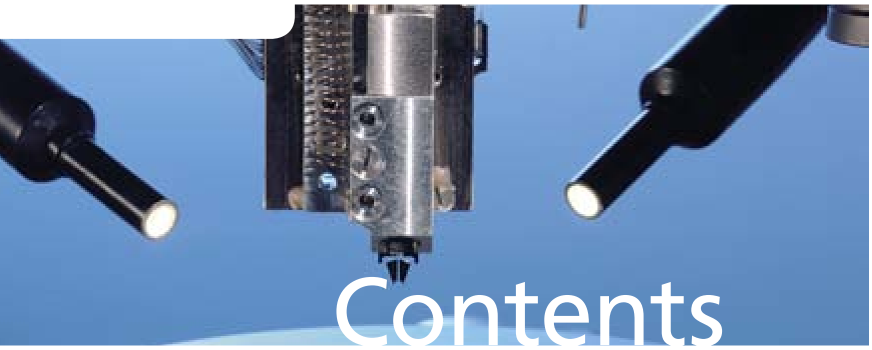
Fraunhofer Institut
Fertigungstechnik
Materialforschung

05

Annual Report 2005

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

Annual Report 2005



Contents

A Profile of the Institute

Department of Adhesive Bonding Technology and Surfaces

Department of Shaping and Functional Materials

The whole is greater than the sum of the individual parts

Ladies and Gentlemen,
business associates and co-operation partner loves,
promoter of the IFAM loves!

"The whole is greater than the sum of the individual parts".

Perhaps it will come as a surprise to you that the foreword to the 2005 annual report starts with a quotation that has been used through the ages by a great many people on a wide variety of occasions.

It is our belief that this quotation aptly describes the goals IFAM has set itself, namely:

To offer expertise, know-how and services as a total package, to meet the individual demands of each specific customer, to increase the effectiveness of collaborative work and to hence offer customers and partners added value.

Using selected articles, this annual report shows the progress IFAM has made in 2005 towards reaching those goals. The path IFAM is following will be continued over the coming years.

The past year has seen our activities in Casting Technology and Functional Structures expanded. The integration of extended functionality into structural components is being very actively pursued. The casting and printing of electronic components are mentioned here as examples. These new technological developments are creating many opportunities for collaborative projects with industrial partners.

In conjunction with the Fraunhofer Institute for Structural Durability and System Reliability (LBF) in Darmstadt, the Fraunhofer Center for Wind Energy and Maritime Engineering has been founded in Bremerhaven. The main focus will be on offshore wind energy and a special test area has been set up for this in Bremerhaven. From 2006 onwards, wind turbine constructors and their suppliers who plan, develop and build maritime structures will be able to utilize the Fraunhofer know-how in Bremen and Darmstadt and benefit from collaborative work with Fraunhofer experts.

Both the aforementioned areas are presenting the Fraunhofer IFAM with new opportunities for joint projects.

Our goal will be reached when our customers and partners view the Fraunhofer IFAM as more than the sum of its employees, business fields and expertise and as a highly professional, efficient partner for successful collaborative work.

Reflecting on the past year it can be concluded that the Fraunhofer IFAM has made substantial progress towards reaching its goal. This was only possible due to the trust shown by our customers and partners and the sterling work of our employees. We would like to gratefully thank all concerned.

O.-D. Hennemann

M. Busse

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

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 organisation wanting to continuously provide its customers with added value at different levels faces a constant challenge. All parts of the organisation must be optimally integrated.

Professor Dr. Hennemann

Professor Hennemann, the expertise of the Department of Bonding Technology and Surfaces comes from the skills of the individual "parts". Knowledge and experience come from individual employees, work groups, organisational 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 research and development 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 brings his/her experience, specific characteristics and very own individuality. All these aspects characterize a person in their 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 organisational unit is then formed from several work groups. These organisational 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 organisational 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 recognise 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 utilised by industry. This is a "skill" which IFAM success depends on.

The people in the work groups and organis-ational units have different interests and knowledge. These are efficiently integrated to give "effective multidisciplinarity". How does this function at the Fraunhofer 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 benefited from throughout the institute. This generates the practical expertise which we can offer customers. Customers then recognise 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 organisational 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 organised? 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 organise 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.

"One step closer to our vision and the turn-around has been achieved"

Professor Matthias Busse smiles: We navigate the right course and a "fresh wind" has allowed our creative and motivated staff to acquire new projects in 2005 as a result of their innovative work. In collaboration with strategic partners, realisation of our vision of manufacturing intelligent components has become ever closer.

Professor Dr.-Ing. Busse

Professor Busse, it has been almost three years since you took over the Department of Shaping and Functional Materials at Fraunhofer IFAM. Now, at the end of 2005, how do you assess your department's position?

2005 was a crucial year for our department. In retrospect, we can say that the course we set in 2003 and 2004 is now showing its positive effects. Such a strategic reorganisation takes a certain time in a research organisation like Fraunhofer IFAM to bear fruit. On the one hand, this is due to the fact that the initiation of major industry projects and also publicly funded projects require a considerable lead time. On the other hand, it takes a while until our modified and expanded work portfolio becomes widely known and registers in the awareness of our customers and partners. However, the positive results of this are now becoming evident.

How do you evaluate and measure the positive effects of the strategic reorganisation?

Some aspects can naturally be easily represented by figures, whilst other aspects have to be recognised implicitly. The economic facts relating to both the past and the future must be mentioned first of all. We have fought our way out of a difficult financial situation in just two to three years and with choppy waters behind us we have now set sail on a new, successful course – if I may say so as an enthusiastic sailor. In industry this would be called a classic turn-around. In 2005 we made key progress. We already have a highly promising project situation and so the outlook for the next two years is very bright.

Does that mean that the new work areas have been positively received by customers?

That is certainly so. On the one side we were very pleased to be able to initiate new projects with customers in our established research areas, involving for example our expertise in powder-metallurgical materials and processes in Bremen and Dresden. On the other side, our new work areas, which largely concern micro-structuring and nano-structuring, have attracted much interest from many sectors of industry and were able to give impulses for many an innovative approach. Our work in the area of casting technology is also benefiting from new ideas which we have been able to successfully implement. For example, we have been able to expand our long-standing experience in the casting of sensitive structures by successfully integrating piezoceramic sensors and actuators and even RFIDs – electronic devices for wireless communication – into cast components.

A year ago you coined the motto "Smarter – smaller – safer". To what extent does this motto still apply now and what work is being carried out to achieve this?

"Higher – faster – further" is the motto for maximum performance in sports. At Fraunhofer IFAM we are concerned with technical and scientific performance and application-oriented implementation. For that reason, the motto "smarter – smaller – safer" applies to our work more than ever. And naturally that is reflected in the thematic areas of our research.

"Smarter" is relevant because we are intensively working on the integration of structural and functional materials into production processes. This involves incorporating sensory and actoric abilities into components without having to mount sensors to the components in a subsequent assembly step. We so want to confer a certain intelligence or at least sensitivity on components. This however also means function-integration in the sense of reducing the number of production steps. Our "Functional Printing" technology platform is playing a key role here, for example for printing electronic structures on virtually any desired surface.

"Smaller" is appropriate because our activities in the area of micro-production are being further expanded. We have been able to build on our powder-metallurgical know-how and have qualified the micro-MIM method, that is, micro metal injection moulding, as a core shaping and production method for small and micro components. As is the case for larger components, 2C technology – namely the combination of two materials in a single component within a single processing step – is playing a trend-setting role and this is also so with regard to function-integration.

The third keyword in our motto, "safer", is also playing an important role. This concerns the safe design of lightweight structures, a feature that is being demanded in many applications, for example in the aircraft and car manufacturing industries. Our goal is to produce components that record, evaluate and communicate their operating status as well as their operational environment.

If a technical component experiences "pain" and communicates this long before it "fractures or fails", completely new ways of developing and designing components can be pursued.

This approach sounds very visionary. How will the required know-how be accumulated?

First of all, the IFAM team has many years of acquired know-how in materials science and production technologies to call upon. In addition, this approach also requires knowledge of electronics, data transfer and system reliability and therefore overlaps with the field of adaptronics, which is one of the leading-edge innovations of the Fraunhofer-Gesellschaft. I believe there are huge opportunities for collaborating with partners in the Bremen region, with other Fraunhofer institutes and naturally in partnerships with industry. We will therefore not do everything alone, but will rather embark on strategic partnerships that offer a win-win situation.

Your activities at the University of Bremen are also demanding. How has the situation there developed?

Very positively. I have intensified collaboration with my colleagues from the production technology faculty. This has increased the mutual understanding of common objectives. As a result, collaborative projects have been set up for the next three years and these offer new opportunities for everybody. This has however also extended beyond the area of production technology, because I believe there are excellent opportunities for carrying out joint projects with colleagues working, for example, in the fields of physics and electrical engineering. And if we also make further headway in the area of biology – and the first fascinating ideas in this area are already on the table – then I believe my objective of creating intelligent components in collaboration with the engineering sciences and with input from biology will be very much closer.

That all sounds very promising. In your opinion what has been the key to the success that has been achieved to date?

The motto of this year's annual report says it all: the whole is many times greater than the sum of the parts and this is certainly very true as we reflect on this past year. Plainly spoken, this means that our success was a team effort. Working as individuals we would not have achieved success – but we have because we have worked together, with an energy and dedication that has been first-rate. I was referring to that earlier, when I mentioned the factors that cannot be directly recorded in figures: The motivation of the whole team is very high and the attitude is optimistic. It is great to see how much creativity there is at Fraunhofer IFAM. This creativity was the key to success in the past and will be the key for our future success.
I would like to take this opportunity here to express my recognition and thanks to everybody for their hard work.

What about the immediate future? What is planned for 2006?

We will primarily continue on the course we have set. In 2005 we drew up plans for increasing the workforce in the years ahead. This will allow us to further expand our work activities. We have many ideas which could lead to collaboration with partners and new core areas of work under the banner "Intelligent components". I am optimistic that in a year's time we will be able to report further success and progress.

A Profile of the Institute

A Profile of the Institute

The Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) undertakes research and development work in the following areas:

Adhesive Bonding Technology and Surfaces, and Shaping and Functional Materials.

The Adhesive Bonding Technology and Surfaces department at IFAM offers industry qualified development work in adhesive bonding technology, plasma technology and paint/lacquer technology. The demand for these services comes from a host of companies in a broad range of industries. Currently our most important customers and markets are the vehicle construction sector – aircraft, road vehicles, rail vehicles, ships – as well as their sub-suppliers, the machinery and plant construction sector, the electrical and electronics industries, household appliance construction and medical engineering as well as information technology and communications technology.

A service that complements the research and development work and one that is used by all sectors of industry is the certified training in adhesive bonding technology. Following the successful introduction of certified training courses in adhesive bonding technology in German-speaking countries and more recently in other European countries, the courses are now also being held in the USA for multinational companies.

The Adhesive Bonding Technology business field is split into the following work groups: adhesives and polymer chemistry, biopolymers, application technology, manufacturing technology, bonding in microproduction, and materials and construction methods.

Plasma technology, which comprises the low pressure plasma technology and atmospheric pressure plasma technology work groups, and the paint/lacquer technology work group fall under the Surfaces business field.

These two business fields are complemented by the Adhesion and Interface Research business field which comprises work groups in applied surface and layer analysis, electrochemistry and molecular modelling.

The Department of Shaping and Functional Materials has facilities in Bremen and Dresden and focuses on three core areas of expertise: casting technology and light metal technology; microstructuring and nanostructuring; powder technology and sintering technology. These areas are reflected in the organisation of our R&D activities into seven fields of expertise:

- Functional structures
- Casting technology
- Lightweight materials and analysis
- Micro engineering
- Powder technology
- Sintered and composite materials
- Cellular materials.

For marketing our services, these fields of expertise form the basis of our business fields: metals – precision components and processes; high-performance materials and functional surfaces; medical engineering; biomaterials; lightweight construction.

Our R&D work largely involves the activity triangle: materials – shaping – components.

The incessant trend towards lightweight construction means that industry is continuously demanding a reduction in the quantity of materials used in vehicles, machines and equipment. In order to meet this requirement, novel lightweight construction materials and casting processes have been developed in recent years.

New opportunities for component miniaturisation are possible using for example the µ-MIM process. The components that have been manufactured to date find application in micro-drive technology, electronics and medical engineering.

The development of new materials and components not only involves improving the mechanical properties and shaping properties. So-called "smart materials" are increasingly becoming the focus of interest. Fraunhofer IFAM develops manufacturing processes which allow the integration of special functions into materials and components. The aim is to tailor components with functional properties in such a way that structural and functional materials are integrated to form smart products.

Brief Portrait and Organigram

Founded in 1968 as the work group for applied materials research, the institute has since that date systematically expanded the scope of its work in manufacturing and processing technology by undertaking research and development activities in the area of joining techniques (welding, brazing/soldering, adhesive bonding, thermal injection).

The institute has sites in Bremen and Dresden.

Professor Hans-Dieter Kunze led the institute from 1976. In 1994 Professor Dr. Otto-Diedrich Hennemann became part of the institute management team. Professor Kunze's successor was made known in October 2002 – and in April 2003 Professor Matthias Busse took up his position in the institute management.

The institute is neutral and independent and is one of the largest R&D establishments in Europe in the area of Adhesive Bonding Technology and Surfaces and Shaping and Functional Materials.

IFAM belongs to the association of 58 independent research institutes of the non-profit making Fraunhofer-Gesellschaft. The Gesellschaft currently totals about 80 research organizations throughout Germany at over 40 different locations. Some 12,500 employees, most of whom are highly qualified scientists and engineers, work on research projects having an annual budget of over a billion euros. More than 900 million euros of this come from contract research. The Fraunhofer-Gesellschaft obtains about two-thirds of this sum from contracts with industry and from publicly financed research projects.

In 2005 the total IFAM budget amounted to about 21.8 million euros. The workforce comprised some 270 employees, with more than half being scientists, Ph.D. students and student auxiliaries.

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

Associate director: Dr.-Ing. Helmut Schäfer

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

Associate director: Dr.-Ing. Frank Petzoldt

Professor Dr.-Ing. Bernd Kieback
Managing director of the Dresden site

Andreas Heller
Head of administration

The Institute in Figures

Budget

The total IFAM budget (expenditure and investment) in 2005 comprised the budgets of the Department of Shaping and Functional Materials and the Department of Adhesive Bonding Technology and Surfaces.

The provisional budget result was in total 21.8 million euros.
The results for the two individual sites are shown below.

Adhesive Bonding Technology and Surfaces
Bremen

Operating budget	11.8 million euros
Own income	7.3 million euros
including	
Business income	6.4 million euros
Federal/state/EU/other	0.9 million euros
Investment budget	0.7 million euros

Shaping and Functional Materials
Bremen

Operating budget	4.7 million euros
Own income	2.6 million euros
including	
Business income	1.8 million euros
Federal/state/EU/other	0.8 million euros
Investment budget	1.6 million euros

Shaping and Functional Materials
Dresden

Operating budget	2.9 million euros
Own income	2.2 million euros
including	
Business income	1.3 million euros
Federal/state/EU/other	0.9 million euros

Figs. 1 and 2 show how IFAM's budget and income have changed over the period 2001–2005.

Investments

During 2005, IFAM investments amounted to 2.3 million euros, split as shown below. The most important acquisitions are indicated.

Adhesive Bonding Technology and Surfaces
Bremen
(0.7 million euros)
- Laser-Plasma-Analyser LIPAN 3002 for the detection of laser induced plasma emission
- Device for Electrochemical Impedance Spectroscopy C14+FAS2
- Chamber filter press
- Automatically foil winding machine
- Robot controlled plasma jet
- Measuring system for the topography of components

Shaping and Functional Materials
Bremen
(1.6 Mio. million euros)
- Printing technology for maskless mesoscale deposition of materials (M3D)
- Rheometer
- Profile meter
- Quality assurance for micro parts
- Kneading heads
- Plant components for Lost-Foam-Casting: Pre expander, drying oven, foam moulding machine, test moulds, steam generation plant and analysis equipment

Workforce

On 31 December 2005 IFAM employed a total of 270 people (90 percent of which in scientific/ technical areas).

Compared to the previous year, the number of permanent employees rose by 7 percent.

Workforce structure 2005

Scientists	104
Technical employees	76
Administration/internal services and work placement students	26
Ph.D. students, trainees and auxiliary staff	64

The growth in the workforce over the period 2001–2005 is depicted in Fig. 3.

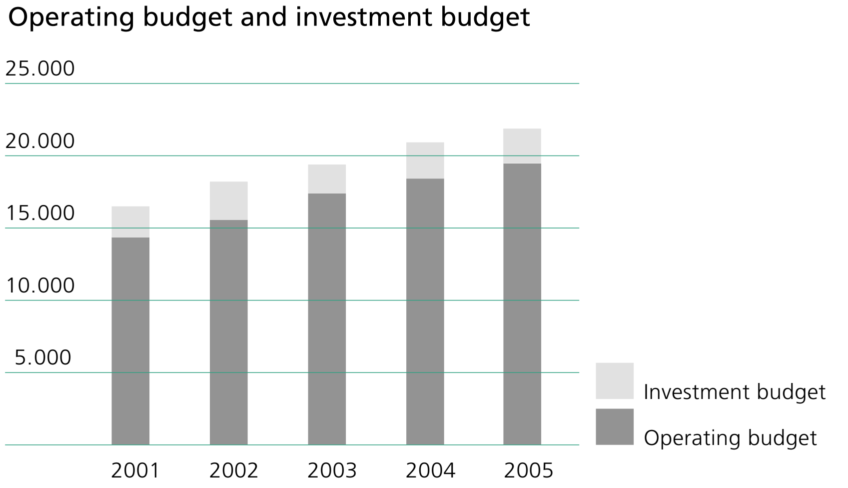


Fig. 1: Total expenditure of IFAM

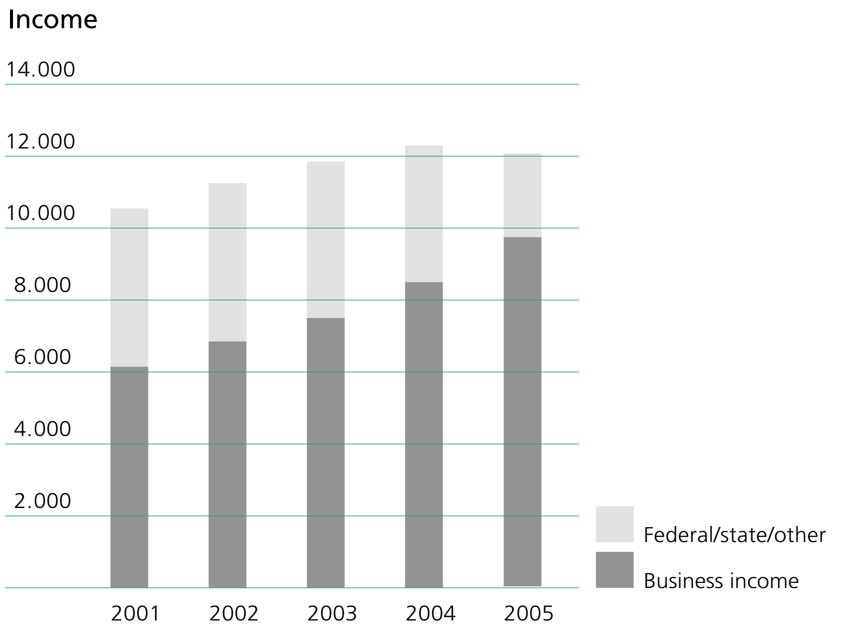


Fig. 2: Total income of IFAM

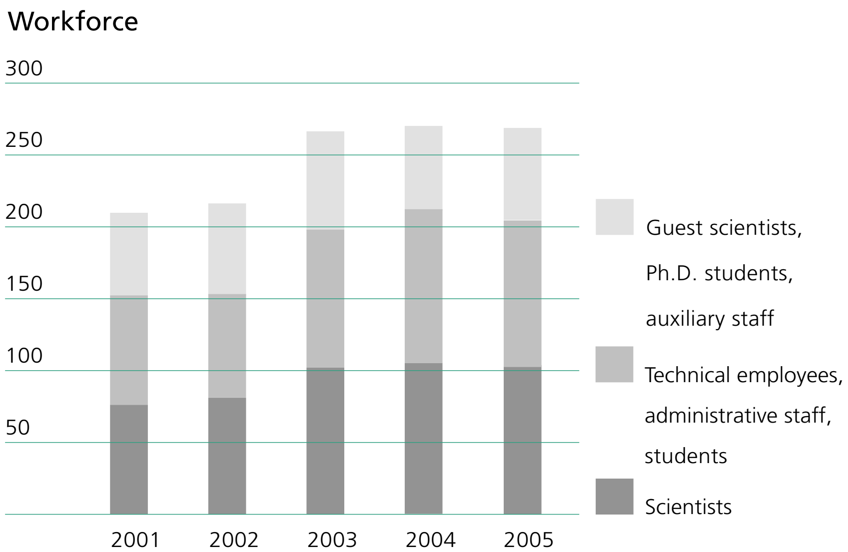


Fig. 3: Total number of employees at IFAM

The IFAM Advisory Board

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Fraunhofer-Institut für Silicatforschung
Würzburg

Science in Bremen

Science has special importance for Bremen: It drives structural change and provides vital impetus for the economic and social development of the region.

Innovation is very evident here and arises from the involvement of Bremen scientists in international research networks. Whereas in the past it was trade that made Bremen a cosmopolitan city, it is today science that links Bremen with the world.

The active scientific community in Bremen is not only characterised by the close collaboration between the university, technical colleges and research organisations but also by the almost unique fusion of science, commerce and politics. Five years ago, this close linking of science with the business community, politicians and citizens resulted in the city marketing itself as "City of science Bremen-Bremerhaven". It is also the chief reason why Bremen/Bremerhaven was named the German "City of Science 2005". This title, which is recognition by the Stifterverband für die Deutsche Wissenschaft for successful science transfer and good communication between the scientific community and the public, represents a further successful step towards changing the image of Bremen – from being merely a shipping and commercial city to being a center of technological innovation.

Regarding the scientific community here, the expertise in material sciences represents one of the most important competence clusters and a major commercial asset for the region. The Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) plays a key role in the interplay between university/technical colleges, research organisations and technology companies and is ideally situated close to the University of Bremen and the Technology Park. The work of IFAM's two departments, Adhesive Bonding Technology and Surfaces and Shaping and Functional Materials, ideally complements the materials science activities of the University of Bremen and ties in excellently with the innovation marketing policy, InnoVision 2010, of Bremen. Despite the high priority given to science funding by Bremen, savings of about one hundred million euros have to be made by 2010. As a result, 35 lecturer posts in the university alone will have to be abolished. I am certain that the alliance of materials science institutions will continue to represent a stable and important element in the scientific community in Bremen and will provide key assistance to local businesses, in particular to the aircraft manufacturing and aerospace industries, shipbuilding and energy technology.

Reinhard X. Fischer, Member of the IFAM advisory board, Assistant Principal for Research and Science Recruitment at the University of Bremen

The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration. The organisation also accepts commissions and funding 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.

By developing technological innovations and novel systems solutions for their customers, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. Through their work, they aim to promote the successful economic development of our industrial society, with particular regard for social welfare and environmental compatibility.

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.

At present, the Fraunhofer-Gesellschaft maintains some 80 research units, including 58 Fraunhofer Institutes, at over 40 different locations in Germany.

The majority of the roughly 12,500 staff are qualified scientists and engineers, who work with an annual research budget of over 1 billion euros. Of this sum, more than 900 million euros are generated through contract research. Roughly two thirds of the Fraunhofer-Gesellschaft's contract research revenue are derived from contracts with industry and from publicly financed research projects. The remaining one third is contributed by the German federal and Länder governments, partly as a means of enabling the institutes to pursue more fundamental research in areas that are likely to become relevant to industry and society in five or ten years' time.

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 was founded in 1949 and is a recognised non-profit organisation. Its members include well-known companies and private patrons who help to shape the Fraunhofer-Gesellschaft's research policy and strategic development.

The organisation takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

The Fraunhofer Materials and Components Alliance

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

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

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

Some areas in which the Group is concentrating its efforts in the medium term include:

- boosting the efficiency of power conversion and energy storage systems
- improving the biocompatibility and functioning of materials used for medical technology or biotechnology
- increasing the integration density and improving the service properties of components used in microelectronics and microsystem technology
- enhancing safety and comfort while reducing the consumption of resources in transport engineering and machine and plant construction.

The Fraunhofer Materials and Components Alliance

The institutes

Fraunhofer EMI
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Fraunhofer IBP
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Prof. Dr. Klaus Sedlbauer

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Internet www.ict.fraunhofer.de

Fraunhofer IFAM
Institute for Manufacturing Technology and Applied Materials Research
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Prof. Dr. Matthias Busse

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Fraunhofer WKI
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Guest Institute:

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Deputy chairman
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Katja Okulla
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For further information please look at:
www.vwb.fraunhofer.de

The Fraunhofer Polymer Surfaces Alliance (POLO)

The Fraunhofer Alliance for Polymer Surfaces brings together the individual expertise of seven Fraunhofer Institutes and develops innovative concepts for the functionalization of polymer surfaces. Fraunhofer POLO is the ideal partner for companies that manufacture and process plastics and for users of plastics. The POLO Management is your partner from the conception of the project right through to implementation in production. The management coordinates the expertise and know-how of the seven institutes.
The institutes possess state-of-the-art analytical equipment for the characterization and analysis of polymeric materials, surfaces and thin layers. The pilot-plant facilities are second to none.
The institutes have expertise in the following areas: processing polymers; encapsulation of polymeric materials; development of functional coating materials; laminating/bonding; molecular design, characterization of polymer structures; polymer processing technology: flat products, injection moulding, deep-drawing, manufacture of laminates, coating, surface modification; roll-to-roll processes for web materials as well as techniques for high-area flat substrates and 3-dimensional components; scale-up, process reliability and automation of treatment and coating processes.

Contact person

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Members

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

The Fraunhofer Nanotechnology Alliance

A buzzword nowadays is nanotechnology, a bundle of cross-cutting 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 with us in everyday life, e. g. in UV-absorbing nanoparticles in sun cremes, nanoparticle reinforced car tires, in easy-to-clean surfaces or scratch resistant coatings. The technology itself is cross-cutting branches and industries dealing with very different applications.

Nearly one third of the currently 58 Fraunhofer Institutes are working in the field of nanotechnology. Manifold competencies and a great number of ideas for developments were compiled before the foundation of the Fraunhofer Alliance for Nanotechnology. The activities were focused on leading themes like multifunctional layers e. g. for automotive applications, the design of special nanoparticles as carrier substance for biomedical applications as well as the use of carbon nanotubes for actuatoric applications.

Contact person

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Members

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

The Fraunhofer Alliance for Numerical Simulation of Products and Processes

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

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

Contact person

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Members

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

The Fraunhofer Adaptronics Alliance

The constantly growing demands on modern structure systems today increasingly cause conventional passive as well as active mechatronic approaches to reach their technical and economic feasibility limits. Adaptive structure technology, in short adaptronics, is an innovative, new cross-sectional technology for the optimisation of structure systems and is included as one of Fraunhofer-Gesellschaft's twelve guiding innovations.
It is based on a function integration by combining conventional structures with active material systems, which extend the classic load-bearing and form-defining structure functions to include sensor and actuator functions. In connection with suitable adaptive controller systems, adaptive structure systems can optimally adapt to their respective operational environment.

In this alliance the competences of these twelve 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.

Contact person

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Members

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

The Fraunhofer Network for Photocatalysis

The Fraunhofer Network for Photocatalysis offers a wide spectrum of research and development services in the area of photocatalysis, from drafting the first notes to a finished solution for the end user. There are many possibilities for cooperation – from advice about joint projects to material, layer, and product development, from prototype and small batch production up to transfer of our technology into your business.

The goal of the alliance is to develop new more effective and efficient photocatalysts. Photocatalytically active layer systems have the following uses: to make self-cleaning surfaces; to destroy bacteria, algae and fungi; to purify air; to reduce misting on glass and mirrors.

Contact person

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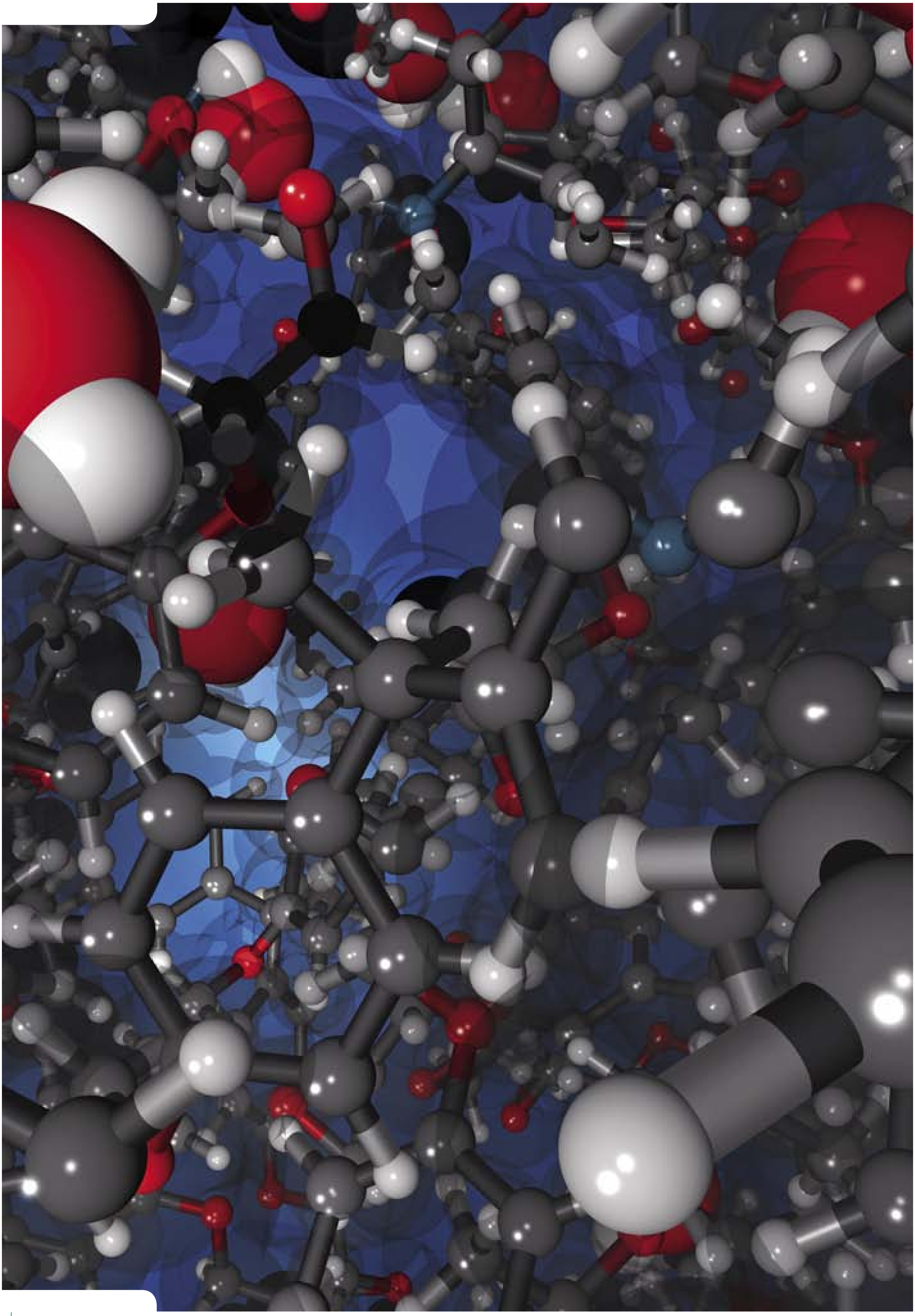
Members

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



Department of Adhesive Bonding Technology and Surfaces

Results Applications Perspectives

←

Molecular model for the transport of water in a polymer coating.

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 largest independent research group in Europe working in the area of industrial bonding technology. Over 120 employees are actively engaged in applied R&D work in adhesive bonding technology and surface technology. The scope of the work extends from fundamental research right through to production and market introduction of new products. The industrial application fields are chiefly vehicle manufacture and mechanical engineering, energy technology (principally wind and solar energy), micro-production and the packaging and electrical industries.

The Adhesive Bonding Technology business field is concerned with the development and characterization of adhesives, the optimized design and simulation of bonded and hybrid joints and their testing and qualification. The planning and automation of adhesive bonding at an industrial scale are also carried out. Further areas of work are process reviews and the provision of certified training courses in adhesive bonding technology. The surfaces business field is split into the work groups Plasma Technology and Paint/Lacquer Technology. Customized modification of surfaces – for example pretreatment of surfaces prior to bonding or coating and corrosion protection coatings – considerably extends the range of uses of many materials.

One area of work which extends to both these business fields is Surface and Interface Analysis. The fundamental knowledge acquired here contributes to the effectiveness of bonded joints and coatings.

The Department of Adhesive Bonding Technology and Surfaces is certified in accordance with DIN EN ISO 9001 and the material testing laboratory is also accredited in accordance with DIN EN ISO/IEC 17025. The Center Adhesive Bonding Technology is an internationally recognised organisation for providing employee training courses in adhesive bonding technology and is accredited by the DVS-PersZert® in accordance with DIN EN ISO/IEC 17024.

Perspectives

When new technologies are introduced or when existing technologies are modified, industry puts high requirements on process safety and reliability. These requirements are taken into account as a matter of course in all research and development work carried out by the Department of Adhesive Bonding Technology and Surfaces and indeed determine the direction of our work. Innovative products are developed in collaboration with the customers and these products are then introduced to the marketplace. The manufacturing technologies are playing an ever more important role here because production processes of high quality and reproducibility are preconditions for market success.

Adhesive Bonding technology is an established joining technique in the car manufacturing industry but its potential is far from exhausted. A few examples of the broad range of activities of the institute are lightweight materials and structures for resource-friendly transport, recycling and the related issue of customized detachment of adhesive bonded joints, and the use of nano-scale materials in adhesive development and modification.

In order to open up new opportunities for adhesive bonding technology, bonding processes and the bonded products must become even safer and more reliable!

This is at the fore in all our work. This objective can only be achieved if all stages of the adhesive bonding process are integrated and consideration is taken of all aspects:

- Application-specific selection, qualification and, where appropriate, modification of the adhesive;
- Design of bonded structures using numerical methods (e. g. FEM);
- Pretreatment of surfaces and evaluation of corrosion protection requirements;
- Evaluation of the steps in the adhesive bonding process via simulation methods and integration into the production process;
- Selection and dimensioning of application devices;
- Training in adhesive bonding technology for all persons involved in the product development and manufacture.

The Department of Adhesive Bonding Technology and Surfaces is using computer-aided methods to an increasing extent. Example applications are the digitisation of processes in the area of production planning and the multi-scale simulation of the molecular dynamics at the molecular level, right through to macroscopic finite element methods for the numerical simulation of materials and components. The use of various spectroscopic, microscopic and electrochemical techniques is giving new insight into degradation and corrosion processes in composite materials. These instrumental tests and accompanying simulations are giving IFAM new knowledge which the empirical test methods based on standardized ageing and corrosion tests cannot provide.

Other key questions for the future are: Where and how is bonding technology used in nature? What can we learn from this for industrial adhesive bonding technology? Studies are already being carried out on a variety of topics ranging from the mechanism of bio-adhesion at a molecular level right through to macroscopic adhesives made from proteins. The need to make processes and products even safer and more reliable is not however limited to adhesive bonding technology. It also applies to plasma and surface technology. Sectors of industry where there are high requirements regarding surface technology are utilising our expertise. Renowned companies, in particular in the aircraft manufacturing and car manufacturing industries, are amongst our many customers.

Main areas of work

- Formulation and testing of new polymers for adhesives, laminating/casting resins, right through to industrial introduction
- Development of additives (nano-fillers, initiators, etc.) for adhesives
- Synthesis of polymers with superstructures and biopolymers
- Computer-aided material development using quantum mechanical and molecular mechanical methods
- Introduction of international training courses for European Adhesive Bonder, European Adhesive Specialist and European Adhesive Engineer
- Manufacturing technology
- Development of innovative joining concepts, e. g. for the car manufacturing industry (bonding, hybrid joining)
- Application of adhesives/sealants, filling compounds (mixing, dosing, application)
- Bonding in micro-production (e. g. electronics, optics, adaptronics)
- Computer-aided production planning
- Economic aspects of bonding technology / hybrid joining
- Constructional design of bonded structures (simulation of the mechanical behaviour of bonded joints and components using finite element methods, prototype construction)
- Development of environmentally compatible pretreatment methods for the durable bonding of plastics and metals
- Functional coatings using plasma techniques
- Qualification of coating materials and painting/lacquering techniques
- Development of paint formulations for special applications
- Determination of key parameters, alternating fatigue strength and operating strength of bonded and hybrid joints
- Modelling of adhesives and polymeric materials (quasi-static and crash)
- Evaluation of ageing and degradation processes in composite/laminate materials
- Electrochemical analysis
- Evaluation and development of new corrosion protection systems.

Adhesive Bonding Technology and Surfaces
Fields of expertise and contact persons
Managing director Prof. Dr. Otto-Diedrich Hennemann

Adhesive Bonding Technology

Dr.-Ing. Helmut Schäfer
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E-mail sch@ifam.fraunhofer.de

Work groups

Adhesives and polymer chemistry
Development and characterization of polymers; nano-composites; network polymers; formulation of adhesives and functional polymers; chemical and physical analysis.
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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.
Dr. Klaus Rischka
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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.
Dipl.-Ing. Manfred Peschka
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Bonding in micro-production
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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Process reviews
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.
Dipl.-Phys. Klaus Vissing
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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
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Adhesion and Interface Research

Dr. Stefan Dieckhoff
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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; micro-tribology.
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Electrochemistry
Corrosion on metallic materials, under coatings and in bonded joints; investigation of anodisation layers; electrolytic metal deposition.
Dr. Michael Schneider
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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.
Dr. Peter Schiffels
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Service centers

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Technology Broker
Dr. habil. Hans-Gerd Busmann
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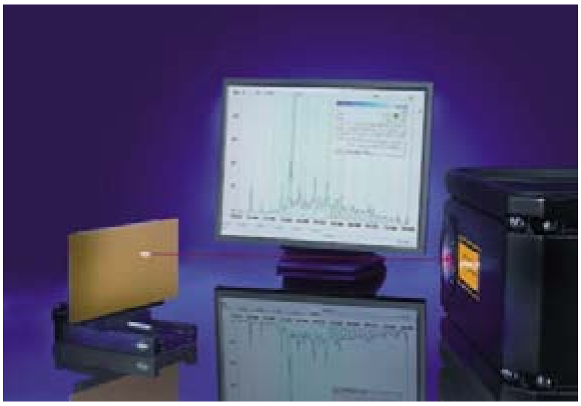
E-mail bu@ifam.fraunhofer.de

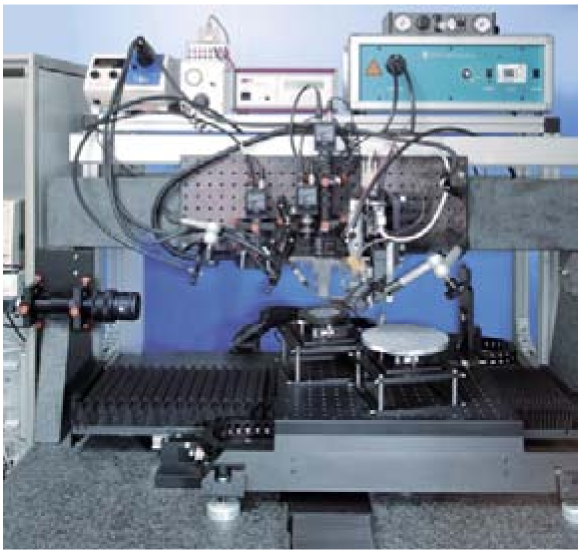
Equipment/facilities

- 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
- 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 characterisation
- Automatic equipment for peptide synthesis
- Light scattering for characterising 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 characterising the processing properties of polymer composites
- 12-axial robot for manufacturing micro-bonded joints
- Linux PC system with 64 CPUs
- Wave Scan DOI
- Colour measurement unit MA 68 II
- Laboratory dissolver
- Haze Gloss
- Automatic paint application equipment
- Paint drying unit with moisture-free air
- Fully conditioned spraying booth



Laser Induced Breakdown Spectroscopy (LIBS).

- 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
- UR hot-melt dosing unit for either bead or swirl application from 320 ml Euro-cartridges (own development).



Micro-assembly workplace at IFAM.

Internationalisation of training courses in adhesive bonding technology

Once a good idea has been accepted, a product has proved successful and a market has arisen then expansion is only a matter of time. This also applies to the training courses in adhesive bonding technology which the Center Adhesive Bonding Technology of the Fraunhofer IFAM has successfully carried out for the past 11 years. The wealth of experience we have gained from giving these courses to participants from German-speaking countries is now allowing the Fraunhofer IFAM to offer these courses beyond Europe in the USA, China, Japan and other countries. High-quality training courses such as those leading to DVS®-EWF Adhesive Bonder, DVS®-EWF Adhesive Specialist and DVS®-EWF European Adhesive Engineer certification are now absolutely essential, and this is also so at an international level. Indeed, the quality of these courses is the reason why Fraunhofer expertise in training is now recognised all over the world.

When the very first Adhesive Bonder training course was given at the Fraunhofer IFAM at the end of January 1994 it was limited to participants from German-speaking countries and it was not envisaged that the course would one day become an "export product". The IFAM course has acted as a cornerstone for market development of adhesive bonding as an advanced joining technique. With the rapid technological innovation in all areas of industry, including bonding technology, it soon became clear that the IFAM training courses had to keep pace with these developments in order to serve users in industry. Over a period of 10 years this has resulted in ever more comprehensive, detailed and customised training for staff working in this area.

Internationalisation was necessary

Further confirmation that internationalisation was necessary was the growing international interest in the contents and didactics of the Fraunhofer courses. Using interpreters for the respective languages, courses had already been given in Poland and the Czech Republic. Even the courses held in Bremen were being attended by an increasing number of participants from foreign countries. Internationalisation of the training courses was hence inevitable. The first international course was held in 2005 in Spartanburg (South Carolina) at BMW's largest plant in North America. Some 15 participants successfully took the 3-week DVS®-EWF Adhesive Specialist training course. This course represented new territory for the IFAM tutors and thorough preparation was essential. The final result however was a very successful course. The 15 participants comprised personnel involved in primary construction and sheet metal production, from both BMW and its suppliers.

Subsequent development steps led to further expansion. The success of the first course in the USA was encouraging and had allowed us to make contacts with key prospective partners. As of 2006 the level 1 (Engineer) and level 2 (Specialist) courses will be given worldwide in English. Detailed discussions are currently underway with the Adhesive and Sealant Council (ASC), the association of North American Adhesive Manufacturers, and the American Welding Society (AWS) to determine how best the IFAM training system can be transferred to these markets. If that was not enough, an agreement has been entered into with Henkel, the adhesive manufacturer, to provide the training courses in China. There is also interest in Japan and negotiations are underway with the government sponsored R&D Institute of Metals and Composites for Future Industries (RIMCOF). In conjunction with our Dutch partner, Sergem Engineering B. V., the training courses are also being marketed in the Benelux countries.

That there is huge interest in the USA in the our training courses is no coincidence. There, the Adhesive and Sealant Council (ASC) commissioned a study "Build the Industry – BTI" to evaluate the potential of adhesive bonding technology to replace or supplement other joining technologies. One of the key conclusions was that staff training is vital for this. The Fraunhofer IFAM, with its training courses, precisely meets American needs here. As industry in the USA will adopt an existing, proven and recognised staff qualification system, it will save considerable costs. The courses that have been held in Germany for many years are now being adapted for the American market.

* DVS = Deutscher Verband für Schweißen und verwandte Verfahren e. V.
EWF = European Federation for Welding, Joining and Cutting

Fig. 1: Theory work at the Center Adhesive Bonding Technology in Bremen.

The motto is "Train the trainer"

The international courses are being specially customised by IFAM personnel for international markets. The courses will be held by experts from the respective countries. The marketing of the specialist knowledge will take place via a type of franchise system. Prospective foreign tutors will acquire their know-how from the Fraunhofer IFAM. The motto is "Train the trainer". It will not only be adhesive bonding know-how that is passed to trainers but also didactics and methodology. After all, the proven system for the IFAM courses is the result of more than eleven years' acquired know-how, namely a wealth of experience that has developed into the quality training products of today.

In all its internationalisation activities the Fraunhofer IFAM is ensuring that its high quality standards are maintained. It is vital that all the courses in adhesive bonding technology are of the same high standard, wherever in the world they are held. The proven, successful training formula will be expanded internationally – this is better than trying to bring together and standardise individual working practices from all corners of the world in several years time. The integration of an already recognised system into many adhesive markets is the sole sensible solution in these times of globalisation. It will be ensured that the training courses held in all foreign countries are supra-company courses.

The Fraunhofer IFAM has benefitted in a number of ways from the success of its training courses. For example, it has truly managed to bring the term "technology transfer" to real life. Undisputable is that the training courses have led to increased acceptance of adhesive bonding technology in all sectors of industry. In addition, the training courses represent a first-class means of

Fig. 2: Practical assignments during the Adhesive Specialist course at BMW in Spartanburg, South Carolina (USA).

Fig. 3: In Spartanburg each participant who successfully completed the Adhesive Specialist course was presented with a medal.

quality assurance. The successful application of adhesive bonding technology in companies is the result of having highly-trained adhesive bonders, adhesive specialists and adhesive engineers to hand. Confidence in the reliability of bonding technology has increased significantly – and that is our objective.

Project acquisition via staff training

Employee training has for the Fraunhofer IFAM long been an indispensable instrument for successfully acquiring industry funded R&D projects. In general, those people who participate in training courses are the decision-makers of both today and tomorrow. Direct contact with people and technical discussions not infrequently result in concrete projects. As the Fraunhofer IFAM covers all aspects of bonding technology, companies that use adhesives can be appraised as a whole and improvements can be proposed – from the planning stage for a bonded product right through to repair aspects. By having a detailed insight into companies, the training material can be constantly customised and improved.

The international involvement of the Fraunhofer IFAM in training is co-funded by the Industrieverband Klebstoffe (IVK), the Deutscher Verband für Schweißtechnik und verwandte Verfahren e. V. (DVS) and the Land Bremen. For example, for the IVK the internationalisation of Fraunhofer IFAM courses, which are recognised throughout Europe, is an ideal tool for market expansion – and an aid for colleagues all over the world. It is also clear to the DVS and the Land Bremen that the IFAM training courses are of huge benefit wherever adhesives are used for structural bonds and hence wherever high-tech applications arise. For that reason, the courses represent an initiative that is very worth supporting.

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Computational chemistry in adhesion and interface research

Modelling of atomic structures as a tool for applied materials research and development

Computer-aided materials research opens up new opportunities for product and process optimisation

Over recent years, computer-aided simulation techniques have become an important tool in all branches of materials science. This growing significance is due to the fact that modern numerical techniques allow various aspects including both properties and behaviour of materials to be simulated on a computer. The range of applications extends from molecular structure simulations right through to the design of complex work pieces and production processes. The term "Computational Chemistry" covers a branch of chemistry that involves simulation at the molecular level and which focuses on the prediction of chemical processes and structural aspects. Experimental work can thus be complemented by molecular scale simulations which provide new opportunities for research that extends the limits of actual experimentation. At the outset, Computational Chemistry was initially used in a variety of disciplines as a specialised, niche technique. Its use has in the meantime become extensive and it is now well-established as part of the Computational Materials Science.

In the Fraunhofer-Gesellschaft, the potential of computational modelling techniques was recognised at an early stage. "Simulated Reality: Materials, Products and Processes" was designated one of the twelve innovative areas under the "Signposts to Tomorrow's Markets" banner. The importance of simulation techniques in all areas of materials development is hence realised.

In adhesive bonding technology as well as in many areas of surface technology, meeting the ever higher requirements being put on bonded materials and functional coatings is a constant challenge. One of the most important applications of Computational Chemistry at the Fraunhofer IFAM hence concerns the study of molecular mechanisms at interfaces and chemical reactions in bonded joints and in coatings. The Fraunhofer IFAM possesses state-of-the-art equipment for carrying out these simulations using high-performance Linux clusters. In addition to possessing highly specialised technical knowledge about the physical and chemical properties of surface structures, interfaces and coatings, a key factor for success in this area is also expertise with computational techniques.

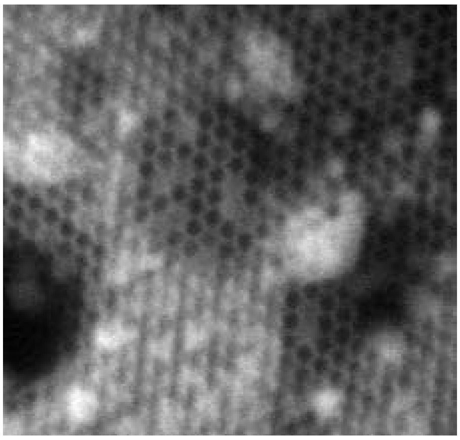

Fig. 1: Electron micrograph (HRSTEM) of zeolite MCM-41. The hexagonal pores in the material can be seen as a honeycomb-like structure. The light areas are larger particles of tin oxide (Sample: M. Wark, University of Hannover).

Chemistry at surfaces and interfaces

Unique features in the atomic structure are often the key to the special properties of a material. For example, the microscopic pores in zeolites, which measure just a few nanometers, determine their ability to function as molecular sieves and result in specific interactions when particles are present in the pores (Fig. 1 and 2). Molecular interactions are also of special significance for adhesives since it is often desired to determine the main mechanism of adhesion on a substrate. A further example are degradation processes – namely changes or damages caused by environmental factors. This degradation can be induced by electrochemical reactions at the interfaces of metallic components. The resulting corrosion can

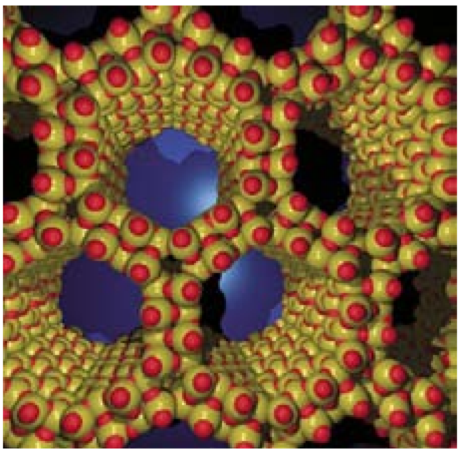

Fig. 2: Computer model of the hexagonal pores in zeolite MCM-41.

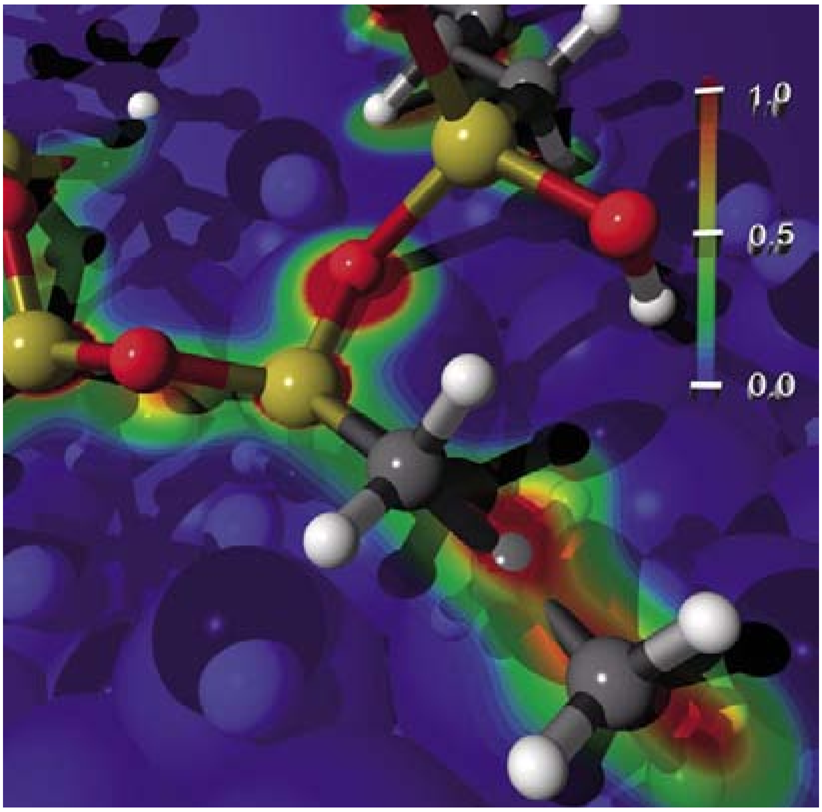

Fig. 3: Representation of the calculated electron density distribution in the surface region when components of an adhesive come in contact with an aluminium substrate. The colour-scale indicates the distribution of the electron density in the surface region.

affect the long-term reliability of the material. In such systems, the underlying chemical reactions cannot always be fully clarified, even by carrying out many experimental studies.

Computational Chemistry can help elucidate the mechanisms of such reactions at a molecular level. An advantage of the simulation is that it permits the study of model structures, which cannot be directly measured by experiment. An example of this is the interaction of adhesive components at aluminium surfaces (Fig. 3). As the bonding is determined by the electron density in the surface region, simulations need to rely on accurate and highly efficient computational codes based on Density Functional Theory (DFT). Consideration of the reactions at the interface at a molecular level also helps to interpret the analytical findings since the calculated electron density can be used to predict experimentally expected X-ray Photoelectron Spectra (XPS). This allows statements to be made about the nature of the bonds and comparisons to be made between the simulated models and real material properties.

Concentration and structure formation at interfaces

Any tendency of individual substances in an adhesive or coating to concentrate at interfaces can have a considerable effect on the resulting properties. In many cases, additives which undergo specific interactions with the material surface are employed. Certain additives can be used to increase the adhesion to the substrate or to provide active corrosion protection for coatings. If there is concentration of an additive at an interface, then the mechanical and chemical properties of the interfacial layer can change. In some cases the adhesion properties of the bonded joint or coating can be affected.

The aim of modelling is to predict the effect of such concentration phenomena. To achieve this, not only the surface activity of the substances has to be considered but also potential chemical reactions in the adhesive or polymer coatings and their mutual dependence. Of special interest is the direct effect of the concentration of individual substances at the surface on the structure of the interfacial region (Fig. 4).

A prerequisite for solving complex problems and developing new ideas is a close collaboration between experts in interface analysis, polymer chemistry and modelling. The major advantage of simulations is the insight into structure-property correlations which can then be experimentally verified.

Potential of multiscale simulation

"Materials by Design" refers to the computer-aided prediction of novel product properties starting from the simulation of the molecular composition of the material. Due to the fact that the molecular composition determines the macroscopic behaviour, research is increasingly concentrating on multiscale techniques which combine various computational approaches. The objective is to carry out simulations comprising different length and time scales by combining complex simulation techniques and suitable approximate methods. These range from material design at an atomic level to the issue of how the component functions in everyday operation.

The Fraunhofer IFAM is developing multiscale techniques as part of a Fraunhofer-Gesellschaft project on Pioneering Market-orientated Research (MAVO). This is being undertaken in collaboration with eight other Fraunhofer institutes that are actively engaged in topical areas of research. One focus of this highly multidisciplinary project is the development of computational tools – "MMM-Tools" – for the multiscale simulation of interfacial phenomena as well as phase and grain boundaries in sintered materials. By participating in this project IFAM aims to implement new computational approaches for industrial applications, if possible in the short-term. This will maximise the benefits for customers and offer them the highest possible level of know-how.

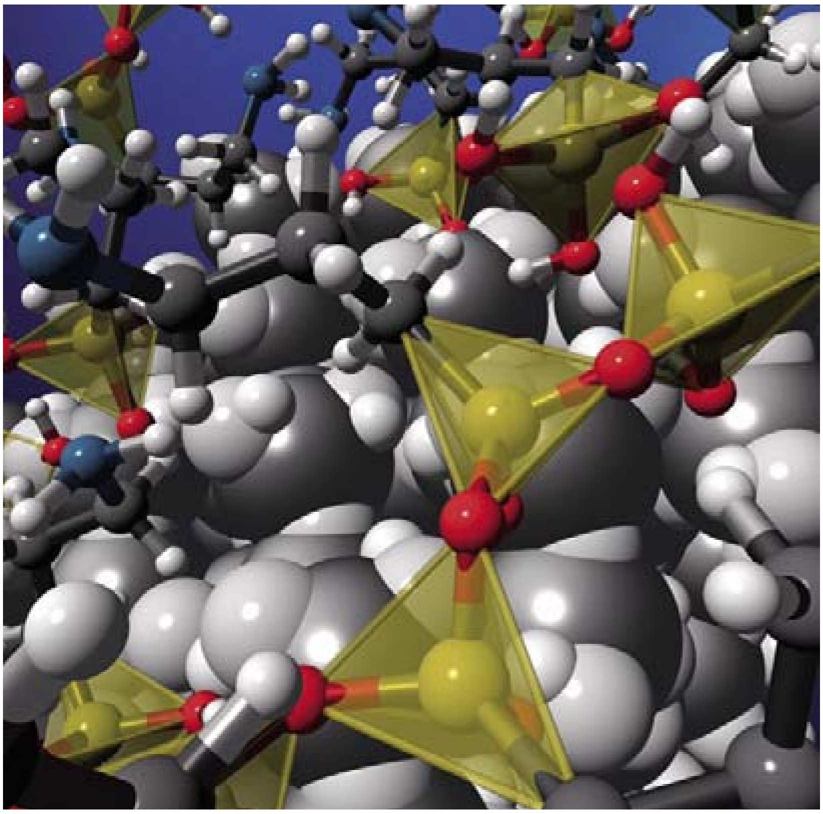

Fig. 4: Film formation due to the cross-linking of a surface-sensitive substance. The simulation studies not only investigate film formation but also the affinities to different surfaces.

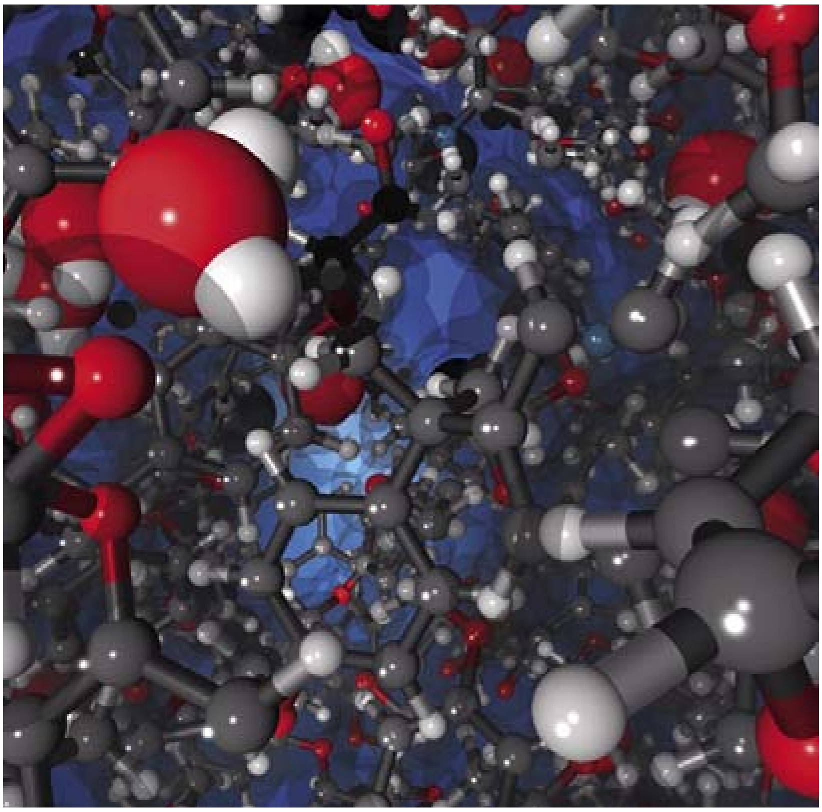

Fig. 5: Molecular model for the transport of water in a polymer coating. The polymer is represented using a ball-and-stick representation and balls were chosen to represent the water molecules.

Transport processes in adhesives and coatings

The diffusion of low molecular weight substances such as water and oxygen often leads to adverse effects. For example, such diffusion can initiate the degradation of bonded joints and polymeric coatings and in some cases it can even lead to the detachment of adhesives and coatings. The presence of water therefore affects the long-term stability of bonded joints and of organic coatings. If moisture penetrates the surface protection layers there is the risk of damage due to corrosion. This is nowadays a major issue from an economic point of view because of costs of millions of euros each year. For this reason, barrier layers, for example plasma-polymer coatings for corrosion protection, are used to hinder the transport of undesired substances to surfaces.

Computer-aided materials research is able to model how moisture is transported to surfaces as a result of diffusion processes. It is also able to model the molecular interactions which take place there (Fig. 5). Different chemical modifications to coatings can be simulated in order to identify ways of limiting the transport of water. In combination with the experimentally determined diffusion properties (Fig. 6), such simulations allow the interpretation of the experimental findings at a molecular level. The results give directions for further materials development. This approach considerably increases the knowledge gained from experimental work and paves the way for new materials optimisation.

Outlook

The simulation of chemical processes at interfaces and in polymers is a field of "Computational Materials Science" and is a key tool for adhesion and interface research. Over recent years this approach has benefitted from the rapid advancement in computer technology and become very effective. It has consequently opened up many research avenues for the Fraunhofer IFAM. The key challenge for us is to further develop and apply modern computer techniques to current issues in the areas of adhesive and coating formulation, surface technology and nanotechnology.

At the Fraunhofer IFAM, the work undertaken in this field concerns topical industrial areas. Current collaborative research projects involve the optimisation of adhesive systems and the study of chemical processes related to adhesion. By combining computer-aided materials research with the knowledge being acquired in experimental R&D work, the Fraunhofer IFAM is truly in a position to provide optimum support to customers.

One current area of work with a very promising future is multiscale simulation. By carrying out simulations covering different length and time scales, issues relating to materials will in the future be considered in their totality – for example ranging from atomic interactions to the mechanical behaviour of bonded components. The simulated total view opens up new opportunities for optimisation, not only for new combinations of materials but also for the design of components and production processes.

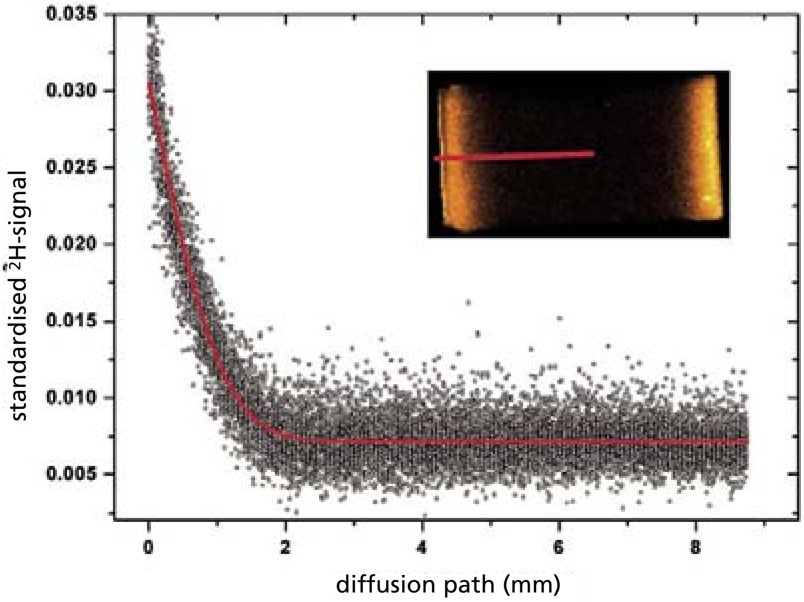

Fig. 6: Experimentally determined moisture profile for the penetration of water into a bonded joint. The experimental curve was determined using tracer-studies via ToF-SIMS (Time-of-Flight Secondary Ion Mass Spectrometry).

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Monitoring the quality of surfaces in production processes a concept for improving the efficiency of bonding and painting processes

Introduction

In order for adhesives and paints to be applied effectively, the surfaces of the relevant components must be of optimum quality. In the field of paint technology, any surface defects or irregularities which arise during the course of a production process are time-consuming and costly to rectify. With regards to bonding processes, it is often difficult or sometimes impossible to rectify such defects or irregularities after the components have been joined and the probability is high that these will only become evident during the usage phase. This is because up until now there have been very limited options available for carrying out a non-destructive test on the end-products. This highlights the importance of quality monitoring strategies. In addition to undertaking tests on the as-received substrate materials, adhesives and paint systems, the complexity of the total process necessitates that all production steps (e. g. pretreatment, application, curing) and all relevant process parameters (pressure, temperature, time, etc.) are monitored.

In bonding and painting processes, very high requirements are put on the quality of the substrate surfaces. Fundamental prerequisites for both these production processes are that the substrate surfaces have good wetting properties and are very clean. Experience has shown that 70 percent of cases of adhesion failure in bonded joints are due to contaminated surfaces. Roughly 25 percent of painted automobile bodies have to be touched up due to particle inclusions and wetting problems caused by surface contamination.

In order to avoid these costs for the reprocessing of inadequately pretreated components it is necessary to directly monitor the surface quality during production. This challenge, to develop methods for monitoring the surface of substrates prior to adhesive or paint application, has been taken up by the Applied Surface and Film Analysis work group at the Fraunhofer IFAM.

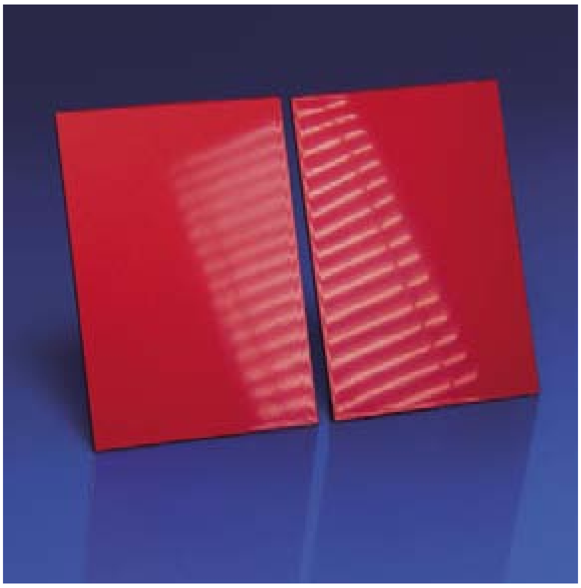

Fig. 1: On the left a defective paint surface: Orange peel formation on a painted surface, on the right a faultless paint surface.

Fig. 2: The left-hand sample shows a cohesion fracture in an adhesive film. The right-hand sample shows an adhesion fracture caused by a release coating developed at the Fraunhofer IFAM.

Pretreatment of surfaces – the key to the overall process

The quality of bonded or painted products ultimately depends on adhesion between the adhesive film or paint film and the surface of the component. There are many adhesion mechanisms, but the key processes occur in a region of just a few nanometers in thickness. And to make clear what we are saying here, the relationship between a meter and a nanometer is the same as between the diameter of the Earth and the diameter of a hazelnut.

Pretreatment plays a key function in the overall production process. Classical pretreatment covers methods to clean and activate the surface. These pre-treatment methods must generate clean surfaces having good wetting properties, and suitable functional groups to interact with the respective adhesive or paint system.

It makes sense to monitor the pretreatment step because even the smallest irregularities or defects can result in ineffective bonds and paint layers. This can for example occur if materials unintentionally enter the production process and contaminate the surface or if the pretreatment process experiences a fault that goes unnoticed. Even fingerprints left behind on the surface of a component, caused by working without protective gloves, can have adverse consequences.

Up until now, the monitoring of the quality of surfaces prior to application of an adhesive or paint is carried out by taking random samples and then carrying out quick tests (e. g. test inks for determining the surface energy) or using surface analysis techniques (e. g. X-ray Photoelectron Spectroscopy (XPS) for analysing the chemical composition of the surface). Quick tests have the disadvantage that they only give a small amount of information for evaluating the quality of the surfaces. More meaningful surface testing is only possible with complex equipment. In addition, neither approach is non-destructive and neither approach can be integrated in an automated way into production lines.

	Information content	Investment	Time requirements	Process integration	Non-destructive
Quick tests	low	low	low	not possible	not possible
Instrumental analysis	very high	high	high	not possible	not possible

Tab. 1: Advantages and disadvantages of quick tests and instrumental surface analysis.

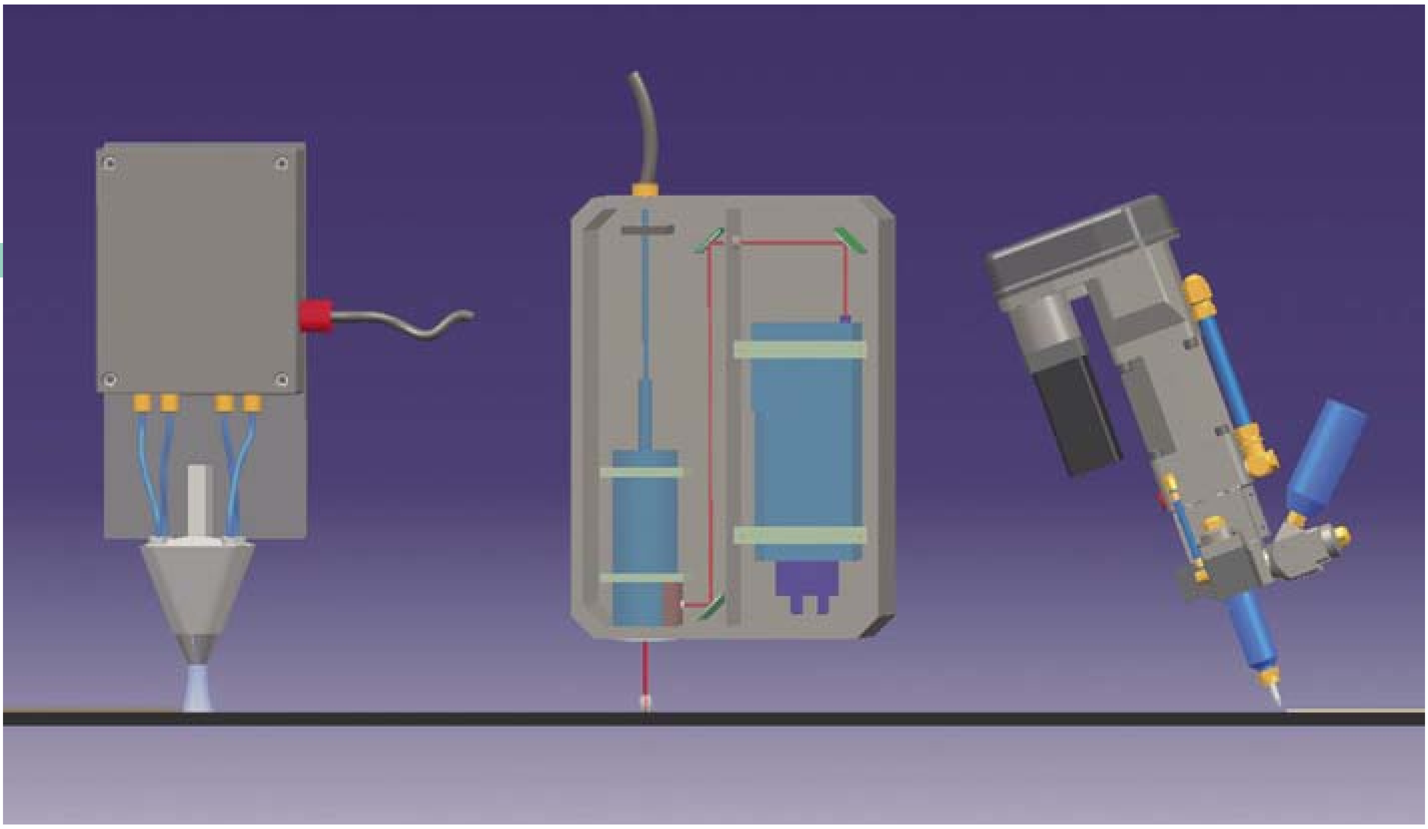

Fig. 3: Schematic representation of the in-line monitoring of surface quality in an automated bonding process. From left to right: Pretreatment of the surfaces via plasma pretreatment, in-line monitoring of the surface quality, adhesive application.

In-line monitoring of surface quality prior to bonding or painting

The ideal solution would be continuous in-line monitoring of the surface quality, as a quality assurance measure, immediately prior to application of the adhesive or paint. Here, the evaluation of the suitability of the surfaces for bonding or painting would be undertaken by continuous advance monitoring using defined limit values for, for example, the degree of contamination. If the surface of a component does not meet these requirements then it would be removed from the process. It would then be pretreated again or declared a reject. This strategy would allow defective components to be identified and dealt with prior to application of an adhesive or paint.

The determination of surface quality in a continuous production process places several requirements on the measuring techniques. In general the measurements must be carried out rapidly and fully automated. The analytical techniques must have high sensitivities for the prospective contaminants, measurement reproducibility must be high and the techniques must be suitable for use in industrial production environments. A number of techniques which meet these requirements have already been identified including spectroscopic methods (e. g. Laser Induced Fluorescence (LIF), Laser Induced Breakdown Spectroscopy (LIBS)) and optical methods (e. g. reflectometry and ellipsometry). In addition, techniques suitable for evaluating the wetting properties of surfaces are being studied and adapted.
The main challenge is to adapt such systems to the particular problems facing specific customers. The complex boundary conditions which can affect the surface quality of components must be identified, evaluated and taken into account in the monitoring strategy. For example, there are the questions as to what potential impurities are associated with the process and what time window is available in the process for monitoring. After that, suitable techniques are chosen and adapted to the measurement task in question. The last step involves transfer of the measurement technique to the production process.

Two practical examples

One area of application for which suitable in-line monitoring methods have already been studied concerns the monitoring of release agents on component surfaces. Silicone-based release agents are, for example, often used to facilitate the removal of plastic components from moulds. If too high concentrations of release agents remain behind on the surfaces of components after pretreatment, this can result in poor adhesion of adhesives and paints. Our work has demonstrated that Laser Induced Breakdown Spectroscopy (LIBS) is suitable for monitoring these contaminants inline. This technique uses a laser to ignite a microplasma at the surface. The optical emission of this plasma namely the spectrum of the emitted light reflects the composition of the surface and is able to identify very small concentrations of contaminants.

Another practical example involves the evaluation of the wetting properties of component surfaces prior to paint application. If a paint layer shows irregularities, this can be due to unidentified surface contamination adversely affecting the wetting properties. By carrying out a water wetting test on components using aerosols prior to application of the paint and then undertaking optical assessment, the wetting properties of a large area of a component surface can be recorded and irregularities identified. Special image recording systems and evaluation routines have been developed at the Fraunhofer IFAM for this application.

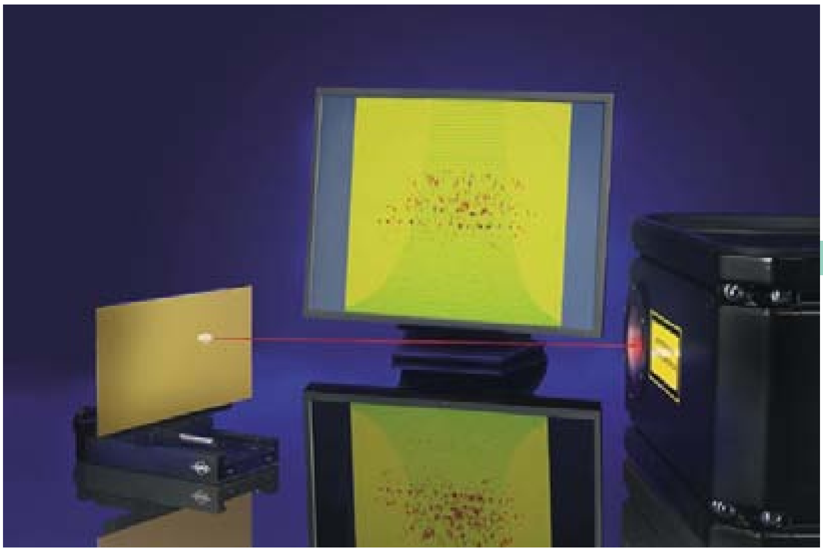

Fig. 4: Laser Induced Breakdown Spectroscopy.

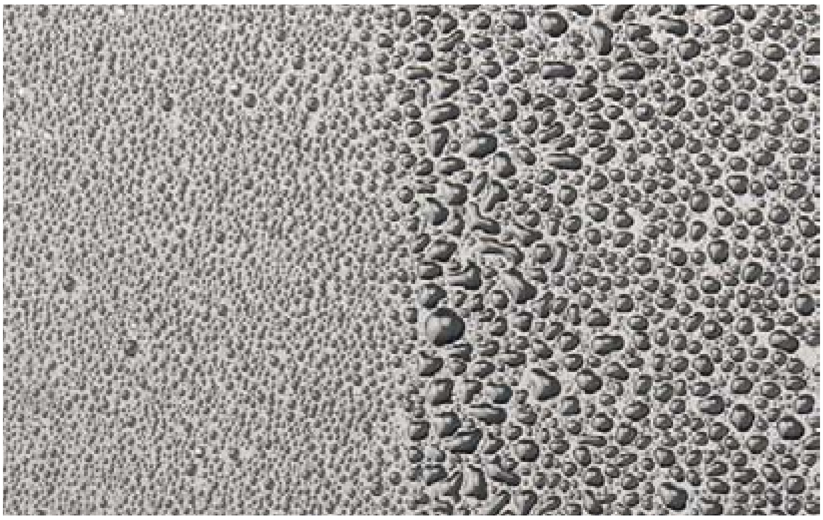

Fig. 5: Wetting properties of plastic surfaces. Left: Non-pretreated region of a sample surface; Right: Pretreated region with improved wetting properties.

Concluding remarks

The objective of the Applied Surface and Film Analysis work group is to design a variety of modular systems that can then be adapted to particular applications. The expertise and infrastructure that are available at the Fraunhofer IFAM are being utilised here to offer solutions for a wide spectrum of problems.

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Transmission electron microscopy: The future for high-resolution 2-D and 3-D materials characterisation

Research and development in both nanotechnology and materials science requires good characterisation of the material properties as well as a detailed analysis of the material's structure. This combination is crucial for understanding processing-structure-property relationships and hence for undertaking systematic, goal-oriented product and process development. For structural analysis, transmission electron microscopy (TEM) combines the benefits of ultra-high spatial resolution in 2-D and 3-D imaging with (sub)nanometer compositional analysis and elemental distribution mapping. TEM is therefore a powerful tool for in-depth material characterisation that can be correlated with bulk material properties.

The high spatial resolution of TEM is crucial for characterising nanostructured materials. Transmission electron microscopy is one of the few techniques that can image the structure of a sample (and not just its surface) on the nanometer or even atomic scale, and at the same time provide compositional information with nanometer resolution. However, as some materials are sensitive to electron beam radiation, low-dose and cryo-techniques sometimes are necessary to image the native structure of a material with optimum resolution. Depending on the information required about a material, electron microscopy is often able to provide all the necessary data. However, there are frequently close collaborations with other groups at the Fraunhofer IFAM to correlate, for example, bulk mechanical, spectroscopic or surface analysis results with TEM data to obtain a full picture of the structure-property relationships.

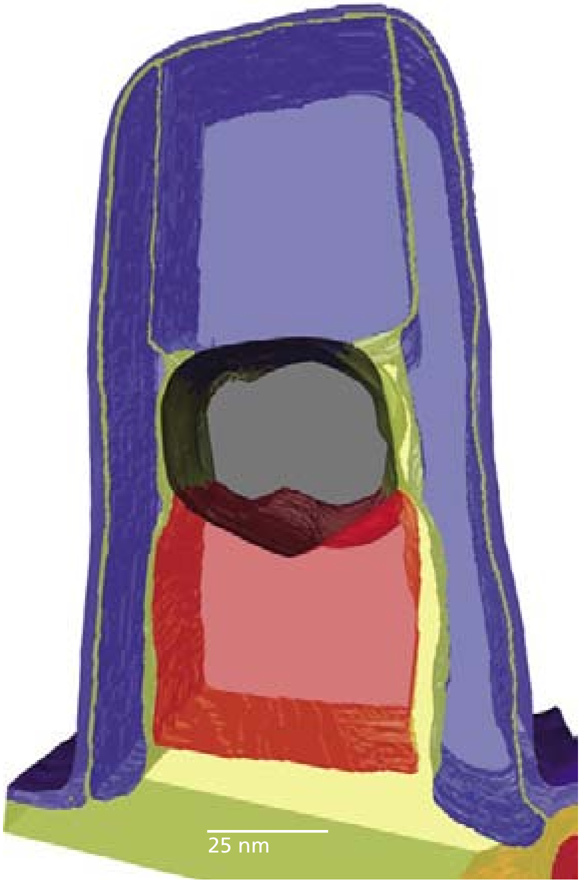
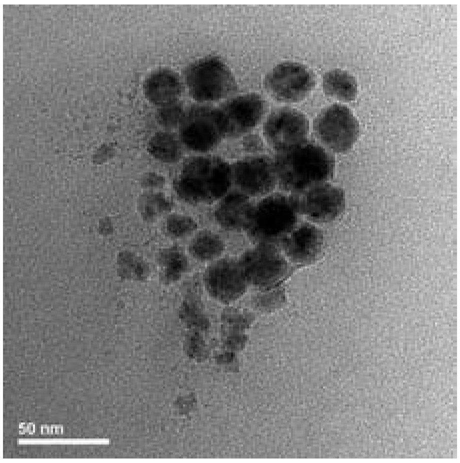
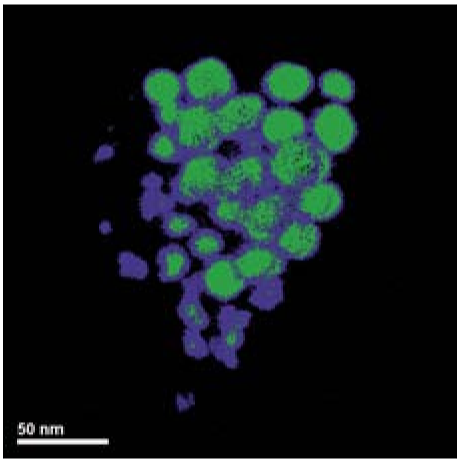


Fig. 1: 3-D representation of the structure of a transistor in a DRAM memory device showing the roughness of the hidden interfaces and enabling 3-D metrology (Si – red, SiO_x/SiO_xN_y – yellow, SiN_y – blue, WSi_x – black).
C. Kübel, J. Kübel, S. Kujava, J. S. Luo, H. M. Lo, J. D. Russell, "Application of Electron Tomography for Semiconductor Device Analysis" in "8th International Workshop of Stress-Induced Phenomena in Metallization", edited by E. Zschech, AIP Conference Proceedings, American Institute of Physics, Melville, New York (2006).

Magnetic nanoparticles

High spatial resolution is vital for the structural characterisation of nanoparticles. The Co/CoO core-shell nanoparticles shown in Fig. 2 are weakly ferromagnetic and are of interest to such diverse fields as high-density information storage, medical imaging and magnetic fluids. The magnetic properties of these nanoparticles differ drastically from the bulk material and depend strongly on their microstructure, especially their size, morphology, composition and 'supramolecular' organisation. Using transmission electron microscopy, it is possible to study the structure of these





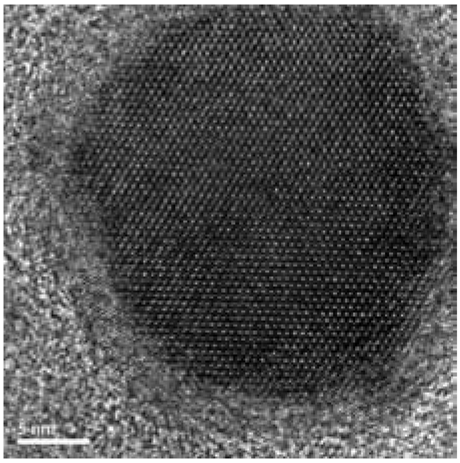


Fig. 2: TEM image of a cluster of Co/CoO core-shell nanoparticles. Multivariate analysis of the corresponding Co and O elemental maps shows the Co (green) and CoO (blue) distribution within the particles. Sample courtesy of Prof. A. Wei, Purdue University.

High-Resolution TEM image of a Co/CoO nanoparticle exhibiting a single-crystal Co core and a 3 nm thick CoO shell.

particles over several orders of magnitude – from the atomic level to the aggregate level. The analysis reveals that the smallest particles are fully oxidised whereas the larger nanoparticles consist of a 5-25 nm single-crystalline or polycrystalline Co core with a 2-4 nm polycrystalline CoO shell.

Corrosion protection – characterisation of coatings

Electron microscopy is not only an essential technique for nanotechnology characterisation, but is also an important analytical technique in classical materials science. A technologically important example is corrosion protection, e. g. protection of aluminium for use in the aircraft or automotive industry. Here, the traditional chromium (VI) containing process used for corrosion protection must be replaced by environmentally compliant alternatives. Main research areas at IFAM are the characterisation of the porous oxide layers generated by alternative anodising processes and analysis of the interface between the oxide and an organic coating applied on top of the anodic layer. The organic coating should wet the oxide and fully penetrate into the pore structure. This is a prerequisite for the long-term durability of the coating. Otherwise, water diffuses through the polymeric coating and condenses in the pores of the oxide layer. Inside the pores, water would react with the oxide, decreasing the mechanical strength and ultimately leading to delamination of the coating. Elemental mapping can be used to characterise the degree to which the pores in the anodisation layer are filled. Fig. 3 shows that the carbon rich primer fills the pores of the aluminium oxide and penetrates into the pores all the way down to the interface with the aluminium metal. To prevent beam damage to the sample during the measurements, cryo-TEM conditions were used.

However, due to the complex 3-dimensional arrangement of the pores, even traditional TEM methods are not able to directly reveal details of the pore structure itself because several pores are projected on top of each other in a 2-D TEM image. An alternative method is electron tomography, which reveals the full 3-D structure with nanometer resolution. The 3-D volume can then be analysed using digital slices through the structure or by volume rendering.

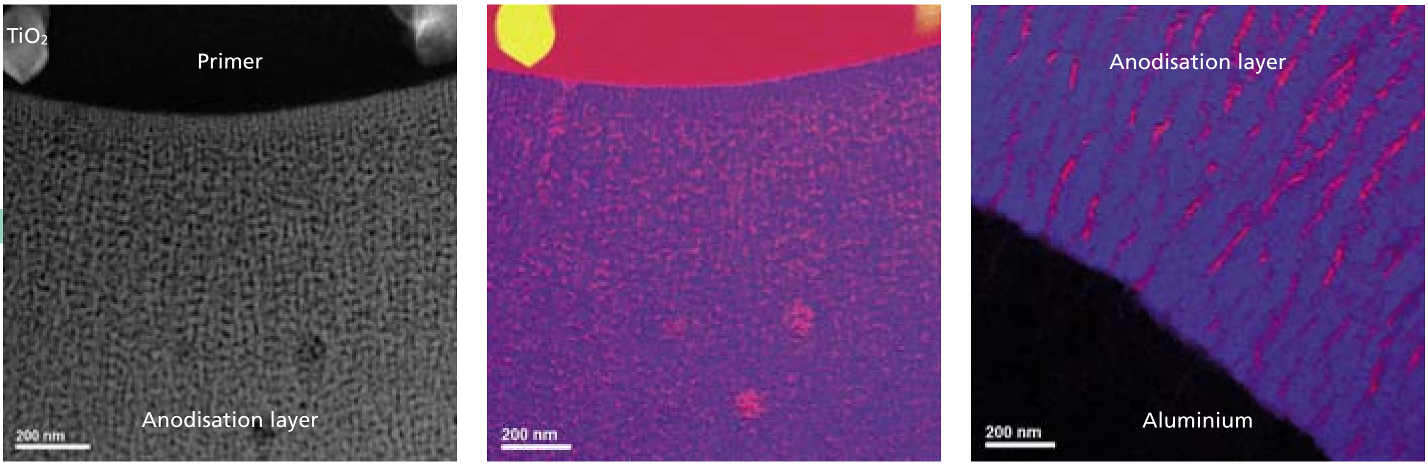


Fig. 3: TEM image of a primer-treated aluminium anodisation layer. The carbon distribution in the corresponding elemental map (carbon – red, oxygen – blue, titanium oxide – yellow) shows that the primer penetrated into the pores down to the aluminium substrate.

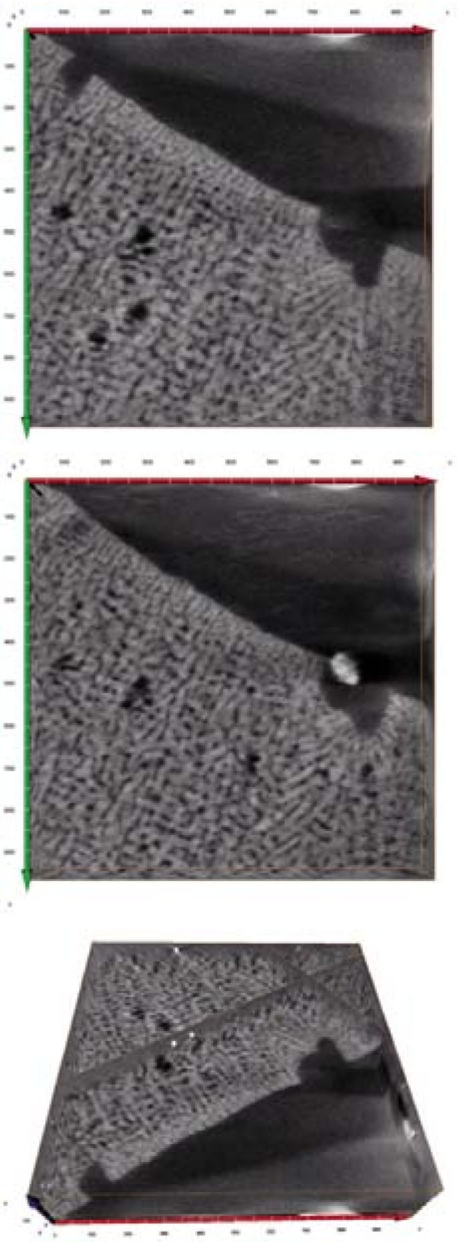


Fig. 4: Digital slices through the volume of the anodisation layer show details of the pore structure and clearly show structural defects.

The electron tomographic analysis of the anodisation layer (Fig. 4) reveals the distribution of the oxide pores in the volume of the sample. In addition to the actual pores, larger voids are visible in the oxide layer, which were presumably formed when intermetallic phases dissolved during the anodisation process. Furthermore, areas with differing preferential orientation of the pore network are revealed in the 3-D reconstruction, which were not recognisable in the original 2-D projection.

Nanocomposites

The modification of adhesives with nanoparticles is a well-established approach at IFAM for improving the properties of adhesives. Using this approach, it is possible to produce adhesives with new combinations of properties. An important goal when preparing these nanocomposites is to prevent aggregation of the nanoparticles within the composite and so maximise the specific effect of the nanoparticles. Conventional TEM techniques are used to measure the average particle size and density within the composite, but they do not provide complete information about the distribution and shape of the particles within the matrix. In contrast, electron tomography allows imaging of the detailed 3-D sample structure to determine the distribution and shape of the particles.
The advantages of 3-D imaging are illustrated in Fig. 5 for a well-separated organo bentonite

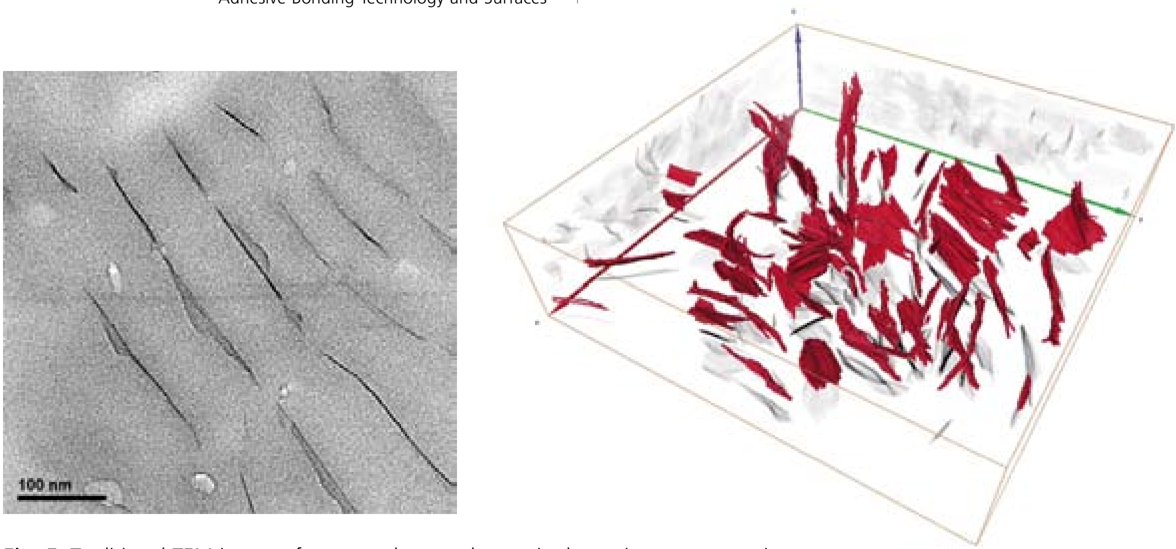


Fig. 5: Traditional TEM image of separated organobentonite layers in an epoxy resin. The 3-D reconstruction reveals the shape and distribution of the nanoparticles.

embedded in an epoxy resin. The traditional TEM image reveals slightly bent silicate sheets orientated perpendicular to the viewing direction. In contrast, electron tomography shows the shape of the bent silicate layers in detail and also reveals the precise 3-D distribution of the nanoparticles.

Semiconductor devices and quantum structures

With the advanced electron microscopic techniques now routinely available at Fraunhofer IFAM, our characterisation facilities are becoming increasingly interesting for new application areas, such as semiconductor devices and quantum structures having complex features just a few nanometers in diameter. High-resolution imaging and elemental mapping are already well-established in the semiconductor industry. However, for failure analysis and 3-D metrology of small device structures, it has become apparent in recent years that high-resolution electron tomography is the most promising method to overcome the projection problem of conventional electron microscopy. An example of the capabilities of electron tomography for characterising semiconductor devices is shown in Fig. 6 for a flash memory. The memory status of the device is controlled by injecting a charge through the reference gate onto the floating gate. The distance between the two gates must therefore be small enough to enable charge injection, but must also be large enough to prevent tunnelling of the charge under normal operation conditions. Due to the surface roughness of the reference and the floating gates, it is difficult to determine the local distance between the two gates using a 2-D projection. However, after 3-D reconstruction, the surface roughness of the buried interfaces can be directly displayed and local distances measured in 3-D.

Regarding quantum structures, electron tomography also offers new analytical opportunities. For example, it is allowing – for the first time – the accurate characterisation of the shape of embedded nanoparticles in 3-D, which permits correlation of their electronic properties with their size and shape. An example is shown in Fig. 7 for $ErSi_2$ and GeSi nanoparticles prepared by ion implantation in SiC followed by rapid annealing. It was initially presumed that the ErSi2 particles had an irregular "hill-like" shape, but electron tomography revealed that the base plane of all the 'hills' was very well defined and all crystals form facets along the low-index planes in SiC.

Summary

The examples described in this report demonstrate that electron microscopy is much more than just a high-resolution imaging tool. Ultra-high spatial resolution is important, but the real power of transmission electron microscopy is the combination of 2-D and 3-D imaging with elemental mapping and local compositional analysis. The result is a complete microstructural characterisation of a material and this provides unique feedback for product or process development. When appropriate sample preparation techniques are used, most inorganic and organic materials can be analysed using TEM, which makes TEM an extremely versatile technique.

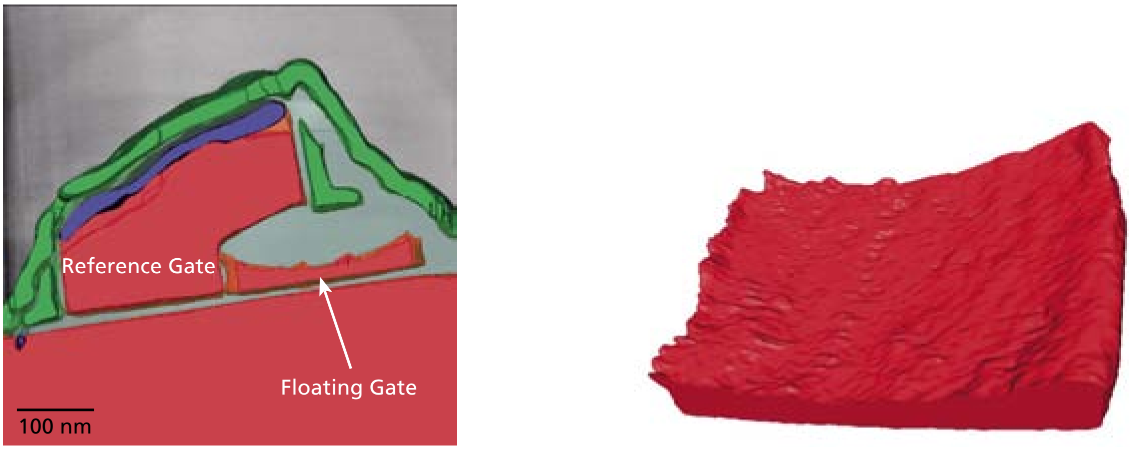


Fig. 6: Surface rendering of the 3-D structure of a flash memory cell (Si – red, SiN_x – green, $TiSi_x$ – blue); the right side shows the surface roughness of the floating gate.
C. Kübel, A. Voigt, R. Schoenmakers, M. Otten, D. Su, T. C. Lee, A. Carlsson, J. Bradley, "Recent Advances in Electron Tomography: TEM and HAADF-STEM Tomography for Materials Science and Semiconductor Applications", Microscopy and Microanalysis, 11 (5) Cambridge University Press (2005), 378–400.

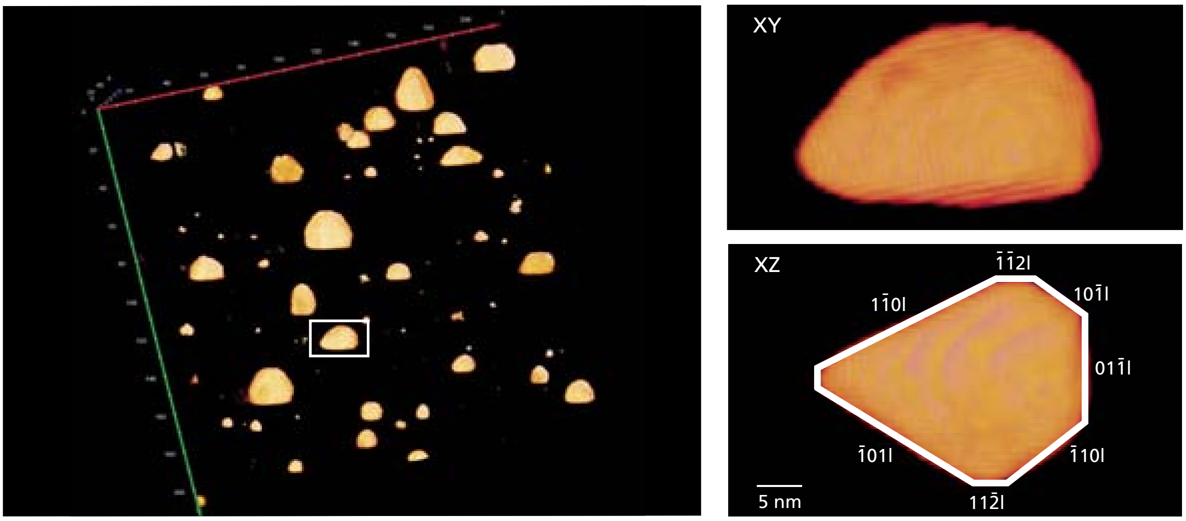


Fig. 7: Volume rendering of $ErSi_2$ nanoparticles having a diameter of 1-20 nm. The close-up on the right side shows a particle from two different directions, revealing the well-defined facets observed for these crystals. Sample courtesy of Prof. U. Kaiser, University of Ulm.

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Use of sound waves to determine the mechanical properties of ultra-thin films

Fig. 1: Lisa Marie Meyer: The Princess and the Pea. Coloured pencil on paper (2005).

Background

The best way to find out how hard or soft a mattress is simply to lie on it. What seems a firm mattress in the shop can however turn out to be a real backbreaker at home when the mattress is put on an old bed base. In truth, it is always sensible to test the quality of the base on which the mattress rests. In the tale of the "Princess and the Pea" (Fig. 1), the princess was unable to sleep despite having twenty mattresses and twenty eiderdown quilts. It is certainly not difficult to imagine how the princess' night would have been had she only had a 10 nm thick base!

For very thin films (sometimes only a few nanometers thick) and very soft films, it is very difficult to determine the softness of the film. Normally, the mechanical properties are determined by subjecting the film to a force using a punch or needle. However, what about if the test object immediately punctures the film?
There are similar problems when testing thin porous films. The pore distribution and geometry have a key effect on the E-modulus. Similar to very soft films, indentation tests here rarely give more than a guide to the strength. Wildly different strength values are obtained depending on whether the test object hits a pore or rather the lattice surrounding a pore. Just think of how toddlers try to press a square block into a triangular opening and it becomes immediately obvious that the relationship between the indenter geometry and the pore geometry considerably affects the values given by the indenter.

What does all this mean?

Who is interested in all this? Is this of relevance to industry? What is patently clear is that the mechanical properties of ultra-thin layers and films are becoming ever more significant and the following examples will amply illustrate this.

In the area of design and construction, one aims to utilise material interfaces to a maximum. With regard to bonded joints, which are becoming ever thinner, attention is being increasingly focussed on the interface between the substrate and the adhesive. Information about how the strength of interfaces can be altered would provide parameters for FEM simulation and so help to optimise bonded joints. Adhesive bonding, the joining technique of the future, would then even more rapidly gain acceptance in industry.
Detailed knowledge about the changes in the mechanical properties in the first hundred nanometers of the adhesive film would also aid making comparisons between molecular modelling simulations and real systems. This represents a small step towards the "bottom-up" development of adhesives.

Everybody who has ever wanted to disturb a barnacle and has tried to prise it from a rock knows the outcome: The barnacle cannot be shifted. A trick used by perfidious barnacles is to deposit multiple layers of adhesive having slightly increasing E-moduli. The result is a gradual transition from the potentially very high modulus of the hard base to the relatively low modulus of the barnacle. In order to mimic this trick used by barnacles and so develop man-made gradient layers in adhesives, special analytical methods are required.

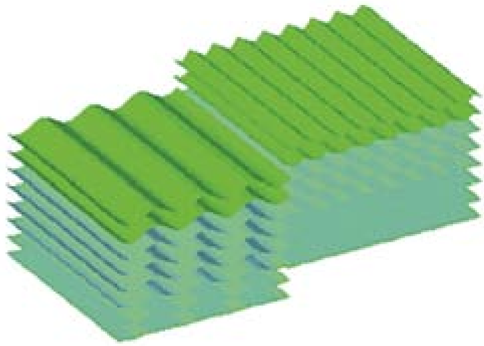

Fig. 2: Penetration of surface waves into a film (light green) – substrate (pale green) system. Front – long wavelengths; Back – short wavelengths.

It is almost unnecessary to mention the many plasma-polymer functional layers, just a few tens of nanometers in thickness, which have a key influence on the functionality of components. Little is known about the elastic parameters of these layers although their lifetime is partly determined by them. Finally, a brief word about porosity. In all the systems that have been mentioned, pores naturally have a key influence on the mechanical properties and can considerably reduce the strength. There are however also systems which are naturally porous, for example thin anodisation layers on metals. The lifetime of these layers is also significantly determined by optimum adaptation of the film and substrate moduli.

In summary it can be said that the mechanical properties of very thin and in particular viscoelastic or poro-elastic films are clearly of considerable interest. Equally evident is that determining these properties is not so easy. So how can this problem be tackled?

The trick

As already indicated in the title to this article, sound waves provide the answer. Instead of analysing the penetration of a point into a film, one evaluates the dispersion of waves. Initially this may seem a surprising approach. It is non-destructive and clean, but can sound waves really be used on polymers? An effective sound-absorbing polymer layer on the hulls of U-boats would have considerably damped the awful sonar "ping" and spared the nerves of many mariners, although the drama of the film "Das Boot" would have been considerably lessened. Indeed, a feature of polymers is that they absorb sound very well. Even cleverer, the absorption increases with increasing frequency of the sound. And in order to study very fine structures it is precisely these high frequencies that are required!

A trick is however required. The bane of the indenter method, namely the need to use a hard substrate to support the thin films, is here a blessing. Acoustically hard substrates such as silicon, steel and ceramics are used as carriers of the sound energy and ensure that the sound energy is not absorbed too rapidly by the polymer film.

Surface waves

In principle ultrasound can be used for analysing very thin weak films. Of the wide spectrum of waves that disperse in a film-substrate system, the method being proposed here only analyses one particular type.
Surface waves, in this case so-called Rayleigh waves, penetrate into the film-substrate system to different depths depending on their wavelength. The penetration depth is defined as the depth at which the wave energy has fallen to a certain fraction of its original energy.

Waves with a very short wavelength penetrate to very small depths and hence virtually exclusively disperse in the film (Fig. 2 back). Waves of longer wavelength penetrate deep into the substrate and largely disperse there (Fig. 2 front).

Dispersion curve

The dispersion behaviour of these waves, in particular their rate of dispersion, is largely determined by the E-modulus. Waves that almost exclusively disperse in the substrate hence move faster or slower than waves that disperse in the weak film. The dispersion curve is a plot of the dispersion rate of the waves against the frequency.

Fig. 3 shows a number of different types of dispersion curves. If the mechanical properties of the film and substrate do not differ, then all waves propagate at the same rate. There is then no dispersion and the dispersion curve is horizontal (middle curve in Fig. 3). A very hard film on a soft base material results in an increasing rate of wave dispersion with increasing frequency (top curve in Fig. 3). Conversely, the rate of dispersion of the waves decreases with increasing frequency when a very soft film material is on the substrate (bottom curve in Fig. 3).

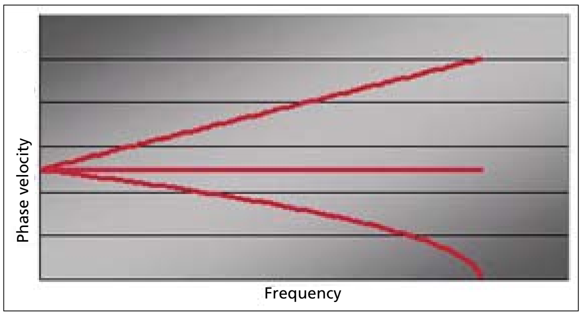

Fig. 3: Types of dispersion curves: Non-coated substrate (middle horizontal curve). E-modulus of the substrate is smaller than the E-modulus of the film (top curve), E-modulus of the substrate is greater than the E-modulus of the film (bottom curve).

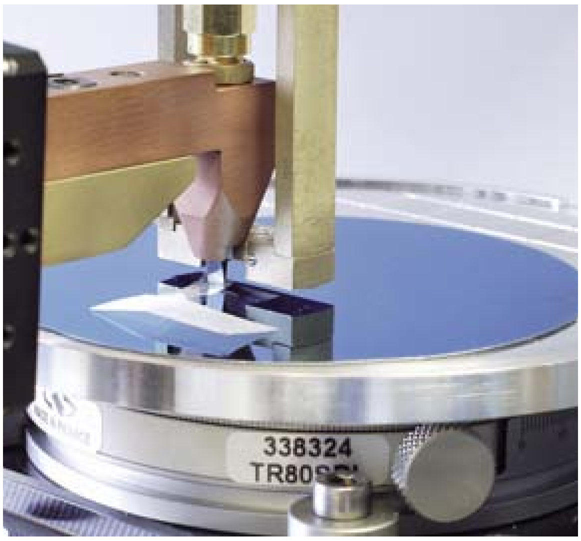

Fig. 4: Measuring head of the LAWave© device.

Measuring device

We use the LAWave© device developed by the Fraunhofer IWS in Dresden. Fig. 4 shows the actual measuring head.

The film to be examined is on the bluish circular silicon wafer. In the foreground there is a steel spatula that presses a small piece of a piezoelectric film onto the sample. Partly hidden by the copper coloured holder is a cylinder lens. A laser pulse from the cylinder lens is focussed on the sample. The sample is heated by the pulse in a narrow, line-shaped region. Similar to how water waves disperse from the place where a stone hits the water surface, these laser pulses initiate surface waves in the sample. The shorter the duration of the pulse, the larger the bandwidth of the resulting surface waves. The waves pass below a steel spatula which presses a piezoelectric film onto the sample. This generates a short voltage signal which is recorded by an oscilloscope. The signal undergoes Fourier transformation and from the phase spectrum the dispersion curve is obtained. If the film is an elastic material then the E-modulus can be directly determined.

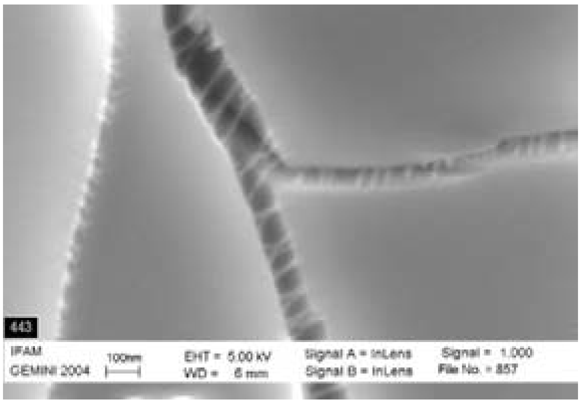

Fig. 5: SEM micrograph of a ca. 9 nm thick PS film on an Si wafer generated by spin-coating.

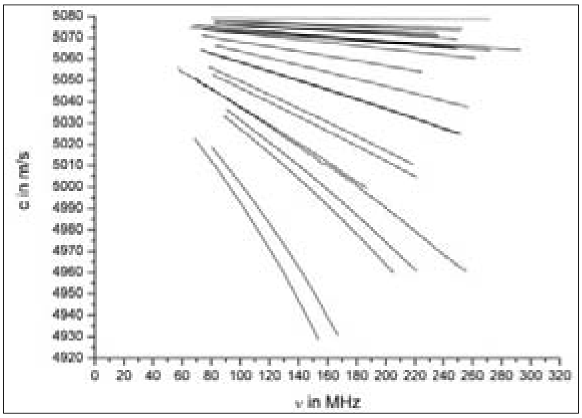

Fig. 6: Dispersion curves of PS films on Si wafers. The virtually horizontal line represents the non-coated substrate. The lowermost line represents a PS film of ca. 1 µm thickness.

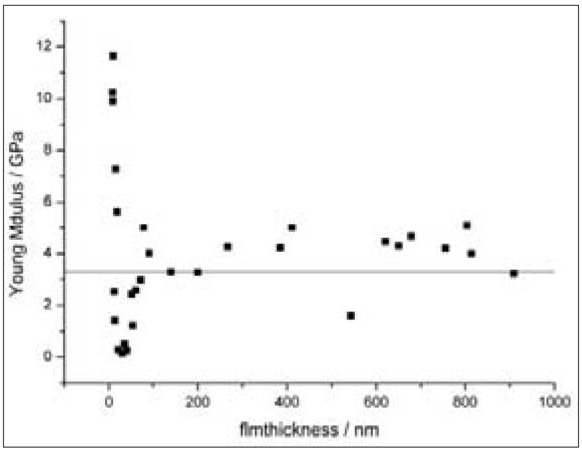

Fig. 7: E-moduli of thin PS films on Si wafers. Full line: bulk E-modulus of polystyrene.

Example: soft film material

Being a thermoplastic, polystyrene possesses viscoelastic properties. This material is extensively described in the literature and as such serves as a good reference system. Fig. 5 shows a ca. 9 nm thick polystyrene film (PS Film) on an Si wafer. The sample was fractured after being coated in order to be able to see the film under the scanning electron microscope. The film is only seen as the stretched, fibre-like structures at the fractured edges.

Fig. 6 shows the dispersion curves of PS films of different thickness. The virtually horizontal curves represent the non-coated substrate. The dispersion curves with a slight negative gradient represent the very thin films and the curves with greater gradient are those of the very thick films. The curves with a slight negative gradient, which represent PS films with a thickness of just ca. 10 nm, are impressive evidence for the sensitivity of the analytical method.

The determination of the E-moduli from the dispersion curves is shown in Fig. 7. A large deviation from the bulk modulus is observed for films have a thickness below 50 nm.

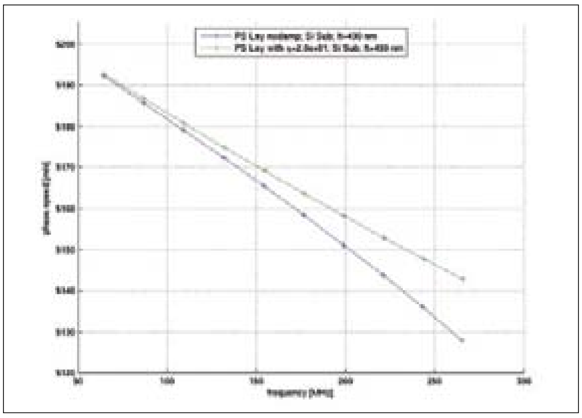

Fig. 8: FEM simulation of a dispersion curve for a 430 nm thick PS film on an Si wafer. The upper line refers to the viscoelastic case, the lower line to the elastic case.

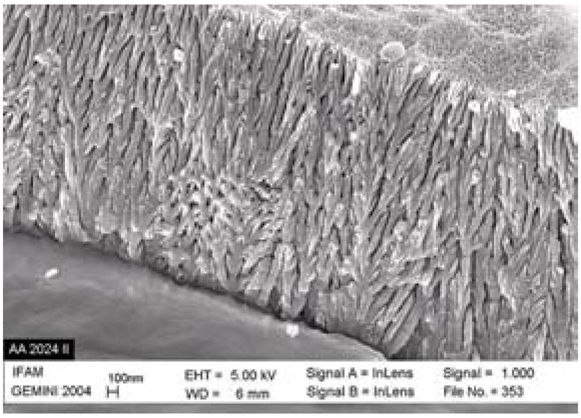

Fig. 9: SEM micrograph of an anodisation layer on aluminium.

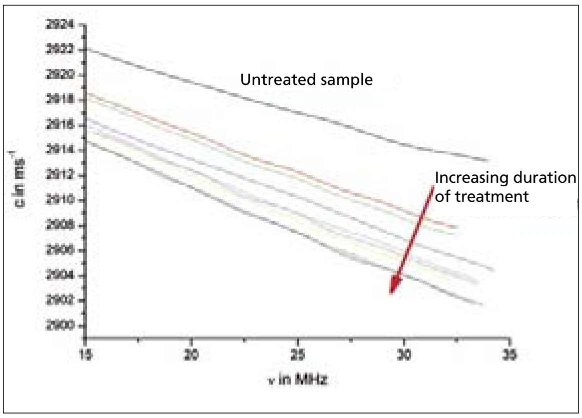

Fig. 10: Dispersion curves for untreated (top curve) and treated samples (lower curves).

The evaluation of the dispersion curves is still based on a pure elastic theory. In order to estimate the effect of viscoelastic contributions on the dispersion curve, we have carried out FEM simulations. Fig. 8 shows the simulated results for a PS film on a silicon wafer. The dispersion curve obtained from the pure elastic simulation (Fig. 8 lower curve) falls off more sharply than the curve obtained when viscoelasticity is taken into account (Fig. 8 upper curve). In the viscoelastic case, the determination of the E-modulus from the dispersions curve hence results in overestimation of the E-moduli.

Example: porous material

Anodisation layers have a pronounced porous structure. Fig. 9 shows an SEM micrograph of an anodisation layer on sheet aluminium.

Due to the hardness of the aluminium oxide, even such an open structure can be analysed using surface waves. Fig. 10 shows the dispersion curves for this layer. The uppermost curve shows the untreated sample, the curves below show the change to the sample during the course of a compaction process.

Summary and outlook

The mechanical properties of thin films are not merely of academic interest. For many thin film systems, regardless of whether they be visco-elastic or poro-elastic, the determination of the mechanical properties by analysing the dispersion of surface waves is a feasible alternative to classical indentation tests. In many cases, this special ultrasound technique is allowing systems to be analysed for the first time.

At present we are still assessing the full range of prospective applications of the technique. The next phase will involve transfer of the viscoelastic theory to the evaluation of the dispersion curves and examining cross-linked polymer films. Ivan Illich states in "Tools for Conviviality": "People need tools with which to work, not devices which do the work instead." In our case, the equipment for determining the elastic properties of materials using surface waves is a tool, and certainly far removed from being a routine testing machine.

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New approach for training in adhesive bonding technology: BoniH – adhesive bonder online

Since 1994, 1133 people have successfully passed the DVS®-EWF accredited Adhesive Bonder training course given by the Center for Adhesive Bonding Technology of the Fraunhofer IFAM. However, considering all the course participants up until the start of 2005, only 5 percent were from the handicrafts sector. This situation is disquieting because of the high and ever increasing importance of adhesive bonding in this sector.

The reasons why the 1-week Adhesive Bonder training course has not been attractive to the handicrafts sector are very evident. Small companies cannot afford or do not wish to release their employees for a whole week for training. These companies do not have the extra manpower to replace absent staff, particular individuals are often difficult to replace and orders often have to be completed under time pressure. On the other hand, technological development is very relevant for the handicrafts sector: Increased requirements on the usage properties of products necessitate that companies use a diverse range of materials in their production processes and these materials can often only be joined using bonding technology.

Against this background, and wanting to provide access for the handicrafts sector to advancements in adhesive bonding technology, the Fraunhofer IFAM, in collaboration with the Technology Transfer Center of the Bremen Chamber of Handicrafts and its Vocational Advancement Center, initiated "BoniH (online training for the handicrafts sector): Adhesive Bonder online". To date this online course has been held twice, with employees from handicraft companies in Bremen and the surrounding area taking part. In the online course, theoretical knowledge about adhesive bonding is taught using a teaching platform developed by "Ivy-Group". The special feature of this platform is that it allows so-called "live e-learning" via tutorials. Participants sit with a headset in front of their monitors for tutorials and see and hear the course tutors in real time. In turn, the tutors can directly reply to questions from participants which are addressed verbally and do not have to be typed.

Fig. 1: Tutor Andrea Paul (IFAM) in the studio.

Considering the special situation of the handicrafts sector, an advantage of this teaching platform is that it records each online activity, meaning that no participant misses a session – a participant can view a session at any later convenient time. The course content was specially prepared for this new training method and the tutors have been trained in media-didactics.

Fig. 2: CD-ROM cover.

* DVS = Deutscher Verband für Schweißen und verwandte Verfahren e. V.
EWF = European Federation for Welding, Joining and Cutting

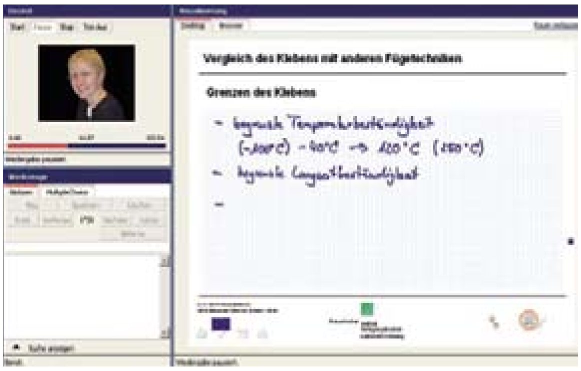

Fig. 3: Screenshot.

In addition to a CD-ROM which allows participants to prepare for the course, and which has been specially customised for the online training, each online participant also receives a further CD-ROM with interactive exercises for each of the individual course modules. This allows participants to test the level of their knowledge (Fig. 3). In addition, a video was used to prepare participants for the 1-day practical session that took place at the end of the course at the Fraunhofer IFAM. Following this the final examination was taken.

After evaluation of the first run of "BoniH – online training for the handicrafts sector" it was concluded that e-learning is a successful approach for providing training in adhesive bonding technology and can effectively transfer knowledge to the handicrafts sector. The special resource-related issues, work methods and time pressures in the handicrafts sector do not diminish the readiness to take on innovative technologies in this sector. They do however often take away the opportunity to participate in certified training courses that are given in the conventional 1-week format. The chosen live e-learning platform not only allows online study sessions and synchronous verbal communication but also allows the online sessions to be viewed again at any later time. After the first successful run the course was adjudged to be an ideal e-learning instrument for the handicrafts sector.

Experience to date has shown that adhesive bonding know-how leads to new approaches for solving problems. This is due to the fact that adhesive bonding technology is often for the first time given consideration as an alternative joining technique. Passing on information about technological advancements creates the conditions for innovation. The task for us is to open up opportunities for sectors of industry which have difficulty coming by this information, either for operational or resource-related reasons, and so ensure that they are kept up-to-date with advances in technology.

This is why the Adhesive Bonder online course will be held again in the second half of 2006.

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Computer simulation of adhesive processing

Background

The trend in industrial production is towards shorter cycle-times and a corresponding increase in the requirements on individual processes. In adhesive bonding technology this applies to the processing speeds and to new, more efficient application techniques. When an adhesive is processed it is subjected to thermomechanical stress by the dosing equipment. The question arises as to whether the system, namely the adhesive and the dosing equipment, functions reliably under these more stringent conditions. The parameters which determine the stress on an adhesive are the pressure, temperature, shear stress and time.

In all dosing equipment, regardless of the design, the sensory systems used to monitor the dosing process are limited to measuring the temperature and pressure in the pipe/hose systems. These are global parameters, but they experience high local variation (i.e. within a dosing pump or valve). These local parameters cannot be recorded using conventional measuring techniques even though they largely determine whether an adhesive can be effectively processed.

Project

The objective was to qualify a method which, based on measurable global parameters, allows the local pressure, temperature and shear to be determined. This knowledge about local parameters would allow accurate description of the real stress to which an adhesive is subjected in the dosing equipment during processing.

Computational Fluid Dynamics (CFD) was used to achieve this objective. CFD has already been used to describe fluid dynamics in a very broad range of technical fields. This range extends from the aerodynamics of aircraft, rail vehicles and road vehicles, to the simulation of filling processes in the injection moulding of polymeric and metallic materials and on to describing combustion processes in engines.

Up until now, very little use has been made of CFD in bonding technology and in particular to describe the machine-processing of adhesives (= non-linear fluids). Fig. 1 shows the benefits of applying CFD to adhesive processing.

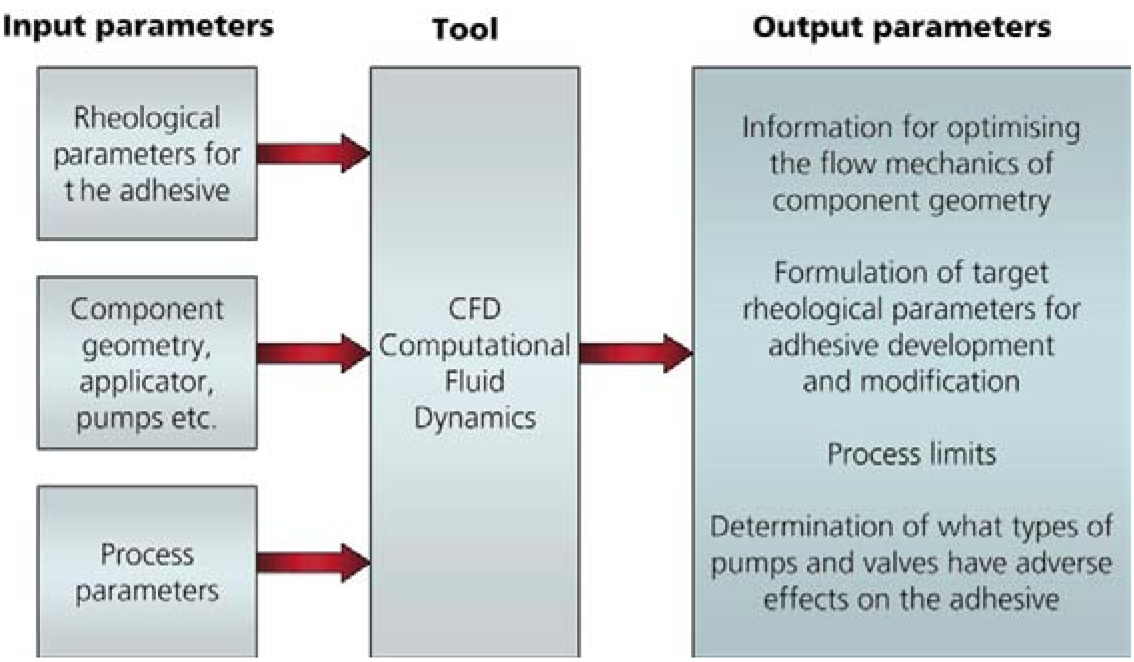

Fig. 1: Input and output parameters for the CFD simulation of adhesive processing.

Example application

In the packaging industry, conveyor belt speeds are increasing and hence the efficiency of the components responsible for the adhesive dosing must be increased in proportion to this. A restrictive boundary condition was the need to realise the increased efficiency of the application valves with a standard design volume. Fig. 2 shows the cross-section of a so-called dosing nozzle for processing hotmelts and the model of the region through which the fluid flows.

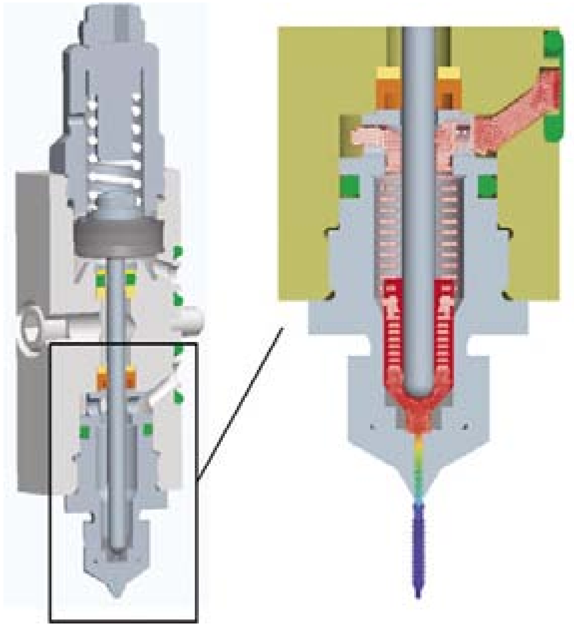

Fig. 2: Cross-section of a dosing nozzle for processing hotmelts.

The model highlights how difficult it is to improve the flow through the valve nozzle and hence the efficiency of application of the adhesive: Mechanical engineering puts limits on the degree to which the flow can be optimised. This demonstrates the general advantage of computational simulation. By making relatively simple virtual modifications to the geometry, the changes to the flow behaviour can be recorded – as shown in Fig. 3 for the pressure in the initial state – and then optimised by iteration.

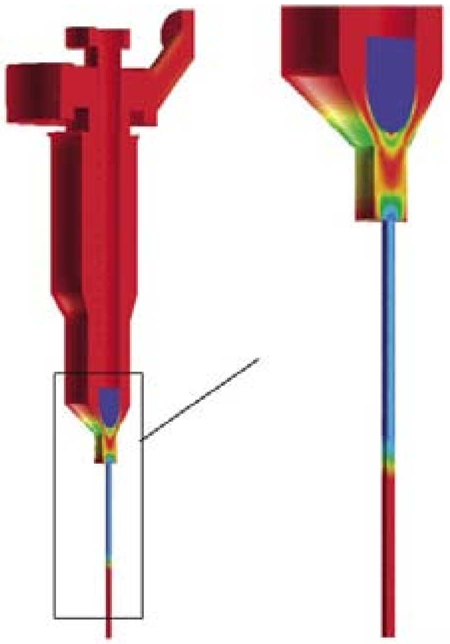

Fig. 3: Pressure of the adhesive in the valve nozzle with an open valve.

Outlook

This example application highlights just one of many uses of CFD for studying the processing of adhesives. Another use is the simulation of local parameters to evaluate the thermomechanical stresses to which adhesives are exposed in dosing equipment. The objective here is to quantify the processing limits for an adhesive system. To achieve this, it is necessary to consider all respective components, for example dosing pumps, taking into account the relative movements of the individual components. Computer simulation gives interesting results, but interpreting those results is difficult. Experiments must be carried out to complement the computational work. Such experiments require a device which allows the individual parameters (namely pressure, temperature, shear and time) to be varied independently of each other. This topic will be covered in next year's annual report.

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Department of Adhesive Bonding Technology and
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Bremen

Micro-bonding with reduced mechanical stress

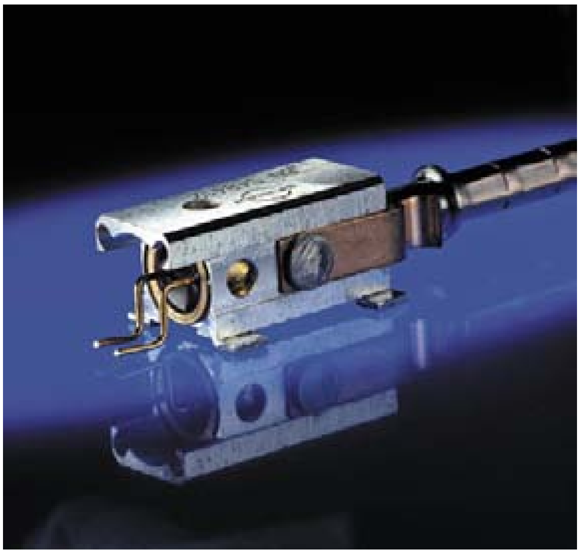

Fig. 1: Micro-bond: VCSEL diode bonded into an SMD housing.

Background

Adhesive bonding technology is being used for an ever wider spectrum of assembly and joining applications in microsystems engineering, micro-circuitry, micro-electronics, etc. The nature and quality of the assembly step have a major effect on the production costs as well as on the performance and reliability of the total system. Assembly-related mechanical stress in joints is one of the chief reasons for faults and failures.

Project

The objective of the project was to acquire knowledge about the origin of micro-stress and so allow stress-optimised bonds to be created and enable more realistic simulation work to be undertaken.

Procedure

The project studied the effect of design, material selection and process management by carrying out real experiments and Finite-Element-Modelling (FEM). On recommendation of the supervisory project committee two applications were studied, one in the area of electro-optics and one involving micro-optics.

Example applications

In the field of electro-optics, the bonding of a VCSEL diode into an SMD housing by means of an active feedback was studied (Fig. 1). As a result of the tolerances of the components to be bonded, in some cases it may be necessary to apply very inhomogeneous adhesive films (thickness 10 µm to 490 µm). In accordance with the required specifications, the bonded joint must guarantee alignment of better than ± 10 µm for 20 years under the conditions of use. Little is, however, currently known about the ageing properties of such joints (e. g. positional changes, misalignment) and how the ageing can be optimised.
As an example of an assembly in the field of micro-optics, a cylindrical endoscope objective was selected (Fig. 2). The bonds are subjected to considerable loads when the optical components, which possess differing diameters, are polished down to a uniform diameter and when subsequent sterilisations are carried out.
In both these example applications, the internal stress in the micro-bonds has a direct effect on the properties of the components.

Preliminary work: Micro-optics and electro-optics

For each of these example applications detailed specifications were drawn up in order to select potentially suitable adhesives. Nearly 50 adhesives were acquired and application-specific screening tests were carried out. In accordance with the specifications, properties such as the dosing characteristics, realisable adhesive film thickness, curing properties, lack of blisters, bond strength and thermomechanical behaviour were evaluated in bulk and in model bonded joints. The most promising adhesives were then used to systematically investigate the effect of different design, process management and load parameters in model bonded joints in order to identify viable, stress-optimised variants. The results were used to produce test bonds with improved stress properties. Concomitant with the manufacture of the test bonds for the VCSEL diode / SMD housing system, an assembly process was developed that utilised an automated micro-assembly plant. After automated alignment by maximising the light intensity

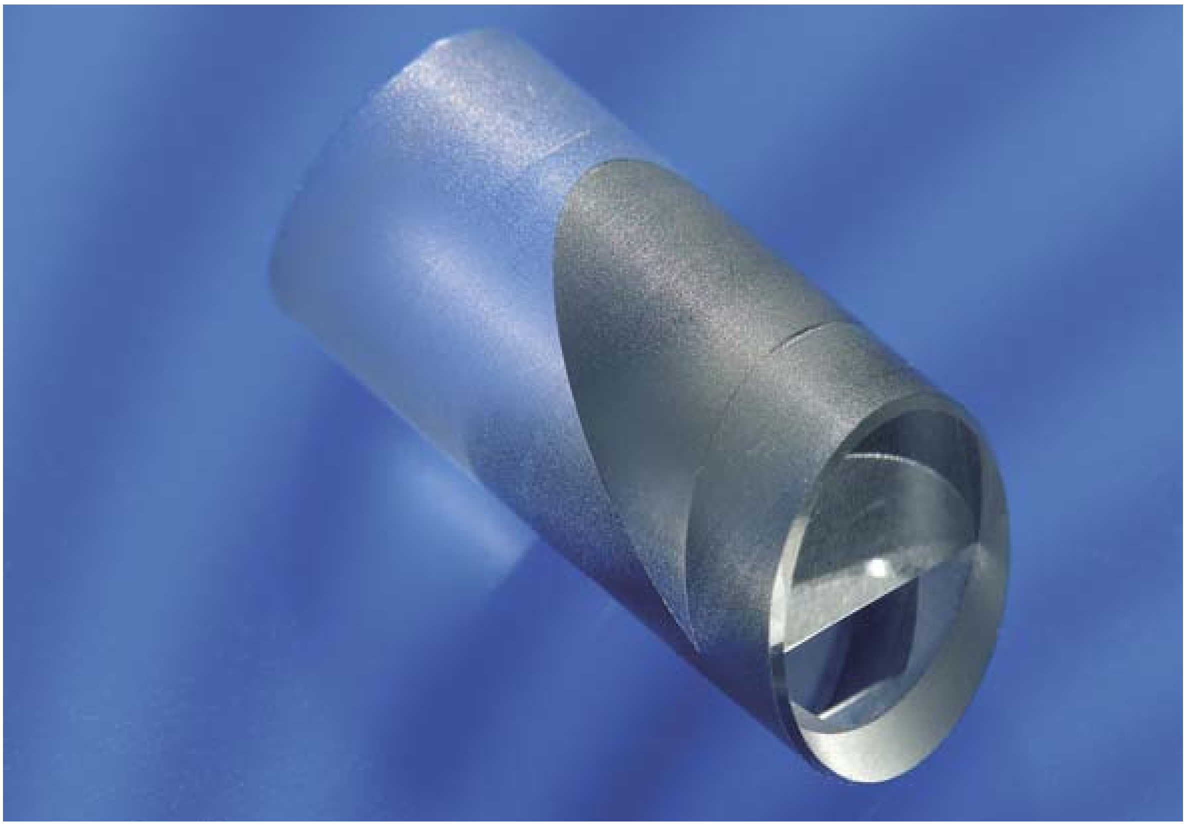

Fig. 2: Endoscope objective bonded in the optical path.

passing into the fibre, UV curing of the adhesive was carried out in the plant followed by a thermal post-curing step. The plateau width of the intensity maximum was determined to amount to ± 10 μm and this sets the required long-term positional stability for subsequent production steps and for use.

Results: Micro-optics

For the model bonds, the most prominent results are the following. For most adhesives, the structural changes in the adhesive film increased with the intensity of the UV curing. However, most of these changes were only visible after temperature cycles. This means that unknown but considerable stress could be present in the bonded joint when there is rapid, inhomogeneous UV curing. Thicker adhesive films in the region of 20 – 100 μm gave no thermomechanical benefits, and in some cases the thermomechanical properties were even less favourable than for thinner films (10 – 20 μm). This indicates the effect of the interfacial layer of the adhesive, although this aspect could not be further investigated in this project. In addition, attempts to suppress the curing shrinkage of the adhesive film in the thickness direction by using 20 μm spacers was disadvantageous. In some instances this resulted in cracks and in general led to lower strength. The ability of the adhesive film to undergo unhindered shrink-related deformation during the curing was important here for keeping the stress in the resulting adhesive film low. Besides the aforementioned systematic relationships, it was evident that accidental imperfections in the adhesive film, due for example to too large filler particles or air bubbles, could induce optically detrimental structural changes when the bond was subjected to alternating temperature loads. These imperfections act as "initiators", which trigger the relief of stress.

In the 100 test bonds, structural changes were only observed in 2 samples (cured very rapidly on purpose). This confirms that the model bonds tested earlier had aggravatedly simulated the real conditions and shows that virtually all test bond variants already realised an effective stress optimisation.

Depending on the adhesive, there was a lesser or greater dependence of the fracture stress on the curing conditions, duration of storage and on the method used to clean the surfaces. Slow UV curing using a low but adequate UV intensity and new, non-corroded glass surfaces were particularly advantageous. In the peel test, which is very unfavourable for bonded joints, the best bonded variants generally showed a substrate fracture, and this represents a very good result.

Results: Electro-optics

The test bonds were examined with regard to the position of the diode (relative to the SMD housing) and with regard to the intensity of light launched into the fibre. This allowed cause-effect correlations to be analysed. In order to determine the diode position, a measuring method that could be used during production and also after ageing was developed and tested. The measurement accuracy was better than 2 µm over a measurement field of 6 x 6 mm².

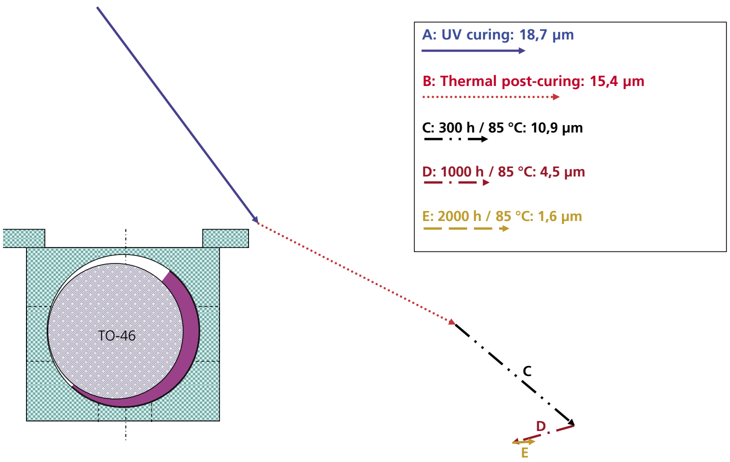

Fig. 3: Misalignment measurement on a non stress-optimised bond.

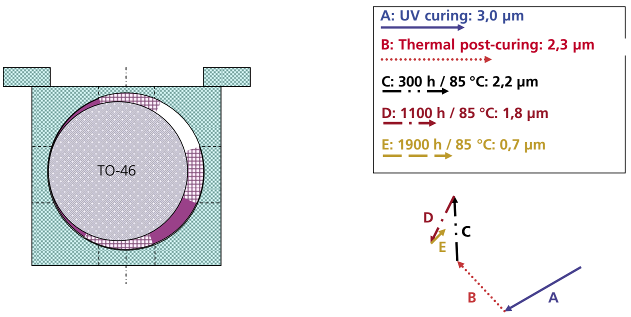

Fig. 4: Misalignment measurement on a stress-optimised bond (movements magnified compared to Fig. 3).

When determining the diode position it became clear that the largest positional shifts occurred during UV curing, during thermal post-curing and during the first 300 hours of the 85 °C ageing. Each of these shifts can be the order of 10 – 20 µm in non stress-optimised, eccentric bonds due to the very inhomogeneous thickness of the adhesive film. The total positional change from prior to the adhesive curing step until after the 2000 h ageing at 85 °C can be up to 40 µm (Fig. 3). The bottom left of the figure depicts a schematic cross-section of the adhesive bond, showing the VCSEL diode (circular, inside), surrounding gap with adhesive and SMD housing (square, outside). The coloured arrows show the relative movements of the diode and housing after the various production steps and ageing periods indicated in the legend. In stress-optimised bonds, the total movement is reduced to ≤ 5 µm (Fig. 4). Compared to Fig. 3, Fig. 4 shows the movements on a larger scale. The precise numerical values of the movements are in each case given in the legend. Only the stress-optimised bonds remain on the plateau of the intensity maximum. Due to the optimisation, the specifications were safely satisfied over a long period without positional changes occurring.

In the studies on the light intensity launched into the fibres, no misalignment-related impairment of the light intensity was observed for any of the bonded joints during the production and ageing. A reference sample verified the assumed correlation of cause (position) and effect (light intensity launched).

Finite element modelling: Electro-optics

Finite element modelling was carried out to further increase our understanding of the factors which cause stress in micro-bonds and hence allow optimisation of such bonds. This work was undertaken on the electro-optical application. The parameters that were calculated were the mechanical stress, strain, movement and tilting of the VCSEL diode. Taking into account the temperature-dependent parameters of the relevant materials it became clear that low temperatures (-40 °C) resulted in higher stress in the adherends and in the adhesive film than did higher temperatures (+80 °C). In addition, eccentric bonds with inhomogeneous adhesive film thicknesses resulted in greater stress than symmetric bonds with homogenous adhesive film thicknesses. This agrees with experimental findings. It was found that optimisation of the geometry of the adhesive film could significantly reduce the stress, and this is also in agreement with experimental results. It is difficult to evaluate curing shrinkage using FEM. From comparison with experiments, it can be concluded that the majority of the curing shrinkage occurs in adhesive that still has a low degree of crosslinking. This part of the curing shrinkage is counteracted by plastic deformation / flow processes, without causing noteworthy mechanical stress. With this information, the curing shrinkage will be able to be more effectively modelled in the future.

Demonstrators

Using the developed processes and sets of parameters, stress-optimised demonstrator bonds were produced. This demonstrated the industrial viability of these assembly techniques for producing low-stress bonds in one selected micro-optical application and one electro-optical application.

This project was funded by the Germany Ministry for Trade, Industry and Employment (BMWA) via the Arbeitsgemeinschaft industrieller Forschungsvereinigungen Otto von Guericke e. V. (AiF) (AiF-no.: 13,361, N/DVS-no.: 10,031) and by the Forschungsvereinigung Schweißen und verwandte Verfahren e. V. of the DVS. We are most grateful for this support.

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

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Results Applications Perspectives

←
Production of casting construction components.

Expertise and Know-how

The Department of Shaping and Functional Materials at the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research is continuously expanding its expertise on integrating functional materials into structural components. With our vision of "smarter – smaller – safer", the aim is to transfer this knowledge to diverse sectors of industry. A prerequisite for this is efficient organisation and expansion of our three core areas of expertise:

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

The expertise and knowledge of IFAM staff and the establishment of networks with partners in other technical disciplines is ensuring that innovative solutions are developed for industry. Our R&D activities extend from fundamental, application-orientated research right through to product realisation and support with implementation into production processes.

The use of combinations of different materials in a single component is playing an ever more important role for meeting the complex requirements of intelligent components. To design such combinations of materials and to control the relevant manufacturing processes are important aspects of our work.

Production processes such as injection moulding are currently used for manufacturing geometrically complex components from a host of different metal alloys and ceramic materials. We have achieved to systematically apply the specific properties of different materials locally in the part. As an example, the combination of magnetic and non-magnetic steel can be mentioned here.

Material combinations can also be realised in micro-component production, with such integrated technical manufacturing solutions obviating the need for micro-assembly work. In addition to optimising the quality assurance of production processes for metallic miniature components, new interdisciplinary approaches in the area of micro-reaction technology and bioreactors are being developed.

The "Functional Printing" technology platform has been expanded with new options for maskless printing using the so-called M³D process. New functional ink and paste formulations were developed and knowledge about applying them to components has been acquired. Hence it is possible to integrate sensorical functions into components, thus allowing, for example, the recording of operating or ambient conditions.

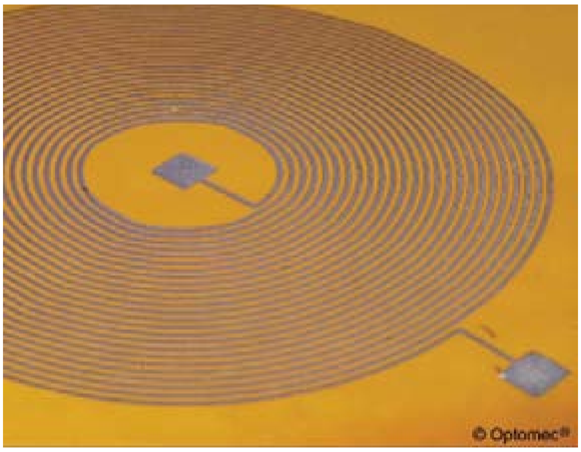

Fig. 1: "Functional Printing": Maskless printing by using the Maskless Mesoscale Material Deposition (M³D) process. Silver micro-antenna on flexible substrate.

A state-of-the-art casting plant and ultra-modern analytical equipment coupled with in-depth know-how of aluminium and magnesium alloy processing via pressure die casting have enabled IFAM to assume a favorable position in the market. Besides optimising casting processes for complex components, other key activities include the integration of piezoelectric elements and RFIDs into cast components and this work is continuing apace.

We have extensive knowledge concerning the transfer of cellular metal technology to commercial products. Customised solutions for industry, for example the use of cellular metals as diesel particle filters, are under development and our process engineering know-how in this area is continually growing.

Perspectives

It is imperative that our service portfolio is continually adapted to the needs of the market, deriving new technological challenges from the change. Considered equally important are product innovations under economically justifiable conditions and the contribution of the solutions towards improving the quality of life and sustainable development in the areas of transport, energy, medicine and the environment.

In any innovative product, the materials and their processing are vital factors for success. This is especially so for moulding processes because the material properties and the component geometry can be influenced during the production process. The resulting market is growing with the increasing product complexity.

Material properties and technologies for structural and functional applications are being customised and characterised. In this area, high-performance materials, composite materials, gradient materials and smart materials are being developed, as are production technologies for integrating the properties into components.

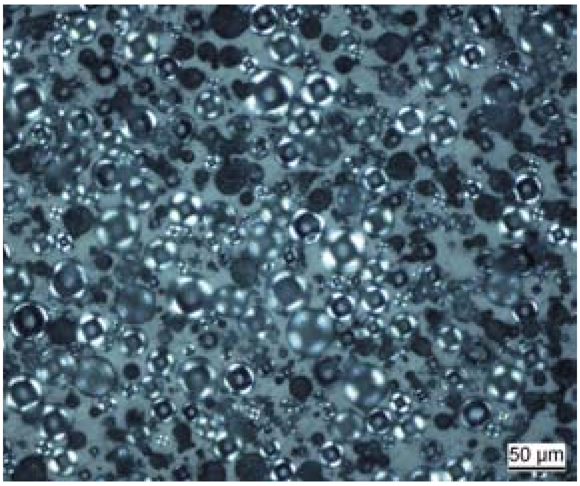

Fig. 2: Composite material based on metals and microscopic small glass bubbles produced by casting. The maximal size of the glass bubbles is 60 microns.

By continuing to enhance our knowledge in the area of functional materials (e.g. thermal management materials, carbon nanotubes and nanocomposites), we are opening up new opportunities for undertaking product development work with existing customers and for attracting new customers.

Of special relevance for future process and product development work is simulation of all the processing steps required for producing a component. For both cast and powder-metallurgical components the aim is to be able to predict the properties of the components before they are manufactured, so allowing the development of robust production processes and efficient component manufacture.

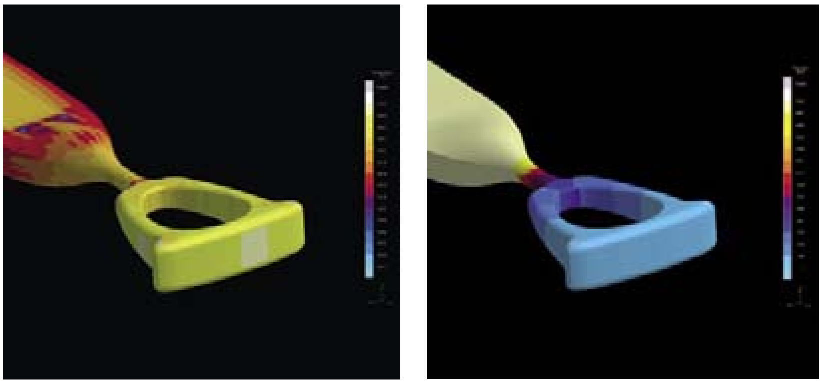

Fig. 3: Simulation of temperature distribution and mould filling behaviour for micro metal injection moulding.

A regional BMBF funded alliance and the Demonstration Centre for Cellular Materials in Dresden are key cornerstones for making the full application potential of porous structures available to small and medium-sized companies. The development work being carried out with industrial partners in the area of diesel soot filters is an example of the utilisation of fundamental know-how to develop product ideas and manufacturing technologies for viable market products right through to implementation in production processes.

In the future, we will place special emphasis on research and development work in the area of medical technology and biomaterials. Networking with other institutes having complementary expertise and with companies and clinical partners will be intensified. Key work areas include antimicrobial surfaces, biocompatible metallic materials and production processes for miniaturisation.

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Equipment/facilities

Component manufacture

- Metal powder injection moulding units (pressure 20 t and 40 t)
- Production cell 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, stereo lithography, fused deposition modelling, multiphase jet solidification and 3-D printing
- Cold chamber pressure casting machine (real-time control, pressure 660 t); hot chamber pressure casting machine (real-time control, pressure 315 t)
- Pilot plants for making metal foam components
- Twin barrel injection moulding machine
- Microwave sintering furnace machine
- Sieve printing machine.

Micro- and nanostructuring

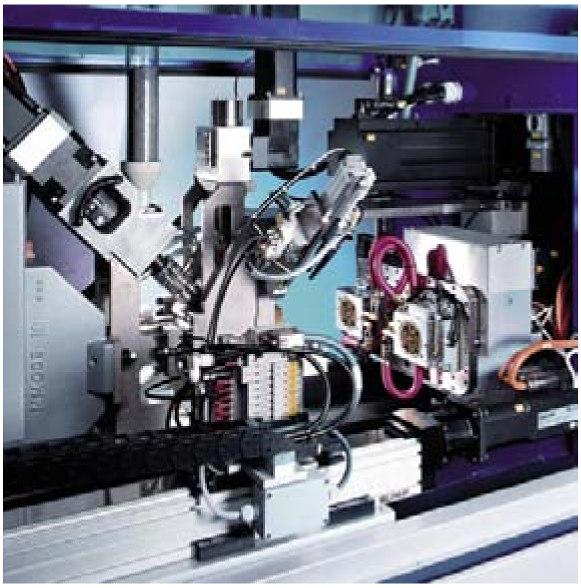
- Ink-Jet-Printing-Technologies
- Aerosol-Printing-Technologies (Maskless Mesoscale Material Deposition M³D)
- Micro injection moulding machine.

Thermal/chemical treatment of moulded components

- Plant for the chemical de-waxing of injection moulded components
- Various sintering ovens (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 roler for feedstock production
- Air classifier for classifying powders.



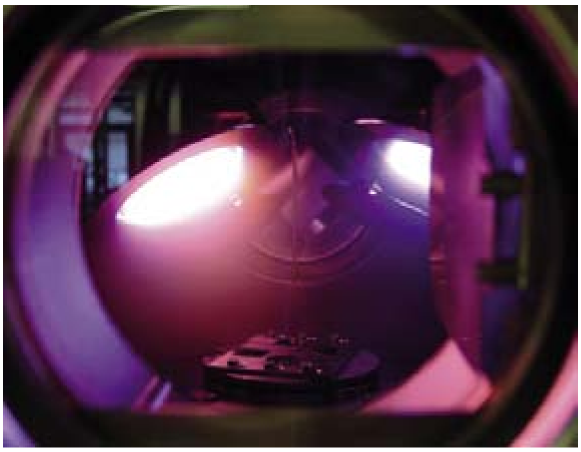
Battenfeld Microsystem 50: Series production plant for micro-components and micro-structured components.

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.

Computer equipment

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



Sputter technology for nanostructured, functional layers.

Intelligent cast components

Background

Advancements in casting technology over recent years have allowed high-tech cast products to be manufactured from a wide variety of different metals. The cast products are used in a broad spectrum of applications ranging from medical technology, the car manufacturing sector to the aircraft and aerospace industries. Positive features of these cast products are the short route from the raw material to the final product, their good mechanical properties and the high freedom of design. The advancement in specific casting techniques allows ever more complex designs and customised design of cast components. These designs often mimic structures found in nature, for example in trees and in the skeletons of mammals. A very significant difference, however, is that conventional cast components cannot detected loads acting on them and are hence unable to react to those loads.

Challenge

On way of mimicking the situation in nature more closely is to combine cast components with sensors, actuators and other electronic components.

A wide variety of adaptronic systems, sensors, actuators, micro-processors and data transfer devices such as transponders and RFIDs (radio frequency identification) are currently available. The present state of the art is to apply these devices in an extra processing stage. Current methods for achieving this are complex and costly. In addition, the devices, namely sensors and actuators for pressure, temperature, electrical resistance, vibration and acceleration, cannot be placed at the correct location in the part for carrying out the relevant measurements. In current applications, for example, actuator systems can only be applied to the outer surface of components and only by using complex processes.
These additional production steps mean increased production time and cost and hence a lower added value. A further disadvantage that must be taken into account is the risk of environmental effects and errors due to poor contact or other auxiliary materials between the sensor/actuator and the matrix material. These disadvantages can be largely obviated by direct incorporation of the components during the actual pressure die casting process. The components to be incorporated are placed in the mould, then the mould is filled using a conventional pressure die casting process. This allows intelligent cast components to be manufactured in a single processing step. The challenge here is to guarantee the positional accuracy of the components during the casting process and to prevent the destruction of the integrated components by excessive heat.

Objectives

Direct integration of sensors, actuators and other electronic components allows casting technology to be combined with advanced electronic functions. The resulting cast components are able to react to their surroundings, both passively via data recording (sensors) and actively via the integrated actuators. In addition, interfaces are created which allow data transfer and hence direct networking of individual components to form a complete system, for example a car.

The first application was the integration of transponders or RFIDs into components for detection and tracking purposes. RFIDs transfer data contact-free and have the following advantages over conventional barcodes:

- Contact-free identification,
- Penetration through a wide variety of materials,
- Reading and writing as desired (product data, etc.),
- Identification in less than a second,
- Simultaneous recording of many transponders,
- Resistance to environmental effects,
- Size and shape of the transponder can be customised,
- Transponders can be completely integrated into the product,
- High security via copy protection / encoding,
- Rapid recording,
- Contamination has no adverse effects on functioning,
- Free positioning,
- Sending, saving and recording of data.

The use of RFIDs hence allows direct recognition and tracking of components and offers new opportunities for improved logistics, quality control and protection against forgery. As an example, product tracking through a production process is mentioned here. For each individual component, all production steps and parameters can be stored in a database and can be retrieved at any time. Therefore, identification by means of RFIDs allows a component to be tracked throughout its production lifetime. When needed, for instance in case of a complaint, the data can be retrieved and checked.
As already mentioned, a further means of increasing the functionality of a component and combining the advantages of different technologies is to incorporate adaptronic components. By combining sensor functions with direct actuator responses, vibrations in structures, for example, can be immediately counteracted and hence minimised or completely eliminated. The use of intelligent systems such as sensors, actuators, processors, electronic components for data processing and storage and electronic components which function as controllers and transfer devices allows adaptronic components/semi-finished products to be manufactured in an integrated production process. Such components/products have "feelings" and respond in an autarkical way to their surroundings.

Current work

Research work at Fraunhofer IFAM has already demonstrated that a variety of electronic components can be integrated into aluminium and zinc components manufactured via pressure die casting. This involved the incorporation of various RFIDs and piezoceramic materials. Both the RFIDs and the piezoceramic materials were protected against excessive heat by appropriate control of the temperature of the casting mould and component. This ensured correct subsequent functioning of the integrated components. Current research work is focussing on the positioning of the integrated components. Simulation tools are also being employed to optimise the position of components and minimise the heat input.

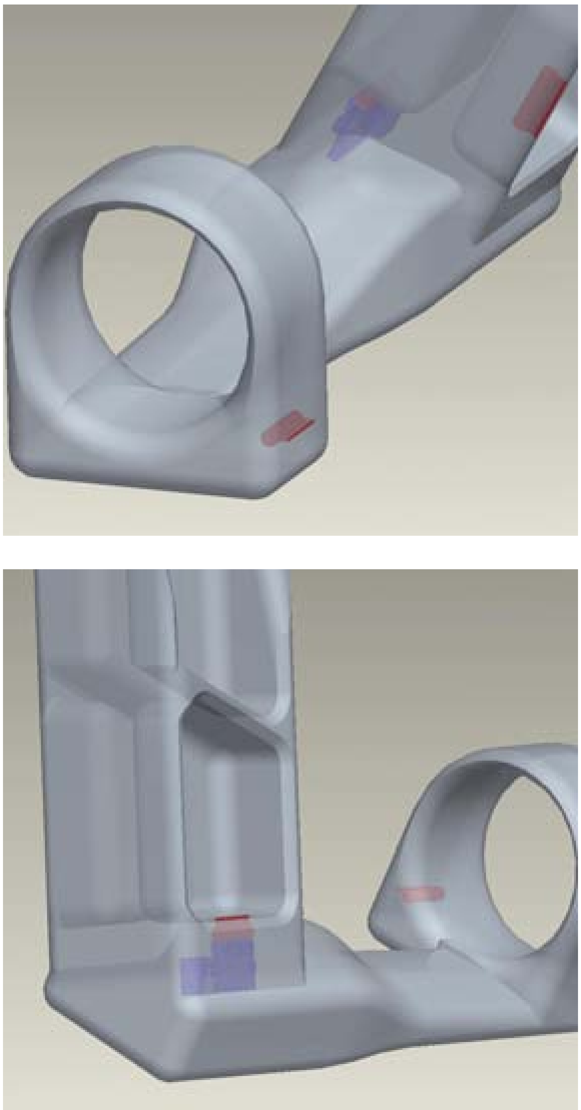


Fig. 1 and 2: Electronic and adaptronic devices integrated into cast components.

In collaboration with the Adaptronics Alliance and other institutes work is being carried out on suitable selection, design and sizing of adaptronic components for the use as sensors and actuators.

Perspectives

Computer processors and sensors and virtually all commercially available electronic components are becoming ever smaller and cheaper. Wireless communication is practically accessible everywhere. The direct integration of these devices into cast components is enhancing function-integration, promoting lightweight construction and allowing networking of intelligent components. Starting in 2006 – the year of Information Technology – a further interface between hardware and software is being created and "Pervasive Computing", the networking of intelligent everyday objects, is being promoted.
These intelligent cast components must be able to experience their surroundings autarkically, adapt themselves to the relevant operating state, detect damage and pass the recorded data to users or a complete system. Such systems can be used for developing and designing components, for data recording during operation, for health monitoring/controlling and for X-By-Wire technology – electronic systems with no mechanical connection between the operating function and operating element.
Direct recording of operating loads allows more suitable design, optimised lightweight construction and decreasing safety factors – in short: Replacement of mass by information. In addition, the load on a component can, for example, be recorded over its operating time, so allowing maintenance intervals to be shortened and the development of new products to be accelerated.

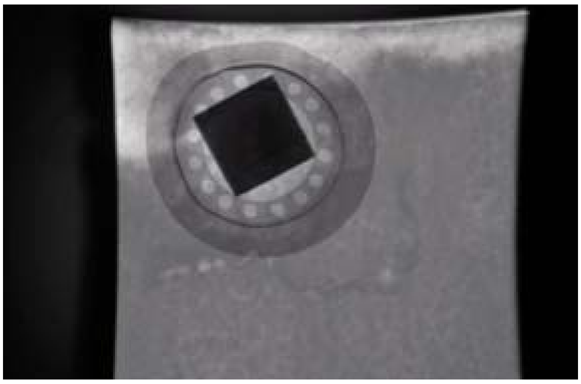


Fig. 3: X-ray image of an integrated RFID: TAG ID 700.

Fig. 4: Reading out an RFID integrated in metal.

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2C-Metal Injection Moulding (MIM) – combining two metals in a single production step

Background

Metal Injection Moulding (MIM) is an established method for manufacturing small, complex-shaped metal components. Fraunhofer IFAM has played its part in applying this method to a wide and ever increasing range of materials. The spectrum of materials to which the technique can be applied, coupled with design freedom – as is also the case for plastic injection moulding – is the reason for the growth and popularity of the MIM method. This technique is meeting the needs of component designers who face the challenge of having to incorporate an ever increasing number of functions in ever smaller components.

Fraunhofer IFAM is currently working intensively on applying a further variant of plastic injection moulding to metal components, namely multi-component injection moulding. Everybody is familiar with multicoloured plastic components. Such components are manufactured by incorporating pigments of different colour into the same polymer. By using an injection moulding process the need for complex joining of components is obviated and the result is a visually pleasing, high-quality component. Another version is the incorporation of additional functions by using different plastics. An example of this is a modern-day toothbrush which contains a softer plastic as a type of hinge. The fine art of modern-day production is also exemplified by the flexible, non-detachable joints created in Playmobil® figures by the manufacturer geobra Brandstätter.

Potential

Transferring this to multicomponent-MIM – for two components (2C-MIM) at first – this involves the direct combination of two metals in a single production step, therefore eliminating the need for a subsequent joining process. The range of components that can be manufactured extends from hollow components with complex internal structures right through to flexible, non-detachable joints. The following combinations demonstrate potential applications of 2C-MIM technology:

- magnetic – non-magnetic
- hard – tough
- dense – porous
- expensive – cheap
- compact – hollow.

The objective in all cases is to manufacture components with enhanced functionality at favourable cost. For example, components that are subject to wear can be strengthened by using a harder or more resistant material at neuralgic points. In particular the combination of magnetic and non-magnetic materials allows completely new designs without an air gap.

Problem

Combining metals using the 2C-MIM technique does however have its limitations. The least few of these limitations are due to the shaping step, the injection moulding. These problems can be overcome, as has been demonstrated in plastic injection moulding.

The major problem, however, is the different behaviour of metals during sintering. If the two metals differ in their sintering properties and thermal expansion properties, this immediately leads to stress in the joint and in some cases even fracture. When selecting combinations of materials, the situation must not be so that one material starts to contract at say 600 °C whilst the other material only starts to sinter at say 800 °C. In the most favourable case, this would cause deformation of the labile brown part, but in most instances fracture would result.

A perfectly sintered composite material becomes unstable if the two components shrink inhomogen-

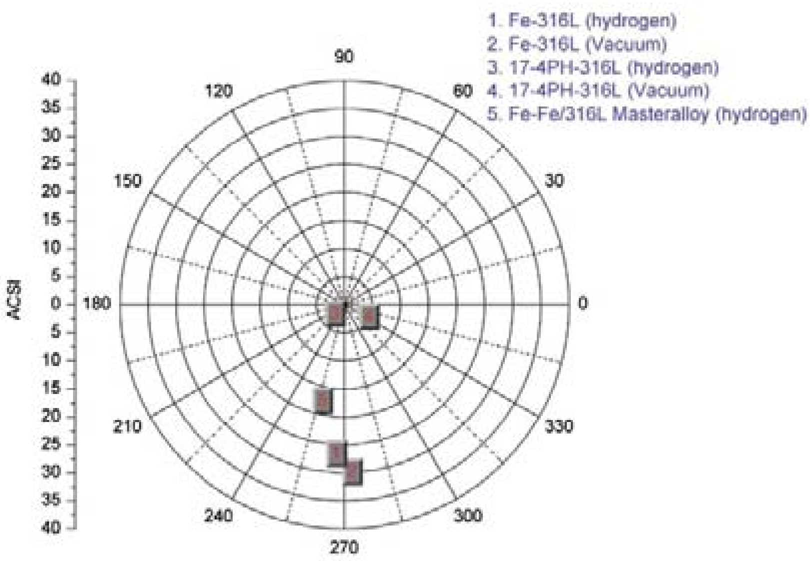

Fig. 1: ACSI (apparent co-sintering index) for five different variants for manufacturing a magnetic – non-magnetic combination of materials. Combinations 3, 4 and 5 have ACSI values < 15 and have been successfully manufactured.

eously during cooling. The resulting stresses usually lead to component failure whilst still in the furnace and in extreme cases lead to premature failure of the component when in use.

These thermal properties can be adjusted within certain limits. Based on experience, suitable tools for this adjustment are being developed at the Fraunhofer IFAM. In order to be able to carry out our work in a targeted way with a good chance of success, we have developed a quick test for the fundamental compatibility of different powder materials based on their thermal properties. The ACSI (apparent co-sintering index, Fig. 1) takes into account the physical parameters of the partners (such as the thermal expansion properties), processing parameters and other properties defined by the powders or powder mixtures (such as temperature, rate and extent of the shrinkage). Evaluation of our own preliminary experiments and of literature data show that this index should have a value of 15 or less in order to have a good chance of successfully manufacturing composite components.

The combination of chemically incompatible materials may require additional development work. Taking a simple example, carbon could diffuse from one material into the other at the joint interface and so alter the mechanical and magnetic properties. Such a problem can often be overcome by judicious selection of the material partners, but this will certainly put limitations on the range of applications of 2C-MIM.

Suitable combinations of materials

The focus was initially put on combining magnetic and non-magnetic materials. This was achieved by combining high-alloy steel grades 316L and 17-4PH. The austenitic 316L is soft and non-magnetic, whilst the 17-4PH can be magnetised due to its martensitic structure. Since the two steel grades were available as comparable powders that could be processed under similar sintering conditions, it was possible to successfully manufacture the micro-MIM tensile test sample in Fig. 2 using the 2C injection moulding machine at Fraunhofer IFAM.

There is greater scope for adjusting the magnetic properties of iron. For this reason, a composite material made of 316L and iron was also manufactured. For this combination of materials, the difference in the sintering behaviour was considerably greater and this is reflected in the ACSI value (Fig. 1, combinations 1 and 2). By employing a suitable mixture of powders comprising pure iron and a master alloy, which includes the alloy components for 316L (Fig. 1, combination 5), the sinter properties were adapted to the pure iron, thus allowing the successful manufacturing of test samples.

Even though the composite material made of 316L and H13 is also magnetic – non-magnetic (Fig. 3), its applications rather tend towards the combination of a hard, strong steel (H13) and a soft, tough steel.

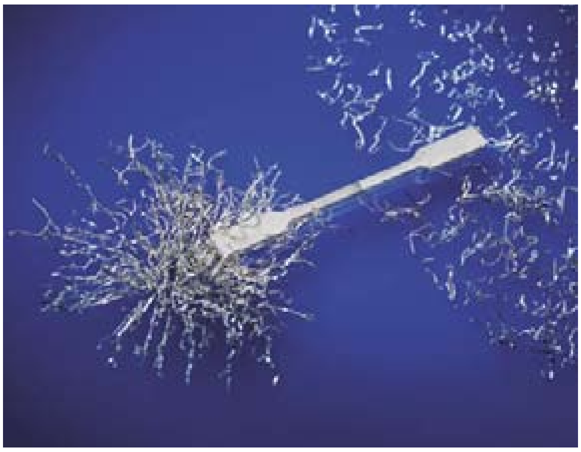

Fig. 2: Micro-MIM tensile test sample made from a combination of 316L and 17-4PH. The left part of the sample made of 17-4PH was magnetised and attracts the iron filings. The right part of the sample remains non-magnetic.

Fig. 3: 2C-MIM tensile test sample made of austenitic high-alloy stainless steel 316L and hard, martensitic hot work steel H13. The H13 was magnetised. In the photo the iron filings can be seen attracted to the H13 and orientated along the field lines. The high-alloy steel is non-magnetic and has no effect on the iron filings.

Micro-MIM and macro-MIM

Development work at Fraunhofer IFAM in the area of 2C injection moulding involves both "regular" MIM as well as micro-MIM. Our work revealed that the size of the contact surface has an influence on the successful manufacture of the composite. The manufacture of a 2C micro-MIM tensile test sample (Fig. 2) proved easier than that of a standard MIM tensile test sample (Fig. 3).

Outlook

Fraunhofer IFAM will continue to manufacture new composite materials using the 2C-MIM method in order to incorporate new and increased functionality into sintered components. We are working towards creating a "tool box" which will allow us to match powders and materials in such a way that current limitations can be overcome. A further objective is to combine metals and ceramic materials. This represents a considerable challenge but is a pressing need due to the interest in such materials from the medical technology and car manufacturing sectors.

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Applications of aluminium foam in the transport sector

Background

Aluminium foams have low density, high stiffness per unit weight, excellent energy absorption properties, good noise and vibration damping properties and good long-term resistance to chemicals. They are also non-combustible. This unique range of properties makes aluminium foams suitable for a large number of applications. These include uses in the car, rail vehicle and aircraft manufacturing industries.

Aim of the project

As part of the EU "LISA" project (Lightweight Structural Applications based on Metallic and Organic Foams, 5th Framework Programme, Project no.: GRD1-2000-25415), a European project consortium was set up comprising end-users, material suppliers and research organisations. Fraunhofer IFAM acted as the project co-ordinator. The aim of the project was to use aluminium and polymer foams to improve the performance of selected components (that are used in cars, rail vehicles and aircraft). In addition to developing relevant components, using amongst other things simulation tools to carry out iterative optimisation, other key aspects of the project involved the integration of "aluminium foam" and the foam components into existing production lines at the various end-users.

Results

During this 3-year interdisciplinary research project several prototypes were produced for the different sectors of the transport industry. For the aircraft manufacturing sector, a protective shield (radome shield) was developed for the cockpit. This was a multilayer composite made from both conventional materials and aluminium foam materials. The lower weight and increased protection against, for example, impacts with birds, were very promising features. As a quasi "secondary product", a model was developed for component simulation/optimisation by means of which the deformation of metal foams at very high speeds (e. g. 160 m/s) can be simulated. This model is now also available for simulating other aluminium foam applications.

Considering now much lower speeds, the high kinetic energies when rail vehicles collide with solid objects (e. g. buffers) or other rail vehicles must be safely dissipated. Weight reduction and cost reduction are desired. In this project, aluminium foam was used to develop a completely new energy absorption system for the front section of rail vehicles. This energy absorption system was of low weight and met all the requirements of the end-user.

Good results were also obtained for application of aluminium foam in the car manufacturing sector. The energy absorption properties of the A-pillar of a medium-sized car in current production were considerably improved by using aluminium foam, without there being a significant increase in the weight.

Fig. 1: Semi-finished product in the foam mould.

It was only possible to reach this objective by using an iterative simulation process to virtually optimise both the position of the foam in the A-pillar and the shape and density of the foam.

Using a minimum amount of aluminium foam positioned in the right place it was possible to maximise the increase in energy absorption. The subsequent mechanical tests fully confirmed the simulation results. The Al-foam filled pillar was able to absorb 40 percent more energy, without design changes having to be made to the original A-pillar. The presence of the Al-foam only increased the weight by 3 percent.

Fig. 2: Foam core for the A-pillar.

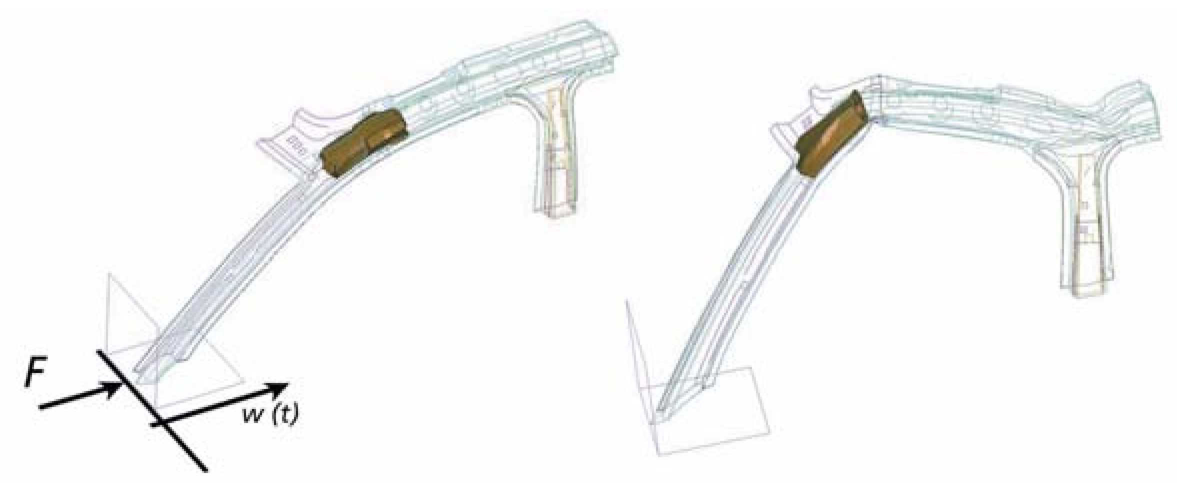

Fig. 3: Position of the aluminium foam core in the A-pillar as determined by virtual optimisation.

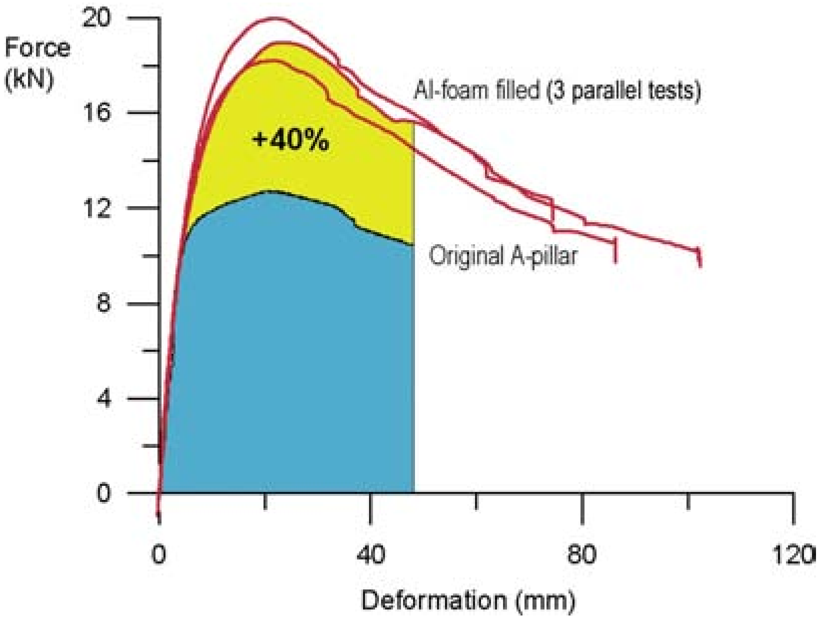

Fig. 4: Crash test results.

All the demonstration components were incorporated directly into the production lines at the end-users and were assembled under similar conditions. The compatibility of the "aluminium foam" with the existing production lines was good. The often expressed concern about the corrosion behaviour of aluminium foam when surrounded by steel materials proved to be unfounded. If the two components are joined together using an adhesive, then the polymeric adhesive insulates the aluminium from the steel, so preventing contact corrosion.

All in all, the results of this project represent a major step towards the wider application of aluminium foam technology in series production. The technological and commercial advantages are clear and nothing now stands in the way of industry employing these materials on a large scale.

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EADS CCR (France)
Ford Forschungszentrum (Germany)
Henkel Teroson (Germany)
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Transfer project: IGC technology

Background

The manufacture of highly porous, nanoscale metal powders by evaporation in an inert gas atmosphere was taken up by Fraunhofer IFAM in 1985 and was further developed up to pilot scale as the IGC process ("Inert Gas Condensation"). A number of industrially and publicly funded collaborative projects have been performed in order to manufacture prototype materials and evaluate potential areas of application. Over the past 10 years, antibacterial nanocomposites have been in the focus of interest: In highly dispersed form, elemental silver embedded in organic matrices can function as a "reservoir" which, under certain conditions, releases Ag+ ions to the surroundings. This mechanism has been successfully demonstrated for several plastic materials having prospective medical applications.

The enormous market potential of silver-containing composites for other similar applications was quickly recognised. This resulted in IFAM's decision in 2001 to invest and build its own IGC pilot plant.

A key step for the product development and marketing was the launch of Bio-Gate Bioinnovative Materials GmbH in 2002, whose business plan included the synthesis of antibacterial plastic compounds using elemental silver. The long-term cooperation with Fraunhofer IFAM was organised in the form of a know-how licence and a contract for the supply of highly dispersed silver powder.

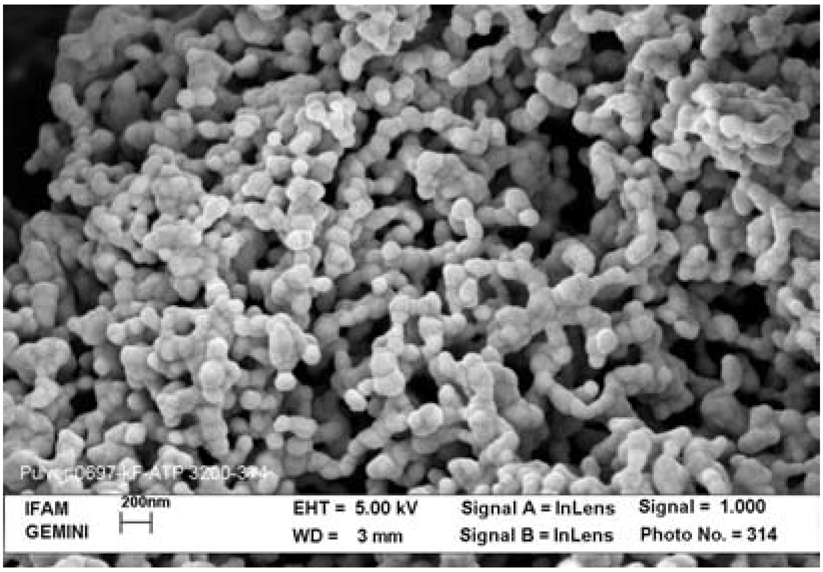

Fig. 1: Typical morphology of the silver powder product.

Bio-Gate was hence provided with large quantities of silver powder (trade name "MicrosilverBG") enabling them, as a future producer-partner, to estimate marketing opportunities and acquire key customers. In order to facilitate this work, the IGC process was audited and certified in accordance with the requirements of EN/ISO-9001. The lack of this accreditation would have been a huge drawback, particularly for quoting manufacturers of medical products. The accreditation meant that potential customers could be assured that even large quantities of the specified silver powder, produced with a verifiable process, could be supplied at short notice.

Fig. 2: IGC pilot plant and associated equipment prior to being relocated.

Project

After successful market positioning during the sampling phase, the acquisition of key customers and the setting up of sound funding, Bio-Gate made the decision in June 2005 to completely take over from IFAM the hitherto developed technology chain for manufacturing the "MicrosilverBG". The equipment had to be reconfigured in the planned production operation. The technical approval of the reconfigured IGC plant was undertaken on the basis of powder manufactured under fault-free full-load production conditions, whose specifications had to correspond to the silver powder that was manufactured throughout the pilot production phase.

Realisation

Once the reconfigured technical infrastructure was in place at the new facilities of Bio-Gate in BITZ (Bremen Innovation and Technology Center), the commercial-scale production had to start quickly in order to resume supplies of the silver filler as fast as possible.
For quality-assured operation under production conditions, the following modifications had to be made to the original IGC pilot plant device:

a) Process control: In the pharmaceutical and medical technology sectors, software must be successfully validated before it can be used. This requirement applies to all software packages which are used in a production chain, for quality assurance and in a product itself. In order to permit delivery of powder to customers who make medical technology products, new process software had to be developed which could be evaluated and validated in accordance with the guidelines of international industry standards and statutory GxP and FDA guidelines.
Another key point for the validation is the carrying out of a risk and hazard analysis.
b) Implementation: Incorporation of the plant technology into the infrastructure of a production hall, including logistics, remote control capability, powder packing and integration into the quality assurance system.

c) Work safety: A constant challenge when scaling up any gas-phase based nanoparticle technology is the minimisation of particulate emissions. According to the current state of knowledge, standard maximum permitted values for particulates in the workplace cannot be transferred to sub-μm particles. This is because such data relate to the weight of particulates /m^3 room air, whereas the specific surface area plays a much larger role for assigning materials to a hazard class. For that reason, essentially integrated powder processing must be striven for under production conditions. This must allow the silver powders to be handled in a closed system, namely there must be no exposure to particulates, from the synthesis stage right through to further processing stages. The IGC technology that has been developed meets these requirements. The only exception to this concerns the necessary cleaning tasks, during which increased release of silver particles cannot be wholly excluded. Fortunately the high sinter activity of nanoscale silver particles will in all probability mean that there are large (soft) agglomerates. Nevertheless, a combination of protective equipment / measures and powder extraction with directed gas flow condition must be used.

In parallel with the production operation, the long-term stability of the Ag powder and the antibacterial effectiveness of the resulting composite materials will be tested under a variety of climatic conditions. The aim of these tests is to achieve maximum storage stability under typical industrial conditions. These tests will also allow the reliability of the process chain to be further increased.

Outlook

In the meantime the IGC process at Bio-Gate has been included in the company's certification audit. Here the respective earlier experience of IFAM has also been utilised. The future focus of process optimisation work will be on the powder processing, in order to further increase the operational reliability and lower costs. This will allow new market segments to be identified for these filler materials in antimicrobial composites, coatings and pastes. The Fraunhofer IFAM will once again provide valuable support for these activities.

Following-up this successful technology transfer, the licensing of other IFAM processes for manufacturing antimicrobial composites and coatings to Bio-Gate is being considered.

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Customised metal components via 3-D-Printing

Background

A promising approach for manufacturing customised products is to use graded materials. A variety of techniques for manufacturing graded materials are currently available. Most of these techniques, however, have limitations regarding the complexity of the component geometry, gradient profiles and/or material selection. There is at present no technology available which allows complex components having any desired 3-D material gradient to be manufactured in a single process. Generative manufacturing methods (Rapid Manufacturing) are suitable for such a technology platform. Such methods are currently at an advanced state of development and the mass production of components from a single material is imminent.

The aim of this collaborative project was to develop a new technology platform which allows complex components having any desired 3-D material gradient to be manufactured in a single process.

The base technology adopted was the 3-D-Printing process for metals. Up until now, only bronze infiltrated steel components have been able to be produced using 3-D-Printing. The idea is to develop functional inks, to introduce a variety of other materials locally into a bed of tool powder via ink-jet pressure. The resulting gradient-structured green bodies are then compacted to form the final component in a subsequent thermal processing step. For example purposes, the aim was to initially apply the new technology platform to metal mould inserts having modified mechanical properties for injection moulding.

Project

The project was undertaken with industrial partners, with the Fraunhofer IFAM acting as the project coordinator. The following tasks were carried out:

- Development of functional nanoparticle inks that can be printed using 3-D-Printing technology;
- Advanced development of the 3-D-Printing process to manufacture dense components made of tool steel – without an additional infiltration process;

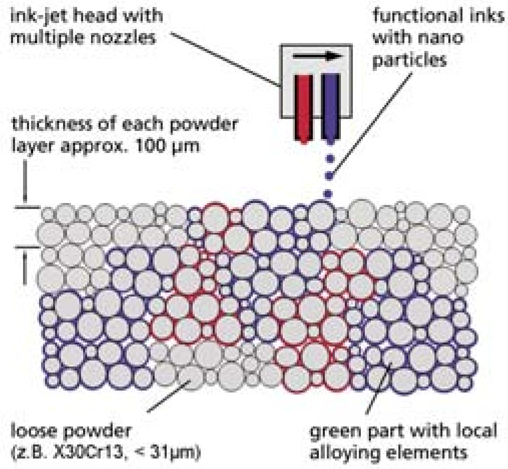

Fig. 1: Schematic representation of the manufacture of gradient structures using 3-D-Printing.

- Adaptation of the 3-D-Printing technology via software and hardware modifications for printing gradients using several functional inks;
- Design, construction, characterisation and application of a graded mould insert for injection moulding.

Project description / implementation

As part of the collaborative plant, material, software and process development activities in this project, the Fraunhofer IFAM first of all carried out development work on the existing 3-D-Printing process (which produces bronze-infiltrated steel components) in order to manufacture dense metallic components made of materials used for mass production. Printed green bodies made of tool steel powder, which – in contrast to high-alloy steel – compact via liquid-phase sintering, are highly suitable for almost achieving the final density. However, due to the presence of a fraction of the liquid phase during the thermal compaction, precise setting of the sinter cycle is necessary: The geometry of the component must be preserved with attainment of the highest possible final density and with uniform contraction. Relatively large inserts of mould steel could be produced with a weight up to 640 g, dimensions of 150 mm and, depending on the heat treatment, a hardness up to 64 HRC. These are currently being tested by Erwin Quarder Systemtechnik GmbH for injection moulding of high abrasive polymer.

Fig. 2: Printed and sintered (compacted) mould insert made of M2 tool steel.

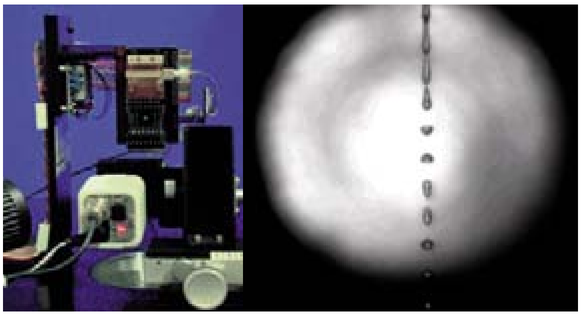

Fig. 3: Ink-jet print head test station for visualisation of the formation of drops of functional inks.

Simultaneously, functional inks were formulated from nanoparticle dispersions and the existing organic binder. The requirements of functional inks for ink-jet printing are freedom from agglomerates, sedimentation stability and a high solids content with as little as possible change in the viscosity and surface tension compared to the conventional binder. In collaboration with Nanosolutions GmbH, carbon, vanadium, chromium, tungsten and titanium containing nanoparticle dispersions were successfully synthesised. As alloy-formers, these materials allow the mould steel microstructure to be customised during the sintering process. The inks were tested on an ink-jet print head test station for their ability to be printed before being used in the 3-D-Printer.

The 3-D-Printer used up until now just has a single print head and has only allowed components to be made from a single material, by printing a binder into the metal powder. Also, up until now the CAD software has only provided geometric surface data for the components to be produced and has provided no information about a customised local material distribution. Prometal GmbH installed several, individually controllable print heads on the printer and modified the printer control system so that several functional inks could be printed simultaneously into the resulting component. The geometric design data, including the desired local material distribution data, must be scanned – like a photo before being printed – before they can be converted to control commands on the printer. Using this modified 3-D-Printer, gradient-structured demonstration components have been printed using two different functional nanoparticle inks.

This collaborative project has developed a new technology platform which allows complex components having local material gradients to be manufactured in a single process. In the future, it will not only be possible to use this technology platform to customise components made of tool steel but also other metallic and non-metallic powders will be able to be used in combination with a wide variety of nanoscale materials.

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Commissioned by

German Ministry for Education and Research (BMBF).
Funding programme: "MaTech – New Materials for Key Technologies of the 21st Century", Gradient Materials

Project partners

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Micro metal powder injection moulding – series production and quality assurance

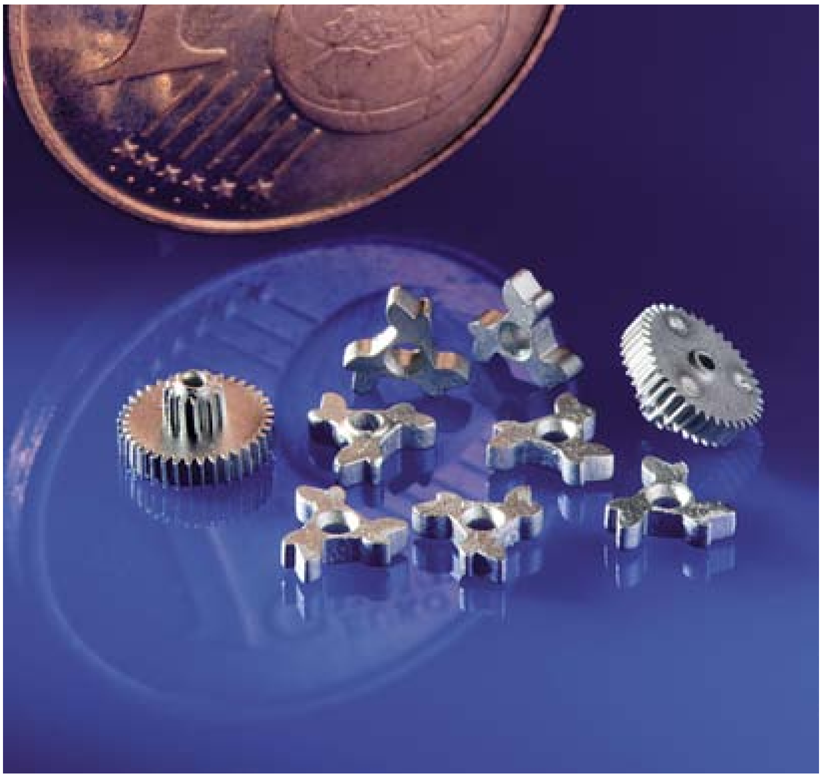

Fig. 1: Gearwheels made of stainless steel 316L (in collaboration with Scholz GmbH, Kronach).

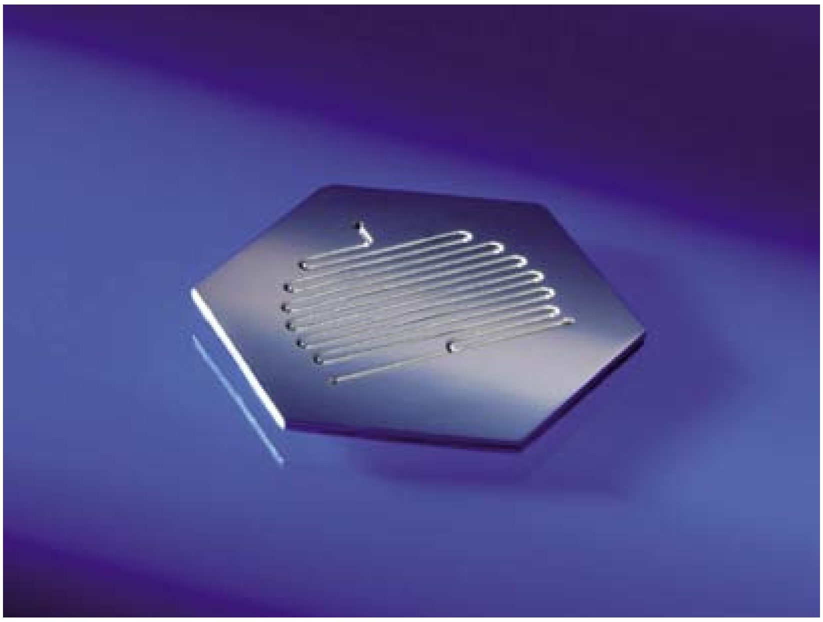

Fig. 2: Micro-mixer made of stainless steel 17-4PH for the micro-reaction module FAMOS of the Fraunhofer alliance.

Background

In many applications there is a growing demand for greater precision, functionalisation and miniaturisation of components and systems leading to an increased demand for miniature and micro-sized components made of metallic materials. Most current micro-production technologies, however, are not applicable for the cost effective mass production of metallic micro-parts. This was the reason for Fraunhofer IFAM to put considerable effort in developing the micro metal injection moulding (µ-MIM) process for the cost effective mass production of complex micro-components and -structures during the recent years. The suitability of the µ-MIM process for the manufacturing of micro sized components and microstructured surfaces was already demonstrated in various projects. An advantage of this processing technology is that a wide range of metals, alloys and polymers can be processed. Fig. 1 illustrates a number of micro gearwheels produced by µ-MIM applied e. g. in micro-mechanical systems. Fig. 2 depicts a micro-mixer with a channel size of 500 µm applied e. g. in micro-reaction technology.

Project

The aim of this project was to characterise and optimise the µ-MIM process with regard to its reproducibility for series production. Aspects related to feedstock preparation, injection moulding and characterisation were studied.
For the µ-MIM technology very fine powders having an average particle size of 3-5 µm and fines fractions of 200-500 nm are processed. Special binder systems allow the complete filling of the moulds in the injection moulding process, due to their low-viscosity at elevated temperature. At room temperature these special binder systems give the moulded part high strength to enable a reliable demoulding of the part.
Especially the feedstock preparation is important for a successful reproduction of micrometer components or structures. It is thus necessary to ensure a homogeneous mixture of the feedstock components (metallic powder and binder material). In order to characterise the homogeneity of the feedstock, it was studied by recording the rheological parameters.

Due to the high requirements on precision and reproducibility of the production parameters of injection moulded micro-components, the precision in dosage and injection of extremely small feedstock quantities were investigated for a large series of micro parts. This was done by recording and subsequent evaluation of the relevant data from the injection moulding process on the micro injection moulding machine (Battenfeld Microsystem 50). Additionally, micro tensile test specimens were manufactured using µ-MIM and their mechanical properties were tested. The potential of the process for mass production was demonstrated by manufacturing a part representing the smallest bone of the human body, the stirrup (lat. stapes), made of stainless steel.

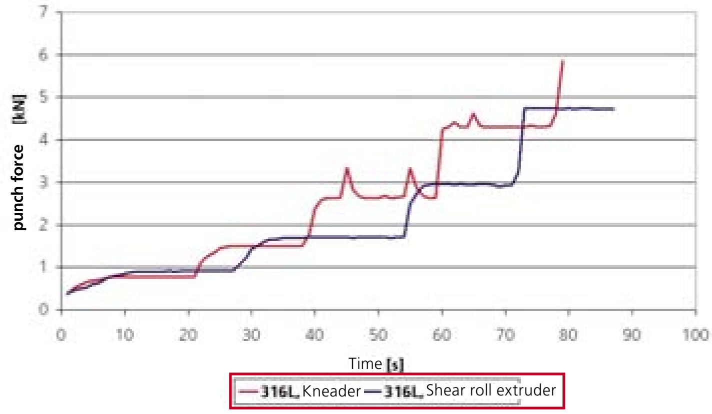

Fig. 3: Online recording of the punch force for the 316L feedstock in the double capillary rheometer.

Results

The experimental work started with the feedstocks preparation of two stainless steels (316L and 17-4PH) in a double sigma blade kneader. The flow properties of the feedstocks were determined in a twin bore capillary rheometer. With this device the shear rates and the necessary forces can be recorded. Repeatedly large fluctuations in the force-time measurements were observed, indicating an insufficient homogenisation of the feedstock, see Fig. 3 as example of the 316L feedstock (red curve). To further homogenise the feedstock, it was processed using a shear roll extruder. Renewed testing of the force-time properties gave significantly better results for all shear rates, indicating improved feedstock homogeneity (blue curve). Due to the extremely fine nature of the powder, there is a greater tendency for µ-MIM feedstocks to agglomerate or separate than there is for conventional MIM moulding materials. Greater care is hence required in their preparation.

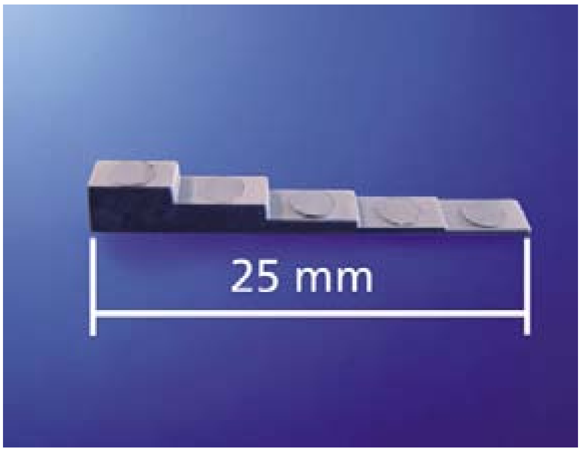

Fig. 4: Moulded sample: micro-steps.

An optimised 316L feedstock was then applied for manufacturing the micro-steps presented in Fig. 4. A series of 1000 parts was manufactured and every 10th sample was weighed on a microbalance. The sample weight was compared with the recorded injection moulding parameters. This way a clear relationship between the maximum internal pressure in the mould and the weight of the micro-component could be detected, see Fig. 5. However, the fluctuations in weight were

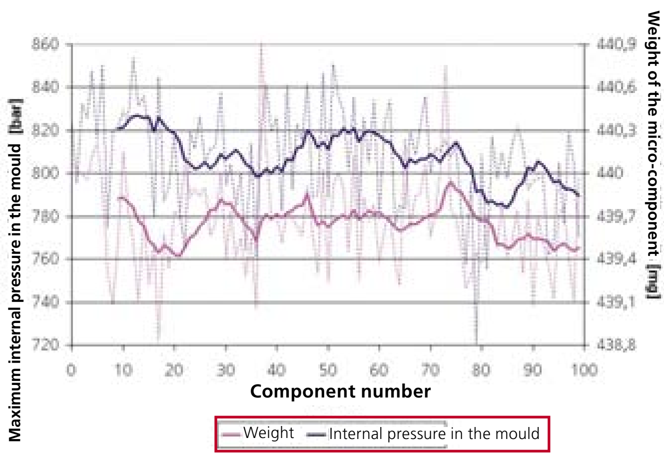

Fig. 5: Relationship between the internal pressure in the mould and component weight for micro injection moulding.

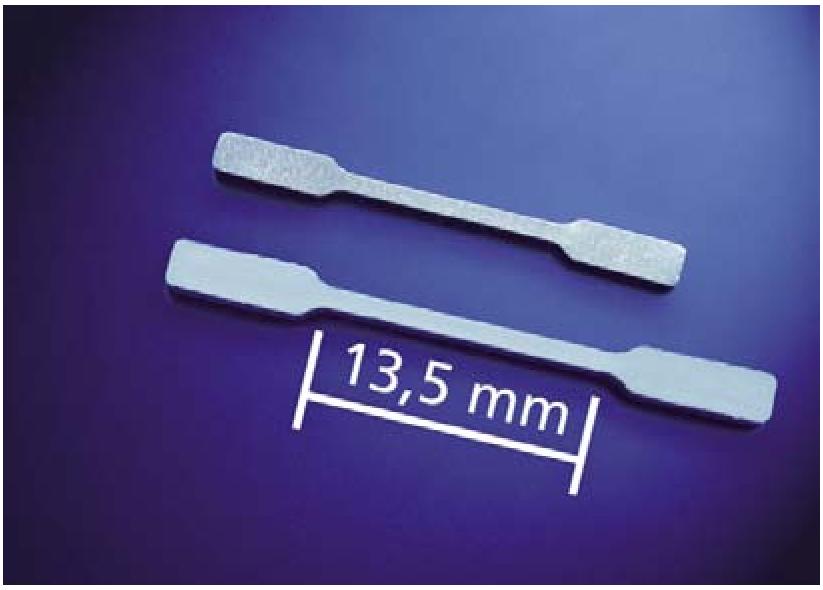

Fig. 6: Micro tensile test specimen: Green component and sintered component.

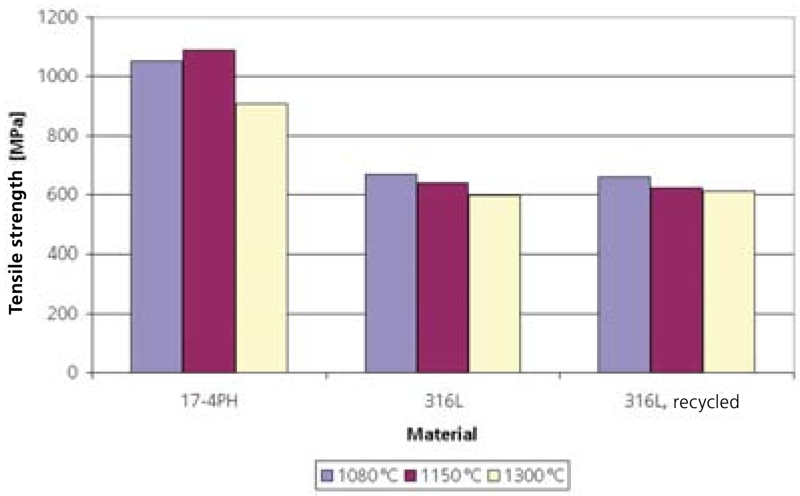

Fig. 7: Tensile strength of micro tensile test specimens (316L and 17-4PH) after sintering at different temperatures.

only of the order of a few tenths of milligrams (439.66 mg +/- 0.34 mg). Overall, the results highlighted the very good reproducibility of the injection moulding process.

Additionally a micro tensile test specimen was designed for production using the µ-MIM process (Fig. 6). Samples made of the 316L and 17-4PH stainless steels could successfully be injection moulded. The test specimen were sintered with different temperatures and tested by using a micro tensile testing device.

The tensile strength results of the tests are shown in Fig. 7. The experimentally determined values are comparable to the literature values for the respective materials. In addition, it was demonstrated for 316L that the feedstock could be recycled without having adverse effects on mechanical strength and demoulding. The differences in strengths at different sinter temperatures between the two materials are due to changes in the microstructure (17-4PH) and in grain growth (316L), respectively.

In collaboration with Krämer Engineering, Rendsburg, a mould replicating the smallest bone in the human body, the stirrup was designed and manufactured for the Battenfeld Microsystem 50. According to the previous results a series of stirrups was injection moulded and sintered with uniform quality (Fig. 8).

Summary and outlook

The here presented results indicate that the µ-MIM process is suitable for the mass production of metal micro-components. Future work will focus on further increasing the reproducibility of the injection moulding parameters, in particular the internal pressure in moulds. In addition, new functional materials will be developed and evaluated for their suitability for the µ-MIM process. New application fields for metal micro-components in sensor technologies (magnetic materials), electronics (e. g. tungsten) and in the area of thermal management (copper materials) will be explored.

Fig. 8: Series production of stirrup made of 316 (cooperation with Krämer Engineering, Rendsburg).

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Thermoelectric nanocomposites

Background

Thermoelectric technology allows reciprocal conversion of electrical and thermal energy via the so-called Peltier effect (generation of a temperature difference by an electrical current) and vice versa via the Seebeck effect. As such, thermoelectric modules can be used for both alternative generation of electrical energy and for temperature control (cooling, heating).

The main issue for thermoelectric applications is the all-important quality of the thermoelectric materials. This quality is referred to as the thermoelectric figure-of-merit (ZT) and is calculated from specific properties of the material (Z) and the temperature (T). This figure-of-merit has remained roughly constant over the past 50 years at a value of 1. However, the advent of nanotechnological methods has in recent years allowed materials to be manufactured having ZT values of up to 2.5.

All over the world the development of thermoelectric materials is continuing apace. These developments will, for example, give Peltier coolers the ability to acts as temperature controllers in a variety of hitherto unviable areas.

Figures-of-merit (ZT) of about 4 are physically conceivable. However, even an improvement in the figure-of-merit from 0.7-1 (currently available and tested) to about 2 (available, but not yet commercially available) will open up opportunities for a range of new products (e.g. sensors, smart cards, smart labels) having an estimated market value of more than 1 billion euros.

Opportunity

In the USA, in particular, investment has been high and a large number of nanotechnological approaches are being pursued. The manufacture of new thermoelectric modules can hence be expected in the medium-term. Up until now, little R&D work has been carried out in this area in Germany or indeed in Europe as a whole.

The commercial developments to date range from nanoscale layer systems using PVD methods, new routes for chemical syntheses using nanoscale elemental layers, growth of nanowires in sealed packaging in suitable templates right through to the development of special material systems. Massive thermoelectric materials, such as those required for the manufacture of larger Peltier coolers and thermogenerators, are very complicated to produce because the materials are either manufactured as single crystals with poor mechanical properties or via deposition (low layer growth rates).

In conjunction with the Fraunhofer IPM (Freiburg) and the Fraunhofer IIS (Erlangen), the Fraunhofer IFAM (Dresden) has formed a strategic, industry-orientated alliance (WISA). The objective of this alliance is to demonstrate the commercial viability

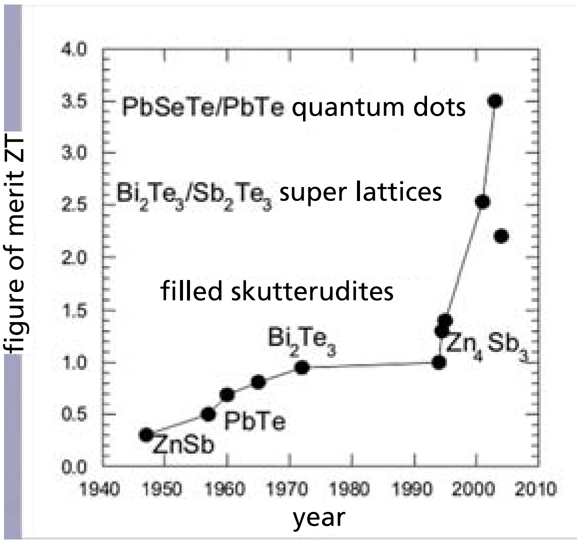

Fig. 1: Figure-of-merit (ZT) improvement over the years in accordance with Venkatasubramanian, Nature 413, 2001, 597.

of nanoscale thermoelectric processes and to demonstrate the suitability of the new materials for application in modules and systems for producing an autarkic energy supply for sensor networks.

Realisation

The difficulties that have been outlined regarding the industrial application of thermoelectric materials for (autarkic) energy provision can be overcome by manufacturing and processing polycrystalline materials using modern powder-metallurgical methods. The relevant materials are produced by melt metallurgy, so allowing properties such as homogeneity and nanostructure to be readily customised. After milling, the next step involves sintering the powder in such a way that the nanostructure is preserved. The feasibility of making thermoelectric materials using powder-metallurgical methods has been demonstrated by researchers in the Far East who used the Spark Plasma Sinter method (SPS). This process, which involves a short sinter method similar to hot pressing, uses very short electrical pulses (microseconds) of just a few volts but several thousand amperes for directly generating heat in the sinter body. As a result of the "SPS effect", which is ascribed to the generation of micro sparcs in the powder, the surfaces of the particles are cleaned of adherent oxide/hydroxide layers, leading to very short sinter times and contaminant-free grain boundaries. As a result, not only can nanostructured massive materials be produced using sinter technology but also the microstructure can be customised for particular applications. High figures-of-merit for, for example, polycrystalline thermoelectric materials can be achieved, with simultaneous improvement of the mechanical properties. The result is that industrial applications are becoming financially viable.

The Fraunhofer IFAM has a modern Spark Plasma Sinter plant. Due to their flexibility and its near-industrial size it is suitable for both fundamental research studies and for contract research on a near-production scale.

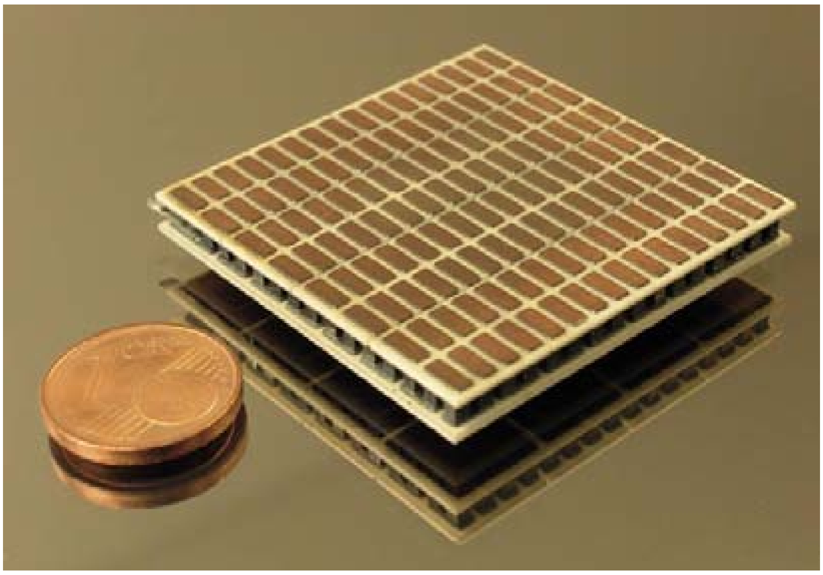

Fig. 2: Peltier element (manufactured by Peltron Peltiertechnik GmbH).

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Open-celled metal foams – versatility via variability

Fraunhofer IFAM in Dresden has many years of experience developing cellular metallic materials. The results of this work are a range of different structures and processes which are suitable for a variety of customer requirements (see also IFAM annual report 2004, pages 96-99). In Dresden, work has been carried out on open-celled metal foams for about 3 years.

Combined expertise

The manufacture of open-celled foams is carried out using a replication technique. This involves coating a reticulated polyurethane sponge in a metal powder / binder suspension. Subsequent heat treatment removes the support structure and the binder. In the last step, the debinded components are sintered. Fraunhofer IFAM is working on open-celled metal foams in collaboration with the Fraunhofer IKTS. There are two main reasons for this:

Firstly, the manufacturing process is closely related to the metal hollow sphere production process that was developed at IFAM. Fraunhofer IFAM in Dresden has a wealth of expertise regarding the technology for pyrolysis of the organic support structures, binders and additives, and this knowledge is constantly being furthered. In this context, it is focussed on the optimisation of the removal of carbon, oxygen and nitrogen. If present in the alloy, high concentrations of these elements lead to embrittlement of the material.

The replication process was originally developed for ceramic materials which are used, for example, in casting filters. These open-celled ceramic structures, and the associated know-how relating to the suspension and coating technology, have been worked on by the Fraunhofer Institute for Ceramic Technologies and Sintered Materials (IKTS) for many years. In order to guarantee effective development of metal foams, the expertise of the two institutes was hence pooled and the project work shared. The suspension development and coating were carried out at Fraunhofer IKTS, whilst the binder removal techniques and sinter technology were developed at Fraunhofer IFAM in Dresden.

Structure

Ideally, the basic pore structure of open-celled foams is that of a dodecahedron. The actual pore structure is shown in the scanning electron microscope picture of a stainless steel foam (Fig. 1). Using the replication process it is now possible to manufacture open-celled metal foams having an extremely homogeneous structure. This applies to both the pore size distribution and the strut cross section dimension.

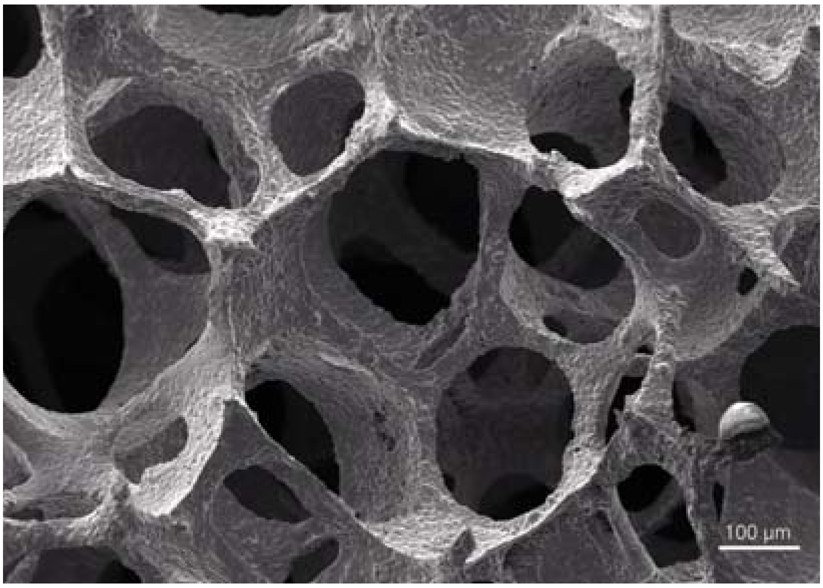

Fig. 1: Scanning electron micrograph of an open-celled structure made from steel grade 316L and having a cell width of 60 ppi.

The strut thickness can be customized by applying different thicknesses of coating. This feature allows the density of the materials – and hence the physical properties – to be adjusted over a very wide range. The densities that can be achieved with foams made of stainless steel 316L range between 0.3 and 2.0 g/cm3. These values correspond to porosities of 70 – 95 percent. Using different support structures it is also possible to customise the cell size. The cell widths that can be achieved using conventional steel powders extend in a very broad range (10 – 80 cells per inch (ppi)). This corresponds to a pore width of 0.2 – 5 mm (Fig. 2).

Development work

The customization of the structure allows a very wide range of different products to be developed: Small cell sizes, for example, have excellent noise adsorption properties and are hence particularly suitable as noise damping materials. Such cell sizes are also applied for filtration purposes, where good separation rates are desired. In contrast, larger cell widths cause much lower pressure losses to flows of materials (Fig. 3).

Fig. 2: Open-celled metal foams made from steel grade 316L and having cell widths of 20, 45 and 60 ppi.

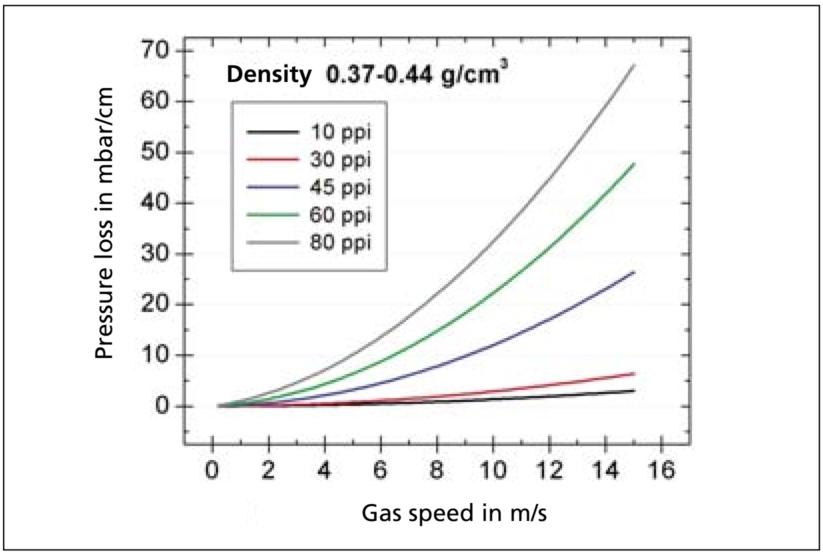

Fig. 3: Permeability of open-celled metal foams. The pore width has a large effect on the passage of materials through the pore structure.

Fig. 4: Composite structures made from steel tubes and steel foam (steel grade 316L, cell width 20 ppi) for use as air heat-exchangers. By shrinking the foam onto the tubes, the surface area of the tubes is greatly increased.

This is important for applications where low energy usage is of prime importance. An example of such an application is in a heat-exchanger. Fig. 4 shows an air heat-exchanger, developed in conjunction with an industrial partner. The manufacture of these composite structures is achieved by shrinking the near-net-shape metal foams onto steel tubes. Here, the resulting shrinkage of the powder-metallurgical foams on sintering is utilized. By increasing the surface area to 16 m² pro m² tube surface, this technology allows significant improvement of the heat transfer properties. By opting for the powder-metallurgical route, an extraordinary range of different starting materials can be employed. For example, all pure metals and alloys which are available as powders can in principle be used.

Summary

The Fraunhofer IFAM and IKTS are developing innovative open-celled metal foam materials. Due to the large structural variability of the foams and the large number of starting materials that can be employed, the foams have an enormous range of properties. These facts and the advantages of near-net-shape production mean that these materials have a broad range of applications.

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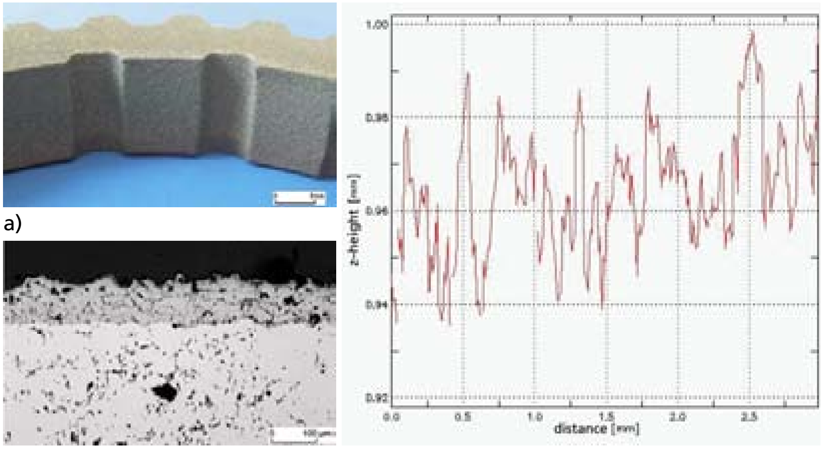
Friction lining for synchronous rings

Background

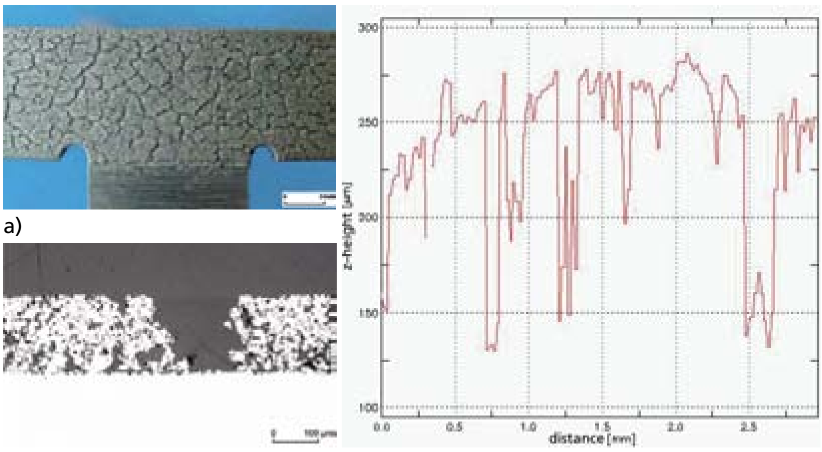
In car gearboxes, synchronisation is very important. It ensures rapid matching of the revolution speed of the gear components and hence problem-free gear changes. Here, one or more conical surfaces are subject to sliding friction. The trend towards weight reduction by using smaller, more compact assemblies and further improvement in the gear change comfort means that increased friction powers have to be transmitted. These friction powers require special friction linings that are connected to the supporting synchroniser ring (Fig. 1). A variety of friction materials are currently in use. Cost aspects and technological properties determine which material is used for a specific application.

Since oil is always present in a gearbox to reduce friction and wear, it inevitably comes into contact with the surface of the friction lining and its friction partner. In order to guarantee short gearshifts, a sufficiently high transmission torque is needed. This requires a high friction coefficient which cannot be attained when there is hydrodynamic lubrication. The friction lining must have a surface structure such that oil is removed as quickly as possible from the friction surface, therefore minimising the hydrodynamic friction and allowing solid-solid contact, thus leading to mixed friction and boundary friction successively. Only in this state does the relative velocity between the two friction partners drop to zero. For the mixed friction and boundary friction, the properties of the relevant solid surfaces play the key role, whereas the major factor for suppressing the hydrodynamic friction is the structure of the relevant friction surfaces from the viewpoint of oil removal. Relevant structural features include grooves, rills, other channel-like recesses and also pores. The friction properties of a friction lining for oil-run are therefore not only dependent on the material but are also determined to a large extent by the lining structure.

Fig. 1: Synchroniser rings with iron-based friction lining.



a) b) c)
Fig. 2: Sprayed on molybdenum lining on a synchronizer ring, a) plan view, b) cross-section and c) in profile.



a) b) c)
Fig. 3: Double cone synchronizer ring with the new iron-based friction lining DS 230, a) plan view, b) cross-section and c) in profile.

Project

At present, sprayed molybdenum linings are most commonly used as friction linings in synchroniser rings (Fig. 2). They can be subjected to higher loads than special brass and suffice for average loads. When subjected to high friction powers however, molybdenum linings tend to seize. This disadvantage is due to the structure of the friction lining, a large area of which has no oil reservoirs in the shape of very fine grooves or open porosity, so that on exposure to high loads no lubricant is available to prevent micro-welding. Based on key properties such as surface structure and porosity, the aim of the project was to develop a high performance lining, in particular for applications where molybdenum is currently used. The development of a new friction lining for synchroniser rings was also driven by cost factors, given the increasing raw material price for molybdenum.

Results

Compared to hitherto known friction linings, the new iron-based friction lining for synchronous rings has two essentially new features. Firstly, the lining surface is covered with an irregular network of channel-like recesses. Secondly, the structure of the lining is characterised by an extremely fine and high porosity of greater than 50 percent (Fig. 3). The cross-section and the measurements of the surface profile indicate that the depth of the channel-like recesses can extend to the base of the friction lining on the support.

These two features create ideal conditions for rapid removal of oil from the friction surface during gear changes. Also, the fine and highly porous structure of the friction lining guarantees that oil is not removed from the friction surface to such an extent that large “non-lubricated” areas arise on exposure to high loads, resulting in pure solid-solid friction and hence high wear or even seizure.

The lining is manufactured by powder-metallurgical means. Only via such a route is it possible to produce a friction material with high porosity. The high porosity, and in particular the irregular network of channel-like recesses, is obtained in such a way that the lining material bonds to the base material at the beginning of the sintering process. This prevents "closing" of the highly sinter-sensitive lining. The extremely high contraction of the lining material then produces the high porosity and the typical channel network in the lining. This contraction is obtained by employing a large quantity of iron oxides in the powder mixture used as basic raw material. By a new technology, the mixture is directly applied and sintered to the synchronizer ring.

Tests were undertaken to compare the new friction lining (Sinter DS230) with molybdenum and carbon DCA on an SSP 180 synchronizer ring test station. First of all, the friction coefficient was measured as a function of the sliding speed using a step-programme. At a constant contact pressure of 4 N/mm², the sliding speed was gradually increased to the allowed maximum for the test station and was then similarly decreased. This procedure meant that the friction energy was first increased in steps and then decreased. The results are shown in Fig. 4. The bars show the gradual change in the sliding speed. The bottom curve shows the friction coefficient of the molybdenum lining. The friction coefficient of this lining decreases considerably with the sliding speed. The middle curve represents the iron-based sintered lining. Its dependence on the sliding speed is significantly less. It lies slightly above the molybdenum curve, therefore confirming the iron-based lining as a good alternative to molybdenum linings. The dependence on the sliding speed is relatively small for the carbon lining (upper curve). Its friction coefficient is considerably higher. This advantage however necessitates the geometric design of the synchronisation to be adapted to the high friction coefficients of the carbon lining. In contrast, synchronizer rings with an iron-based sintered lining can replace Mo-coated rings without problems.

In comparison to the previous graph, the contact pressure is increased and then decreased in steps at a constant sliding speed of 4 m/s. The results show that the molybdenum lining seizes and fails when exposed to high loads. Otherwise, the results confirm the previous test, namely the good

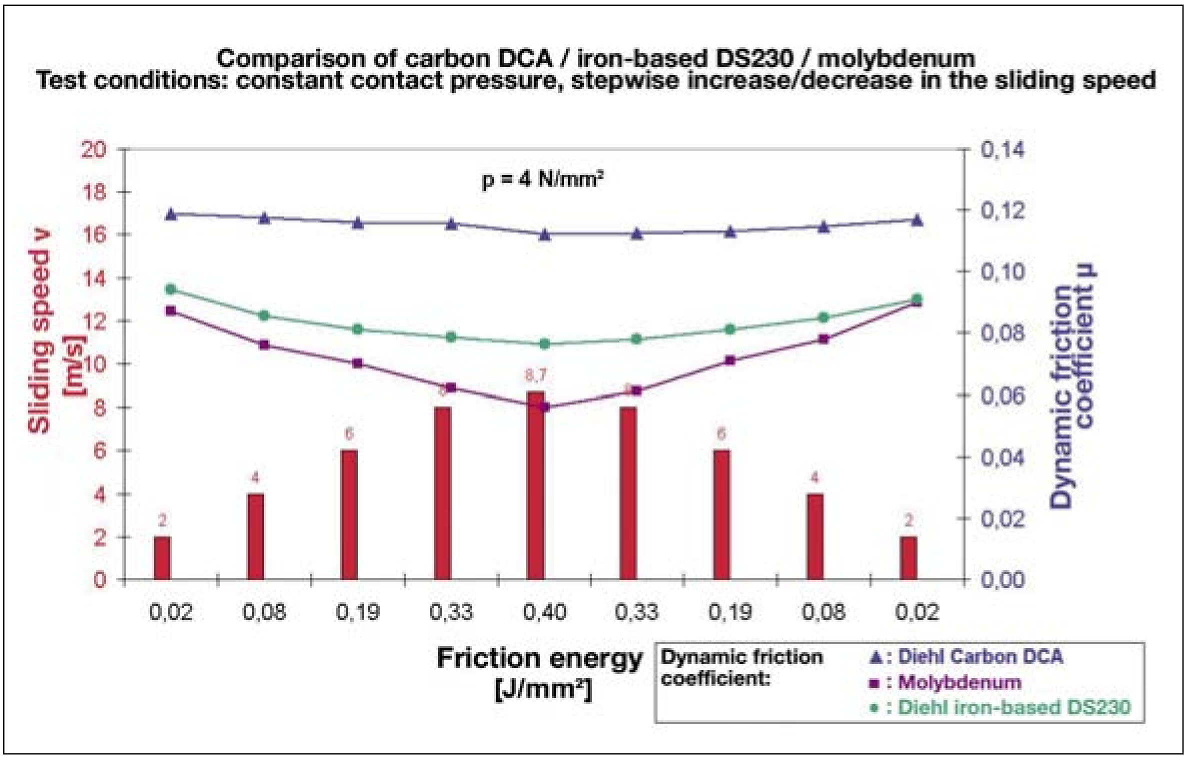


Fig. 4: Results of the stepwise sliding speed test for determining the friction coefficient.

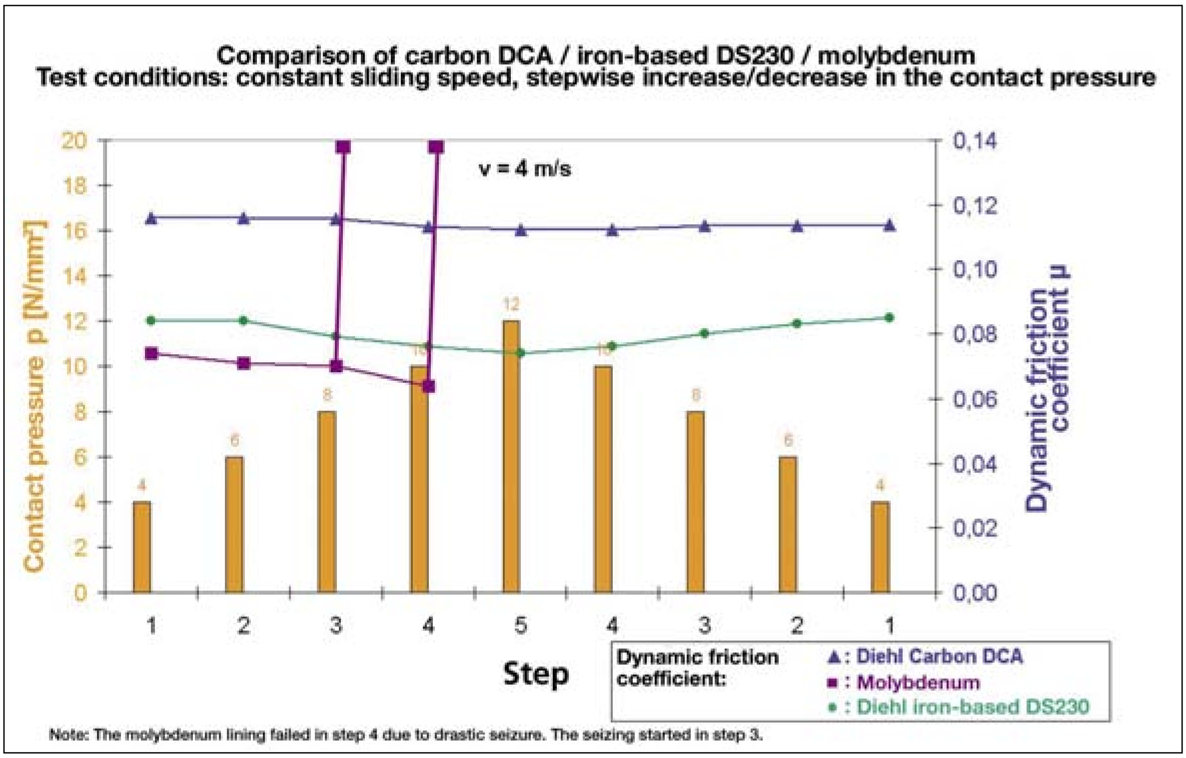


Fig. 5: Results of the stepwise contact pressure test for determining the friction coefficient.

performance of the iron-based sintered lining and the carbon lining, with the friction coefficient of the iron-based lining being slightly higher and that of the carbon lining considerably higher. It must be pointed out that the other features of the iron-based lining are very similar to those of the carbon lining. This concerns the very low axial wear, even at high loads, and the good constancy of the friction coefficient over a large number of gear changes. Also worthy of mention is the very low sensitivity to the effect of different types of oil. A special feature of this friction lining is the low static torque required to move an engaged synchronisation and whose value is identical to the dynamic friction torque. This situation means that these friction linings are also attractive for bearing applications.

A patent has been issued for the iron-based friction lining with its new features. The high performance of the iron-based sintered friction lining together with the new cost-efficient production technology were the crucial factors for the decision to now transfer this technology to industrial production.

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Awards/Honours

1. VDI Award 2005 for Innovative Application of Materials
Metal foam based on Ni-superalloys (INCOFOAM®HighTemp)

2. EPMA Award 2005 for Powder Metallurgy Materials Development of INCOFOAM® HighTemp

In order to stimulate and promote the development of materials, the VDI-Gesellschaft Werkstofftechnik and Springer-VDI-Verlag offer the Award for Innovative Application of Materials. This award has been presented since 1991. The recipient of this award is chosen by a panel appointed by the VDI-Gesellschaft and must have demonstrated exceptional innovation in an application-related area of materials science. The innovation must result from a multidisciplinary collaboration and must have involved the use of innovative and customised materials and manufacturing technologies for producing functional components. In 2005 the award was bestowed on Gunnar Walther and Tilo Büttner (of the Fraunhofer IFAM in Dresden), Dr. Alexander Böhm and Dr. Dirk Naumann (INCO), and Stefan Fuss (SÜD-CHEMIE) for their contribution to the development of a metal foam based on Ni-superalloys for use in particle filtration at high temperatures. The new, highly porous material has a very wide range of uses, extending from the filtration of diesel particulates in vehicle exhausts to the use as a catalyst support material in chemical plants. The properties of the new material can be customised for particular applications.

This development work was also recognised at the Euro PM 2005 in Prague with Fraunhofer IFAM (Dresden) and INCO Europe Ltd. receiving the EPMA Award 2005 in the materials category.

Radial filter made of INCOFOAM® Hightemp.

VDI Award: Sculpture "Idea and Material."

Gunnar Walther (IFAM Dresden) and Dr. Alexander Böhm (INCO) at the Euro PM 2005 in Prague receiving the EPMA Award 2005.

3. Euro PM 2005 Poster Award

The Euro PM 2005 Poster Award was won by the following poster:

"Sintering and Properties of New P/M Aluminium Alloys and Composites"
A. Dudhmande[1], Th. Schubert[2],
M. Balasubramanian[1], B. Kieback[2,3]

1 Composites Technology Centre, Department of Metallurgical and Materials Engineering, IIT Madras, Chennai – 600036, India

2 Fraunhofer IFAM
Winterbergstrasse 28
01277 Dresden

3 TU Dresden
Institut für Werkstoffwissenschaft
01062 Dresden

Aluminium materials produced by powder-metallurgical means are highly attractive materials due to the ever growing demand for lightweight components in the car manufacturing industry. New materials have been developed and comparative tests have been carried out. The main focus of this work was optimisation of the wear resistance and mechanical strength. This work was undertaken within the framework of the IIT Master Sandwich Program of the DAAD.

Dr. Thomas Schubert receiving the award at the Euro PM 2005 in Prague.

Prof. Dr. rer. nat. O.-D. Hennemann
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ISSN 1439-6009

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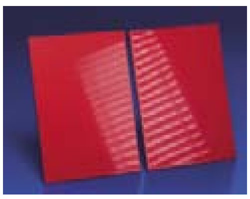
Kai-Uwe Bohn held the interview
with Prof. Hennemann.

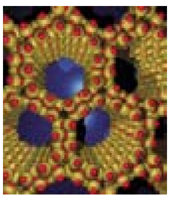
Figure captions on:

Page 38



Page 69

Page 33



Page 59

Page 73

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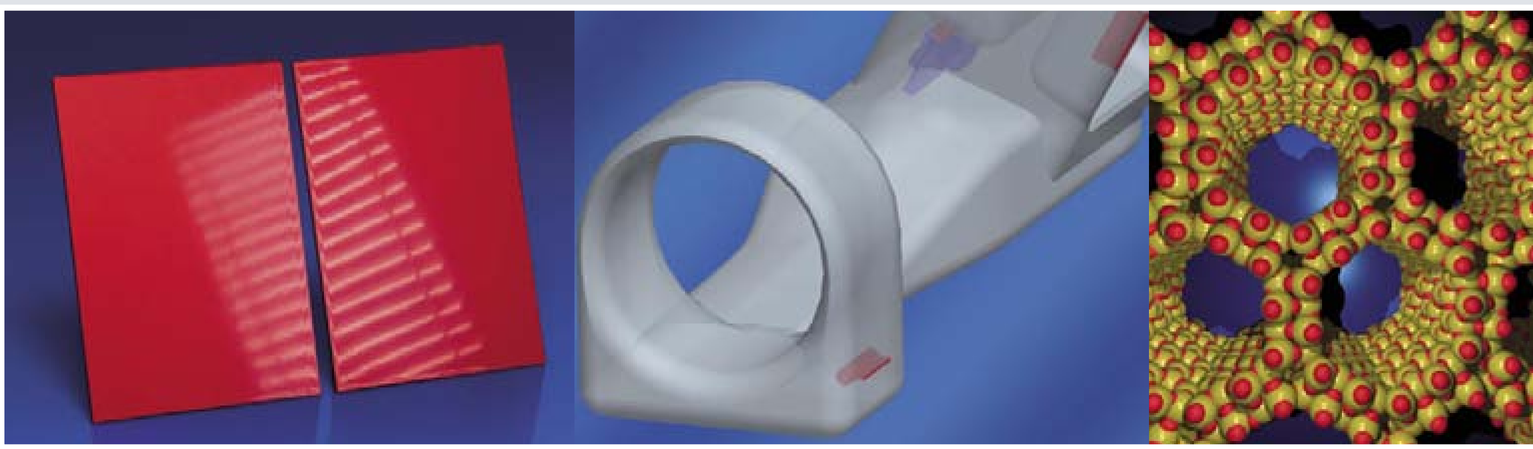

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Annual Report 2005

Names, dates, events

Contents

Cooperation with R&D organisations in other countries

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Moskau, Russia
Nano-crystalline components

Ufa State Aviation Technical University
Institute of Physics of Advanced Materials
Ufa, Russia
Nano-crystalline components

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Madrid, Spain
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Nano-crystalline components

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TNO Building and Construction Research
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Princeton, USA
B. Kieback, F. Petzoldt (Members)

International Liaison Committee of the International Journal of Powder Metallurgy
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EGL
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National

AWT
Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e.V.

Work committee
Plasmaoberflächentechnologie
U. Lommatzsch (Member)

Berufsgenossenschaft Chemie
Unterausschuss IV

Work committee
VSK Reaktive PUR Hotmelts
M. Popp (Member)

DFO
Deutsche Forschungsgesellschaft für Oberflächenbehandlung e.V.

Work committee
Kunststofflackierung
V. Stenzel, A. Kaune (Members)

Work committee
Leichtmetall
R. Wilken

DECHEMA
Deutsche Gesellschaft für Chemisches Apparatewesen, Chemische Technik und Biotechnologie

Technical section
Klebtechnik
E. Born, M. Brede, A. Groß, A. Hartwig, O.-D. Hennemann (Members)

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

Deutsche Gesellschaft für Biomedizinische Technik im VDE

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

DGM
Deutsche Gesellschaft für Materialkunde

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

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

Technical committee
Computersimulation
A. Burblies (Member)

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

Work group
Heterophasengrenzen
of the technical committee
Werkstoffwissenschaftliche Probleme der Mikroelektronik
O.-D. Hennemann (Member)

Work group
Mechanisches Verhalten bei hohen Temperaturen
of the technical committee
Werkstoffverhalten unter mechanischer Beanspruchung
A. Burblies (Member)

Work group
Edelmetall-Matrix-Verbundwerkstoffe
of the technical committee
Metall-Matrix-Verbundwerkstoffe
G. Lotze, T. Weißgärber (Members)

Work committee
Zellulare Metalle
O. Andersen, G. Rausch (Members)

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

DGO
Deutsche Gesellschaft für Galvanik und Oberflächentechnik e.V.

Work committee
Plasmaoberflächenbehandlung von Polymeren
A. Baalmann, G. Ellinghorst (Members)

Work committee
Plasmaoberflächentechnologie
U. Lommatzsch (Member)

DGPT
Deutsche Gesellschaft für Plasmatechnologie e.V.

Work committee
Plasmaoberflächentechnologie
U. Lommatzsch (Member)

DPG
Deutsche Physikalische Gesellschaft

Work committee
Oberflächenphysik
S. Dieckhoff (Member)

Work committee
Festkörperphysik
M. Noeske (Member)

DVG
Deutsche Vakuumgesellschaft e.V.

Work committee
Plasmaoberflächentechnologie
U. Lommatzsch

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

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

Work committee
Plasmaoberflächentechnologie
U. Lommatzsch (Member)

Technical committee 8
Kleben und Kunststoffschweißen
O.-D. Hennemann, M. Peschka (Members)

Technical committee 9
Konstruktion und Berechnung
O.-D. Hennemann, M. Brede (Members)

Technical committee 10
Mikroverbindungstechnik
O.-D. Hennemann, H. Schäfer (Members)

Work group V 8
Klebtechnik
A. Groß (Chairman)

Work group
Schulung und Prüfung
A. Groß (Member)

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

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

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

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

Examination and certification committee (PZA)
Klebtechnik
A. Groß (Chairman)
O.-D. Hennemann, M. Peschka (Members)

DIN
Deutsches Institut für Normung

Work committee 5.1
Metallpulverspritzguss
F. Petzoldt (Chairman)

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

Work committee ISO/TC 119
Pulvermetallurgie
K. Kümmel (Member)
Standards' committee: Material Technology (NWT)

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

EFDS
Europäische Forschungsgesellschaft Dünne Schichten e.V.

Work committee
Plasmaoberflächentechnologie
U. Lommatzsch (Member)

FEE
Fördergesellschaft Erneuerbare Energien e.V.

Country wide work committee
Biogene Gase – Brennstoffzellen
I. Morgenthal (Member)

FhG
Fraunhofer-Gesellschaft

Alliance
Adaptronik
T. Gesang (Member)

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

Alliance
Nanotechnologie
B. Günther, A. Hartwig (Members)

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

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

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

DIN/DVS
Gemeinschaftsausschuss

Work committee 14/work committee AG V 7
Thermisches Spritzen und thermisch gespritzte Schichten
H. Grützner (Member)

Gemeinschaftsausschuss
Pulvermetallurgie

Work committee
B. Kieback (Chairman)

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

Expert group
Metallpulverspritzguss
F. Petzoldt (Chairman)
T. Hartwig (Member)

Expert group
Metallpulvererzeugung
B. Günther (Member)

Expert group
Sintern
B. Kieback (Chairman)

Expert group
Simulation in der Pulvertechnologie
A. Burblies (Member)

Work committee
Sinterstähle
G. Veltl (Member)

FZK/PFT
Projektträger für Produktion und Fertigungstechnologien

Industry work group
Strukturoptimierung
A. Burblies, H. Fricke (Members)

GDCh
Gesellschaft Deutscher Chemiker

Technical group
Anstrichstoffe und Pigmente
A. Hartwig (Member)

Technical group
Festkörperchemie und Materialforschung
M. Noeske (Member)

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

GfKORR
Gesellschaft für Korrosionsschutz e.V.

Work committee
Kontaktkorrosion
M. Schneider (Member)

Work committee
Korrosion und Korrosionsschutz von Aluminium und Magnesium
M. Schneider (Member)

Work committee
Korrosion von Polymerwerkstoffen
T. Kowalik, R. Wilken (Members)

IVK
Industrieverband Klebstoffe

Technical committee (TA)
A. Groß (Member)

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

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

Work committee
Industrieklebstoffe
A. Groß (Member)

VDG
Verein Deutscher Gießereifachleute

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

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

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

Initiative
Zink
F.-J. Wöstmann (Member)

Lost Foam Council e.V.
F.-J. Wöstmann (Director)

Regional

GfT
Gesellschaft für Tribologie

Work committee
Sachsen
G. Walther (Member)

Materialforschungsverbund Dresden e.V.

Work committee
Öffentlichkeitsarbeit
I. Morgenthal (Member)

Work committee
Materialforschungsverbund Dresden
B. Kieback (Member)

VDI
Verein Deutscher Ingenieure

VDI Bremer Bezirksverein
F. Petzoldt (Chairman)

Work committee
Kunststofftechnik
G. Pauly (Member)

Work committee
Plasmaoberflächentechnologie
U. Lommatzsch (Member)

Work committee
Systemplanung und Projektgestaltung
G. Veltl (Chairman)

Work committee
Werkstofftechnik
D. Lehmhus (Chariman)

Wachstumskern
InnoZellMet
O. Andersen (Member of management)

Other

adhäsion/Kleben&Dichten
Editorial
O.-D. Hennemann (Member)

FOSTA – Forschungsvereinigung Stahlanwendung e.V.
im Stahlzentrum Düsseldorf
Advisory board
O.-D. Hennemann (Member)

Journal of Adhesion Science and Technology
Editorial advisory board
O.-D. Hennemann (Member)

Conferences, seminars and fairs

Workforce Qualification Center Adhesive Bonding Technology 2005

European Adhesive Bonder – EAB in accordance with guidelines DVS®-EWF 3305 1-week module incl. examination

Termin EAB 1	24.–28.01.2005
Termin EAB 2	21.–25.02.2005
Termin EAB 3 GL	09.–13.05.2005
In cooperation with Germanischer Lloyd	
Termin EAB 4	10.–14.10.2005
Termin EAB 5	14.–18.11.2005
Termin EAB 6	28.11.–02.12.2005

E-Learning

Termin BoniH 1 EAB	21.–22.04.2005
Termin BoniH 2 EAB	24.–25.11.2005

External courses

Delo, Landsberg	13.–17.06.2005
Arvin Meritor, Gifhorn	19.–23.09.2005

European Adhesive Specialist – EAS in accordance with guidelines DVS®-EWF 3301 three 1-week modules incl. examination

EAS Part I: Principles of adhesive bonding

Termin EAS GL 1	31.01.–04.02.2005
Termin EAS GL 2	07.–11.03.2005
Termin EAS GL 3	26.–30.09.2005
Termin EAS GL 4	17.–21.10.2005

EAS Part II: Adhesive bonding of metals with other materials

Termin EAS MK 1	28.02.–04.03.2005
Termin EAS MK 2	11.–15.04.2005
Termin EAS MK 3	24.–28.10.2005
Termin EAS MK 4	14.–18.11.2005

EAS Part III: Adhesive bonding of plastics with other materials

Termin EAS KK 1	04.–08.04.2005
Termin EAS KK 2	30.05.–03.06.2005
Termin EAS KK 3	21.–25.11.2005
Termin EAS KK 4	05.–09.12.2005

EAS: Examination

Termin EAS P 1	26.04.2005
Termin EAS P 2	14.06.2005
Termin EAS P 3	25.11.2005
Termin EAS P 4	09.12.2005

External courses

ALSTOM, Salzgitter	17.–21.01.2005
BMW, Spartanburg, USA	24.01.–11.02.2005
ALSTOM, Salzgitter	21.–25.02.2005

European Adhesive Engineer – EAE in accordance with guidelines DVS®-EWF 3309 eight 1-week modules plus examination

Termin EAE 1. week	17.–21.01.2005
Termin EAE 2. week	14.–18.02.2005
Termin EAE 3. Week	14.–18.03.2005
Termin EAE 4. week	18.–22.04.2005
Termin EAE 5. week	06.–10.06.2005
Termin EAE 6. week	12.–16.09.2005
Termin EAE 7. week	10.–14.10.2005
Termin EAE 8. week	07.–11.11.2005
Examination	11.11.2005

Seminars

DGM-Fortbildungsseminar
Pulvermetallurgie
Dresden
13.–15.4.2005

Workshop
Bonding for the Future
IFAM
Bremen
28.4.2005

Klebtechnische Fertigung
IFAM
Bremen
10.–11.5.2005

International Symposium
Cellular Metals for Structural and Functional Applications
CellMet 2005
Dresden
18.–20.5.2205

Spring meeting
Arbeitsausschuss Pulvermetallurgie des Fachverbandes Pulvermetallurgie
Dresden
15.6.2005

Seminar
Kleben in der Elektronik
Bremen
20.–21.6.2005

Celebration
4. Bremer Klebtage
IFAM
Bremen
21.–22.6.2005

Seminar
Kleben in der Elektronik
Stuttgart
21.–22.6.2005

Lange Nacht der Wissenschaft
Dresden
1.7.2005

FEICA European Adhesives Conference 2005 / Exhibition
St. Hélier, Great Britain
14.–16.9.2005

Workshop
In Zukunft Zink
IFAM
Bremen
27.–28.9.2005

Technical seminar
Fertigungssystem Kleben – FSK 2005
Klebtechnik für Fahrzeuge von morgen
Hotel Strandlust
Bremen
29.–30.9.2005

Bremer Oberflächentage
Aktuelle Entwicklungen der Oberflächentechnik
IFAM
Bremen
11.–12.10.2005

Seminar
Kleben in der Elektronik
Reutlingen
6.–7.12.2005

Seminar
Kleben in der Elektronik
Bremen
14.–15.12.2005

Seminar
Elektronikkleben für Automobilzulieferer
Bremen
19.12.2005

Fairs

Auftaktveranstaltung
Stadt der Wissenschaft 2005
Bremen
16.2.2005

Hannover Messe 2005
Lackiertechnik
Praxispark
Hannover
11.–15.4.2005

Hannover Messe 2005
Micro Technology
IVAM Gemeinschaftsstand
Hannover
11.–15.4.2005

Hannover Messe 2005
Simulation
FhG Gemeinschaftsstand
Hannover
11.–15.4.2005

Hannover Messe 2005
Subcontracting
Innovationszentrum INGENIEUR-WERKSTOFFE
Hannover
11.–15.4.2005

Hannover Messe Industrie 2005
SurfPlaNet
Praxispark/Hannover
11.–15.4.2005

SMT/Hybrid/Packaging 2005
Systemintegration in der Mikroelektronik
Nürnberg
19.–21.4.2005

European Coatings Show
Nürnberg
26.–28.4.2005

Transfertag
Stadt der Wissenschaft 2005
Bremen
9.6.2005

Schweißen und Schneiden
Structural Bonding International – SBI
Essen
12.–17.9.2005

HUSUMwind
Windenergie
Husum
18.–22.9.2005

MetFoam 2005
Kyoto, Japan
21.–23.9.2005

Euro PM 2005
Prag, Czechia
2.–5.10.2005

BerufsInfoMesse - BIM 2005
Bremerhaven
7.–8.10.2005

Nanosolutions 2005
Köln
8.–10.11.2005

IndustrieFachMesse IFM
Fachausstellung mit 5. Dresdner Material-
forschungstag des Materialforschungs-
verbundes Dresden (MFD)
Messe Dresden
9.–11.11.2005

1. Technologietransfer- und
Netzwerkmesse TransferX
Messe Dresden
9.–11.11.2005

material_vision 2005
Neue Materialien für Design und
Architektur
Conference and technical fair
Forum Messe Frankfurt
Frankfurt am Main
10.–11.11.2005

Technical exhibition
Hagener Symposium Pulvermetallurgie
Hagen
24.–25.11.2005

WISSENSWERTE
Bremer Forum
für WirtschaftsJournalismus
Bremen
28.–30.11.2005

Hausmesse Continental
Frankfurt am Main
29.11.2005

Highlights
Stadt der Wissenschaft 2005
Bremen
30.11.2005

EuroMold 2005
Rapid Prototyping
FhG Gemeinschaftsstand
30.11.–3.12.2005

Scientific publications and presentations

Ph. D. theses

D. Fata
Epoxidsysteme im Verbund mit rostfreien Stählen – Vernetzung und Alterung
Universität des Saarlandes
Examiners: Prof. Dr. W. Possart
Prof. Dr. rer. nat. O.-D. Hennemann
Oral examination: 26.9.2005

J. Götz
Dispensen von gefüllten Klebstoffen im Sub-Nanoliter-Bereich in der automatisierten Fertigung
Universität Bremen
Examiners: Prof. Dr. rer. nat. O.-D. Hennemann
Prof. Dr.-Ing. G. Sepold
Oral examination: 27.1.2005

T. Kaese
Synthese monomorer flüssigkristalliner Diepoxide, deren Charakterisierung und Ausrichtung im elektrischen Feld
Examiners: Prof. Dr. D. Wöhrle
Prof. Dr. rer. nat. O.-D. Hennemann
Oral examination: 28.1.2005

S.J.-M. Kim
Eine rechnergestütze Methode zur Passungsanalyse von tolerenzbehafteten Fügeteilen mit abschließender Programmierung eines automatisierten Klebstoffauftrags
Universität Bremen
Examiners: Prof. Dr. rer. nat. O.-D. Hennemann
Prof. Dr. W. Possart
Oral examination: 3.11.2005

Lectures

A. Burblies
Finite Elemente Methode
Hochschule Bremerhaven
SS 2005

A. Burblies
Werkstoffmodelle und Simulation
Hochschule Bremerhaven
WS 2005/2006

M. Busse
Forschung und Entwicklung im Automobilbau
Universität Bremen
Fachbereich Produktionstechnik
SS 2005

M. Busse
Leadership im Automobilbau
Universität Bremen
Fachbereich Produktionstechnik
WS 2005/2006

U. Echterhoff
Werkstoffkunde und Schweißtechnik
Hochschule Bremen
SS 2005

H. Fricke
Simultaneous Engineering and Rapid Prototyping
Hochschule Bremen
Studiengang Master of Engineering in Computer Based Mechanical Engineering (CBME) – Fachbereich 5
WS 2005/2006

A. Groß
Werkstoffe: Klebtechnik
Hochschule Bremen
SS 2005

B. Günther
Funktionswerkstoffe im Automobilbau – Funktionalisierung von Oberflächen
Universität Bremen
Fachbereich Produktionstechnik
SS 2005

A. Hartwig
Grundlagen der Makromolekularen Chemie
Universität Bremen
Fachbereich Chemie
WS 2005/2006

O.-D. Hennemann
Niedertemperaturfügen
Universität Bremen
Fachbereich Produktionstechnik
SS 2005

O.-D. Hennemann
Polymertechnik
Universität Bremen
Fachbereich Produktionstechnik
WS 2005/2006

B. Kieback
Pulvermetallurgie und Sinterwerkstoffe II
Technische Universität Dresden
Institut für Werkstoffwissenschaft
SS 2005

B. Kieback
Festkörperchemie II
Technische Universität Dresden
Institut für Werkstoffwissenschaft
SS 2005

B. Kieback
Verbundwerkstoffe
Technische Universität Dresden
Institut für Werkstoffwissenschaft
SS 2005

B. Kieback
Pulvermetallurgie und Sinterwerkstoffe I
Technische Universität Dresden
Institut für Werkstoffwissenschaft
WS 2005/2006

B. Kieback, T. Schubert
Technologien zur Werkstoffherstellung und -verarbeitung I
Technische Universität Dresden
Institut für Werkstoffwissenschaft
WS 2005/2006

B. Kieback, M. Zumdick
Festkörperchemie I
Technische Universität Dresden
Institut für Werkstoffwissenschaft
WS 2005/2006

U. Meyer
Mathematik und Physik I
Hochschule Bremen
SS 2005

U. Meyer
Laborrechnung und Statistik
Hochschule Bremen
SS 2005

U. Meyer
Grundverständnis wissenschaftlicher Technik
Hochschule Bremen
SS 2005

U. Meyer
Mathematik und Physik II
Hochschule Bremen
WS 2005/2006

U. Meyer
Das Funktionieren technischer Systeme
Hochschule Bremen
WS 2005/2006

U. Meyer
Mathematik Vertiefung II
Hochschule Bremen
WS 2005/2006

F. Petzoldt
Endformnahe Fertigungstechnologien I und II
Universität Bremen
Fachbereich Produktionstechnik
SS 2005 und WS 2005/2006

P. Plagemann
Korrosionsschutz
Hochschule Bremerhaven
WS 2005/2006

M. Popp
Klebstofftechnologie
Fachhochschule Bremerhaven
WS 2005/2006

J. Weise
Metal Foams
Universidade Estadual de Campinas, Brasilien
Oktober 2005

R. Wilken
Grundlagen der Chemie I
Hochschule Bremen
WS 2005/2006

R. Wilken
Grundlagen der Chemie II
Hochschule Bremen
SS 2005

R. Woltmann
Bauteilentwicklung für automobile Gusskomponenten
Universität Bremen
Fachbereich Produktionstechnik
SS 2005

R. Woltmann
Leichtmetallgießen im Automobilbau
Universität Bremen
Fachbereich Produktionstechnik
WS 2005/2006

Publications

J. Adler, K. Kümmel, P. Quadbeck, G. Standke, G. Stephani
Synthesis of Open-Celled Metal Foams
Proceedings, International Symposium Cellmet 2005, Dresden, in Druck

B. Ballóková, P. Hvizdoš, M. Besterci, M. Zumdick, A. Böhm
Microstructure and Mechanical Properties of $MoSi_2$-based Composites
Powder Metallurgy Progress, 5, 1 (2005), 65-70

B. Ballóková, P. Hvizdoš, M. Besterci, J. Ivan, M. Zumdick, A. Böhm, T. Weißgärber, B. Kieback
Microstructure and Mechanical Properties of ZrO_2-reinforced $MoSi_2$ Matrix Composites
International Journal of Materials and Product Technology (IJMPT), 22, 4 (2005), 322-327

J. Baumeister, D. Labuhn, L. Pambaguian
Space Applications for Highly Porous Materials
Proceedings, MetFoam (2005), in Druck

J. Baumeister
Metallschäume machen Maschinenteile leichter und leiser
Maschinenmarkt (2005), in Druck

A. Berg, J. Weise, G. Rausch, M. Haesche, F.-J. Wöstmann, M. Busse
Druckgießtechnische Herstellung von offenporösen Aluminiumschäumen und Aluminium-Polymer-Hybridstrukturen
Gießerei, 92, 2 (2005), 24-27

R. Brüning, P. Scholz, I. Morgenthal, U. Waag, A. Weißbach, F. Hollstein, B. Ondruschka
Innovative Katalysatoren zur oxidativen Dehydrierung in der Gasphase – beschichtete Eisenhohlkugeln
Chemie Ingenieur Technik 77, 1-2 (2005), 119-124

R. Brüning, P. Scholz, I. Morgenthal,
O. Andersen, J. Scholz, G. Nocke,
B. Ondruschka
Innovative Catalysts for Oxidative Dehydrogenation in the Gas Phase – Metallic Short Fibers and Coated Glass Fabrics
Chemical Engineering & Technology 28, 9 (2005), 1056-1062

S. Bryde, I. Grunwald, A. Hammer,
A. Krippner-Heidenreich, T. Schiestel,
H. Brunner, G.E. Tovar, K. Pfizenmaier,
P. Scheurich
Tumor Necrosis Factor (TNF)-funtionalized Nanostructured Particles for the Stimulation of Membrane TNF-specific cell responses
Bioconjug. Chem., 11/12, 16, 6 (2005), 1459-1467

M. Busse, F.J. Wöstmann,
Rapid Casting for Manufactures and Suppliers – Trends, Potentials, Concepts and Synergies
Proceedings, Euro-uRapid 2005
Leipzig (2005)

M. Busse,
Zink bietet zahlreiche innovative Lösungen
Giesserei 11 (2005), 14

M. Busse,
Neue Wege in der Gießerei – Kombination von Adaptronik und Gießereitechnik
Tagungsband, Schlüsseltechnologie Leichtmetallguss im Automobilbau,
Bad Nauheim (2005)

E.C. Chirwa, D. Lehmhus, M. Mao,
T. Chen, L. Lanzi
Mechanics of Lightweight Aluminium Foam Wrapped in Carbon Fibre Reinforced Composites
WIT Trancactions on Engineering Science,
WIT PRESS, 49 (2005)

A. Dudhmande, T. Schubert,
M. Balasubramanian, B. Kieback
Sintering and Properties of New P/M Aluminium Alloys and Composites
Proceedings, EuroPM2005, 2 (2005), 293-298

S. Esmaeelzadeh, A. Simchi, D. Lehmhus
Effects of AlSi7-TiH2 Powder Compacts
Proceedings, MetFoam (2005), in Druck

T. Gesang, U. Netzelmann
Reproduzierbares Dispensen von Leitklebstoffen im Sub-Nanoliter-Bereich
Adhäsion Kleben und Dichten, 3 (2005), 18-24

T. Gesang, V. Klocke
Die Welt unter der Lupe – Modular konzipierte Mikroproduktionsanlage setzt für die Montage auf das Mikrokleben
MM Maschinenmarkt, 21 (2005), 48-51

A. Godin, L. Kramer, F. Petzoldt,
A. Balashov, V. Ryabinin, A. Radaev
Development and Tests of MIM Feedstock Based on Carbonyl Iron Powder and Wax Polymer Binder
Proceedings, New Materials and Parts from Metal Powders – TPP PM 2005 Conference, Joshkar Ola, Russia (2005), 33-36

A. Godin, L. Kramer, F. Petzoldt,
A. Balashov, V. Ryabinin, A. Radaev
Development and Tests of MIM Feedstock Based on Carbonyl Iron Powder and Wax Polymer Binder
Proceedings, Ural Forgers 2005 Conference, Werchnjaja Salda, VSMOP, Russia
(2005), 380-381

D. Godlinski, S. Morvan
Steel Parts with Tailored Material Gradients by 3D-Printing Using Nano-particulate Ink
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U. Lommatzsch
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J. Weise
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T. Studnitzky
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J. Schmidt
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P. Quadbeck
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U. Klotzbach
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Protection rights

Registrated trade names and trademarks

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