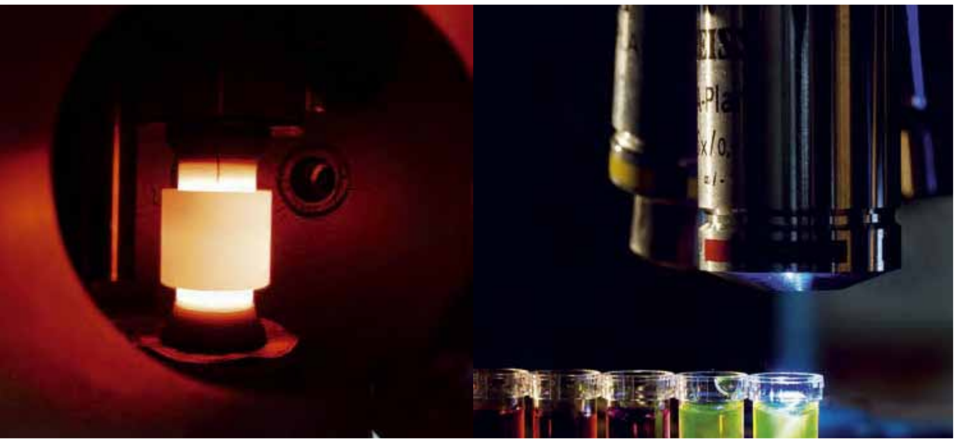
IFAM

Fraunhofer Institut Fertigungstechnik Materialforschung



06/07

Annual Report 2006/2007

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

Annual Report 2006/2007

A Profile of the Institute

Department of Shaping and Functional Materials

Department of Adhesive Bonding Technology and Surfaces

"Vision is the art of seeing the invisible"

Jonathan Swift, Anglo-Irish writer, 1667–1745

Ladies and gentlemen,
Business associates and cooperation partners,
patrons of IFAM!

"Treasures of Research"

The speed of progress has been accelerating drastically since the middle of the 19th century. When we consider that hundreds of years lay between the invention of writing and the printing of books, the candle and the light bulb, we see that nowadays the intervals between knowledge acquisition and its application are growing shorter and shorter.

With our knowledge and vision, it is incumbent upon us to constantly reevaluate the treasures our research has put in our hands. When the first enormous computers – filling whole suites of rooms with thousands of tubes and emitting intolerable heat – emerged for commercial use in the early fifties, Watson estimated the demand of the US economy to be a maximum of five units. Today all of us know the extent to which the computer has changed our lives.

Rapid progress in the technology sector demands R&D services that are production-oriented, services that can be implemented almost simultaneously by industry. Even in 2006 IFAM connected vision and knowledge, recognized and made visible the riches of our research. Our customers' interest in new development trends, as well as consistent implementation, demonstrates their needs in terms of innovative objectives and applications. After all, we know that only success on the market makes an invention an innovation.

New interdisciplinary approaches aimed at the technological implementation of functional integration resulted in promising developments in a wide range of applications at IFAM in the past year. "Functional Printing", direct casting of RFID tags in aluminium components, and the application of functional layers to structural components are only a few selected examples demonstrating that synergies among various fields of expertise lead to very promising results.

Projects on long-term stability of material composites and surfaces subject to environmental strain have been and continue to be emphasized in the Department of Adhesive Bonding Technology and Surfaces. Interdisciplinary work is the key to success and also the trendsetting domain of "Biomolecular Surface- and Material Design". Nature already has the answers to many technical problems. Bringing together materials science and biology makes it possible to implement these natural concepts in technical solutions and to make industrial use of them. We intend to continue this strategy.

Our institute's progress is based on many ranges of activities. We would like to particularly acknowledge our employees for their inventive, highly motivated and important work. We can only explore new issues and phenomena when we are driven by a thirst for knowledge and commitment and have the courage to think laterally. We are extremely happy to be able to impress our customers and cooperation partners with outstanding results and successful projects even just this year and thank you for the confidence you have shown us.

We would like to express our gratitude to everyone who helped to make our success possible.

M. Busse

O.-D. Hennemann

„We intend to develop our leading position and simultaneously provide the preconditions to produce new ideas“

The success story of the IFAM Department of Shaping and Functional Materials is ongoing. In retrospect, Professor Dr. Matthias Busse is pleased that he worked closely with his employees to make the right decisions. The trend toward growth should be followed – but with a sense of proportion. It is not only the goal of the department, but the entire IFAM, whose managing director is now Matthias Busse, to hold on to these achievements without losing the longterm goals for development.

Professor Dr.-Ing. Busse

Mr. Busse, the first three years that you worked at IFAM were mainly characterised by reorientation and redefinition of the objectives of the Shaping and Functional Materials department. Last year, you could say with satisfaction: We succeeded in the turnaround and moved a bit closer to our visions. Now we can look back on another twelve months. Did you enter into a stage of consolidation in which you harvested the fruits of your earlier endeavours, or did you go on to sow seeds for the future?

The order situation is better than ever before. Consequently, we did not consolidate in 2006; the positive development rather continued with the same energy and without a break. We again adopted a course of growth – in fact, this was true not only in the number of scientists and engineers we hired, but also in the quantity of technicians. Employment even rose at the university in my department, Near-net-shape Manufacturing Technology. We achieved a gain overall – not only in quantity, but also in quality, that is, in research topics. At present we are actively creating new jobs in a high tech domain. This way, students and graduates of the above-mentioned department have better employment opportunities.

The scope of your duties grew in the spring 2006. Since then you have managed the business of the whole IFAM institute: What does that mean for you in practice?

Having been at the institute for three years, I was appointed to the position of managing director of the whole institute. In a position like this, one’s understanding of the well-being and perspective of the entire facility sharpens very quickly. It takes some time to learn and understand the entire IFAM institute, but I took this time to do so. In the medium- and long-term, my fondest wish is to make better use of the opportunities within IFAM. We want to maintain the technical autonomy of both departments, on the one hand. On the other hand, we intend to make a wider use of synergies arising from the closely related research areas of the departments in the future.

Retrospect makes possible and simplifies the ranking and evaluation of many activities whose consequences cannot be foreseen at the moment they are undertaken. To get to the point: What makes the department of Shaping and Functional Materials so successful today?

A strategic reorientation is really a little like a leap in the dark. Today we are aware of the reasons for success. It has been demonstrated that we took up the subject areas predefined by the market in our R&D and implemented them in activities. In retrospect, we are convinced that we had the right touch when focussing our core expertise and defining our business segments. We obviously concentrated on the key topics. Furthermore, we found the appropriate partners in industry, partners, who were ready to collaborate with us and advance these topics. What I judge to be just as important is the Human Resources aspect, going beyond the technical subject. I have in mind the people who work here and who make our goals a reality. In this environment, the employees clearly performed more than the standard workload, working together to produce an extraordinary team performance. At present, we really have this high level of motivation and commitment – and this is the second important reason for our success.

As we know, a department is – in spite of the “integral behaviour of a team“ – a formation including many distinctive individuals. You employ a lot of people who have been with IFAM a great deal longer than you. How do you get them to move in a new direction, to believe in it and to pull together?

What is essential is to engage in indepth discussion with all those involved at this stage. It takes several sessions of joint analyses and discussions – even controversely, to really reach some aspects of difficulties. But at the end of this process of discovery, after joint discussion, it is necessary to reach a consensus. We continuously work on this subject to derive joint solutions to problems – directed by a vision understood by all participants. If everyone accepts the common long-term objective epitomised by our slogan „Smarter – Smaller – Safer“ and gets behind it, then we have only to figure out: How do we now implement this strategy? Everyone here joined in this process in a very creative manner, and thus we succeeded and really all worked in concert, following the same orientation. We bolstered the overall objective with intensive work, in close co-operation with firms, partners and sponsors.

What about the department’s establishment in Bremen and the surrounding region? What can you say about its ‘standing’ in Germany or abroad? And where do you want to go from here?

Let’s give an example: Industrial companies or particular automotive manufacturers have a reputation. It takes time to establish such an image, it takes time to grow. The same is true for us. I think we have made significant progress in our PR activities in recent years. We are becoming known to a greater and greater extent. Within the Bremen region, this is certainly caused by the fact that we collaborate as part of the Excellence Initiative not only with the university, but also other institutes and firms in the region in a fruitful way. This development is also applicable to our national activities. The range of our contacts is constantly growing wider. Both in quantity and quality, our contacts with German industry are very strong. And all goes well even at the international level. We have initiated some projects in Asia, projects we hadn't even thought of one or two years ago. We can also record expanded projects in the emerging markets: We have projects underway in Russia and China, and we are initiating projects in South Korea. The casting engineering department maintains close contacts with partners in the USA, supported by signed agreements. In this context, we plan an Application Center focused on the Lost Foam technology. This center will be established for worldwide leadership in technology and equipment. At the same time that I took office, establishing and expanding the Lost Foam technology was declared a mean-term goal. By mid-2007, we will have built up the development center to a degree described above. Thus we have acquired another important unique selling point for this kind of technology. Even this investment provides us with opportunities for worldwide acquisition and for attracting customers to Bremen.

Since you mention that your services are in increasing demand and that you are going to continue your development, then you will also need additional personnel ...

That's right. In 2006 we gained about 10% new employees, this trend will continue at almost the same level in 2007. But one must keep growth within reasonable limits, that is to grow step by step, because newly employed people need personal support and training. We don't want to grow too rapidly; it is a matter of balance between finding suitable people and integrating them. Recruiting the adequate people is a demanding activity for us. We are always looking. The search is a continuous process using all of the channels available to us. Our new generation of scientists and engineers, that is people who have studied at the University of Bremen and who have become known at IFAM through their student research projects, play an important role. They don't just come from the Production Engineering Department – we also employ graduates from natural sciences and electrical engineering. In addition to this channel for the „Bremen region", we publish advertisements for a wide range of job openings. We try to gain employees not only from other locations and universities, but also from industry. We have succeeded on many occasions in getting experts from industry into the IFAM. This is a success we proudly present. Getting people from industry into IFAM means that we have here working conditions and an atmosphere that makes experts decide in favour of IFAM. Apparently it is getting around still more that IFAM is a prime address and attractive as an employer. This is surely also a consequence of the continuous growth of the whole institute's reputation.

If I remember correctly, you have always regarded external presentation as a very important factor in your strategy ...

... and consequently, the attention that is paid to our institute is obviously greater. One of the strategic points on our agenda, namely the establishing of marketing, yielded outstanding results. We push this point in a proactive and prudent way and the institute benefits from these endeavours on a grand scale. Here the assortment ranges from adequate placement of our publications in interesting reports and journals to an accurate choice and professional preparation of tradeshow- and company presentations. Altogether we improved both quantity and quality. Although the majority of our publications are dedicated to technical journals, we also make a point of publishing in popular scientific magazines as well. This is because today it is more important than ever to showcase our own results for the benefit of a wider public rather than focusing exclusively on an audience of specialists. The efficacy of activities like these is amazing, and in sum, it has played a role in our being better known and much more intensively perceived than we were just a few years ago.

Where do you see your institute in twelve months, where in ten years?

In the short- and medium term, our intention is to grow further and thereby generate new jobs. But with a sense of proportion: We don't want to go too fast and stumble. It will be a challenge in the coming 12 months to implement our current growth, recruit the adequate people and to integrate them. We have many orders to fill and projects to do, on the one hand. On the other hand, we must not lose sight of the necessity to make acquisitions for additional projects in the medium term – even if, for example, acquisition for 2007 was at a pleasantly advanced state by mid-2006, which is really very exceptional. That means we must not slow down in the acquisition of new projects. What we have to do is in fact to find a balance between respectable processing of projects with a new team, and making available the background and the conditions for creative work, particularly for our experienced employees. What we want is for everyone – in addition to their everyday tasks – to think ahead to the next project, which they may not start until two or three years later. Thus we bring continuity into our business. We have to avoid a situation in which we may currently have a flood of orders, but will have a drought three years later, because we don't have the time to think about new research subjects now. Consequently, in the next twelve months, we will have to find the balance between project support and project acquisition. And if I project this objective further ahead, then I ask that we – together with IFAM as a whole – grow further and continue our development, and that we become robust enough to become the leader in our technical domains even at the European level. Our perspective on the future is open-minded and ambitious: We want to expand our cutting edge position.

"Success depends on the expertise and know-how of our employees"

Professor Dr. Hennemann

Professor Dr. Otto-Diedrich Hennemann is absolutely sure that the maxim "the whole is greater than the sum of the individual parts" is particularly apposite for the strategic approach of the Department of Adhesive Bonding Technology and Surfaces at the Fraunhofer IFAM. Any organization wanting to continuously provide its customers with added value at different levels faces a constant challenge. All parts of the organization must be optimally integrated.

Professor Hennemann, the expertise of the Department of Adhesive Bonding Technology and Surfaces comes from the skills of the individual "parts". Knowledge and experience come from individual employees, work groups, organizational units and networks. Added together, the whole is greater than merely the sum of the parts . . .

That is absolutely correct. Our expertise, as you know, is in the field of materials. At the primary level, materials consist of very small building blocks, namely atoms. A component is usually made by combining different materials. Were a component to consist of only a single material then its use would often be limited. By bringing together selected different materials optimally suited for an application there is a large benefit, namely an added value. This applies analogously to the Fraunhofer IFAM.

The R&D areas being studied at the Fraunhofer IFAM therefore portray how the institute actually works?

And there are two aspects to consider here. The maxim "the whole is greater than the sum of its parts" applies not only to IFAM internally but also to its relationships with the outside world. These internal and external relationships must be linked to each other.

Let's consider for a moment the "primary building blocks" of IFAM, namely the employees. An employee contributes his/her expert knowledge but also bring his/her experience, specific characteristics and very own individuality. All these aspects characterize a person in his/her interactions with fellow employees.

Precisely. Personal individuality is very important for us. Individuals come into contact with other people at the Fraunhofer IFAM. Work groups are formed by linking specific ideas, interests and knowledge. An organizational unit is then formed from several work groups. These organizational units are also technical "discussion groups" into which the special knowledge of individuals can be incorporated in a beneficial way. The institute comprises all the organizational units – and that is hence far more than can be indicated by merely employee numbers or economic figures. IFAM employees are able to use their knowledge and skills for the benefit of everybody and the IFAM infrastructure is designed such that employees have optimum opportunity to do this.

How do you "position" employees effectively – in the institute and in contact with customers?

If somebody already has special expertise in a particular area of work of the institute – for example in wind energy – then this can be taken into consideration. Naturally, such employees need different boundary conditions to somebody working at IFAM for the automotive industry. I must point out that work methods differ in different sectors of industry and specific "technical jargon" has even developed. The task of the Fraunhofer IFAM is to link specialists and sectors. We must be able to understand the different "languages" of the different sectors, otherwise we will not be accepted. If one does not possess insider knowledge, one is unable to provided added value for industry – and the result is offers having no chance of being accepted. It is our task to create boundary conditions for employees which allow them to recognize the needs of industry and convert their knowledge into innovation for industry. Our employees must be able to convert their knowledge in such way that it can be utilized by industry. This is a "skill" which IFAM success depends on.

The people in the work groups and organizational units have different interests and knowledge. These are efficiently integrated to give "effective multidisciplinarity". How does this function at the Fraunofer IFAM?

We have many experts, for example engineers, physicists, chemists, mathematicians, material scientists, technical staff, laboratory technicians and specialist administration staff. They think in different ways and speak different technical languages. They teach at technical colleges and universities and hold regular discussions with industrial partners. They must possess a number of key technical abilities and think in a flexible way. They are constantly receiving a wealth of different information which is continuously "processed" in the employee networks. These employees must be given work freedom, namely the opportunity to exchange information via groups. Their specialist knowledge then becomes general knowledge that can be benefitted from throughout the institute. This generates the practical expertise which we can offer customers. Customers then recognize that by working with us they get added value. Firstly, though, it is essential to precisely understand what customers require. For that reason, we intimately identify ourselves with customers in order to be able to offer them tailored, practical solutions that they can use.

Does this not involve too much communication? Do employees have to be continuously reminded of the importance of communicating knowledge and expertise with all other relevant parties both inside and outside the institute?

We have for this reason purposefully created communication levels. Meetings are held to keep all employees informed of developments. In turn, the various work groups present their project work and any special developments. There is very efficient communication beyond the group level due, for example, to the fact that employees in a particular organizational unit are not congregated in one part of the building but are spread throughout the institute. In addition there are meeting places in the institute such as the secretariat, the photocopying area, the kitchen, etc., namely places where different people meet, exchange information with each other and so learn. This is also intentional. A network is so generated in which all employees are integrated.

The network does not stop at the front door of the institute. The network principle is highly important for the whole of the Fraunhofer-Gesellschaft. How is this organized? How does a Fraunhofer employee know where in the Fraunhofer community he/she can generate additional knowledge and expertise for a customer?

There are many ways by which the employees of the 58 Fraunhofer institutes can communicate with each other. The directors of institutes involved in Fraunhofer alliances meet on a regular basis. We belong, for example, to the "Materials and Components" Alliance which involves collaboration between 11 institutes. The level below this involves thematic alliances covering specific technical fields. Joint projects are carried out and employees are able to increase their knowledge of the relevant areas. In addition, the Fraunhofer-Gesellschaft initiates self-funded research programs to generate expertise in technical fields of the future. The aim of these self-funded projects is to promote collaboration and communication between the institutes and generate new knowledge. This allows all employees to learn about what is going on in the Fraunhofer-Gesellschaft. We also have several periodic publications which provide excellent information.

The Fraunhofer IFAM has state-of-the-art technical equipment and facilities. The laboratories are well equipped, production conditions can be replicated and the small pilot-plant facilities are second to none. Taken all together, this also brings added value. How is all this strategically planned?

In order to pursue a network approach, it is vital to define the network at the outset – and also decide what one wants to do. One concentrates on one's objectives and pursues these both internally and externally. Once a decision has been taken, strategic investments must be made. There is then a sequence, with each investment, each laboratory, each pilot-plant facility being a step on the way towards the planned total system. Even for equipment and facilities, it is necessary to organize matters in a systematic way. Assessment of the objectives and new investments are constantly necessary to advance the growth of such a system. With regard to the dynamics of the overall innovation process it is imperative to keep pace with developments in industry. Only then can companies be provided with expertise, namely added value. Everything must "fit", because failed investments cannot be afforded. It is always difficult to make a decision about an investment that will only repay itself in the future. If a wrong decision is made, it is only later that the pain is felt. Up until now we have always got things right. It is however a never-ending task to maintain the sound position of the institute and so pave the way for the future.

Annual Convention: Celebration of Research in Bremen

Prof. Dr. Hans-Jörg Bullinger.

Impetus for Innovations

The Fraunhofer-Gesellschaft supports the Federal government's high-tech strategy with a series of activities. The association's president Prof. Dr. Hans-Jörg Bullinger emphasized this commitment at the annual Fraunhofer conference in Bremen on 18 October 2006.

"Germany is a country of ideas. But we don't make the best of them and frequently leave their implementation in successful products to others. What we need is for Germany also to become a country of action, a country which applies, sells and converts its inventions into cash", Prof. Hans-Jörg Bullinger, the President of the Fraunhofer-Gesellschaft, elucidates the most essential challenge for Germany. Innovative products and services bring higher added value in Germany and assure employment. The Federal government recognized this and consequently instituted the "High-tech Strategy for Germany". This paper defines 17 technology subjects expected to offer particular impetus to the economy. The Forschungsunion, a board of leading representatives from industry and science, appointed by the Federal Minister of Education and Research, Dr. Annette Schavan, assists in implementing and advancing this High-tech strategy.

"With its High-tech strategy for Germany, the Federal government for the first time developed

Dr. Annette Schavan.

a national innovation strategy across all disciplines, in order to guide Germany to the top of the relevant future markets. In this way, the government is following an unambiguous strategy to create more innovations from partnerships between industry and science to secure locations in German for the long term", explains Bullinger, who manages the Forschungsunion together with Dr. Arend Oetker, President of the Stifterverband für die Deutsche Wissenschaft.

It is impossible for Germany to generate excellence in every domain; the country has to concentrate on its core competencies. With 17 subject areas, the High-tech strategy marks clear focuses on the promotion of innovation in the coming years. First, it is necessary to build up and expand

Dr. Arend Oetker.

areas of expertise. For this reason, the Federal government will invest much more into science: An additional six billion euros will be made available for research, development and innovation from 2006 to 2009.

This sum is intended to generate new ideas. The innovations arising from it should revitalize industry and create wealth. Investment will only have been profitable, if knowledge generates new values. These additional funds give the participants from science and industry the security to plan and enjoy creative freedom. These funds are above all to support the departments in areas in which Germany already has a rich potential. "The principle of 'Strengthening strengths' is the right way to develop areas of research and applications that are competitive on the global market", Prof. Bullinger outlines.

Clusters of Innovation – Together We Are Stronger

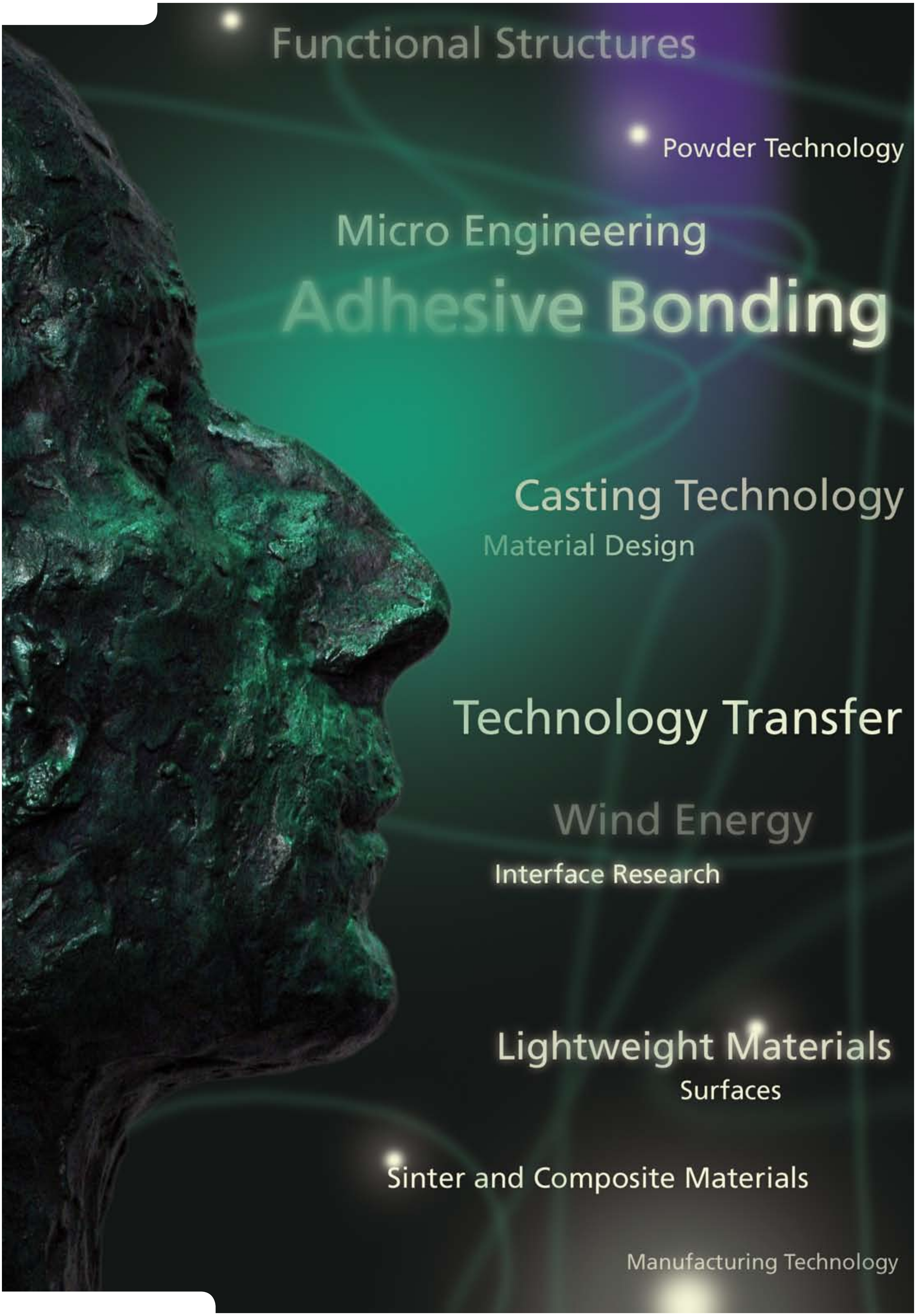
If we want to innovate more quickly, we have to network with potential partners in the field, moving beyond the borderlines of companies and organisations. The Fraunhofer institutes are ready to exchange their knowledge in networks in order to implement the High-tech strategy. The objective is to become the technology leader in the Bremen region by means of special innovations in the field of multi-functional materials and processes. This also means that firms and research facilities are open to new ways of bundling resources and crosslinking expertise. The Fraunhofer IFAM proposed the establishment of an FhG cluster of innovations entitled "Multifunctional Materials and Technologies".

This cluster of innovations aims to be a network linking small-, medium- and large-sized enterprises, as well as institutions from materials science. In this cluster, specific areas of research and associated manufacturing processes are to be addressed in the field of new materials in Bremen across business lines at the most advanced level. The R&D activities of the cluster of innovations are primarily addressed to the industries of aircraft engineering and space travel, automotive engineering, wind energy, shipbuilding and maritime engineering.

Prof. Dr. Matthias Busse.

Over five years, the Fraunhofer-Gesellschaft in association with the state of Bremen and the industry will sponsor this cluster. Afterwards, it should be self-supporting. Willi Lemke, Senator for Education and Science in Bremen, is strongly committed to these goals.

Senator Willi Lemke.


Functional Structures
Powder Technology
Micro Engineering
Adhesive Bonding
Casting Technology
Material Design
Technology Transfer
Wind Energy
Interface Research
Lightweight Materials
Surfaces
Sinter and Composite Materials
Manufacturing Technology

A Profile of the Institute

←
Joseph von Fraunhofer · Sculpture, bronze casting · by Florian Rödl, 1987

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 Portrait 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 subject areas and extended systematically, IFAM works closely with the University of Bremen. The directors of the institute are also appointed to a chair in the Production Engineering department of the University of Bremen.

The institute is located in Bremen, Bremerhaven and Dresden. Prof. Dr. Otto-Diedrich Hennemann joined the institute's senior management in 1994 and is the head of the Adhesive Bonding Technology and Surfaces department.

Prof. Dr. Matthias Busse took up his position in the institute's management and as head of the Shaping and Functional materials department in 2003. In April 2006, he became the executive manager of the entire IFAM institute.

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 of the non-profit organization Fraunhofer-Gesellschaft. At present, the organization maintains about 80 research facilities at more than 40 locations throughout Germany. A staff of approximately 12,500 employees – most of whom are highly qualified scientists and engineers – generate an annual research volume of more than 1.2 billion euros. More than one billion euros of this amount 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 2006 the overall IFAM budget amounted to approximately 24 million euros. The workforce comprised some 316 employees, 88 % 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

Professor Dr. Otto-Diedrich Hennemann
Managing director Adhesive Bonding Technology and Surfaces

Deputy director: Dr.-Ing. Helmut Schäfer

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

Andreas Heller
Head of administration

The Institute in Figures

Budget

The total IFAM budget (expenditure and investment) in 2006 comprised the budgets of the two departments of Shaping and Functional Materials and the Department of Adhesive Bonding Technology and Surfaces.

The provisional budget result was in total 24 million euros.
The results for the individual departments are shown below.

Shaping and Functional Materials Bremen

Operating budget	5.8 million euros
Own income	3.8 million euros
Including	
Business income	2.4 million euros
Federal/state/EU/other	1.4 million euros
Investment budget	1.6 million euros

Shaping and Functional Materials Dresden

Operating budget	2.8 million euros
Own income	2.0 million euros
Including	
Business income	1.2 million euros
Federal/state/EU/other	0.8 million euros
Investment budget	0.2 million euros

Adhesive Bonding Technology and Surfaces Bremen

Operating budget	11.8 million euros
Own income	8.3 million euros
Including	
Business income	7.3 million euros
Federal/state/EU/other	1.0 million euros
Investment budget	1.0 million euros

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

Operating budget	0.8 million euros
Own income	0.8 million euros
Including	
Business income	0.1 million euros
Federal/state/EU/other	0.7 million euros
Investment budget	0.05 million euros

Investments

During 2006, IFAM investments amounted to 2.9 million euros, split among the several departments as given below. The most important purchases are indicated.

Shaping and Functional Materials Bremen (1.6 million euros)
- Extruder system BRABENDER Plastograph
- Ink jet test bench
- MCP-KSA100 injection moulding equipment
- Rotational rheometer with peltier tempering unit
- Axio Imager M1 fluorescence microscope
- Casting system »the black side of Lost Foam«
- Low-pressure die casting system with handling unit
- Detector for X-ray equipment

Shaping and Functional Materials Dresden (0.2 million euros)
- Wire EDM system
- Starting hole drilling machines

Adhesive Bonding Technology and Surfaces Bremen (1.1 million euros)
- Light-optical microscope
- IR- and micro spot upgrade ellipsometer VASE
- Servohydraulic test system for statical and dynamical tests, max. test force ±15 kN
- UV excimer lamps
- AD linear plasma source
- Speed mixer
- Thermomechanical analyzer

Workforce

On 31 December 2006 IFAM employed a total of 316 people (88 percent of which in scientific/technical areas).
Compared to the previous year, the number of permanent employees rose by 10 percent.

Workforce structure 2006

Scientists	125
Technical employees	78
Administration/internal services and trainees	27
Ph.D. students, interns and auxiliary staff	86

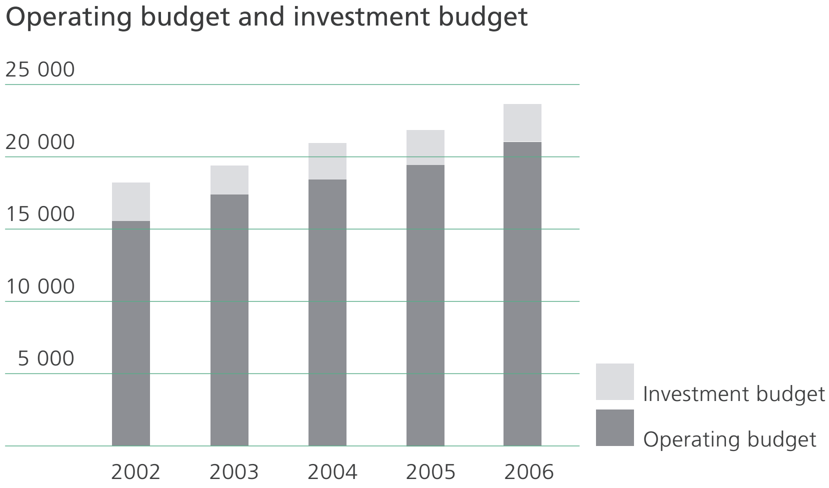


Fig. 1: Total expenditure of IFAM (BHH and IHH)

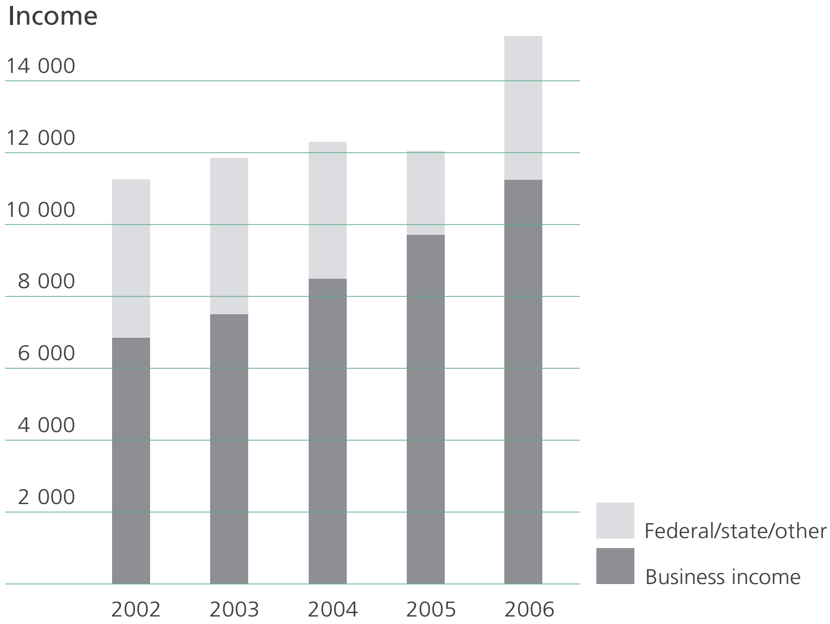


Fig. 2: Total income (BHH) of IFAM

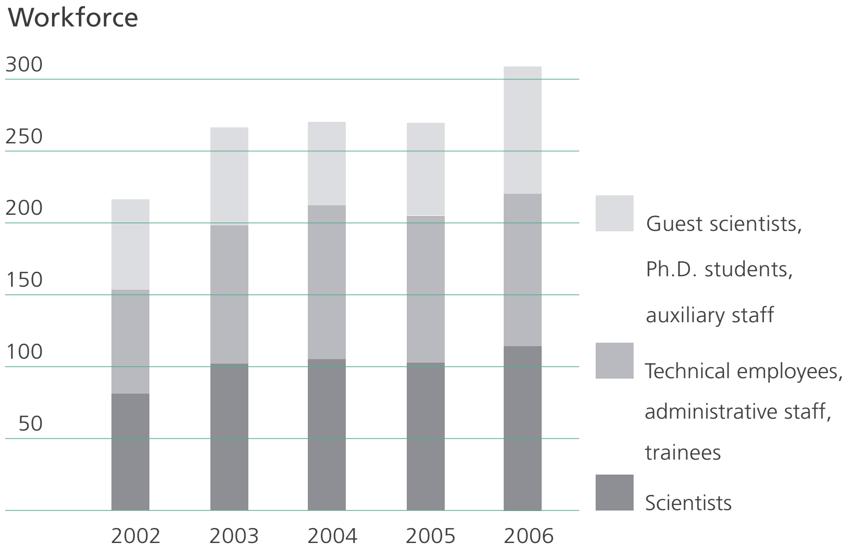


Fig. 3: Total number of employees at IFAM

The IFAM Advisory Board

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Research for Our Everyday Life

The Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) could scarcely have found a more appropriate slogan for this year's report than the following quotation by Jonathan Swift: "Vision is the art of seeing the invisible".

The ability to make fundamental research visions visible, understandable and available in conjunction with applied research for the collective good is what makes IFAM unique. Highly innovative ideas arising from the researchers' visions are put into action at IFAM.

The ability to think ahead is one of the strengths of the IFAM scientists. This can be clearly illustrated by the activities of the Bremen materials scientists in recruiting an Excellence Cluster in intelligent materials and components within the Federal and States' Excellence Initiative for Bremen. IFAM played a decisive part in this acquisition. The background of this activity is the involved scientists' visionary expectation that this crucial research will be the catalyst for an entirely new discipline in research and teaching at the University of Bremen. The whole field of Intelligent Materials and Components clearly reveals the vision upon which all research work is based. Generating "sensitive" or "self-reasoning" multifunctional products implies the potential to significantly advance materials science.

Another benefit is the joint strategy of the Bremen materials scientists who clarified their common strengths and worked out an innovative research program together.

From a strategic perspective, the co-operation between IFAM and the other Bremen materials scientists is explicitly desired and should be widely accepted. Thus, we may only hope that this application will be successful so that this collaboration can be further reinforced.
Even the second slogan of the Annual Report – "Treasures of research" – is illustrated by a variety of suitable examples associated with IFAM activities.

Professor Hennemann is to be especially thanked for having established the adhesive bonding technology, which has had only a shadowy existence in materials science for many years, as a real highlight. The department has achieved a worldwide reputation due to its outstanding R&D activities at IFAM as the greatest European autonomous research facility in the field of industrial adhesive bonding technology. More than 120 employees work in this domain at IFAM. Major enterprises from industry, such as Airbus and DaimlerChrysler, have been connected with IFAM by numerous co-operation projects for years. In the next year, we hope to find a successor for Professor Hennemann who is as reputable as a scientist and a visionary and is also as energetic and highly appreciated.

The report presented elucidates how important research is for our every-day life, and what opportunities and resources can result from research. Let us wish for IFAM that they might win many future employees as highly committed as those they have now, so that they may maintain their ability to make vision reality.

Dr. Göttrik Wewer, Privy Counsellor at the Senator for Education and Science.

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 12,500 staff are qualified scientists and engineers, who work with an annual research budget of € 1.2 billion. Of this sum, more than € 1 billion is generated through contract research. Two thirds of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Only one third is contributed by the German federal and Länder governments in the form of 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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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.

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Members

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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.

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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.

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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.

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Fraunhofer Network 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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Fraunhofer Network 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.

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Fraunhofer Network 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.

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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

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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.

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Pilot Series Production
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Aerospace Technologies
Medical Technology
Mechanical Engineering
Feasibility Studies
Automotive Industry
Micro Engineering
Systems Solutions

Department of Shaping and Functional Materials

Results Applications Perspectives

Expertise and Know-how

Transferring application-oriented fundamental research into solutions that can be implemented in production engineering or component-related development is a task demanding continuous improvement of the knowledge base and procedural competency. For this reason, the continuous expansion of the special expertise of the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research – Shaping and Functional materials – is a top priority. The following fields of core expertise are the basis for successful co-operation with our customers:

- Powder and sintering technologies
- Casting- and light metals technology
- Micro- and nanostructuring.

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 up to its implementation in a product and support aimed at introducing it into production.
Material combinations in one component play an ever increasing role in the complex requirements to be fulfilled by an intelligent component. For the expansion of expertise, designing these material combinations and dealing with them in manufacturing processes are major tasks.

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 have now succeeded in providing specific local areas on the component with distinct material properties. As a good example, the combination of magnetic and non-magnetic steel can be mentioned here.

This can also be implemented for micro component manufacturing, where additional micro assembly can be avoided as a result of these integrated manufacturing solutions. We not only deal with development projects for quality assurance of manufacturing processes for metallic miniaturised components, but also elaborate new interdisciplinary conceptual approaches in the range of micro reaction technology and bioreactors.

The "Functional printing" technology platform was enhanced with new printing options using the so-called Maskless Mesoscale Materials Deposition – M³D® – method. We determined formulations for functional inks and pastes, as well as the knowledge of their applicability to components. Thus, it has become possible to equip components with sensors and, in turn, to record e. g. operational- or environmental conditions.

IFAM has established itself on the market with state-of-the-art foundry equipment and analysis, as well as comprehensive know-how in processing aluminium- and magnesium alloys with pressure diecasting. In addition to casting process optimization for sophisticated components, our expertise has expanded most dynamically in the realm of the integration of piezoactuators and RFIDs into castings.

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

Perspectives

Our own portfolio of topics is steadily tuned to the requirements of the market, resulting in a new technological challenge. Here problems of product innovation under stringent economic marginal conditions 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 higher product complexity.

Material properties and technologies for structural and functional applications are tailored to the application and specified. To do this, high-performance materials, composites, gradient materials and "smart materials" must be developed, and manufacturing technologies to integrate the characteristics into the components have to be elaborated.

More in-depth materials expertise in the special areas of functional materials, such as thermal management materials, carbon nanotubes and nano-composites opens 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 the 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 improve the efficiency of component production.

An initiative for regional industrial growth of the BMBF and the Demonstration Center "Cellular materials" in Dresden offers the relevant preconditions to make available the full potential of porous structures even to small- and medium-sized companies. The innovative development in the Diesel particle trap domain, expedited by industrial project partners, demonstrates how we transfer basic research information into materials concepts and manufacturing technologies for marketable products up to production maturity.

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 supplementary expertise, as well as enterprises and medical partners. The tasks are related to e. g. antimicrobial surfaces, biocompatible metallic materials and manufacturing processes suitable for miniaturisation.

The wide potential of directly integrating functions into metallic components is being made accessible based on 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 be additionally developed.

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Bremen

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Cellular Metallic Materials
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Equipment / facilities

- Metal powder injection moulding units (pressure 20 t and 40 t)
- Production unit for micro injection moulding
- Hot press (vacuum, inert gas, 1800 °C)
- Uniaxial powder presses (up to 1000 t)
- Powder press for heat compaction (125 t)
- Extruding press (5 MN)
- Plants for rapid prototyping via laser sintering, stereolithography, fused deposition modelling, multiphase jet solidification and 3-D printing
- Cold chamber pressure diecasting machine (real-time control, pressure 660 t); hot chamber pressure diecasting machine (real-time control, pressure 315 t)
- Pilot plants for making metal foam components
- Twin barrel injection moulding machine
- Microwave sintering furnace
- Screen printing machine
- Model manufacturer for lost foam processes

Micro- and nanostructuring

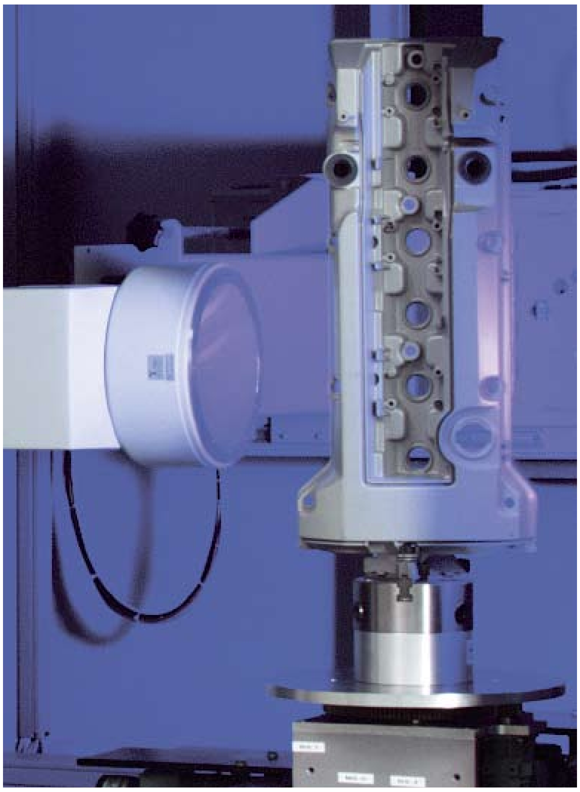
- Ink Jet Printing Technologies
- Aerosol Printing Technologies (Maskless Mesoscale Material Deposition M³D®)
- Micro injection moulding machine
- Four-point measuring station
- Particle size analysis
- Ink test stand – drop on demand

Thermal / chemical treatment of moulded components

- Plant for the chemical de-waxing of injection moulded components
- Various sintering furnaces (up to 2400 °C, inert gas, hydrogen, vacuum)
- Walking beam furnace

Synthesis and processing of materials

- Induction furnace for metal foams
- Plants for manufacturing gradient materials (sedimentation, wet powder injection)
- Plants for manufacturing metallic nanopowders and nano-suspensions
- Test rig for characterising functional inks for the ink-jet printing method
- Melt extraction unit (metal fibres)
- Centrifugal mill for high energy milling of metallic and ceramic powders (5–10 kg, also inert gas, vacuum)
- High speed mixing machine and shear roller for feedstock production
- Air classifier for classifying powders



X-ray tomograph.

Analytical equipment

- FEM scanning electron microscope with EDX
- X-ray fine structure analysis
- Insulation resistance
- Thermal analysis (DSC, DTA, TGA)
- Sinter- / alpha dilatometry (accredited laboratory)
- Powder analysis with BET surface area and laser granulometry
- Rheometer
- Trace element analysis (C, N, O, S)
- Materialography
- Emission spectrometer for elemental analysis of Al, Mg and Zn alloys
- Micro tensile testing equipment
- X-ray tomograph (160 kV)

Computer equipment

- High-performance work stations with software for non-linear finite element analysis, for simulating mould filling and solidification and for component optimization

Printed Sensors

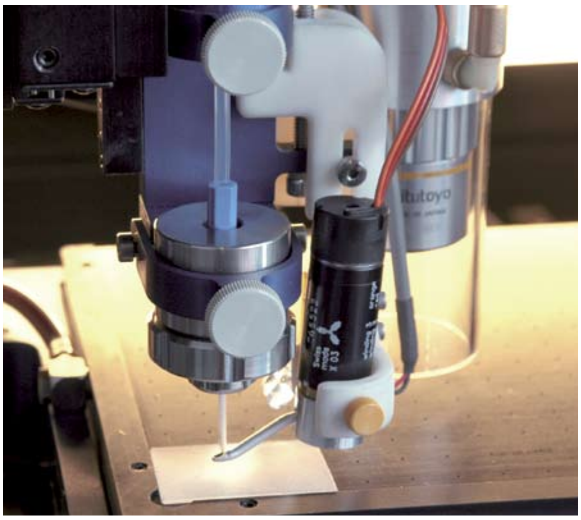
Background

Sensors are designed to record various physical parameters such as temperature or pressure. The sensor records the physical parameter and transforms it into an electrical signal. The ranges of sensors' application are manifold and steadily expanding. Apart from the classical business lines, such as the automotive industry, noteworthy ranges of application mainly arise from future technologies, e. g. Life Science and Structural Health Monitoring. Sensors produced in clean rooms by means of silicon technology are the state of the art. After manufacturing, the sensor is bonded via deposition- and connecting technologies and applied at the component, for instance by bonding. These post-production steps are very expensive in comparison with sensor production itself. Furthermore, it is impossible to place the sensors on some surfaces (e. g. curved surfaces).

A Fraunhofer IFAM employee producing a nanosuspension.

Challenge

A primary goal of the several ranges of sensor application is to get a representation of the environment which is as detailed as possible. This can be achieved by a high concentration of different sensors per surface, e. g. by miniaturisation of the individual sensors. Another objective is to ensure that the increased number of sensors does not result in higher component costs. This goal may be primarily achieved by direct contact, as well as applying the sensors to the component. 3D printing techniques, in which the sensor structures (sensors and circuit paths) may be immediately printed onto the corresponding component, provide this option. At Fraunhofer IFAM, not only are screen printing- and ink jet technologies available, but also an aerosol printing technology (Maskless Mesoscale Materials Deposition, M³D®). With this technology, it is possible to print nanoscale materials with an aerosol jet.



Print head of the M³D® system.

In the production or application of sensor structures, the M³D® technology offers some advantages over conventional techniques. The M³D® technique makes it possible to print the sensor structures immediately on the component so that additional assembly or bonding steps become unnecessary. Furthermore, it is possible to apply the sensor structures to all components (heat sensitive, planar, complex geometry) so that we are very flexible in design. Another plus is that this is a maskless technology enabling easy structural changes (Rapid Prototyping). The high level of miniaturisation is achieved by line widths of up to 10 micrometers resolution.

Motivation and Goals

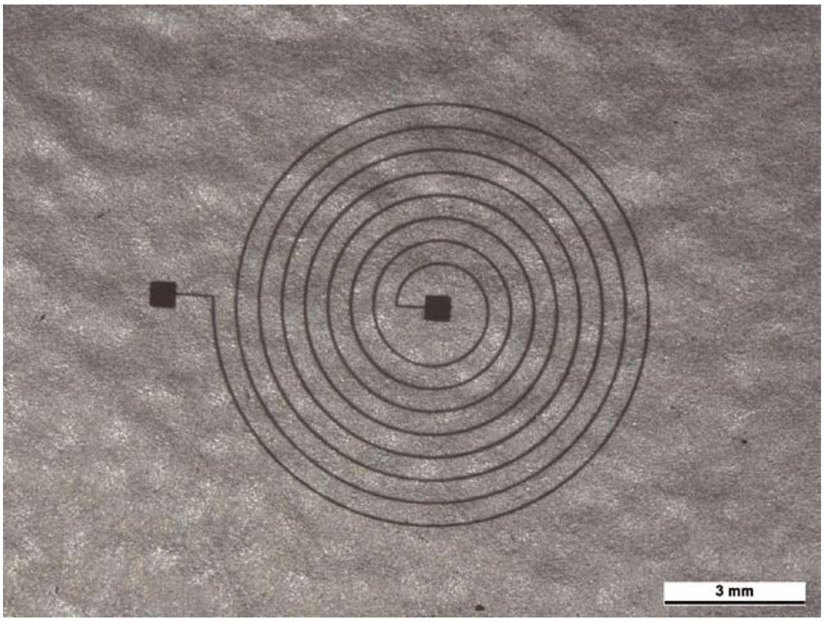
The aim is to apply sensor structures on arbitrary surfaces with various printing techniques. In this project, we track two intents: First, to use the low-cost application of sensor structures to classical components or surfaces, e. g. strain gauges on metal or plastic; and second, to develop sensor structures on new materials or surfaces in order to discover new ranges of application. These might include, for instance, the application of sensor structures to textiles or surfaces and components with sophisticated geometry.

To produce the sensor structures with ink jet- and M³D® techniques, it is first necessary to specify a so-called functional ink, which consists of a nanoscale functional material (e. g. metal), a liquid (e. g. alcohol) and a stabiliser, if necessary. In this context, the inks' stability with regard to sedimentation and agglomeration is decisive.

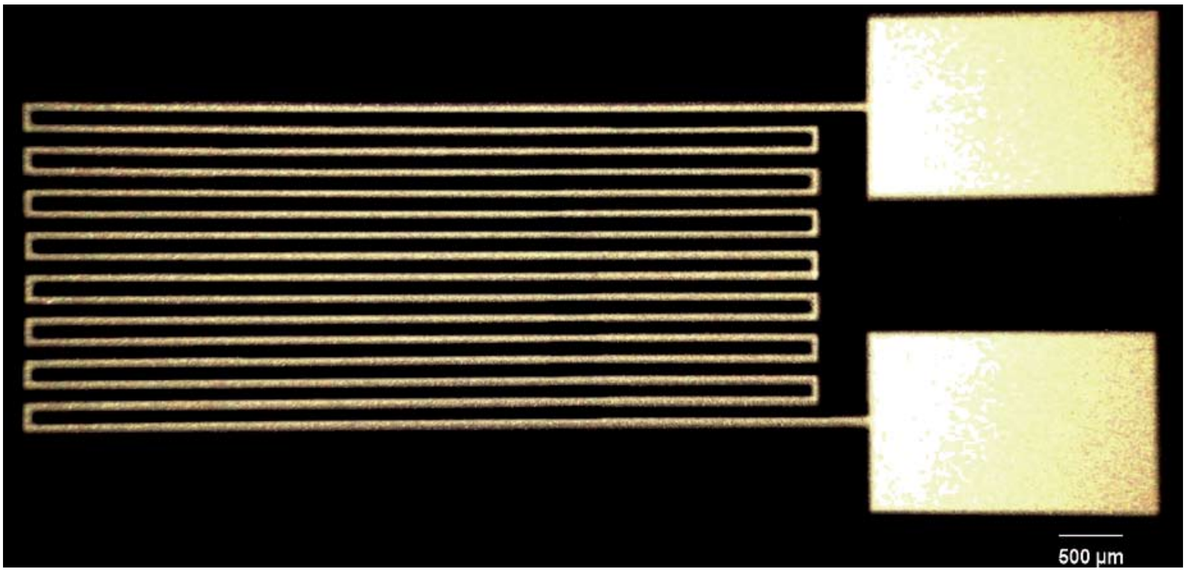
Afterwards, by M³D® technique, the ink is atomised and thereby transformed into an aerosol, and then guided to the substrate with a focusing gas. The structure is defined by a CAD file. This way, the structure can be dimensioned as flexibly as possible. After printing, the structure can be laser-sintered to achieve the desired functionality (e. g. conductivity). In sintering, it is relevant to optimally adapt the laser's energy deposit to the printed material and, more importantly, to the substrate surface. The sintering effect is influenced by the laser energy and the speed of the laser motion.

Current Projects

We succeeded in producing and printing the first functional inks for the ink jet- and M³D® technologies. Initially we used conductors (among them silver and copper), since these materials are crucial for the manufacturing of sensor structures. We succeeded in applying this material not only to planar surfaces, but also to surfaces with sophisticated geometry. To determine resistivity, four-point-measurements were carried out. The initial measurements proved that the M³D® technology is able to generate conductive structures. In another achievement, we printed the first sensor structures onto various substrates by means of M³D®.



Printed antenna (silver).



Printed strain gauge (copper).

Outlook

The future in the printing of Functional Materials provides a wide range of potential technological use. One trend leads to refining the inks and expanding the assortment of materials which can be used for printing. Another effort is aimed at printing both miniaturised and low-cost sensor structures, as well as complete sensor systems with the ink jet and M³D® technologies. This means that we not only apply the intrinsic sensor and contact, but also the passive components and the power supply to the component. This way, several process steps, such as sensor production, bonding, application of passive components etc., are carried out simultaneously or with one technology, thereby saving additional costs. The printing of biological materials, e. g. in the field of Tissue Engineering, is another range of application.

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Perspectives on Foam – Lost Foam

Background

From the time he took office as the managing director of Fraunhofer IFAM's department of Shaping and Functional Materials, Prof. Busse has regarded the introduction of additional innovative procedures in the various areas of expertise as a central part of his strategy. In the field of casting technology, he has already developed the vision of establishing the Lost Foam technique, which is one of the latest and most advanced casting methods. In this technique, each later casting is initially made from either expandable polystyrene (EPS), expandable polymethyl methacrylate (EPM-MA) or a copolymer. This model is fitted with a runner, which is also made of foamed material, and coated with a ceramic back wash. Afterwards, the nest is inserted into a flask and embedded with sand. In contrast to conventional casting techniques, the embedding sand, frequently glass sand, is free of binder and pourable. Flask vibrations during sand input ensure that the sand is fluidised, runs into all cavities and undercuts of the single models, and is compacted. Thereby, something like a mould is formed around the model. Intrinsic casting is performed in the next step. The metal melt is put onto the gate, where it decomposes the foamed material, directly fills the emerging cavity and exactly replicates the model. The flask is emptied after solidification, and the sand oozes out of the casting cavities without additional mechanical support. With this strategy, it is possible to synthesize simple model segments into highly sophisticated models without any wear on the foaming moulds. Another advantage is that we can work without drafting angles, thereby reducing weight according to lightweight construction. Simultaneous casting of multiple parts results in higher productivity, and removing the cores becomes unnecessary. The technique is already in use in series processes in order to produce aluminium, cast iron and steel components of difficult geometries.

Fig. 1: Molten bath (courtesy of Dr. H. Pleteit).

Fig. 2: A Fraunhofer IFAM employee at the prefoamer.

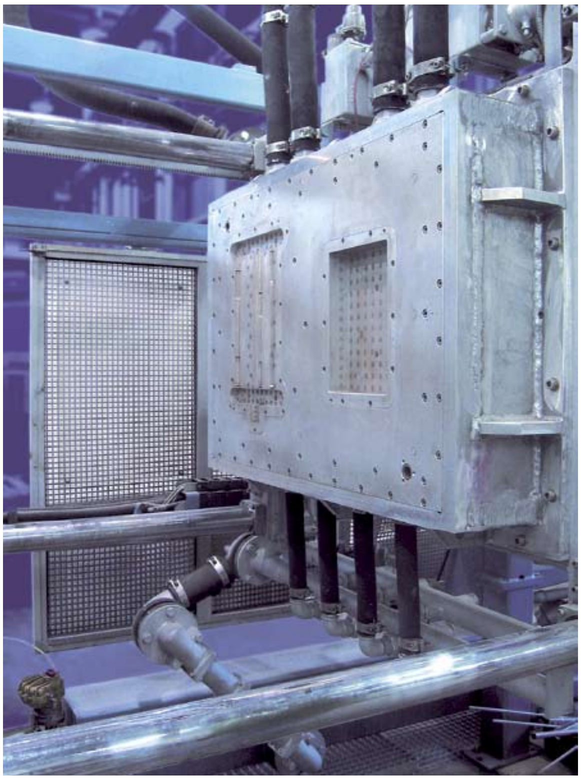

Fig. 3: Final foamer of the K710 LF type by Kurtz.

Equipment to implement the first part of the process chain, which includes the production of the polystyrene model, was installed at IFAM in 2006. This first part of the foaming technology is also known as the "white side". In this installation, the focus was on establishing a truly state-of-the-art system, and one which can be used for explorations under near-industrial conditions. We installed a prefoamer by Vulcan (Fig. 2) and a final foamer of the K710 LF type (Fig. 3) in co-operation with the Kurtz company at IFAM.

The equipment with its ample moulding space is able to foam even cylinder heads and engine blocks. We installed a rapid steam generator of 400 kg/h steam generating capacity by Loos to supply the required saturated steam. We put a three-cubic meter steam accumulator between the steam generator and final foamer in order to make available dry steam during the process cycles. In these extension installations, we focused on optimal dimensioning and high efficiency for environmental reasons. The emissions of the gas-driven steam generator were accordingly conducted through a heat exchanger and utilized to preheat the feeder water.

The apparatuses described above prove that the "white side", the production of the polystyrene model, at IFAM has reached a common standard in terms of its technical level, as well as equipment size. In 2007 we will add to and complete the production of the polystyrene model (the white side) with the casting equipment and procedure called the "black side". We will install a vector Flo® compressor table (Fig. 4) with four flasks in co-operation with the company Vulcan Engineering Co.

The size of the flasks is 8,000 x 8,000 x 10,000 mm. One flask is equipped with a glass plate. Through this plate, we can explore the sand compression procedures and visualise mould filling. The "black side", the casting equipment, will be designed to be very flexible so that various moulding materials can be used.

Outlook

For IFAM, it makes sense on many counts to establish this innovative casting procedure:

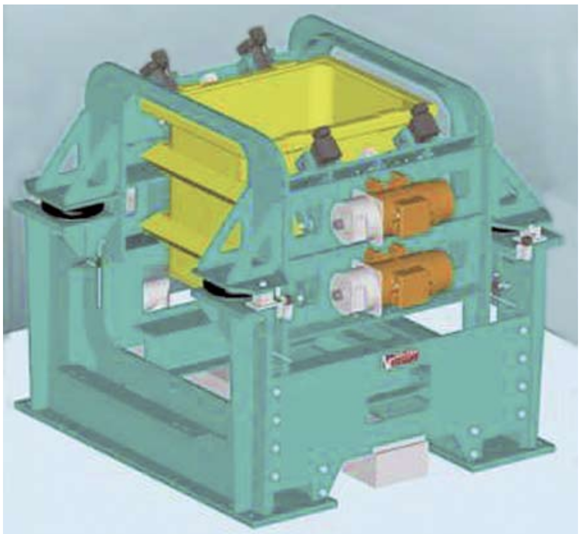

Abb. 4: Vector Flo® compressor table.

- The technique has not yet achieved wide distribution in Europe up to now, but it is successful in use for aluminium, iron and steel parts. The latter is impressively demonstrated by, for instance, the six-cylinder head by BMW. Consequently, exploration of this technology implies a great future potential for IFAM.

- In Europe, IFAM has in hand a unique selling point with the machinery described.

- The technique conforms extraordinarily well to the institute's strategy for the casting department, which is aimed at the investigation of innovative, sophisticated, as well as functionally integrated, components.

- Given the two central subjects of this technique – the "white side" and the "black side" –, this method complements existing IFAM polymeric engineering know-how in the production of the polystyrene model, as well as casting know-how in the "black side" area. Even today, IFAM possesses an almost unique analysis system for the "white and the black side". The new method means that the available machinery and know-how can be used to a wider extent and that they tightly connect the individual areas of competency.

A project on Lost Foam by order of the Lost Foam Council e. V. is already in progress at this time; even though the machinery is not yet completely installed. Here, to secure the quality of model-building, we are exploring a non-destructive method of determining the foamed models' density. These activities provide a targeted use of the machinery immediately after commissioning of the "white side".

Future research objectives

From our current perspective, future research projects aimed at the Lost Foam Technology have to fulfil different requirements from industry, such as:

- Increasing strength of aluminium castings
- Enhanced anticorrosive characteristics of steel castings
- Using alternative materials for models
- Better quality assurance of model building.

To speed up this procedure, we want to achieve cutting edge expertise in co-operation with our partners from industry. Another objective is to expand the casting technology domain of expertise as a development platform for sophisticated castings with functional integration.

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Advanced Protection Systems (APROSYS) for Higher Safety on European Streets and Highways

Project

According to EC statistics, about 40,000 people die each year on European streets, and 1.7 million people are injured. So it is not amazing that this topic and the costs arising from these numbers are considered particularly important by society and the EC promotion of research. New dimensions in the budget were determined for corresponding projects within the scope of the 6th Frame Program for Research: APROSYS, as an "Integrated project" (IP) has a budget of about 30 million euros (promotional grants 18 million euros, project period: April 2004 to March 2009), split among more than 50 partners, managed by TNO (NL). This project is embedded into a greater »Integrated Safety Programme«, supported by, among others, the EUCAR (Association of European car producers). The Safety Programme connects projects with similar budget on related topics, such as active safety. In this context, APROSYS at present represents the central research effort of the European Community aimed at enhancing passive safety in road traffic. This concerted action goes back to the European Vehicle Passive Safety Networks, of which Fraunhofer IFAM, with its responsibility for material problems, has been a member from the beginning.

APROSYS itself is subdivided into 9 subprojects (Fig. 1), whose subprojects No. 1 to 4 are dedicated to specific accident scenarios. Four additional subprojects dealing with cross-sectional topics exist autonomously and have corresponding research subjects, but they are simultaneously available to support the work of the subprojects 1 to 4. Fraunhofer IFAM is involved in subproject 2, which is aimed at minimizing accident consequences for car passengers in collisions with lorries, and in subproject No. 7, on the acquisition of basic knowledge and technologies for virtual testing methods. The total budget of the Fraunhofer IFAM in this project amounts to approx. 340,000 euros, split between the subprojects 2 and 7 to 40 % and 60 %.

Assignment and results

Up to now, activities have been concentrated on subproject No. 7 with the focus on enhancing the materials' and structure deformation simulation in crashes. Aluminium foams are innovative materials characterized by high energy absorbance. They have a great potential to increase crash safety. For this reason, aluminium foams were subject to detailed exploration in subproject No. 7. As a team,

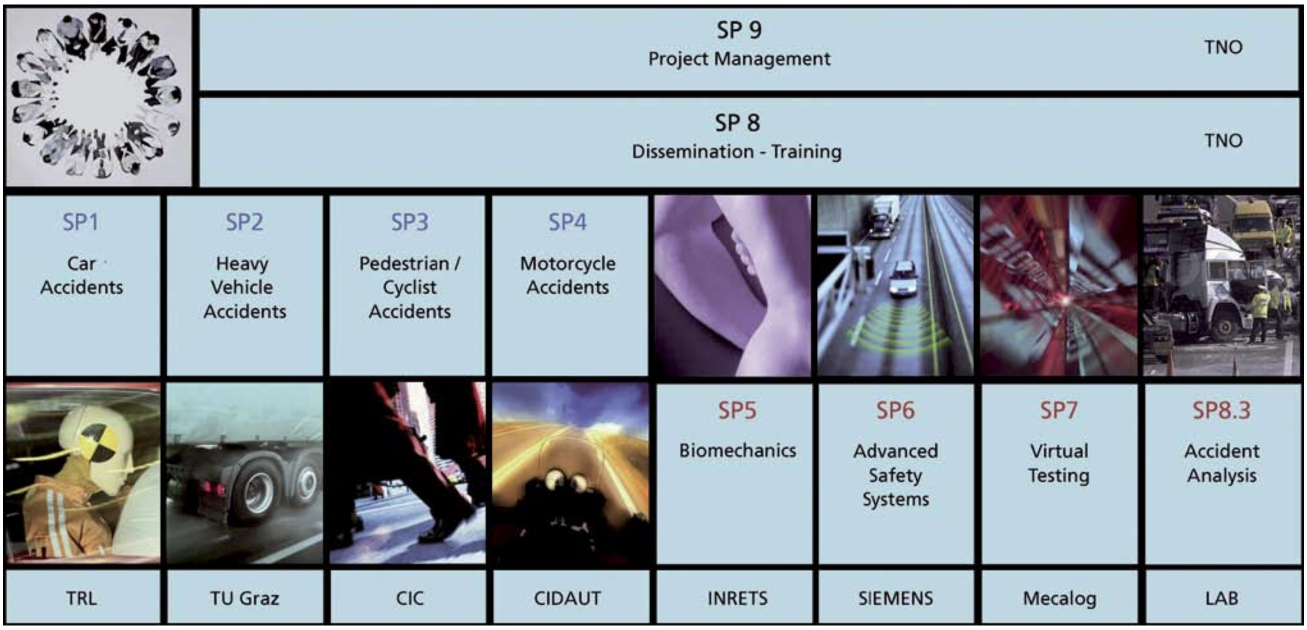

Fig. 1: APROSYS project structure – subprojects and subproject managers (www.aprosys.com).

Fraunhofer IFAM and the Politecnico di Torino represented by Prof. G. Belingardi, Prof. M. Avalle and Dr. L. Peroni, established a test program for this material group, and, within this class, for the AlSi7 foams, produced by the Fraunhofer technique. When running and evaluating this program, it should be possible to redetermine the parameters for various established material models for FE simulation, as well as to assess these material models. Additional measurements were carried out to determine typical density variations inside the foams and to estimate how they affect on the dispersion of global material characteristics.

The test matrix first of all includes axial and hydrostatic pressure tests necessary to verify the parameters of the Deshpande/Fleck model as well as the ABAQUS "Crushable Foam" model. Moreover, we performed not only tension- and torsional tests, but also axial compression tests with superimposed hydrostatic strain. The last three types of tests were designed to find out whether the types of failure surfaces given by the material models are really able to exactly reproduce the material characteristics, on the assumption that parameterisation was only based on the axial and hydrostatic tests. Earlier studies were frequently related to other types of metallic foams, and they do not span the entire technically relevant density spectrum, which is about 0.3 to 0.8 g/cm^3 for this material variant.

Analysis of the material properties as a function of the strain rate by means of compression tests was another aspect of the project. To do this, in addition to quasistatical tests, classic dynamic tests with a drop weight, as well as highly dynamic tests with a so-called Split Hopkinson Pressure Bar (SHPB) were performed in conventional setup and in the configuration by Taylor. This way, it was possible to achieve test speeds from 10^{-4} to $>10^3$ m/s. The final conclusion was that, independent of density, no relationship with strain rate has to be considered.
Figure 2 elucidates stress-strain curves for the three central load cases. We determined strength values or proof stresses as a function of density using these curves. The notation of these relationships follows (is oriented to) the approach by Gibson and Ashby ($R_p = C \cdot p^n$). The boundaries of the failure surfaces for varied density values (see Figures 3 and 4) are based on the approximations found in this way. Figure 3 describes the general form with predefined k_f ratios between hydrostatic tensile strength and compressive strength (0.1 for the ABAQUS "Crushable Foam" model, by definition 1 for the Deshpande/Fleck model) for both models considered on the basis of two density values.
By contrast, in Figure 4, the k_f value was modified with the objective of achieving an accurate representation of the axial tension tests ($k_f = 0.45$). Comparing simulation and experiment, we see

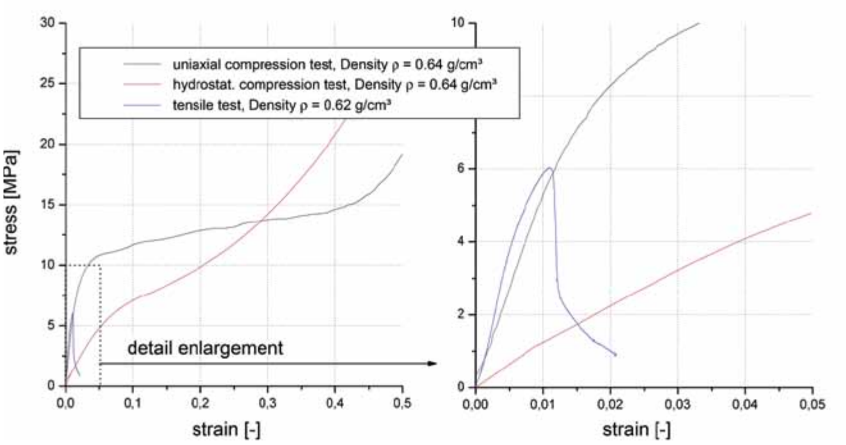

Fig. 2: Examples of AlSi7 foam stress/strain curves tested under uniaxial compression, in hydrostatic pressure testing and in the tension test.

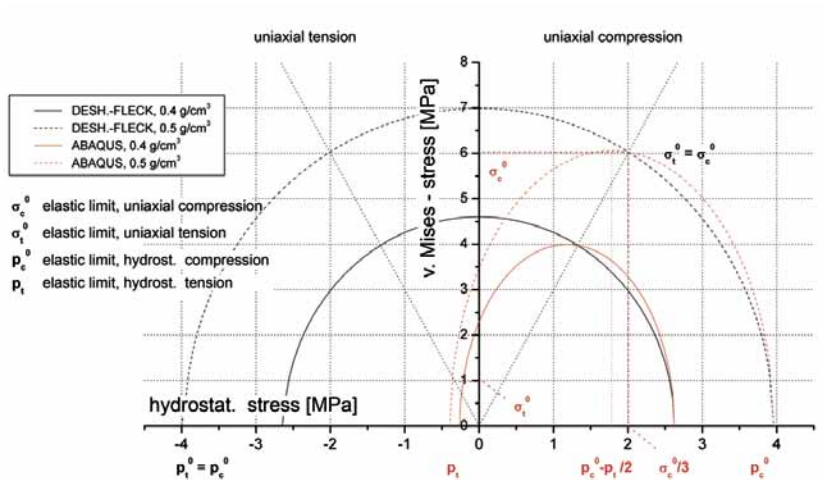

Fig. 3: Yield surfaces according to the Deshpande/Fleck- and ABAQUS "Crushable Foam" model from uniaxial and hydrostatic compression tests.

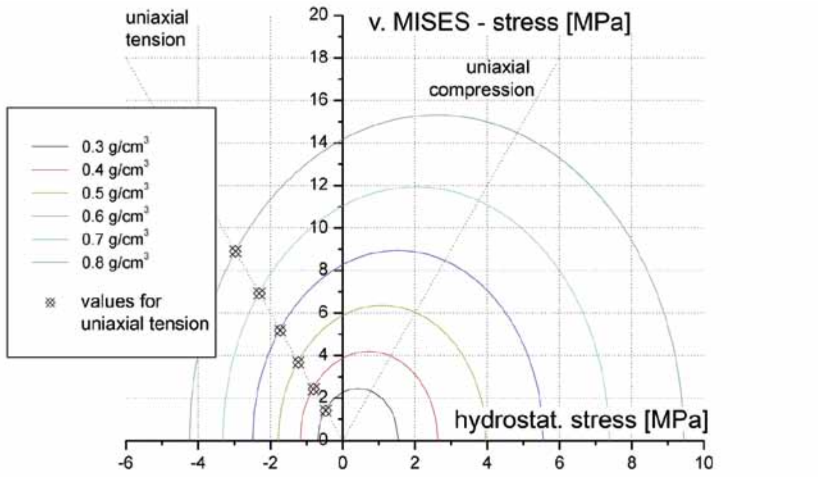

Fig. 4: Yield surfaces according to the ABAQUS "Crushable Foam" model under additional consideration of tension tests.

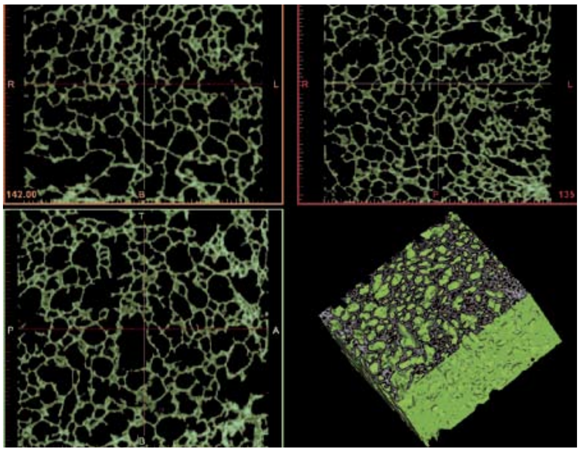

Fig. 5: Inner structure of a foam sample, created using computer tomography sections and 3D reconstruction (reverse

that both broadly coincide for load cases dominated by compression. Evaluation is ongoing.

The estimation of how the statistic density distribution influences the material properties has not yet been completed. As a first step, we determined the internal structure of several samples with computer tomography (Fig. 5). Second, we derived approximation formulae for systematic density deviations (boundary layers, drainage) and statistic local density derivations. In parallel, we engineered software to be used to allocate the FE models of simple samples to the density variations coping with the statistic distributions found. Our next step will be to use this instrument to run a stochastic simulation program, which will give us a conclusion on the strength variance resulting from different characteristics of the density distribution in the material. Afterwards, this variance can be compensated with the variance found in the experiment. These studies should contribute to defining sound safety factors for the dimensioning of aluminium foam components.

Summary and Outlook

We expect to integrate the results of the investigations carried out under subproject 7 immediately into the development of sidewise underrun protection systems for lorries (planned in subproject No. 2). The results obtained and the conclusions drawn from them will be disseminated in scientific publications. The activities described show that Fraunhofer IFAM itself is substantially ahead in its efforts and capability to simulate aluminium foams. Bilateral co-operation with the Politecnico di Torino on this subject will continue beyond the APROSYS project. This collaboration is, among others, aimed at simulating the APM structures' characteristics – a new generation of aluminium foams.

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Gas-phase Synthesis of Intermetallic Alloys Acting as Catalysts

Background

Raney nickel is a commercial material that is not only indispensable as a heterogeneous catalyst for the synthesis of various hydrocarbons, but is also a promising material for layers that oxidize hydrogen in alkali fuel cells. On an industrial scale, the nanoporous Raney nickel is made by leaching aluminium out of a powdery intermetallic nickel-aluminium basic alloy. The specific surface typically ranges from 50 to 70 m^2/g. A certain percentage of residual aluminium, which remains alloyed in this procedure, as well as additional transition metal additions influence the activity and selectivity of this catalyst material. Investigations carried out within the scope of an integrated EC project aim at significantly refining catalyst characteristics of Raney nickel in order to find low-cost alternatives for catalysts that oxidize hydrogen in alkali fuel cells. Here, nanoporous layers based on nickel synthesized from the gas phase are intended to function as a "benchmark", since this is the only way it is possible to get a similarly refined, i. e. nanostructured nickel-master alloy like Raney nickel without residual aluminium.

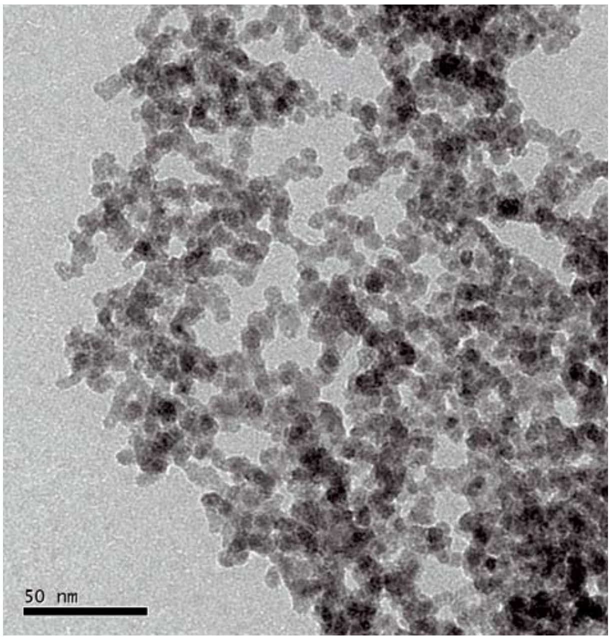

Fig. 1: Highly porous nickel-chromium powder – made by sputtering in argon.

Fig. 2: Typical agglomerate structure of metallic nanoparticles formed at evaporation in an inert gas atmosphere (here: Silver in helium).

Project

For the subproject »Benchmark experimentation«, IFAM has to obtain nanoscale nickel master powders in defined composition in an inert gas atmosphere and to explore how a shortterm thermal treatment (radiation-induced) acts on its morphology. Radiation like this should e. g. enhance the nanoparticles' cohesion in the agglomerate's bond by the sintering effects induced, without significantly reducing their specific surface. To optimise the synthesis conditions, it is intended to use various microgravitation platforms, such as the parabolic flight, co-ordinated by the European Space Agency (ESA). Using these microgravitation platforms, it is possible to effectively eliminate convection and sedimentation effects which would be unavoidable under laboratory conditions due to the high evaporation temperature used.

To do this, it was necessary to build an experimental setup capable of parabolic flying, in order to evaporate molten baths in helium, and to heat in situ the nanoporous agglomerates formed hereby with a radiation source. We plan to collect the powder immediately afterwards, and in a precise manner that will make it possible to analyze later individual agglomerates modified by radiation.

Project Description and Results

A specially built experimental setup was successfully shown to be generally suitable for use within the scope of the 43rd ESA parabolic flight campaign in March 2006. We succeeded in performing evaporation tests of the silver (model material) in helium at reduced pressure under microgravity. The metal agglomerates move without convection and homogeneously. However, we still had problems with the high evaporation temperature of about 1,800 °C that was necessary to evaporate nickel alloys to a sufficiently high extent. Here it is absolutely necessary to refine the evaporator – presumably by inductive heating. Another test series, in which a radiation source is integrated in addition to the in-situ heating of the metal agglomerates, is planned for the end of 2007.

Fig. 3: An A300 unit run by Novespace in Bordeaux; it enables tests of 20 seconds each to be run in 30 consecutive parabolas under near-microgravity (typical value ±0.02 g) for about 15 different experiments. Top: The fearless researchers; Middle: A300 ascending ("injection phase"); Bottom: IFAM test equipment (Fig.: Courtesy of ESA).

Client

Supported within the 6th EU Framework Program as an "Integrated Project" with over 40 additional partners: »IMPRESS« – Intermetallic Materials Processing in Relation to Earth and Space Solidification
Duration: November 2004 to September 2009
Co-ordination: ESA, Noordwijk (Niederlande)

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Bremen

Materials for Cooling of Electronics

Background

Increasing density of integration and power input of electronic semiconductor components in power-, micro- and optoelectronics demand efficient materials and approaches to effectively discharge the lost heat emerging inside the component. Optimal »thermal management« makes possible a high standard of reliability, as well as ensures the long life of the electronic components. In addition to optimized package design, it is necessary to implement refined additional cooling by using highly efficient passive conductors or enhanced active components.

Passive cooling demands materials with the greatest possible heat conductivity and low thermal extension, such as could be employed in the electronics packaging. Metallic material composites (MMC) provide a promising approach to solving the problem. Aluminium reinforced with silicon carbide is regarded as a reference material, since it has until now sufficiently fulfilled the aforementioned requirements of 200 W/(mK) thermal conductivity and a coefficient of thermal expansion ranging from 6 to 8 ppm/K up to now. However, still higher thermal conductivity values may be required in the future.

The disadvantages attached to active units (cooling by ventilators or cooling units) include limited life and reliability, as well as noise pollution and space requirements. The alternative on the current mass market are the so-called »heat pipes«, which are limited at present by their high cost. Thermoelectric components are another active cooling method. These components are very interesting, due to their simple functionality, robustness and compact design, long life, and insensitivity to vibrations. A major use of peltier elements consists in active cooling of "hot spots" in electronic or optoelectronic components, such as laser diodes and processors. To do this, one needs miniaturised peltier elements of very high arearelated refrigeration capacity (about 300 W/cm^2), which can only be used in components made of new materials with a high thermoelectric quality ZT.

The Challenge

The desired increase in the conductivity of composites should be made possible by replacing aluminium with a matrix of higher conductivity, that is, copper or silver, or by inserting second phases of higher conductivity or reduced expansion, e. g. diamond, C-nano fibres, pyrolytic carbon. In combination with a low coefficient of thermal expansion, thermal conductivity values markedly higher than 400 W/(mK) could be feasible.

In all material combinations, the interface between the metal matrix and reinforcement phase is particularly important. Given a very low interface resistance, the range of variations for the

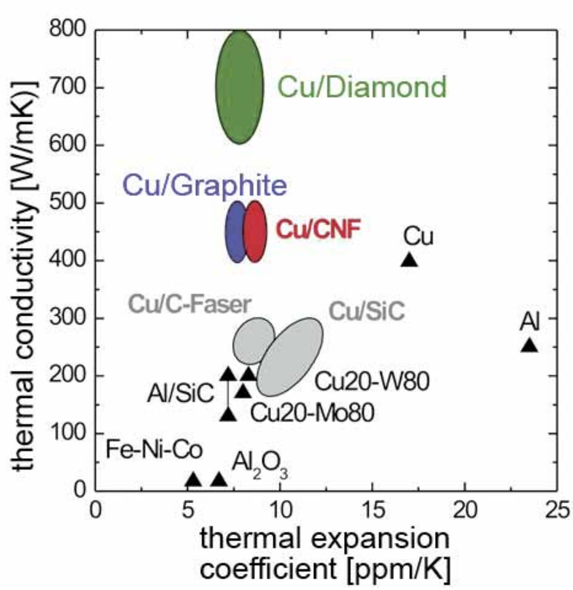

Fig. 1: Selected development objectives of new composites for heat sinks in comparison with traditional materials.

type and size of the second phase is hardly limited at all, on the one hand. On the other hand, however, the transmission of stresses to reduce the coefficient of thermal expansion requires a sufficient bond between matrix and second phase. The quality of the corresponding materials, specified by their thermoelectric quality ZT, is crucial for thermoelectric cooling applications. Materials whose ZT > 1 are commonly called high-ZT materials. New results from materials research have demonstrated that nanostructuring may offer new options to increase efficiency for thermoelectric materials. If we succeed in manufacturing these highly efficient materials as solids in larger quantities by means of Spark Plasma Sintering, then we will have available more effective peltier cooling units which can also be produced more cost-effectively in the future.

Research Potential and Current Projects

Current activities at IFAM Dresden are focused on the use of highly conductive reinforcement phases, such as diamond and highly graphitised carbon systems (C-nanofibre/VG-CNF, C-micro fibre/VGCMF) and natural graphite in copper composites. Due to the bond characteristics of the carbon atoms, diamond and graphite have thermal conductivity values from 1,500 to 2,000 W/(mK), whereas the coefficient of thermal expansion ranges from 0 ... 1 ppm/K. The characteristics of particle composites are more or less isotropic. In contrast, in the case of graphite materials, it should be possible to achieve anisotropic parameters in terms of heat conduction and thermal expansion by means of vectored consolidation methods. Composites with vectored cooling characteristics will also be more important in future electronic applications of three-dimensional package structures.

Previous explorations carried out with the copper/diamond system with more than 40 percent diamond per volume demonstrate the feasibility of thermal conductivity values of more than 600 W/(mK) with a reduced coefficient of thermal expansion of less than 10 ppm/K. Here, optimal interfaces are designed using a chromium- or boron-carbide formation, since it is necessary to maintain parameters within a technological and alloy-technical range of constraints.

We succeeded in elaborating an appropriate process to manufacture homogeneous copper powder/fibre mixtures out of copper/C-nanofibre composites. To utilize the highly graphitised materials in an optimum manner for the material composites, we apply hot pressing, hot isostatic pressing and extrusion in conjunction with the material systems copper/graphite and copper/C-micro fibre.

Evaluating the first investigation results, these graphitic copper-composites proved to be excellently machinable; however, their thermal conductivity

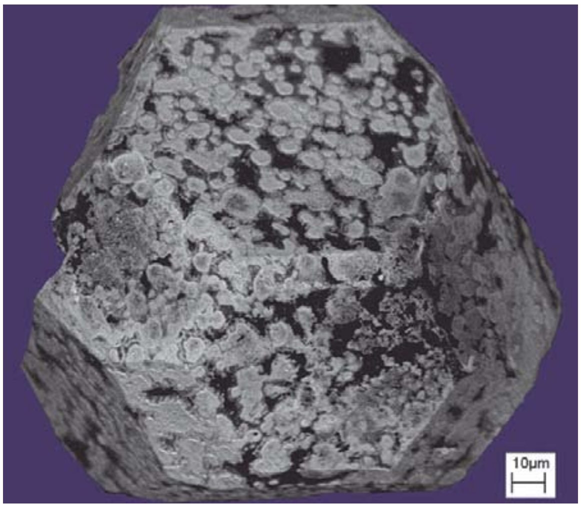

Fig. 2: Carbide formation to shape the interface in copper-diamond composites (REM recording [BSE signal] of a diamond after removal from the CuCr-diamond composite).

values are greater than 400 W/(mK) with a coefficient of thermal expansion from 7 to 8 ppm/K in two-dimensional orientation of the reinforcing component. Overcoming these obstacles in order to profitably apply thermoelectric materials in electronic cooling is the subject of the current project WISA "Nano-TEC" in alliance with the Fraunhofer Institute for Physical Measurement Techniques IPM in Freiburg and the Fraunhofer Institute for Integrated Circuits IIS in Erlangen. Thermoelectric solid materials can be Spark Plasma Sintered (SPS) from modified Bi_2Te_3 powders (with n-and p-doping). The quality parameters of these solid materials already exceed the corresponding performance of materials available at present and at the same time they are also stronger.

Optimization of these materials and of the sintering technique for producing polycrystalline thermoelectrical material is still to be done, since all of the currently available materials are used as a mono-crystal.

Implementation and Outlook

The IFAM Dresden is performing R&D activities on fibre- and particle-reinforced copper-composites in several joint projects (CuCNF/BMBF, ExtreMat/EU). The materials developed already fulfil the thermophysical requirements of the involved final users now, so the plan is to build initial demonstrators for electronic applications with these composites and to test them comprehensively in the near future.

In all metallic composites, the design of the interfaces between the matrix and the reinforcing component and their influence on the thermophysical or -mechanical properties, including their durability under cyclical thermal stress is of central scientific and technological interest. Systematic and fundamentally oriented explorations of this problem are now being prepared in co-operation with the Dresden University of Technology and the Leibniz Institute for Solid State and Materials Research IFW Dresden.

Last but not least, there is also a tremendous demand for innovation and development in terms of interface materials with higher conductivity, designed for the thermal contact between the electronic component and the dissipater. These transitions, which are more and more considered to be the Achilles heel in modular structure, will be integrated into future R&D work on thermal management at the IFAM Dresden.

The WISA "NanoTEC" results of a procedural implementation of the nano-scale thermoelectric concept may open up future additional acquisition options in all those market segments for which targeted nano-engineering is a promising approach (e. g. high-temperature light metals, magnet materials).

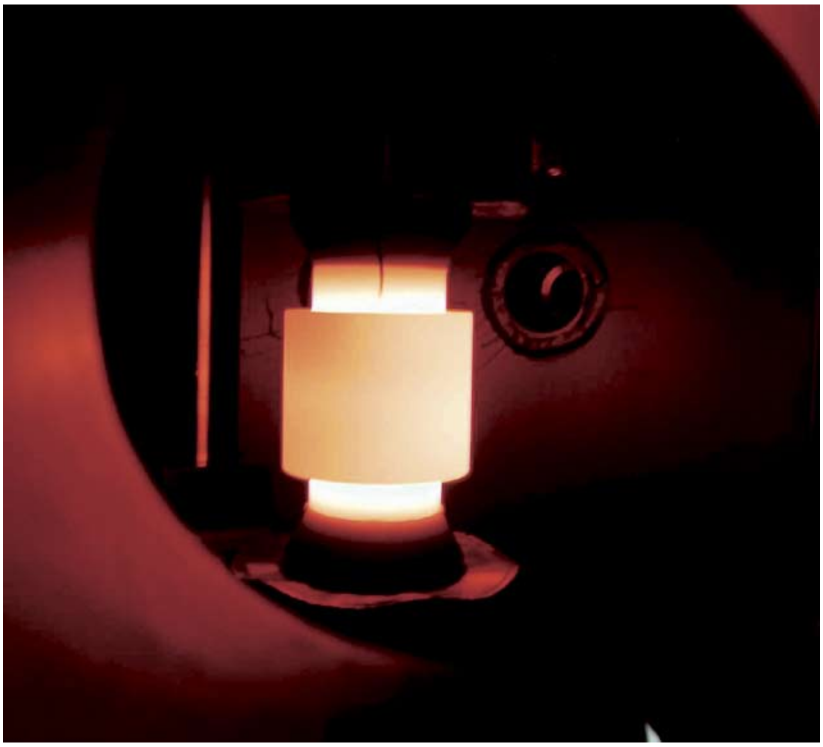

Fig. 3: Spark Plasma Sintering technology.

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Metallic Screen Printing as a Manufacturing Technology to Build Three-dimensional Microstructured Components

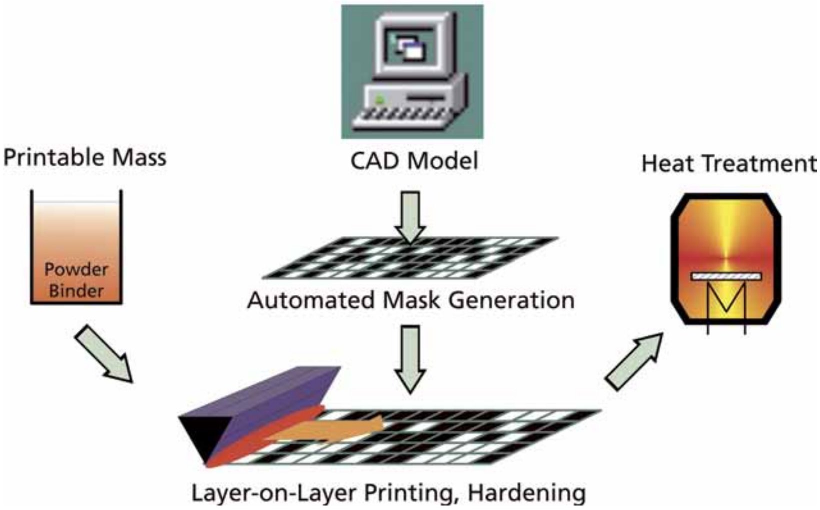

Fig. 1: Screen printed metallic structures – manufacturing principle.

Background

In recent years, miniaturisation and functionality in microsystems technology have been able to make significant progress. However, many areas demand a type of manufacturing technology which makes possible a profitable implementation of highly specific components for final use. Particularly in the techniques used up until now, it is frequently impossible to combine feasibility in three dimensions with component quality and large part quantities. In many areas, low-cost procedures that are simultaneously suitable for large series are lacking. Procedures like these could propel a breakthrough in costs, e. g. in the production of compact fuel cell stacks. It is also true that, in order to break into new areas of application, we need a technique with free-forming capability for many domains, such as medical engineering or the designing and building of special-purpose machinery.

To overcome this obstacle, Fraunhofer IFAM began a co-operative effort with Bauer Technologies and developed with them an innovative series process suitable for mass production. With this procedure, small metallic precision components can be made in large quantities. This method is based on a patented screen printing technique for ceramic structures, which has provided components of up to 150 mm height up to now.

Technology

In the variant used at IFAM, a suspension of metal powder and organic binder is screen printed onto a substratum. Further layers can be deposited after a hardening procedure. This way, the structures develop a three-dimensional shape step by step (Fig. 1). It is no problem to produce closed runners and inclined walls by changing the screen or with a lateral screen shift. In the subsequent heat treatment, the binder is removed and the residual metal powder particles are sintered together. This process provides mechanically robust microstructured parts whose cellular wall thickness and runner diameters are minimally 100 micrometers. Depending on the material used, the maximal component height may amount to several centimeters. Figure 2 shows sintered demonstrator parts highlighting the technical options of the screen printing technology. We sintered a fine steel powder (stainless steel 316L, 1.4404) whose d_{90} is less than 10 micrometers. After sintering, the components were characterised by an isotropic shrinkage of approx. 12 % and were mostly free of distortion. It was especially proven that the specially introduced horizontal structures of 1x1 mm^2 were maintained. We observed that none of the components were prone to cracking. Resultant micro-porosity ranges from 3 to 10 % depending on the heat treatment parameters. It is possible to close the cell walls by sintering to prevent an unintentional connection between two runners.

Moreover, we can obtain an excellent aspect ratio. Up to now, we have achieved an aspect ratio of 25 in previously produced demonstrator components made of the chromium-nickel steel 316L, wherein the printed component heights remained far below the maximum potential. At this stage, aspect ratios of 300 and more are feasible with ceramic systems. Chemical analysis (Table 1) of the sintered structures proved evidence that the binder used in heat treatment could be completely removed, and is thus compatible with the steel used.

Perspectives

This technology has many advantages for mass production: First, assuming an adequate printing area, a large number of parts may be printed simultaneously. Second, quasi-continuous manufacturing with numerous printing areas, alternating between hardening and printing, is easily feasible due to the circulation process. Third, screen printing is a well proven and robust technique and affords accuracy identical to that of the powder used without any problem. The powder metallurgy route also has advantages in terms of the material variety, because, in general, one can process any metal or alloy that is available as powder. Since this technique works without a compact powder bed, only a small amount of surplus material is needed. It is difficult to estimate the constraint for maximal shaping size based on our experience with ceramic screen printing. A true 3D print in the shape of horizontal panels with

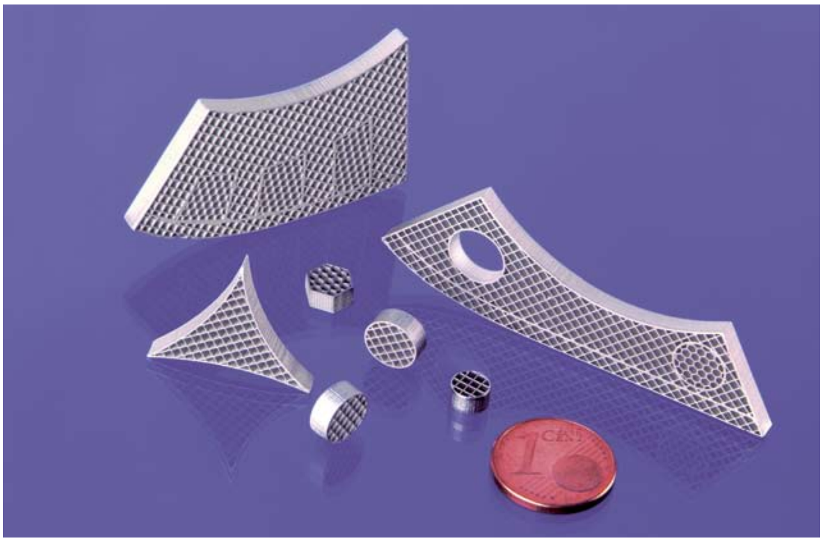

Fig. 2: Examples of metallic screen printing structures made of chromium-nickel steel 316L.

	Sintered structures	Specifications 316L
C (m.-%)	0.017	< 0.03
O (m.-%)	0.040	–
N (m.-%)	0.001	< 0.11

Tab. 1: Chemical analysis of sintered screen printing structures.

overprinted runners of several millimeters width is considered feasible, so that one can imagine producing a microfluidic stack in only one component, without assembly.

This method achieves another increase in functionality that is not easily achievable with other techniques. It encompasses ranges of application going well beyond micro materials processing (micromachining and energy management); they include catalyst carriers or implant materials, like those used in biotechnology (Fig. 3).

In early 2007, IFAM Dresden will have procured a quasi-continuous screen printing machine with special auxiliary equipment which can be run for fundamental studies and industrial R&D projects up to prototype series. Developing real metallic 3D structures and expanding the material variety to other, commercially relevant metals and alloys in close co-operation with the partners from industry are the primary goals in the qualification of this method.

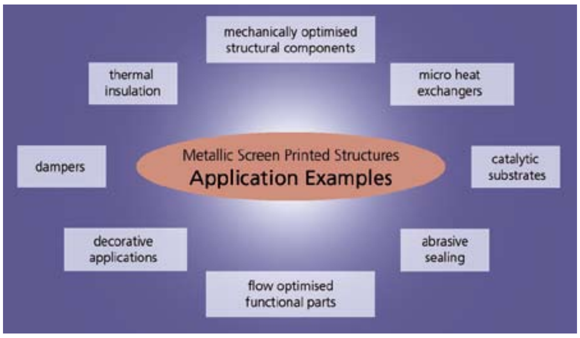

Fig. 3: Selected potential applications for metallic screen printing.

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PM Aluminium for Lightweight Components

Background

Continuous and targeted materials research and product development in conjunction with the optimization of industrial manufacturing processes set the stage for outstanding opportunities for the use of, and new application areas for, lightweight aluminium components made by powder metallurgy. The increasing demand for lightweight components to reduce weight, particularly in vehicle manufacturing, make aluminium components produced by powder metallurgy more and more interesting. Some sinter aluminium components have already been developed and are ready to be produced, such as the camshaft lobe control or the camshaft bearing cap, increasing the likelihood of implementing PM aluminium components in industry and introducing them to the market. Examples of applications, which are under development, are oil pump rotors (Fig. 1), wheels for synchronous belt drives, chain wheels and engine connecting rods (Fig. 2). But sintered aluminium alloys are also applied as miniaturised parts outside the realm of automotive engineering, in domains demanding not only high strength characteristics, but also wear resistance and anticorrosive qualities, as well as non-magnetic characteristics, such as in connecting rods in office- and sewing machines or power mowers, or for housings for electric micro motors or medical devices. Fulfilling the material requirements of each component and co-ordinating the powder metallurgical component's manufacture offer a great challenge in terms of materials science and powder technology.

Fig. 1: Examples of oil pump rotors (GKN Sinter Metals Engineering GmbH).

Fig. 2: Examples of sinter-forged connecting rods for engines (GKN Sinter Metals Engineering GmbH).

Project

The publicly funded BMBF project was aimed at weight reduction of the engine- and gear components in automotive engineering by the rigorous use of lightweight materials and moulds.

In the manufacture of car gears, it is current practice to fit oil pump rotors made of sintered steel tightly into grey cast iron- or aluminium cast housings. In the latter case, during operation, the gap between housing and rotors increases due to the different thermal expansion rates of the two components. This caused tremendous oil losses and consequently diminished the pump's output. Powder pressing and sintering of suitable aluminium powder mixtures provides a promising manufacturing technology for such precision parts. The materials science investigations mainly aimed at the development of aluminium sintered materials featuring high wear resistance, adapted dilation, and a minimal part strength up to about 180 °C, thereby guaranteeing long-term shape- and dimensional stability at the same time. With regard to the intended aluminium pump rotor, it is also possible to make the pump housing of aluminium. This would carry a 1 kilogram reduction in weight in comparison with the steel pump Engine connecting rods are components subject to great dynamic load; the connecting rod, crankshaft, piston and wrist pin, as a whole, form the so-called crank gear in the engine. The connecting rods in current use are made of steel for mass motorization. The requirements typical for this application are shown in Table 1. When we consider the lightweight material aluminium, we obviously recognize that we have to modify or enhance many of the properties of the traditional alloys, in order to achieve the abovementioned goal. Sinter- or powder forging should be developed as the technology of choice.

Temperature range	-50 °C to +180 °C
Tensile strength	450 MPa
0.2% technical elastic limit	> 300 MPa
E modulus	> 80 GPa
Hardness	> 150 HB
elongation (all temperatures)	> 1.5
Notch sensitivity	fraction parting
Thermal expansion coefficient	$< 16.5 \cdot 10^{-6}$/K
Fatigue strength	> 180 MPa

Tab. 1: Profile of motor connecting rod requirements.

Results

Siliceous alloys with hypereutectic compositions are promising material variants to fulfil the required feature profiles. As is the case for the aluminiumsilicon cast alloys, adding silicon makes the alloys harder and stronger; primary solidified silicon crystals provide an increase in wear resistance and decreased dilation. These useful characteristics are also achieved in the case of the aluminium-silicon-sintered materials. Within this material group, powder mixtures of pure aluminium and a major alloyed powder can be subject to Supersolidus Liquid Phase Sintering (SLPS), thereby producing components with high sintering densities (>99 % theoretic density) and excellent mechanical characteristics. One can tailor the range of materials characteristics to specific stresses through optimal proportioning of content, size and distribution of the silicon particles.

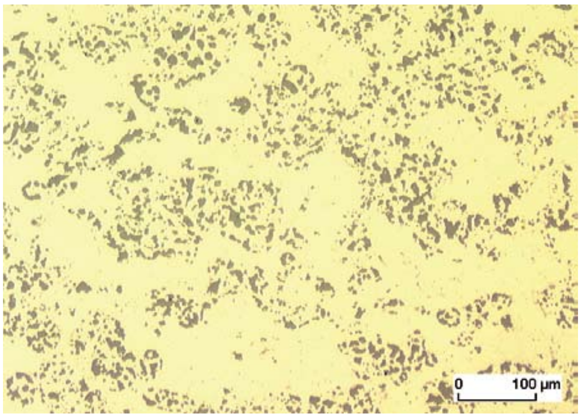

Fig. 3: Duplex sintering structure of AlSi14CuMg (ECKA Alumix 231); sintered in dinitrogen (N_2) at 555 °C over 60 min.

During the project period, we developed pressing and sintering techniques suitable for the oil pump wheels even under conditions relevant for production. First die-dropping rotor sets for oil pumps were manufactured and subjected to relevant gear tests (Fig. 4).

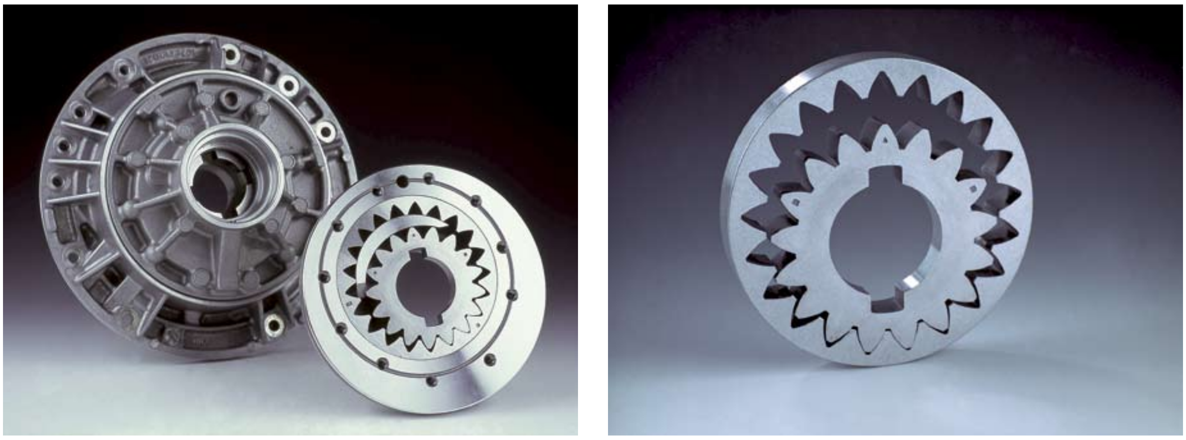

Fig. 4: Aluminium oil pump for automatic gearbox with a rotor set sintered from AlSi14CuMg (ZF Getriebe GmbH).

Beginning with these results, we recommended an advanced test of aluminium oil pumps with sintered aluminium rotors. Special attention was to be paid to the affinity to adhesion of the frictional partners used. In this context, ongoing structure optimization, e. g. in silicon particle size and silicon-free regions are intended.

For the motor connecting rod application, the best mechanical characteristics were attainable with the sinterforged alloy AlSi20CuMgZr (alloy variant No. 5). We moved to straight "powder forging" to get a very fine structure formation.

The dynamic strength of these materials fulfils the requirements of the specs, whereby maximal

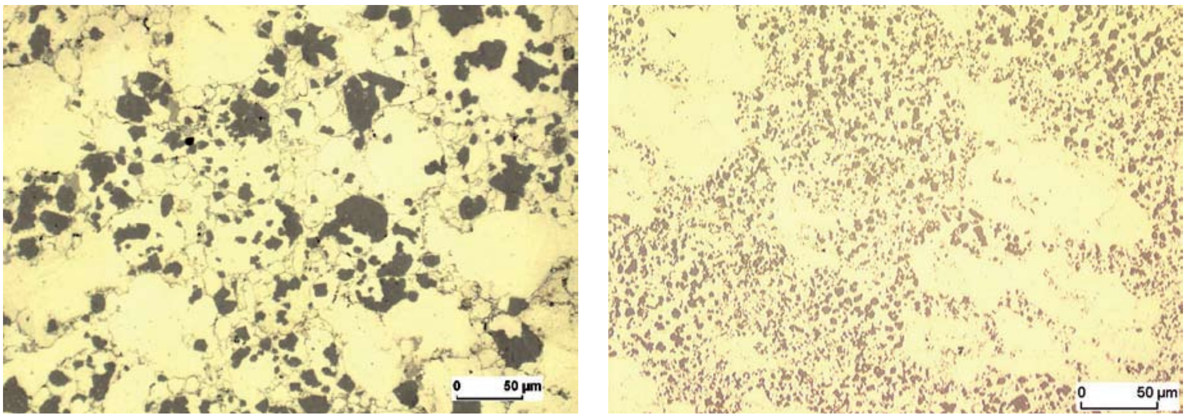

Fig. 5: Light-optical structure images of a sinter-forged AlSi20CuMgZr alloy; left: using original sinter-forging mode (coarse-grained Si, coarse-grained (rough) Al_7Cu_2Fe- and $Al_2Cu_5Mg_8Si_6$ precipitations), right: altered sinter-forging mode (fine-grained Si).

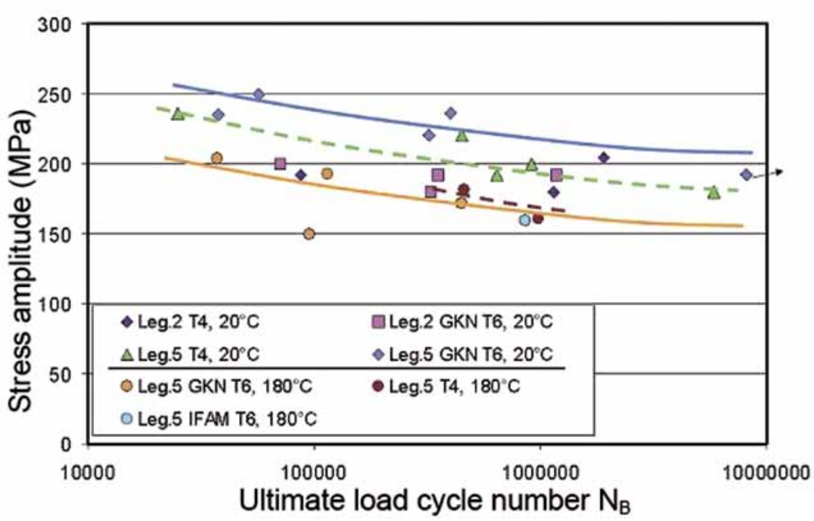

Fig. 6: Dynamic strength values of the powder-forged alloys, determined at room temperature and 180 °C according to the DIN 50100.

fatigue strength was found in the state T6, at 192 MPa and room temperature and R = –1, with more than $8 \cdot 10^6$ alternations of load (Fig. 6). However, elongation achieved at break-values is too low, so that further development activities will be required. In this regard we proposed changes in alloy composition and additional surface treatment.

In the future, the materials developed in the project will also be compared with other components' requirements to explore an extended area of application. There is still a chance for economic success, since there is a great demand of materials for lightweight construction, driven in particular by the automobile industry.

Client

Bundesministerium für Bildung und Forschung (BMBF)

Project partner

GKN Sinter Metals Engineering GmbH
ECKA Granulate Velden GmbH
Ford AG
ZF Getriebe GmbH
Erhard & Söhne GmbH
FEM, Schwäbisch Gmünd

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Awards / Honours

Excellent Material

The International Forum Design rewarded the Golden IF Material Award to Fraunhofer IFAM's casting working group. The award was presented for a metallic composite from metal mixed with microsized hollow glass spheres with a maximum diameter of 60 micrometers. The material can be machined very well; it looks and feels like metal but has distinctly reduced density. Thus, the density of aluminium is cut from 2.7 g/cm^3 to 1.2 g/cm^3, that of zinc from 7 g/cm^3 to 2.6 g/cm^3. The sealed microporosity of the materials means that they can be subjected to coating techniques – from dip-coating to galvanising – that cannot be used with most porous materials. The production of lighter chrome-plated zinc components is an example of this strategy.

The award was presented to the inventor Dr. Jörg Weise at the trade fair Hannover-Messe on 24 April 2006.

Laureate Dr. Jörg Weise speaks with Franz Miller (head of the PR department of the Fraunhofer-Gesellschaft).

Chrome-plated zinc component reduced in weight.

Best Exhibitor Award 2006

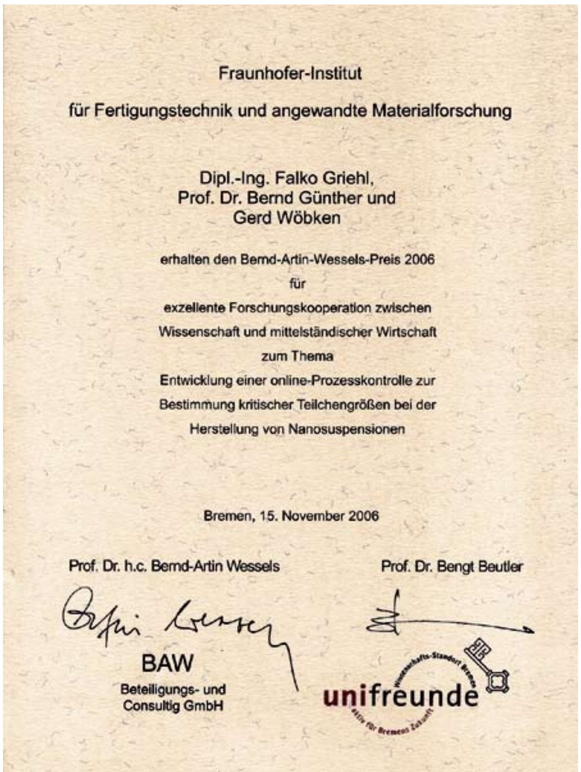
The booth of Fraunhofer IFAM was particularly recognized at the Powder Metallurgy World Congress PM 2006 in South Korea. Together, Fraunhofer IFAM's departments from Bremen and Dresden demonstrated outstanding development projects in the fields of powder technology, micro engineering, composites and cellular metallic materials. The quality of the exhibition and the technical content were deemed excellent. This decision was confirmed by the great response on the part of the visitors, as well as the active discussions which took place at the booth.

Best Exhibitor Award 2006, Powder Metallurgy World Congress PM 2006, 24–28 September, Busan, South Korea.

Bernd-Artin-Wessels Preis

The Fraunhofer-Institute IFAM was awarded the Bernd-Artin-Wessels-Preis for excellent research co-operation between science and industry.

The award recognized a co-operative effort between the Bio-Gate AG and Fraunhofer IFAM. In this project, they developed an online process control to determine critical particle sizes in the production of nanosuspensions. This technology developed by IFAM is expected to be used in series production. The Bremen benefactor Bernd-Artin Wessels gave the award to Prof. Dr. Bernd Günther, Falko Griehl and Gerd Wöbken on 15. November 2006.


Fraunhofer-Institut

für Fertigungstechnik und angewandte Materialforschung

Dipl.-Ing. Falko Griehl,
Prof. Dr. Bernd Günther und
Gerd Wöbken

erhalten den Bernd-Artin-Wessels-Preis 2006
für
exzellente Forschungskooperation zwischen
Wissenschaft und mittelständischer Wirtschaft
zum Thema
Entwicklung einer online-Prozesskontrolle zur
Bestimmung kritischer Teilchengrößen bei der
Herstellung von Nanosuspensionen

Bremen, 15. November 2006

Prof. Dr. h.c. Bernd-Artin Wessels | Prof. Dr. Bengt Beutler

BAW
Beteiligungs- und
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Bernd-Artin-Wessels-Award.

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Department of Adhesive Bonding Technology and Surfaces

Results Applications Perspectives

←
Fluorescence microscope

Expertise 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. Specialised 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. The materials testing lab also received accreditation according to DIN EN ISO/IEC 17025. The Center for Bonding Technology has an international reputation as an accredited authority for the Personnel Qualification for the Adhesive Bonding Technology in Europe upon DVS-PersZert® according to DIN EN ISO/IEC 17024.

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 digitising 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 standardised 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

Business fields and contact persons
Managing director Prof. Dr. Otto-Diedrich Hennemann

Bonding Technology

Dr.-Ing. Helmut Schäfer
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Work groups

Adhesives and polymer chemistry
Development and characterization of polymers; nanocomposites; network polymers; formulation of adhesives and functional polymers; chemical and physical analysis.
Dr. Andreas Hartwig
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Biomolecular design of surfaces and material
Peptide and protein chemistry; determination of the structures of proteins at surfaces and in solution; marine protein-based adhesives.
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Manufacturing technology
Production planning; dosing and application technology; automation; hybrid joining techniques, production of prototypes; selection, characterization and qualification of adhesives, sealants and coating materials.
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Bonding in microproduction
Electrically/optically conductive bonding; adaptive microsystems; dosing very small quantities; properties of polymers in thin layers; production concepts.
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Materials and construction methods
Material and component testing; fibre-reinforced structures; lightweight construction and multi material design; design of structural bonded joints.
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Technology transfer and training
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.
Prof. Dr. Andreas Groß
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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.
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Surfaces

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Work groups

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.
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Atmospheric pressure plasma technology
Surface modification (cleaning, activation, functional coatings) and functional layers for in-line applications and (large) 3-D objects.
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Paint/lacquer technology
Testing and consultancy in the area of paints, lacquers and coating materials; characterization and qualification of paint/lacquer systems; color management.
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Adhesion and Interface Research

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Work groups

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.
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Electrochemistry
Corrosion on metallic materials, under coatings and in bonded joints; investigation of anodization layers; electrolytic metal deposition.
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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.
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Service centers

Center Adhesive Bonding Technology
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Technology Broker
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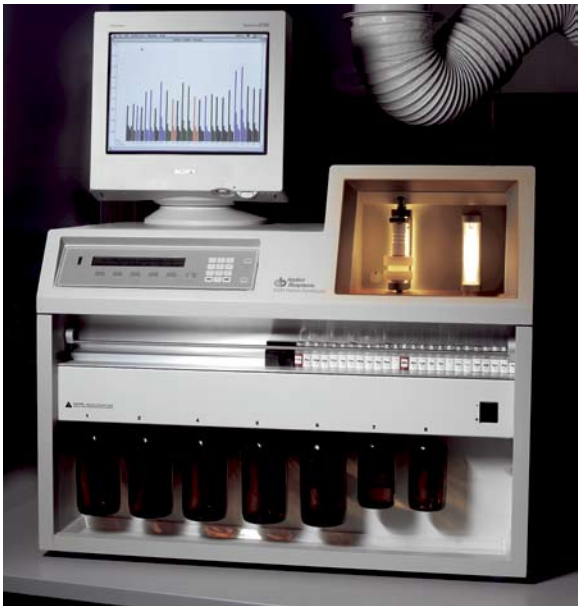
Equipment/facilities

- 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
- 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
- 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



Automatic equipment for peptide synthesis.

- 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

Gas chromatograph with mass spectrometer (GC-MS).

Nature Shows the Way for the Biomolecular Design of Surfaces and Materials

Multidisciplinary collaborative work at the Fraunhofer IFAM brings rapid progress and promising ideas for products. Background: It is difficult to believe that many fish live in the polar regions where water temperatures are very low and that insects survive in Siberia at temperatures of minus 60 degrees Celsius. What makes life under these conditions possible is the special proteins in these creatures which prevent the growth of ice crystals. Such an "antifreeze mechanism" would also be highly desirable in many materials. Everybody will remember the many electricity pylons which collapsed in Münsterland in November 2005. At that time, very wet snow in combination with strong gusts of wind caused thick layers of ice to build up on the cables in a short period of time. As thousands of kilometers of cables cannot be treated with conventional antifreeze agents, a highly active biological coating which prevented ice formation would in this case have been the ideal solution.

We can learn much from the natural world. Mussels, for example, show how effective adhesion in nature can be. Despite being exposed to highly unfavorable environmental conditions – saltwater, currents and surf – mussels are able to adhere to rocks, cliffs, hulls of boats and harbor walls by forming very strong bonds. The adhesive substances here are also proteins and these are able to cure and adhere. Wouldn't it be beneficial to be able to transfer such properties to the adhesives that are, for example, used in medical applications? There would surely be a large market for high strength bioadhesives that could be used on moist or wet regions of the body without adverse reactions occurring.

These examples demonstrate that nature possesses solutions to many problems of everyday human life. It is, however, a huge challenge to adapt these solutions to technical and medical applications – a challenge which is chiefly about optimizing the interactions between the organic and inorganic components. This topic is the focus of the Biomolecular Design of Surfaces and Materials (BIOM) work group at the Fraunhofer IFAM. Special attention is put on the interface between inorganic materials – e. g. metal, plastic, glass, ceramic or oxide layer – and the organic biomatter, for example proteins or nucleic acids. This is because in order to use biomolecules in technical applications the biomolecules must adhere optimally to the inorganic support. For other applications, the adhesion of proteins must be prevented, for example when it is desired that only certain areas of a biosensor react. In this case the surface must possess protein-repelling layers at defined locations to make it "unreactive". The activities of the BIOM work group therefore involve the fundamental principles of both adhesion and non-adhesion.

Adhesive bonding in water – barnacles and mussels.

Interactions between molecules and surfaces are being researched in a variety of projects. The objective of each of these projects is to use biomolecules to form efficient bonds or to functionalize materials. One example of functionalization is the attachment of antibodies which react to pathogens, body-substances or other types of cells and bond these. Biosensors developed on this basis would be able to detect specific conditions and even actively counter these. In medicine, for example, blood values or illnesses would be able to be detected.

How do biomolecules get to the inorganic surface and how do they become attached there? This question has many answers – because the many different surfaces and biomaterials mean that there is a large number of useful combinations. A classic variant of biomolecule-attachment is that on gold-based silicon wafers; however, gold surfaces are clearly not encountered in everyday life. The BIOM work group is for that reason endeavoring to determine how different types of materials must be adapted in order to bond biomolecules to them and hence functionalize these surfaces.

Success in the Bionik Idea Competition

Following an "idea competition" of the Bundesministerium für Bildung und Forschung (BMBF – federal ministry for education, science, research and technology) at the start of 2006 entitled "Bionik – Innovation from Nature", 20 of the most promising ideas were selected from the 150 entries. One of the selected ideas was from the BIOM work group. Funded by the BMBF, researchers are now determining how feasible their ideas are in practice. The IFAM project concerns the biomimetic antifreeze coatings mentioned at the start of this report. A feasibility study carried out by the BIOM work group demonstrated that peptide-functionalized antifreeze-protein lacquers (in short: AFP lacquers) are effective.

Ice formation on cables is not only an issue for electricity cables. De-icing the surfaces of aircraft before taking off is a familiar, time-consuming and costly procedure. The same problem arises in aerospace technology because ice can form on satellites. On wind turbines and rolling shutters ice build-up adversely affects functionality and operational safety. The approach being adopted by the BIOM work group to tackle this problem is to identify the "antifreeze" proteins found in plants, fish and insects and to synthesize these either as partial-sequences or in full. In this work the peptides are modified during the synthesis so that they can be attached to the lacquer surface via a link. The technical lacquer systems being used are those that can be optimized for a specific area of application.

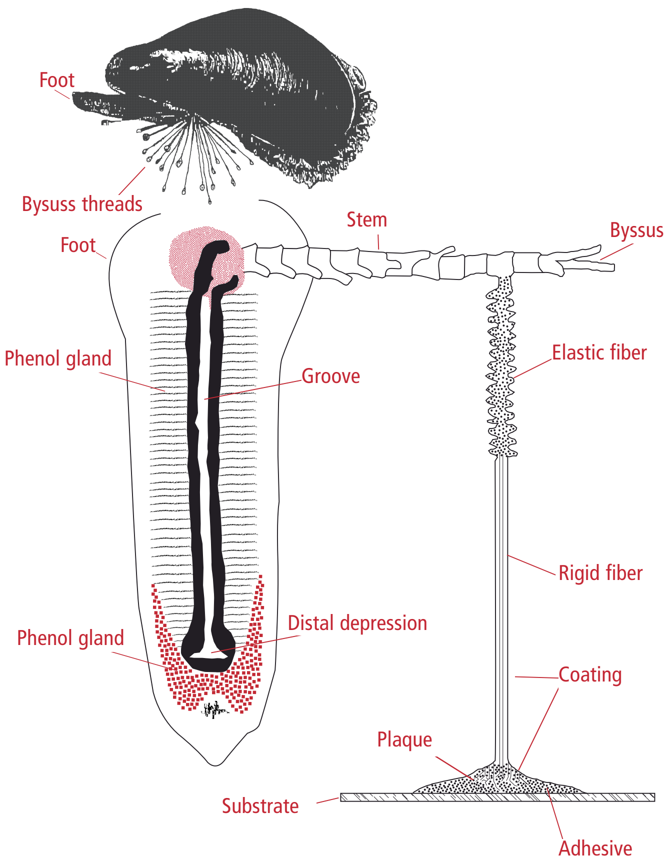
Close collaboration between the BIOM work group and the Paint/Lacquer Technology work group at the Fraunhofer IFAM proved to be highly beneficial for the BMBF idea competition and subsequent execution of the project. One group in the Paint/Lacquer Technology work group is currently engaged in a project funded by the Arbeitsgemeinschaft industrieller Forschungsvereinigungen (AiF) to develop highly abrasion-resistant coatings that reduce ice adhesion – namely, a theme closely related to the research being carried out by the BIOM work group. The interdisciplinary approach of IFAM means that the AFP lacquer project can utilize the technical knowledge of the lacquer technicians to augment the biological knowledge of the BIOM team. This interaction between chemists, biologists and lacquer technicians brings synergies and allows rapid progress to be made, the likes of which is virtually impossible at technical colleges and universities because of the separate nature of their departments. Product conception is also accelerated as a result of our interdisciplinary approach. In the future, collaboration with industry will be strengthened in the area of AFP lacquers in order to realize specific applications. We already have contact with aerospace companies and lacquer manufacturers and with a company which produces rolling shutters and doors.

Another major area of work of the BIOM work group is the application of biomimetic adhesives in medical technology and biotechnology. Within the framework of an internal Fraunhofer project (being directed at medium-sized companies), peptides are being synthesized and combined with polymer materials and particles. This work is being carried out by the BIOM work group in collaboration with the Fraunhofer Institute for Silicate Research (ISC) in Würzburg and the Fraunhofer Institute for Biomedical Engineering (IMBT) in St. Ingbert.

Blue Mussels Show the Way

Natural "examples" of the peptides to be synthesized are key components of the adhesive secreted by blue mussels (Mytilus edulis). The protein-based adhesive materials have already been identified and the adhesion mechanism is known. The curing mechanisms, however, has not yet been fully elucidated, but can be triggered by simple oxidizing agents, transition metal ions or enzymes. A hindrance up to now has been the high cost of recovering the materials: 10,000 mussels are required to obtain one gram of material, with the cost per gram being 130,000 euros.

Blue mussel with adherent byssus threads.



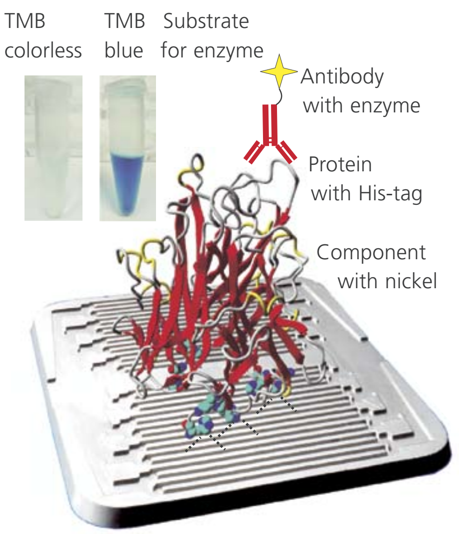
Potential areas of application in medicine and biotechnology suggest that there is a large demand for biofunctional adhesives. Adhesives for tissue could obviate the need for post-operation stitches and could help secure bone-ligaments or bone-tendons. Biocompatible bone adhesives for load-bearing regions would also very be useful. Other potential fields of application are dental applications (adhesives), ophthalmology (repairing the retina) and biotechnology (e. g. for cell positioning). Discussions with small and medium-sized companies have indicated there is a high interest in biofunctional adhesives and the availability of suitable fields of application.

Another ambitious internal Fraunhofer project (being directed at medium-sized companies) is also being carried out in the area of medicine. This is a collaborative project between the BIOM work group and a work group in the Department of Shaping and Functional Materials at IFAM. Synergies are once again here resulting in rapid progress and promising product developments. The project is entitled "Development of materials for customized attachment of biomolecules", in short: IFAM-BioMAT. The multidisciplinary team of material scientists and biologists is developing biofunctionalizable materials. Favorably-priced plastics suitable for the series production of biochips and sensors will soon be able to bind biomolecules such as nucleic acids and proteins. A composite material is being developed at IFAM for this which allows controlled bonding of the biomolecules. As no complex chemical treatments are required using this approach, manufacturing costs can be considerably reduced.

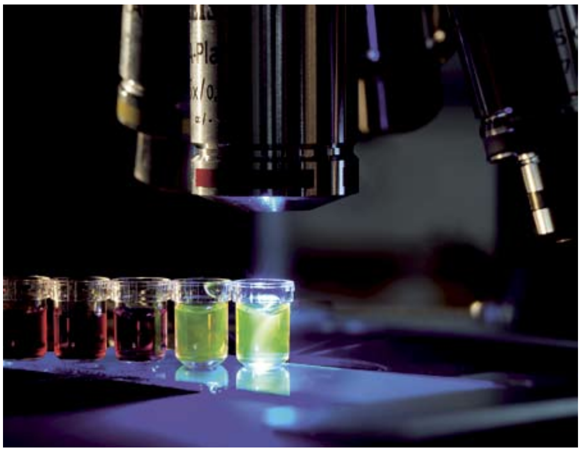
Product Ideas for Specific Medical Applications

The expertise at the Fraunhofer IFAM in the manufacture of injection moulded components, the development and processing of composite materials, plasma activation of the surfaces of materials and the biomolecular design of surfaces and materials have come together so successfully in the BioMAT project that products for specific medical applications have already come to light. Initial contacts with industrial companies (including small and medium-sized organizations) and a university clinic have resulted in ideas for developing an integrated microsystem with microfluidic, microoptical and micromechanical components for use in the molecular-medical diagnosis of illnesses.

For all these R&D activities the BIOM work group has easy and uncomplicated access to all the knowledge and expertise within the Fraunhofer IFAM and to IFAM's excellent equipment and facilities. For example, peptides can be synthesized, purified and analyzed using a variety of techniques including high pressure liquid chromatography (HPLC) and a MALDI-Time-of-Flight (ToF) mass spectrometry. An optical microscope and a fluorescence microscope are also available in order to view samples under transmitted light or surfaces under incident light. The structure of proteins (α-helix, β-pleated sheet or coil) and determination of the structural changes that occur on contact with interfaces can be analyzed using FT infrared spectroscopy. Computer simulation is also becoming increasingly more important in this area of research.



Schematic representation of a blue mussel with foot and byssus thread.



Fluorescence microscope.

Contact persons

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Institute

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Department of Adhesive Bonding Technology and
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Color-Matching in the Car Manufacturing Industry: New Development Brings Time and Cost Savings

The car manufacturing industry is once again undergoing radical change: Up-to-date studies indicate that by 2015 car manufacturers will be outsourcing significant parts of their development and production activities to suppliers. As a result, the supply sector is forecast to grow by 70 percent. Whilst this form of collaboration brings many benefits and opportunities for production, it does however also present a number of challenges. One such challenge – and a huge one at that – concerns color-matching: If different parts of cars are painted at different locations and at different times, it is vital that all the parts of the car are absolutely uniform in color after assembly. Up until now the release and correction of color shades between car manufacturers and parts' suppliers has been carried out by all parties by comparing sample panels and sample parts – and this is a time-consuming and hence costly procedure. A project, funded by the Arbeitsgemeinschaft industrieller Forschungsvereinigungen (AiF) has been carried out by the Paint/Lacquer Technology work group at the Fraunhofer IFAM to develop a process which considerably accelerates the release and correction of color shades within the supplier chain of the car manufacturing industry. This project also involved a leading German car manufacturer, ColorAIXperts (the measuring instrument manufacturer) and i2s Industrielle Informationssysteme (a software company).

Each day dozens of packages are currently sent between car manufacturers, parts' suppliers, paint companies and other parties. These packages contain colored sample panels and painted reference parts. Several hundred times per day decisions are made based on optical inspection and tests using special color measuring instruments about whether a batch of paint or the quality of the paintwork is suitable or not – with all this being done to ensure that all painted parts of a car are absolutely identical. This is because a car with a wing mirror that is too light in color, a bonnet that is too dark or with other color mismatching cannot be sold in the commercially demanding car marketplace.

Fig. 1: Prototype measuring instrument.

Communication between the many paint manufacturers, companies which paint individual parts and the painting department of the car manufacturer largely involves the exchanging of samples. Once a paint manufacturer has mixed a specific color in follow-up to a series of discussions, even the waiting time until the final decision is made about the release of larger quantities of paint involves costs: Until that final "go" decision is made, the machinery of the paint manufacturer cannot be used for other work. If the shade of color has to be subsequently altered this is also time-consuming and costly. In order to alleviate the workload of all parties involved, color measuring instruments have been in use for many years. These give numerical color values which can be communicated by telephone or e-mail, so accelerating the whole decision-making process.

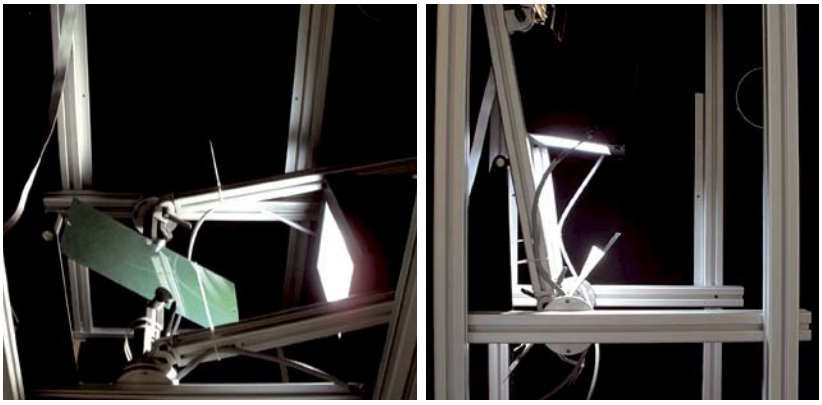

Fig. 2: Prototype measuring instrument. (Source: ColorAIXperts GmbH).

Limitations of Conventional Color Measuring Instruments

The issue of color in the car manufacturing industry has different importance today than it did 20 years ago, due to the enormous progress in paint technology that has been made in recent years. New "effect-paints" – in addition to other extra functions which modern paints possess – lure customers to purchase cars, for example a sparkling car with unusual paintwork is very eye-catching. However, these paints present big limitations for conventional color measuring instruments. This is because special colors are special because of their effects – large glitter particles give the paintwork a coarse-effect and small glitter particles give the paintwork a fine-effect. The shade of color differs depending on the angle of incidence of the light. Innovative pigments are also being developed which give a color-travel effect, also known in the industry as a "color flop". Depending on the angle of incidence of the light these give dramatic color changes, for example from copper red to turquoise blue.

Each individual particle in the paint contributes to such an effect – but current color measuring instruments analyze small areas of the paintwork comprising several thousand particles, with measurements being carried out at different angles of the incident light. The resulting measured color values are unsatisfactory because they say nothing about structures and effects. Even computer comparisons contain possible errors and tolerances which are too large. The eyes, however, are able to detect abnormalities which the values obtained from color measuring instruments do not show

Fig. 3: Left: All angles. Right: Individual angles. In each case, the standard is on the left and the sample on the right. (Source: i2s Industrielle Informationssysteme GmbH).

up. Technical personnel can therefore not rely on color measuring instruments when they are dealing with advanced effect-paints, with the result being that comparing data via e-mail and telephone is not possible. Experts are unanimous that there is a need for better measuring instruments which can also be used on effect-paints to give unambiguous color values which can then be rapidly communicated between parties by electronic means.

Against this background, the AiF funded a project entitled "Development of a color communication system for effect-paints based on the multispectral technique" in which the Paint/Lacquer Technology work group at IFAM played a leading role. The objective was to develop a special measuring system suitable for unambiguous characterization of paints possessing extreme color-travel. For this a panel, about one square meter in size and coated with an effect-paint, was placed in the light booth of a major German car manufacturer. Using a special camera and goniometer the observation positions were determined for which the color change was particular good to see, and hence to document.

IFAM Determines Illumination and Observation Angles

ColorAIXperts transferred these findings into a prototype measuring device which can detect the full spectrum for each individual color pixel, and not just for a larger spot. The company had developed and patented the principles of this multispectral technology at an earlier date for applications in the textile industry. The expansion of this technology to application in the car manufacturing industry was however only possible using the knowledge of the Fraunhofer IFAM. Many experiments were carried out. The project team measured the exact illumination and observation angles for different light sources and adapted the solution of ColorAIXperts to the requirements of paint testing – because only a functioning system which can be used reliably and easily by car manufacturers, companies which paint car parts and paint manufacturers will have a future in the commercial marketplace. The IFAM scientists added two other angles to the standard measuring angle. Significant changes in the color phenomena can be seen at these other angles. The multispectral scanner was modified so that the illumination unit and object support unit can be rotated continuously.

The project team used shades of color which covered the full color space. In addition to testing metal panels painted in standard colors, four samples with small color deviations were in each case tested. The test series were carried out with both a conventional measuring instrument and with the new measuring instrument and the results were compared. More important, however, was comparison of the camera images with the sight of the color testers: After 47 colors on panels from paint manufacturers and car manufacturers had been visually assessed and classified (in order – partly in order – not in order), the images of these colors were once again compared on the monitor. The monitor displayed the images of the colors from the new measuring device, with the ColorAIXperts technology giving an absolutely identical representation of the color differences in each case. The degree of agreement was thus surprisingly high at 82 percent, namely in greater than 3 of 4 cases the evaluation using the new system agreed with the visual evaluation of the color testers. This degree of agreement is even more astonishing given that the visual evaluation by the color testers was actually at a variable angle of observation and contains error sources – because no person can actually stand still.

The development of the prototype measuring device by IFAM and our partners plus the successful verification of the new technique means that we have fully demonstrated the viability of this technology. The technology will be of interest to all companies that use effect-paints – and in particular the car manufacturing industry. In addition, the new technology represents a significant improvement for evaluating advanced "conventional" paints such as shades of silver. Also conceivable is use of the technology for in-line monitoring of bodywork painting. The search has started for industrial partners who in collaboration with IFAM wish to further develop the prototype measuring instrument for application in series production.

The project was funded by the Arbeitsgemeinschaft industrielle Forschungsvereinigung "Otto von Guericke" e. V. (AIF) (funding reference: KF 0045805KDA2). We would like to thank DaimlerChrysler AG (Bremen Works), DuPont Performance Coatings GmbH & Co. KG (Wuppertal) and Karl Wörwag Lack- und Farbenfabrik GmbH & Co. KG (Stuttgart) for their support and assistance with this project.

Contact person

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ColorAIXperts GmbH, Aachen

Institute

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Angewandte Materialforschung IFAM,
Department of Adhesive Bonding Technology and
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The Dream of Being Able to Bond and Debond "at the Press of a Button" Gets a Little Nearer

Adhesive bonding technology is nowadays essential in virtually all advanced areas of technology: It allows high-strength bonds to be created, ideal combinations of materials to be joined and is an exceptionally versatile joining technique. "Not versatile enough" though for many engineers who have wanted to use adhesives but have not been able to do so due to one major drawback – namely that up until now adhesive bonds have been very difficult to debond. Where this has been possible the original strength of the bond generally had to be rather low – or there remained stubborn residues of adhesive on the separated substrates. At the Fraunhofer IFAM two promising approaches have been simultaneously developed which allow facile debonding of high-strength adhesive bonds.

The work piece is bonded directly to the work bench for machining procedures.

The requirements of a modern adhesive are straightforward: The adhesive should bond two defined substrates together without adversely affecting their specific properties and the adhesive should cure rapidly and efficiently. Even better would be if the substrates – when necessary – could be easily separated again from each other. Such debonding is for example desirable when repairs have to be carried out. Another application for debonding is when a short-lived bond is required: For example, when a work piece is secured for machining it is usually affixed mechanically. It would be better if an adhesive bond could be used to secure the work piece which could then be subsequently debonded "at the press of a button".

The Fraunhofer IFAM has developed a solution for this based on electrochemical separation. It does however have the limitation that it is only suitable for debonding metal substrates. Despite this limitation, the desired effect, which is customized for each specific application, is able to elegantly solve many problematic tasks.

In order to secure a work piece for machining procedures, a rapid solidifying polyamide hotmelt was developed. This adhesive forms strong bonded joints. The desired debonding properties were realized by the presence of additives in the adhesive formulation. These had to be developed in a complex process and added to the adhesive in compatible quantities. A variety of different starting materials were tested here.

The adhesive can be easily removed from the work piece by hand after debonding.

Key Combination: Electrical Voltage and Heat

The debonding was achieved by applying an electrical voltage (48 volts) and simultaneously heating the bonded joint (to 65 °C). Both these conditions are decisive: The electrical voltage or heating alone does not cause debonding. This so prevents debonding occurring due to one erroneous signal. In the warm state the adhesive can be removed as an intact film without adhesive residues remaining on the substrate materials. The advantage: The substrate materials can be reused immediately without the need for cleaning procedures. Numerous potential applications for this solution come to mind, for example the aforementioned short-lived securing of work pieces prior to processing. The required temperature could for example be achieved using a heated work bench and the application of a DC voltage of 48 volts to metal substrates is not problematic. The heating of the work bench is also desirable to prevent the hotmelt solidifying immediately on cold substrates.

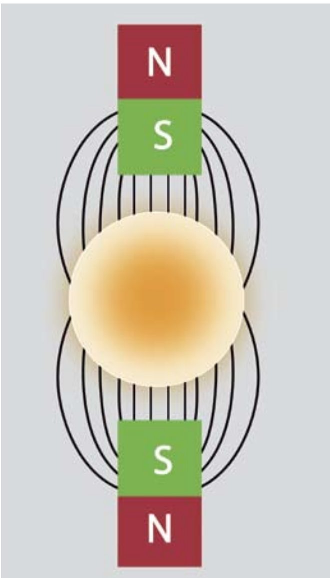
The new process can be transferred to other classes of adhesives, for example epoxy resins or polyurethanes. Polyamide hotmelts have already been extensively tested: Bonded specimens were stored in a conditioning cabinet at 40 °C and 80 % humidity for up to 1000 hours – and thereafter still possessed a lap shear strength of approximately 70% of the starting value. This demonstrated high load capacity and satisfactory resistance to conditioning. An adhesive manufacturer is already producing the material in a pilot plant on a scale up to 10 kg. It seems it will not be long before there is widespread marketing of this product.

Key Feature: the High-Frequency Electromagnetic Field

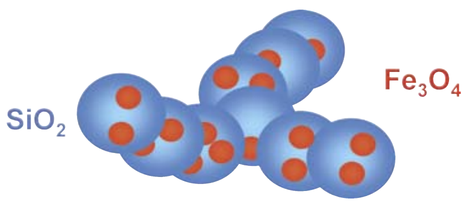
Considerable progress has been made by the Adhesives and Polymer Chemistry work group at IFAM in the area of rapid curing. Adhesives which can be both cured and debonded using a high-frequency electromagnetic field have been developed in collaboration with researchers at Degussa AG. This is possible due to the presence of superparamagnetic nanoparticles admixed with the adhesive. These nanoparticles are iron oxide particles which are embedded in silicon dioxide. This nanopowder was developed by Degussa and bears the trade name MagSilica®. The key feature when using this innovative adhesive is excitation by the said alternating field which causes the particles to oscillate. This principle has enormous benefits for curing. When the high-frequency electromagnetic field is applied, it cures the adhesive – without external heat being required. The heat required for curing is generated internally. That is gentle for the material and saves the time that would otherwise be required for heating the materials in the oven.

In conventional bonding processes the adhesive and substrates are heated together in order to cure the adhesive bond. This has the disadvantage that heat-sensitive substrates, for example many plastics that are used in the automotive industry, cannot be bonded with single-component ad-

Schematic representation (Source Degussa).



The liquid contains finely-dispersed nanoscale magnetic particles (diameter ca. 22 nm). When such a "ferro-fluid" is exposed to a magnetic field, the supramagnetic particles become aligned with the field.



As the nanoparticles are very small they are not pulled out of the carrier liquid. Rather, on switching on the electromagnet the liquid is attracted as though it was magnetic itself. On switching off the magnet the liquid loses its magnetism.

There is therefore a characteristic "hedgehog" structure which is dependent, amongst other things, on the strength of the magnetic field, the magnetizability and the surface tension of the liquid.

hesives which cure on being supplied with heat. To get around this problem, two-component adhesives were opted for and optimized. Although the use of two-component adhesives has been successful, these adhesives need to be mixed just before the bonding process. In addition, processing times are high due to the long curing times and processing is energy-intensive due to the necessary heating of all components in the oven. All these effects, which are a hindrance to production and incur costs, can be avoided by curing suitable adhesives using a high-frequency alternating magnetic field.

Under certain conditions the principle of internal heating of the adhesive can also be used to debond bonded joints. Higher field strengths are used for this in order to generate higher temperatures in the bonded joint. In the ideal case one would equip the adhesive to be debonded with thermally labile groups or additives so that purposeful thermal degradation of the material can occur.

The adhesive is subjected to a high-frequency alternating magnetic field via a magnetic coil.

Transfer to Industrial Applications

The basic principles involved have already been successfully tested on a variety of combinations of materials and different sample formulations. The Adhesives and Polymer Chemistry work group is now on the threshold of transferring the curing of adhesives in alternating fields to applications in industry. Commercially available adhesives will be combined with MagSilica® for this work. There are diverse potential applications for this technology and interest has been shown by all sectors of industry. Equipment for generating high-frequency electromagnetic fields is already widely available in the metal processing industry because such equipment has been used in the sector for many years for metal hardening.

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Early Detection of Slow Corrosion Processes: Electrochemical Methods for Rapid Testing of Protective Coatings

Besides measuring technical parameters, an engineer must also monitor those values over time. Take, for example, the phenomenon of corrosion. It is estimated that an amount equivalent to about four percent of the gross national product is lost due to corrosion each year. For 2006, this means a loss to Germany of about 90 billion euros.

Large structures exemplify just how demanding it is to maintain technical values over a long period of time. Although most technical products that are used personally are replaced by innovative new products after only a few years, large technical systems such as passenger aircraft, ships, oil rigs, offshore wind turbines, bridges and buildings often have to be kept in use for several decades to be economically viable. It is essential, therefore, to develop and apply corrosion protection measures in order to guarantee adequate protection for long periods of operation. So how are engineers able to look into the future and ensure that protective measures are effective over the entire period of operation?

By far the most common method of corrosion protection for aircraft, ships, cars, etc. is to apply coatings, namely protective paints/lacquers. Their protective effect is due to a number of features. For example, a coating acts as a barrier between the base material and the corrosive surroundings, for example damp air, rainwater and seawater. At a defect, for example a scratch, the coating must maintain its protective function. This is achieved, for example, by adding corrosion protection pigments to the coating system which slowly release so-called inhibitors when a scratch occurs. These inhibitors attach to the exposed metal surface and suppress the corrosion process.

The simplest method for determining the effectiveness of corrosion protection coatings is to expose coated sample objects to the same corrosive environment and to observe what happens. However, corrosion processes are often very slow and so this approach is very time-consuming. This is also problematic due to the fact that development times for products are nowadays necessarily becoming ever shorter. One approach is to intensify the corrosive conditions to which the sample objects are exposed. The danger here, however, is that this intensification may not only accelerate the corrosion processes but may also alter them. Ultimately this means that the results from such accelerated corrosion tests cannot be wholly transferred to practical situations.

Another approach is to develop and apply suitable test methods which allow the corrosion processes to be detected at an early stage, namely not only when the corrosion is visible. This approach allows the time required for corrosion testing to be drastically reduced. In principle any measuring technique that can detect the corrosion process at an early stage can be used. Electrochemical methods are particularly suitable here because most corrosion processes that occur around us are electrochemical in nature. Electrochemical methods are also ideal for laboratories because no complex instrumental procedures are required – test samples often only have to be fitted with electrical contacts and can then be exposed to a corrosive environment.

The development and application of rapid corrosion tests and degradation tests is one main area of work of the Electrochemistry/Corrosion work group. The three examples below exemplify the principles of the test methods, the procedures involved and the advantages of electrochemical methods.

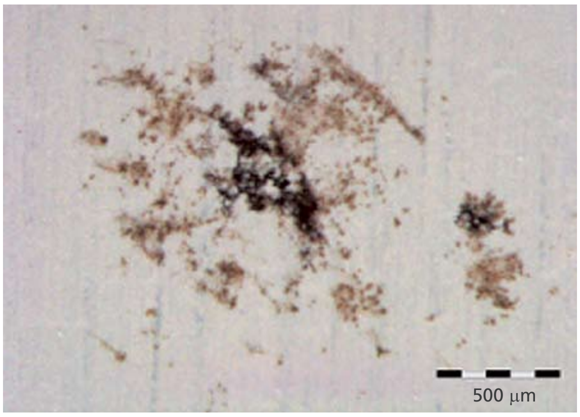
Method 1: Electrochemical Impedance Spectroscopy

Electrochemical Impedance Spectroscopy (EIS) involves subjecting the coating system to an electrochemical potential modulated at different frequencies and measuring the electrical response (Fig. 1). From these two parameters the impedance spectrum can be determined over a wide frequency range (e. g. 0.01 Hz – 100 kHz). Normally a sufficiently small amplitude for the potential is chosen so that the degradation and corrosion processes of the coating system are not affected by the measurements.

The impedance spectra (after adaptation to models) provide much information about the degradation processes in the coating and corrosion processes in the substrate, for example the transport of water and chemical species through the coating, changes in the coating material with regard to its dielectric properties and changes in the reactions at the coating/substrate phase boundary (Fig. 2a and 2b).

This information allows detailed evaluation of the protective function of the coating systems long before corrosion phenomena, such as rusting, become visible.

Fig. 1: Test cell for Electrochemical Impedance Spectroscopy.



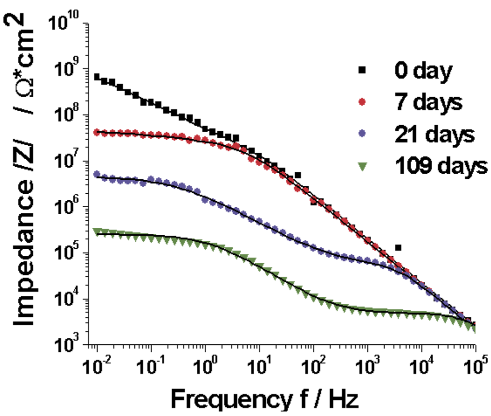


Fig. 2a und 2b: Growth of a spot of corrosion in a coating (see above), which was ca. 1.5 mm in size after 109 days, monitored using Electrochemical Impedance Spectroscopy.

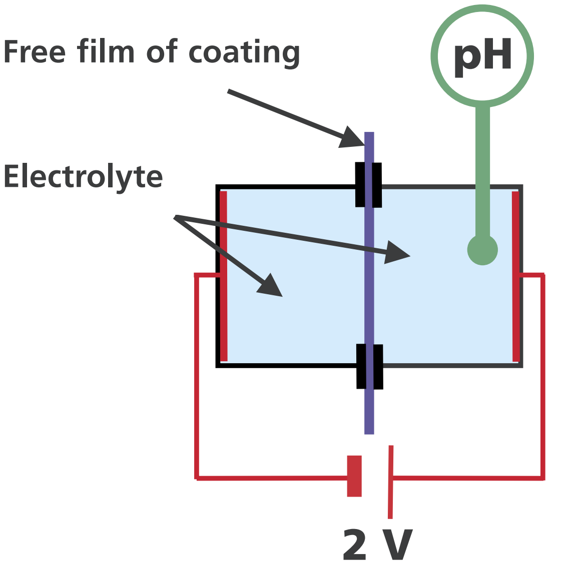


Fig. 3: The very simple experimental set-up for measuring ion permeability.

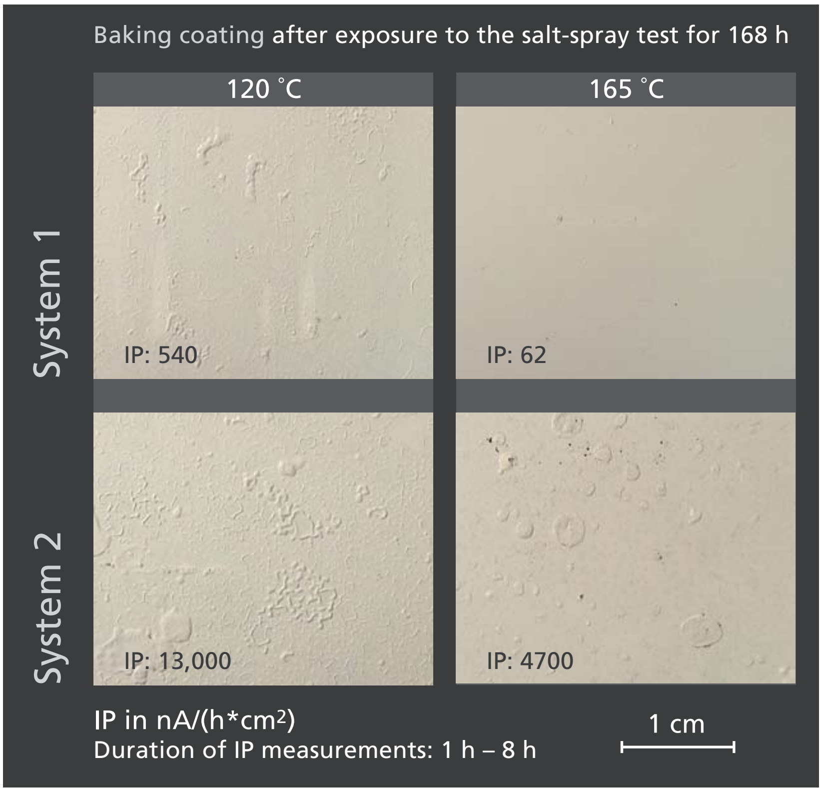


Fig. 4: The degree of blistering of different coating systems correlates with the ion permeability.

Method 2: Determination of the Ion Permeability of Coating Systems

A measure of the protective effect of a coating is the ion permeability. The fewer ions that diffuse or migrate through a coating the greater the barrier effect.

A relatively simple method for determining the ion permeability is the so-called Ph method which has been further developed in the Electrochemistry/Corrosion work group at IFAM in collaboration with the patent-holding customer. The method involves mounting a free film of coating between two half-cells filled with electrolyte and subjecting this to a direct voltage of 2 V via two electrodes (Fig. 3). As a result of this voltage, ions flow through the free film of coating. If this flow of ions was measured by amperometric means, very sensitive and hence expensive current measuring equipment would be necessary. The innovative feature of the Ph method is the determination of the ion flow using Ph measurements.

The oxygen reduction reaction at the cathode: $O_2 + 2\ H_2O + 4\ e^- \rightarrow 4\ OH^-$ causes the pH to change around the cathode. Due to the electron-neutrality in the region of the cathode there is a direct relationship between this change in pH and the ion transport. As pH measurements are very sensitive, commercially available pH meters are suitable for this application. This means that very small ion flows can be detected sufficiently accurately and at favorable cost.

Empirical equations show a quantitative correlation between ion permeability and the degree of blistering of coating systems (Fig. 4) which have been exposed to the salt-spray test. The results of the salt-spray test were determined after 168 hours, whilst the determination of the ion permeability requires only 1 to 8 hours depending on the coating system under test.

Method 3: Determination of the Leaching Properties of Coatings via Electrochemical Noise Analysis

Leaching is the property of a coating to release corrosion-reducing substances, so-called inhibitors, in the event of damage occurring (e. g. scratching). These inhibitors are then absorbed on the exposed metal surface and suppress dissolution of the metal. Such inhibitors are added to the liquid coating systems in the form of pigments.

The effect of these inhibitors is substrate-specific, but also depends on the coating system that has been used. Very effective inhibitors can also be ineffective if they are not efficiently released by the coating system.

A research project funded by the AiF – Arbeitsgemeinschaft industrieller Forschungsgesellschaften "Otto-von-Guericke" – is underway to develop a method that is able to measure the leaching effect in real-time using electrochemical noise analysis.

This method involves immersing two identical sample objects, which have been coated and then purposefully damaged in a defined way, in a corrosive medium (Fig. 5). A measurable galvanic current is generated between two different metals which are immersed in an electrolyte. As the two coated sample objects are identical in this case, it is to be assumed that the galvanic current here would be zero. However, the onset of corrosion does not occur simultaneously in the two samples. Under conditions suitable for pitting corrosion, for example, the formation pitting nuclei and the growth of those nuclei does not occur at the same time. As a result, it is possible to measure fluctuations in the current signal, so-called electrochemical noise, if the measuring equipment is sufficiently sensitive.

Fig. 5: Test specimens for electrochemical noise analysis.

This noise is therefore a measure of the corrosion activity in the samples. If inhibitors effectively leach out of the coating system and protect the metal surface, then the reduction in the noise can be measured (Fig. 6).

The noise fluctuations have an order of magnitude of nA to µA and therefore special current amplifiers are necessary for the analytical work. A so-called "Multi Channel Zero Resistance Current Amplifier" has been designed at IFAM (Fig. 7) which allows many measurements to be carried out simultaneously, so increasing the sample throughput rate. The software for controlling the amplifier and for evaluating the noise signals was also developed at IFAM.

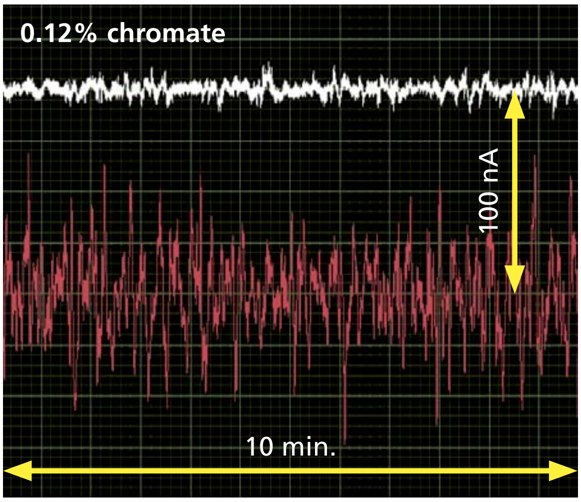


Fig. 6: Noise pattern for effective inhibitor leaching.

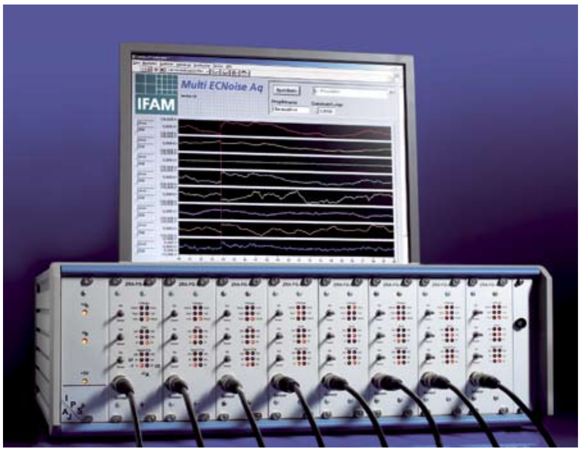


Fig. 7: Equipment for electrochemical noise analysis for high sample throughput rates.

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Demoulding Removal of Fibre Reinforced Plastics from Moulds without Liquid Release Agents Using Functional Plasma-Polymer Coatings

Introduction

Mould release agents are employed in the industrial production of plastic components, and in particular those made of reactive plastics (e. g. polyurethane and epoxide), in order to manufacture high-quality moulded components that are ready for use. Release agents (RA) prevent or reduce adhesion between two surfaces in close contact with each other. They hence reduce the force that is required to remove the moulded component from the mould. In addition to the aforementioned properties, a release agent must also allow the moulded component to be removed undamaged and in general before it has fully cured.

History of Release Agents

Over the last 50 years the development of release agents has essentially proceeded in parallel with progress in the production of fibre reinforced plastics. A fundamental distinction is made between external and internal release agents: Internal release agents are mixed as additives to the resin system in amounts of 0.5 to 1.0 percent based on the weight of the resin. An external release agent, in contrast, is an extra component that is applied directly to the mould. During the formative years of fibre reinforced plastic production the choice of release agent was limited to waxes. These conventional release agents – which include oils and silicones in addition to waxes – were also called “sacrificial layers” and formed a thin film on the surface of the mould. This film forms a physical barrier which prevents contact of the resin with the surface of the mould. This hence prevents direct chemical attachment. The removal of the component from the mould is achieved by breaking the film (cohesive fracture). Residues of the release agent remain in the mould and on the component. As a result, further processing of the component is necessary before it can be painted/ lacquered or bonded and in some cases there is also build-up of release agents baked onto the mould. The next generation of release agents, the so-called semi-permanent release agents (SPRA), which were first developed in the 1960s, did not have these disadvantages. SPRAs were usually applied to the mould with brushes or by wiping or spraying techniques and formed a thin film on the mould after evaporation of the solvent. This film facilitated the demoulding operation mould removal. An SPRA, which is traditionally solvent-based, has a variety of advantages over conventional “sacrificial layers”, for example little transfer to the component, minimum build-up of release agent residues in the mould and in theory the potential to be used for multiple demoulding operations mould removals. Statutory regulations led the release agent industry to replace solvent-based systems with water-based systems. These new systems have safety and environmental benefits, although they have still some way to go to match the good release properties and minimum transfer under production conditions of their predecessors.

All conventional mould release agents have the disadvantage that the separation and cleaning procedure must be repeated for each component / demoulding operation mould removal and as such are very work-intensive and hence cost-intensive materials.

Plasma-Polymers as Release Coatings Parting Layers

In order to overcome the disadvantages of conventional release agents, the Fraunhofer IFAM has over a number of years been developing (quasi-) permanent release coatings parting layers using plasma-polymerization. Plasma-polymerization allows contour-clinging nanoscale functional layers, having a thickness of several tens of nanometers up to a few hundred nanometers, to be deposited on virtually any substrate material and substrate geometry. A plasma is a (partially) ionized gas which contains free electrons and ions in addition to neutral gas molecules and gas molecule fragments. There are also a large number of excited molecules. By emitting electromagnetic radiation, for example, these excited molecules are able to relax and this leads to the characteristic light of plasma. By far the most common means of generating plasma is excitation of a gas by application of an electrical field. Depending on the frequency that is used a distinction is made between audio frequency (kHz) plasma, radio frequency (MHz) plasma and microwave (GHz) plasma. Plasmas are employed in surface technology for, amongst other things, fine-cleaning, activation and deposition of functional layers via plasma-polymerization.

Plasma-polymerization is a process which involves the deposition of layers, crosslinked to a greater or lesser degree, on freely chosen substrates from gaseous monomers excited by a plasma. A pre-condition for this process is the presence of chain-forming atoms such as carbon, silicon or sulphur in the monomer molecules. As the monomer molecules are mostly broken down into reactive fragments in the plasma, the chemical structure of the monomer molecules usually only remains partially intact, and this results in crosslinking and a poorly ordered structure. This mechanism for the formation of plasma-polymers produces layers with special properties which are suitable for a variety of applications:

- excellent layer adhesion to virtually all substrates
- chemical, mechanical and thermal stability
- high barrier effect

Plasma-polymer layers can be deposited from plasmas at atmospheric pressure (AP) or low pressure (LP). Compared to LP plasma technology, the use of AP plasma technology, which is available at IFAM as nozzle technology (Fig. 1), has the advantage that even very large moulds which do not fit into a vacuum-reactor can be coated. AP release coatings parting layers were developed following the good results that were obtained for permanent LP release coatings parting layers (Fig. 2). For this a special precursor feed system for the nozzles was developed and constructed. Layers were then formed, although this involved elaborate complex experimental work. The composition of these layers was virtually identical to that of the films parting layers formed using LP plasma.

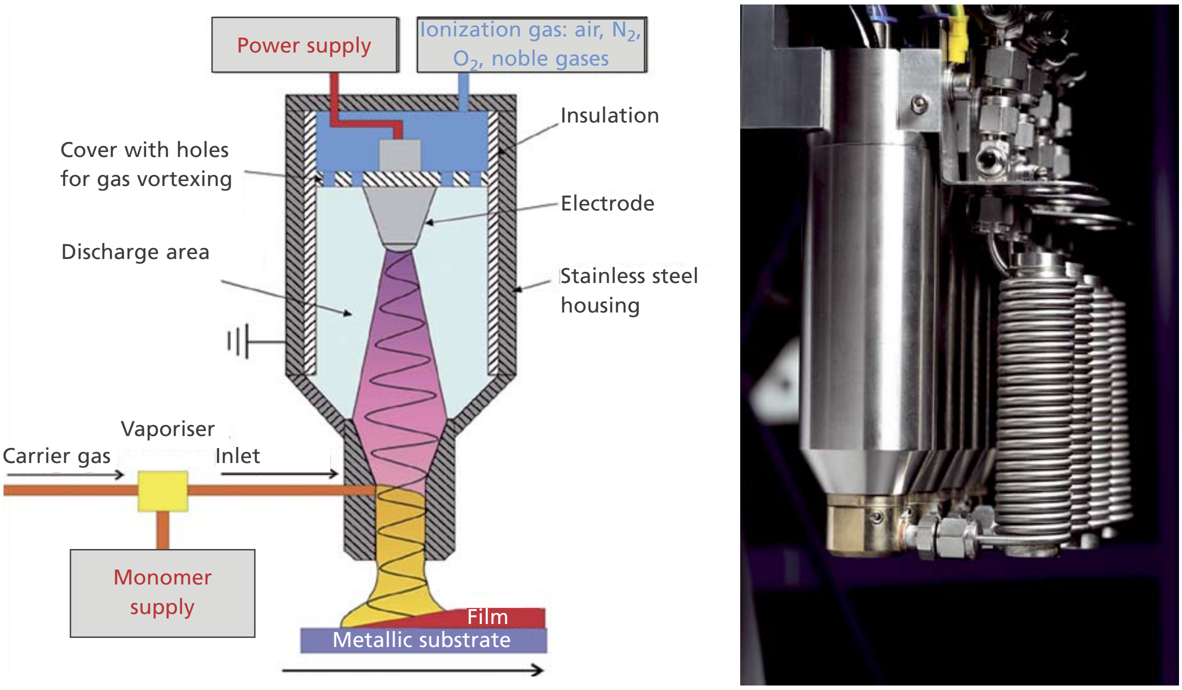

Fig. 1: Atmospheric pressure plasma technology (plant manufacturer OEM: Plasmatreat); left: schematic representation. Right: plasma nozzle for plasma-polymerization.

Suitability of Plasma-Polymer Release Coatings Parting Layers for Carbon Fibre Reinforced Plastic (CFRP) Component Manufacture

The dominant CFRP production processes in the aircraft industry are resin infusion, e. g. Resin Transfer Moulding (RTM), and prepreg technology (prepreg = pre-impregnated sheet). These processes place different requirements on the release agents that are used: In the RTM process the "dry" non-woven fibre plies are first of all placed in the mould. This is then closed and slowly heated to the process temperature. Compaction of the non-woven fibre plies takes place. After reaching the injection temperature the hot liquid reactive resin (e. g. epoxide) is pressed into the mould at a pressure of six bar and cured at a temperature of 180 °C. After cooling the mould the component is removed. This production technology places special requirements on the release agents that are used, because in the first process step the fibres are under pressure in direct (mechanical) contact with the release agent. When using conventional release agents the entire internal surface of the RTM mould must therefore be cleaned after removal of each component and then recoated, namely treated with liquid release agent and aerated. For future automation of the RTM process the release agent application is therefore a key time-consuming factor. This can be considerably lessened by using permanent, plasma-polymer release coatings parting layers. Studies are currently ongoing to test plasma-polymer release coatings parting layers on RTM moulds used in the aircraft industry (Fig. 3).

In contrast to RTM technology, CFRP component manufacture using the prepreg method places lower requirements on the release agents, despite the similar curing pressures and temperatures. The reason for this is the structure of the prepreg material used in the aircraft industry: The fibres are preimpregnated with the reactive resin and hence there is virtually no direct contact with the release agent in the production process. The result is increased resistance of the plasma-polymer release coating parting layers with regard to the number of demoulding cycles mould removals (increased permanence) for prepreg technology. Fig. 4 shows a mould for CFRP component manufacture using the prepreg process. Due to the large dimensions of the component it is particularly suitable for coating using AP plasma technology.

Fig. 2: Demonstration of the application of release coatings parting layers: The uncoated sample on the left shows a cohesive fracture in the sealant (polysulphide), whereas the sample with a release coating on the right shows an adhesive fracture. The substrate material is ZEP-steel.

Fig. 3: Removal of a CFRP panel from an RTM mould (Resin Transfer Moulding) coated with parting layer at IFAM – mould coated with release coating using LP plasma technology at IFAM.

Fig. 4: Potential application of atmospheric pressure plasma-polymer release coatings parting layers: mould for CFRP component manufacture prepared using the prepreg process.

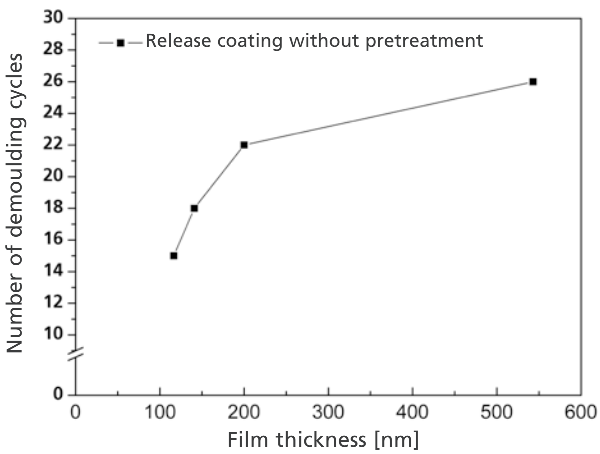

Fig. 5: Effect of the thickness of AP plasma-polymer release coatings parting layers on the number of possible demoulding cycles mould removals. Moulded material: carbon fibre/epoxy resin.

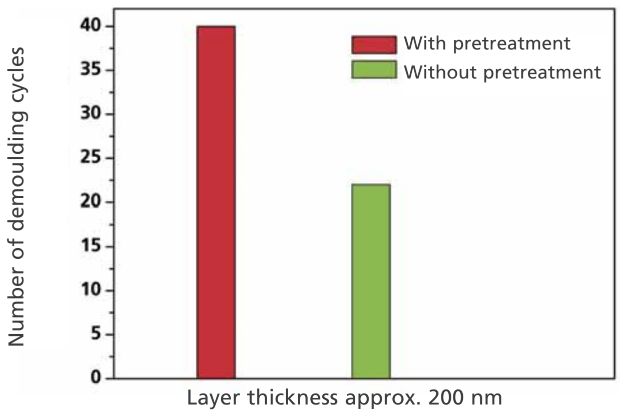

Fig. 6: Effect of pretreatment on the number of possible demoulding cycles mould removals.

Process Optimization

Research at Fraunhofer IFAM concentrated on improving the release properties of thin films deposited by the AP plasma technology. The thickness of the plasma-polymer films was varied as part of the optimization. of the deposition of parting layers using atmospheric pressure plasma technology. With AP plasma technology this can be achieved by customization of the plasma parameters (e. g. speed of the nozzle across the substrate, amount of precursor fed). The effect of surface pretreatment was also studied. The function and the permanence of the plasma-polymer parting layers was demonstrated in demoulding mould removal tests. In this work high importance was put on having test conditions as near as possible to actual production conditions. The test mouldings specimens coated with release coating parting layers were covered with prepreg material used in the aircraft industry, cured under pressure and temperature in a hot press according to material specifications and then removed from the mould. This process was repeated until a release parting effect was no longer evident. It has been shown that the number of possible demoulding cycles mould removals correlates with the thickness of the plasma-polymer release coating parting layer: This increases with increasing thickness, with this effect being more pronounced at thicknesses under 200 nanometers (Fig. 5).

From this follows that there is an uneconomic relationship between coating effort complexity and release permanence resistance to mould removal for higher layer thicknesses. Experiments also showed that pretreating the substrate surface with an adhesion promoter considerably increased the number of possible demoulding cycles mould removals (Fig. 6).
These results indicated that the optimum thickness for future coating processes is in the region of 200 nanometers. Pretreatment with adhesion promoter is imperative to achieve high release coating parting layer resistance.

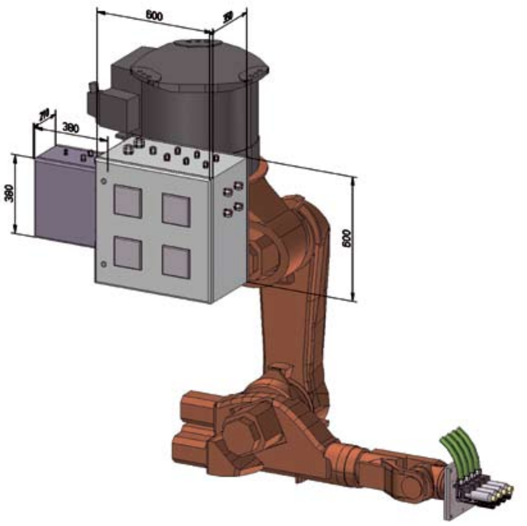

Fig. 7: Schematic representation of a robot-aided atmospheric pressure plasma plant including multiple nozzle assembly for treating large surfaces.

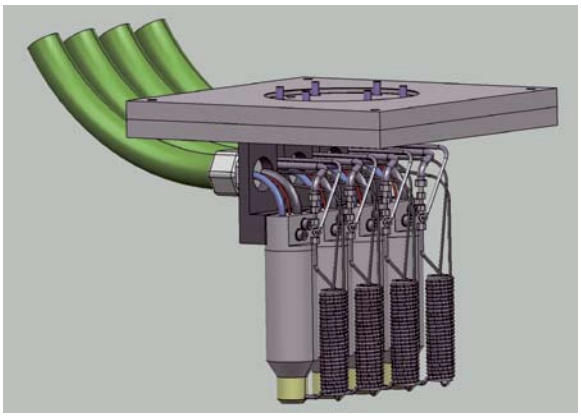

Fig. 8: Multiple nozzle assembly.

Outlook

It has been demonstrated that the removal of CFRP components (made from epoxy resin) from moulds is aided by permanent AP release coatings parting layers. However, the long-term resistance of those layers must still be demonstrated and optimized for the different CFRP production processes.

The layer system that is available must be transferred to larger moulds in order for industry to be able to utilize AP release coatings parting layers. The use of an industrial robot is planned (Fig. 7 and 8) in order to enable flat and slightly curved surfaces of moulds to be treated in a (semi-)automated process. In addition to optimization of the nozzle technology, another key activity is the development and evaluation of suitable processing strategies for large surfaces.

Acknowledgement

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Influence of Process Parameters and Curing Conditions on the Properties of UV Cured Acrylates and Epoxides

Introduction

UV curing adhesives and coatings now have an established share of the adhesive market. A distinction is made between radical curing systems, most of which are based on acrylates, and cationic curing systems, which are mostly based on epoxides. These adhesive systems are widely used in the electronics and microelectronics industries and for bonding glass, acrylic glass and polycarbonate. This is because of their favorable curing properties, very rapid strength development and good optical properties.

The work described in this report was funded by the AiF (AiF no.: 13.647 N/5). The objective of this work was to determine the effect of the UV dose, atmosphere and other parameters, in particular the temperature, on the rate of curing and material properties of the cured adhesives.

Two different model adhesive systems were used for these studies, namely a cycloaliphatic epoxide system flexibilized with polyethylene glycol and an acrylate system based on a polyurethane acrylate. In each case 1 wt. % initiator was added to the epoxide formulations and 3 wt. % initiator was added to the acrylate formulations (Fig. 1).

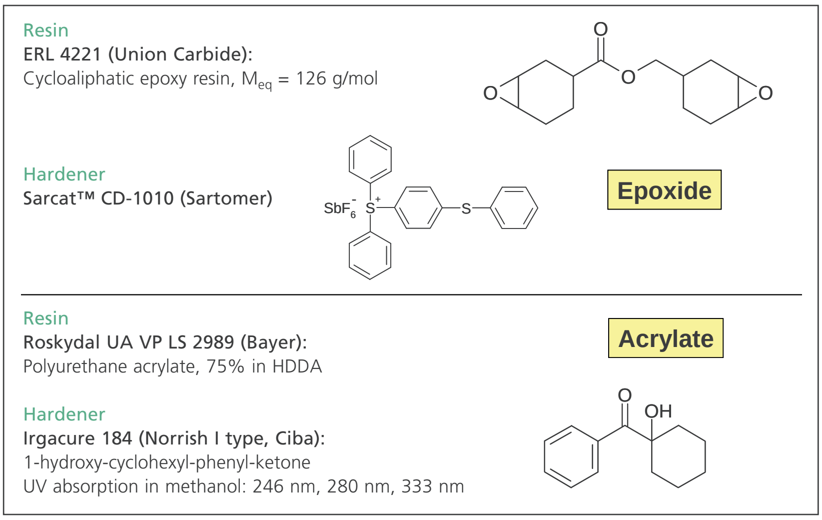

Fig. 1: Model epoxide and acrylate systems used in this work.

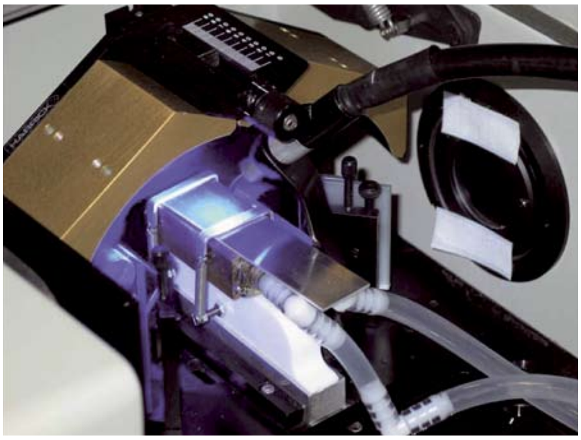

Fig. 2: Experimental set-up for monitoring UV curing under defined temperature conditions using external reflection IR spectroscopy.

In addition to non-filled formulations, adhesives containing functionalized fillers were also studied (see below).

Influence of Atmosphere and Temperature on the Curing of the Model Acrylate System

The IR rapid-scan technique allows IR spectra to be recorded at a rate of up to 100 spectra per second under defined temperature and atmospheric conditions. Figure 2 shows the experimental set-up for studying rapid UV curing processes.

The rate of curing of acrylate systems is known to often drastically decrease in the presence of atmospheric oxygen. The sample geometry here has a major effect on the degree to which oxygen inhibits the curing process. If, for example, the rate of curing of a film of adhesive is compared to that of a drop of adhesive, the latter cures significantly faster and is not affected by the composition of the atmosphere. The surface energy of the substrate also affects the rate of curing of the acrylate system. The more hydrophilic the surface, the greater the tendency of the adhesive drops to form a film. This retards the curing reaction and atmospheric conditions play a more important role.

In addition to the composition of the atmosphere, the temperature also has an effect on the curing of acrylates. For example, the curing of the above-described model system can be significantly accelerated by increasing the temperature as can be seen in Figures 3 and 4. It is clear that this acceleration is particularly marked in an oxygen-containing atmosphere, namely under conditions which are expected to be unfavorable for the curing reaction.

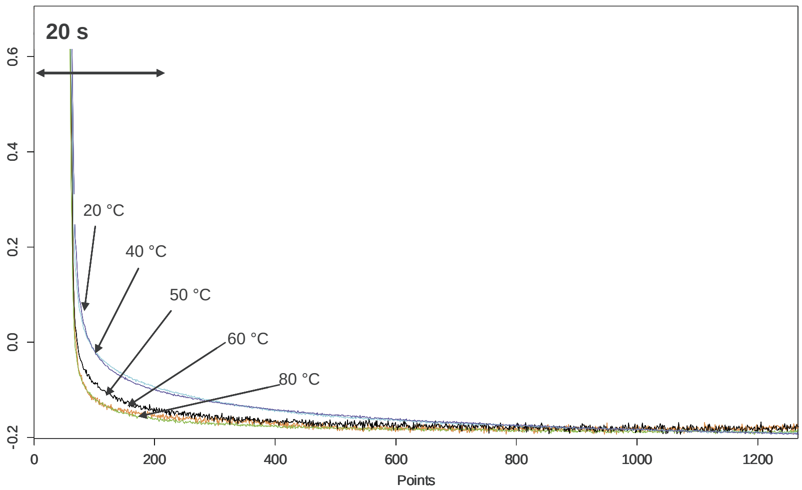

Fig. 3: Curing in nitrogen: IR analysis of the decrease in the C=C band at 1620 cm^{-1} during UV curing of the acrylate system; 100 points = 8 seconds. Curing temperature (from top to bottom): 20 °C, 40 °C, 50 °C, 60 °C and 80 °C. UV light switched on after 5 seconds.

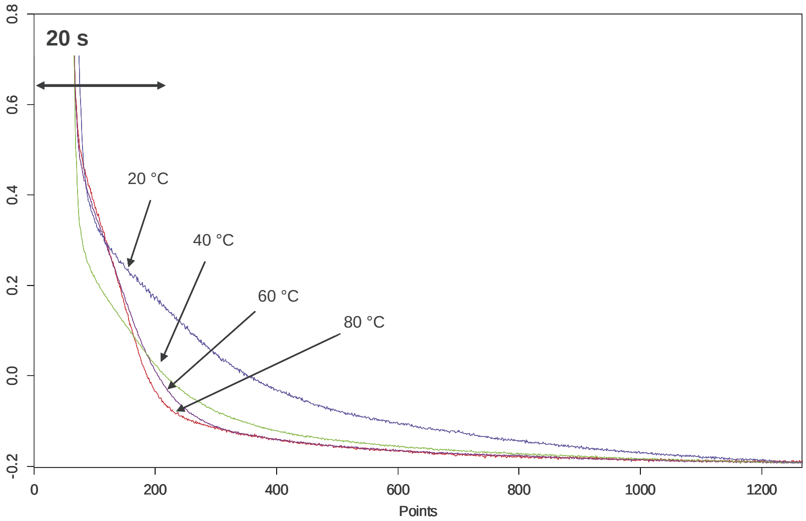

Fig. 4: Curing in air: IR analysis of the decrease in the C=C band at 1620 cm^{-1} during UV curing of the acrylate system; 100 points = 8 seconds. Curing temperature (from top to bottom): 20 °C, 40 °C, 60 °C and 80 °C. UV light switched on after 5 seconds.

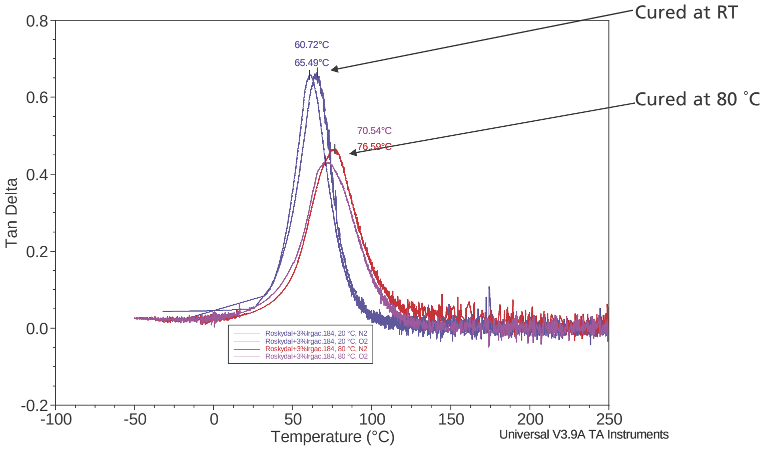

Fig. 5: DMA results for the acrylate system cured under different conditions.

Curing temperature	Atmosphere	Glass transition temperature
20 °C	Air	65 °C
20 °C	Nitrogen	61 °C
80 °C	Air	71 °C
80 °C	Nitrogen	77 °C

Tab. 1: Glass transition temperature of the acrylate system cured at different temperatures.

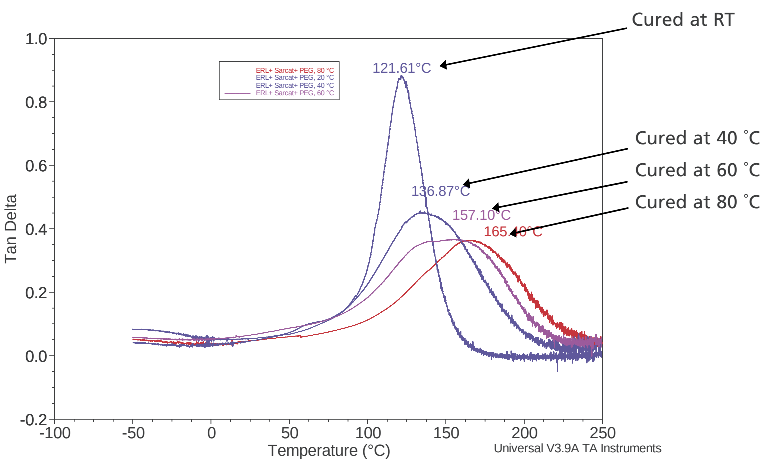

Fig. 6: DMA results for the epoxide system cured at different temperatures.

Dynamic mechanical tests were carried out on the acrylate films that had been cured at different temperatures (film thickness = 90 µm). For both the films cured in air and in nitrogen there was a slight shift in the glass transition temperature (Tg, defined as the temperature at which tan delta reaches its maximum) to higher values with increasing curing temperature (Fig. 5, Tab. 1). A systematic effect of the atmosphere was not apparent or was outside the measuring accuracy.

Influence of Atmosphere and Temperature on the Curing of the Model Epoxide System

Regarding the photochemical curing of cationic curing epoxides, the humidity of the air can have a major effect on the curing rate and on the mechanical properties of the cured adhesives. For example, cycloaliphatic diepoxides with endocyclic epoxide groups cure considerably faster with increasing air humidity. The curing rates of epoxides with exocyclic epoxide groups based on bisphenol A diglycidyl ether do not increase with increasing air humidity, rather there is a small decrease in the rate of conversion.

Similar to the acrylate system, the rate of curing of the epoxide system based on cycloaliphatic diepoxide also increased with increasing temperature. Dynamic mechanical tests on the cured epoxide films (film thickness = 90 µm) showed a significant increase in the glass transition temperature with increasing curing temperature (Fig. 6 and Tab. 2).

The cationic curing of epoxides is a so-called "living polymerization", meaning that after initiation of the curing reaction the polymerization would theoretically continue, even in darkness, to 100 % conversion of the reactive centers due to the absence of chain termination reactions. Figure 7 shows that for a system having low initial conversion the dark reaction over a period of several hours does result in a considerable increase in the conversion (lines 1–4, Fig. 7). However, the degree of conversion that can be achieved after curing with a high-power UV-lamp (200 W/cm) cannot be achieved via a dark reaction (lines 5–7, Fig. 7).

For cationic curing epoxide systems the dose of radiation hence significantly determines the final properties of the cured system.

Influence of Curing Temperature on the Cure Shrinkage

The effect of the curing temperature on the cure shrinkage of adhesives was determined using the afore-described model acrylate and epoxide systems. This involved time-resolved measurement of the volume of a drop of the respective adhesive before and after photochemical curing at different temperatures. The method allowed the temperature-dependent evaporation shrinkage and the actual curing shrinkage to be differentiated. The results showed that the reaction-related shrinkage is only slightly influenced by the curing temperature whereas the evaporation shrinkage, in particular for the acrylate adhesive, increases considerably with temperature (Tab. 3). The acrylate system shows significantly greater total shrinkage than the epoxide system (Fig. 8).

Curing temperature	Tg	Storage modulus at 150 °C	Storage modulus at Tg +20 °C
20 °C	122 °C	10 MPa	10 MPa
40 °C	137 °C	50 MPa	40 MPa
60 °C	157 °C	80 MPa	40 MPa
80 °C	165 °C	160 MPa	40 MPa

Tab. 2: Storage modulus and glass transition temperature of the epoxide system cured at different temperatures.

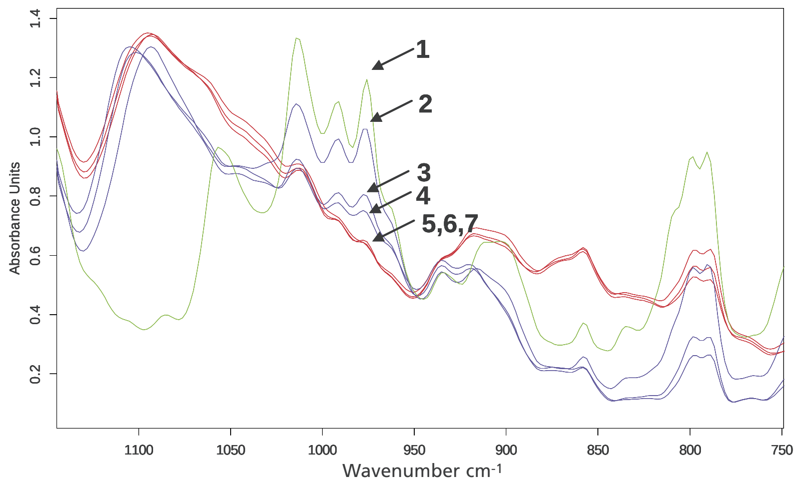

Fig. 7: Decrease of the epoxide band at 975 cm^{-1} for a film of ERL 4221 containing 1 wt. % Sarcat ™ CD 1010: before irradiation (1, green line), immediately after irradiation for 10 seconds with a spot UV-lamp (2, blue line), 30 minutes after irradiation (3, blue line) and 2.5 days after irradiation (4, blue line); immediately after irradiation with a high-power UV-lamp (5, red line), 30 minutes after irradiation with the high-power UV-lamp (6, red line) and 1 day after irradiation with the high-power UV-lamp (7, red line).

Model-system	Curing temperature	UV-A [s / mW/cm^2]	Evaporation shrinkage [%/min]	Cure shrinkage [%]
Acrylate	RT	30 / 120	0.2	5.0
Acrylate	50 °C	30 / 120	0.6	5.4
Acrylate	80 °C	30 / 120	4.0	3.9
Epoxide	RT	60 / 170	0.0	2.2
Epoxide	80 °C	60 / 170	1.6	1.2

Tab. 3: Evaporation shrinkage and cure shrinkage of the model acrylate and epoxide systems after curing at different temperatures.

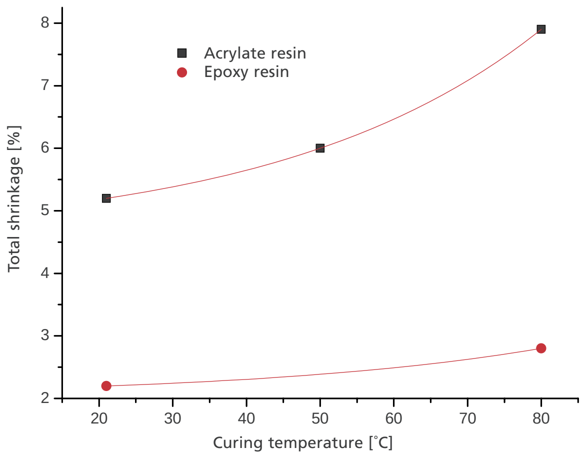

Fig. 8: Total shrinkage of the acrylate and epoxide systems after curing at different temperatures.

Studies on UV Curing Formulations Containing Functionalized Fillers

The mechanical properties of cured resins can be significantly altered using fillers. This is particularly so if the surface of the fillers has been functionalized with silanes, so enabling the materials to function as a nano-filler finely distributed in the resin matrix. In order to investigate whether the presence of a functionalized filler influences the properties of UV curing formulations, 10 wt. % filler was added to a base formulation comprising ERL 4221, 1 wt. % Sarcat™ CD 1010 and 10 wt. % polyethylene glycol. These filled systems were then cured. The following fillers were tested in these studies: 1. Aerosil 200 (fumed silica), 2. Aerosil 200 modified with a silane containing exocyclic epoxide groups (GLYMO) and 3. Aerosil 200 modified with a silane containing endocyclic epoxide groups (ECHTMO). After curing the films the dynamic mechanical properties of the films were measured. The loss factor (tan delta) values show that the fillers shift the glass transition temperature to considerably higher values. This is particularly marked for the system with the silane with endocyclic epoxide groups. This effect suggests there is covalent bonding of the filler with the polymer matrix. The flattening of the tan delta curves with increasing glass transition temperature indicates less change in this temperature region compared with the non-filled system (Fig. 9 and Tab. 4).

Similar studies were also carried out on the model acrylate system based on Roskydal UA VP LS 2989 and Irgacure 184. The filler used was Aerosil 200 modified with a silane containing acrylate groups (MEMO). 20 wt. % of this filler was used in the formulation. The results of the dynamic mechanical tests on the filled and non-filled formulations showed there was a very small shift in the glass transition temperature to a lower value for the formulation containing the filler.

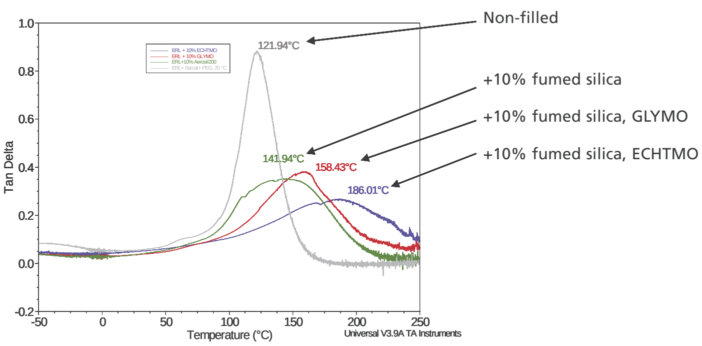

Fig. 9: Tan delta values for formulations comprising ERL 4221 with 1 wt. % Sarcat™ CD 1010 and 10 wt. % polyethylene glycol for differently filled samples, with increasing maximum temperature: non-filled, 10 wt. % Aerosil 200, 10 wt. % Aerosil 200 modified with a silane with exocyclic epoxide groups (GLYMO) and 10 wt. % Aerosil 200 modified with a silane with endocyclic epoxide groups (ECHTMO).

Summary

The key results of these studies are summarized below:

- The rate of photochemical curing of the tested acrylate and epoxide systems is considerably accelerated by increasing the temperature, and particularly so in atmospheric conditions that are unfavorable for the curing reactions. This may for example allow curing to be carried out without the need for a protective gas atmosphere.

- For the tested epoxide system, the glass transition temperature and the storage modulus increase significantly with increasing curing temperature.

- The evaporation shrinkage increases with increasing curing temperature, although the actual cure shrinkage is only slightly influenced. This also demonstrates that the shrinkage can be significantly reduced by using raw materials having lower vapor pressure, which is also advised for reasons of work hygiene.

- Photochemically cured nanocomposites based on ERL 4221 show a significant increase in the glass transition temperature and the storage modulus at temperatures > Tg enabling, for example, these systems to also be used at elevated temperatures.

Acknowledgement

These studies were funded by the German federal ministry for trade and industry via the Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" e. V. (AiF) (AiF no.: 13647 N /5) and supported by the DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e. V. We are grateful for this funding and support.

Filler	Tg	Storage modulus	
		at 150 °C	at Tg +20 °C
Non-filled	122 °C	10 MPa	10 MPa
10% fumed silica	142 °C	120 MPa	80 MPa
10% fumed silica, modified with a silane containing glycidyl ether groups (GLYMO)	158 °C	220 MPa	100 MPa
10% fumed silica, modified with a silane containing cycloaliphatic epoxide groups (ECHTMO)	186 °C	590 MPa	210 MPa

Tab. 4: Storage modulus and glass transition temperature of the cured epoxide system containing different fillers.

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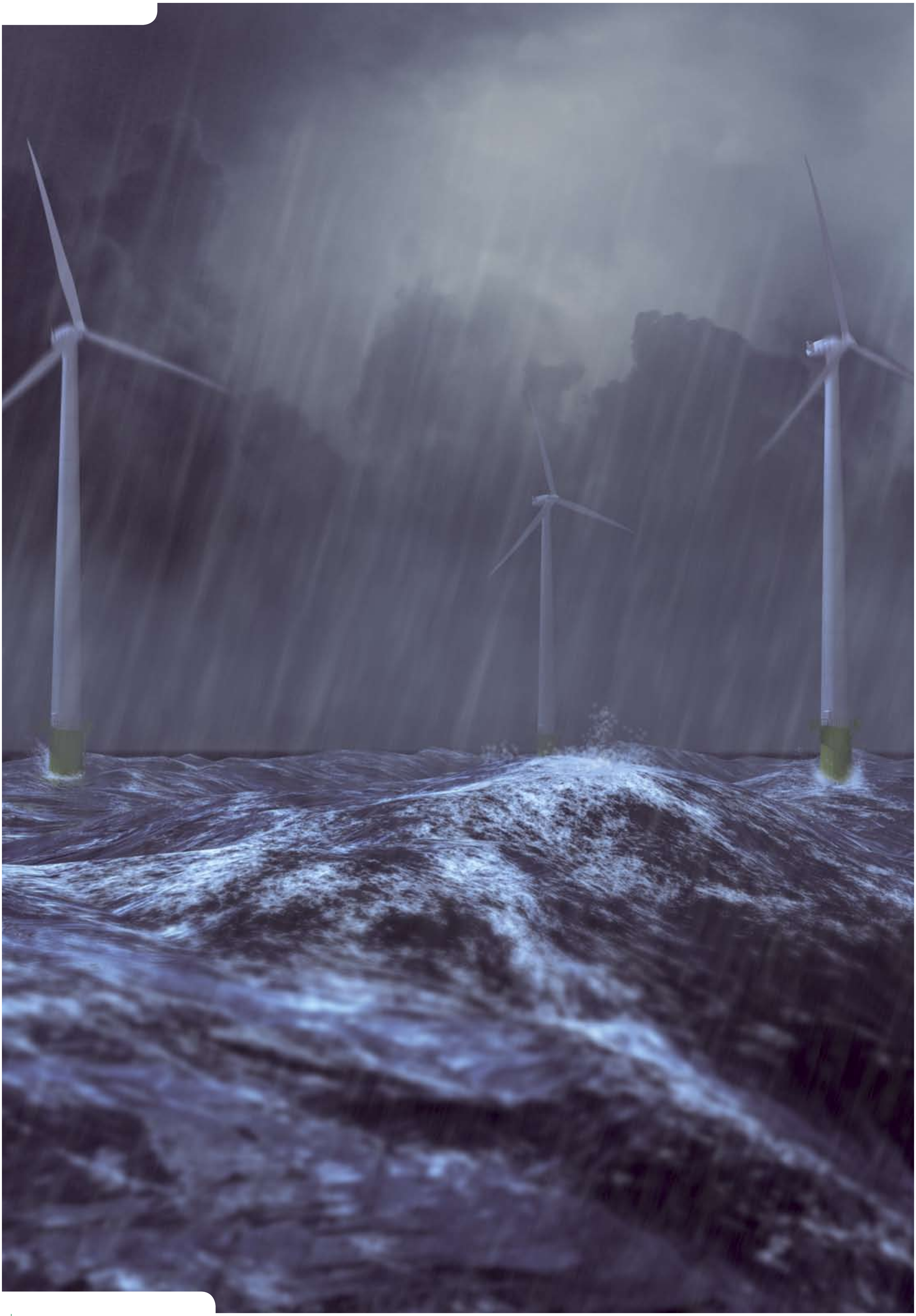

Fraunhofer Center for Wind Energy and Maritime Engineering CWMT

The Fraunhofer Center for Wind Energy and Maritime Engineering (CWMT) in Bremerhaven undertakes research and development work on the utilisation 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 metres.

The main task of the Fraunhofer CWMT is to focus the expertise of the Fraunhofer IFAM and LBF on wind energy utilisation 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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Energy of the Future is Being Generated off our Coast

The New Fraunhofer Center for Wind Energy and Maritime Engineering (CWMT) in Bremerhaven is Developing Innovative Solutions for Improving and Prolonging the Operational Lifetime of Wind Turbines

Wind is a free and renewable resource: Energy generation from renewable resources is becoming enormously important not only in Germany but worldwide. Energy will be generated in the future from sources such as solar rays and biomass- and in particular the wind. Reserves of fossil fuels are finite and the prices of these resources have rocketed in recent years. This has resulted in Germany and other nations becoming increasingly dependent on supplier-countries. Another aspect is the ongoing debate about climate protection which is being continuously enflamed by regular reports about the increasing size of holes in the ozone layer and the already tangible effects of climate change.

Against this background, Germany, like many other industrial nations, has been restructuring its energy supply industry. In recent years virtually no other sector has experienced growth on a part of the wind energy industry. Wind turbines were initially constructed on land, but now they are being constructed out to sea: By 2030 it is intended that 15 % of the total electricity required by Germany will be generated by offshore wind farms. Generation of 25 gigawatts is the goal – sufficient for almost two million households. It is planned to invest some 45 billion euros in this technology over this period of time.

Offshore wind turbines are about 50 % more efficient than those on land. They represent an extremely promising, job-creating future technology for the sectors concerned with the construction of the machinery, foundation structures and rotor blades and for the maritime sector, electrical engineering industry and energy industry. However, offshore turbines also bring special challenges – because they are more difficult to install, must be able to withstand greater loads and maintenance offshore is more complex. For these reasons, the planning of these wind turbines must involve a total integrated approach: Design and construction, materials and processes, production and installation as well as technical reliability and monitoring of the operational condition must be adapted in such a way that a wind turbine is an optimum "product" with a long operational lifetime. The new Fraunhofer Center for Wind Energy and Maritime Engineering (CWMT) in Bremerhaven was established to meet this challenge. The CWMT was founded in 2006 by the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) in Bremen and the Fraunhofer Institute for Structural Durability and System Reliability (LBF) in Darmstadt. This alliance, comprising the CWMT, IFAM and LBF, possesses extensive knowledge and experience with the technologies and systems that are required for successful design and efficient operation of wind turbines.

Cluster of Excellence in Bremerhaven

That the know-how of two Fraunhofer institutes is being united to take on the major challenge of offshore wind energy and that the CWMT is based in Bremerhaven is a logical development. Over a period of many years a regional cluster of excellence has developed in Bremerhaven, focussing on the commercial and technological development of offshore wind energy, and maritime engineering in general. These themes offer enormous economic opportunities for the underdeveloped coast region – because they concern future technologies which can best be researched, developed and constructed near to the coast. From a scientific point of view the themes involve a variety of technical issues and development needs regarding materials, surfaces, joining techniques and technical reliability, and this is the reason why IFAM and LBF became important parts of this cluster of excellence at an early stage. The first phase of development of the Fraunhofer Center for Wind Energy and Maritime Engineering (CWMT) up until 2009 is being funded by the Land Bremen (ca. 4 million euros) and the federal government (ca. 8 million euros), with the remaining funding coming from industrial partners and the Fraunhofer-Gesellschaft. The first phase of development involves a testing hall and complex test stands. The second phase of development will include a further hall and a new office and laboratory building for the CWMT in Bremerhaven. The CWMT workforce will grow continuously.
The CWMT is a research, development and test center for wind turbines and has set up two competence centers: The Competence Center for Rotor Blades and the Competence Center for

Maritime Structures and Plants. In the first phase it is intended to combine and further develop the existing know-how of the parent institutes (IFAM and LBF) in the area of wind turbines and maritime engineering. This involves merging two pools of extensive knowledge and experience. The Fraunhofer IFAM employs more than 230 people and carries out applied R&D projects in areas of direct relevance to wind turbines – including special projects already being directed at this area. The work covers adhesive bonding technology, materials research, surface pretreatment and process optimization. The Fraunhofer LBF has more than 65 years of experience working on structural durability and – following the rapidly increased integration of sensors, actuators, electronics and control technology – also on system reliability. Following adaptation and merging of the IFAM and LBF expertise for the wind energy industry by the CWMT, an expanded technology and development portfolio will be set up in a second phase.

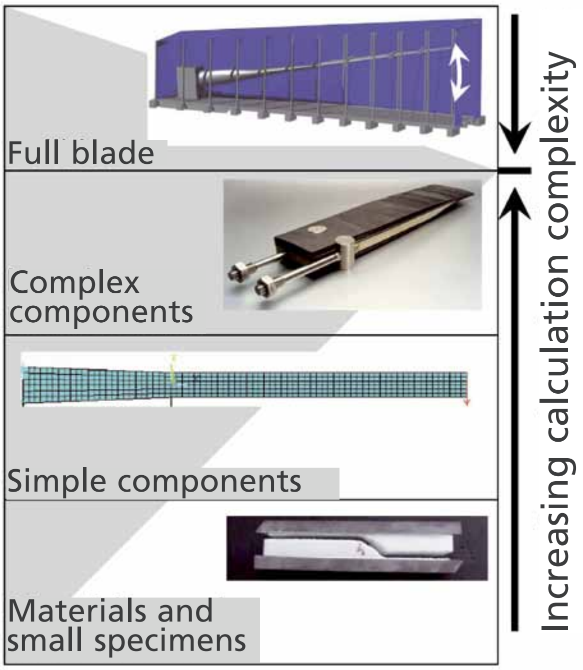
Damage to connecting elements and surfaces on existing offshore turbines demonstrates that major R&D work is still required in order to improve the operational lifetime of offshore wind turbines. A guaranteed 20 year lifetime for the total wind turbine structure together with all components is one of the aims of the CWMT. The systems must be extremely robust and low-maintenance in order for industry to risk the high investments required in this sector. Key questions regarding design and construction, materials and processes, production and installation as well as technical reliability and condition monitoring during operation must be answered or solved prior to construction and incorporated into an integrated total system. As no experience is available for offshore plants of this size, the CWMT is primarily engaged in experimental testing and computer simulation work.

Competence Center for Rotor Blades: Tests and Predictions

The Competence Center for Rotor Blades aims at making lifetime predictions for wind turbines more reliable and aims at keeping the time and cost of tests within reasonable limits. A variety of different individual approaches is being used to solve fundamental problems and form an integrated total process. For example, the closeness to reality of the stresses exerted in the tests should be improved. One example of a rotor blade family will be chosen as being representative for the whole product series and will be comprehensively tested. This will include tests on the materials, components and assemblies of the rotor blade series. As blades are nowadays extremely large – diameters of up to 200 meters are planned – this work will only be carried out on a downsized example. It is natural that new calculation methods and virtual test methods are being increasingly used.

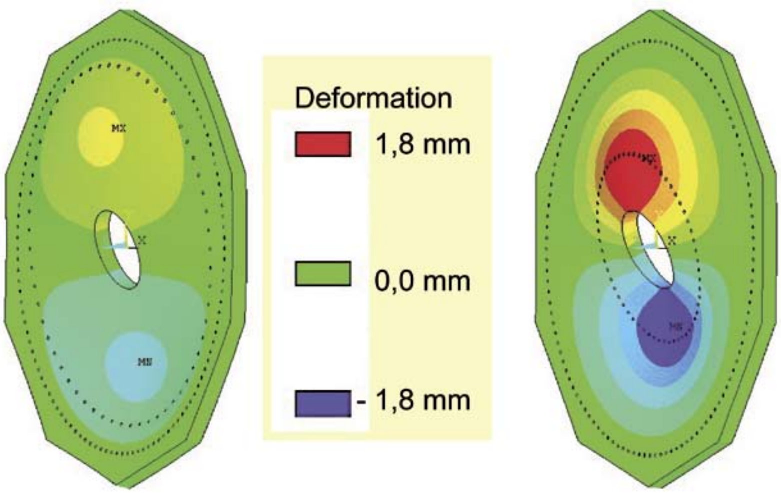
Test stand for the static and cyclic testing of rotor blades having a length of up to 70 m. The maximum torque is 50 mega-newton meters.

The importance of research on rotor blades and the loads to which they are subjected becomes clear when their everyday operation is considered. The rotor blades in the proposed multi-megawatt wind turbines will be subjected to enormous external forces. The envisaged sizes of the rotors will mean rotor blade weights of 50 tonnes and more. This puts very high requirements on, for example, the stiffness of the rotor blades and their resistance to the conditions encountered offshore. It is therefore necessary to investigate the use of new materials and new construction methods. Availability and costs play an important role for materials such as carbon fiber composites or renewable raw materials. The CWMT therefore provides support with constructional design, joining technologies for the rotor blade connection and in the blade itself, material selection, manufacturing concepts, proof of structural durability and condition monitoring during operation. This requires a combination of analytical, numerical and experimental methods.



Schematic representation of the hierarchy of various test methods as a function of the complexity of the test components. This complexity increases from bottom to top, whereby in general the number of tests to be carried out simultaneously decreases.

Rotor blade testing is also carried out for customers. One main focus of our work concerns fundamental studies on the use of new composite materials, with the aim being increased strength, favorable processing properties, improved recyclability and lower costs. In addition to mechanical stress caused by wind, waves and heavy seas, special focus is also placed on the effects of environmental factors such as moisture, corrosive media, heat, cold and UV radiation. To this end, work is carried out on the development and application of suitable surface protection systems. Other work includes the evaluation of thick laminates and the development of advanced failure hypotheses for multi-axial stress on composite materials. There is considerable scope for optimizing quality and costs in adhesive bonding technology, namely the development and application of improved adhesive systems and technologies and the study of near-real operating stresses via both simulation and practical tests.



Finite-Element calculation of the deformation of the adapter plate between rotor blade and test stand for a 70 m rotor blade (left) and a 30 m rotor blade (right). Due to the larger “lever arms”, the maximum deformation is greater for the small blade (1.8 mm) than for the large blade (0.8 mm).

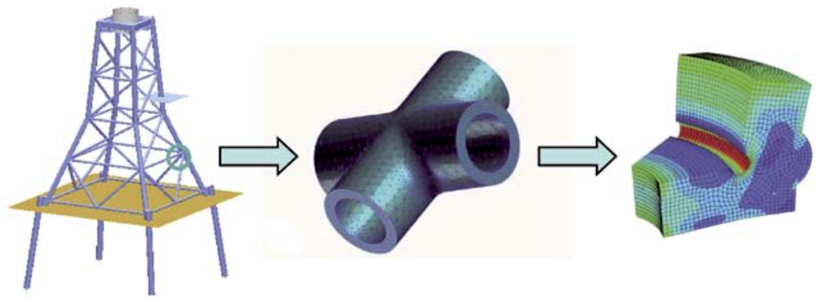
Competence Center for Maritime Structures and Plants

The Competence Center for Maritime Structures and Plants is mainly involved with the integrated development of foundation structures for offshore wind turbines. This involves consideration of materials, surface protection, construction, production and processing technologies, assembly and logistics. In addition, new transport concepts are being developed and evaluated and the simulation of the structural durability of existing and future plant designs is a key aspect of our work. The foundation, tower and gondola of a wind turbine in deep water weigh more than 1000 tonnes under extreme conditions. From a turbine constructor's point of view, reducing the weight of the gondola is the most effective way of saving weight and lowering costs. Other potential savings come from considering design, production, transport, logistics and installation and their mutual dependencies. Although there is much experience available from the onshore business regarding gondolas and rotor blades, there is little know-how concerning offshore foundations.

In collaboration with experts from the private and public sectors, the specialists at the Competence Center for Maritime Structures and Plants offer optimization of the entire value-creation chain from the production of individual components to erection offshore. Special challenges are presented by the large weights and geometrical sizes of individual components and assemblies. It is therefore very important to closely link design and production planning. For example, one possibility is to consider production procedures for different means of construction or assembly designs in order to optimize production times and production costs. Based on experience in the evaluation of highly stressed welded joints and the use of cast node in the offshore area, the Fraunhofer CWMT offers support with the selection of materials and the design of the tower construction.

This always involves numerical simulation of stress based on operational loads. This can be customized for the special location of the turbine, whereby the operational stresses are determined for the location, extrapolated for the intended duration and then compressed. This example of numerical simulation and engineering using the latest software packages is representative for the reasoned and concerted way computing is used in the work of the CWMT at all levels. The development, adaptation and use of methods and tools for computer simulation are based on the many years of experience of the Fraunhofer LBF in this area. The basis of the work is the "global to local" approach. The computer simulations allow the critical areas of the total system to be identified. Insight into these areas is then deepened by a combination of further detailed simulations and experimental tests on real structures.

Optimization of the foundations



For finite-element simulation (far right image) of the complex foundations fo offshore wind turbines, first of all the total structure is considered (left image) and then using a stepwise procedure the area under consinderation is decreased, with simultaneous refinement of the detailed representation.

The Fraunhofer CWMT is also developing solutions for time-saving and cost-saving condition-oriented maintenance. Constant recording of the state of ageing of the drive rod and rotor blades and also the foundation and tower is necessary. For this reason, highly stressed regions can be monitored during operation using integrated sensors. The development and application of customized condition-monitoring concepts allow comparison of real stresses with stress limits, and allow statements to be made about residual lifetimes. Changes in the system behavior of the turbine allow to detect damage early, and enable targeted maintenance to be undertaken. Other developments – for example for future rotor blades – concern functional structures for deicing, the aerodynamic properties of rotor blade surfaces and prediction of the active lifetime of surface protection systems.

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Adhesive Bonding Connects

Adhesive Bonding is Art – Art is Adhesive Bonding: Exhibition in Front of and in Bremen Rathaus Amazes IVK Members and the Wider Public

June 2006 in the center of Bremen: Astonished people, disbelieving faces, open mouths and the same question being asked over and over again: "What on earth is that?" Several dozen white structures are attracting the attention of the people. Plastic tubes filled with air have been joined together to form snowflake-like structures. These three meter high "nanos" stand between the Rathaus, Bürgerschaft, Schütting and Roland – a gigantic representation of tiny nanoparticles. The background: The key processes in adhesive bonding occur on the nanoscale and are hence not visible to the human eye. These huge exhibits, however, which attract so much attention during the day – and also at night when floodlit – bring over the message. And anyone who wants to know more is invited to visit the art exhibition "New connections – the phenomenon of adhesive bonding" in the Bürgerschaft and Lower Rathaus Hall. Both tours and introductions are offered into the world of adhesive bonding and art.

Never before has adhesive bonding and the joining of different materials attracted the attention of the public so much, not in Bremen nor anywhere else in Germany. From 8 to 12 June it was not only those members of the public with an interest in science and technology who marvelled at the exhibits but also art lovers, people wandering through the city and those passing by. The original idea of linking adhesive bonding and art in this way came about from a discussion between Professor Dr. Otto-Diedrich Hennemann, Director of the Fraunhofer IFAM, and Arnd Picker, Chairman of the Industrieverband Klebstoffe (IVK) – the Industrial Association of Adhesive Manufacturers. Both had pondered over an appropriate way of celebrating the 60th anniversary of the IVK in June 2006. In discussion they quickly came up with the idea of linking adhesive bonding and art.

"Nanos" in front of Bremen Rathaus and in front of Bremen Cathedral.

The Phenomenon of Adhesive Bonding Visualized

IFAM and IVK took on board a third partner, the Hochschule für Künste (University of the Arts) Bremen. "The link between science and art excited us from the outset. Even during the first meeting with Professor Dr. Peter Rautmann, the HfK Rector, a torrent of ideas came forth", recalled Arnd Picker when on 8 July he welcomed participants to the 60th IVK congress on the steps of the Rathaus (Bremen City Hall). Young artists took part in a student competition and a competition for school pupils. The competitions were sponsored by IVK member companies. The innovative works of art visualized the phenomenon of adhesive bonding. Without words, the young artists made highly complex physical and chemical processes understandable via their artwork. The fascination of adhesive bonding as a joining technique was made perceptible and brought to life in a unique visual way.

Arnd Picker, the IVK Chairman, enthused: "I am amazed at what the school pupils and students have achieved. If projects such as this succeed

From left to right: Prof. Dr. Peter Rautmann (Rector of the HfK, Bremen), Prof. Dr. Otto-Diedrich Hennemann (Director of the Fraunhofer IFAM, Bremen) and Arnd Picker (Chairman of the IVK, Düsseldorf).

in generating trust in adhesive bonding technology and its applications – then all the effort has been worth it." Thomas Röwekamp, the Bremen Interior Minister, who welcomed the representatives of the German adhesive manufacturers to Bremen, was in agreement and added: "The art competitions have caused quite a stir in the city because everybody is wanting to know what the objects in the Marktplatz are." Professor Dr. Peter Rautmann, the HfK Rector, pointed out that the art world possesses creative potential the likes of which industry needs: "That these two separate areas have been brought together in this way could only have happened here in Bremen. What you are actually involved with, namely adhesive bonding, is invisible and hence has marketing limitations. For us artists that was a huge challenge!"

A short time later – at the reception marking the 60th anniversary of the IVK in the Upper Rathaus Hall – Arnd Picker and Otto-Diedrich Hennemann gave more insight into how this extraordinary

Right: Bremen Interior Minister, Thomas Röwekamp, welcoming the congress participants. Left: Ansgar van Halteren, managing director of the IVK and a board member.

As the weather was so good, the Interior Minister welcomed the congress participants in front of Bremen Cathedral.

event came about. "Creativity got the better of us", admitted Picker – and referred to Hennemann as the person with the original idea. The director of the Fraunhofer IFAM explained the background to the event: "Our motto is: 'Adhesive bonding connects'. That, however, does not merely mean that we bring together and connect materials using complex bonding processes – rather we also bring together people due to the interdisciplinary nature of our field of technology. Namely, scientists from a wide variety of disciplines carry out the development work and – in order to implement a bonding process in industry – those scientists interact with the company and R&D management and also with the technicians who undertake the actual bonding work in practice." Making the invisible processes of adhesive bonding visible in art form was the objective of this artistic challenge. Hennemann went on: "In order to further develop the market, we have to make ourselves, our work and the phenomenon of adhesive bonding understandable and perceptible."

IVK reception in the Upper Rathaus Hall.

First of all, however, the participants in the two competitions had to be introduced to the world of adhesives. Adhesive bonding – what is that? How does it function? What implications does it have for us and our environment? In order to answer these questions, Otto-Diedrich Hennemann gave a presentation to the tutors and students at the HfK in which he explained the technological fundamentals of adhesive bonding technology, answered technical questions and subsequently acted as a contact person. No preconditions were laid down for the competition, namely the students were allowed to freely choose how they wanted to translate adhesive bonding into art.

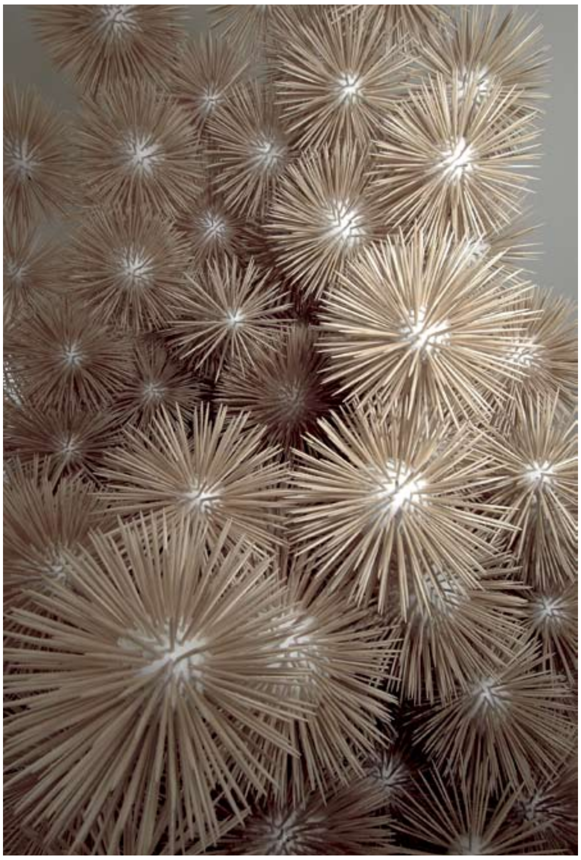
Spontaneity as one of the Features of the Project

"On pondering how to transfer adhesive bonding into art, we initially considered many of the aspects too banal to take further artistically", recalls the project leader, Professor Oliver Niewiadomski of the HfK. "When we glue things together we normally never think about what we are actually doing. In this regard adhesive bonding is the most spontaneous and most direct of joining techniques. No holes have to be drilled, no threads have to be cut, no rivets have to be forged and no welding equipment is required. This spontaneity was a theme throughout the project."

The result was an impressive array of artwork in which not only materials but also functions, ideas, opinions and feelings were joined with each other. The huge nanostructure in turn connected the Bürgerschaft, Rathaus, Schütting and Marktplatz with each other. The exhibition in the Rathaus hall – impressive works of art which visualized adhesive bonding – was not only praised by those participating in the IVK anniversary congress but also by the wider public who had the opportunity of visiting the exhibition over a number of days.

The artwork of the three student prize-winners highlighted the innovative ideas and thought that had been put into this project. The first prize was awarded to Mendy Arp for her artwork entitled "Stinger" which was on exhibit in the foyer of the Bürgerschaft. She had stuck toothpicks into polystyrene spheres, so forming molecule structures – sea urchin like figures which in turn were joined to form other figures. "With this work of art Mendy Arp went to the bounds of possibility", said HfK Rector Peter Rautmann at the prize-giving and "and that won over the jury". A further related work of art by Mendy Arp was also much appreciated: In "das Gros" she had bonded porcelain vases to porcelain spheres so giving modules which – when pushed into each – gave a connected form.

Second place was awarded to Eyke Schröder for her "artwork" in the center of Berlin, a video of which could be viewed during the exhibition in Bremen. At night Eyke Schröder had removed advertising posters from the walls in the city and glued them together again. According to Peter Rautmann, "Eyke Schröder's artistic bonding successfully brought over a cultural message". Third place went to Tim Klausing, Tilman Richter and Li Shu-Shi. Their exhibit "Hands-on: adhesive bonding" was especially appreciated by the IVK representatives: The most important principles of bonding processes at the molecular level were put over in a clear way as were the key steps of adhesive bonding. Their "learning module", a mixture of visual information and personal experience, made complex physical and chemical relationships readily understandable – akin to the "Universe" at the Bremer Science-Center. The IVK representatives were taken with it: "Finally we ourselves now understand what adhesive bonding is all about", they joked amongst themselves.



1st prize – Stinger by Mendy Arp.

2nd prize – The "artwork" of Eyke Erk Schröder in the center of Berlin, a video of which could be viewed during the exhibition in Bremen.

3rd prize – Hands-on by Tim Klausing, Tilman Richter and Li Shu-Shi.

Competition for School Pupils: 286 Inspiring Entries

That it is not necessary to be in higher education to successfully translate adhesive bonding into art had earlier been emphatically demonstrated by German and Swiss school pupils in an art competition "Alles Kleben" that was initiated, planned and organized by Professor Dorothea Mink (HfK), Professor Andrea Rauschenbusch (HfK) and Beate Pohlendt (Landesinstitut für Lehrerbildung und Schulentwicklung Hamburg). This competition was also supported and funded by the Fraunhofer IFAM and the IVK. Once again the objective was to make adhesive bonding visible. The school pupils were given total freedom how to do this – to create an object, an image, a piece of clothing, etc. or a combination of these. There was huge interest in this competition, with the work being carried out both in class and in the pupils' free time. In total 286 works of art from 450 school pupils were submitted.

The 92 works of art which were ultimately exhibited in the Rathaus on the occasion of the IVK anniversary congress left many exhibition visitors amazed at the creativity in the minds of these children. "I am truly astonished by the diversity, carefreeness, openness and complexity of the exhibits here", stated Otto-Diedrich Hennemann as one of the promoters of this competition. Katharina Schill, for example, who is currently in the 12th school year at Kantonsschule Rychenberg (Winterthur, Switzerland), attached suckers to the end of colored wires, so making these "fun-sticks" suitable for bathtubs – by bending the wires new shapes and structures can be created – and "bonded" via the suction effect on the bath walls. A good idea which looks great and excellently represents the idea of "flexible connections". Her fellow pupils at the Kantonsschule Rychenberg also impressed with their works and one of the three school prizes went to this school. The other school prizes were awarded to the Julius-Leber-Schule in Hamburg and the Adolf-Kolping-Schule in Münster. Individual prizes were bestowed on Johanna Kirsten and Elisa Farid-Amin (both from Hamburg); eight year old Mikel Ohndorf-Lopez de Munain from Bremen received a special prize as the youngest participant.

One Hamburg teacher commented: "The competition was enormously beneficial for art classes at school because of the number of ideas that came forth". A whole dress made of threads of

adhesive from an adhesive gun; animals shaped from chewing gum and Klebgummi; the "stickiness" of foods and confectionery made visible; a jacket made solely of newspaper advertisements bonded together; a plaster cast chair onto which many colored buttons had been glued: it would truly take up far too much space in this article to mention the full wealth of ideas. Considering the competitions for students and school pupils, the exhibits on display in the Rathaus and in the Marktplatz, the presentation for IVK members and tours for the wider public, what is clear is that rarely before has the phrase "Adhesive bonding connects!" been brought to life in so many ways.

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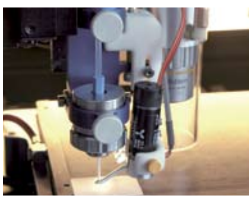

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