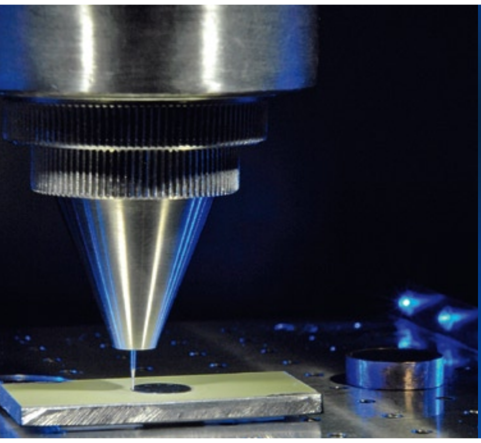
Fraunhofer Institut
Fertigungstechnik
Materialforschung



07/08

Annual Report
2007/2008

Fraunhofer Institute for
Manufacturing Technology and
Applied Materials Research (IFAM)

Annual Report 2007/2008

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A Profile of the Institute

Department of Shaping and Functional Materials

Department of Adhesive Bonding Technology and Surfaces

Ladies and Gentlemen,
Business Associates and Co-operation Partners,
Patrons of IFAM,

Prof. Dr.-Ing. Matthias Busse (left), head of the IFAM institute, and Dr.-Ing. Helmut Schäfer.

This annual report demonstrates the successful business activities of our institute in 2007. Both institute locations can look back over outstanding development – both in terms of technical progress and statistics. In 2007, we succeeded in continuing the course of growth we began years ago. This achievement is not only made clear by the acquisition of so many new projects, but also by the rising numbers of employees. During the last 12 months, the number of employees at the institute as a whole increased by approx. 9 %. This development trend is expected to continue in the future. In the meantime, the IFAM institute is one of the largest facilities in the Fraunhofer-Gesellschaft. The wide technical range of issues researched at IFAM has by now firmly established our research and development services in many diverse markets. Rather than focusing on a single specific niche, our activities at IFAM have a wide range of applications.

The efforts of the Shaping and Functional Materials department, which were aimed at the acquisition of new customers, paid off in the long run. In project work, the department of Adhesive Bonding Technology and Surfaces was very successful in 2007. This was another instance in which close co-operation with the aircraft manufacturer Airbus proved to be a source of significant business activities. Moreover, intensive application for subsidies meant that a high percentage of project proposals presented by both institute locations were approved. In general, we may state that the German industry's demand for new solutions able to guarantee its technological leadership in global competition is mainly satisfied by institutes such as Fraunhofer IFAM.

Here we would like to mention the new regional innovation cluster "Multi-functional materials and technologies", or MultiMaT, which is representative of the many innovative projects IFAM undertook with its industry partners in 2007. This cluster is aimed at achieving technological leadership in the Bremen region through innovations in the field of multi-functional materials and their processing. After extensive preliminary work, a network linking not only both institute locations, but also additional materials science research facilities and small, medium and large enterprises has now been established. The industries which are prominent in the Bremen region, such as the automotive industry, aeronautics and space travel, wind energy production, shipbuilding and maritime engineering, have a strong demand for new multi-functional materials and their processing. The aim is to meet this demand through targeted research and development activities within the innovation cluster. Initially, basic research results will be elaborated in five prototype solutions and implemented in special-purpose applications in close co-operation with the partners. IFAM's wide-ranging competency in materials research and development, as well as in processing technologies, is the cornerstone of the cluster's successful work. An especially noteworthy feature of the recent past is our greatly increased interaction with the University of Bremen. As part of the Federal and

States' Excellence Initiative, IFAM was heavily involved in activities in Bremen. The institute was responsible for writing the application for the establishment of an excellence cluster in engineering sciences, "Merging Technologies for Sensorial Materials and Smart Products", which focuses on the development of intelligent components. The institute also played an important part in the application for a graduate program in "Multi-Scale Design of Functional Hybrid Materials and Devices". Both applications were consistently favourably evaluated, though they were not ultimately accepted. Nevertheless, our commitment within the excellence initiative has borne fruit, since it has intensified co-operation with important scientific institutes at the University of Bremen, in particular with the Production Engineering department. Intensified interdisciplinary exchange of ideas led to new research interests, which are expected to be further developed in the future as a joint effort by scientists from IFAM, the University of Bremen and the Jacobs University of Bremen. The department of Shaping and Functional Materials has already been involved with the Production Engineering department through its professorship in near-net shape manufacturing techniques, while the Adhesive Bonding Technology and Surfaces department is working as quickly as possible toward the reoccupation of its own chair at the University of Bremen.
IFAM as a whole has traditionally maintained close ties with other technical departments, as well as many institutes in Bremen. We intend to intensify and extend co-operation both with the Bremen scientific community and, in particular, with industry.

The present annual report is designed to familiarise you with numerous project reports and discusses trends as well as the positive development of the institute. This outcome, combined with strong growth in all segments, is mainly based on the diligence and creativity of our employees, to whom we are especially grateful. In times when there are insufficient natural sciences and engineering personnel in Germany, many tasks can only be performed with extra effort. The passion and the interest with which the employees at IFAM face up to this challenge are really admirable. We are proud of the fact that many scientists and engineers have decided to work at our institute – despite attractive offers in the private sector. IFAM allows its personnel room to do creative, autonomous work, as well as a degree of scientific and entrepreneurial freedom that is simply impossible in an industrial environment. The opportunity to design, plan and perform one's work obligations independently has an extremely positive effect on people and obviously releases energies without which our successful work would be impossible. We thank them very much for their commitment.

We hope that you enjoy reading this annual report.

Matthias Busse

Helmut Schäfer

Bremen in March 2008

A Profile of the Institute

←
Fraunhofer IFAM in Bremen.

The Institute's Profile

The Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) pro-actively provides R&D activities in the areas of **Shaping and Functional Materials,** as well as **Adhesive Bonding Technology and Surfaces.**

The Institute's department of Shaping and Functional Materials with facilities in Bremen and Dresden focuses on three core areas of expertise: casting- and light metal technologies, micro engineering and nanostructuring, and powder and sintering technologies. The subjects of our seven fields of expertise are:

- Functional Structures
- Casting Technology
- Lightweight Materials and Analysis
- Micro Engineering
- Powder Technology
- Sinter and Composite Materials
- Cellular Materials.

Regarding the market, the fields mentioned above are mainly addressed to business segments like metals (precision components and processes), high-performance materials and functional surfaces, medical engineering and biomaterials, and lightweight construction. Our R&D activities emphasise the triangle formed by the materials, shaping techniques and the components.

The continuing trend towards lightweight construction forces industry to constantly reduce material consumption in vehicles, machines and equipment. In recent years, innovative lightweight materials and casting processes have been developed in order to meet these requirements.

Thus, for instance, the μ-MIM process introduces new opportunities for components miniaturisation. The components produced up to now are applied in micro drive engineering, electronics and medical engineering.

However, in the development of new materials and components, not only improved mechanical or shaping characteristics are in demand. In fact, so-called "intelligent materials" (smart materials) are attracting more and more interest. Fraunhofer IFAM designs manufacturing processes to integrate functions into materials and components. The objective is to create components whose parameters are tailored to a desired functionality, thereby integrating structural and functional materials with "intelligent components" or smart products by means of manufacturing 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, 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 extended systematically, 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.-Ing. Matthias Busse took up his position in the institute's management and as head of the Shaping and Functional Materials department in 2003. In April 2006, he became the executive manager of the entire IFAM institute.

Dr.-Ing. Helmut Schäfer entered the institute's management in 2007 and since then has been the head of the Adhesive Bonding Technology and Surfaces 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 56 institutes which make up the non-profit organisation Fraunhofer-Gesellschaft. At present, the organisation maintains about 80 research facilities at more than 40 locations throughout Germany. A staff of approximately 13,000 employees, most of whom are highly qualified scientists and engineers, generate an annual research volume of more than 1.3 billion euros. Of this amount, more than one 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 2007 the overall IFAM budget amounted to approximately 27 million euros. The workforce comprised some 343 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

Priv.-Doz. 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 investments) in 2007 comprised the budgets of the two departments of Shaping and Functional Materials and Adhesive Bonding Technology and Surfaces as well as the CWMT.

The provisional budget result totaled 27.1 million euros.
The results of the individual sites/departments are shown below:

Shaping and Functional Materials Bremen

Operating budget	6.0 million euros
Own income	3.9 million euros
Including	
Business income	2.3 million euros
Federal/state/EU/other	1.6 million euros
Investment budget	1.9 million euros

Shaping and Functional Materials Dresden

Operating budget	3.0 million euros
Own income	2.4 million euros
Including	
Business income	1.3 million euros
Federal/state/EU/other	1.1 million euros
Investment budget	0.1 million euros

Adhesive Bonding Technology and Surfaces Bremen

Operating budget	11.8 million euros
Own income	9.6 million euros
Including	
Business income	7.2 million euros
Federal/state/EU/other	2.4 million euros
Investment budget	2.0 million euros

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

Operating budget	2.0 million euros
Own income	1.8 million euros
Including	
Business income	0.1 million euros
Federal/state/EU/other	1.7 million euros
Investment budget	0.3 million euros

Investments

During 2007, IFAM investments amounted to 4.3 million euros, split among the various sites as given below. The most important purchases are indicated.

Shaping and Functional Materials Bremen (1.9 million euros)
- Processor tensiometer
- 3D printer
- Mould for injection moulding of metal powder feedstock
- Laser sintering system
- Sintering furnace
- Planetary mixer (high-speed)
- Electron microscope (desk model)
- Micro-compounder
- Micro injection moulding machine
- ThermoCalc software

Shaping and Functional Materials Dresden (0.1 million euros)
- Retrofit of a hydrogen furnace (MUT GmbH)
- Melt spinner

Adhesive Bonding Technology and Surfaces Bremen (2.0 million euros)
- Laser Induced Fluorescence Spectroscopy (LIFS)
- Infrared camera
- Optical Stimulated Electron Emission (OSEE)
- Gamry potentiostat
- Corrosion measuring system (chamber)
- Microscope with attachment to determine surface topography
- Experimental circulation line for paints
- CO_2 snow jet cleaning unit (mobile)
- Source for sputtering 1,000 mm
- Excimer coating system
- Biaxial extensometer
- Parting-off grinder
- Autoclave

Personnel Development

On 31 December 2007, IFAM employed a total of 343 persons, 89 % of whom were employed in the scientific-technical domain. In comparison with the previous year, the number of permanent employees grew by 9 %.

Personnel structure 2007

Scientists	135
Technical employees	84
Administration / internal services and trainees	37
Ph.D. students, interns and auxiliary staff	87

Operating and investment budget

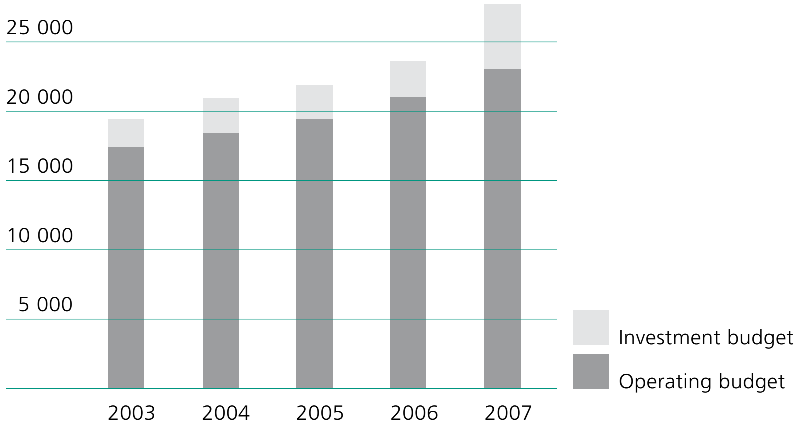

Figure 1: Expenditures (operating budget and investment budget)

Income

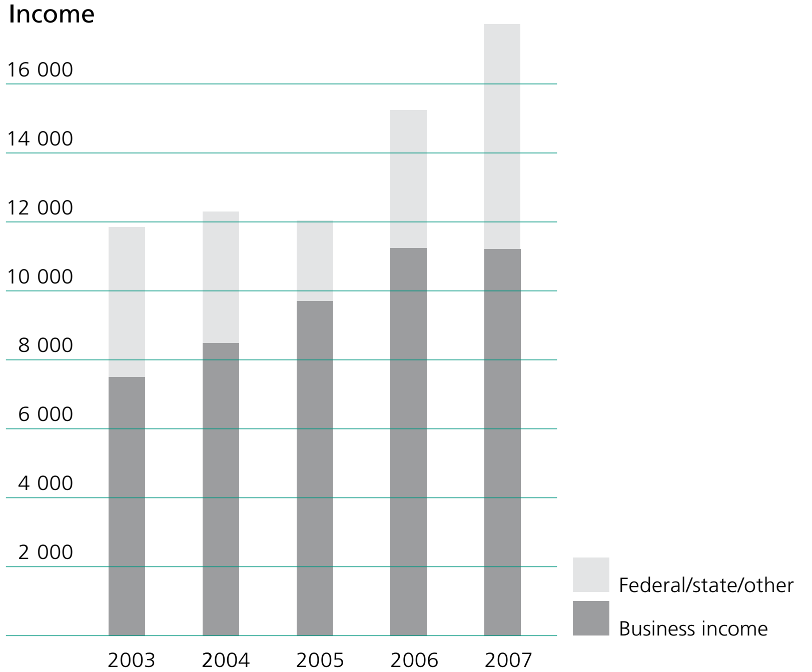

Figure 2: Income (operating budget) "IFAM – in total"

Personnel development

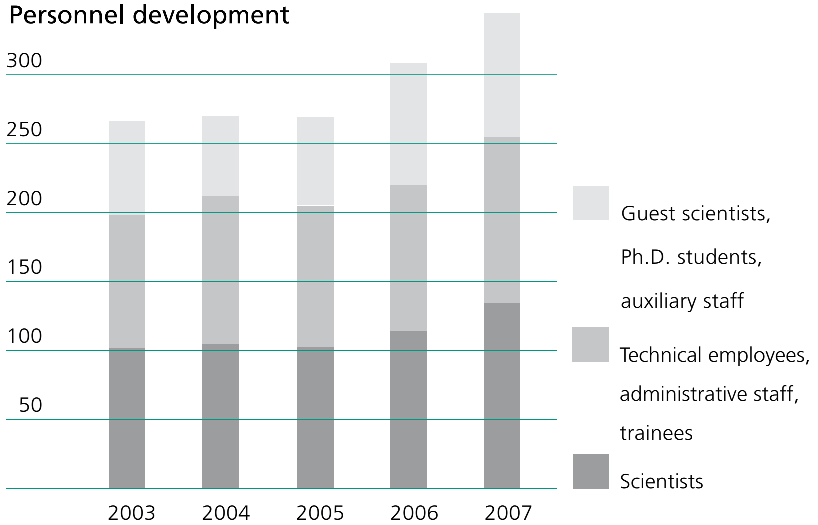

Figure 3: Personnel development "IFAM – in total"

The IFAM Advisory Board

Members

A. Picker
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Henkel Adhesives Technologies
Japan, Tokyo

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Evonik Industries AG
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Deutsche Forschungsgemeinschaft
Bonn

Prof. Dr. R. X. Fischer
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HDO Druckguss- und
Oberflächentechnik GmbH
Paderborn

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C. Weiss
BEGO Bremer Goldschlägerei
Bremen

Dr.-Ing. G. Wolf
VDG Verein Deutscher Gießereifachleute
Düsseldorf

MinR Dr. rer. nat. R. Zimmermann
Sächsisches Staatsministerium für
Wissenschaft und Kunst
Dresden

Staatsrat Dr. G. Wewer (until June 2007)
Der Senator für Bildung
und Wissenschaft der
Freien Hansestadt Bremen
Bremen

Staatsrat C. Othmer (since June 2007)
Die Senatorin für Bildung
und Wissenschaft der
Freien Hansestadt Bremen
Bremen

Guests

K. Dröder
Volkswagen AG
Wolfsburg

Dr. S. Kienzle
Daimler AG
Ulm

Research in Close Proximity

The Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) is situated not far from BEGO GmbH & Co. KG in Bremen's Technology Park. The fascinating idea of living and working in, and mutual benefiting from, a knowledge community is consequently implemented here on a daily basis. As the Indian philosopher Jiddu Krishnamurti put it: "You must begin near to go far".

First and foremost, the R&D activities carried out at BEGO shared in the same scientific community as IFAM, and consequently this area offered a spectacular symbiosis between theory and practice. Thinking ahead and implementing knowledge from fundamental research by means of applied research are the special strengths of IFAM's scientists, and we at BEGO have learned to value this ability very highly. Some years ago, we began the teamwork of IFAM and BEGO with a big project on "Selective Laser Melting". This co-operation has continued in smaller and larger projects in the research units of Shaping and Functional Materials as well as Surface Engineering up to now. Thanks to the special and in-depth technical knowledge of the IFAM scientists and engineers, and the fact that, as a result, we can work close to our products and processes, we have succeeded in engineering or refining significant innovations that are not only important for our current business, but will also shape the future of our enterprise to a great extent.

The fact that IFAM is situated close to BEGO is also very significant. Being in immediate vicinity contributes to rapid flow and exchange of information among experts. All of this affects progress in research and development in an extremely positive manner. Since it is established as a regional provider of scientific results and associated services, IFAM not only makes available technical know-how, but also offers temporary use of equipment and devices from its extremely well-equipped machine laboratory for R&D projects.

Factors that contribute to successful co-operation include not only being in the same scientific and geographical "neighbourhood", but also the personal relationships among the scientists and specialists. In the "Casino" cafeteria of BEGO, where they have lunch together, they certainly discuss interesting and useful technical subjects. The open personal relationships that have grown up over time between the employees of IFAM and BEGO surely contribute to some extent to confidential and trusting co-operation.

The present annual report demonstrates the comprehensive and in-depth scientific work of IFAM last year and clearly proves how essential research is to our everyday life. After all, this process is carried out by the very committed people working at IFAM, who make use of this "neighbourhood" every day, and who exchange and apply their knowledge, thereby taking part in the creation of the future. We hope that, in the future, IFAM will have the proximity to BEGO that is so crucial to their important work.

Christoph Weiss
Managing partner of the BEGO group and member of the Advisory Board.

The Fraunhofer-Gesellschaft

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration. The organization also accepts commissions from German federal and Länder ministries and government departments to participate in future-oriented research projects with the aim of finding innovative solutions to issues concerning the industrial economy and society in general.

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, accelerating technological progress, improving the acceptance of new technologies, and not least by disseminating their knowledge 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, in other scientific domains, in industry and in society. Students working 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.

At present, the Fraunhofer-Gesellschaft maintains more than 80 research units, including 56 Fraunhofer Institutes, at 40 different locations in Germany. The majority of the 13,000 staff are qualified scientists and engineers, who work with an annual research budget of 1.3 billion euros. Of this sum, more than 1 billion euros 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 institutional 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.

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

Fraunhofer Materials and Components Alliance

The Fraunhofer Materials and Components Alliance couples the expertise of the Fraunhofer-Gesellschaft's institutes focusing on materials science with the Fraunhofer Institute for Industrial Mathematics ITWM as a permanent guest.

Materials research at Fraunhofer comprises the entire value added chain – from developing new and refining existing materials to the manufacturing technology on a scale oriented to industry, specifying the characteristics of properties up to the evaluation of performance characteristics. This is also the case for the components made of those materials, and their characteristics inside systems. In all of these areas, numerical simulation and modelling methods are used in equal measure, as well as experimental studies in labs and on shopfloors. From a materials perspective, the Fraunhofer Materials and Components Alliance covers the whole range of metallic, anorganic-non-metallic, polymeric materials and those generated from renewable materials.

The group focuses its know-how on the economically important areas of energy, health, mobility, information- and communication technology, as well as construction/living. The objective is to implement system innovations through material- and component development tailored to each application.

In the medium term, the R&D topics of the alliance are concentrated on:

- Boosting the efficiency of systems for transfer of energy and energy storage
- Enhancing biocompatibility and functionality of materials used for medical engineering or biotechnology
- Increasing the density of integration and improving the usage properties of components of microelectronics and microsystems technology
- Enhancing safety and convenience, as well as consuming fewer resources in traffic engineering, as well as mechanical- and equipment engineering

Fraunhofer-Institutes are involved:

- Angewandte Polymerforschung IAP
- Bauphysik IBP
- Betriebsfestigkeit und Systemzuverlässigkeit LBF
- Chemische Technologie ICT
- Fertigungstechnik und Angewandte Materialforschung IFAM
- Holzforschung, Wilhelm-Klauditz-Institut, WKI
- Keramische Technologien und Systeme IKTS
- Kurzzeitdynamik, Ernst-Mach-Institut, EMI
- Silicatforschung ISC
- Solare Energiesysteme ISE
- Techno- und Wirtschaftsmathematik ITWM (Guest)
- Werkstoffmechanik IWM
- Zerstörungsfreie Prüfverfahren IZFP

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Members

Fraunhofer-Institutes EMI, IAP, IBP, ICT, IFAM, IKTS, ISC, ISE, ITWM (Gast), 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.

In the Adaptronics Alliance the competences of 12 Fraunhofer institutes, which lie in the areas of development, application and optimization of intelligent material systems and components, systems and applications are combined. Through this cooperation the institutes want to make a substantial contribution towards efficiently solving complex tasks in the field of adaptronics and towards offering the user a common, central contact person for his system development. As a result of the participation of the institutes in other groups of the Fraunhofer Gesellschaft an active exchange of information is guaranteed.

Contact persons

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Members

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

Fraunhofer Nanotechnology Alliance

A buzzword nowadays is nanotechnology, a bundle of crosscutting new technologies for the next years to come, dealing with materials, systems and devices where something very small (below 100 nm) determines functions and applications. Nanotechnology is an integral part of our everyday life: As an example, nanoparticles in suntan lotions protect the skin against UV radiation, nanoparticles are used to reinforce car tires; nanotechnology can help to produce easy-care scratch-resistant surfaces, and ultrathin 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 over 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 and automotive 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.

Contact person

Spokesman for the alliance:
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Fraunhofer Polymer Surfaces Alliance (POLO)

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

The alliance works to achieve concrete results in preliminary development and secures the relevant industrial property rights for polymer products that have new or significantly enhanced properties.

Products already developed in the areas of “flexible ultra-barriers” and “anti-microbial polymer surfaces” are targeted at the optical and opto-electronic industry, the building and construction industry, and the packaging, textile, medical and automobile industries.

Contact person

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Members

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

Fraunhofer Alliance for Numerical Simulation of Products, Processes

In the Fraunhofer Alliance for Numerical Simulation of Products and Processes, twenty institutes pool their expertise in the development and improvement of simulation techniques. The simulation of products and processes today plays a decisive role in all phases of the product life cycle, from model-based materials development and simulation of manufacturing processes to operating characteristics and product placement on the market.

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

Contact person

Spokesman for the alliance:
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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 Alliance for Photocatalysis

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 Network.

The aim of the network 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 network: material, coating and process development, analysis techniques and test and measurement systems for assessing biological activity and ecotoxicological environmental impact.

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

Fraunhofer Alliance for Rapid Prototyping

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 Network has earned a reputation as the largest interdisciplinary European network of competence for high-speed processes enabling individual small-batch manufacturing of products made of metals, plastics, ceramics and other materials.

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

Contact person

Spokesman for the alliance:
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Members

Fraunhofer-Institutes ICT, IFAM, IFF, IGD, IKTS, ILT, IOF, IPA, IPK, IPT, IWM, IWS, IZM

Fraunhofer Alliance for Cleaning Technology

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 network, 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 network 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.

Contact person

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Members

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

Fraunhofer Technology Academy

The Fraunhofer-Gesellschaft is the leading organization for application-oriented research in Europe and is driving innovation for industry. To promote successful implementation of innovations in industry, the Fraunhofer-Gesellschaft systematically relies on order-oriented research for industry, spin-offs of companies and transfer by 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 characterised by innovation. In co-operation 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

Universität St. Gallen und die Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen

Contact person

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Members

Involved institutes: Klebtechnisches Zentrum im 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 wind energy network in co-operation 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

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Department of Shaping and Functional Materials

Results Applications Perspectives

←
Vortexmixer.

Competencies and Know-How

Transferring application-oriented fundamental research in solutions that are to be implemented in production engineering or projects focussed on component engineering is regarded as 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 Shaping and Functional Materials department is a top priority. Based on our core competencies, such as powder- and sintering technologies, casting- and light metals technology, as well as micro- and nanotechnologies, we develop innovative and profitable solutions for our customers.

Networks of partners from industry and research facilities, which co-operate in an interdisciplinary manner, 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 to its implementation in products and support during production.

Multifunctional components fitted with integrated sensors make special demands on the materials used. Compounds of various materials in one component make it possible to optimise properties according to the customer's needs. To expand expertise, designing these material combinations and dealing with them in manufacturing processes are major tasks. Possible combinations range from metal-metal, to metal-ceramic all the way to combinations with CFRP.
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 material characteristics into, for example, 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 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 aluminium- and magnesium alloys with die casting. We not only optimise casting processes using a permanent mould, but are also constantly refining our expertise in the Lost Foam casting procedure. Our latest development, called "CASTtronics®", 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 continually adapted to the requirements of the market, resulting in new technological challenges. Here problems of product innovation under stringent economic constraints are as important as the contribution to research results aimed at improving our quality of life, 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 emphasised 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 to be tailored to the application and identified. To do this, high-performance materials, composites, gradient and smart materials will be refined, and manufacturing technologies to integrate the characteristics into the components will be 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 in the network with 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.

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 should also be developed.

Quality inspections within the production process are of greater and greater interest for cyclic 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.

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.
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Functional Structures
Nanopowders; nanosuspensions; nanoporous layers; functional integration; INKtelligent printing®; ink-jet-printing; aerosol-printing (M³D®); specialty equipment.
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Micro Engineering
Micro injection moulding for metals and plastics; micro-structuring; series production of miniature components; 2-component injection moulding for micro components; microreaction technology; microfluidics.
Dr.-Ing. Astrid Rota (until 31th March 2008)
Dr.-Ing. Frank Petzoldt (since 1st April 2008)
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Lightweight Structures and Analysis
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Casting Technology
Zinc, aluminium and magnesium pressure diecasting; thixocasting; pressure diecasting moulds; lost-foam processes; sand casting; simulation.
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Cellular Metallic Materials
Fibre metallurgy; high porosity structures; metallic hollow sphere structures; open cell PM foams; screen-print structures; 3D wire structures; applications for e. g. lightweight structures; crash-absorbers; heat exchangers; catalyst support materials.
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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.
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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, 1,800 °C)
- Uniaxial powder presses (max. 1,000 tons)
- Powder press for heat compaction (125 tons)
- Extruder (5 MN)
- Rapid Prototyping systems for laser sintering and 3D 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 process

Micro- and Nanostructuring

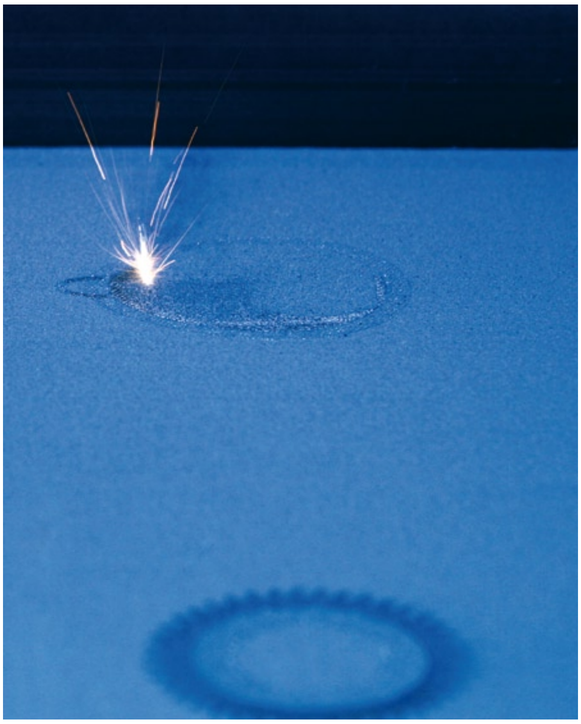
- Inkjet printing technologies
- Aerosol jet printing technology (Maskless Mesoscale Material Deposition M³D®)
- Micromanufacturing cell
- Four-point-bend stand
- Ink test stand – Drop on demand
- Sputtering technology

Heat/Chemical Treatment of Mouldings

- Unit for chemical de-waxing of injection moulded parts
- Several sintering furnaces (up to 2,400 °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 characterise functional inks for inkjet printing methods
- Melt extraction unit (metal fibres)
- Centrifugal mill for high-energy milling of metal- and ceramic powders (5 to 10 kg material to be ground, inert gas, vacuum)
- High-speed mixer and shear roll extruder for MIM feedstock production
- Air separator for separation of powders



Laser sintering.

Instrumental Analytics

- FE scanning electron microscopy with EDX
- X-ray fine structure analysis
- Insulating resistance
- Thermoanalysis with 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 element analysis of Al-, Mg-, Zn alloys
- Micro tensile testing equipment
- X-ray tomograph (160 kV)
- Tensiometer
- Particle size analysis
- 2D / 3D laser surface profilometer

Computers

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

Lost Foam Technique to Produce Small Parts

Background

In the Lost Foam casting technique, patterns are made from expandable polystyrene (EPS), coated with ceramic slurry and embedded with binderless sand. During subsequent casting, the heat of the molten metal decomposes the EPS model, and the volume originally occupied by the model is outlined by the melt. Extremely sophisticated component geometries can be filled in this way. It is very simple to remove the components. In comparison with conventional sand casting techniques, the Lost Foam procedure is environmentally friendly. However, in Europe, the use of this casting technology is limited to a relatively small number of series parts (e. g. BMW cylinder head for six cylinder motor).

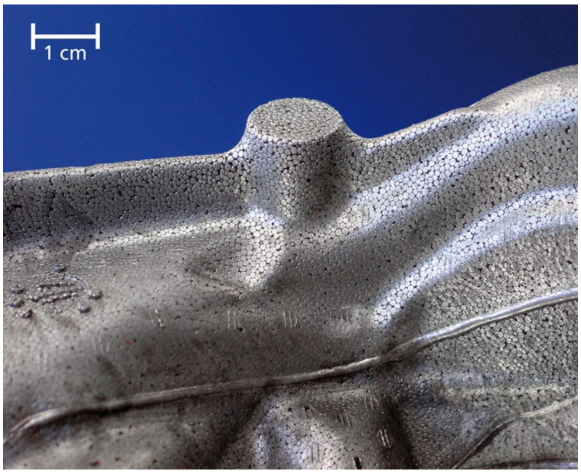


Fig. 1: Surface of an aluminium Lost-Foam part (series part).

Challenge

To extend the range of applications for Lost Foam techniques, various development trends are currently occurring worldwide. Among these are improvement of the manufacturing process and the quality inspection methods for the foamed models, refinement of surface quality both of patterns and castings, the use of alternative pattern materials with better decomposition characteristics, and expansion of the casting process to include alloy groups which have not been used up to now, such as magnesium.

Current Projects

Current research activities at Fraunhofer IFAM are, for instance, aimed at overcoming the existing technical constraints of the Lost Foam technique – a surface quality insufficient for small parts (Fig. 1) and the limitation to large components. This will make it possible to use the technique for a range of components previously restricted to, for instance, investment casting.

To fulfil these requirements, the following issues need to be addressed:

- Improvement of the EPS models' surface quality
- Reproduction of small-sized structure details in the EPS models
- Development of a modified casting technology for mould filling in cases involving very small components (overcoming capillary forces)
- Engineering of slurry- and moulding materials suited to the process
- Investigation of structure formation of the Lost Foam cast components in comparison with investment casting parts according to the state of the art

In the investigations performed thus far, we have succeeded in making improvements in surface quality and acutance of the EPS models over the state of the art by technological optimisation. The qualitative effect may be observed in the foam models, but quantitative evidence can also be detected by interferometrie (Fig. 2 and 3). Now it is possible to manufacture EPS models with very dense surfaces and exact detail reproduction down to a range of a few 10 micrometers.

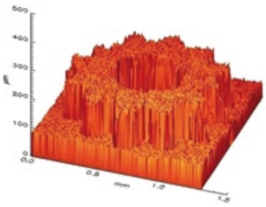


Fig. 2: Interferometer measurement of an EPS model of a micro gear structure.

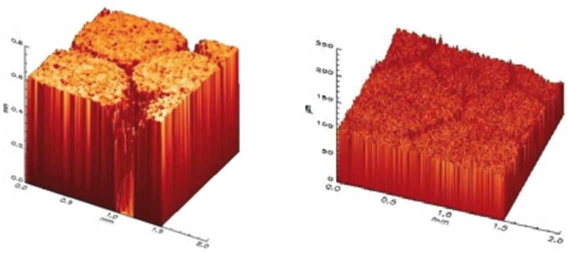


Fig. 3: Surface roughness values of an EPS part (conventional manufacturing) (left) and an improved EPS model for Lost Foam casting (right) in comparison.

Fig. 4: Demonstrator of an EPS model and a casting.

Furthermore, we investigated different casting procedures in terms of their applicability to the production of small parts with the Lost Foam technique in co-operation with BEGO Bremer Goldschlägerei Wilh. Herbst GmbH & Co. KG. Here the main problem is to generate thermal energy sufficient to decompose the EPS model and overcome the capillary forces, which work against moulding the casting exactly along the nominal contour. The technological breakthrough was achieved by using an additional vacuum system at the bottom of the casting mould. This system generates a negative pressure in the casting process, which extracts the EPS gases of the slurry and pulls the melt into the cavity. Using this system, as well as additional modifications to and compositions of the moulding sand and the model slurries, we achieved complete mould fillings and thus very good casting results (Fig. 4). For our test alloy, we used Wirobond C (Co61Cr26Mo6W5SiFeCe) provided by BEGO. This alloy is frequently used in dental engineering, and we can rely on a wealth of existing knowledge of its casting characteristics.

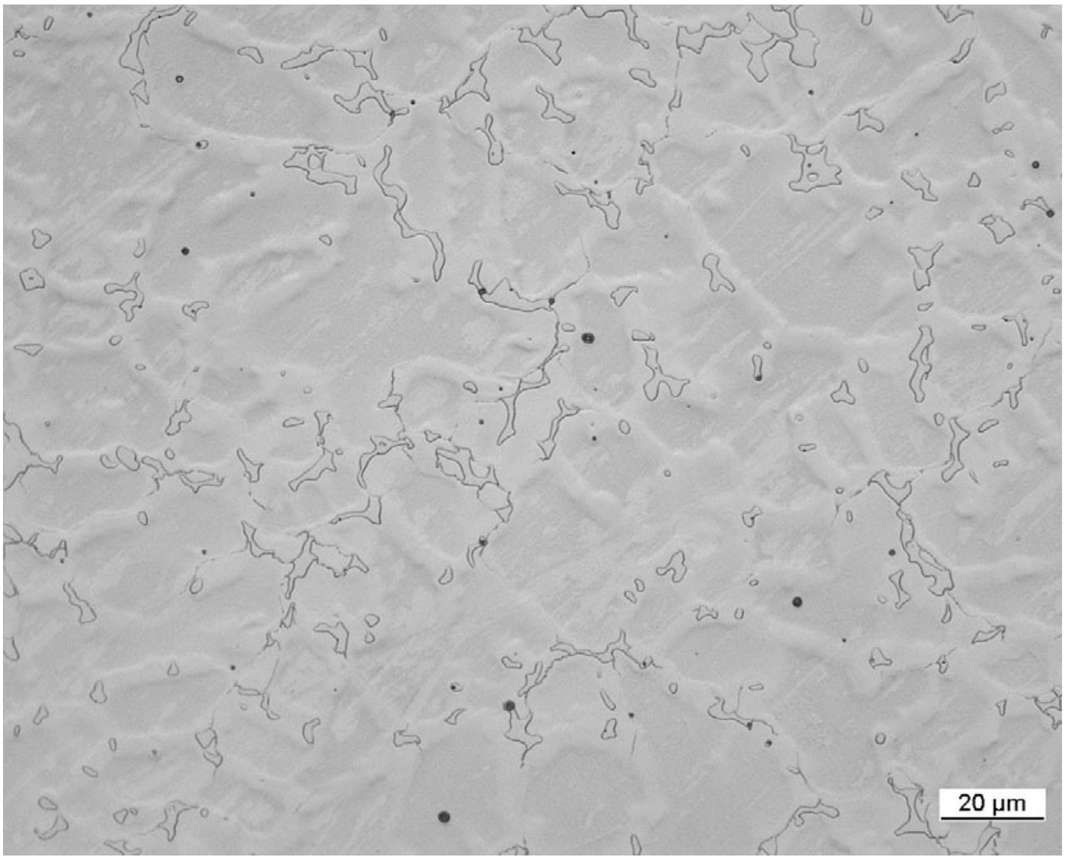


Fig. 5: Wirobond-C component structure generated with the Lost Foam technology.

The structure formation achieved with the Lost Foam technique is comparable with those achieved for conventionally made components using dental investment casting (Fig. 5).

Outlook

The results achieved thus far have contributed to employing the Lost Foam technique on a laboratory scale for a broader range of components. Even now, this technique is clearly more productive than methods commonly in use, such as the investment casting technique. We see the range of application of the newly developed Lost Foam procedural variant in particular in the field of small batch manufacturing of parts made of refractory alloys. In addition to this application, we can also use the investigation results to improve the conventional Lost Foam technology, so that they may contribute to a wider acceptance of this highly productive technique.

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Institute

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Aluminium Sponges in Air ConditioningTechnology

Background

Air conditioning surrounds us everywhere all the time. It is not only necessary to cool food during transport, but also makes everyday life more pleasant – even if we just consider air conditioning in passenger cars and buildings. Applications in refrigeration engineering are still dominated by advanced compression refrigerating methods, although these consume vast amounts of energy. Air conditioning in buildings demands a great deal of electricity, and those in passenger cars a lot of fuel.

In order to use our natural resources responsibly for air conditioning, it is recommended to utilise thermally driven techniques that make use of waste heat out of technical procedures or to use renewable energy sources. However, this approach does not work for air conditioning in buildings and passenger cars, which can demand up to 20 Kilowatts of power, due to the lack of compact and low-cost equipment. One opportunity to overcome this obstacle arises from physically adsorbing gases onto highly porous solids. Only prototypes that use this approach have been made up to now. The principle has not been implemented commercially yet because its power density is less than that of commercial compression refrigerating machines.

If the new adsorption refrigerating technology, which is environmentally friendly and economically viable, is to be established on the market, the overriding goal must be to achieve an increase in power density in comparison with state-of-the-art machinery. In the following, we illustrate the basic process for better understanding.

The core of the adsorption refrigerating machine is the adsorber for evaporation and condensation of the working substance. The adsorber is an open-porous structure that serves as a carrier, and is coated with a sorbent. There must be a tight volumetric bond between carrier structure and sorbent so that the emerging adsorption heat may be fed into the thermal fluid as quickly as possible and with as little loss as possible. For this kind of transport, we assume the high thermal conductivity of the carrier structure. The more of the sorbent there is, and the thinner the coat in which it may be deposited onto the carrier structure, the greater its efficiency. For this reason, a high level of open porosity and a large inner surface in the carrier structure have a positive effect on the adsorbing characteristics.

Motivation and Goals

The Fraunhofer project WISA "Thermally driven high-performance refrigeration techniques" is aimed at developing an adsorber technology with high power density for low power ranges up to 20 Kilowatts in air conditioning. The tasks include the manufacturing both of a suitable open-porous carrier structure and of the material compound carrier structure – sorbent, as well as the entire adsorber with heat exchanger, simultaneous modelling and optimisation and, last, but not least, development and building of a prototype.

The open-porous aluminium foams made with the fusion infiltration technique at IFAM Bremen, met the requirements of the carrier structure mentioned above. These foams offer all of the essential functional properties at a glance: They allow liquids or gases to flow through them sufficiently, are highly open porous and have a large specific surface, and are anticorrosive and strong enough to act as a structural supporting component.

Manufacturing is carried out reproducibly and very reliably through infiltration of polystyrene granulates with aluminium fusion. First the polystyrene granulates are sintered with one another through heat treatment. Fusion infiltration is executed in a die casting procedure at high metal-filling speeds and – pressures, as well as very high cooling down- and solidification speeds. Despite considerable differences in the melting points of polystyrene and aluminium, these conditions make it possible to use polymer granulates as placeholders for the future pore structure.

In thermal decomposition by heat (pyrolysis), the polystyrene content is completely removed from the aluminium-polystyrene granulate compound, and the aluminium sponge is made visible. With this procedure, one can generate reproducible pore structures with porosities ranging from 60 to 83 per cent and pore sizes greater than 1.5 mm.

Fig. 1: Placeholder structure of polystyrene granulates and the resulting aluminium sponge.

In addition to the other significant properties, like flow capacity for the passage of liquids and gases, given for the aluminium sponges represented here, it is important that we achieve a tightly adhering and dense coating of the adsorbent on the aluminium sponge structure. This significantly influences the quality of the ongoing adsorp-

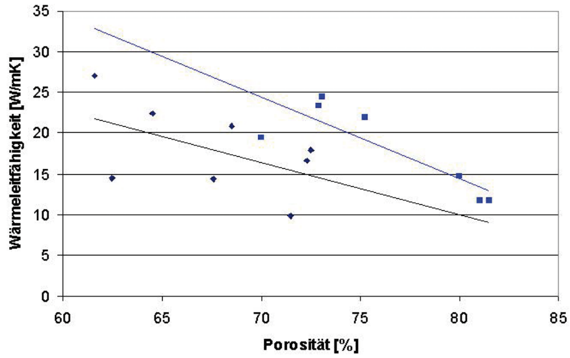

Fig. 2: How open porosity and alloy affect thermal conductivity of aluminium sponges.

Direct mapping of the placeholders makes it possible to create both homogeneous and specifically refined pore structures (Fig. 1).

Current Projects and Results

To establish this innovative adsorbing technology on the market, it is necessary to optimize the aluminium sponge in terms of its open-porous structure. What we strive for is high open porosity coupled with fine pore structure and, consequently, large specific surface, which makes it possible to deposit as much as possible of the adsorbent. What we also need is a preferably high thermal conductivity that enables heat to be quickly transferred to the heat-carrying fluid. However, optimization has to be done with compromises: Aluminium content in the entire structure and thus its “contribution” to thermal conductivity is diminished as a function of increasing porosity. Figure 2 illustrates thermal conductivity as a function of open porosity in aluminium sponge structures. However, with the average porosities of aluminium foams used, about one tenth of the matrix material’s thermal conductivity is achieved, which is definitely still a very high value.

tion- and desorption procedures. It turned out that crystallizing of zeolites as an adsorbent functions very reliably for aluminium sponges. For this project, coating is done at the University of Erlangen and at Sortech AG. Examples of generated structures like these are demonstrated in Figures 3 and 4 (overview structure of a sponge and detail view of an SEM image). The quality of the aluminium sponge-adsorbent compound is verified at the Fraunhofer Institute for Solar Energy Systems ISE by measuring adsorption kinetics. The results, in direct correlation with the sponge structure used, allow conclusions about further optimization of the carrier matrix.

The potential to implement a significantly higher power density with aluminium sponge structures as the carrier material in the adsorber instead of with the state-of-the-art equipment used previously is estimated to be very great. This innovative material gives us the chance to develop a new technology for air conditioning in the lower power range in the automotive sector and building engineering that is more environmentally friendly and profitable.

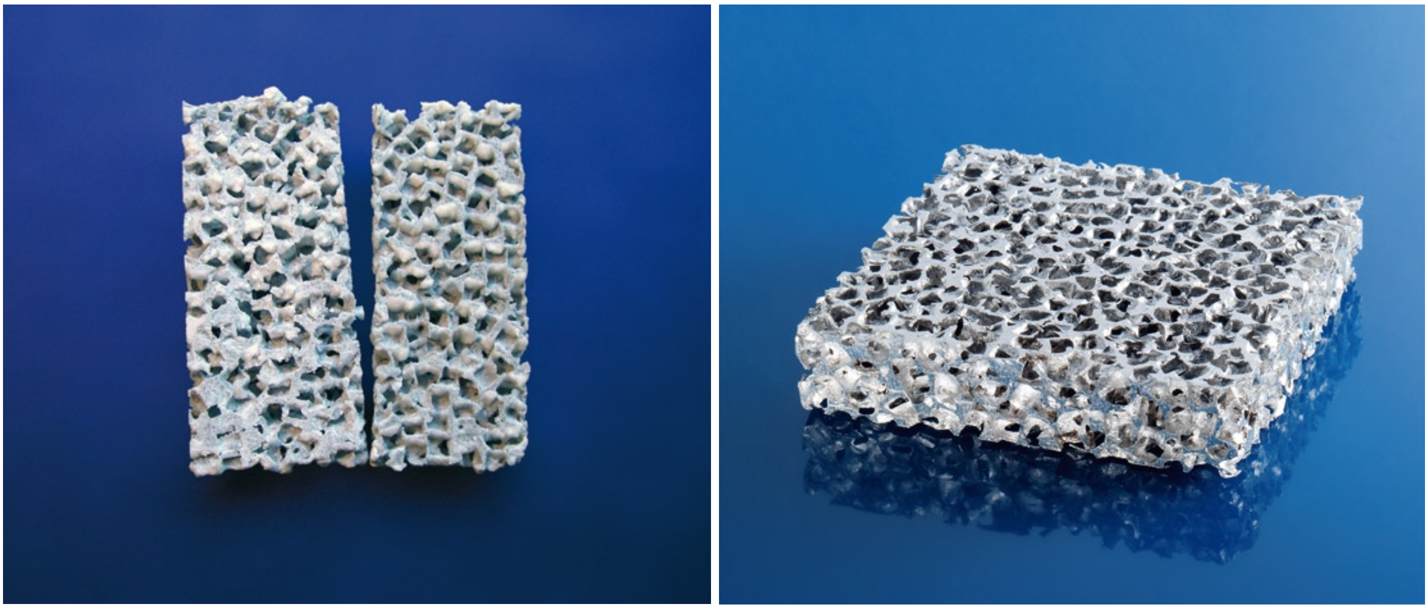

Fig. 3: at the left: Crystallized zeolite structure on aluminium foam (Chair of Chemical Reaction Engineering at the University of Erlangen). At the right: Aluminium sponge without zeolite structure.

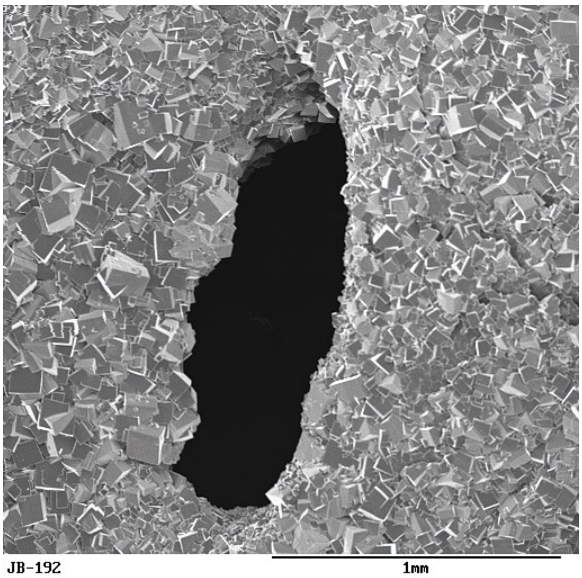

Fig. 4: SEM image of the zeolite crystal on the aluminium sponge.

Project Partners

Fraunhofer Institute for Solar Energy Systems ISE
Fraunhofer Institute for Industrial Mathematics ITWM
Fraunhofer Institute for Process Engineering and Packaging IVV
Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM in Dresden

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Safe Cooling of Electronics by Means of Miniature Heat Pipes Made of Copper

Background

Today miniature heat pipes are being used more and more to cool electronic units, both in terrestrial and space travel applications. The challenge of today's development lies in the reduction of the high manufacturing costs, in improving the low transmission power values at low temperatures and in the demand to make reproducible units.

Heat pipes are used on a grand scale, for instance in space travel, to cool electronic units of high dissipated power. The material combination aluminium / ammonia is predominantly in use. Heat pipe profiles made of aluminium can be extruded easily, at low cost and in a reproducible manner. The advantages of ammonia are its transportability and the fact that the material only freezes at very low temperatures (minus 80 °C). However, the great disadvantage of ammonia is its toxicity.

For terrestrial applications and due to increasing safety concerns in space travel, we are looking for alternatives. In searching for more harmless liquids, water and alcohol come to mind first. Water has excellent transmission characteristics, but it freezes at 0 °C. Methanol also has properties that make it feasible, but, by contrast, it is characterized by low working temperatures (down to minus 60 °C).
Copper and stainless steel, for instance, are suitable as heat pipe material, but copper is preferred due to its high thermal conductivity. However, one disadvantage of both materials it that is impossible to extrude miniature profiles without more work.

Consequently, to be capable of delivering huge quantities, e. g. for computers, the material combination copper / water must be a technical and economical alternative to the state of the art.

The Problem

The project is designed to engineer a new manufacturing procedure for copper in order to overcome the obstacles mentioned. The basic approach is to transfer copper into the desired geometry for miniature profiles via powder extrusion. The component is made by extruding a copper-binder mixture, the feedstock. Extruder outlet geometry (matrix or die) defines the geometry of the component's cross-section. In theory, component length is endless, however, in practice it is limited by the length of the furnaces to be used for the necessary follow-up steps.

After shaping, the extruded component – the green part – is thermally debinded and sintered. Before intrinsic sintering of the metal fractions, organic portions of the metal binder mixture (feedstock) must be removed in debinding. During sintering, the component shrinks to its final dimensions.
Several feedstock compositions were prepared for the extrusion experiments. The feedstock mixtures are based on polymers and waxes, and they are used in similar compositions for metal powder injection moulding.

In extrusion, the technological challenge is to maintain adequate temperature control of the extruder's tempering zones. Since the extruder's heating up- or cooling down properties are characterised by a certain thermal inertia, and the feedstock strongly reacts to temperature changes, it took us a series of tests to determine an adequate temperature profile. Material homogeneity and geometric stability of the extrudate at the nozzle output, as well as its macroscopic surface quality, were used as criteria for the applicability of the temperature profile.

Two different extrusion profiles were tested according to the project goal, focused on the production of miniature profiles: One profile followed a comb-like structure, with a single runner width of 0.7 mm, while another profile had an inverted comb structure and a single runner width of 0.35 mm (Fig. 1).

Surface quality, shape and general geometric stability strongly varied during the first extrusion tests. Subsequently, we were able to generate optically acceptable specimens with high dimensional accuracy, adequate surface and sound reproducibility of the comb-like profiles (Fig. 2). Manufacturing of an inverted comb profile is made possible by changes in the temperature control in combination with granulated feedstock.

There were no problems in chemical debinding of all the profiles with n-hexane at room temperature. None of the specimens showed visible defects, such as, for instance, cracks or faults. After thermal debinding and sintering of all extruded and then chemically debinded profiles, we also obtained parts without cracks, with a dense structure according to macroscopy.

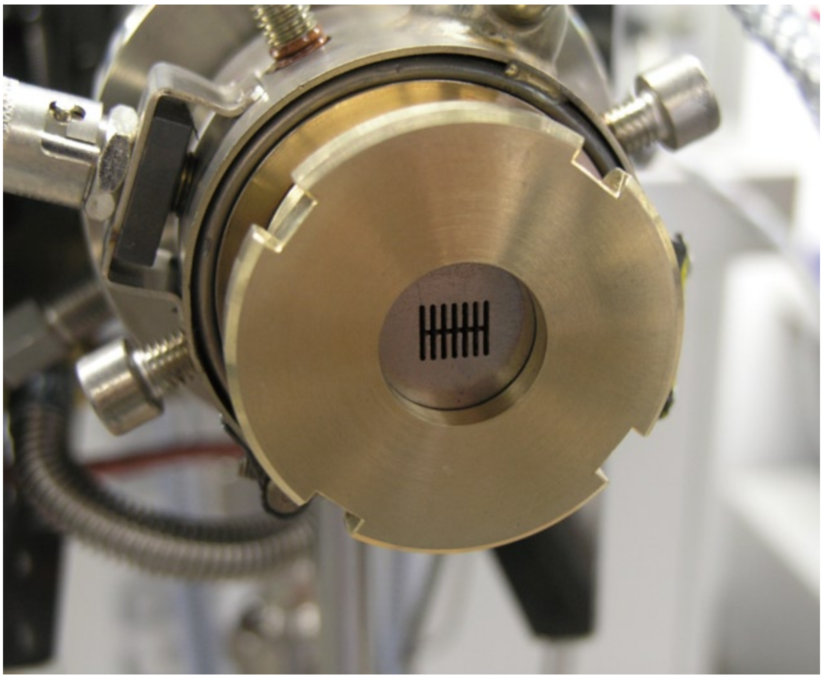

Fig. 1: Die (nozzle) for a comb-like profile – web width 0.70 mm.

Results and Outlook

Extrusion of modified MIM feedstocks on a copper powder basis is feasible. This is a very promising approach to produce linear structures of high complexity at low production cost, and thus offers a reasonable alternative to previous techniques for heat pipe manufacturing.

Nevertheless, it is necessary to carefully co-ordinate the necessary feedstock formulations and extrusion parameters in order to generate green parts of corresponding dimensional stability and sound surface. Temperature control during extrusion, which has to balance product geometry and -stability against each other, is a significant function here. We see one opportunity to improve the extrudate's dimensional stability in installing a calibration line behind the extrusion die.

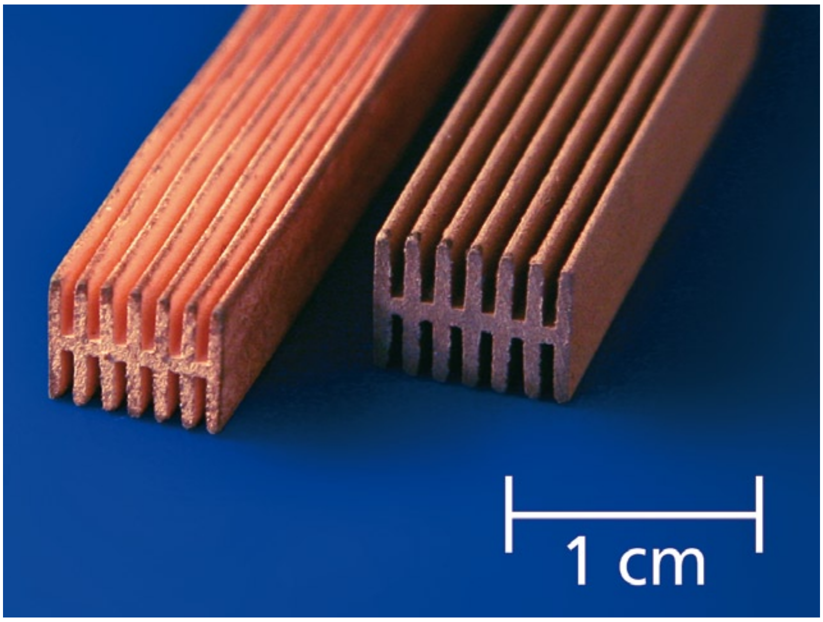

Fig. 2: Sintered comb-like profile (left) and green part (right).

As assumed, the extrusion of the feedstock based on gas-atomized powder was more successful than those where feedstock is based on water-atomized powder. We also recommend the gas-atomized material type with spherical particles for a possible continuation of the project. Reducing the percentage of binder from 50 to 35 % was another efficient measure towards improved dimensional stability.

Additional prospects for improvement of the heat pipe's efficiency result from the fundamental ability to make deliberate adjustments to the material's porosity and thus the dimensions and structure of its inner surface during final debinding and sintering of the miniature heat pipe.

Customers

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New Microsystems for Innovative Synthesis of Ionic Liquids – NEMESIS

NEMESIS stands for a joint project to develop a microreaction system for the synthesis of ionic liquids, a new, innovative group of materials (solvents). The project objective is to engineer a microreactor system that can continuously synthesize ionic liquids of high purity in a reduced synthesis time.

IFAMs role in the NEMESIS project is to develop a modular concept of the microreactor system. Additionally a modular injection moulding tool was designed. The whole µ-MIM – micro metal injection moulding – process from feedstock development to the manufacturing of the microfluidic components was contrived in this project. In the first part a microreactor test system (Fig. 1) enabling continuous synthesis of ionic liquids was developed. Within this task IFAM contributed in the system concept including the electronic-, measuring- and controlling unit. In conjunction with the Center for Environmental Research & Technology (UFT) at the University of Bremen, IFAM worked at dimensioning and designing the required microfluidic mixers. Another project result was a modular constructed injection moulding tool, which is able to mould a wide range of different microfluidic geometries.

This modular tool is important in order to adapt geometric modifications at low costs. The injection moulding tool with a modular design is shown in Figure 2. For this mould, 13 mould inserts were designed and manufactured.

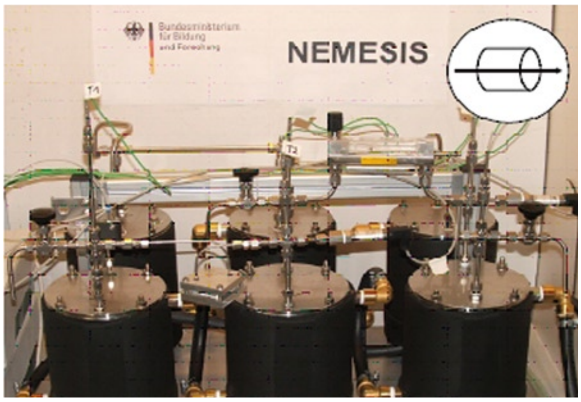


Fig. 1: Microreactor test system for the synthesis of ionic liquids.

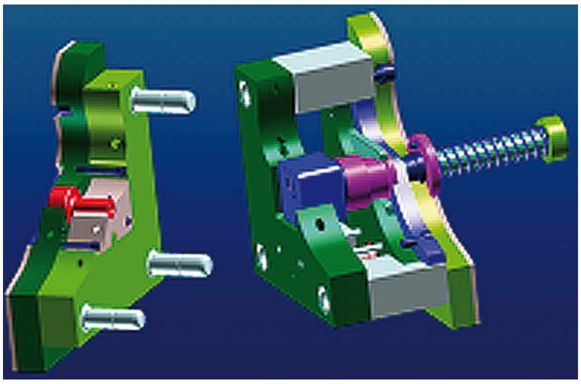


Fig. 2: Injection mould (modular construction) for the injection moulding machine Arburg 320C.

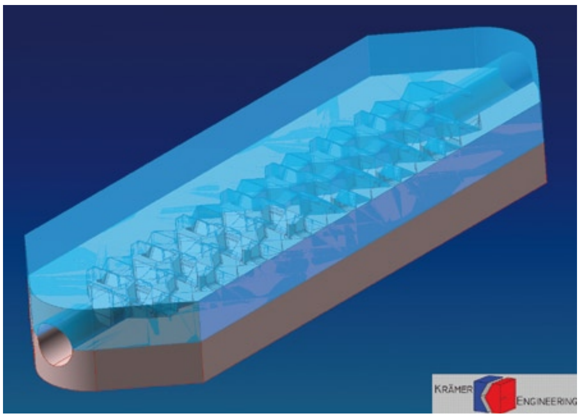
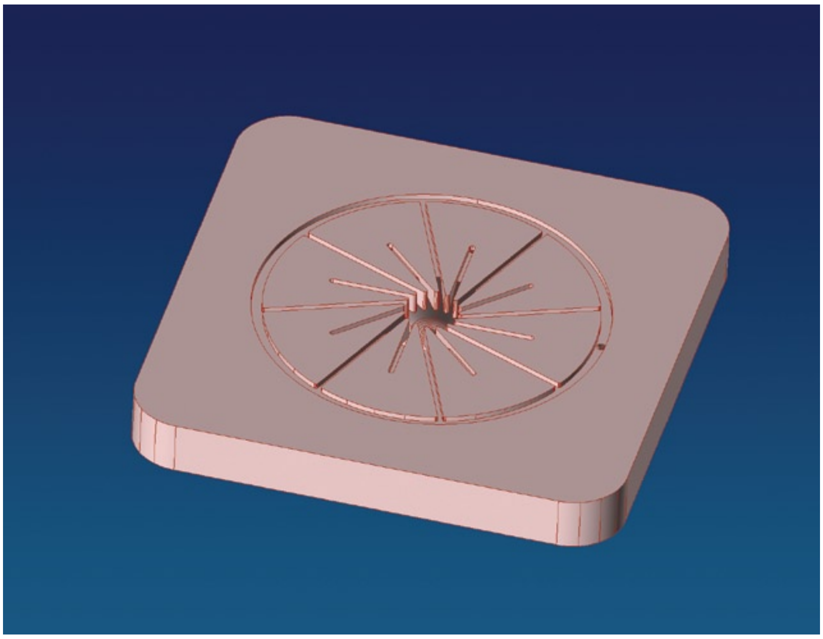


Fig. 3a: Component drawing of the mixer (split-and-recombine mixer) with a 4 mm diameter inlet and outlet runner.



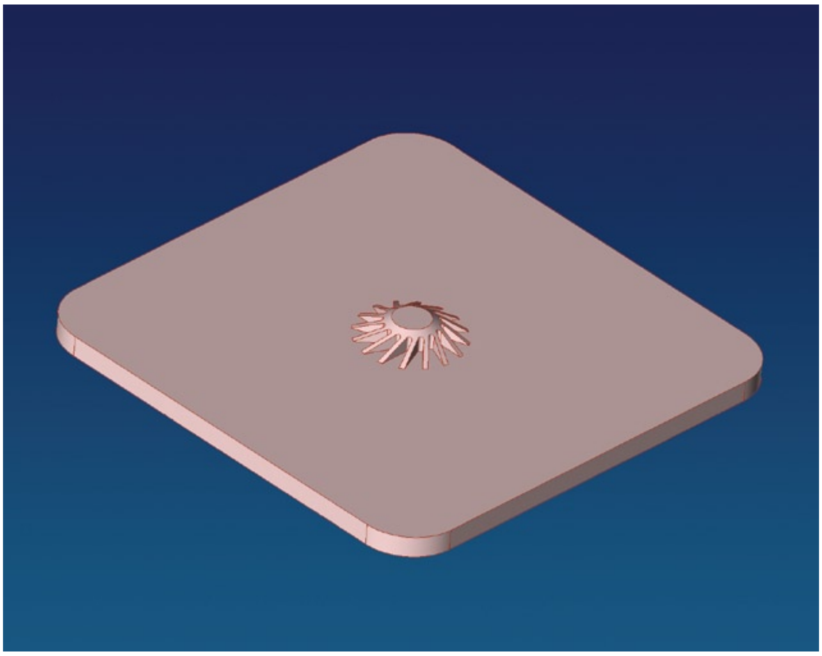


Fig. 3b: Component drawing of the Vortex mixer (channel width 500 micrometers) with cover. This is designed for optimal mixing of educts during the synthesis of the ionic liquids.

The modularity of the new NEMESIS injection moulding tool enables to manufacture a wide range of geometries with just one mould. This flexibility lowers part production costs. In addition, the reset time needed to exchange mould inserts was significantly reduced – from half a day down to less than 15 minutes. Figures 3a and 3b demonstrate two different microfluidic structures that were developed in this project and produced by the company Krämer Engineering as inserts for the modular injection moulding tool.

Stainless steel mixers made by applying the µ-MIM technology are shown in Figure 4. In this method, metal powder is mixed with a binder system to form a so-called "feedstock". In the µ-MIM process the feedstock is heated up and subsequently injected into the mould (see Fig. 2) on a conventional injection moulding machine. The feedstock cools down and solidifies. The injection moulded parts are in a following step debinded. During this thermal procedure the binder is removed out of the component. In another heat treatment process the component is sintered to full density. During sintering, the component shrinks, in the case of the illustrated mixers by approx. 10 %. The metallic microfluidic mixers, in this case Vortex- and split- and recombine mixers, can now be used for the synthesis of ionic liquids. The Vortex mixer (Fig. 4a) is applied for an optimal mixture of educts at the beginning of the reaction process. However, the split- and recombine mixer (Fig. 4b) is dimensioned so that the ionic liquid, which becomes progressively more viscous in the course of the process, is mixed much more effectively. This is necessary to prevent possible separation of the mixture during the synthesis reaction.

Fig. 4a: Vortex mixer (mixing range) made by metal injection moulding.

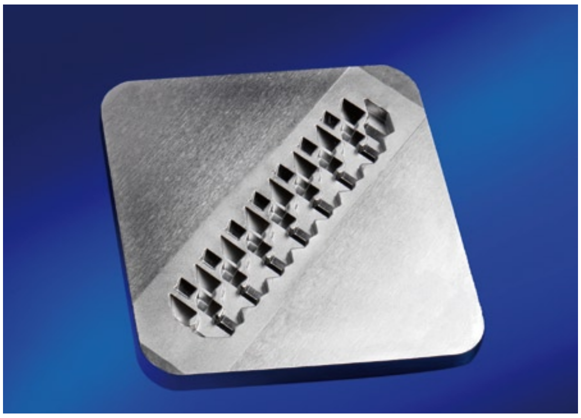


Fig. 4b: Split- and recombine mixer made by metal injection moulding.

To insert the mixers shown in Figure 4 into the new microsystem for the synthesis of ionic liquids, it is necessary to integrate inlets and outlets into the components. Furthermore, the design needs to be accomplished without using sealing materials, which would normally be needed. Here the advantages of powder metallurgy are utilised by integrating the metallic connections into the components during the sintering procedure. This way, material shrinks around the capillary tubes, a leak-proof path between the component and the connections (Fig. 5) results. Figure 5 also demonstrates co-sintering of components. In this procedure, several components are laid on top of each other during thermal debindering and sintering. During sintering, they are mutually adhered under pressure. This is a method to keep the components as small as possible since no retainer and additional seals are required to insert the mixers into the microreactor system.

The co-sintering method was also applied to the split- and recombine mixers. In this procedure, it is impossible to sinter the connections into the part, since they are located directly on the edges of the two halves of the mixer. Subsequently the inlets and outlets are inserted into the mixer. To do this, a thread is tapped into the mixer and onto the fitting tubes, and both parts are tightly screwed on (Fig. 6).

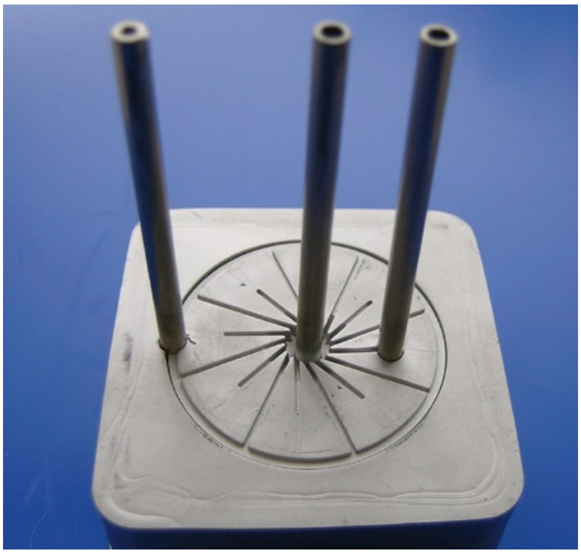


Fig. 5: Finished Vortex mixer with connections. The components are joined by co-sintering, no seals are necessary.

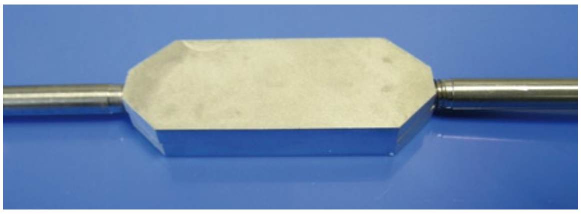


Fig. 6: Co-sintered split-and-recombine mixer with screwed on connections.

Results and Outlook

As a result of the NEMESIS project, we were able to show that the metal powder injection moulding technique is suitable to produce metallic mixers for applications in chemical industry. The problem to be overcome was to produce parts of relatively large dimensions, but with filigree structures. This problem could be solved by optimizing the process parameters in the μ-MIM technology. Components with microfluidic structures in the micrometer range, which had excellent contour sharpness, were this way manufactured. We also succeeded in engineering a mould with modular construction to be used for micro metal injection moulding. Co-sintering of the material itself or of metallic components was also tested within this project. Gas-tight connections were realized this way.

Future investigations will focus on further aspects of co-sintering. Additionally the mixer design will be adapted to the conditions of the second test system, which will be built by the end of the project. Fraunhofer IFAM will also be involved in the electronic, measuring and controlling technique of the second test system.

Customer

The Federal Ministry for Education and Research – BMBF, represented by the sponsor, VDIVDE-IT, in Berlin. Sponsorship code: 16SV1964

Project partners

Ionic Liquids Technologies GmbH & Co. KG, Denzlingen (co-ordinator)
BIAS Bremer Institut für Angewandte Strahltechnik GmbH, Bremen
Merck KGaA, Darmstadt
Schulz Automatisierungstechnik GmbH
Universität Bremen, UFT

Project Duration

1 January 2005 to 30 September 2008

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µ-MIM of Nickel-Titanium Shape Memory Alloys

Background

So-called "smart materials", which belong to the intermetallic materials group, have enormous potential for future industrial applications, mainly in the automotive and aeronautics sector. The best known representative of this material class, nickel-titanium (NiTi), may appear as super-elastic or shape memory material, depending on composition and heat treatment. NiTi is applied in industry for different actuators, mostly in the form of wires, pipes or thin sheet metals. In the NiTiBiT (Nickel-titanium for biomedical and transport applications) project, powder metallurgical processes are investigated in terms of their suitability for low-cost and net-shape manufacturing 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 34 international partners.

Project Description

In the project, IFAM is developing the micro metal injection moulding (µ-MIM) to manufacture filigree components made of NiTi. This task includes the entire process chain, from choice of powder and powder conditioning over debinding and sintering technology to identifying physical and mechanical properties. One essential challenge is to adjust the temperature determining the phase transformation from martensite to austenite – a criterion that is decisive for the superelastic or the shape memory effect – in a reproducible manner. If the nickel-titanium proportion changes by as little as ±2 atomic percent, the transformation temperature may shift by up to 350 °C. It is also the case that oxygen- and carbon content have a significant effect on the transformation temperature and the mechanical properties. Consequently, the level of these impurities has to be kept as low as possible. This means that we have to apply with stringent requirements for debinding- and sintering technology, since, in particular in the µ-MIM process, very fine powders with a strong affinity to absorb oxygen and carbon are processed. The following chapter describes the process development and the material properties obtained.

Results

For the initial material, a prealloyed powder with a Ni-Ti percentage of 50.7 to 49.3 atomic percent was used. Mean powder particle size was 11 micrometers, nominal transformation temperature of the materials 37 °C. Figure 1 shows an SEM image of the powder. We obtained a predominantly spherical particle size, which is desirable for the MIM process.

For feedstock conditioning, a binder based on waxes and polymers was used. The ratio of the volume of the powder to the binder was 65 to 35 percent. At first, powder and binder were mixed in a sigma blade mixer. The feedstock that was optained was finally homogenized on a roller

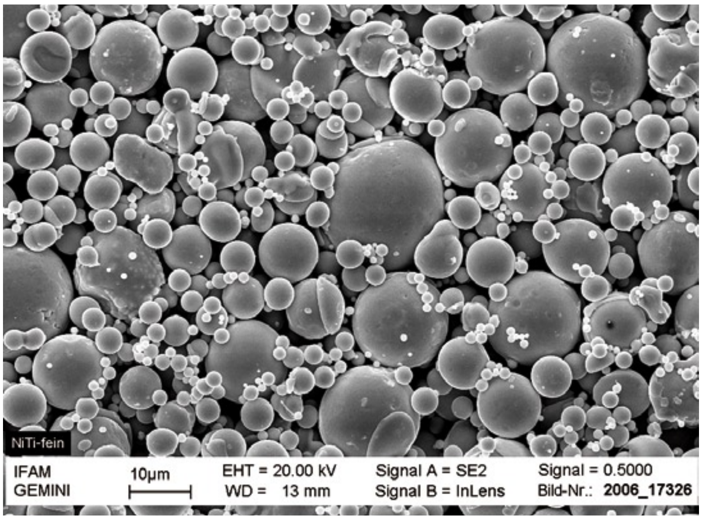

Fig. 1: NiTi powder in SEM.

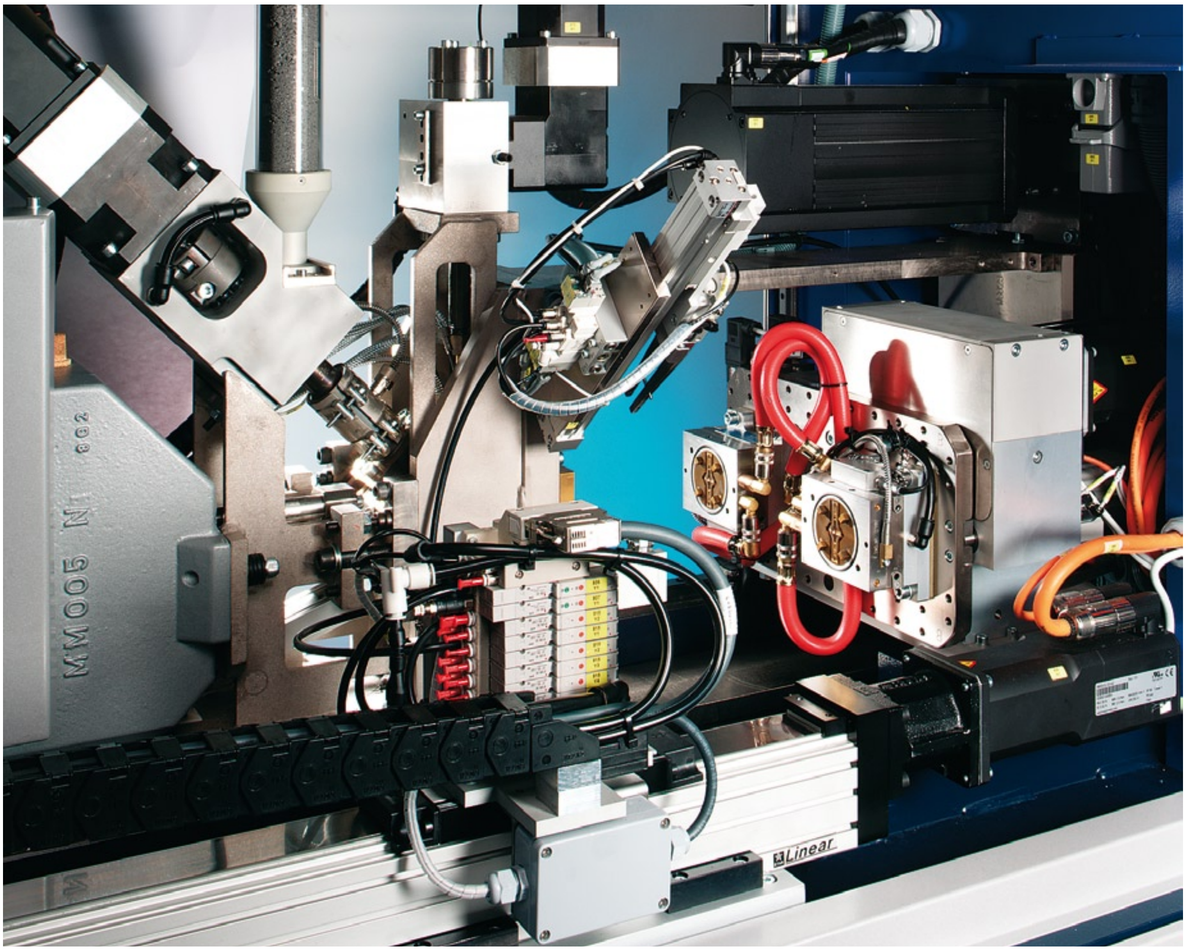

Fig. 2: Micro injection moulding machine Battenfeld Microsystem 50.

Program No.	Heating rate [K/min]	Sintering temperature [°C]	dwell time [h]
1	5	1200	6
2	5	1230	6
3	5	1250	6
4	5	1270	6
5	10	1270	6
6	15	1270	6

Tab. 1: Sintering programs.

extruder. Injection moulding was carried out with a micro injection moulding machine, Microsystem 50, made by Battenfeld (Fig. 2).
Several test specimens, including micro tensile test specimens of 26 millimetres length and a test cross-section of one square millimetre, were moulded. In the next step, the specimens were chemically and thermally debinded and sintered under various processing conditions. The different sintering programs are listed in Table 1.

Figure 3 shows some specimens after sintering. Density measurements carried out after sintering evidenced an increase in relative density from 90 % to about of 96-97 % as a function of rising sintering temperatures (sintering programs 1 to 4). Paralleling this, at higher sintering temperatures, we recognised a reduction in dispersion among the individual measured values (Fig. 4).

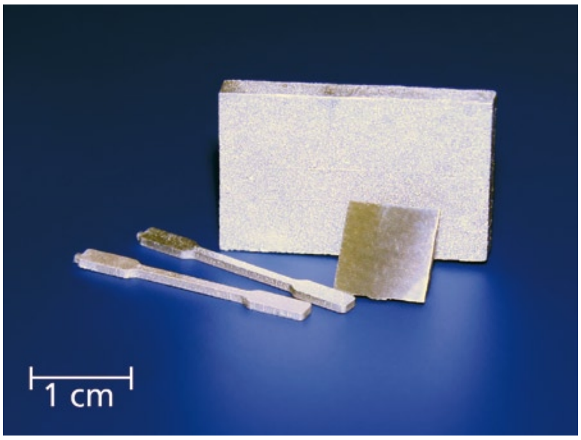

Fig. 3: NiTi specimen after sintering.

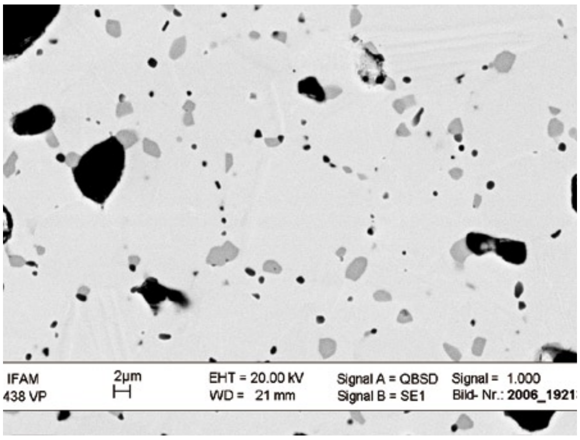

Fig. 5: SEM image of a typical NiTi structure (program 3).

The structural analyses in principle yielded a multi-phase structure for all sintering conditions, with a matrix appearing light grey in SEM. A typical structure like this is illustrated in Figure 5. The light grey matrix was identified as NiTi by means of energy dispersive X-ray spectroscopy (EDX). Following this analysis, the dark grey phases consist of $NiTi_2$. The small black points to be seen

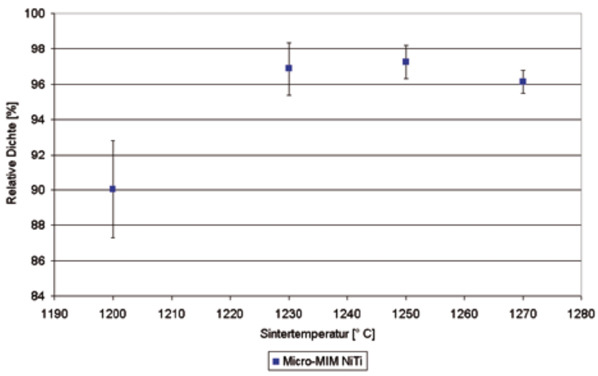

Fig. 4: Influence of sintering temperature on density.

on the grain boundaries are inclusions rich in titanium. The larger black regions to be seen on the image are pores. The first positive result to be stated is that the desired NiTi phase represents the predominant structural ratio, even if an ideal one-phase NiTi structure was not yet achieved.

The measurements of the carbon and oxygen rates clearly show the influence of the heating rates on the corresponding portions. Thus, if heating up was done not at 5 K/min, but at 10 or 15 K/min, both oxygen- and carbon content were diminished. Sintering time, which is reduced overall and probably contributes to reduced oxygen absorption from the process atmosphere, could be a possible reason for this phenomenon. The measured values are summarized in Figure 6.

The mechanical properties of the NiTi specimens were tested using micro tensile tests at room temperature. The stress-strain curve (Figure 7) verifies high tensile strength values up to 1,000 MPa and elongations of 14 %. A distinctive plateau was seen at around 450 MPa. This confirms that the microstructure was subject to stress induced martensitic transformation, as is typical for

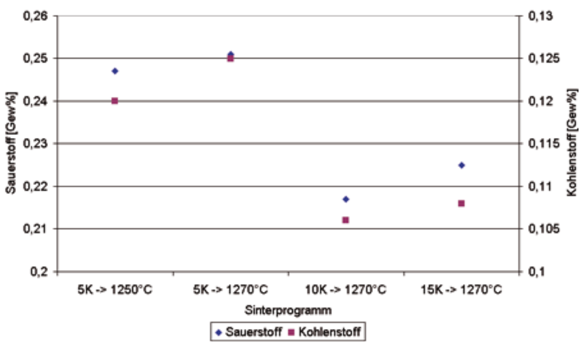

Fig. 6: Oxygen and carbon content of the NiTi specimens.

the shape memory effect. In the sintered parts, transformation temperatures of 19 to 22 °C were found, whereas Differential Scanning Calorimetry (DSC) of the powders provided a transformation temperature of 37 °C. This shift of the transformation temperature is presumably due to the formation of $Ni_2Ti_4O_x$ oxides, which may result in a reduction of the Ti portion in the matrix and thus lead to a lower transformation temperature. At the moment, tests exploring the characteristics during cyclic deformation as well as structural changes after treatment with pulsed current (for grain refining) are being executed at the partners' institutes.

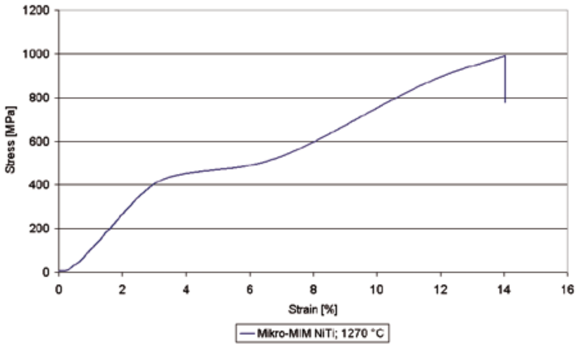

Fig. 7: Stress-strain curve of MIM-NiTi after sintering 5.

Outlook

During the project period, the described µ-MIM development of nickel-titanium was carried out and resulted in the design of a demonstrator, which could be used as a sealing element in a car. In the new project year, which is just starting, the material characteristics of this component will be optimized for application. A transformation temperature of 60 °C is desired. In the event of successful process development, there is an opportunity to find further applications in immediate follow-up projects.

Acknowledgement

The project was co-financed in the Network of Excellence "Knowledge-based Multicomponent Materials for Durable and Safe Performance (KMM)" in the Sixth Frame Program of the EU (www.kmm-noe.org).

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Materials for Hydrogen Storage
Improved Storage Capacity and Kinetics through Nanostructuring

Motivation

In view of worldwide climatic changes, geopolitical dependencies related to sources of fossil energy, and the global competitiveness of German industry, hydrogen is regarded as a clean, reliable and innovative future source of energy. To make a hydrogen-based energy circuit reality, it is essential to solve the problem of hydrogen storage. In particular for portable and mobile applications, the problem of finding a reliable, volume-efficient technology to store hydrogen at low cost and low weight remains unsolved.

The storage of hydrogen both in compressed and liquid states, a process that is already feasible under laboratory conditions, is characterised by extremely high system reliability requirements, on the one hand. On the other hand, with these modes of storage, it is impossible to fulfil the objectives – a gravimetric hydrogen storage density of 6 mass percent – outlined by the US Department of Energy (Fig. 1).

Consequently, some inorganic materials, such as metal hydrides, complex hydrides, carbon-nanostructures and compound materials (Fig. 1 and 2), which offer solid hydrogen storage, are regarded as extremely promising alternatives. Future application research and development is aimed at the technological implementation of the theoretical fundamentals in natural sciences that are now available about this subject into practical system solutions.

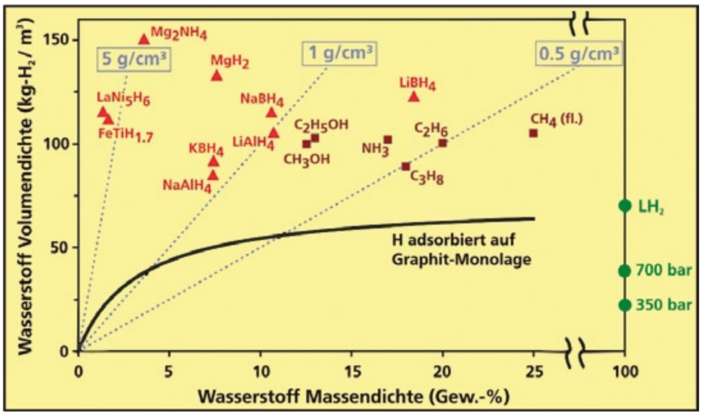

Fig. 1: Several variants of hydrogen storage compared according to their volumetric and gravimetric hydrogen storage density. Metal- and complex hydrides are marked in red.

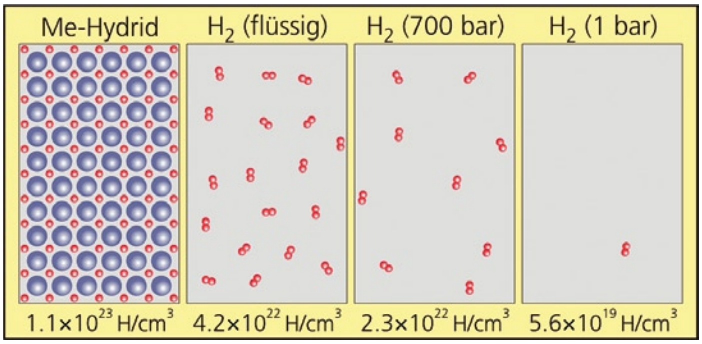

Fig. 2: Schematic comparison of volumetric hydrogen storage densities: Metal hydride, liquid hydrogen, compressed hydrogen, hydrogen under standard conditions.

New Direction of Research

Against this background, the new working group "Hydrogen storage" was established at IFAM Dresden in September 2007. Utilizing the fundamental research already done, its task is to engineer reversible solid matter storage systems, resulting in a prototype for portable and mobile, as well as stationary applications. R&D will be focused on metal hydrides, magnesium-based light metal hydrides, complex hydrides, and compound materials, which will be used in nanostructured form.

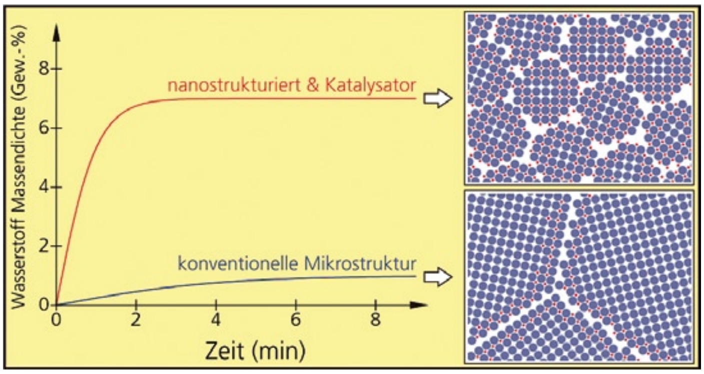

Fig. 3: Schematic view of the hydrogen storage characteristics of nanocrystalline materials charged with a catalyst, in comparison with conventional microcrystalline materials.

Owing to the very large "inner surface" (grain boundaries, dislocation) and the high number of defects, it is possible to achieve both a higher storage capacity and increased reaction kinetics (Fig. 3). Furthermore, nanodispersing particles acting as a catalyst are in use in order to reduce the barriers to reaction that must be overcome for absorption and desorption.

This new work group will be installed within the scope of the Fraunhofer-internal sponsorship program "Fraunhofer Attract" over the next 5 years. Lars Röntzsch, a physicist, is the head of the group. He received his PhD degree for research and development carried out at the research center Dresden-Rossendorf in the field of synthesis of nanostructures and their modification through external forces and arrays. Thus, he is very experienced in working with atomistic reaction kinetics of condensed matter, which is necessary for the extraordinarily complex hydrogen sorption mechanisms in solid matters. The group is expected to be fully operational after a period of 3 to 4 years. At this stage, the research group is intended to consist of three scientists.

Project Goals

Based on findings in fundamental materials science research, the Attract project is aimed at the development and testing of reliable hydrogen storage systems for portable, mobile and stationary applications with high hydrogen storage densities and higher reaction kinetics of charging / discharging than conventional systems of this type have.

The materials science aspect of the project is focused on exploring nanostructuring and catalytic activation for solid matter storage of hydrogen of suitable material classes. For material synthesis, we mainly refer to technologies established at Fraunhofer IFAM Dresden, such as high-energy milling and melt spinning. Besides the conventional structure analysis methods (XRD, SEM, TEM), thermal analysis methods (most of all thermogravimetry with compressed hydrogen and under high temperatures) are used to determine the reaction kinetics of the hydrogen sorption (that is, charging / discharging of solid matters with hydrogen).

Beginning with fundamental research of the mechanical modification and activation of the solid matter storage, the project is aimed at generating technologies and investigation methods for hydrogen storage materials and systems that enable development work with material quantities relevant for practice. In the advanced project stage, industrial co-operation should be established to a greater extent. To do this, it is necessary to expand the material-oriented competencies to include system competencies involving both thermal- and pressure management of the solid matter storage and safety aspects in order to present and make available to the industrial project partners storage system prototypes for selected applications.

Strategic classification

Fraunhofer IFAM Dresden has many years of experience in nanostructuring of metallic materials in the field of powder modification and -processing. The new working area is directly linked to these competencies: Available and new technologies are expected to refine the charging / discharging characteristics of hydrogen storage materials by nanostructuring. Concerning hydrogen technologies, projects have already been done in hydrogen extraction via catalytic reforming and in hydrogen storage in metallic hollow spheres at Fraunhofer IFAM Dresden. Thus the research activities planned are immediately connected to existing competencies and are a desired extension of previous materials research, since they are oriented toward functional characteristics.

Even if the planned project work in the field of hydrogen storage comprises a clearly delineated discipline of hydrogen-based technologies, with its group of co-operation partners in industry, this project expands the system competency of the Fraunhofer-Gesellschaft for the use of hydrogen as a secondary energy carrier. There are connections to the following Fraunhofer institutes, which are already experienced in hydrogen technologies: IKTS Dresden (fuel cells), ISE Freiburg (hydrogen generation, micro energy technology), ICT Pfinztal (hydrogen safety engineering), IVI Dresden (mobile hydrogen infrastructure, fuel cells in traffic engineering), IGB Stuttgart (hydrogen generation via membranes, hydrogen cleaning), ISI Karlsruhe (energy policy and energy systems). Since the subject deals with a very sophisticated change of technical and economic structures in the broadest sense, experience covering the whole process from generating to storing to using hydrogen will still improve the position of the Fraunhofer-Gesellschaft and its institutes in global competition.

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The innovative Growth Core inno.zellmet

inno.zellmet is a major project sponsored by the BMBF. The project objective is to move ahead the commercialization of multifunctional cellular metals based on fibres and hollow spheres. The core of this project is the so-called technology platform, which is still under development in the field of production, refinement, finishing and characterisation of this material group. In the context of the BMBF's innovation initiative "Entrepreneurial regions", six research facilities and 17 partners from industry have received sponsorship in the amount of almost four million Euros over a period of three years.

The process of achieving the global objective includes four joint projects carried out simultaneously, dealing with different central subjects. Overall control is performed by a centralized management team, consisting of one representative of Fraunhofer IFAM Dresden and one from the project partner Glatt Systemtechnik GmbH. Task forces investigate general topics, such as finishing, characterization or marketing. The project was started in March 2005. Its first stage was completed in February 2008.

The technological fundamentals of the intended developments were explored in Fraunhofer IFAM (Dresden) projects in the field of sintered short fibre structures and metallic hollow sphere structures (Fig. 1) in the 1990s. The manufacturing procedures were described in detail in several publications [1 and 2] and are not discussed in this report. Powder metallurgy processes make it possible for both materials to be produced in an almost unlimited variety of metals and alloys, including intermetallic compounds, noble and refractory metals, as well as special materials with magnetostrictive and shape memory properties. Fraunhofer IFAM Dresden and Glatt Systemtechnik GmbH from Dresden, a company that is working closely with Fraunhofer in this project, deliver the materials to the project partners.

These "engineered" materials are designed to be used in lightweight construction, decentralized electric supply, medical engineering and biotechnology, as well as in silencing and explosion protection for stationary equipment. Figure 2 summarizes the main topics and development objectives of the four joint projects. In the following, two of these development paths will be exemplary introduced.

Metallic hollow sphere structures demonstrate good wideband sound absorption capacity. It is possible to adjust the properties to accommodate a certain spectrum of frequencies by changing sphere diameter, wall thickness, shell thickness and other parameters. The wide variety of materials represented means that some of them are highly resistant to thermal and mechanical stress. As a result, this material opens up special opportunities for sound absorber design under demanding environmental conditions. In co-operation with the MASCHA project partners – the society

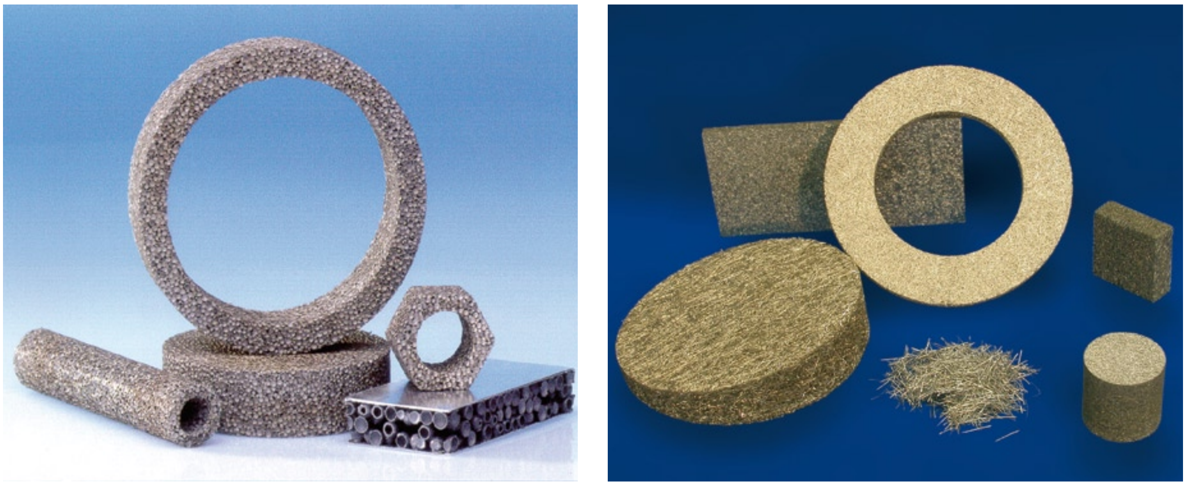

Fig. 1: Hollow sphere structures (left) and sintered short fibre strucktures (right) – examples.

Project	Development objectives	Ranges of application
MAKOMP	Lightweight and stiff hollow sphere composites; connection technology	High-speed machine parts in Laser cutting - and packaging machines
MASCHA	Structural supporting, sound absorbing hollow sphere; Sintering technology	Sound insulation and -dissipation for machine tools and air exhaustions
CASMEDUM	Metal fibre structures with large specific surface; Functional coatings for fibre structures	Biosensors, Oxygen generators, Catalytic air and water cleaning
HOTFAS	Large high-temperature resistant fibre structures	Explosion protection devices, Finishing of regenerators for Stirling engines, Porous surface burners

Fig. 2: Objectives and ranges of applications of the growth core in summary.

Fig. 3: Hollow sphere structure for sound encapsulation of a high-speed milling cutter.

for acoustic research (Gesellschaft für Akustikforschung Dresden mbH) and the machine manufacturer Portatec GmbH, an encapsulation for a high-speed milling cutter (Fig. 3) was created, for example. The hollow sphere structure made of stainless chromium nickel steel replaces a robust bell made of aluminium, and, in addition to reducing weight, diminishes the measured sound level by up to 6 decibels (Tab. 1).

Spindle speed	Feed [m/min]	Sound level [dB(A)]	
		Robust bell	MHKS bell
20,000	3.0	74.0	72.0
25,000	3.6	77.0	74.0
30,000	4.5	81.0	75.5
35,000	5.1	83.5	77.5

Tab. 1: Measured sound levels as a function of spindle speed.

In the HOTFAS project, in addition to other subjects, development is focused on a sintered fibre structure to be used as a porous surface burner. This type of burner has especially advantageous properties, such as high power density and, consequently, robust design. The burners have extreme modulation capacity and, at the same time, very low emissions. These characteristics can be achieved by flame stabilization in a microporous structure, including homogeneous macropores. Today, burners like these are predominantly made of special ceramics. However, there are at present no solutions for non-stationary applications that are compact enough to withstand the occurring mechanical stresses. In this field, metallic solutions are advantageous, and they are being developed together with the Amovis GmbH for their use in an auxiliary power unit for rail vehicles.

The required high oxidation stability demands an extremely resistant material. Commonly the FeCrAl materials, protected by an aluminium oxide layer, are used here. The operating life is determined by the alloy's aluminium reserve, which is 5 %, as a rule and which cannot be exceeded significantly in conventional manufacturing. However, using the approach to produce the metallic fibres by fusion extraction presented here, it was possible to increase the aluminium proportion up to 15 percent.

Figure 4 shows the results of a test in which two sintered fibre structures with different percentages of aluminium were oxidized in air at 1000 °C. It became clear that both specimens oxidize at the same speed, and they are both characterized by the typical parabolic increase in mass due to bound oxygen. The specimen's aluminium reserve, including 5 percent

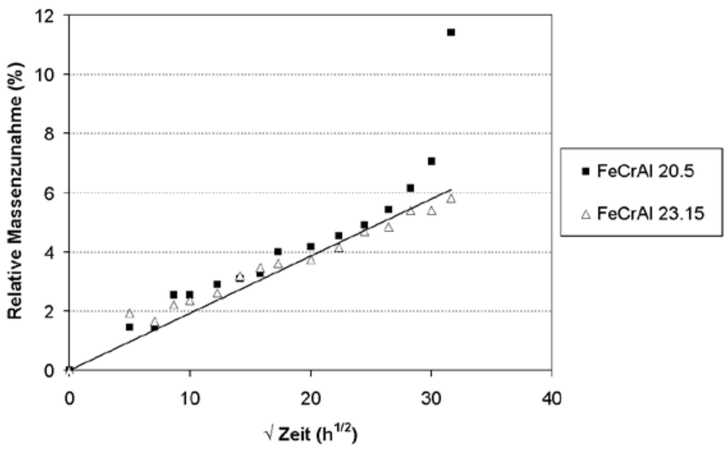

Fig. 4: Relative increase in mass at 1000 °C in air for sintered fibre structures with 75 % porosity as a function of time and aluminium content.

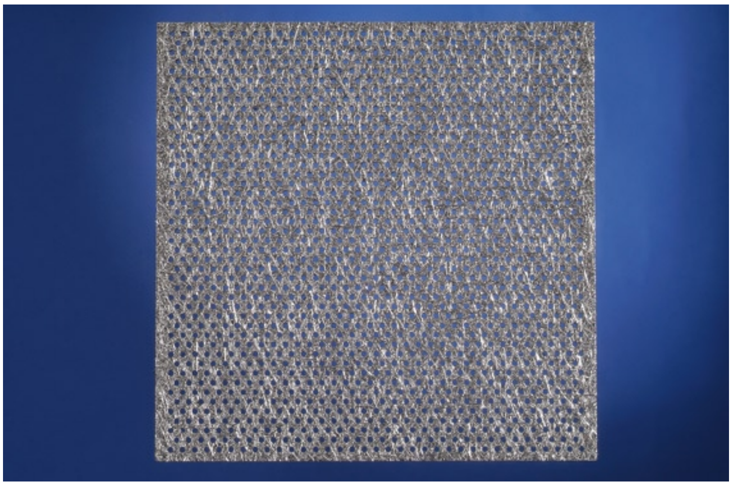

Fig. 5: Burner plate made of sintered FeCrAl fibres.

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aluminium by mass, had already been consumed within 600 hours after removal from storage, and oxidation speed increased dramatically. Consequently, shortly after that reaction, complete failure occurred, whereas the specimen with an increased percentage of aluminium showed significantly longer life, which was not yet exhausted after 1,000 hours period of removal from storage. Extrapolating from this measurement, one is able to calculate a dramatically extended operating life of 2,500 hours for this specimen.

Along with the development of a suitable material, macroporosity is also significant for the burner plate's functionality. To achieve this property, we engineered suitable methods to introduce a large number of holes into the fibre structure, in co-operation with the project partners Pretec GmbH and proforma GmbH. Jet-cutting methods were used to cut about 800 holes of approx. one millimeter diameter (Fig. 5) into each burner plate. With these structures, it is possible to generate combustion characteristics that are largely equivalent to the state of the art. At present, continuous tests and emission measurements are being executed. We plan to integrate the procedure in a small batch production in 2009.

Reference

[1] O. Andersen, C. Kostmann, G. Stephani, G. Korb: Application-related properties of sintered metallic fiber structures. Cellular Metals and Metal Foaming Technology (MetFoam 2003), Berlin, Verlag MIT Publishing, Bremen, 2003, S. 481–486.

[2] U. Waag, L. Schneider, P. Löthman, G. Stephani: Metal Powder Report 55 (2000) 1, S. 29.

Development of Nickel-Based Foams to be Used in the After Treatment of Exhaust Fumes

Background

A series of nickel-based (e. g. Inconel®) and iron-based (e. g. Incoloy® or Fecralloy®) alloys was particularly designed for use at high temperatures in a corrosive environment. Some of these applications, such as the Diesel particle filter (DPF), heat exchangers and catalyst carriers, need open-cell porous structures with material characteristics tailored to special conditions. These requirements are realized using high-temperature- and anticorrosive metallic foams of the alloy classes mentioned above. A metallic nickel foam is the basis for the engineered technology. This foam is commercially available in large volumes and is mainly produced for battery technology. The process designed at IFAM Dresden makes it possible to transform nickel foam into materials that are highly temperature resistant. In this method, the foam is coated with a highly alloyed metal powder and subjected to heat treatment afterwards (Fig. 1). In this procedure, the powder particles are sintered to the foam webs, and different concentrations of the alloying additions are balanced by diffusion, so that a homogeneous, high-temperature resistant metal foam is the result of the manufacturing process.

The problem

The foams, which were first made based on Inconel® 625, have already demonstrated high oxidation resistance at temperatures up to 800 °C and excellent resistance to sulphuric acid. The successful results of tests on the first prototypes, as well as high customer demand, motivated intensified development activities, on the one hand. On the other hand, they were accompanied by a new challenge. For the application as a DPF or a Diesel oxidation catalyst (DOC), a washcoat, which is a coating that acts as a catalyst, is deposited on the carrier material. The washcoat is able to reduce soot combustion temperature and increase efficiency in gas transformation (e. g. CO in CO_2). In this procedure, the washcoat's activity has to be maintained over the entire life of the filter or catalyst. However, elements such as chromium may diffuse out of the metal foam into the washcoat at increased temperatures and cause the washcoat to age. As a consequence, its catalytic effect diminishes as a function of increasing operating time. Consequently, our challenge was to design an alloy that was able to form a barrier to diffusion at the surface and particularly prevented immigration of chromium from the carrier material into the washcoat. Thus, for instance, an α-aluminium oxide layer is suitable as such a barrier. This coat can be formed by oxidation after sintering. The prerequisite is that there must be a sufficient proportion of aluminium in the alloy.

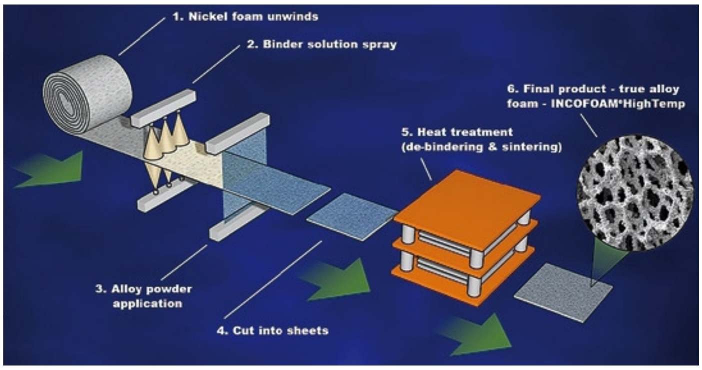

Fig. 1: Technology to produce high-temperature resistant foams (INCOFOAM®HighTemp) from commercially manufactured nickel foams (INCOFOAM®) through a coating- and heat treatment procedure.

Results

Based on well-known aluminium oxide creators such as Fecralloy®, we engineered a FeNiCrAl alloy tailored to nickel foam, wherein the nickel proportion, which mainly comes from the foam substrate, causes the formation of a γ-matrix and thus enhances the alloyed foam's ductility and formability. We succeeded in optimizing the process parameters to alloy the foam (in particular the sintering conditions) for this new alloy. Now the challenge was to create oxidation conditions making possible the emergence of only one homogeneous aluminium oxide layer, without significantly affecting the mechanical properties. As is generally known, FeCrAl alloys with α-matrix form an aluminium oxide layer in air at temperatures above 900 °C, the aluminium's speed of diffusion in the γ-matrix of the FeNiCrAl alloy is significantly lower, so that mixed oxides, first of all chromium oxide, occur. Furthermore the high proportion of nitrogen in air causes aluminium nitride formation, making the material less ductile. The depletion of aluminium has a particularly negative effect on the formation of an efficient barrier to diffusion.

To overcome this obstacle, we analysed the oxygen partial pressure values of the possible metal oxide equilibrium states in the FeNiCrAl system. From this, one may conclude that the formation of Fe, Ni and Cr oxides is suppressed at temperatures >1,000 °C and oxygen partial pressure values of $<10^{-21}$ bar, whereas pure aluminium oxide may be formed (Fig. 2). As a function of growing temperature, the equilibrium states shift towards higher partial pressures. Based on this experience, we carried out oxidation tests in inert, reducing atmospheres free of nitrogen, with correspondingly low oxygen partial pressures. To identify the quality of the coating, the preliminarily oxidized foams were first aged in air, and afterwards, the increase in mass was measured. The more homogeneous the formation of the aluminium oxide layer, the less mass increase to be expected from oxidation, since oxygen diffusion into the inside of the material is hindered by passivation of the surface.

Considering a passivation layer like this, one may also expect an efficient reduction of chromium diffusion. This was confirmed in investigations carried out on specimens coated with washcoat and aged afterwards. In the washcoat, neither

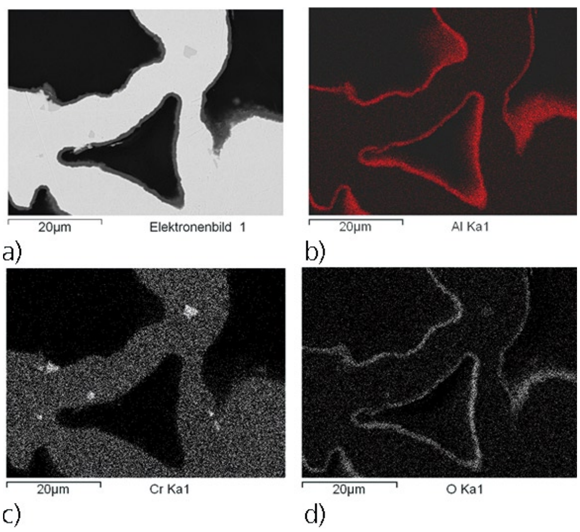

Fig. 2: Dispersion of elements (EDX mappings) of a specimen with homogeneous oxide layer, which was preliminarily oxidized according to the new technology and then aged in air at 1,000 °C over 20 hours: a) BSE image, b) Aluminium, c) Chromium, d) Oxygen.

chromium nor significant impurities introduced in the washcoating procedure were able to be seen in so-called "CO-Light-Off" tests. We determined the temperature at which 50 percent of the CO is transformed to CO_2. The temperature should be as low as possible to keep efficiency high even in the cold exhaust pipe. While the "light-off" temperature has been increased over the operating life by maximally 100 K up to now, the temperature difference with preliminary oxidation is only <15 K after the new method. Thus we obtained the most important goal, which was to achieve more advantages for the new material properties.

The diagram in Figure 3 shows increase in mass after aging of foam specimens of the new FeNiCrAl alloy in sintered and preliminarily oxidized state in comparison with the foam made of Inconel® 625 in air at temperatures from 700 to 1,000 °C. The newly developed alloy including aluminium shows a significantly smaller increase in mass even in the sintered state in comparison with Inconel® at temperatures >900 °C. This means that the new alloy is more resistant to oxidation, a property due to the formation of an aluminium oxide layer. The Inconel® alloy does not contain any aluminium. Its resistance to oxidation is only guaranteed by a protection layer made of chromium oxide, which, however, is no longer stable above 900 °C, so that the material is eventually completely destroyed at 1,000 °C. Preliminary oxidation according to the newly developed procedure means that the FeNiCrAl alloy's resistance to oxidation is refined by more than twentyfold.

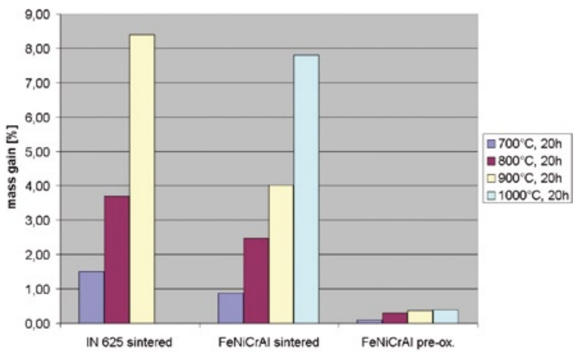

Fig. 3: Comparison of mass increase. Inconel® 625 (IN 625) versus FeNiCrAl alloy in sintered and preliminarily oxidized state (Note: no measured value for IN 625 at 1000 °C, since completely destroyed by oxidation).

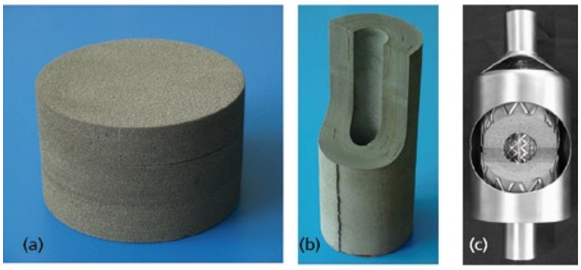

Fig. 4: Design variants for Diesel particle filters: a) Axial filter, b) Radial filter made of coiled foam layers, c) Encapsulated filters.

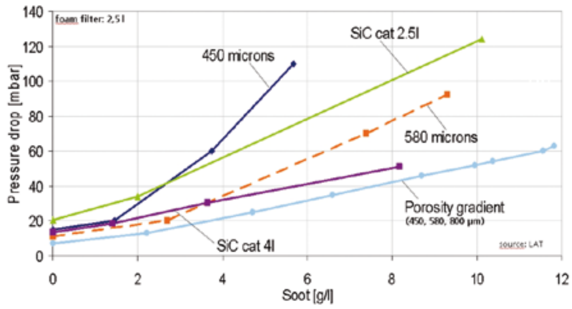

Fig. 5: Drop in pressure as a function of soot load of filters made of foam – in comparison with commercial SiC filters (motor speed: 1,700 rpm, with courtesy of LAT, Thessaloniki).

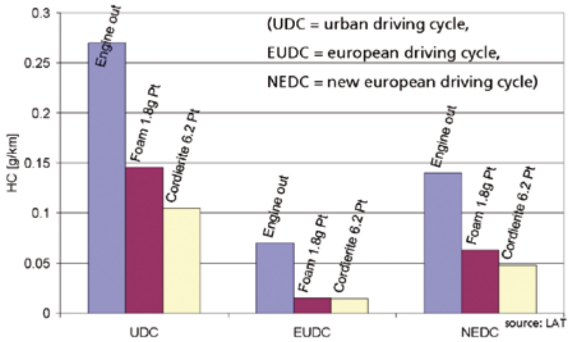

Fig. 6: Hydrocarbon emission variants in comparison – without Diesel oxidation catalyst (DOC), with foam-DOC and commercial Cordierite DOC with triple the volume of the foam catalyst.

At present, the foam is produced in a pilot plant, based on a technology developed at Fraunhofer IFAM Dresden. For this purpose, the firms Süd-Chemie AG, a leading manufacturer of catalysts, and Inco ECM GmbH, a subsidiary of the leading provider of nickel and special nickel products CVRD Inco Limited, established a Joint Venture called Alantum. The current focus in development is on Diesel soot filters and Diesel oxidation catalysts. Prototypes of different designs, as illustrated in Figure 4, are currently being tested.

The great flexibility in design due to the foam material's availability in a wide range of pore sizes should be emphasized. Combining various foam qualities, it is possible to minimize the drop in pressure. In a soot particle filter (2.5 liter) made of foams of refined porosity, the drop in pressure is less than in a SiC filter with 4 liter volume (Fig. 5). Another advantage lies, e. g., in the high catalytic efficiency as a Diesel oxidation catalyst. The diagram in Figure 6 clearly indicates that emission of hydrocarbons is commensurable with the use of a foam-DOC with only 30 % of the volume of a conventional Cordierite catalyst. This results from the specific surface, which is larger than those of extruded ceramic structures, and the generation of a turbulent flow in the foam material. Consequently, there is a more intensive contact of washcoat and exhaust gas. A reduction by a maximum 70 % volume not only saves building space, but also costs, since a correspondingly smaller quantity of platinum is needed in the washcoat.

The great interest shown by the automotive industry and its subcontractors, which results from the outstanding material characteristics, confirms the outstanding application potential of the high-temperature resistant foams we have developed.

Material and part design can be refined in a customized manner. To do this, Fraunhofer IFAM Dresden guarantees, in close co-operation with the users, continuous material optimization and customization for each application.

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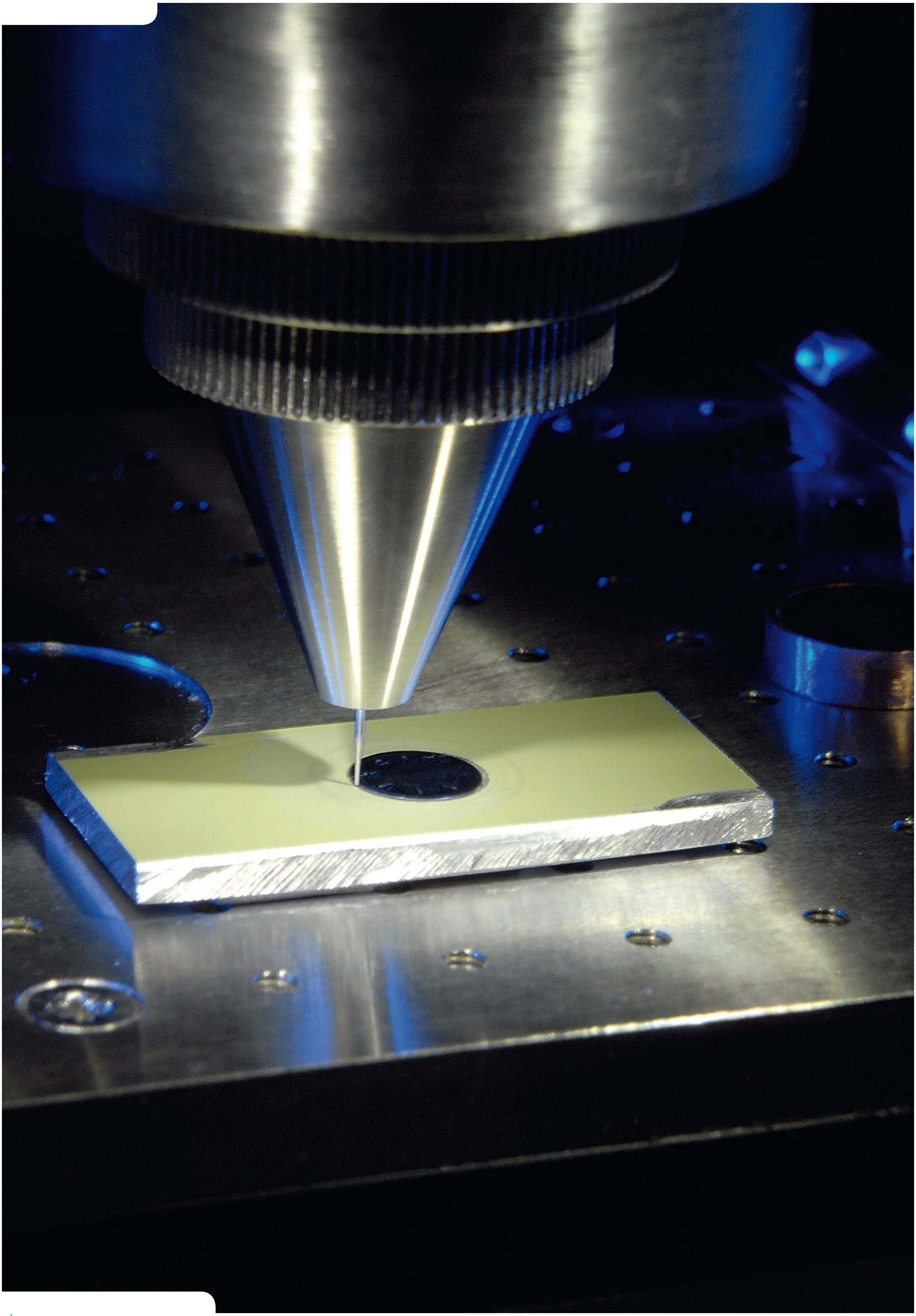

Department of Adhesive Bonding Technology and Surfaces

Results Applications Perspectives

←

Scanning Kelvin probe.

Competencies and Know-how

The Department of Adhesive Bonding Technology and Surfaces of the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research is the biggest independent European research facility in the area of industrial adhesive bonding technology. More than 120 employees perform industry-oriented R&D activities in the field of bonding and surface technology. Activities in this field range from fundamental research to technical implementation and market introduction of new products. Industrial uses can be predominantly found in the auto industry and in equipment engineering, power engineering focused on wind and solar energy, micromachining, and the packaging and electronics industry.

Activities of the Department of Adhesive Bonding Technology are aimed at the development and specification of adhesives, design layout tailored to specific stress situations, simulation of bonds and hybrid joints and their specification, testing and qualification. Planning and automation of the generation of bonds in industrial production are additional topics. Process reviews and certified courses in adhesive bonding technology are carried out. The working group Surfaces is subdivided into the areas of plasma technology and paint / lacquer technology. Specialized surface modifications, such as surface pretreatment suited to bonding and coating or the application of anticorrosive coatings, clearly make possible or expand the technical applicability of many materials in industry.

Both departments analyze surfaces and interfaces. The basic knowledge acquired in this work is a contribution to higher safety and reliability of bonds.

The Department of Adhesive Bonding Technology and Surfaces is certified according to DIN EN ISO 9001:2000. The materials testing laboratory has also received accreditation according to DIN EN ISO/IEC 17025:2005. The Center for Adhesive Bonding Technology has an international reputation as an accredited body for personnel qualification in adhesive bonding technology via DVS-PersZert® in accordance with DIN EN ISO/IEC 17024. The Competence Center for Plastics is accredited in accordance with the German quality standard for further training, AZWV. The Certification Body for Manufacturing 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 45012:1998.

Perspectives

The industry makes enormous demands on process reliability when introducing new technologies and modifying technologies already in use. These requirements are decisive and directive for the R&D activities in the department of Adhesive Bonding Technology and Surfaces. Working with our customers, we engineer innovative products, which are later successfully brought onto the market by the enterprises themselves. In this chain, manufacturing technologies are becoming more and more important, since high quality and reproducibility of manufacturing processes are essential to success on the market.

Adhesive bonding is a technology which has been established in vehicle construction as a whole for a long time. However, its potential cannot be utilized to its full extent. Lightweight construction for transport as a means of saving resources, recycling and the problem of intentional debonding which is closely related to it, as well as the use of nanoscale materials in the development and modification of bonds are only some of the issues relevant to the widely varying activities of the institute. To attract more businesses to adhesive bonding, the motto for all of our activities is:

The bonding process and the bonded product should always be made safer!

We can only achieve this objective if all of the stages of the bonding process chain in product manufacturing are subject to an overall inspection.

This Inspection Implies:

- Selection of bonds tailored to each application, qualification, modification if necessary
- Structural design and dimensioning fit for bonding, using numerical methods (e. g. FEM)
- Pretreatment of surfaces and finding of anticorrosive concepts
- Development of bonding stages by means of simulation and integration into the products' manufacturing sequence
- Selection and dimensioning of application equipment
- Qualification in the field of bonding for all involved in product development and manufacturing.

In all departments, IFAM is relying more and more on computer-aided methodologies, from the digitizing of processes in production planning and multiscale simulation from Molecular Dynamics (MD) into molecular dimensions to macroscopic Finite Element Methods in the numerical representation of materials and components. Various spectroscopic, microscopic and electrochemical techniques deliver insight into the procedures during degradation and corrosion of material composites. The IFAM employees gain expertise with these "orchestrated testings" and accompanying simulation runs that the empirical test methods based on standardized aging and corrosions tests do not provide.

Other essential problems to be solved in the future include in the following: Where and how is bonding accomplished in nature? What can we learn from nature for the industrial adhesive bonding technology? The path from bioadhesion on a molecular level to the macroscopic bonding of proteins is just now being explored. However, the demand to make processes and products ever safer is not only limited to adhesive bonding technology. It is also valid for plasma and surface engineering. Industries with very stringent requirements in terms of surface engineering go back to the excellent technological standards of the institute. For this reason, famous enterprises, in particular from aircraft- and automotive engineering, are among our customers in this area.

Key Activities:

- Formulate and test new polymers for adhesives, laminating / cast resins, up to implementation in industry
- Develop additives (nanofillers, initiators etc.) for adhesives
- Synthesize polymers with superlattice and biopolymers
- Computer-aided material development with quantum-mechanical and molecular-mechanical methods
- Build up international courses for vocational training (targeted qualifications: Adhesive practitioner, Adhesive assistant, European Adhesive Engineer)
- Manufacturing technology
- Develop innovative bonding concepts e. g. for automotive engineering (bonding, hybrid bonding)
- Apply adhesives / sealing compounds, casting compounds (mix, dose, deposit)
- Bonding in micromachining (e. g. electronics, optics, adaptronics)
- Computer-aided production planning
- Economic aspects of the bonding / hybrid bonding technology
- Engineering design of bonded structures (simulation of the mechanical characteristics of bondings (adhesive joints) and components with the Finite Element Method, prototyping)
- Develop environmentally compatible pretreatment methods for longterm resistant bonding of plastics and metals
- Achieve functional coatings through plasma techniques
- Qualify coating materials and varnishing procedures
- Find lacquer formulations for special applications
- Determine characteristics, vibration and in-surface strength of bonding and hybrid bonds
- Material models for bonds and polymer materials (quasi-static and crash states)
- Evaluate aging- and degradation procedures in material composites
- Electrochemical analysis
- Evaluate and develop new corrosion prevention systems

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Manufacturing Technology

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Training courses for Adhesive Bonder, Adhesive Specialist and Adhesive Bonding Engineer with Europe-wide DVS®-EWF accreditation; in-house courses; advice; studies; work and environmental protection.
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Prozess Review

Analysis of development processes and / or production processes in terms of adhesive bonding technology and with regard to guideline DVS® 3310; processes and interfaces; design; product; proof of usage safety; documents; production environment.
Dr. Dirk Niermann
Phone: +49 421 2246-439
E-mail dirk.niermann@ifam.fraunhofer.de

Surfaces

Dr. Alfred Baalmann
Phone: +49 421 2246-473
E-mail alfred.baalmann@ifam.fraunhofer.de

Low Pressure Plasma Technology

Surface modification (cleaning, activation for bonding, printing or painting) and deposition of functional coatings (corrosion protection, primering, scratch resistance, easy-to-clean coatings, permanent release, permeation barrier) suitable for bulk goods; batch and web material; conceptions for and construction of pilot devices for production.
Dr. Klaus Vissing
Phone: +49 421 2246-428
E-mail klaus.vissing@ifam.fraunhofer.de

Atmospheric Pressure Plasma Technology

Surface modification (cleaning, activation, functional coatings) and functional layers for in-line applications and (large) 3-D objects.
Dr. Uwe Lommatzsch
Phone: +49 421 2246-456
E-mail uwe.lommatzsch@ifam.fraunhofer.de

Paint / Lacquer Technology

Testing and consultancy in the area of paints, lacquers and coating materials; characterization and qualification of paint / lacquer systems; color management.
Dr. Volkmar Stenzel
Phone: +49 421 2246-407
E-mail volkmar.stenzel@ifam.fraunhofer.de

Adhesion and Interface Research

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

Applied Surface and Layer Analysis

Analysis of surfaces, interfaces, and layers; investigation of adhesion, separation and degradation mechanisms; analysis of reactive interactions at material surfaces; failure analysis; microtribology.
Dr. Ralph Wilken
Phone: +49 421 2246-448
E-mail ralph.wilken@ifam.fraunhofer.de

Electrochemistry

Corrosion on metallic materials, under coatings and in bonded joints; investigation of anodization layers; electrolytic metal deposition.
Dr.-Ing. Peter Plagemann
Phone: +49 421 2246-530
E-mail peter.plagemann@ifam.fraunhofer.de

Applied Computational Chemistry in Interface Science

Modelling of molecular mechanisms of adhesive and degradation phenomena; structure formation at interfaces; enrichment and transport processes in adhesives and coatings.
Dr. Peter Schiffels
Phone: +49 421 2246-567
E-mail peter.schiffels@ifam.fraunhofer.de

Service Centers

Center Adhesive Bonding Technology

Prof. Dr. Andreas Groß
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Internet www.kleben-in-bremen.de

Technology Broker

Dr.-Ing. Helmut Schäfer
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Certification Body of the DIN 6701-2

Dr. Dirk Niermann
Phone: +49 421 2246-439
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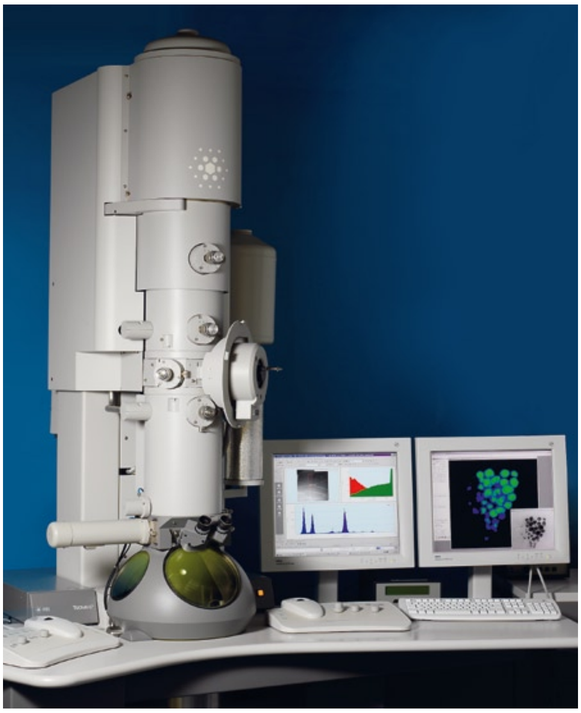
Equipment / Facilities

- Low pressure plasma units for 3-D components, bulk products and web materials up to 3 m³ (HF, MW)
- Atmospheric pressure plasma units for 3-D components and web materials
- Robot-led atmospheric pressure plasma device (6 axles) for laminar and line treatment and coating
- Laser scanner for 3-D measurement from construction units 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, max. compressive force: 70 kN, drill spindle for speeds up to 18,000 rpm and internal lubrication and high speed work-space monitoring
- Laboratory vacuum press with PC control for manufacturing multilayer prototypes, small production series and as a test press in the laboratory
- 300 kV and 200 kV transmission electron microscopes with EDX and EELS
- Surface analysis systems and polymer analysis using ESCA, UPS, ToF-SIMS, AES und 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
- Spectroscopy ellipsometer
- LIBS (Laser Induced Breakdown Spectroscopy)
- Small-scale pilot plant for organic syntheses
- IR, Raman, UV VIS spectrometers
- IR-VCD-spectrometer (Infrared Vibrational Dichroism)
- Rheology (Rheolyst AR 1000 N, ARES – Advanced Rheometric Expansion System)
- Equipment for measuring heat conductivity
- Dielectrometer
- Electrochemical Impedance Spectroscopy (EIS) and Noise Analysis (ENA)
- Twin-screw extruder (25/48D) and kneader for incorporating fillers into polymers



Transmission electron microscope.

- Single-screw extruder (19/25D) for characterizing the processing properties of polymer composites
- 12-axial robot for manufacturing micro-bonded joints
- Linux PC system with 64 CPUs
- Wave Scan DOI
- Color measurement unit MA 68 II
- Laboratory dissolver
- Haze gloss
- Automatic paint application equipment
- Paint drying unit with moisture-free air
- Fully conditioned spraying booth
- Scanning Kelvin probe
- 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
- Material feed from 320 ml Euro-cartridge up to 200 liter drums, can optionally be combined with the t-s-i dosing system
- PUR hot-melt dosing unit for either bead or swirl application from 320 ml Euro-cartridges (own development)
- Fluorescence microscope

Economic Aspects of Adhesive Bonding Technology: What Does Adhesive Bonding Cost?

Adhesive bonding has generally become established as a high-quality joining technique. Sectors of industry which have long used other joining techniques are now also increasingly turning to the versatility and diverse uses of adhesive bonding technology. After all, adhesive bonding is a unique joining technique: It differs from established methods such as riveting, brazing and welding by its completely different and more complex processes and quality assurance methods. In order for adhesive bonding to replace or supplement another joining technique, significant investment is often required in people and machinery. Companies – and in particular those with little or no experience in adhesive bonding technology – justifiably ask what the cost is of introducing adhesive bonding technology into their production operations.

Over recent years, tools and methods have been developed at the Fraunhofer IFAM in order to describe the economic aspects of adhesive bonding projects in a structured and transparent way. Feasibility studies allow not only the technical viability of a bonding process to be demonstrated but also allow evaluation of the required financial investment for different process variants. The costs incurred by an adhesive bonding application can be evaluated in any desired degree of detail.

Companies considering using adhesive bonding technology generally require decision-making assistance before they implement new manufacturing processes and procure the necessary machinery. Each advantage of adhesive bonding must not only be evaluated from a technical point of view but also from a cost point of view compared to other joining methods. Once the decision has been made to opt for adhesive bonding, several process variants are often feasible. The technical and economic appraisal and representation of all the key aspects of the various options is one of the main services provided by the Fraunhofer IFAM. In this regard, preliminary calculations can be carried out as part of a technical appraisal as can comprehensive economic project analysis with detailed calculations for all relevant steps.

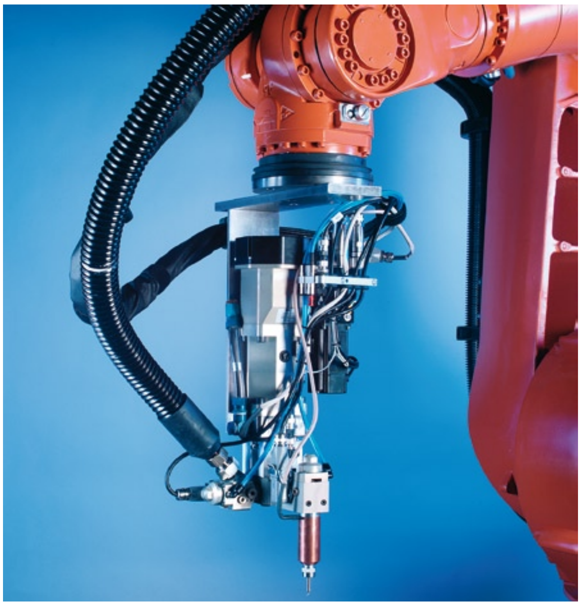
List of Requirements Leads to an Initial Rough Concept

There are no automatic economic advantages when switching to adhesive bonding merely because the joining technique used up until now is being replaced by another technique. In order to benefit from all the advantages of adhesive bonding, it is necessary to adapt the design of the product and process. In order to demonstrate to different options for realization, it is necessary to analyze the situation at the customer. Based on a list of requirements, a rough concept for the bonding process and production can first of all be drawn up. Individual process steps – for example the application of the adhesive – can be represented as manual, mechanized or fully automatic steps. These rough concepts already show up bottlenecks or problem positions in the manufacturing process. These concepts allow initial estimates to be made of the staff requirements, investment costs, project costs and project duration.

As part of a detailed description, conceptual production processes are evaluated, including the form of drawings. The individual process steps and relevant process materials and equipment are precisely described. Special staff training (including in accordance with the Guidelines of the German Welding Society – DVS e. V. Deutscher Verband für Schweißen und verwandte Verfahren) also plays an important role. Depending on the production concept, trained staff who monitor the process may be required in order to meet specific quality standards. Opting for adhesive bonding not only means investing in machinery but also investing in the knowledge and skills of adhesive users: How to successfully use adhesives has to be learned.

Action Plan Takes into Account All Important Aspects

All these aspects are put into an action plan which covers matters such as the make-up of the project team, adhesive selection, staff training and plant construction through to start-up and the initial production phase – subdivided into different production alternatives, for example manual or fully automatic adhesive application.



Manual or automatic adhesive bonding? – The optimum variant from technical and economic points of view can be determined using the tool developed at the Fraunhofer IFAM.

When developing and evaluating a concept for a manual production process, factors such as the number of persons required per shift are of major importance. With regard to running costs, capacity planning can be undertaken based on the estimated performance of each worker in the relevant process step during work hours.

When weighing up between manual and automatic production, staff costs have to be compared with investment in machinery. In addition to staff salaries, other staff costs such as training costs, loss of working hours and initial staff training costs are incurred; in contrast, considerably higher initial investment in machinery is required for automatic production. A total cost overview for manual or automated production takes into account all key parameters such as effective working hours, technical plant availability, salary costs, period of use, depreciation, interest rates, energy costs and many other factors. As a result, a realistic comparison of costs is possible. It clarifies the piece cost advantages of the relevant investment options. The relevant amortization times can also be calculated. It is for example conceivable that an initially higher investment for automatic production is "worth it" above a certain piece number and is hence more favorable than the variant with the supposed initially lower costs for manual production.

In addition to the pure costs, the Fraunhofer IFAM can also estimate the technical risk of using adhesive bonding. Here, matters such as the technical discrepancy, technical uncertainty and the complexity of the product and project play a role. The technical discrepancy refers to the difference between the useable know-how of the hitherto used technology and the "new" technology. The technical uncertainty is the extent to which the technical realization meets the requirements of the planned system. The complexity of the system concerns the mutual dependence and interaction of all the parts and components of a closed system. An example of the many aspects used to estimate the technical risk concerns the most suitable adhesive. Here, factors such as the availability of the adhesive, the number of alternative adhesives and the complexity of any new formulation of the adhesive that is required must be discussed.

A major risk factor is not only the matter of technical realizability, but also the general ability of a company to implement automation projects. It is not rare for technology projects to fail for human or organizational reasons. For successful realization of a project, the following three factors play key roles:

1. Active participation of the management in the project and everybody concerned as well as the motivation of staff.
2. Knowledge of the state of technology.
3. The degree of innovation of the production.

Realistic Self-Assessment Increases the Chance of Success

A survey can for example be carried out to determine the extent to which the manufacturer possesses the abovementioned success factors. The key is to undertake as realistic as possible a self-assessment. The differently weighted results allow calculation of a probability of success which can be a further important basis for the decision-making.

The reliable evaluations made by the Fraunhofer IFAM concerning the introduction of adhesive bonding processes at a company combine classical investment methods with the special challenges of adhesive bonding technology. The total evaluation of an adhesive bonding project provides a solid and transparent information basis for decision-makers – so that the use of adhesive bonding is not only technically successful but is also totally successful from an economic point of view!

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DIN Standard for Rail Vehicle Construction – Developed in Part by IFAM and Monitored by IFAM

Role and technical obligations: Since December 2006 the Fraunhofer IFAM has been a certification body of the Federal Railway Authority (EBA) for adhesive bonding technology

The success story of adhesive bonding technology in the construction of all means of transport is well known: An optimum combination of materials has resulted in rail vehicles, aircraft, cars and ships becoming ever lighter over recent years. The consequence is that they reach higher speeds whilst consuming less fuel and are cheaper to produce. Combining the different types of materials has only been possible due to clever use of adhesive bonding technology. This has led to considerably increased use of adhesives and this trend will continue in the future. In the area of rail vehicle construction the considerably increased importance of adhesive bonding has now led to a new DIN standard – DIN 6701-2 for the adhesive bonding of rail vehicles and parts of rail vehicles. This standard was initiated by the Federal Railway Authority (Eisenbahn-Bundesamt (EBA)) as the state body responsible for monitoring and approval. And to take care of its interests, the EBA commissioned the leading organization in Europe when it comes to adhesive bonding know-how, namely the Fraunhofer IFAM. Since December 2006 the Fraunhofer IFAM has been a "Certification body of the Federal Railway Authority for Adhesive Bonding Technology".

This role requires IFAM to monitor whether companies utilizing adhesive bonding technology in the construction of rail vehicles and parts of rail vehicles meet the quality standards laid down in DIN 6701-2. With effect from the beginning of 2007, all companies in the rail sector carrying out adhesive bonding work, trading bonded products or offering other services involving construction and design with adhesive bonding must possess the relevant accreditation. The Fraunhofer IFAM issues such certification and is the larger of the two certification bodies in Germany.

Expert Committee under IFAM Leadership

The Federal Railway Authority initiated this standard due to the ever increasing importance of adhesive bonding in the rail vehicle sector, akin to the DIN standards for welding which were introduced many years ago. The objective of DIN 6701-2 is to ensure quality assurance and safety and so minimize from the outset any risk of, for example, damage and the far-reaching consequences which would result from defective adhesive bonds. In order to establish a suitable DIN standard an expert committee, under the leadership of the Fraunhofer IFAM, worked intensively over several years to identify the fundamental requirements. Application companies, adhesive manufacturers, research organizations and monitoring authorities were represented in the committee. The EBA work group for DIN 6701 has also continued since the coming into force of the DIN standard. The chairman is Professor Dr. Andreas Groß of IFAM; also present in the work group for IFAM as technical representatives are Dr. Andreas Brede and Dr. Dirk Niermann.


Eisenbahn-Bundesamt   Zentrale

Bescheinigung über die

Anerkennung

für das

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

als

"Anerkannte Stelle"

für das

Kleben von Schienenfahrzeugen und -fahrzeugteilen
nach DIN 6701

Identifikationsnummer: EBA - 06/6701 - 01

Diese Bescheinigung beruht auf der im Schreiben vom 11.12.2006 - 3.531 - ... ausgesprochenen Anerkennung und den dort genannten Voraussetzungen.

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

Dr.-Ing. Thoma[illegible]   Bonn, 11.12.2006

Certificate.

DIN 6701 makes Germany a global pioneer: Nowhere else is there such a comprehensive quality standard for the application of adhesive bonding technology in the rail vehicle sector. This may have consequences which could be very positive for IFAM: The "related" DIN 6700 for welding in rail vehicle construction was also a global first and in the meantime has become established all over the world, on account of its qualitative excellence, as the welding benchmark. A similar development is expected for the standard on adhesive bonding. Although formally only set up for the area of responsibility of the Federal Railway Authority, this standard will in all probability, analogous to what happened with the welding standards, also become the reference for the quality standard of all companies using adhesive bonding, for construction tasks and for design regulations and quality assurance. If, in the future, China or another country orders a passenger train from a Canadian company, it is quite likely that the DIN 6701 standard will also apply here.

Adhesive Bonding Technology Becomes Even More Reliable

The standard itself is split into several parts. The first part is a glossary of technical terms, followed by a detailed description of the certification procedure for companies. The third part describes calculations and designs of bonded joints in rail vehicle construction and the fourth part regulates the correct application of adhesives. For IFAM and also the adhesive industry and users, DIN 6701 is especially important because it makes adhesive bonding technology in the important and large application area of rail vehicle construction even more reliable. A rail accident due to a defective adhesive bond would have devastating consequences for the adhesive industry. Also beneficial for IFAM has been its involvement with the development of the standard at the technical level. Whilst strictly separated from the certification body from an organizational point of view, other IFAM groups possessing in-depth knowledge of adhesive bonding are available as partners for companies. Collaborative projects allow development work to be carried out quickly and effectively in order to meet the certification criteria. The Fraunhofer IFAM is also a world leader in employee training at different levels for fault-free and intelligent application of adhesive bonding.

The certification itself follows a set procedure. A company striving for certification of one or more of its production sites can obtain information on the Internet (http://www.ifam.fraunhofer.de) and download an application form. On the website there is also a link to an online register (https://www.din6701.de) which lists all companies which already possess DIN 6701 certification; this is also an extra incentive for companies that are not yet certified to become certified. After the requirements have been specified in advance, the company is audited on-site by IFAM auditors for one to two days, depending on the size of the company, to determine whether there is compliance with all the provisions of DIN 6701. If successful, the relevant production sites receive accreditation along with a certificate. This is valid for a maximum of three years, thereafter a new audit must be carried out.

The first company to be certified at the start of 2007 was Stadler-Pankow GmbH in Berlin. This respected company builds both trams and rail vehicles. A short time later Bombardier Transportation GmbH in Henningsdorf near Berlin, another well-known company, acquired certification. Like all leading companies, they today use adhesive bonding technology widely in order to meet customer demands for modern design, optically attractive construction, low weight, torsional rigidity and comfort. The numbers speak for themselves: Back in the 1980s about 10 kg of adhesive were used in the construction of a locomotive car for a local train – by 1996 this had risen to 500 kg.

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Adhesive bonding technology in rail vehicle construction: FLIRT regional train manufactured by Stadler Pankow GmbH (Photo: Stadler Pankow GmbH).

Prevention of Ice Adhesion and Ice Growth on Surfaces: One Problem, Two Prospective Solutions

The success story continues: In 2007, the work of the Fraunhofer IFAM on the technical and biomolecular design of surfaces and materials has once again found far-reaching acclaim. Of particular note was the development of new functional and biomimetic surfaces for reducing and even preventing ice growth. At present, two trend-setting projects funded by the Federal Ministry of Education and Research (BMBF) are being undertaken by the Polymer Chemistry, Paint/Lacquer Technology and Adhesion and Interface Research groups at the Fraunhofer IFAM. The relevant scientists were also successful in 2007 on occasions when they had to gain recognition for their work in the face of competition from other projects: Convincing concepts and research results amounted to in approval for the application-orientated projects which are currently being conducted with partners from research organizations and industry.

Ice on the car is always an irritation.

Whenever the matter of reducing or even totally suppressing ice formation on surfaces is under discussion, then commerce and industry listen attentively. This is because ice on surfaces causes high costs in many sectors. Perhaps the best known example is the de-icing of aircraft. Passengers only see this prior to the aircraft taking off, but de-icing is also carried out during the flight if ice crystals form on wings at altitude. Ice formation on electricity pylons and wind turbines can cause irreparable damage – especially during extreme weather conditions. Nobody will forget the many electricity pylons which collapsed in Münsterland in November 2005 as a result of ice build up on cables. Ice formation is also a huge problem for rail vehicles, ships and rolling shutters. Common to all these areas is that downtime, maintenance time and time-consuming repairs add up to a considerable extra financial burden – costs which every company and all sectors of industry would really like to save, both now and in the future, via the development of innovative solutions for this problem.

Two Potential Solutions Being Developed in Parallel at IFAM

The Fraunhofer IFAM is working in parallel on two approaches to solve this problem. The Biomolecular Design of Surfaces and Materials (BIOM) work group, which falls under the Polymer Chemistry group, and the Paint/Lacquer Technology work group are investigating the incorporation of synthetically manufactured antifreeze proteins into lacquers. Work is also being carried out in the Paint/Lacquer Technology work group on coatings having reduced ice adhesion and lower freezing points. Although there are fundamental differences between these approaches, there are also numerous overlaps because new functions can only be developed by customized modification of the paint/lacquer surface. This work is also being supported by the Applied Computational Chemistry work group. Computer simulation of the chemical processes at the relevant interfaces will allow prediction and optimization of the material properties for effective development of lacquer formulations. Due to the short lines of communication within IFAM and the structurally inherent close collaboration between the Polymer Chemistry, Paint/Lacquer Technology and Adhesion and Interface Research groups, valuable synergies can be realized, so allowing rapid scientific progress. Multidisciplinary cooperation between chemists, biologists, physicists and paint technologists plus the exchange of ideas and thoughts between technical areas which normally operate separately will accelerate the development of concrete applications.

Nature provides the model for the strategy we are adopting. For example, there are insects which can survive at temperatures down to minus 60 degrees Celsius without freezing and there are certain fish which survive at extremely low temperatures. There are also comparable phenomena in the plant world. So-called antifreeze proteins, or AFPs for short, suppress ice formation here. One R&D approach at IFAM concerns the binding of synthetically produced AFPs to technical lacquer surfaces. A feasibility study has already demonstrated that this leads to surfaces which are more resistant to icing.

This study has an interesting prehistory. At the beginning of 2006 the Paint/Lacquer Technology work group and the Biomolecular Design of Surfaces and Materials group of the Polymer Chemistry work group were one of the successful entries in an "idea competition" of the Federal Ministry of Education and Research (BMBF). "Bionics – Innovation from Nature" was the title of this national competition. From 150 project concepts the 20 most convincing were selected for funding and one of these was the Fraunhofer IFAM entry. With this BMBF funding, the Fraunhofer researchers went on to demonstrate the viability of their "anti-icing" idea in a feasibility study.

"Biomimetic anti-icing surfaces based on peptide-functionalized lacquers" was the title of this feasibility study which was presented on 19 and 20 June 2007 in the German Museum of Technology in Berlin to a large audience of experts and project reviewers. The objective of the study was to modify lacquer surfaces with antifreeze proteins and to test the anti-icing effect of these molecular-bionic surfaces. First of all, suitable creatures which were resistant to freezing had to be selected whose AF-proteins served as "models" for the proteins that were to be subsequently synthetically manufactured. Via chemical solid-phase peptide synthesis, peptide sequences from winter flounder and the European fir budworm were produced on a laboratory scale and characterized.

The bonding of peptides and proteins to commercially available lacquer systems was achieved by IFAM scientists using three different strategies. The first approach involved spraying an aqueous protein solution onto the lacquer using an ultrasound nebulizer. The coating system here consisted of an epoxy resin and a polyamine curing

Model of a lacquer surface with antifreeze peptides.

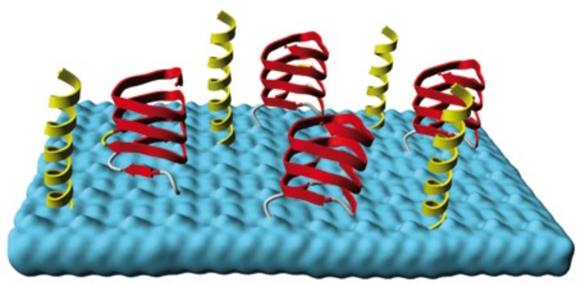
agent. The amino groups of the proteins reacted with the epoxide groups on the lacquer surface and became incorporated into the polymer. In a second approach the peptides were bonded by photochemical means. For this a photochemically active molecule was integrated into the lacquer system. The third approach was to bind the peptides using linking molecules between the lacquer and the peptide – an approach which proved very promising from the results of subsequent surface tests. In this type of link, the AF-proteins are mobile on the surface.

Reference tests were then carried out on the different coatings in a frosting chamber. Here, model surfaces with and without AF-proteins were subjected to frosting conditions by passing a temperature-controlled flow of air over them. The results showed that considerably less ice formed on the surface functionalized with AF-peptides than on the control surface. A non-uniform coating with AF-peptides also resulted in non-uniform frosting. In principle, it was demonstrated that the approach to incorporate AF-peptides into technical surfaces was feasible and – taking into account its effectiveness – has enormous potential. The feasibility study also highlighted the short-term, medium-term and long-term development stages for realizing a technically utilizable anti-icing surface. Here, the suppression of ice formation is not the sole issue. The binding of proteins and peptides can also be used in general to equip technical surfaces with additional functions. For example, an "anti-soiling" coating with enzymes is conceivable which, for example, could degrade insects on aircraft surfaces – an application which could lead to significantly improved aerodynamic properties. Better aerodynamics in turn means lower fuel consumption and – in addition to the lower costs – there is a benefit for the environment due to the lower emission of CO_2.

Major Anti-Icing Project with Leading Industrial Partners

The presentation of the feasibility study in Berlin made a lasting impression on the reviewers. From the top twenty projects they selected six which will now be funded for a further three years. One of those chosen was the biomolecular anti-icing project at IFAM. Over the next three years a major project will therefore be undertaken with leading industrial partners to study the key anti-icing mechanisms of the proteins and their binding to surfaces, followed by transfer to real applications. There are many detailed questions which require answers, and these will be obtained from strictly application-driven fundamental research. The Polymer Chemistry and Paint/Lacquer Technology work groups are working on this project together with companies in the aircraft and aerospace industries and in the household appliance sector.

"Anti-icing" has been a subject of research for a long time in the Paint/Lacquer Technology work group at IFAM. Work is being undertaken on coatings with high abrasion resistance and reduced ice adhesion which are, for example, of interest to the wind energy sector. Ice-repelling coatings are also, however, of much interest in refrigeration engineering: Heat exchangers for refrigeration technology, which enable for example low temperatures to be attained in fridges



Example of the icing up of heat-exchangers in cooling units.

and cold rooms, often ice up themselves and then have to be thawed out again. These steps reduce the efficiency and also lead to downtimes and hence incur costs. The prevention of this icing up and obviation of thawing steps results in energy savings. There are further savings of costs and energy because thawing equipment is no longer necessary.

Such opportunities and objectives are attune with the goals of the Federal Ministry of Education and Research who back in 2004 started their "Forum on Sustainability" initiative. The objective of these activities, which involve numerous projects and a funding budget of millions of euros, is to transfer results of research in this area to widespread utilization. In order to achieve this, a variety of approaches, which are being evaluated in a large number of separate research projects, will be rationally combined with each other – so resulting in sustainable technological innovations which will be transferred by commerce and industry into marketable products.

In this connection, the promising research work of the Paint/Lacquer Technology work group on "anti-icing" has as of September 2007 resulted in IFAM being one of a total of ten project partners participating in the BMBF project "New functional and biomimetic surfaces for preventing/reducing ice growth". This is part of the larger "Research Agenda – Surfaces" initiative being funded by the BMBF and coordinated by the Deutsche Forschungsgesellschaft für Oberflächenbehandlung e.V. The background to this is the unarguable need for new multifunctional surfaces, for virtually all sectors of industry. And one of these desired new functions is the prevention of ice formation on surfaces.

In the past, there have been various attempts to suppress or even totally prevent this ice formation. These include passive methods such as coatings which absorb infrared radiation and so result in an increase in the substrate temperature. In summer, this effect can however result in excessive heating and the risk of damage to the substrate. Another approach has concerned the manufacture of ice-repelling layers. Up until now a number of processes have only been realized on a laboratory scale; transfer to large-scale, market-ready applications has not hitherto been successful or has proved unviable due to too high costs.

Objective: Reduction or Complete Prevention of Ice Formation on Surfaces

Working together with nine other project partners, the Paint/Lacquer Technology and Adhesion and Interface Research work groups at IFAM are working on two different solutions in this new BMBF funded project aimed at reducing or completely preventing ice formation on surfaces. On the one hand, it is planned to utilize the "de-icing salt effect" for surfaces. The feature of de-icing salt is its ability to depress the freezing point due to dissolution of the salt. As a result, water does not freeze at 0 degrees Celsius, but rather at a considerably lower temperature. This effect is also evident for water-soluble polymers and there should also be an effect even if polymer chains are only bound to a few places on the surface. The second approach concerns the generation of chemically structured lacquer surfaces, which act like antifreeze proteins but without containing such proteins. The Paint/Lacquer Technology work group also benefits here from all the other know-how at IFAM and from the intensive multidisciplinary collaboration within the institute.

Initial work on the first approach will involve coating metallic surfaces (aluminum, copper and steel) with thin films of functional polymers. The bonding to the substrate surface is achieved via binding groups and anchoring groups specifically customized to the relevant substrate. Post-crosslinking provides the necessary mechanical stability of these films. There are two options for depressing the freezing point. Firstly, utilizing the "de-icing salt effect", using polyelectrolytes with special functional groups for binding to the substrate. The lowering of the freezing point is achieved due to alteration of the water structure. The second option is to generate water-repelling or water-binding nanostructures by using polymers whose structure mimics that of "antifreeze" proteins. In addition to the binding and anchoring groups, other reactive units are present here which enter into specific interactions with the ice surface. The result should be a change to the ice crystal structure and hence reduced ice growth. The goal is to employ a combination of the two methods in order to realize as lasting an effect as possible.

The second approach involves the generation of structured surface coatings with clearly demarcated hydrophilic and hydrophobic regions. The hydrophilic regions will initially act as the starting point for ice growth. The surrounding hydrophobic regions serve to keep the region to which ice crystals bond small and to guarantee that once above a certain size there is "abrasion" of the ice crystals by air and water flows or natural vibrations. The first experiments in this area have already been successful.

For manufacturing these structured films the Paint/Lacquer Technology work group is utilizing its many years of experience in surface pretreatment, coating development and coating testing. Within the institute we benefit from the extensive knowledge of the Plasma Technology group for creating hydrophobic and hydrophilic surfaces. The excellent technical facilities at IFAM offer a variety of methods for providing hydrophobic surfaces with hydrophilic regions. In addition to the aforementioned experimental work, the Adhesion and Interface Research work group will undertake computer-aided modeling of the adhesion and detachment mechanisms for the coating systems that will be developed. The simulation of the adhesion and detachment processes under different conditions and parameters will accelerate identification of viable practical solutions which will be further developed up to large-scale applications as part of this project.

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High-Strength Clear Polyurethane Lacquer – via Novel Stabilization of Nanoparticles

A real headache for the owners of expensive cars is scratching in the car-wash. Such damage is particularly noticeable with dark-colored cars. Of course, there is a certain risk of a car being scratched at any time – not only by the mentioned car-wash but also by small stones on roads and other misfortune. Many buyers of expensive designer furniture also suffer similarly when they see the first scratches on the surface of their furniture against the light.

For industry, therefore, there has been a requirement over recent years to produce surfaces with ever better scratch-resistance. This is achieved using clear lacquers which contain nanoparticles and which are hence considerably harder. A harder lacquer surface is also, amongst other things, desirable in lacquers which are still reshapeable and only cure completely in their final form. This is the case with so-called coil-coating applications, where a coated composite material comprising a metallic substrate and a colored coating is processed. In addition, foil-coating applications also increasingly require scratch resistance.

The increase in the scratch-resistance of clear lacquers is chiefly achieved by adding microscopic quartz-like particles. These are mostly smaller than 50 nanometers and hence of a size less than the wavelength of visible light, which ranges from about 400 to 700 nanometers. Such particles can therefore not be seen by the human eye. On adding the nanoparticles the ductility of the lacquer initially decreases; this can however be regained if the particles are embedded in a soft resin which once again increases the flexibility.

Mixing Two-Component Lacquer Systems: Rrisk of Flocculation

Up until now a major problem has been achieving effective distribution of the added solid inorganic particles. Although the scratch-resistance of the cured lacquer increases with the quantity of solid particles, the particles do tend to flocculate, namely to agglomerate. The lacquer becomes turbid if the size of the agglomerates is in the wavelength range of visible light – an undesirable effect which nevertheless occasionally occurs. There is in particular a risk of flocculation during

Lacquer surface, as desired by the customer.

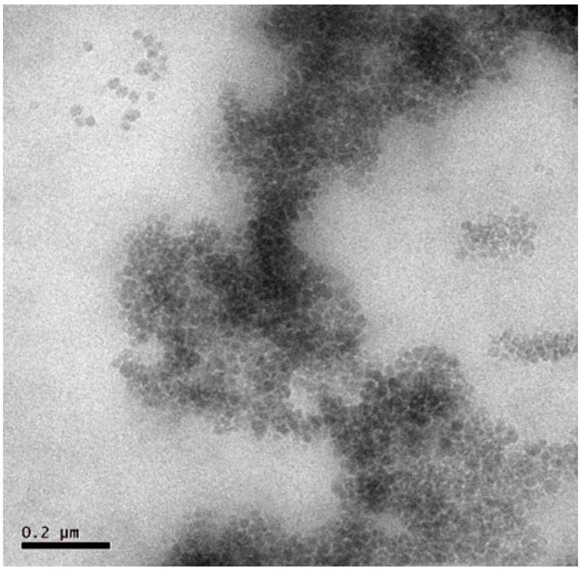
Damage which can occur to conventional lacquers.

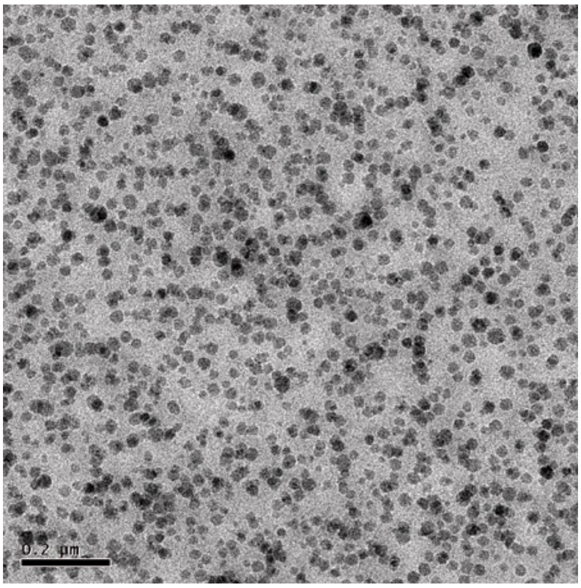
the mixing of the base lacquer and chemical hardener in two-component lacquer systems. Besides causing turbidity, flocculation also reduces the scratch-resistance.

The Paint/Lacquer Technology group at the Fraunhofer IFAM has been involved in a joint project with industrial partners. This project has been funded by the Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guerike" e. V. (AiF) (German Association of Industrial Research Associations). In this project work nanoparticles have been successfully stabilized in a dual-cure lacquer such that they become uniformly distributed. They hence considerably increase the scratch-resistance and the lacquers remain totally free of turbidity. Due to the uniform distribution, a nanoparticle content of up to 25 percent is possible – based on the solids.

Two-component dual-cure lacquer systems are attractive for a number of reasons. They are a new and highly interesting option for lacquering expensive cars because they possess two separate curing mechanisms. On the one hand they cure on being irradiated with UV light; on the other hand they cure via a slow chemical reaction. In the car industry the cars are lacquered, the lacquer is dried by heat and finally UV radiation gives the lacquer its end-properties. In dark regions where there is no UV radiation, the secondary chemical reaction provides the desired result. For foil-coating or coil-coating applications, a dual-cure lacquer system also provides advantages because the lacquered material is still workable. In its final form the lacquer film is then finally cured by the UV light.

In order to prevent flocculation of the nanoparticles in dual-cure lacquer systems, the Paint/Lacquer Technology group subjected nanocomposites manufactured by Nanoresins AG (Geesthacht) to a surface treatment with unsaturated organic acids. In the extensive tests, a nanocomposite which contained 40 percent sol-gel based particles up to a size of 20 nanometers was initially used in a two-component dual-cure lacquer. During mixing there was incompatibility and destabilization of the nanoparticles; in the further chemical process there was formation of agglomerates of a size up to the visible range.





TEM micrographs of the cured dual-cure lacquer.
Top: Variant without stabilization.
Bottom: Variant with stabilization.

The Solution: Unsaturated Organic Acids

In order to suppress the chemical processes which ultimately promote this agglomeration of the particles, the lacquer experts at the Fraunhofer IFAM coated the surfaces of the particles with unsaturated organic acids. These acids bond to the surface of the nanoparticles and prevent flocculation. The lacquer remains liquid and is completely free of turbidity in the cured state. Under a transmission electron microscope (TEM) it can be observed that there is a very uniform distribution of the nanoparticles in the polymer matrix.

The particles in the binder are optimally stabilized due to the treatment with the organic acids. Tests showed that the abrasion resistance of a dual-cure lacquer system can be increased by 30 percent by adding the stabilized sol-gel nanoparticles. The new stabilization method, for which the ideal dosage of stabilizer was also determined by the Paint/Lacquer Technology group, has in the meantime been patented.

This work was funded by the Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" e. V. (AiF) (German Association of Industrial Research Associations) (Funding reference: PRO INNO II, KF0100307SU5).

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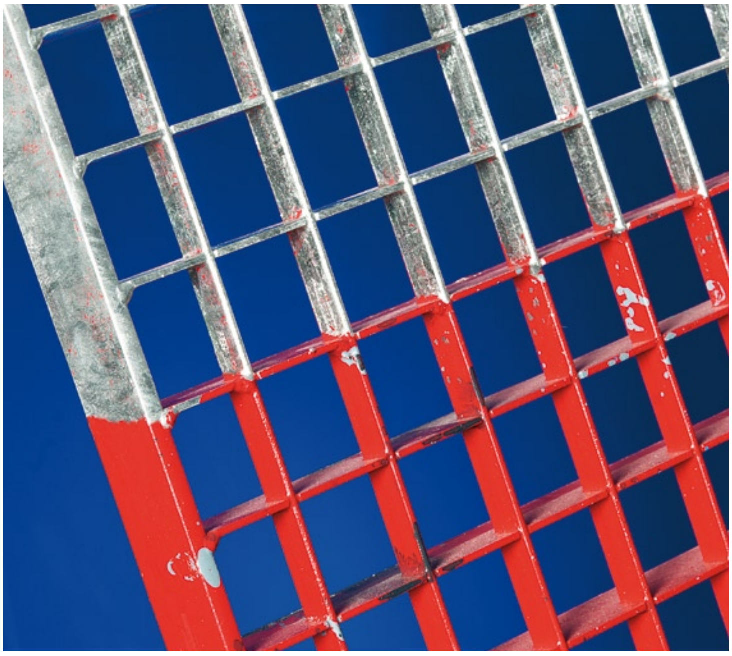
PermaCLEAN$^{PLAS®}$: New Coating Allows Environmentally-Friendly Paint Removal at Favorable Cost

Industrial painting is one of the most demanding steps in the production of all types of goods. Each day in Germany alone, many thousands of tonnes of paint and lacquer having protective, decorative and special technical properties are applied to products.

However, it is not only the painting itself which is a challenge – there are also extremely high demands on the plant technology. For example, clean plant components are an indispensable prerequisite for a stable painting process: Paint must regularly be removed from booths, machinery and fittings in order to keep everything functioning trouble-free – a necessity which up until now has been time-consuming and costly and disruptive for production operations. For a painting booth in the aircraft or car manufacturing industries, this for example involves regularly removing paint from several hundred square meters of grating.

Against this background, the Fraunhofer IFAM has developed a new paint removal technology in collaboration with the medium-sized service company Hugo Claus GmbH & Co. KG. Compared to other paint removal methods used hitherto, this new technology gives perfect results and involves considerably lower costs. Using a novel paint removal machine, major users now have the opportunity to carry out the paint removal process in-house at their own companies. Consequently, this indispensable extra work can be undertaken as part of the process and can be integrated into production operations. Decentralized service centers are able to undertake this paint removal work for companies with smaller requirements.



The effect of the PermaCLEAN$^{PLAS®}$ coating on a galvanized grating: Paint residues can be easily removed using high pressure water.

Shavings are produced wherever planing work is carried out – and likewise wherever painting work is undertaken drops of paint or coating end up not only on the substrate but also on machinery, fittings and devices in the painting booth. Such booths are fitted with gratings through which the majority of the excess paint falls. The gratings themselves have to be regularly cleaned of paint – an unpopular task which is time-consuming and costly. A number of approaches to solve this problem have been tried but up until now none have really improved the situation. Thermal paint removal in ovens consumes a lot of energy and the coarsely cleaned gratings then have to be further cleaned using sand blasting techniques. Chemical paint removal has not become widespread due to the high costs involved. Attempts to use a wide range of coatings to facilitate paint removal in high pressure plants have also not resulted in an optimal solution for the paint removal problem.

A breakthrough has, however, now been achieved by the Fraunhofer IFAM and Hugo Claus GmbH & Co. KG. The company in Leonberg has already developed a cleaning system for painting companies for cleaning conveyor chains and running rails and this system has been successfully employed for some time. The paint removal technique which has now been developed in collaboration with the Fraunhofer IFAM will be further developed by our business field. The starting point for the collaborative work was the need for an effective paint removal process for gratings. After extensive preliminary work using a variety of new processes, Hugo Claus favored a solution employing high pressure water technology (WHD). Up until this time, however, this was only possible at pressures

PermaCLEAN$^{PLAS®}$ (a trade mark of the Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Munich) of 1500 bar and above. This involved enormous technical complexity and high costs. In addition, a very large amount of space was required and the cleaned components bore distinct signs of attack, so making these systems uneconomical.

A non-stick coating developed by the Fraunhofer IFAM and based on a low pressure plasma process has opened up totally new opportunities for Hugo Claus GmbH & Co. KG. Now available in the marketplace under the brand name PermaCLEAN$^{PLAS®}$, this coating is compatible with a high pressure water cleaning technique which operates in the medium pressure range. This has made the construction of a compact paint removal machine possible. The two components – the PermaCLEAN$^{PLAS®}$ coating and the CLAUSwhd paint removal machine – represent a new, highly efficient, favorable-cost concept for paint removal.

Ultra-thin non-stick coating from the Fraunhofer IFAM

PermaCLEAN$^{PLAS®}$ is an ultra-thin, plasma-polymer, non-stick coating which was developed at the Fraunhofer IFAM by the "Paint/Lacquer Technology" and "Plasma Technology and Surfaces" groups. A multidisciplinary team has worked for many years at the Fraunhofer IFAM successfully developing non-stick coatings for a variety of applications.

The key feature of PermaCLEAN$^{PLAS®}$ at a film thickness of less than 0.5 microns is that common paint systems only adhere very weakly to its surface. It can withstand high water pressures of 500 bar without a problem. Important for the painting technology industry is the fact that even coating particles which become abraded do not cause crater formation in the paint. The coating also has an adhesion that is resistant to sub-surface migration. This is so on metals and also on plastics and composite materials. A prerequisite is however a very clean surface which, in particular, must be absolutely free of loose corrosion products.

The first long-term tests at a car manufacturer have shown that the effect of PermaCLEAN$^{PLAS®}$ on gratings is still present after more than two years and after about 400 cleaning cycles. When the coating eventually loses its effectiveness, the components can simply be recoated.

Using this 5 m³ low pressure plasma plant, components can be coated with PermaCLEAN$^{PLAS®}$.

The coating is applied in a low pressure plasma reactor. At present the maximum component size is 2.5 m × 1.1 m for flat components and 2.5 m × 0.75 m × 0.75 m for 3-dimensional components. The complexity of the components hardly plays a role.

At present the new process can be used for cleaning operating equipment contaminated with wet paint. Besides gratings this can be suspension gear, hooks and other equipment which needs to be regularly cleaned of paint. The method is however not suitable for fragile objects due to the hard jet of high pressure water. Substrates for the coating which have been tested to date are hot dip galvanized and cold galvanized surfaces, aluminum, high-grade steel and plastics. Painted surfaces can also be coated with PermaCLEAN$^{PLAS®}$ without problems.

CLAUSwhd paint removal plant with rotating high pressure water nozzles for cleaning gratings (Photo source: Hugo Claus GmbH & Co. KG, Photographer: Britt Moulin).

Proven and Scalable Machine Technology

The paint removal machine consists of three units, namely the paint removal module, pump system and water supply system. The paint removal module essentially comprises the nozzle system, the transport and attachment units for nozzles and the substrates to be cleaned as well as the disposal system for the coarse paint residues. Depending on the amount of paint to be removed the module is operated as either a batch or continuous system. The batch system requires a space of ca. 20 square meters and the connection for the electrical power is 120 kW. In three-shift operation it allows paint to be removed from up to 800 gratings or comparable components each day. In continuous operation up to 4000 components per day can be cleaned. All machines operate with a closed water cycle. Whereas in the past several hours were needed to remove paint from a component, today only a few minutes are required.

Operating the paint removal machine is extremely simple: The components to be cleaned are placed or suspended on a trolley which can be removed at the side of the machine. This trolley is then pushed into the machine. After selecting the desired program number, the paint removal takes place in an automatic process. A rotating nozzle crosspiece positions itself over the components to be cleaned and passes along the components, moving along linear axes, in accordance with a stored program number. At the end of the process the trolley is taken out of the machine and the components are removed. At the same time they are blown with air by an integrated nozzle system. In the continuous mode paint removal machine several nozzle crosspieces are in use in parallel and are at fixed positions. The products to be cleaned are simply passed linearly through the machine.

The direct costs for paint removal using the new technique are considerably less than the cost of conventional methods, when comparing similar quantities. The cost of the non-stick coating is essentially not a factor because this layer has a long lifetime. The amount of water that is consumed can be neglected. Whereas considerable logistical costs are incurred with the conventional paint removal methods that have been used to date, the new technology can also be used in-house. This means that the component stock in circulation – and the associated capital requirement – can be considerably reduced: Instead of keeping 750 gratings, of which 250 were constantly away at an external company undergoing cleaning, considerably fewer gratings are required for an in-house cleaning operation.

Direct on-site paint removal at the operator of the painting plant is hence possible, but this does require a certain quantity of paint removal to be undertaken. The customer can hire the technology and have his own employees operate the equipment. In this case, Hugo Claus Service GmbH provides servicing and technical support for the machinery. The customer can alternatively let employees of Hugo Claus Service GmbH operate the machinery. With this arrangement he then only pays the costs for the cleaned components. A guaranteed minimum quantity of cleaning is required for this model. Hugo Claus Service GmbH aims to process smaller cleaning quantities in their own decentralized service centers. The first such center is already in operation in Leonberg.

Positive Environmental Aspects

The removal of paint from plant components is generally currently carried out via chemical or thermal processes. These processes produce considerable quantities of substances which are harmful for the environment. At the end of the processing these substances then have to be neutralized again in complex processes. In addition, there are logistical aspects which cause an environmental impact and there is a not inconsiderable material requirement because the lifetime of components cleaned in thermal paint removal processes is shortened. In the new paint removal process – and in the plasma coating process – there are practically no emissions of environmentally harmful substances. The paint removal machinery is highly efficient from an energetic point of view: The energy required for the paint removal is only a fraction of that needed for conventional techniques. As such, the new technology also represents a major advancement from an environmental perspective.

The new technology is currently suitable for wet water-based and solvent-based paints. In a joint project funded by the Deutsche Stiftung Umwelt (DBU), advanced development work is at present being carried out on a non-stick coating suitable for powder coatings and paints used for electrodeposition coating. Also, favorable-cost processes are being studied which can guarantee the high quality requirements of the component surface for the plasma coating. Work is also being carried out on developing paint removal modules which can be integrated into painting booths.

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Development of Storage-Stable 1-C Resin Formulations Using Chemically Modified Nanozeolites with Controlled-Release Functionality

Nanocomposites for Adhesive Bonding Technology

Modern adhesives, sealants and surface coatings often contain solid, inorganic filler materials in addition to highly advanced organic polymer systems. The amount of each filler that is used depends on the specific application. For example, fillers considerably influence the rheologic behavior and the application properties of the non-cured fluid formulation, and they also affect the deformation behavior, permeability and conductivity of the cured organic-inorganic composites. The adhesion between the polymer system and the substrates and fillers plays a significant role in determining the strength and durability of the bonded resin/filler/substrate system.

When nanoscale fillers having high specific surface areas are used, then the polymer-particle interfaces – more precisely, the 3-dimensional interphases – increasingly determine the properties of the overall composite, and hence the bonded joint. This is since several years a main area of work of the Fraunhofer IFAM. In the 2004 IFAM annual report, an article by Andreas Hartwig entitled “Application of nanocomposites in adhesive bonding technology” discussed novel composites based on layer silicates and fumed silicas. Layer silicates – for example in the form of modified bentonites – are suitable as additives for fire-protection applications or as effective curing initiators in adhesive formulations.

The NanoModule Project – Function-Integration Using Nanofillers

As part of the NanoModule project funded by the German Federal Ministry for Education and Research (BMBF), the Fraunhofer IFAM is currently undertaking further synthesis work to develop novel nanoparticles as functional additives. In addition to modified bentonites and fumed silicas, zeolites also form a central part of the IFAM development work. Zeolites – also commonly known as molecular sieves – are porous silicates whose chief feature is their cavities and channels of a few nanometers in size (Fig. 1, 2). Foreign ions and also organic molecules can become incorporated into the porous structure.

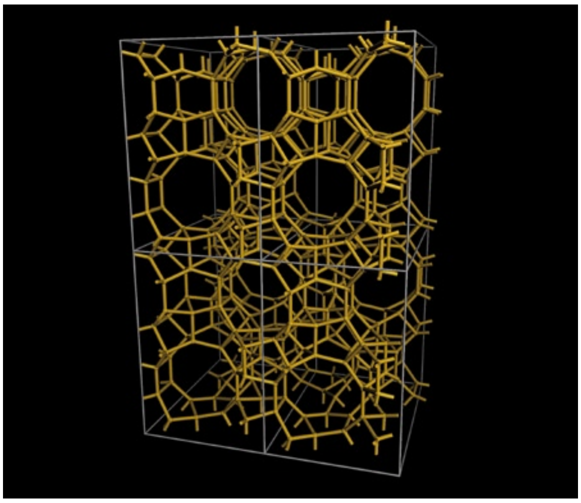

Fig. 1: Molecular model of a typical zeolite: In the 2.5 × 2.5 × 5.3 nanometer section of the base framework that is shown each point of intersection represents either a silicon or an aluminum atom.

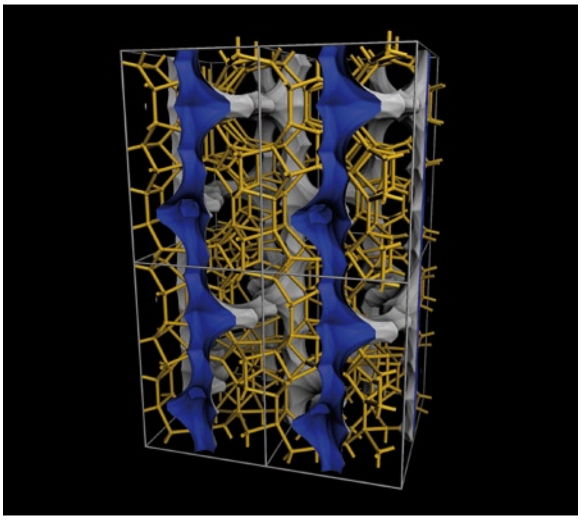

Fig. 2: Representation showing the internal surface of the zeolite which is accessible to solvent molecules – for example water molecules. Foreign ions and also organic molecules become immobilized in the tortuous channel structures.

The objective of the BMBF project is to incorporate different functionalities into nanoscale fillers and so customize the nanomodules. For zeolites it is in particular the cavities and channel structures which can be utilized for this. Active materials – for example curing accelerators – can be immobilized in the zeolites in order to finally produce composites and joints having an innovative range of properties. By using the nanomodules in resin formulations for 1-C processing, the BMBF project aims in particular to tailor the curing behavior and storage properties.

The storage stability and curing behavior have to be individually optimized because for industrial application both a low curing temperature and good storage properties must be guaranteed. The mechanical properties of the composites should be better than conventional composites, namely those with non-encapsulated curing accelerators.

Chemically Modified Nanozeolites as Controlled-Release Additives

There are a number of reasons why zeolites are suitable substrates for the immobilization of active agents for the NanoModule project. These include the large number of known zeolite structures having different chemical compositions and the different effective pore sizes. Many zeolite structures can be synthesized and some are also commercially available. By means of an external stimulus – for example, by increasing the temperature – the active agents that are immobilized within the zeolite framework can be released, leading to rapid curing of the 1-C resin.

A filler based on a zeolite can play a particularly beneficial role when the dimensions of the primary crystals are in the nanometer range. Due to the large specific surface area, there is then immediate release of active agent from the nanomodules on reaching the release-temperature. A reduction of the crystallite size to below 0.1 µm leads to dramatic acceleration of the effective material transport. Simultaneously, a considerably more homogenous distribution of the active agents in the composite is to be expected than for release of active agents from microscale capsules. NanoScape AG has been a valuable joint partner in this project. NanoScape AG has for many years been a leader in the synthesis of nanoscale zeolites and gives this key knowledge to the project consortium.

Computer-Aided Selection of Suitable Host-Guest Systems

Just as there is a large number of known zeolite structures having voids and channels of different dimensions, there is an equally large number of potentially active curing accelerators such as salts, complexes, Lewis acids and derivates of organic nitrogen bases. Not all possible zeolite/accelerator combinations can be tested in experiments. For this reason, simulation methods are used by the Fraunhofer IFAM in order to be able to predict the chemical interactions in the zeolite pores and hence the immobilization of organic molecules in the channels and cavities. The computer allows virtual simulation of the molecular interactions within the nanometer-sized zeolite cavities.

The objective of the simulation work is to identify promising zeolite (host) / accelerator (guest) combinations. This preselection allows the synthesis work to be focused on the most promising combinations of accelerator and zeolite. The first selection criterion to be simulated was the steric hindrance of the zeolite pores. This showed that suitable zeolite hosts are available for many potential accelerators. For geometric reasons, however, not every accelerator can be immobilized in the small pore zeolites.

The second criterion to be studied was how strongly the guest molecules are bound to the host. It was found here that the chemical interaction between the guest molecule and zeolite host was decisive. In particular, the adsorption properties and the release behavior can be decisively influenced by doping the zeolite framework with foreign ions – in the simplest case by changing the sodium and aluminum content. Immobilized alkali metal or alkaline earth metal cations not only affect the surface chemistry but also influence the effective pore diameter. This highlights the third criterion for the preselection because ultimately the host/guest nanomodule systems must be able to function as effectively as possible in applications. In the molecular simulations, the maximum degree of loading of a nanomodule can be predicted for each potential host-guest combination. If the degree of loading is too low, then use of the fillers would be disproportionately costly.

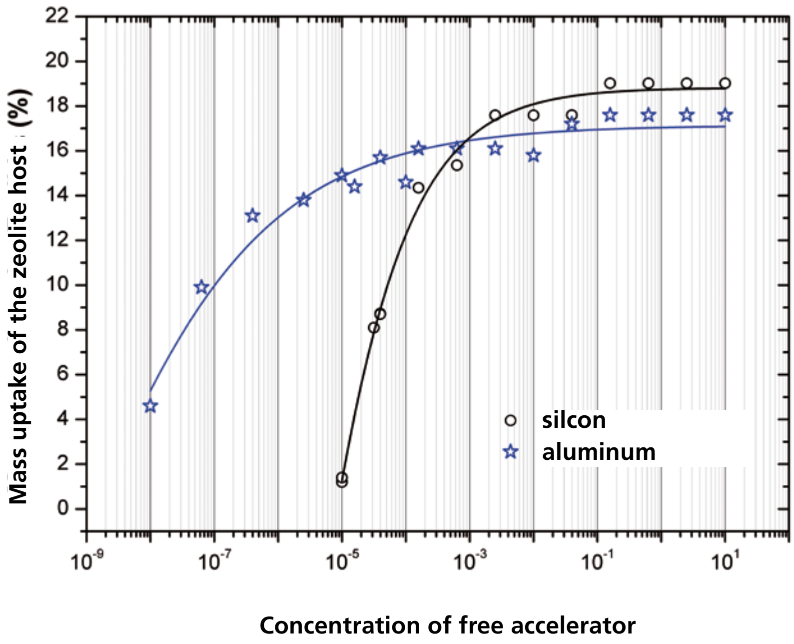

Fig. 3: Simulation of the loading of a zeolite framework as a function of the concentration of free active agent in a mobile phase. A higher aluminum content (Al_2O_3 / SiO_2 ratio) results in a significant increase in the mass uptake of the nanomodule at low accelerator concentrations.

The simulations show how sensitively the degree of loading and the energetics of the interaction depend on the foreign ion content of the zeolite framework. By way of example Figure 3 shows how the adsorption properties of the nanoporous material are influenced by the aluminum content of the aluminosilicate framework. Both the bonding of the initiator and the total adsorption capacity can be customized by purposefully varying the foreign ion content. The same applies for utilizing the release-properties of the nanomodules. By varying the way the host materials are synthesized, the release-properties can be optimized.

Customized Synthesis and Chemical Modification of the Nanozeolites

Following the predictions obtained via computer simulation, NanoScape AG manufactured customized chemically-specified zeolites as host materials for the nanomodules. For example, Figure 4 shows the scanning electron micrograph of a zeolite powder whose chemical composition was optimized for the load of active material.

For synthesizing the nanomodules the second step was to condition the powders at the Fraunhofer IFAM in order to make the pore surface optimally accessible, so favoring interaction with guest molecules. After the conditioning, specific surface areas of several hundred square meters per gram were measured using low temperature nitrogen adsorption. The methods for synthesizing nanomodules that have been developed at the Fraunhofer IFAM within this project allow in particular controlled loading and also give

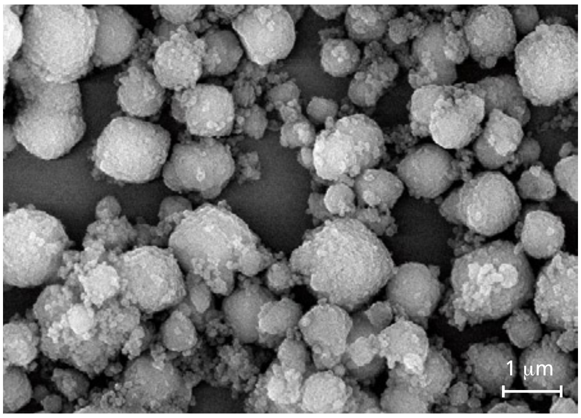

Fig. 4: Scanning electron micrograph of a nanomodule development product based on zeolites which contain active curing accelerator.

a specific radial distribution of the adsorbates in the zeolite grains. In addition, technical processes for modifying the hosts and the load of active agent were developed in the laboratory, then on a small pilot-plant scale and will finally be scaled up to industrial production conditions.

The release of the accelerator from the nanomodules was characterized at the Fraunhofer IFAM, e. g. using thermoanalytical methods (Fig. 5). This showed for a given host that the maximum loading of 20 weight percent which was predicted from the simulation work and is reached on saturation of the adsorption sites, agrees very well with the experimental findings. Comparison of the experimental data with the simulation results gave valuable information for customizing the adsorption processes as well as for further optimization of the synthesis. The observed maximum value of 20 weight percent is sensible from a technological point of view.

The thermoanalytical tests showed there were temperature regions within which there was very marked weight loss (Fig. 5). A more strongly bound guest molecule must be more strongly thermally activated in order to leave the zeolite cavities. It consequently desorbs at a higher temperature than a more weakly adsorbed molecule. The desorption temperatures are therefore on the one hand characteristic of the strength of interaction of different surface groups for the accelerator molecules. On the other hand, they allow estimation of the release-temperature of accelerator molecules into a heated resin formulation. Reliable prediction of these desorption temperatures based on simulation-calculations is extremely helpful for the customized development of materials.

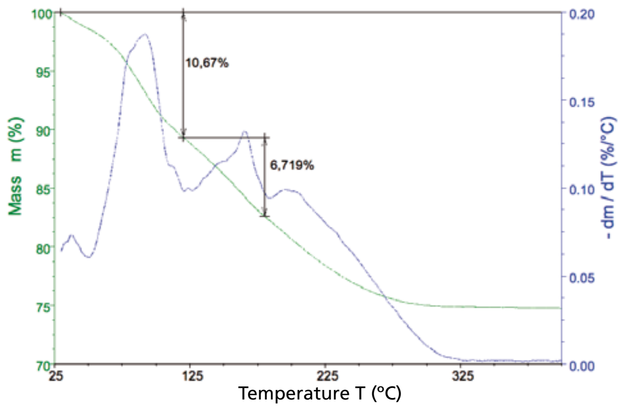

Fig. 5: Thermogravimetric analysis (TGA) of a nanomodule based on a zeolite loaded with active agent. The mass loss is mainly due to the release of the guest molecules. Noteworthy is the fact that the active agent for accelerating the curing reaction already starts being released at about 95 °C – a relevant release temperature for technical implementation.

Future Work to be Carried out as Part of the BMBF Funded NanoModule Project

The results presented here regarding the synthesis of the nanozeolites and in particular the described thermal release of the immobilized active agents are very promising. It is possible to synthesize nanomodules based on zeolites. For optimizing the synthesis, computer simulations can be used to predict the material properties. The customized development of multifunctional materials can be very effectively inspired and accompanied by the simulation work.

Future project work must demonstrate the practical effectiveness of the release properties of the chemically modified nanomodules in adhesive formulations. The next step is to tailor the controlled-release functionality of the fillers to technologically advanced adhesive formulations and cast resin formulations. To achieve this, nanomodules will be incorporated into different 1-C resin formulations and then adhesively bonded joints will be prepared in order to demonstrate the effectiveness of the innovative materials. Of special importance here is the manufacturing and dispersing process for the nanoscale accelerator systems which must be optimized for specific applications. The same applies for the production costs and production safety.

Finally, the project work will investigate how the mechanical and thermal properties of the nanocomposites can be controlled by the curing conditions. The technologically required application properties are prescribed by an experienced consortium. Achieving the project objective will be aided by the extensive analytical expertise available in the consortium and will be tested under technologically relevant conditions.

This approach allows effective, knowledge-driven optimization of the polymer systems. The formulation of systems for specific applications will focus on control of the network structure and dynamics as well as on the application, cohesion, adhesion, wetting and ageing properties.

Project funding

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Project partners

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Evonik Degussa GmbH, Rheinfelden
Sika Technology AG, Zürich
Kömmerling Chemische Fabrik GmbH, Pirmasens
Christian-Albrechts-Universität, Kiel

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Information about the current progress of the project can be found on the project website at www.nanomodule.de

Cyclic Fatigue Test for Qualifying Fiber Reinforced Plastics for Offshore Wind Turbines

Introduction

Natural fluctuations in wind speed mean that the rotor blades of wind turbines are subject to stochastic alternating stresses. This type of stress leads to the formation of microscopic cracks in materials. These cracks grow as the number of stress cycles increases and this can ultimately result in failure of the material. This tallies with the observation that the strength of a material decreases as the number of stress cycles increases.

The relationship between the stress and the number of cycles that can be endured by a material is described by the S-N curve, whose slope and position are material-dependent. For plastics, the position of the S-N curve is highly dependent on the temperature and humidity. The parameters of the S-N curve are excellent mechanical-technological parameters for qualifying fiber reinforced plastics and also represent a necessary precondition for the constructional design of rotor blades to withstand alternating loads.

New fiber reinforced materials with improved properties are required for the construction of offshore wind turbines. The ever higher performance of wind turbines means that larger and slimmer blade structures are required and the offshore location means that the effects of special environmental conditions must be taken into account. The aim of this study was to determine S-N curves for new, commercially available materials, to evaluate the effects of temperature and humidity and to develop and validate a concept for component calculations.

Tests and Modeling

In order to determine the elastic constants and strengths for the modeling, uniaxial tensile and compressive tests parallel and perpendicular to the fiber direction and – for shear loads – at a 45° angle to the fiber direction were carried out. The tests were carried out in accordance with the relevant valid standards (DIN EN ISO 527, DIN EN ISO 14126, DIN EN ISO 14129). Fatigue tests were carried out at a stress ratio of R = 0.1 (positive mean stress) and at R = –1 (zero mean stress). Here, unidirectional-reinforced specimens were tested parallel to the fiber direction and bidirectional-reinforced specimens in the 45° direction.

The numerical calculations were carried out with ABAQUS. The utilization and standby factors based on Puck's failure condition were implemente dinto the user-subroutine UVARM. An indication of the calculated values of these variables was therefore possible in the post-processor as a contour diagram, so considerably simplifying the evaluation.

Material Properties

Resin and reinforcing materials

In order to evaluate the fatigue behavior of new types of composite materials, S-N curves were plotted for different series of laminates, with each series having the same matrix and same layer structure. The results were then compared with each other. In order to achieve uniform infusion with resin, the laminates were manufactured using the vacuum infusion method. The fiber volume fraction was ca. 45 percent. Figure 1 shows experimental data for a new generation material compared to a conventional material. Two properties of the new composite material clearly stand out. Firstly, the lifetime is considerably higher than

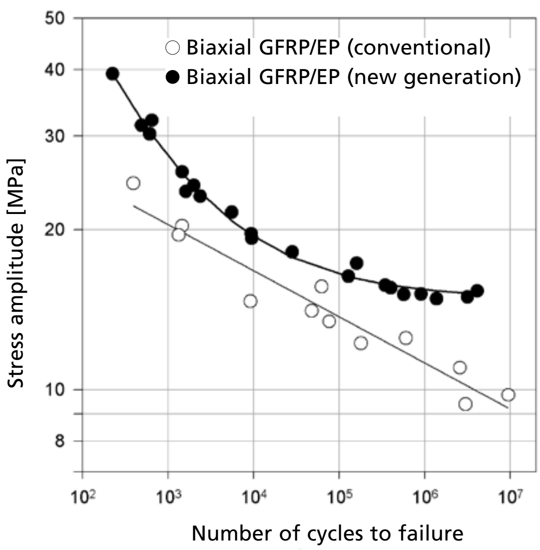


Fig. 1: Differences in the lifetime of ±45° GFRP laminates (conventional and new generation). The shear stress amplitude from 45° tensile tests is shown. The stress ratio is R=–1.

that of the conventional material. Consequently, the material needed to attain equivalent lifetime for a construction can be reduced, and hence the weight can be considerably reduced. Secondly, the data for the new material is represented by a curved line which tends to a constant value at high cycle numbers. This points to the existence of a fatigue limit. As oscillations having amplitudes below the fatigue limit – provided this exists – do not cause damage, this considerably simplifies calculations for component dimensioning. The difference between the new materials and conventional systems is in the nature of the bonding, which results in a more even overall fiber distribution and fewer stress concentrations. The latter are deemed to be sites where damage is initiated.

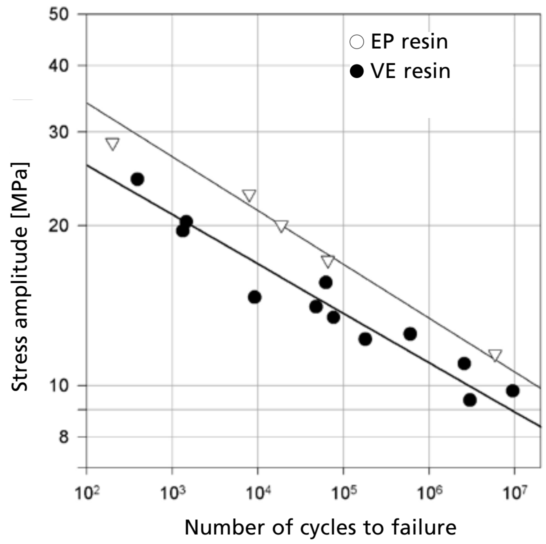


Fig. 2: Effect of the matrix resin on the lifetime of ±45° GFRP laminates. The shear stress amplitude from 45° tensile tests is shown. The stress ratio is R=–1.

The fundamental reaction mechanisms of the new resin systems only differ slightly from conventional systems. There are, however, large differences in processing parameters such as the viscosity and curing temperature. These changes are in harmony with the trend to change over from hand lay-up to moulding processes for the production of rotor blades and to shorten the cycle times. A variety of epoxy resin systems (EP), an unsaturated polyester (UP) and a vinyl ester (VE) have been tested. The layer structure and fiber content were kept constant in each case. Figure 2 shows that VE systems have lifetime advantages over EP systems.

Surface analysis of the fracture surfaces indicate that in conventional glass fiber reinforced plastics (GFRP) the fiber matrix interface represents a weak point during exposure to cyclic stresses. For carbon fiber reinforced plastics (CFRP) the fracture surface was without exception within the polymer matrix. Furthermore, the oxidative degradation of the polymer matrix appears to play a role during exposure to cyclic stresses.

Effect of the ambient conditions

In order to evaluate the effect of temperature and humidity, fatigue tests were carried out in a climate chamber. Extreme conditions were purposefully chosen so that trends could be clearly identified and clear conclusions drawn. Figure 3 shows that the S-N curve at 70 °C under dry conditions is shifted downwards. The average value is reduced to about three-quarters of the original value. If there is humidity at 70 °C, there is a further decrease in the average value to about a half of the original value. Increased temperatures and the effect of moisture also increase the scatter. The combined effect of temperature and humidity results in the scatter increase becoming the same as the decrease in the average value (Fig. 3). This makes it clear that when dimensioning the use of knock down factors based on average values has risks because the true knock down is underestimated. Knock down factors should be defined and used taking into account scatter limits.

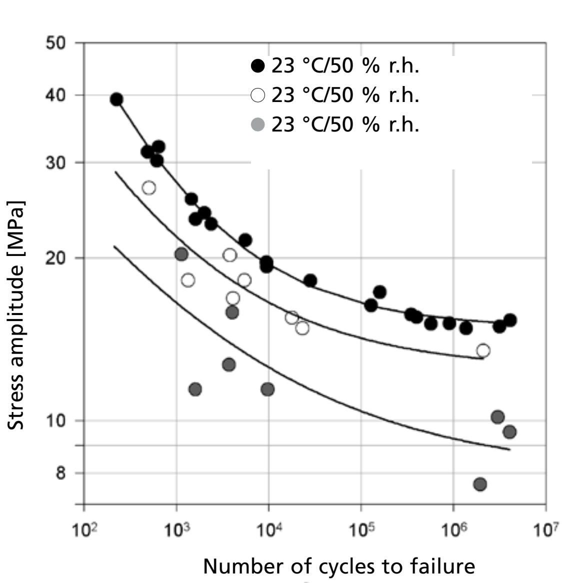


Fig. 3: Effect of the ambient conditions on the lifetime of ±45° GFRP laminates. The shear stress amplitude from 45° tensile tests is shown. The stress ratio is R=–1.

Stress Analysis and Lifetime Estimation

Failure Criterion and Utilization Factor

The calculation of the stress in the component was carried out with ABAQUS. Here, each unidirectional-reinforced single layer (UD single layer) is analyzed separately. The failure criterion according to Puck was used (Fig. 4) in order to describe the relationship between the strength of each UD single layer and physical failure due to fiber fracture and inter-fiber fracture. It describes inter-fiber fractures caused by stress perpendicular to the fiber direction, shear stress parallel to the fiber direction and the overlapping of these two stresses. Here it is taken into account that the tendency for inter-fiber fracture decreases if there is an overlapping stress parallel to the fiber direction. For this reason the fracture function takes the form of a stretched ellipsoid. The apexes of this ellipsoid are cut by planes which describe fiber fracture under tensile and compressive stress parallel to the fiber direction.

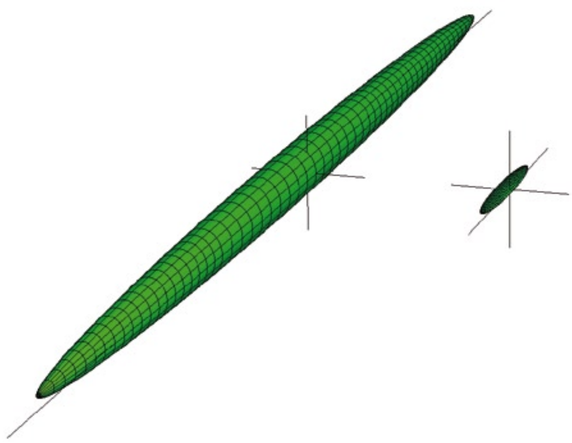


Fig. 4: Failure criterion for 2-D orthotropic material behavior for failure modes according to Puck.

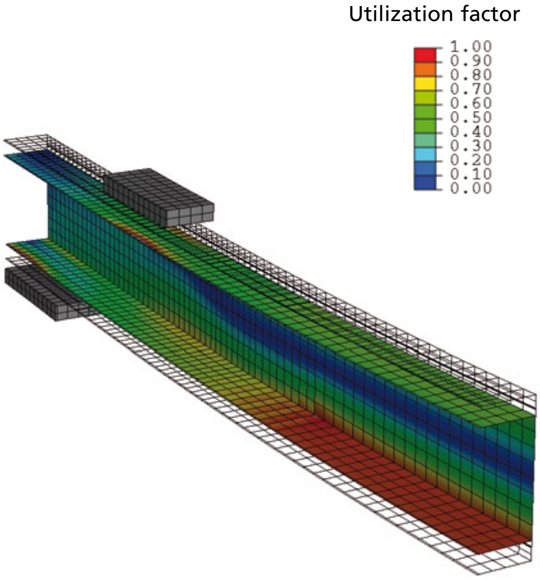


Fig. 5: FE model of the test rail (4-point bending test). Shown is the utilization factor, based on the Puck failure criterion, in the shear web calculated for 1,000,000 cycles at a load amplitude of 22.8 kilonewtons.

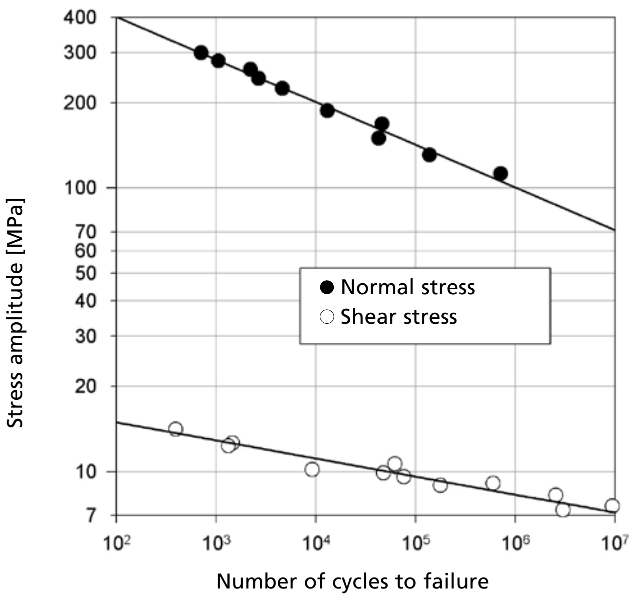


Fig. 6: S-N curves for tensile stress parallel to the fiber and for shear stress.

Based on the failure criterion, the utilization factor was calculated, which gives a rapid statement about how far the material is from fracture under the relevant prevailing stress. The utilization factor was defined such that it has values between zero (no stress) and one (fracture). Figure 5 shows the utilization factor in the shear web of the test component under a bending stress. It can be seen that the utilization factor just attains a value of 1 in the tension zone on the lower side of the rail for the stress used in the model. In this region there is a high probability of failure.

Failure Under Cyclic Stress

When subjected to cyclic stress, the stress which the component can endure decreases. This is described by the S-N curve which gives the relationship between the number of cycles to failure and the stress which can be endured by the material. For the component to endure a prescribed number of cycles, reduced strengths must be used in the failure criterion described by the S-N curve. This task is made difficult by the fact that the gradient of the S-N curve depends on the nature of the stress. For example, the S-N curve for tensile stress parallel to the fiber is steeper than for shear stress (Fig. 6). In order to reduce the experimental testing somewhat, it was assumed that in each case one gradient parameter for fiber-dominated behavior and one gradient parameter for matrix-dominated behavior adequately describe the material. Therefore, in each case only one S-N curve for a unidirectional-0°-material and one S-N curve for a biaxial-±45°-material was required. The failure criterion in Figure 4 encloses a smaller volume for cyclic stress.

Dimensioning

Based on the reduced strengths for the prescribed number of cycles to be endured, the dimensioning stage involves defining the material cross-sections which are required to endure the prescribed forces. The test component was of such dimensions that at a load amplitude of 22.8 kilonewtons and a mean load of 27.9 kilonewtons (in accordance with a stress ratio of R = 0.1) it can endure on average 1,000,000 cycles up to inter-fiber fracture. No safety factor was given here, on purpose, so that the utilization factor was one. This gave the opportunity to verify the basis of the calculations. The optimization of the layer structure was carried out using the Finite Element Method (FEM) stepwise by evaluating the stress profile and the main stress directions, followed by corresponding modification of the layer structure (adding, omitting or switching individual layers having specific orientations). For selecting the number of layers and orientation, practical factors such as the type of composite, fiber volume fraction, web-flange ratio and forces were taken into account.

When dimensioning components it is vital that the stress is smaller than the stress limit. In the case of cyclic stress this means that the number of cycles to be endured (n) must be smaller than the number of cycles to failure (N). When testing a component, a Gaussian stress distribution is used rather than a single magnitude of stress. The stress magnitude was chosen such that the test component had a 95 percent probability of withstanding the test without inter-fiber fracture. Figure 7 shows the distribution of the shear stress amplitude along with the line representing a 95 percent probability of withstanding the test. The normal stress amplitudes parallel to the fibers only make a small contribution to the damage. The probability of fiber fracture is low.

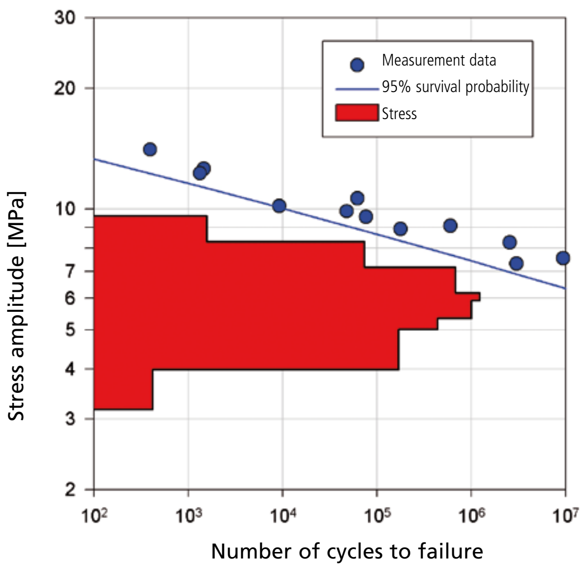
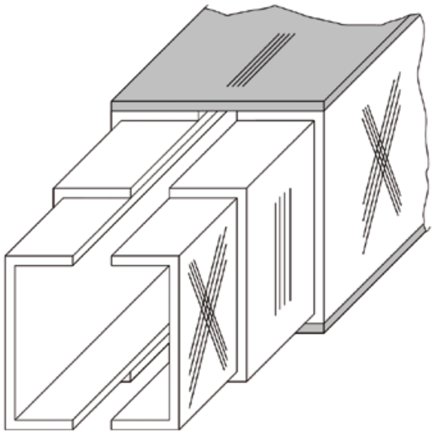


Fig. 7: Distribution of the shear stress amplitude on the test rail and the line representing 95 percent probability of withstanding the test.



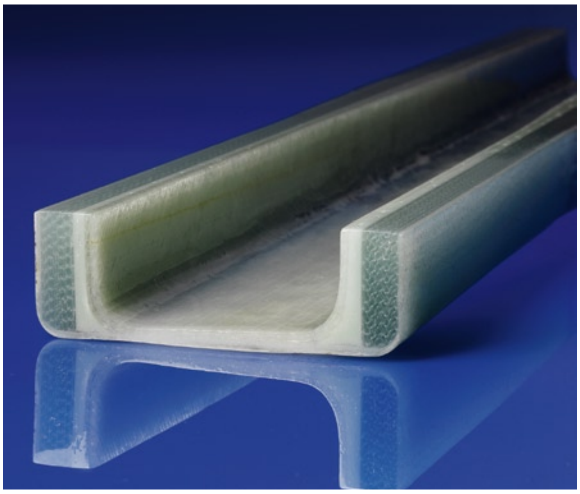


Fig. 8: Test component – box-support with split web of C-sections.

Manufacture of the Test Component

The predominant stress in a rotor blade during operation of a wind turbine is bending. Accordingly, the main component of the bearing structure of a rotor blade is a joint comprising a shear web and a flange, which essentially behaves as a cantilever. A cantilever was therefore chosen as a demonstration object, whose design was derived from the structure of a blade (Fig. 8). The shear web and flange were separately manufactured following the known vacuum infusion method. The individual parts were then joined by bonding them together. The adhesives and curing methods which were used matched conditions in the rotor blade production industry. Finally, load transfer elements were attached to ensure that the component did not fail in the region of the load transfer.

Component Testing

The test component was tested in a servo-hydraulic testing machine under cyclic 4-point bending. The number of cycles at the relevant stress level were completed without the component failing. As the test was carried out according to the requirement of "stress = stress limit" with a 95 percent probability of surviving inter-fiber fracture, it was not necessary to query the applicability of the calculation method for the dimensioning. There is however a limitation regarding the sequence of stress application. The component test was carried out with the lowest amplitudes at the start through to the highest amplitudes, whereby all the cycles were completed at each stage. On changing the sequence or stochastic stress, failure may occur earlier. This sequence effect is a special aspect of fatigue testing which represents an extension of the alternating fatigue test examined in this project.

Summary

Comparative fatigue tests on fiber reinforced plastics (FRP) have shown that the use of modern composites with optimized bonding and improved fiber-matrix adhesion can increase the lifetime of materials under cyclic stress. The lifetime can also be significantly increased by selecting suitable resin systems which have customized properties such that there is optimum infusion and no forming of pinholes.

The lifetime is significantly reduced by the effects of temperature and humidity. Here, the increase in the width of the scatter band can be the same as the decrease in the average value. For this reason, the knock down factors used for dimensioning to describe the effects of the ambient conditions should not be based on the average value but rather on the lower scatter limit for a given probability of remaining intact.

Using a cantilever it was demonstrated that the design of new FRP components can be carried out based on a local stress concept. The laminate is analyzed layer by layer and a distinction is made between fiber fracture and inter-fiber fracture. The basis for the calculations was tested on the component under multi-step cyclic stress. The results showed that calculations which assume linear damage accumulation are conservative. Further studies will be carried out to determine the effect of the sequence of the stress application on the total damage.

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Fraunhofer Center for Wind Energy and Maritime Engineering CWMT

The Fraunhofer Center for Wind Energy and Maritime Engineering (CWMT) in Bremerhaven undertakes research and development work on the utilization of wind energy. The work covers materials, surfaces, joints, production techniques as well as the structural durability and system reliability of plants. The Fraunhofer CWMT is operated jointly by the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM, Bremen) and the Fraunhofer Institute for Structural Durability and System Reliability (LBF, Darmstadt). The Fraunhofer CWMT hence has access to the expertise of 360 employees plus an infrastructure comprising test fields, laboratories and analytical facilities covering an area of more than 20,000 square meters.

The main task of the Fraunhofer CWMT is to focus the expertise of the Fraunhofer IFAM and LBF on wind energy utilization and maritime engineering in close collaboration with the wind and offshore industry. The services on offer range from fundamental research to the introduction of products to the marketplace. The activities include the use of new materials, surface protection systems, joining technologies, integrated sensors and actuators plus the associated process engineering and production technologies. For example, the design of offshore structures is being optimized with regard to weight, production costs and technical availability.

The activities of the Fraunhofer CWMT involve two distinct areas: Technical Reliability and Rotor Blade Testing. Technical Reliability covers the development of numerical tools and analytical methods and adaptation of specific tasks. The objective is to increase the quality of lifetime predictions and simultaneously reduce the experimental testing work that is necessary. Rotor blade testing involves using ultra-modern test stands for the static and dynamic testing of rotor blades and their components from both current and next-generation plants. The correlation of results from experimental and numerical methods allows new test methods to be developed, new structures to be tested and lifetime determinations to be undertaken.

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Land Bremen

Bremen Ministry for the Environment, Building, Transport and Europe
Bremen Ministry for Economic Affairs and Ports
Bremen Ministry for Education and Science
BIS Bremerhavener Gesellschaft für Investitions-förderung und Stadtentwicklung mbH
(Economic Development Company Ltd.)

Federal government

Federal Ministry for the Environment, Nature conservation and Nuclear Safety (BMU)
Federal Ministry of Education and Research (BMBF)

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Bremerhaven Bremen

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

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Aeroelastic-Hydrodynamic Simulation for Optimizing Offshore Wind Turbines

The Fraunhofer CWMT uses dynamic simulation programs which include the effects of wind and waves and the properties of the seabed. The wind turbines are considered as total systems and hence the aeroelastic and hydrodynamic properties and operational management of the turbines are taken into account. This approach is used, for example, to improve the support structures for offshore wind turbines in deeper waters.

Driving through the countryside, it will have become apparent to everybody that over the years onshore wind turbines have become bigger and bigger from one generation to the next. The same is also true for offshore wind turbines: Experience gained with turbines of one specific size have enabled the next generation to be larger – and generate more power. For offshore wind turbines, the trend has been to site turbines at greater water depth further from the shore because this allows more potential locations and because near-shore locations are often not desirable for environmental and aesthetic reasons.

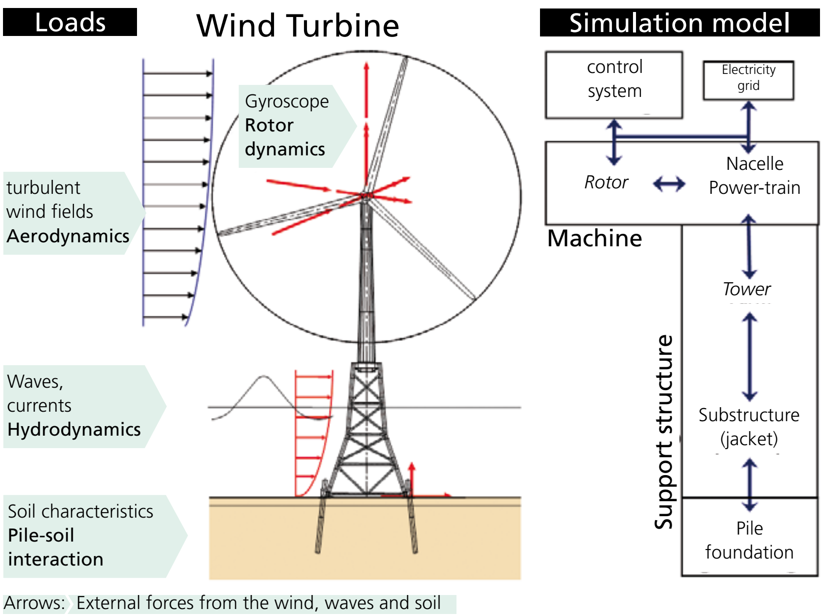

Fig. 1: Schematic representation of an offshore wind turbine (center of the diagram), the loads to which turbine is exposed (left) and the main components of the turbine (right), as taken into account in aeroelastic-hydrodynamic simulation.

At greater water depth and for larger turbines, the established gravity-based and monopile-based support structure concepts for wind turbines do however become increasingly unsuitable. For this reason, novel, predominantly branched, bottom-mounted support structures are currently being developed. These concern three-legged substructures, so-called tripods, or even more complex jacket sub-structures.

Modern wind turbines are currently simulated with the help of aeroelastic models. The following components, properties and loads are taken into account here: Operational management of the turbines, turbulent wind fields, aerodynamic and mechanical loads on the rotor, non-linear effects of the rotor as a rotating and accelerating system (gyroscope), machine house and support structure, elastic properties of components, mechanical damping as well as the coupling of the mechanical system with the generator and electricity network (Fig. 1). The CWMT is extending the modeling approaches to include as realistic as possible offshore influences, whereby, amongst other things, branched elastic support structures, regular waves and irregular sea states as well as the forces between the seabed and the foundation structure are considered in detail. In order to carry out this work the CWMT is collaborating with ADC (Aero Dynamik Consult Ingenieurgesellschaft mbH). ADC uses an aeroelastic simulation program to calculate the total dynamics of wind turbines (ADCoS, Aero-elastic and Dynamic Computation of Systems). It is based on a non-linear finite-element approach and has been continuously developed over a period of more than 10 years.

Modeling of the Support Structure

A beam model for the support structure is generated in the finite-element software ANSYS® Hydrodynamic loads due to waves and the properties of the seabed are determined using the special offshore simulation software ANSYS® ASAS™. With these results and the beam model there then follows total aeroelastic simulation in ADCoS.

The following calculations carried out by the Fraunhofer CWMT with ADCoS are for an offshore model turbine. This consists of a jacket in the submerged zone, which is continued a few meters above the water-line as a tubular tower up to the nacelle. The most important parameters of the model turbine are as follows:

- Support structure: water depth 30 m, weight 800 t, height of the jacket 50 m, tower height 60 m, resulting hub height above mean sea level 80 m, tower diameter 5.5 m

- Seabed and foundation: 8 piles in the seabed, diameter 1.5 m, length 35 m, location: FINO test platform off Borkum

- Nacelle: power output 5 MW, nominal rotor speed 12.3 rpm, upwind turbine, variable speed, pitch angle control, rotor diameter 126 m, mass of rotor, machine above support structure 350 t, nominal wind speed 13 m/s.

Figure 2 shows the support structure as a beam model in ANSYS® and the resulting beam model in ADCoS. The positions of the nodes around the welded joints are parameterized in the model (Fig. 3). This parameterization covers geometric properties (diameter and wall thickness of the tubes) and material properties (density, modulus of elasticity, Poisson's ratio). This procedure allows the model to be rapidly adapted to the results of the detailed simulation of the welded joints. Very important here is the flexibility of the joints. This can be of relevance for both the fatigue properties of the joints and for the eigenfrequencies of the total construction.

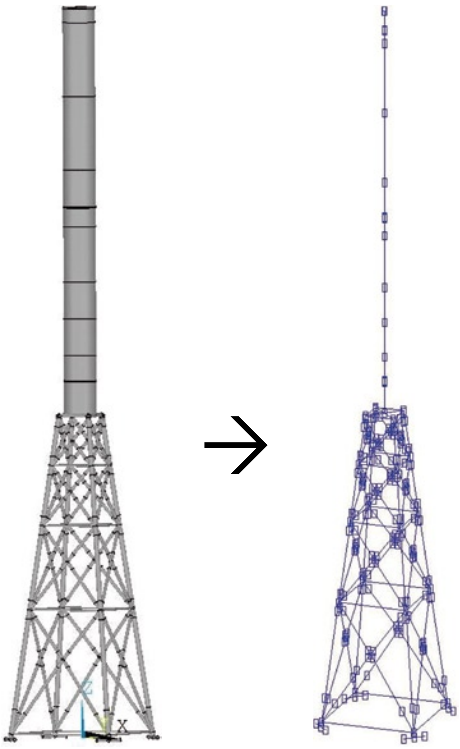

Fig. 2: Representation of the support structure as a beam model in ANSYS® (left) and ADCoS (right).

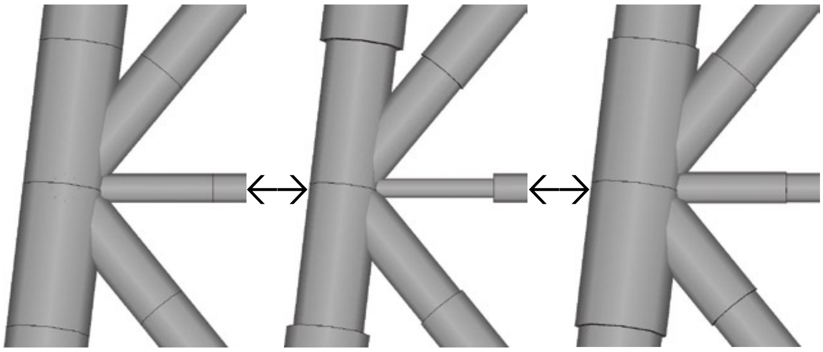

Fig. 3: K-joint with varying diameters of chord (thick, almost vertical tubes) and brace members (thin tubes).

Fig. 4: Second eigenmode of the support structure in ANSYS® (left) and ADCoS (right).

The geometric properties and material properties of the residual beam elements of the truss structure are also parameterized. This allows efficient optimization of the support structure as a whole. ASAS™ calculates the wave loads quasi-static. The beam model for the ADCoS calculations is validated by comparing the self-weight, eigenfrequencies and eigenmodes of the support structure in ADCoS and ANSYS®. It has been shown that the masses of ca. 800 metric tons differ from each other by less than a kilogram and the eigenfrequencies by less than one percent. A further test is comparison of the dynamic oscillation properties. Figure 4 schematically shows the second global eigenmode in ANSYS® and in ADCoS and it is clear that there is excellent agreement. Both the global bending across the total height and also the local deformation in the lower region are very similar in ANSYS® and ADCoS.

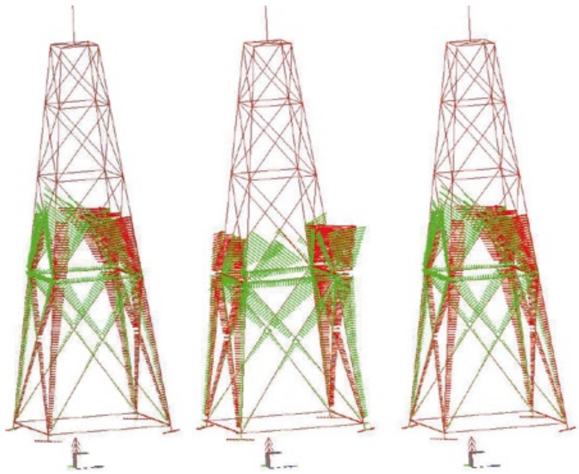

Fig. 5: Load on the support structure (load per unit length in N/m) from a linear Airy wave of a period of T=5.5 s at t=0 (left), t=T/2 (center) and t=T (right).

Calculation of the Wave Loads and Soil-Pile Interaction

Figure 5 shows the wave loads on the submerged braces of the jacket structure calculated in ASAS™ for a simple load scenario. Here, the described structure was subjected to a linear Airy wave of height H=2.5 m for a wave period of T=5.5 s. The figure shows the loads at t=0 s (left), t=T/2 (middle and t=T (right)). The periodicity of the wave and the decrease in load with water depth are clear from the results.

ASAS™ also allows the non-linear calculation of individual piles and groups of piles, including the interactions between the piles caused by pressure propagation in the seabed. The seabed at the reference location consists of a layer system of sands compacted to differing extents and is characterized by load displacement curves as a function of the depth. Relevant reference lines can be defined by both users and also automatically for given seabed properties. There are non-linear reference lines for pile displacement and seabed pressure. Incorporating of stiffness properties into ADCoS is achieved via a stiffness matrix for each transfer node support structure/pile head.

Examples of Aeroelastic-Hydrodynamic Simulation

Selected results of our aeroelastic-hydrodynamic simulations are presented below. They highlight the complexity of the total system. Using an example, the contribution of hydrodynamic load to the total load is then calculated. The following assumptions were used in the calculations: average wind speed 12.5 meters per second, standard wind turbulence model according to Kaimal, significant wave height 2.5 meters, standard wave spectrum according to JONSWAP, simulated time 600 seconds, direction of the wind and waves according to Figure 6.

Figure 7a depicts the resulting wind speed on blade 1, the rotor speed, the blade pitch angle and the power output during the time series of over 600 seconds. The four time series correspond to the expected properties of a wind turbine with variable speed generator and collective pitch control, namely electronically controlled blade angle adjustment. Between 0 and 400 seconds, the wind speed (green curve) oscillates around the nominal wind speed of 13 meters per second. The pitch angle control for the rotor blades (red curve) responds sensitively, as a result of which the rotor speed (blue curve) and hence the power output (black curve) remain essentially constant.

Figure 7b shows the result after Fast Fourier transformation (FFT) of the wind speed from Figure 7a. As this concerns the local wind speed on the rotor blade, the periodic decrease as a result of the tower shadow is seen as a sharp peak in the spectrum. For an average rotor speed of 12 rpm, this value is 0.2 Hertz; its harmonic values are correspondingly 0.4 and 0.6 Hertz.

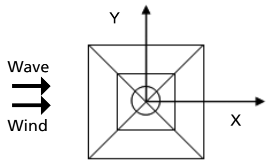

Fig. 6: Directions of the wind and wave loads on the turbine as used for the calculations.

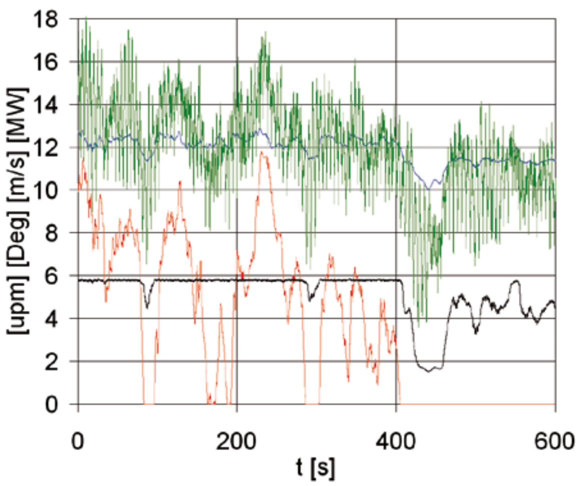

Fig. 7a: Wind speed on blade 1 (green), rotor speed (blue), pitch angle (red) and power output (black) as a function of time.

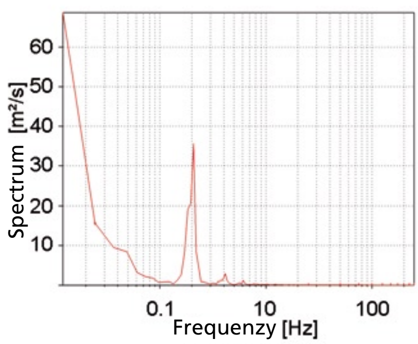

Fig. 7b: Spectrum of the wind speed on blade 1 with the peak due to the tower shadow.

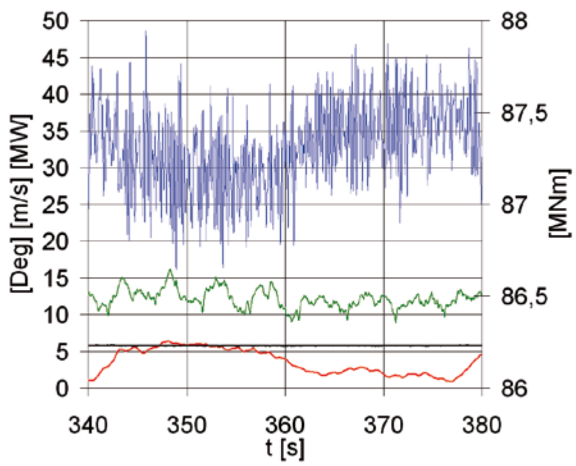

Fig. 7c: Wind speed on blade 1 (green), pitch angle (red), power output (thick black line) and tower base bending moment (blue) as a function of time.

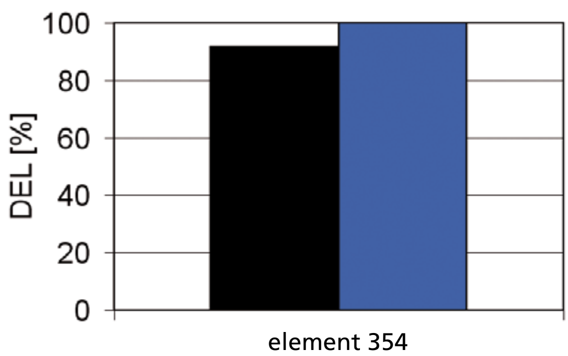

Fig. 8: Damage equivalent axial load (DEL) on a corner element of the substructure (black: only wind; blue: wind and waves).

Other information can be gleaned by considering a shorter time scale. Figure 7c shows the tower base bending moment in the time range from 340 to 380 seconds (blue curve) as well as the relevant time series for wind speed (green curve), pitch angle (red curve) and power output (black curve). With a value of about 87 mega newton meters, the tower base bending moment is of the expected magnitude. At constant power output, higher wind speeds (340 to 360 seconds) and higher pitch angle mean lower rotor shear and hence also lower tower base bending moment; and also vice versa (360 to 380 seconds).

The rotor loads are transferred via the nacelle and support structure to the foundation, whereby the individual braces are predominantly exposed to tension and compression. In order to estimate the contribution made by the waves to the support structure load compared to the total load due to wind and waves, a transfer node – support structure/pile head – on the side exposed to the wind and waves was analyzed.

ADCoS allows direct classification of loads using the so-called "Rainflow method" as well as determination of the resulting load spectrum and damage equivalent loads (DEL). Figure 8 shows the damage equivalent axial load on the described node for a pure wind load (black bar) compared to the damage equivalent axial load for wind and waves (blue bar). Exposure of the turbine to both wind and waves gives a damage equivalent load that is only about 10 percent higher than that for solely wind loads. Consequently, for the described jacket construction, the effect of wave loads in the combined load scenario is of significantly less importance than the effect of the wind loads. This is a typical result for wind turbines with jacket substructures and is due to the relatively small diameter of the submerged support structure braces.

Outlook

Future development work will focus on several areas: The properties of the piles will be incorporated directly in ADCoS via non-linear pile elements. This step will mean that the pile rigidity in ADCoS is independent of the specific load scenario. This will increase the accuracy of the calculations and simultaneously significantly reduce the work involved.

In addition, so-called "super elements" will be incorporated into ADCoS for the nodes of branched support structures, which will allow precise account to be taken of the flexibility of complex nodes. The stiffness properties of these super elements are being determined in detailed simulations using volume elements.

As part of voluntary collaboration, the simulation results of the Fraunhofer CWMT / ADC will be compared with the corresponding results of leading research organizations and companies in this field (including Risø (Denmark), Garrad Hassan (UK) and NREL (USA)). This will involve comparing results for more complex load scenarios and on different support structures.

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Promising Future for Adhesive Bonding: A Celebratory Colloquium Looking Ahead – in Recognition of a Successful Past

A welcoming get-together, gladness at seeing colleagues again, interesting scientific presentations and much recognition and appreciation for the lifelong work of the former director of IFAM, Professor Dr. Otto-Diedrich Hennemann – these were the main themes of the celebratory colloquium "Promising future for adhesive bonding" on 26 September 2007. The colloquium was held in the institute building in Bremen and was attended by more than 100 representatives from the worlds of commerce, industry, research and development (R&D). The purpose of the meeting was to look ahead at what the future holds for adhesive bonding technology – and to reflect on the past and on the influence of one man who turned the Fraunhofer IFAM into the largest independent R&D organization in Europe in the area of adhesive bonding technology. Over many years the success of a whole sector of industry was underpinned by the work of Otto-Diedrich Hennemann and his staff – "the adhesive bonding team in Bremen".

Professor Ulrich Buller (right) and Professor Otto-Diedrich Hennemann (left) show colloquium guests the medal and certificate.

The date of the celebratory colloquium was deliberately chosen to be the day before the 11th conference on Manufacturing Technology – Adhesive Bonding (2007) which was held on 27 and 28 September in Bremen. From its very beginning Professor Hennemann played an active part in this event. In the time between the celebratory colloquium and the conference the participants had the opportunity during an entertaining evening event at the Atlantic Hotel Galopprennbahn to have technical and private discussions with the former institute director. From his arrival at IFAM in 1978 – when the adhesive bonding technology group had only six employees – up to his retirement 29 years later, Professor Hennemann not only played a major role building up the Adhesive Bonding Technology and Surfaces Department at IFAM but also built up many contacts and networks. Today the department has more than 130 permanent employees and is a key player working with the adhesive bonding industry on future developments.

The presentations of the invited speakers focused on the future, although in one of the breaks Professor Dr. Ulrich Buller, Senior Vice President Research Planning at the Fraunhofer-Gesellschaft, took to the floor to pay tribute to Professor Hennemann. He recalled his first meetings with Professor Hennemann at the end of the 1980s and about his "envy" at the slogan which had already been coined: Kleben in Bremen (Bonding in Bremen). One of Professor Hennemann's many trendsetting ideas was to transfer the knowledge and expertise at IFAM into applications in different sectors of industry by setting up supra-company training courses. Professor Buller also paid tribute to the rapid growth of the Fraunhofer IFAM under the leadership of Professor Hennemann – as indicated by the splendid new building in the Wiener Strasse: "In the Fraunhofer-Gesellschaft there must be considerable accomplishment in order to acquire a building of this size." Professor Buller, on behalf of the Executive Board of the Fraunhofer-Gesellschaft, then awarded Professor Hennemann the Fraunhofer Medal in recognition of his dedicated service and added: "You have earned this!".

The first technical presentation was given by Professor Dr. Wulff Possart of the University of Saarland in Saarbrücken. Using examples from the bonding of metals, the importance of interfaces and interphases between adhesives and substrate materials was discussed. It was pointed out that the mechanisms of adhesive interaction at the interface and the subsequent structures in the interphase are still not fully understood.

The following presentation concerned industrial practice. Rudolf Henrich, leader of the test department at Airbus Deutschland GmbH in Bremen, gave a talk on the "Non-destructive testing of bonded joints". There are equally high requirements on test methods for bonded joints as there are on, for example, fiber reinforced composite materials. Of course, the adhesion between interfaces cannot be directly measured in a non-destructive way. For that reason, quality assurance uses indirect methods which often have to be used in combination in order to identify and evaluate defects. In the future, "Structural Health Monitoring" will be employed whereby non-destructive testing is permanently incorporated into the structure.

Everybody who uses adhesives knows that correct pretreatment of the surfaces of the substrates plays an important part in determining the subsequent quality of the structural bond. This topic was discussed by Dr. Alfred Baalmann of the Fraunhofer IFAM who has been involved with this matter at IFAM for more than two decades. His talk was entitled "Adhesive bonding from a 'surface' viewpoint – methods and concepts for surface pretreatment". "About a half of all defective bonded joints are attributable to incorrect surface pretreatment", a fact which made the importance of surface pretreatment clear. "The use of modern methods of surface analysis, e. g. inline monitoring methods, in combination with suitable pretreatment methods such as plasma methods, allows the reliability of production processes to be significantly increased."

The final talk was given by Dr. Olaf Lammerschop of Henkel KGaA Düsseldorf on "Reliable bonds for structural applications". The polymer chemist described the history of structural bonding and the latest trends. He made clear that adhesives are here to stay for structural joints due to the enormously improved crash performance. The advantages of adhesives speak for themselves: reliability, environmental friendliness, comfort and economic viability. In the adhesive – application/testing – design/simulation triangle, an important aspect for achieving reliable bonds is the training of personnel – and the

Professor Otto-Diedrich Hennemann (right) with guests.

Fraunhofer IFAM has also devoted itself to this task. Following the technical and formal afternoon session, there then followed a casual yet informative evening session in the Atlantic Hotel Galopprennbahn. The occasion was used for further chat and there were two further informal speeches. Professor Walter Brockmann, the predecessor of Professor Hennemann as head of adhesive bonding technology at the Fraunhofer IFAM recalled in his inimitable way the beginnings of the institute. After the founding of IFAM in 1968, it was initially solely engineers who were engaged with adhesive bonding technology. Later, due to the increasing complexity of the subject matter, physicists (such as Professor Hennemann) and chemists were needed. Just as today, there came important impetus from the aircraft manufacturing industry.

A landmark joint project (FertigungsTechnologie Kleben (FTK) – Manufacturing Technology – Adhesive Bonding), funded by the Federal Ministry for Education and Research and involving 22 partners from R&D as well as adhesive manufacturers and users, for the first time brought together companies who compete in the marketplace. A sub-project of the main project – whose inclusion was due in no small part to Professor Hennemann – was the bonding of oiled sheet steel. "The Bremen team carried out pioneering work here in collaboration with other project partners. They showed that it was possible to bond oiled sheet steel – and also to create structural bonds. This

Katrin Plümpe (left), Professor Otto-Diedrich Hennemann and his wife Edeltraud discussing the talk on "Art and adhesive bonding".

Professor Walter Brockmann during his presentation on the development of adhesive bonding technology and on the contribution made by the Fraunhofer IFAM.

was particularly important for the use of adhesive bonding technology in the car manufacturing industry", explained Professor Brockmann. "This project greatly advanced and promoted adhesive bonding technology." Professor Brockmann praised his successor by going on to say: "Without the persistence of Professor Hennemann it would have taken adhesive bonding technology much longer to break through into certain sectors of industry."

There was an unexpected end to the day's presentations by Katrin Plümpe, the Hamburg-based art and cultural scientist. As a surprise guest she gave a talk on "Art and adhesive bonding" – a connection that had long been close to Professor Hennemann's heart. In contrast to many, he always had a clear vision of the proximity of bonding to art. That there is indeed such a link was confirmed by Katrin Plümpe's presentation. She started her talk about the history of art long before IFAM's foundation – namely with the paintings in the famous cave of Lascaux. At that time, just as today, the artists used the adhesives that were available in the "marketplace". For this reason, the developments in adhesive bonding technology have considerably influenced art through the ages.

There was loud applause at the end of a splendid talk – as indeed there had been many times during the day to mark the lifelong work of Professor Hennemann.

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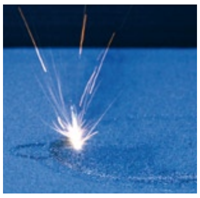

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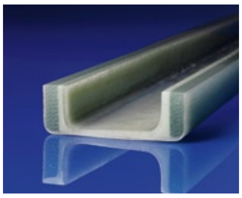

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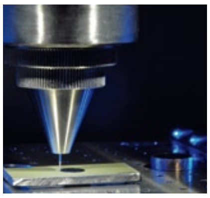

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