Demonstrator Award for their heat exchanger made of open-porous Al foam, whereas the Application Award was given to the Institute for Materials and Machine Mechanics Bratislava/Slovakia for a crash absorber in the rail vehicle sector.

CELLMET2008

Cellular Metals for Structural and Functional Applications

DRESDEN - GERMANY

Demonstrator Award and Application Award.

Contact person

Dr.-Ing. Günter Stephani
Phone: +49 351 2537-301
guenter.stephani@ifam-dd.fraunhofer.de

Institute

Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM, Department of Shaping and Functional Materials, Dresden

Imprint

Prof. Dr.-Ing. Matthias Busse
(Managing director)
– Shaping and Functional Materials –

Phone: +49 421 2246-100
Fax: +49 421 2246-300
info@ifam.fraunhofer.de

Dr.-Ing. Helmut Schäfer
– Adhesive Bonding Technology and Surfaces –

Phone: +49 421 2246-401
Fax: +49 421 2246-430
ktinfo@ifam.fraunhofer.de

Bremen:

Fraunhofer-Institute
for Manufacturing Technology and
Applied Materials Research IFAM

Wiener Strasse 12
28359 Bremen / Germany
Phone: +49 421 2246-0
www.ifam.fraunhofer.de

Dresden:

Fraunhofer-Institute
for Manufacturing Technology and
Applied Materials Research IFAM

Winterbergstrasse 28
01277 Dresden / Germany

Bremerhaven:

Fraunhofer Center for
Wind Energy and Energy
System Technology IWES

Am Seedeich 45
27572 Bremerhaven / Germany

Publisher:

© Fraunhofer-Institute
for Manufacturing Technology and
Applied Materials Research IFAM

ISSN 1439-6009

Editorial team:

Martina Ohle
Anne-Grete Becker

Support:
Kirsten Bögner
Dagmar Fischer
Frauke Jäger

External Services:

Layout:
SOLLER Werbestudios GmbH
Gerhard Bergmann

Figures:
(except Fraunhofer IFAM)
PR Fotodesign
Britta Pohl
Jochen Roeder

Preface and celebratory colloquium:
Kai-Uwe Bohn

WWW.IFAM.FRAUNHOFER.DE

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research IFAM

Wiener Strasse 12
28359 Bremen

info@ifam.fraunhofer.de