IFAM

Fraunhofer Institut
Fertigungstechnik
Materialforschung

Annual Report 2004

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

Annual Report 2004

A profile of the institute

Department of Adhesive Bonding Technology and Surfaces

Department of Shaping and Functional Materials

Looking back and looking ahead

The annual report 2004 looks back at our work over the past year and also looks ahead to the coming twelve months.

This year we have also chosen a symbolic photo to portray the theme of this annual report. On the photo, the view into the IFAM building and view out of the building merge with each other, so symbolising the seamless transition from research to development and application. The work being undertaken by IFAM today was the outlook of yesterday. Our outlook of today will be our projects of tomorrow. It is important for us that IFAM is continually changing and advancing.

The fields of expertise in the "Shaping and Functional Materials" department which were redefined in 2003 have been marketed intensively. In the "Adhesive Bonding Technology and Surfaces" department, the "Biopolymers" and "Molecular Modelling" work groups increased their workforce in order to expand their activities and so meet future needs.

The establishment of networks was successfully intensified in both departments. It is also important here that internal and external cooperation is linked, that IFAM cooperates via networks and collaborates in alliances with industry and other research establishments.

Looking back on the past year we would like to make it clear that the further development and success of IFAM have only been made possible by the dedicated work of our employees and the trust of our customers and partners. We are grateful to all concerned.

M. Busse

O.-D. Hennemann

M. Busse

"We want to be actively involved in shaping technological developments"

Professor Dr. Hennemann

Despite the stagnating economy, the Department of Adhesive Bonding Technology and Surfaces headed by Professor Dr. Otto-Diedrich Hennemann was able to expand in 2004 and reach its financial goals. Professor Hennemann is sure that there will be great demand for IFAM services in the future and that work must be carried out now to find solutions for tomorrow's needs.

Professor Hennemann, throughout 2004 there were complaints from all quarters of commerce and industry about the poor economic situation. Given that IFAM carries out contract research, how were you affected by the economic climate and was 2004 a financially successful year?

We are unfortunately not an island in an industrial environment and indeed about 50 per cent of our budget involves contracts with industry. For that reason, the economic situation is always very important for us. The year 2004 was a year of stagnation for the economy just like the year before. From a technological point of view we moved ahead but from a budget perspective we lagged behind. The question in 2004 was: For how long can we withstand a stagnating economy, namely how will this ultimately affect our budget? The answer is however positive: Despite the indifferent economic situation, we have attained our economic goals within the Fraunhofer-Gesellschaft. We have even taken on more personnel in order to tackle new areas and demands. I am sure these are signals that our strategy is the right one.

The manpower structure in the present work groups is in a state of change. IFAM specialists are increasingly finding themselves working on site for customers. Why is that?

If we want to optimize our services for our largest economic partner, namely industry, then we must recognize very precisely and rapidly where we can make our contribution, both now and in the future. When working on site with customers, the two main questions are: What can I do right now to help the customer and what are the problem areas for which the institute must be able to offer solutions for the customer one day in the future? It is essential that we ask ourselves these questions again and again: Is our manpower structure optimal? Is the expertise of our employees suitable for tackling future challenges? In what direction must our expertise develop in order that we remain a suitable partner for industry? Even now we must put in place the necessary support measures for future challenges, so that when needed they can be immediately put to use. If we do not pursue this "preventive approach", a day will come when we no longer have the opportunity to generate our income. We therefore monitor industry and its needs very closely in order to be able to adapt to their needs and hence stay in business.

Collaboration with industry and involvement in networks can be thought of as the pulse or lifeline of IFAM. Was 2004 a good year for IFAM in this regard?

One main area of focus is the large industries around Bremen: Airbus, DaimlerChrysler and the Arcelor Steelworks are all involved with materials. We have collaborated with these companies for many years. The industrial area around Bremerhaven, which up until now has been dominated by shipbuilding, is now becoming important for offshore wind energy. In the offshore sector the challenges concerning logistics and materials are even higher than for shipbuilding – a huge challenge but our know-how is playing a key role here. New contacts are in turn made via all of these partners – for example contact with the Stade technology region where there is an Airbus production plant for composite components. There we are one of the founders of the CFK-Valley Stade e.V. This is an alliance of IFAM, Airbus, DLR, the Composite Technology Center (an Airbus subsidiary) and other partners. The challenges there include developing a process chain for large fibre reinforced composite structures that are for example required in the construction of aircraft, rail vehicles, commercial road vehicles, rail vehicles and ships. New contacts are in turn being made via the CFK-Valley Stade e.V. One of the key tasks is to involve many small and medium-sized companies – and currently the network already comprises 20 companies with whom we are able to start joint research projects. This example shows how networking develops and constantly opens up new opportunities.

Induflex Coating Systems GmbH (in short: ICS) was founded in 2003 and is now an established company in the marketplace. What was the reason for setting up this company?

The ICS is involved in low pressure plasma technology. IFAM had so much success providing its services, ranging from surface functionalisation right through to production start-up, that the institute reached a limit. We were receiving ever more requests and eventually decided to transfer this service into a private company, namely ICS. Such spin-off companies from research are the goal of the BMBF (German Ministry for Education and Research) and the German government. The FhG supported this move and detailed regulations were put in place. Requests for services in this area are now passed to ICS. However, it is not solely one-way traffic and ICS refers suitable research and development requests back to IFAM. We also want to use ICS as the starting point for building further networks.

IFAM is also becoming more and more involved in networks within the Fraunhofer-Gesellschaft ...

The Fraunhofer Alliance for Materials and Components is very active and collaboration is excellent. Other Fraunhofer alliances include POLO (polymer surfaces) and in 2004 the Fraunhofer Alliance for Nano-Technology was established. Most recently the Fraunhofer Alliance for Numerical Simulation of Products and Processes has been set up. A leading role here is played by IFAM – and this also involves the Department of Shaping and Functional Materials. In summary, alliances are becoming more prevalent and the networks are hence growing. The result is that industry can be provided with excellent system solutions.

You often point out that in addition to carrying out application-related contract research IFAM also undertakes fundamental research which is paving the way for the future. What exactly does that mean?

Part of our work concerns the medium-term approach that has already been described, preparing for the upcoming needs of industry. However we also have a long-term strategy in place. In Germany there are major issues which will have to be addressed in the future – for example energy, health, ageing of the population, ecology, etc. Work is currently being carried out on "Learning from nature". We are endeavouring to analyse and understand the adhesion mechanisms that are encountered in nature. If this work is successful, we want to transfer the key mechanisms to industrial adhesive systems. Research and development projects in this area are already underway in Germany and we are trying to promote our expertise. However, in order to be able to even apply for project funding to third party organizations, a certain level of knowledge and also the availability of manpower as well as machinery and equipment must be able to be demonstrated. Our own investment has allowed us to establish the "Biomolecular Surfaces and Material Design" work group. I am convinced that this area will be successful in the years ahead.

In 2004 IFAM aggressively marketed itself to the outside world. The new extension building was officially opened – and the opening was marked by a series of informative workshops and a symposium. In addition, 2004 was the 10th anniversary of the IFAM training courses in adhesive bonding technology and the "Bremer Klebtage" took place for the third time. On reflection, has your marketing approach been successful?

Our marketing approach in 2004 was more specific and more concentrated. Our brochures combined with direct contact with potential customers have enabled us to obtain very good feedback. This takes more effort, but it means we reach our customers more effectively. We want to continue this approach. We will also hold workshops in 2005. This gives companies the opportunity to familiarise themselves with our range of services and discuss with us the topics that are most important to them. That is a two-way dialogue: The companies learn how we can be of benefit to them and from the questions we are asked we learn whether the institute is effectively organized for the challenges of the future.

The challenges facing IFAM in 2005 will certainly be no less than in the near past. What issues do you plan to tackle and what do you want to achieve by the end of the year?

At the start of this interview I mentioned the economic situation. Germany will at some stage experience an upturn. In this regard, I have for some time been of the belief that there will soon be major restructuring and change in Germany's large industries. For example, the car manufacturing industry will modernise and reorganize its production technology. The same applies for the aircraft manufacturing industry and offshore wind energy. IFAM must prepare itself now if it wants to make a constructive contribution to these major changes. In 2005 we will find out how effectively we have organized ourselves and how effectively we have developed as an institute over recent years – or whether we still have to optimize some of our services. The aim is for IFAM to make an aggressive contribution. We do not wish to merely be pulled along but rather want to actively shape technological developments! I am certain that we will achieve this.

“Smarter – Smaller – Safer” – the new strategic course of the Department of Shaping and Functional Materials

Professor Dr.-Ing. Busse

In 2004, Professor Matthias Busse and his team saw the financial position of the department improve. A clearly outlined strategy and transparent expertise as well as know-how should allow successful continuation along the department’s new course. A key aspect here is the increased collaboration with suitable partners.

Professor Busse, you are now in your second year as managing director of the Department of Shaping and Functional Materials at IFAM. One of the first decisions you took was to set the department on a new strategic course. Now that some time has passed and there has been time for reflection, do you believe this was the right decision?

Yes, this step was right and important. There has been new verve generated in our department. Initial evaluation tells us that we have chosen the right path – even though this very dynamic process is not yet complete. It will certainly take a little time before the measures take full effect and the changes become established. In embarking on this new course, there have been changes at various levels: firstly, naturally, the change in the technical orientation, secondly greater orientation towards markets and customers and thirdly a paradigm shift which should bring increased co-operation with partners from other technical disciplines. We so aim to open up new opportunities in areas in which our own expertise and that of our partners complement each other. Our focused core expertise, clearly defined business fields and new approach will allow us to closely follow the course we have set out on. The IFAM facility in Dresden will play a key role here and its development activities will make an important contribution to the work of the Department of Shaping and Functional Materials.

Your aim was to create a clearly demarcated and transparent range of services and expertise ...

... and we have now defined a clearly outlined portfolio. At the start of the restructuring we carried out work in several new fields, evaluated the “market pull” and “technology push” and assessed what fields of expertise appeared to have a promising future. The results have enabled us to focus our efforts. Three core areas of expertise now describe the Department of Shaping and Functional Materials. Firstly there is Powder Technology and Sintered Materials – our employees in Bremen and Dresden have many years of experience here and we possess an excellent range of plants and equipment. We will strengthen this area and expand into special areas of functional integration. The second core area is Foundry Technology and Light Metal Technology – an area which IFAM has been involved in for about eight years and which we wish to expand with new technologies. The third and final core area of expertise is Micro-Structuring and Nano-Structuring – an area which we believe will be very important for the future of the department. A series of new technical fields, based on previously established know-how at IFAM, have come to prominence in a very short time. New technologies and projects abound in this dynamic area.

What is new about the Department of Shaping and Functional Materials which will attract industrial partners?

We are combining our established expertise in materials and shaping, for the design and manufacture of precision metallic components, with the world of functional structures. “Smart Products” – intelligent components – will in the future encompass a whole range of functions: In addition to the “structural” properties of components such as dimensional stability, strength, etc., “functional” properties such as sensory capability and telemetric communication will be integrated into components. Our aim here is to develop concepts and solutions based on materials science and manufacturing technology. Post-assembly of individual sensory functions will so be replaced by the integration of sensory functions into the component. Functionality will hence become an integral part of future components and will come about from the integration of functional materials and structural materials. Our future fields of work hence lie at the heart of application-orientated technology roadmaps. From an industrial perspective, these roadmaps describe firstly the need for functional integration via materials and construction methods and secondly the increased use of electronic and sensory functions in technical systems.

Was there increased collaboration with industry in 2004?

We have noticeably increased our revenue from industry. I deem this a huge success given the difficult economic conditions and the fact that we only changed direction a short time ago. We have also been able to gain new customers and are actively evaluating and opening up new market segments. We have also increased our activities relating to publicly funded projects, in order counter the fewer number of funding opportunities. I would like to stress here that this would not have been possible without the great dedication of all involved. For that reason, let me take this opportunity to express my recognition and thanks to the whole team for their hard work.

New measures have also been taken to market IFAM more effectively and to change how IFAM is viewed by the outside world.

How we are seen by the outside world plays a key role in IFAM's success. It is very important that we market ourselves optimally so that our results and services are viewed by the outside world as being of use to them and of benefit to them. Our renown in our new fields of work must be increased so that all our core areas of expertise are fully established and become synonymous with the IFAM name.

One of your objectives was to have close links with the University of Bremen where you presently occupy the Chair for Near Net-Shape Production Technologies. Has this objective been achieved?

Last year I was able to build up a small group of employees at the university and others will follow soon. There are very close ties with IFAM staff. There is growing collaboration with the university lecturers in the area of production technology and we are now undertaking joint projects with industry, taking out joint patents and making joint applications for public funding. I have been pleasantly surprized by the high numbers of students attending my lectures. I want to especially utilise that close contact with students in order to ensure there is a stream of new scientific talent for IFAM.

Looking ahead: What do you want to achieve by the end of 2005?

After the intensive restructuring and change of direction, I would like to see stability and continuity this coming year. The implementation of the changes and the integration of the new core areas of expertise should form the basis for further improvement in our financial position. Regarding collaboration with the University of Bremen, my aim is to set up a large joint project on intelligent components and get this underway – and we also want to underline our contribution to the "City of Science" event. Last but not least, I want to urge everybody at IFAM to seek enjoyment in their work as they strive for success!

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 micro-production, 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; Micro-structuring and nano-structuring; Powder technology and sintering technology. These areas are reflected in the organization 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 2004 the total IFAM budget amounted to about 20.9 million euros. The workforce comprised some 271 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. Frank Petzoldt
Professor Dr.-Ing. Bernd Kieback
Managing director of the Dresden site
"Powder metallurgy and composite materials"

Andreas Heller
Head of administration

The institute in figures

Budget

The total IFAM budget (expenditure and investment) in 2004 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 20.9 million euros. The results for the two individual sites are shown below.

Adhesive Bonding Technology and Surfaces
Bremen

Operating budget	10.5 million euros
Own income	8.0 million euros
including	
Business income	5.7 million euros
Federal/state/EU/other	2.3 million euros
Investment budget	1.0 million euros

Shaping and Functional Materials
Bremen

Operating budget	5.2 million euros
Own income	2.3 million euros
including	
Business income	1.4 million euros
Federal/state/EU/other	0.9 million euros
Investment budget	1.4 million euros

Shaping and Functional Materials
Dresden

Operating budget	2.7 million euros
Own income	2.0 million euros
including	
Business income	1.4 million euros
Federal/state/EU/other	0.6 million euros
Investment budget	0.1 million euros

Figs. 1 and 2 show how IFAM's budged and income have changed over the period 2000 – 2004.

Investments

During 2004, IFAM investments amounted to 2.5 million euros, split as shown below. The most important acquisitions are indicated.

Adhesive Bonding Technology and Surfaces
Bremen
(1.0 million euros)

- IR-VCD-Spectroscopy (Infrared Vibrational Circular Dichroism Spectroscopy)
- LIBS (Laserinduced Breakdown Spectroscopy)
- 3-D tomography for TEM/STEM

Shaping and Functional Materials
Bremen
(1.4 million euros)

- SIGMASOFT (injection moulding simulation)
- MAGMASOF (casting simulation)
- IMAGE-Access 5.0 (image analysis)
- Thermo-Calc software
- Sputtering plant
- Microwave treatment unit
- Sputtering plant
- Particle analysis
- Monomode microwave plant
- Impression injection mould
- CAD/CAM measuring arm

Shaping and Functional Materials
Dresden
(0.1 million euros)

Workforce

On 31 December 2004 IFAM employed a total of 271 people (90 per cent of which in scientific/technical areas).

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

Workforce structure 2004

Scientists	105
Technical employees	79
Administration/internal services and work placement students	28
Ph.D. students, trainees and auxiliary staff	59

The growth in the workforce over the period 2000 – 2004 is depicted in Fig. 3.

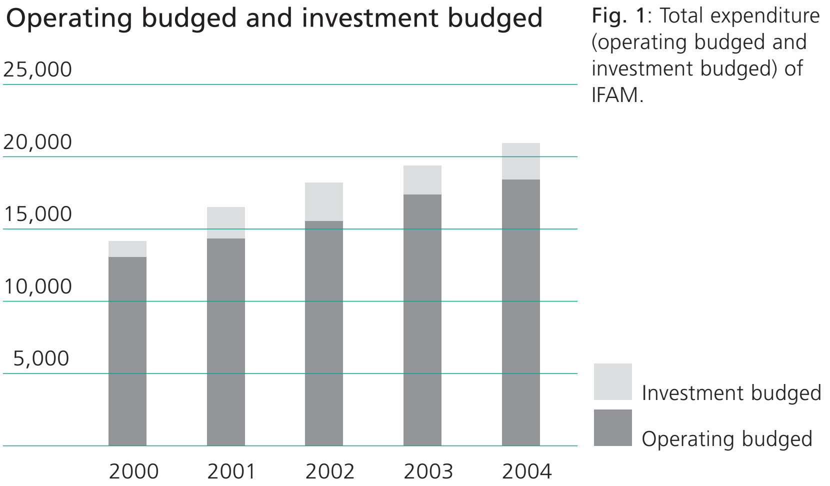

Fig. 1: Total expenditure (operating budged and investment budged) of IFAM.

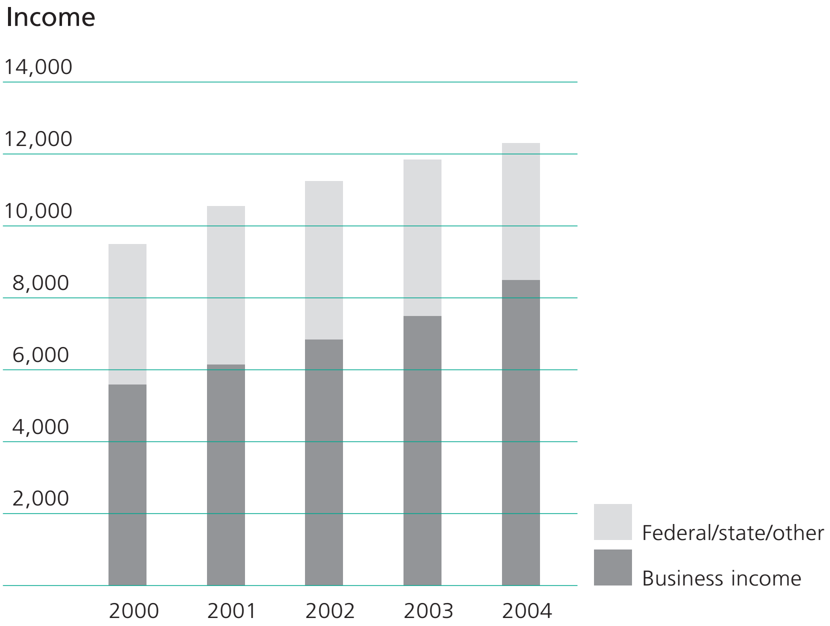

Fig. 2: Total income of IFAM.

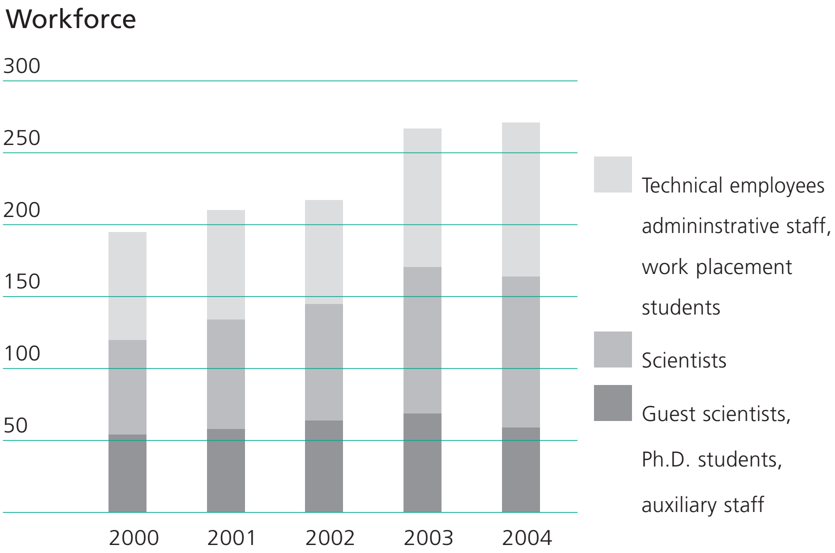

Fig. 3: Total number of employees at IFAM.

The IFAM committee

- **A. Picker**
  Chairman
  Henkel KGaA
  Düsseldorf

- **O. R. Dr.-Ing. F. Fischer**
  Deutsche Forschungsgemeinschaft
  Bonn

- **Prof. Dr. R. X. Fischer**
  Universität Bremen

- **Dr.-Ing. F.-J. Floßdorf**
  Forschungsvereinigung
  Stahlanwendung e.V. (FOSTA)
  Düsseldorf

- **M. Grau**
  Mankiewicz Gebr. & Co.
  Hamburg

- **H.-H. Jeschke**
  HDO Druckguss- u. Oberflächentechnik GmbH
  Paderborn

- **Prof. Dr.-Ing. J. Klenner**
  AIRBUS Société par Actions Simplifiée
  Toulouse, France

- **Staatsrat R. Köttgen**
  Der Senator für Bildung und Wissenschaft
  Bremen

- **V. Kühne**
  Modelltechnik Rapid
  Prototyping GmbH
  Waltershausen

- **Prof. Dr. rer. nat. Dr.-Ing. E. h. mult. emer. E. Macherauch**
  Karlsruhe

- **R. Nowak**
  Glatt GmbH
  Binzen

- **Dr. rer. nat. A. De Paoli**
  Robert Bosch GmbH
  Stuttgart

- **Dr. W. Schreiber**
  Volkswagen AG
  Wolfsburg

- **M. Sc. J. Tengzelius**
  Höganäs AB
  Höganäs, Sweden

- **Dr. sc. K. Urban**
  Bundesministerium für Bildung und Forschung
  Berlin

- **C. Weiss**
  BEGO Bremer Goldschlägerei
  Bremen

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

- **Min.-Rat Dr. rer. nat. R. Zimmermann**
  Sächsisches Staatsministerium für Wissenschaft
  und Kunst
  Dresden

- Permanent guest:
  Prof. Dr. G. Müller
  Fraunhofer-Institut für Silicatforschung
  Würzburg

Current and future challenges

The political world, industry and the scientific community face the challenge of maintaining and strengthening the position of industrial manufacturing in Germany, otherwise not only the production itself but also the development of new products will shift to low-cost countries. The Fraunhofer IFAM is tackling this issue and during 2004 the range of services offered by IFAM was further focussed. The work being carried out in the Department of Adhesive Bonding Technology and Surfaces and in the Department of Shaping and Functional Materials provides a sound base for innovative product development and favourable-cost manufacture, so fulfilling the growing desire of customers for customized products of high functionality and quality which can be manufactured at attractive prices.

Near-net shape production technologies such as casting and powder injection moulding allow process chains to be shortened and a variety of functions to be integrated into complex-shaped components. This means that products of high quality can be manufactured at favourable cost, because, for example, the need for machining and assembly work is reduced. Powder metallurgy offers additional flexibility for designing materials that meet compositional and property requirements, without the lengthy procurement of large quantities of preforms or semi-finished products. In collaboration with industry, the advantages of these technologies for new products are being utilised and implemented in industrial production. The challenge for IFAM is on the one hand to make these technologies controllable in order to prevent there being quality problems and on the other hand to explore new opportunities for integrating functions into materials or components, for example by using functional materials or sintered components in multi-component injection moulding technology.

Against this background, the Department of Adhesive Bonding Technology and Surfaces has expanded its range of services and fields of work. The “Biomolecular design of surfaces and materials” work group was set up and additional personnel were taken on in the paint/lacquer technology work group. The aim of both these measures is to be able to offer new products and services and reach out to new groups of customers.

Adhesive Bonding technology today is used for a very broad range of applications and further improvements in the performance of adhesives are expected in the future – directed at industrial production.

A key task of IFAM in this regard is to organize all its fields of expertise around adhesive bonding technology and in particular to further develop methods and tools for assessing and safeguarding quality and reliability.

The building up of networks to link industry and research is viewed by IFAM as very important and is continuing apace. The IFAM committee deems this a key issue for the future of the institute. This will allow new research and development results from IFAM to be transferred more rapidly to industry and will allow problems facing industry to be recognized earlier and user-orientated solutions to be developed.

I would to take this opportunity to thank all employees for the work they have carried out in 2004 and urge them to enthusiastically take on the new challenges and hence contribute to the well-being of society and the success of IFAM customers.

Dr. rer. nat. A. De Paoli
(Robert Bosch GmbH, Member
of the IFAM committee)

Research and life-long training: Symposium on 18 May 2004

According to Aristotle: “By nature, man strives for knowledge”. This striving has in the meantime become a growing challenge. Indeed, the rapid pace of technological developments and the rapid outdating of knowledge necessitate one thing more than anything else: continuous training of staff. This is particularly so in research and technology, industry and commerce. In this age of global competitiveness, an organization which does not react in time and which does not have up-to-date training plans is quickly left behind – regardless whether that organization is a private company or an institution. The Fraunhofer IFAM recognized long ago that the continuous training of staff is imperative for successful introduction and implementation of new technologies. However, this is not the case everywhere. In order to highlight the importance of this relationship the institute held a symposium on 18 May 2004 entitled “Research and life-long training”. This symposium stressed the value of training and the role of the state, industry and universities/technical colleges was outlined. The symposium was organized to coincide with the IFAM committee meeting and the opening of the extension building – which houses the new IFAM Training Center.

Arnd Picker
(Henkel KGaA, chairman of the IFAM committee)

IFAM director, Professor Otto-Diedrich Hennemann, welcomed about 100 participants from all over Germany to the new auditorium. These included participants from R&D and leading training professionals involved in the issue of life-long learning. The symposium was chaired by Arnd Picker (Henkel KGaA), the chairman of the IFAM committee. He was warmly greeted by the guests in the auditorium.

Practical knowledge must be immediately utilised by industry

Professor Hennemann pointed out that IFAM occupies a special position in Germany: “Our work generates practical, application-related knowledge which we then transfer immediately to industry.” This situation is however rather unusual. Normally, the organization generating that knowledge would first pass this knowledge to a “knowledge administrator” who would then take care of the training and follow-up training. To clarify the difference to the IFAM approach, Hennemann went on: “As a result, the administrator is dependent on the input of the knowledge-generator, and the administrator has absolutely no practical knowledge of technology!”. The “traditional” approach results in loss of time and information – and this is no longer affordable today. Hennemann hence demanded a fundamental change in philosophy to make the knowledge-generator the teacher, namely to enable him to directly pass on his knowledge. Hennemann knows from IFAM experience: “This approach is more successful. The one who first translates that knowledge and know-how into innovations in the marketplace will ultimately be able to guarantee well-being and employment!”

Professor Hans-Jörg Bullinger, President of the Fraunhofer-Gesellschaft, is of the same opinion. In his talk, Bullinger referred to the radically changed conditions in the employment market. “Knowledge and qualifications have become an

Prof. Dr.-Ing. Hans-Jörg Bullinger
(President of the Fraunhofer-Gesellschaft)

important factor for the production, and this importance is likely to grow considerably", declared Bullinger. "In many sectors of industry, information and knowledge (i.e. resources) are the chief input factors for performance." Bullinger reflected on the demographic changes, which also make further training vital for older people. Young technical staff and new graduates alone can no longer bring the required knowledge into companies. "For that reason, employee training is an extremely important factor for business success", said the FHG president.

Training to maintain career opportunities

With the situation as it is, employee training has a higher value than ever before. Hans-Jörg Bullinger viewed training as a "necessary precondition" for an employee furthering his/her career. In addition, today's employees must learn new skills for successful functioning in a world of networks. Bullinger views follow-up training and qualifications as a means for an employee to direct his/her own career: "Many employees are able to plan their daily work very rationally and effectively, but the same cannot be said about their career planning." This is desirable but it requires expert advise.

The FHG president praised IFAM's approach of direct knowledge transfer: "New models for training and follow-up training with an ever closer link between science and industry are part of the innovation offensive of the German government of which we are a part."

Dr. Uwe Bake, Ministerial Director in the Federal Ministry for Education and Research, underlined this aspect at the symposium: "Innovation is determining the future of our society. For this we above all need highly educated people and an excellent research base. Practically relevant training is becoming increasingly important." For that reason, the BMBF contributed ca. 3.6 million euros to the extension building at IFAM. The aim of the German government is to increase the total investment in R&D with industry to three percent of GNP by 2010. "However, we not only need money for the research, but also more research for the money."

Dr. Uwe Bake
(Ministerial Director in the Federal Ministry for Education and Research)

With that in mind the BMBF will enter into a "pact for research and innovation" with research and science organizations. This mainly concerns more competition, more networks, more unconventional research and more opportunities for young scientific talent. Where possible and where promising, technical colleges and research organizations should form training alliances – and this will also improve the transparency of training. According to Bake, "the state should tread carefully here to prevent its funding from distorting a training market which comprises many private providers".

"Trained by Fraunhofer": as a recognized trade name?

A training network between research and users has been in existence for many years at IFAM with the Adhesive Bonder, Adhesive Specialist and Adhesive Engineer training courses. This emphasises that Fraunhofer institutes are ideal for carrying out such training tasks. Due to their direct collaboration with companies they are constantly acquiring new knowledge. By holding training courses, this know-how can be quickly spread throughout industry. "Trained by Fraunhofer" could one day be a recognized trade name and the model for direct, rapid transfer of knowledge and know-how.

Prof. Dr. Ulrich Lehner
(Chairman of the board of Henkel KGaA)

The importance of collaboration between companies and external research institutes was iterated by Professor Ulrich Lehner, chairman of the board of Henkel KGaA. Henkel Technologies – the industry section of Henkel – is a partner of the Fraunhofer IFAM. Direct knowledge transfer, according to Lehner, has benefited Henkel Technologies. For many years the company has carried out joint development projects and training programmes with IFAM. Professor Lehner stressed the importance of continuous follow-up training. Henkel welcomes the increased training and research activities at IFAM that the new extension building will allow, so investing in knowledge in order to preserve the position of German industry in the global economy. Ulrich Lehner praised the R&D initiatives of his company with scientific and industrial partners. An example is development work being carried out – in conjunction with the central Henkel research group – on lightweight composite materials. Henkel is putting a great deal of effort into training measures, because well qualified employees clearly improve the company's position in the marketplace. In 2003 some 10,000 Henkel employees participated in training courses – including some organized by the Fraunhofer IFAM.

Rapid introduction of technology by training

Professor Jürgen Klenner, Manager of CoC-Structure at Airbus Engineering in Toulouse and a member of the IFAM committee, also put forward similar thoughts in his talk. "The big success of Airbus in the past 30 years is in part due to the rapid introduction of new technologies", says Klenner. Interacting with R&D institutions is absolutely vital. Although Airbus collaborates very well in this respect, he is of the belief that technology development must be further improved. "In addition to increasing the funding, there are 2 other key steps: Even closer collaboration between industry and R&D organizations in all phases as well as support for rapid introduction of technology by customized training measures!" Research institutes can play a considerable role here, as IFAM has done for many years.

Wilfried Müller, the Rector of the University of Bremen, then outlined the enormous challenge faced by his university to provide follow-up training to experienced people. "For the technical colleges the link between research and training has promise", said Müller. The reason for this is not least because knowledge is becoming outdated ever more quickly as time goes by – and this has never been more the case than for today's graduates. "The old approach of carrying out further training at the workplace no longer suffices in today's world", according to

Prof. Dr.-Ing. Jürgen Klenner
(Manager of CoC-Structure at Airbus Engineering, Toulouse)

Müller. "The universities must also do something for their graduates beyond the end of their courses. That matter has been addressed in the technical colleges for about 10 years now."

Even the student selection phase nowadays takes into account not only the research potential of students but also their ability to communicate their knowledge. The university rector expects there to be sustained growth in science education as a result of the enormous number of bachelor and masters courses that are now available. "The modular design of these courses should allow us to deliver complete knowledge packages for training of practical relevance. With adult-orientated didactics and scheduling considerations – I am thinking here of evening courses and weekend courses – we must pass on the knowledge from research to where it is needed." With further bachelor and masters courses to be offered over the coming years the university will "radically change". This will even further improve the opportunities for follow-up training in science. We are cooperating to an increasing degree here with professional associations, industrial associations and professional training bodies.

In her talk Dr. Jutta Sywottek, Senator for Education and Science of the *Land* Bremen, recalled the position of the Science Council in 1998: "It was clear back then that the first course of study taken by a person was no longer effective for the whole of a person's career. Today, continuous, career-relevant follow-up training is absolutely vital." In its Science Plan 2010, the *Land* Bremen puts great emphasis on follow-up training and is striving,

Prof. Dr. Wilfried Müller
(Rector of the University of Bremen)

Dr. Jutta Sywottek
(Senator for Education and Science, Bremen)

The tour around the institute.

via contacts with technical colleges and research organizations, to expand the follow-up training courses that are offered. According to Dr. Sywottek: "The benefits of follow-up training are also benefits for those who provide the follow-up training, because practical issues are brought close to research and development." Nevertheless, the value of follow-up training is not as highly appreciated by scientists as is desirable. Dr. Sywottek commented that it would be possible for IFAM to develop courses for follow-up training in conjunction with the University of Bremen.

That the Fraunhofer IFAM is investing in follow-up training became clear from a tour around the institute. The new IFAM Training Center in the extension building was especially praised. Also recognized was the expertise of IFAM employees and the excellent facilities and equipment which play a key role for carrying out joint R&D projects with industry.

The day was rounded off with an event in the Bremen Ratskeller at which Professor Matthias Busse, Director of the "Shaping and Functional Materials" department at IFAM welcomed the guests. A special honour was presented with Professor Dr. Eckard Macherauch, the long-standing chairman of the IFAM committee, being awarded the Fraunhofer Medal.

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 organization 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 is generated through contract research. Roughly two thirds of the Fraunhofer-Gesellschaft's contract research revenue is 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 recognized non-profit organization. Its members include well-known companies and private patrons who help to shape the Fraunhofer-Gesellschaft's research policy and strategic development.

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

The Fraunhofer Alliance for Materials and Components

Materials Research in the Fraunhofer-Gesellschaft involves the whole value-creation chain from the development of new and improved materials via manufacturing technology on a near-production scale and the characterization of material properties right through to evaluating the use of materials in components and systems.

The Alliance

The Fraunhofer Alliance for Materials and Components comprises eleven Fraunhofer institutes that are largely orientated towards materials science. The spectrum of current R&D work that is undertaken ranges from machine construction, production technology, transport technology, construction technology and energy and environmental technology via microelectronics and optics right through to medical engineering. The Alliance hence comprises the entire Fraunhofer know-how for the whole technological chain, starting from materials development at a molecular level right through to the prototype of a component. Modern numerical simulation methods aid and accelerate the experimental work. Innovative techniques for non-destructive testing of materials and testing the engineering strength of materials increase the reliability of materials, components and systems.

An important objective is also to externally promote the collaborative nature of the work of the Fraunhofer-Gesellschaft, beyond the borders of the alliance's immediate interests. For example, this year a joint policy paper from the whole Fraunhofer-Gesellschaft was prepared on the topic of materials research for the German Federal Ministry for Education and Research. In particular, the information and communication technology of the Fraunhofer Alliance allows good contacts to be made. For example, the Fraunhofer ITWM has become a permanent guest member of the Fraunhofer Alliance for Materials and Components.

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Fraunhofer Alliance for Polymer Surfaces (POLO)

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

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

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Members

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

Fraunhofer Alliance for Nanotechnology

The topic of nanotechnology covers a broad spectrum of new widely used technologies involving materials, components and systems whose function and application are based on the special properties associated with nanoscale orders of magnitude (< 100 nm). Nanotechnology is a regular part of everyday life: For example, nanoparticles are present in sun creams to protect the skin against UV rays. They also strengthen car tyres and give rise to easy-maintenance and scratch-proof surfaces. The technology is already used throughout industry in a host of different applications.

Within the Fraunhofer-Gesellschaft, more than 20 institutes are actively working this area. The broad range of expertise and large number of ideas for development were assimilated, evaluated and focussed prior to the founding of the Fraunhofer Alliance for Nanotechnology. The activities of the alliance are concentrated in two main areas: Multifunctional films in car technology and the design of special nanoparticles as support materials for biotechnology and medicine.

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Fraunhofer Alliance for Numerical Simulation

IThe Fraunhofer Alliance for Numerical Simulation of products and processes is an alliance of sixteen Franhofer institutes which brings together their expertise in the development and improvement of simulation methods. The simulation of products and processes plays a key role today in all phases of the life cycle of a product, from modelling-aided material development and simulation of the production process right through to its operating properties and positioning of the product in the marketplace.

The objective of the alliance is to take on cross-institute tasks and to represent the interests of the member institutes as a contact partner for public and industrial customers. The combining of the expertise in the ICT area with material and component know-how and surface and production technology promises innovative results.

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Department of Adhesive Bonding Technology and Surfaces

Results Applications Perspectives

Expertise and know-how

The Department of Adhesive Bonding Technology and Surfaces of the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) is the largest independent research group in Europe working in the area of industrial bonding technology. Over 120 employees are actively engaged in research and development work in this field. Their objective is to generate application-orientated bonding technology solutions for industry. Multifunctional products, lightweight structures and miniaturisation – achieved by combining materials in an intelligent way – are creating new opportunities. IFAM is a specialist in bringing such opportunities to realisation. The scope of the work of the institute extends from fundamental research via production right through to the market introduction of new products. The industrial application fields are chiefly plant and vehicle manufacture, microproduction and in the packaging, textile and electrical industries.

The Adhesive Bonding Technology business field is primarily concerned with the development and characterization of adhesives, the design of bonded joints and their realisation and qualification. A further main area of focus is certified training courses in adhesive bonding technology because timely and effective training of staff is becoming ever more important for technology transfer. The Surfaces business field is split into the sub-areas Plasma Technology and Paint/Lacquer Technology. These areas are concerned with pretreating the surfaces of materials to give them additional properties, so making them suitable for new applications. One area of work which extends to both these business fields is Surface and Interface Science. The fundamental knowledge acquired here guarantees the reliability of bonded joints and coatings.

The Adhesive Bonding Technology and Surfaces department is certified in accordance with DIN EN ISO 9001 and the material testing laboratory is certified in accordance with DIN EN ISO 9001 and accredited in accordance with DIN EN ISO/IEC 17025. The Center for Adhesive Bonding Technology is recognized in accordance with DIN EN 45013 as an approved organization for providing certified training in bonding technology.

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 an 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:

Fig. (opposite): Flammability test on nanocomposites.

- 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 aging and degradation processes in composite/laminate materials
- Electrochemical analysis
- Evaluation and development of new corrosion protection systems.

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Adhesives and polymer chemistry

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Protein-based materials

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Application technology

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Manufacturing technology

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Bonding in micro-production

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Materials and construction methods

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Technology transfer and training

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Low pressure plasma technology

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Atmospheric pressure plasma technology

Surface modification and functional layers for in-line applications.
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Paint/lacquer technology

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Applied surface and layer analysis

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Molecular modelling

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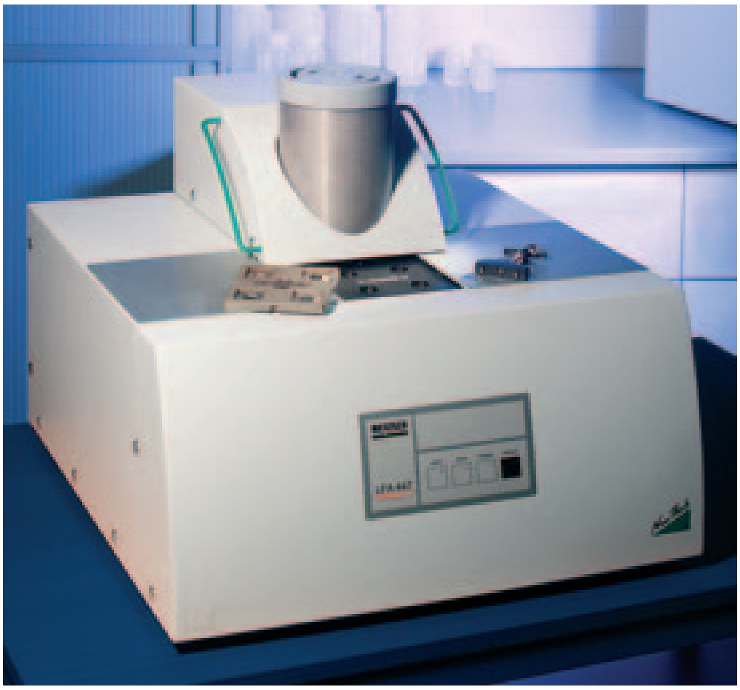
Equipment/facilities

Department of Adhesive Bonding Technology and Surfaces

- 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
- Gas fluorination unit
- 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
- Atomic force microscope (AFM)
- Surface analysis systems and polymer analysis using ESCA, UPS, TOF-SIMS and AES
- Chromatography (GC-MS, pyr-GC-MS, thermal desorption, HPLC, GPC)
- 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
- Small-scale pilot plant for organic syntheses
- IR and Raman spectrometers
- Rheology (Rheolyst AR 1000 N, ARES – Advanced Rheometric Expansion System)
- Equipment for measuring heat conductivity
- Dielectrometer
- Electrochemical Impedance Spectroscopy (EIS)
- Electrochemical 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
- sgi Origin 3400
- Linux PC system with 32 CPUs
- Spectroscopic ellipsometer
- Wave Scan DOI
- Colour measurement unit MA 68 II
- Laboratory dissolver
- Haze Gloss
- Units for applying sealants
- Automatic paint application equipment
- Paint drying unit with moisture-free air
- Fully conditioned spraying booth
- Scanning Kelvin probe
- 6-axle industrial robot, 125 kg bearing load, on additional linear axis, 3000 mm
- 1-C piston dosing system SCA SYS 3000/Sys 300 Air
- 1-C/2-C geared dosing system t-s-i, can be adapted to eccentric screw pumps
- Material feed from 320 ml Euro-cartridge up to 200 litre drums, can optionally be combined with the t-s-i dosing system
- 2-C mini dosing unit for automatic processing using 50 ml double cartridges (own development)
- PUR hot-melt dosing unit for either bead or swirl application from 320 ml Euro-cartridges (own development)



Instrument for measuring heat conductivity.

Industrial robot with 1-C piston dosing system.

Automatic paint/lacquer application unit.

Technology Broker: Closer collaboration with industry and institutes pays off

Everybody is talking about technology transfer – but what is the most efficient way of achieving this? This is a question we asked ourselves in Bremen a few years ago. In institutes such as the Fraunhofer IFAM there is enormous expertise and in the Bremen area there are a host of large companies involved in for example aircraft manufacture, car manufacture, shipbuilding and wind energy. Such companies want relevant research and development results to be implemented into their production as quickly as possible in order to maintain their global competitiveness. Over recent years these two sides have become closer due to establishment of the Technology Broker. A key role has been played here by the Bonding Technology and Surfaces department at the Fraunhofer IFAM. Following the success of a "prototype" technology broker – the TBB Technology Broker Bremen – which achieved very positive results in its collaborative work with Airbus, the idea of an on-site "broker team" involving technical experts from industry and commerce is now gaining a foothold in other areas.

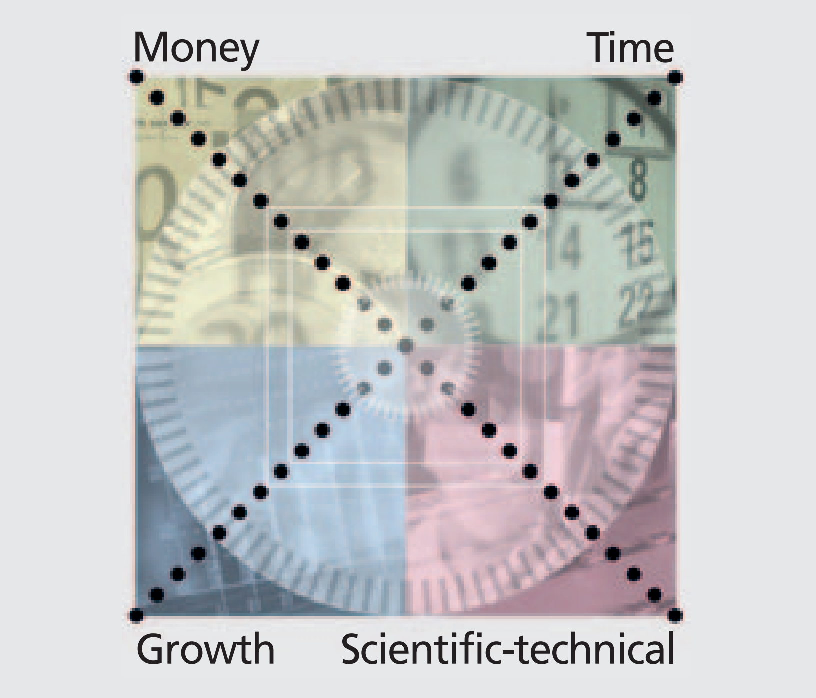


Fig. 1: The Technology Broker organizes a round table for companies, R&D establishments, funding bodies and service providers in order to carry out development work in an optimal way for customers, taking into account financial, time, commercial and scientific-technical considerations.

The Technology Broker Bremen (TBB) has been in existence since 1999. At that time this involved collaboration between IFAM and the Bremen Institute for Applied Beam Technology (BIAS) and the Stiftung Institut für Werkstofftechnik (IWT). The primary goal of the TBB was to create a network for the Airbus development work as one of the strategic components of a supportive measure known as Airbus Material and System Technology (AMST). Against the background of a reorganization of the European aircraft manufacturer, the particular aim of AMST was to link the scientific know-how present in public organizations in Bremen in the area of materials and processes more closely to Airbus and to customize further development work to the needs of the aircraft manufacturing industry. It was the technical focus of AMST which enabled the Airbus Works in Bremen to assume overall responsibility for these company development areas and so maintain their competitiveness within the Airbus organization to the present day.

The on-site TBB team at Airbus was able to get the key people from industry and science around the same table. Ultimately, even a company as renowned as Airbus cannot carry out all their development work alone. Companies, funding bodies and R&D institutes then organized who was to do what and how the know-how of different areas can be brought together to get an optimal solution. The service package must also include thorough project planning.

36 new positions at the institute – thanks to AMST

The transfer of external knowledge that was initiated by this approach has over recent years benefited Airbus and other renowned companies in Bremen, and has also benefited IFAM. All participants have profited and also Bremen itself – for example jobs have been created, often for highly qualified specialists. Now the AMST program has finished, Airbus has 669 more employees than in 1997. The Bonding Technology department at IFAM has also grown as a

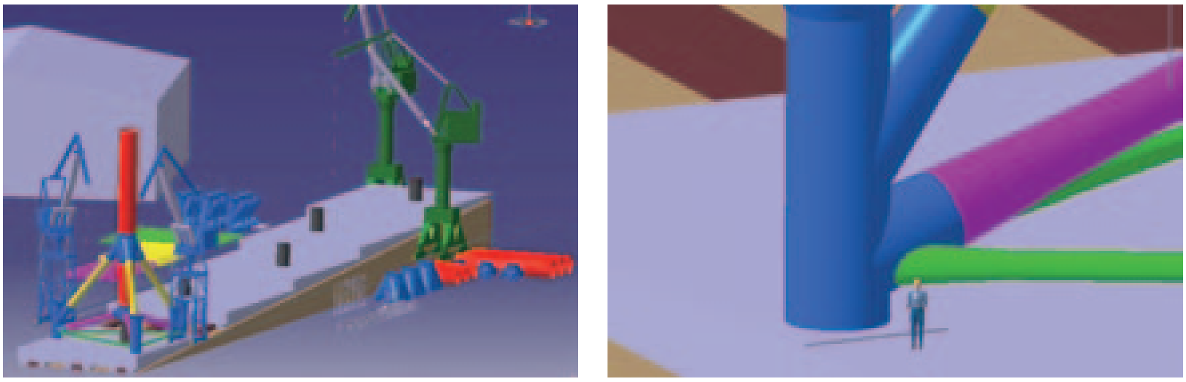


Fig. 2: Virtual planning of the junction and pipe section assembly for heavy steel foundations for offshore wind farms. The figure on the left shows the so-called TRIPOD structures of up to 40 m height that are assembled using cranes. For size comparison, the figure on the right shows a so-called pile sleeve of a foundation and an adult person. In order to determine the target section geometries, their best fits and any subsequent work required for the assembly, a system was developed for aircraft construction with virtual fit analysis.

result of the TBB activities: As a direct and indirect result of AMST, 36 new positions have been created. From the outset the intention was to safeguard the fields of expertise that were exploited with the TBB for the future, namely beyond the lifetime of the AMST programme, and to transfer the results to other areas. As such, the positive effects of AMST will be felt for years to come.

As a result of this approach, there have been bilateral projects between the institute and the aircraft manufacturer. Now the AMST has ended, the desire of the partners is to continue collaboration for the long term as part of a network. These projects involve surface technology, polymer technology, bonding technology and mechanical joining methods.

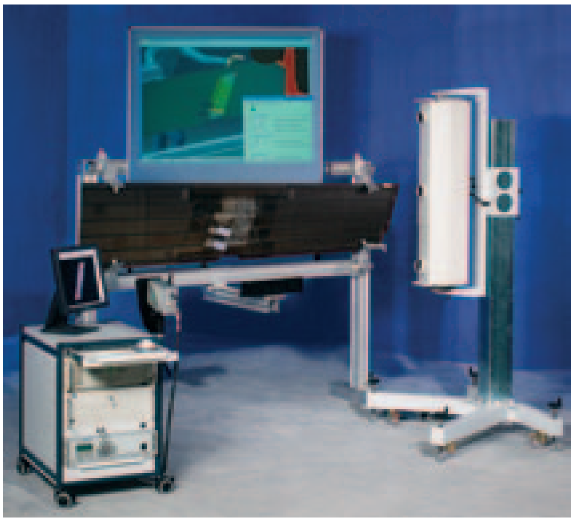


Fig. 3: Fit analysis for high-lift devices.

Virtual methods for automatic bonding

An area where there is very close collaboration between Airbus and the institute is Production Technology and Planning, in particular for structural bonding. As part of AMST, extensive expertise in the automated bonding of high-lift devices was built up at IFAM. This covered the optical determination of component geometries (with BIAS), the development of comprehensive data management systems (with BIBA) and the virtual joining of components. Complemented by the Center for Automated Bonding at IFAM, these AMST developments have in the meantime awakened much interest amongst suppliers to Airbus. This area of application can be expanded to vertical tails (produced by Airbus in Stade) or to wings (manufactured in the UK). The Technology Broker is also concerned with the transfer of this expertise into other sectors of industry. For example, collaborative work is currently being carried out with a company in Bremerhaven for the design of a workplace for Tripod foundation structures – the "feet" of offshore wind turbines. Also in this sector of industry there is the simulation-aided development of a workplace for the manufacture of five megawatt gondolas, the "tops" of offshore wind turbines, in conjunction with the Fraunhofer IFF.

Permanent, dry release layers by plasma coating

Over recent years the plasma technology and surfaces groups at IFAM have carried out work in three areas as part of the AMST "Functional surfaces" project. The anti-soiling, "easy-to-clean" surface was patented. It is being used as a PermaClean^{PLAS} coating for components and painting booths/lines at DaimlerChrysler; marketing of this application by a small or medium-sized company is planned – it is already used by licensed partners as a Best Skin^{PLAS} coating for components in baking businesses. Another patent is being drawn up for a permanent, dry release layer via plasma coating. This is applied to metal moulds in a vacuum chamber. CFRP components are manufactured in the moulds. With the help of the Airbus subsidiary Composite Technology Center (CTC) in Stade this process has already been successfully tested and it is now being validated for permanent use. In a follow-up project now being carried out, atmospheric pressure processes are being developed for coating very large moulds for CFRP components. The release layers can now be transferred to other sectors of industry: they can for example be used for rotor production for wind turbines and as release layers for moulded metallic components for the supply sector to the car industry. Within AMST, a low-drag surface for aircraft was developed and patented, and the aim is now to prepare this for application. Work on transferring this to rotor blades is also underway, in collaboration with companies in Bremen.

Environmentally friendly paint and lacquer systems and polymers for aircraft

Another highly successful joint project between IFAM (Adhesive Bonding Technology and Surfaces department) and Airbus in the area of surfaces was the project on environmentally friendly lacquer/paint technology for aircraft. The results were immediately utilised with the introduction of first-generation chromate-free surface protection systems and will in the future be used for the new Airbus A380. Further work on fundamental knowledge, weight reduction and cost reduction is continuing in a joint EU project "LiSA" involving the Technology Broker, the Fraunhofer IFAM and Airbus.

The AMST project "Materials development – flame-proof design of thermosets and thermoplastics" has enabled in-depth know-how to be acquired over recent years in the manufacture of fire-proof polymers. The focus of the work was on the use of nano-particles to create fire-proof properties and their combination with conventional fire-retardants. As well as discovering nano-fillers with fire-retarding properties, fire-promoting particles were also found. It was discovered that nano-fillers can function as thermal stabilisers and also as curing initiators or accelerators. This research enabled extensive expertise with chemical nano-technology to be built up at IFAM, and IFAM is now one of the leading centers in Germany in this area of technology. The knowledge can be put to use for a wide range of applications, both in aircraft manufacturing and in other sectors of industry.

IFAM extends strategic cooperation

IFAM is expanding its strategic cooperation to other sectors of industry following the positive experience with the Technology Broker "prototype" (TBB) and the collaboration with Airbus, BIAS and IWT. This on the one hand involves expansion into other sectors of industry and on the other hand involves collaboration with other research organizations inside and outside the Fraunhofer-Gesellschaft. This diversification – in particular involving small and medium-sized companies – is resulting in a constant stream of new contacts, new areas of application and new matters to address. The resulting multiplier effect with regard to the development opportunities and synergistic effects is bringing new returns for all involved.

IFAM is forming partnerships with public organizations in order to augment the joint work being carried out with our industrial partners. For example, BIAS has expertise in laser-aided and optical technologies and IWT has expertise in metallic materials. The Fraunhofer IFF in Magdeburg complements the IFAM (Manufacturing Technology) in the area of production and plant planning and the Fraunhofer IZFP in Saarbrücken has expertise in non-destructive test methods for materials and joints. The Fraunhofer LBF in Darmstadt carries out industrial reliability analysis for large complex components and plants.

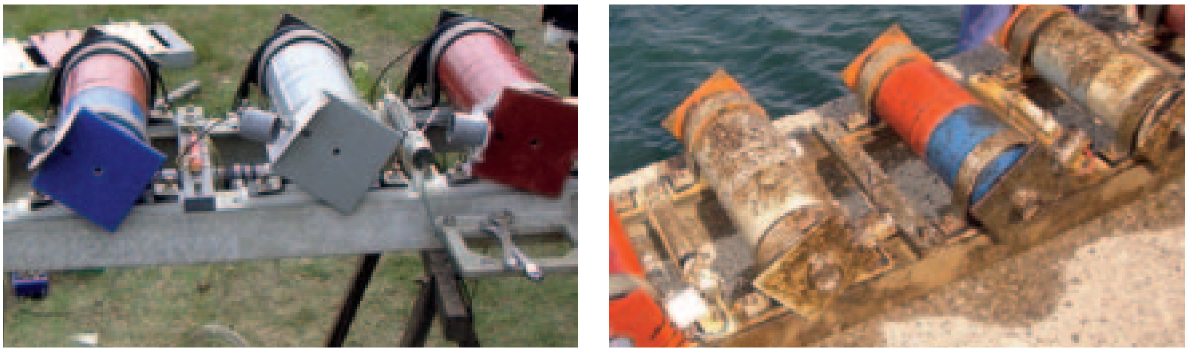


Fig. 4: Practical evaluation of new corrosion protection systems for offshore steel structures. The left figure shows test samples with different coating systems and structural elements prior to exposure to the North Sea at Helgoland. The right figure shows the same samples after 30 months exposure. Except for the left test sample, all samples show clear evidence of corrosion.

IFAM is also a member of the CFK-Valley Stade e.V. This alliance develops processing chains for large fibre-reinforced composite structures used for vehicle construction. Other partners in the alliance include Airbus (Stade Works), the German Center for Aircraft and Aerospace DLR, CTC GmbH (an Airbus subsidiary), the Fraunhofer LBF, Saertex and Hexel as well as other public organizations and private companies. The establishment of small and medium-sized supply companies and development partners is promoted.

The institute is following a similar strategic approach in the wind energy sector. For example, IFAM represents materials and surfaces at the research and coordination center for wind energy at the Technical College of Bremerhaven. There is close collaboration with Bremerhaven GmbH on joint development work on offshore wind turbines. This is being carried out in conjunction with the Fraunhofer IFF and Fraunhofer LBF as well as other companies. The key objectives of the joint projects are to make the turbines more efficient and reliable and to construct competitive production structures. The technical areas concern heavy offshore foundation structures of up to 800 tonnes (primarily in conjunction with WeserWind GmbH), lightweight machine housings (with Multibrid GmbH) and rotor blades.

These activities in Bremen, Stade and Bremerhaven mean that IFAM possesses an extremely effective local network of contacts and partners, comprising large, medium and small companies and public R&D establishments. Over the coming years it will be vital to intensify that collaboration and to link the activities in Bremen, Stade and Bremerhaven more closely. For example, the TBB will work more closely with the research and coordination center for wind energy at the Technical College of Bremerhaven. The collaboration between IFAM/LBF on the technical efficiency/reliability will in turn bring synergies in the area of CFRP structures – in Stade for aircraft components and in Bremerhaven for rotor blades.

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Application of nanocomposites in adhesive bonding technology

Bonding and nanocomposites – synergism

The success of bonding, coating and all process of surface technology is largely determined by the control of adhesion. This involves processes of interaction between the adhesive and the substrate, namely processes which take place in a thickness of just a few nanometres. Current knowledge indicates that even the aforementioned traditional areas of work of IFAM are deeply associated with nanotechnology. Indeed, IFAM started working on nanocomposites way back in 1997 – a long time before nanotechnology became a fashionable area for research.

In adhesive bonding technology, good interaction between the substrate and adhesive is a necessary prerequisite for producing a high-quality bonded joint. Correspondingly good interaction is also a requirement for the manufacture of nanocomposites: An optimum interaction between the particle surface and polymer is indispensable for forming nanocomposites and utilising the associated special effects. Conventional research in bonding technology and the preparation and application of nanocomposites are hence synergistic fields of work. The use of nanocomposites as adhesives, cast resins or coatings also allows many new fields of application to be opened up.

When preparing nanocomposites there is always a risk of the individual particles agglomerating or aggregating. When this occurs the interaction between the particles is stronger than the interaction between the particles and the binder. Such a composite therefore contains microparticles which, although having nanostuctures, do not provide the specific benefits of nanoparticles. Creating the required affinity between the particles and the binder is only possible by customising the interfaces between the two materials. Usually this is achieved by chemically treating the surface of the particles. In order to achieve an adequately rapid nanoscopic distribution, an input of energy is also required, usually in the form of mixing technology optimized for the specific application. In addition to understanding the interactions at the interface, the key to preparing good nanocomposites is hence selection and control of suitable process technology.

By modifying resin systems with nanoparticles a whole range of properties can be improved. In some cases it is possible to optimize material parameters which normally counteract one another in conventional formulations. An example is the simultaneous improvement of strength and toughness. Other properties which can be achieved with nanoparticles are, for example, scratch-resistance and wear-resistance or a decrease in the permeability, e.g. to improve the resistance to hot-wet-conditions and the resistance to solvents. It is also possible to lower the combustibility or – by using nanoparticles that can be excited by high frequency radiation – it is possible to produce bonded joints that can be rapidly cured and debonded. Other fields of application of nanocomposites are to reduce shrinkage on curing, to lower the coefficient of thermal expansion, to produce medical adhesives with high x-ray contrast, to manufacture trans-

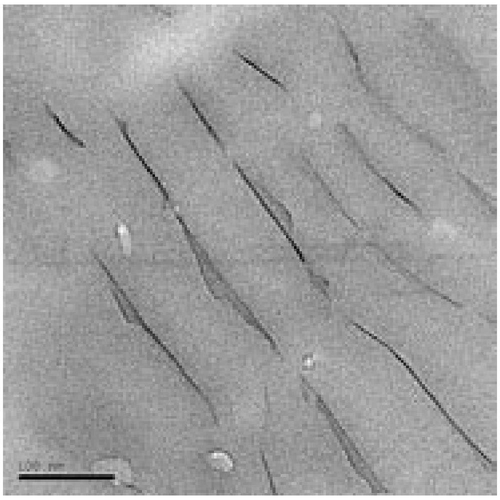

Fig. 1: Homogeneously distributed organo-bentonite in an epoxy resin as an example of a nanocomposite with exfoliated layered nanofiller.

parent electrically conductive lacquers, to customize the refractive index and to produce materials with hygienic surfaces due to the presence of silver-containing nanoparticles. A number of selected examples from this broad range of applications will now be discussed in greater detail.

Nanocomposites with globular particles

Fumed silica consists of aggregates and agglomerates of nanoparticles of different primary particle size. Fumed silica has long been used in adhesives because of its thixotropic properties. When present in quantities of just a few percent there is significant thickening. Using a suitable combination of process technology and surface modification it has been possible to counteract the mutual interaction between the particles themselves. This has allowed filler levels of up to about 50 wt. % to be used in organic binders. Nanocomposites produced in this way are a good alternative to sol-gel materials: They can be more easily adapted to different binders, are more cost-effective to manufacture and are simpler to process. These composites are applicable for coatings with significantly lower abrasion as well as for the preparation of dental materials with improved mechanical properties and chip-underfill with reduced shrinkage on curing. In addition the solvent uptake and solvent resistance were also considerably improved. The strength of bonded joints can be considerably increased or decreased with even small amounts of nanocomposites, depending on the particular surface modification of the particles. Such materials – also with other types of fillers – have a wide range of potential applications and these include the automotive industry, electronics and food products.

Fig. 2: Flammability test on nanocomposites.

Rapid curing and debonding

The curing speed of a bonded joint is often the rate-limiting step in a production process. There is also often the desire to be able to debond the joint at a later stage. This is particularly so for carrying out repairs, for recycling and for bonds which are merely used during production for positioning a component. Work is being carried out with Degussa on adhesives with superparamagnetic particles. These are nanoscale iron oxide particles, embedded in nanoparticles of silica. These particles – and hence the polymers containing these particles – can be heated using a high-frequency alternating field. Although this is a completely new application area, the necessary equipment is already widely used in industry for the surface-hardening of metals.

When bonding with nanocomposite adhesives, it is now possible to heat the adhesive and leave the substrates largely unperturbed. As metals also heat up in an alternating field, this technology is most suitable for non-metallic substrates. For example, it has been possible to develop a one-component adhesive with excitable particles which is stable at room temperature for at least a few months. This adhesive bonds to many different substrates and high frequency induced curing takes from only a few seconds to several minutes depending to the applied power. With this adhesive it was even possible to bond heat-sensitive thermoplastics to be bonded without any heat damage. The use of one-component adhesives is usually not possible for such applications due to the thermal sensitivity of the thermoplastics. The resulting bonded joints can be debonded by application of the high frequency field for a longer time or by choosing a higher power. In this way poly(carbonate) could be adhesively bonded as well as poly(styrene) handles to glass coffee pots.

Bentonites as curing initiators and fire-retardants

Layered silicates (usually bentonites) modified with organic compounds are often used to improve the mechanical properties of polymers. It is, for example, possible to prepare nanocomposites with increased strength, without a loss of toughness. It is also possible to increase the fracture strength. The glass transition temperature also often increases and hence in many cases the maximum temperature of application of the materials. In addition, suitably selected and treated bentonites can be used to decrease the permeability. They are therefore ideal additives for packaging adhesives to improve the resistance of bonded joints to moisture, heat and solvents. It was also demonstrated that organically modified bentonites have a big influence on the curing of epoxy resins. In classical addition-curing, they can be used as accelerators. They are also able to act as curing initiators. It has been known for years that the presence of organo-bentonites at an adequately high temperature leads to the self polymerisation of epoxides. This produces “popcorn-like” polymer particles for which no use has been found up until now. By altering the process technology used for the surface modification and processing it was possible to cure the epoxy resins receiving homogeneous and strong polymers. As such these are suitable for bonding and casting.

When using bentonites as fire-retardants there is, in addition to the barrier effect, often also a catalytic effect at play. In the case of epoxy-based elastomers, the onset of decomposition measured by TGA was increased from about 150°C to 320°C by adding the nanofillers. Simultaneously the fire propagation rate (horizontal burner test) and the peak heat release rate (cone calorimetry) decrease. Bentonites are usually not suitable as the sole fire retardant. In many cases a synergistic effect has been demonstrated with conventional fire retardants. Namely: In order to achieve equivalent or better fire-retarding properties the required amount of fire retardant plus organo-bentonite was lower than for sole use of classic fire retardants.

Fig. 3: Modified layer silicates as curing initiators for epoxy resins. Left: conventional processing technology; right: customized processing technology resulting in a homogenously cured polymer.

Analysis of nanocomposites

For the systematic development of nanocomposites, in-depth instrumental analysis of the composites is necessary in addition to application-related characterization. This concerns measurement of the particle size distribution (IFAM developed a new light scattering method for this) and analysis of the particle distribution and structures using high resolution electron microscopy. Regarding the latter, transmission electron microscopy plays a special role because not only the structures and particle distributions can be characterized but in addition laterally resolved elemental analysis is possible with resolution down to the nanometre range. There are also various methods of surface analysis and IR spectroscopy which allow, for example, the nature of the bonding of the particles to the polymer matrix to be determined. Using VCD spectroscopy – a special form of IR spectroscopy – one is even in a position to investigate conformation changes of the molecules caused by interactions with particle surfaces. This method is especially helpful in nanotechnology, for example for developing adhesives as found in nature or for developing protein chips.

A further tool is molecular modelling. The interactions at surfaces and reaction mechanisms can both be investigated in detail. Molecular modelling is also used for calculating spectra. This aids interpretation and allows comparison between real spectra and spectra based on theoretical molecular considerations. This is especially useful if the analysed substances cannot be isolated – for example adhesively interacting compounds at an interface. The overall analysis is however only as good as the extent to which the results can be correlated with the application properties of the prepared materials and composite materials. This provides a basis for further optimization work.

Fig. 4: Light scattering unit developed for measuring the particle size distribution.

Summary

The use of nano-fillers gives rise to many interesting properties. A prerequisite for successful preparation of nanocomposites is a suitable combination of chemistry and process technology. Nano-fillers are certainly not "magic powders" which – as often maintained – can be used to solve all problems. Moreover, the defined property profile of a new material must be carefully tested to check whether the goal can be reached using nano-fillers, and if yes then with which nano-fillers. For the subsequent experimental development work and later industrial implementation, in-depth knowledge of the chemistry and process technology are necessary in order to actually utilise the nanoscopic properties in the new product. Success is not achieved by merely mixing some powder in some way into the product.

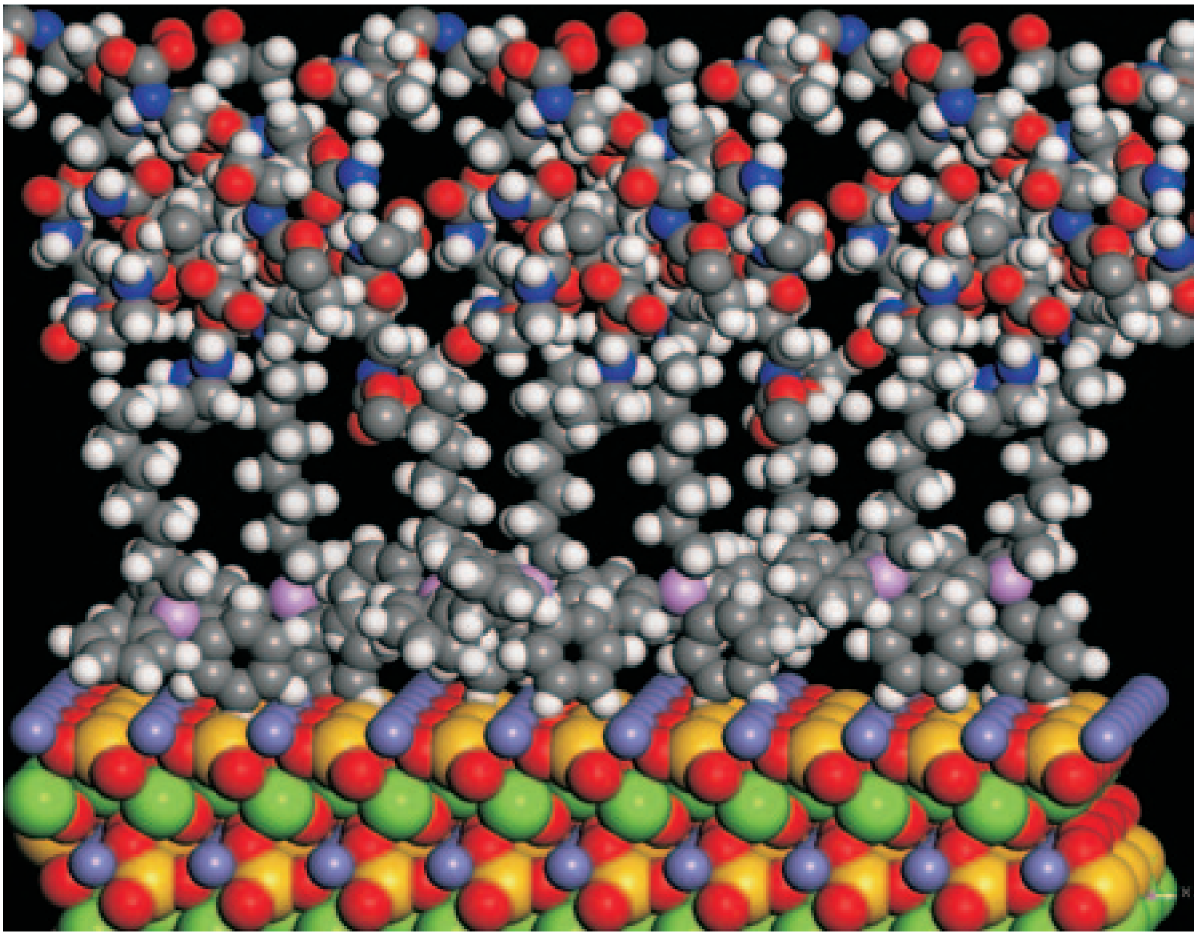

Fig. 5: Molecular model of the interphase between a resin matrix and bentonite particles.

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Simulation:
computer-aided design and evaluation of bonded joints

Over recent years, bonding technology has become a key technology in many sectors of industry and has paved the way for new means of construction. In vehicle and plant technology, bonding allows hybrid construction methods to be used and brings considerable additional benefits for the products – for example due to the adhesive functioning as a corrosion inhibitor, insulation material, sealant, electrical conductor, etc. Bonding technology nowadays allows products to be manufactured on a modular basis, enabling the individual components to be manufactured virtually anywhere in the world. The time factor also plays a role for optimized and favourable-cost manufacturing. A shorter product development phase reduces the time up to market introduction and this saves money and increases competitiveness. For these reasons, numerical simulation is becoming an increasingly valued tool. In the materials and construction methods work group at IFAM, new methods and more powerful computers have resulted in the computer-aided design and evaluation of bonded joints becoming an indispensable part of the institute's facilities and services.

No other technology is quite like bonding technology when it comes to the interdisciplinary nature of the work. The Fraunhofer IFAM is in an excellent position here with its expertise in adhesive chemistry, surface physics, application technology, manufacturing technology and materials and construction methods. The totality of this expertise means that the Department of Adhesive Bonding Technology and Surfaces at IFAM has the necessary know-how to develop bonded joints having long-term stability. Computer-aided design of bonded joints has become an important part of the IFAM portfolio. It allows the evaluation of different constructional and bond variants from quality, reliability and safety viewpoints, without such bonds having to actually exist. However, a lot of preliminary work and experiments have to be undertaken in order to determine the relevant key parameters for the models.

The numerical calculation and design of bonded structures has to take into account features that are typical of bonds. In a structure, the bond seam is generally very thin but very long. The thickness of the adhesive film is between 0.1 mm and a few millimetres. The length depends on the dimensions of the structures to be bonded. In addition, from a physical material point of view the adhesive has either hyperelastic, rubber-like properties or is elastic-plastic (thermoset or thermoplastic material) with time-dependent or viscous properties.

In the materials and construction methods work group the simulations mainly involve determining the expected mechanical properties of materials and joints. Parameters such as temperature, humidity, cleaning agents and environmental effects must be taken into account as must the material parameters, the load distribution for a specific application, ambient conditions and many other factors. The factors laid down in the customer's specifications describe the entire life cycle of the product and are required for the simulation.

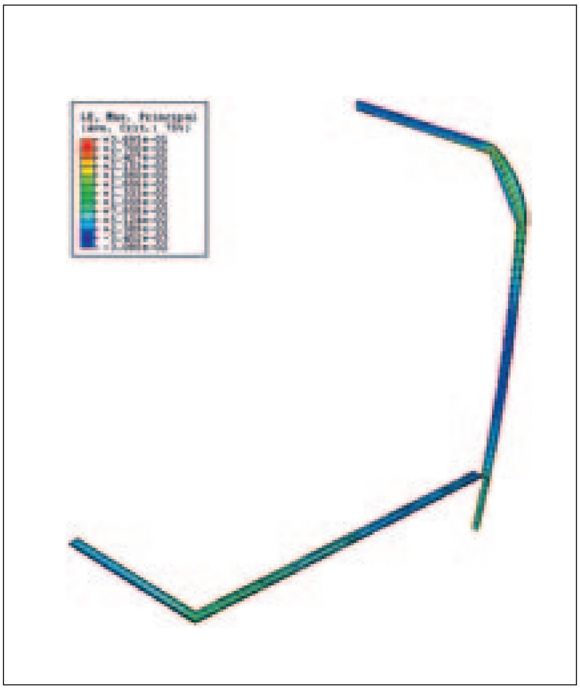

Fig. 1: Example of a long, thin adhesive film in rail vehicle construction.

Fig. 2: Model of the front module bonded onto the railcar.

An example: In rail vehicle construction, the front module of a railcar is to be bonded. The simulation of the state of the bond under different conditions requires all data in the requirement profile to be determined and must also take into account regulations of the Eisenbahnbundesamt (German Railway Board) and also geometries, CAD data, etc. For simulating the properties of the adhesive and materials to be used, data are also obtained from preliminary experiments either at the customer or at IFAM. This can be data from lap shear samples, impact peel samples, T-peel samples and KSII samples. All available data ultimately form the basis for a material model that is the mathematical description of the material behaviour under loads.

In many cases, the unbelievable number of different parameters – especially for complex geometries – means that even the modern computers that are used today for modelling are operating near their capacity limit. For that reason, bonded joints are initially simulated using analytical, linear elastic approximations. This serves to give a first estimate of the bond area and the bond design. In general, analytical approaches of suitable accuracy can only be carried out for exposure of bonded joints to purely shear loads. For linear-elastic approaches, a safety factor must also be taken into account, which considers the insufficiencies of the analytical solutions.

For complex bond seams and components, finite element analyses are necessary in order to design a bonded joint suitable for bearing the expected loads. The procedure involves "splitting up" the structure into many elements and then carrying out calculations on these elements individually. When using this method, the splitting up of the bonded joint must take account of the permitted aspect ratio of the finite elements. At the same time, these must be split into elements in several layers – in order for the simulated adhesive film to be sufficiently accurately represented. For adhesive films, which are thin compared to the structure, this means: The entire structure must either be split up into very many small elements, which in general causes the computing capacity to be exceeded, or there must be greater human input in order to increase the number of elements in the vicinity of the bonded joint in the geometric model.

There is however an alternative approach being worked on at IFAM involving an efficient pre-processing and post-processing concept for simulating bonded joints. The problem is being solved by globally modelling a structure that is coarsely split, and then carrying out local analyses on sections of ever greater resolution. Using this procedure the critical areas of the bonded joint are found and evaluated. Another alternative involves representing the joint using self-developed bond elements which only contain the key parameters for the calculation and so only reflect the major aspects of the bonding behaviour. The difficulty here is determining the correct parameters and their magnitudes. In collaboration with industry, the Fraunhofer IFAM has developed and implemented a variety of concepts.

To design a bonded joint requires evaluation of the numerical or analytical computation of the permitted stress and strain. These parameters are determined experimentally, in accordance with the loads in the requirement profile. IFAM possess the necessary analytical equipment and know-how for studying bonded structures. The stress and strain are determined with a conditional probability of survival or probability of failure and these are included in the evaluation of the calculations. In general, alternating, dynamic (crash), quasi-static and relaxing loads/stresses must be considered at near-application temperatures and humidities. The special features of bonding on painted/lacquered surfaces and exposure to cleaning agents and process media mean that the design of a bonded joint often has an influence on the overall design.

The design of bonded joints is dependent on a suitable combination of experimental methods and calculation methods if reasoned analysis of stresses and stress limits is to be carried out. One aspect requiring considerable experience of bonded joints is evaluation of the long-term stability. New numerical approaches and methods based on quantum mechanics and molecular dynamics are striving, as part of a multi-scale approach, to increase the number of simulation options, in particular regarding prediction of the expected ageing and degradation mechanisms.

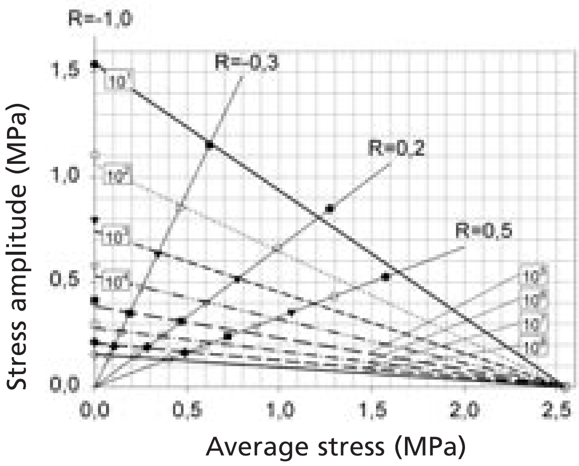

Fig. 4: Fatigue test results (test frequency: 5 Hz) on bonded joints (flexible MS adhesive system and steel substrates). The figure shows the dependence of the stress amplitude for stress ratio R on the average stress. The numbers in boxes show the relevant number of stress cycles to fracture. The relationship between the stress amplitude and average stress is linear for R values between -1.0 and 0.5.

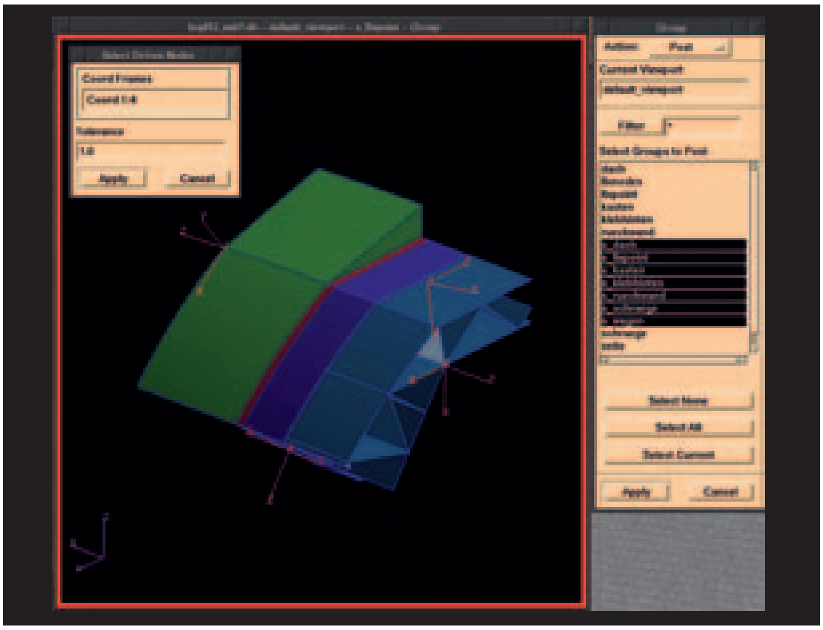

Fig. 3: Pre-processing tool for simulating bonded joints.

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Chromate-free corrosion protection systems: testing and development

Each year in Germany, the damage caused by corrosion amounts to billions of euros. In order to guarantee the long-term stability of components and products, R&D work is being carried out in the area of surface technology to optimize corrosion protection systems – for example using electroplating, organic coatings (primers, lacquers) and other modifications of surfaces and interfaces (anodisation, enamelling, plasma treatment, etc.).

The relevant sectors of industry – such as the galvanising sector and paint/lacquer sector – are of considerable commercial importance in Germany. They provide key technologies for many other areas of industry such as the electric industry and car manufacturing industry. At present, one of the most important challenges in the surface technology area is the search for chromate-free corrosion protection systems. This has been necessitated by new legislative requirements regarding environmental and health protection.

In the near future, coatings and processes that use chromate-containing compounds will no longer be able to be operated as these substances represent a risk to work safety, health and the environment. For example, under the EU End-of-Life Vehicles Directive 2002/86/EG the switchover to chromium (VI) free coatings becomes mandatory on 1 January 2007.

New methods of corrosion testing

Long-established corrosion tests such as the salt-spray test at present appear to be irreplaceable, despite the limited conclusions that can be drawn from the results. More meaningful conclusions from the results of such tests, and also time-savings, can however be achieved – without having to accept undue tightening of the test conditions – by carrying out accompanying electrochemical, surface and structural analyses. The corresponding data allow detailed assessment of a corrosion protection system and the time required for the testing is short. Using surface analysis techniques, for example, changes to the surfaces of components can be detected and characterized long before visible damage can be seen by the naked eye. Valuable development work time can hence be saved and additional information can be acquired about the fundamental mechanisms responsible for the damage. The same applies for electrochemical techniques and indeed development work is currently being undertaken at IFAM on a real time corrosion test based on electrochemical noise measurements.

These tests give information about the first signs of degradation and the active corrosion mechanisms at the material surface. They also provide information about the mechanisms of action of the inhibitors that are for example used for

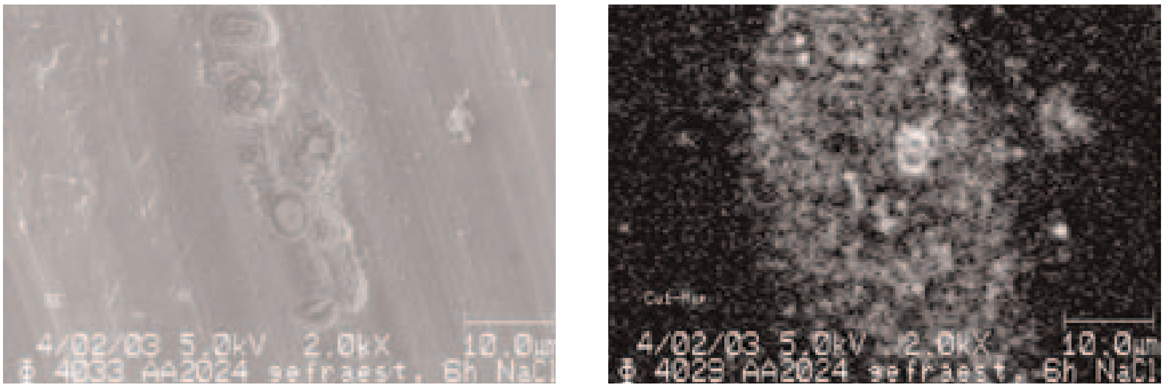

Fig. 1: Early stages of corrosion of a high-strength aluminium alloy (AA2024) as measured by scanning auger microscopy (SAM). Local corrosion is observed after 6 hours exposure to aqueous NaCl solution (3 wt. % NaCl, corresponds approximately to seawater conditions). Left: Secondary electron image of the surface of the aluminium alloy. Right: Cu distribution in this area – copper-rich particles on the surface as a result of dissolution of intermetallic phases in the initial stages of the corrosion process.

active corrosion protection in primers and paint/lacquer systems (see Fig. 1). This information aids the customized development of chromate-free inhibitors.

A new test method has been developed at IFAM to assist the search for suitable inhibitors and so allow development of chromate-free primers, paints and lacquers. It allows the corrosion protection effect of paint/lacquer systems and inhibitors to be tested under practical conditions. The test can be combined with optical microscopy, surface analysis measurements (x-ray photoelectron spectroscopy (XPS)) and electrochemical analyses. It permits both quantitative and qualitative evaluation of the corrosion protection effect of inhibitors and paint/lacquer systems. This new test method, which is already being used by companies in their search for chromate-free inhibitors, allows considerably faster assessment of a system than is the case when solely conventional, empirical test methods are used.

Development of chromate-free inhibitors for primer/paint/lacquer systems

During industrial production processes and during the usage phase of a component, damage to the corrosion protection layers – for example scratches, pores, cut edges and drilled holes, etc. – can never be totally prevented. In situations where high corrosion protection is prescribed, for example in the aircraft manufacturing industry, so-called active corrosion protection must be guaranteed in the event of such damage to the corrosion protection occurring. This provides passivation of the damaged area and actively suppresses the corrosion processes. Inhibitors, added for example to paint/lacquer primers, should carry out this task. Water or liquid electrolytes leach the inhibitor substances out of the primers onto the area where there is mechanical damage. They hence end up on the area of metal that must be protected (see Fig. 2).

Corrosion protection primers containing chromate pigments suppress, for example, the corrosion of coated aluminium sheets having defined scratches for several hundred hours in the salt-spray test.

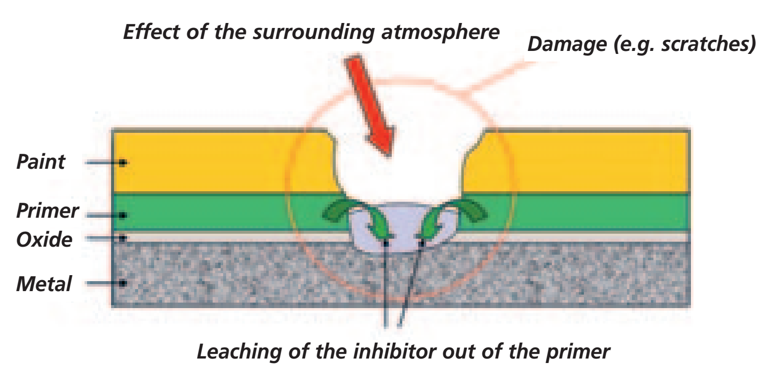

Fig. 2: Schematic representation of a surface protection system for metals: Active corrosion protection is achieved by water (condensation) or liquid electrolytes leaching inhibitor pigments out of the primers onto the area where there is mechanical damage (e.g. scratches, pores, cut edges, etc).

Chromate-free inhibitors based on phosphates, titanates and organic compounds are very promising alternative inhibitors for organic coatings. The intrinsic effectiveness of these alternative materials has been demonstrated using the abovementioned corrosion tests and analytical methods, but without incorporating them into a paint/lacquer matrix. The challenge is now to modify these materials so that they are compatible with the components of the paint/lacquer systems (binders, additives, etc.) and to minimise any adverse effects on the properties of the paint/lacquer (processing properties, adhesion, resistance to different media).

In order to carry out this work, different model primer systems were developed at IFAM in order to test and analyse the fundamental interactions between the components of the primer systems and the inhibitor substances. As part of this work, theoretical simulations of the molecular interactions between individual substances were carried out using molecular modelling methods.

For active corrosion protection, defined amounts of the effective inhibitors should quickly be able to access the damaged metal surface so that they can form a protective layer. IFAM studies have shown that the stabilisation of the natural oxide layer, which is immediately formed if there is damage to a metal surface, plays a key role. This passivating oxide layer must in particular be protected against conversion into a hydroxide layer. Hydroxide layers provide no effective protection to aggressive electrolytes and hence inevitably lead to corrosion (see Fig. 3).

Characterization and development of chromate-free anodisation layers

Anodizing is used to create protective oxide layers on metals, and in particular light metals. Oxide layers are formed due to reaction of the uppermost metal layer and have a thickness of up to 40 µm. They are initially microporous. For many applications, the porous oxides are sealed by a subsequent treatment with hot water, steam or metal salts. Anodizing in chromic acid baths has proved particularly effective for the corrosion protection of aluminium alloys. For the reasons iterated at the start of this article, alternative chromate-free anodizing techniques are currently being sought to meet the needs of the car manufacturing industry and aircraft manufacturing sector.

In addition to providing corrosion protection, the oxide layers which are generated must also provide good long-term adhesion for organic coatings that are applied in the form of paints/lacquers or adhesives. In addition to the chemical properties of the oxide layers, the structure of the oxide layers, namely the porosity, is very important. The pores allow penetration of the adhesive or paint/lacquer into the structure (see Fig. 4) and hence allow

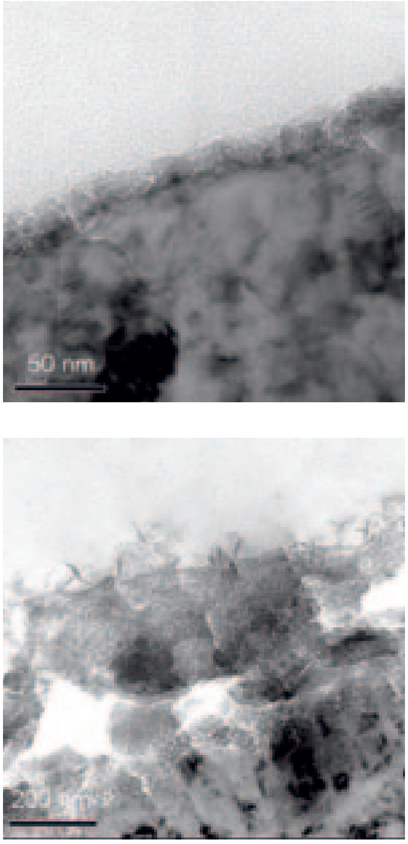

Fig. 3: Hydroxide formation as a result of exposure to corrosive conditions, as studied using transmission electron microscopy (TEM). Above: Initial state with natural oxide layer; below: Hydroxide formation after exposure to aqueous NaCl solution (3 wt. % NaCl). The hydroxide layer provides no effective protection against corrosion.

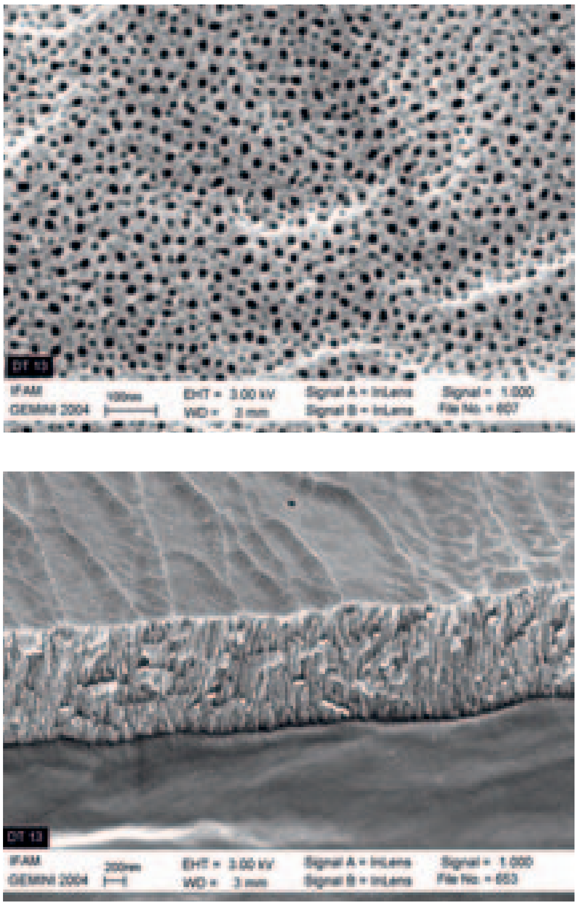

Fig. 4: Scanning electron micrographs of the surface (above) and fractured edge (below) of an anodic layer (PSA anodisation) on a clad aluminium alloy (AA7475).

greater interaction between the oxide and polymer and also enlargement of the active surface for the bonding of the organic molecules.

If the anodised component is subjected to mechanical loads during its use, the effect of anodic layers on the fatigue properties of the coated material also play a key role. Due to the brittleness of the oxides, a growing crack in the oxide layer presents a risk: Due to the possibility of subsequent local crack propagation into the base material, this represents a potential point of fracture for the component. When developing anodic layers, an aim is hence to minimize the inevitably poorer fatigue properties of the component.

Current development work being carried out at IFAM has shown that it is possible to perform non-destructive characterization of the elastic properties of anodic layers using a novel laser-acoustic test method. This method could be used in the future for developing anodic layers and for the quality control of such layers in production processes.

Summary and outlook

Currently one of the most pressing challenges facing surface technology is the search for alternatives to replace chromate-containing processes and materials in applications where strict corrosion protection requirements are prescribed. One strategy being investigated is based on a combination of selected and newly developed test methods involving electrochemical, surface and structural analyses. It allows the corrosion properties and inhibition mechanisms of materials to be characterized and also brings time-savings. This procedure has proved particularly effective in the search for new inhibitors and for the development and evaluation of corresponding chromate-free organic coatings. For detailed analysis of molecular reactions and interactions of the inhibitors, increasing use is being made of theoretical simulations (molecular modelling) – as part of the further development of software tools for materials development.

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Permanent release layers for moulds via plasma polymerisation

Background

In the industrial production of plastic components, and in particular plastics which cure via chemical reaction (e.g. polyurethanes or epoxides), it is necessary to use release agents to reduce the adhesion between the moulding and the mould surface. Only then are mouldings of the highest quality obtained. The mouldings must not only be undamaged but must be able to be easily removed. This is generally carried out before the moulded component has fully cured.

Conventional release agent systems (solutions or dispersions), which are normally sprayed onto the mould surface, consist of release-promoting materials and a carrier medium (generally organic solvents or water). The separating function of such systems always involves a combination of cohesive fracture and adhesive fracture, with release agent remaining on the separated component. This causes many problems for the further processing of the mouldings (lacquering, bonding, laminating). There hence has to be an intermediate cleaning step and for users this means extra costs. In addition, release agents have to be applied to the surface of the mould before each moulding procedure (or at least on a regular basis). This is also costly and can lead to non-uniform results on removal of the mould. A further disadvantage is that these release agent systems emit large quantities of solvents into the environment.

Project

The aim of this project was to develop a permanent release layer which allows even non fully hardened components to be removed from the mould cleanly and without the use of force. Prerequisites were that the surface structure of the component is not impaired and that the layer does not become spent or transferred to the component.

These requirements meant that the separating effect had to be at the interface between the coating and the component.

The coating methods to be employed were low pressure and atmosphere pressure plasma polymerisation. Plasma polymerisation allows structured, nano-scale functional layers (a few tens up to a few hundred nm) to be deposited on any desired substrates and geometries.

Plasma polymerisation

Plasma is a (partially) ionised gas which in addition to neutral gas molecules and gas fragments also contains free electrons and ions. There are also a large number of molecules in excited states. These emit electromagnetic radiation and return to the ground state, and this is the reason for the characteristic luminance of plasma.

By far the most prevalent means of generating plasmas is customized exposure of a volume of gas to electric fields. Depending on the frequency that is used, a distinction is made here between alternating current (50 Hz), audio (kHz), radio (MHz) or microwave (GHz) plasmas. Plasmas are being increasingly used in surface technology, e.g. for precision-cleaning, for activating and for depositing functional layers via plasma polymerisation.

Plasma polymerisation is a process in which gaseous monomers are excited by a plasma and layers, crosslinked to differing extents, are deposited on a desired substrate. A precondition for this process to take place is the presence of atoms that can form chains in the working gas, e.g. carbon, silicon and sulphur. As the monomer molecules in the plasma are largely "broken down" into reactive fragments in the plasma, the chemical structure of the starting gas at best only remains partially intact in the product, resulting in crosslinking and a disorganized structure. Structure stability and the degree of crosslinking can be controlled by process parameters such as the pressure, flow rate of the working gas and supplied electrical power. It is thus possible to build up so-called gradient-layers in which for example the degree of crosslinking increases with the thickness of the layer.

This generation of polymers using plasma creates special layer properties and makes these materials suitable for a host of applications:

- Excellent layer adhesion to virtually all substrates;
- Chemical, mechanical and thermal stability;
- High barrier effects.

Layer formation using low pressure (LP) plasma polymerisation

One layer that meets the aforementioned requirements has a stable, three-dimensional Si-O-Si framework and a high density of chemically repelling methyl groups. A plasma-generated polymer film, designed as a single layer, does not have the desired chemical structure because the methyl groups are always end groups which cannot undergo crosslinking. The permanent release layers developed by IFAM are therefore gradient layers (see Fig. 1) in which the degree of crosslinking decreases towards the surface, accompanied by a corresponding increase in the density of methyl groups.

This structure allows the release layers to adhere well to the substrate. Due to the high degree of crosslinking, the layers also have adequate mechanical stability. The quality of the release effect (described below) is indicated by the number of times a mould can be removed without repairs and also by the force needed to remove the component from the mould.

Permanence of the release properties

The permanence of the release layers was first of all determined using ESCA[1] by measuring the characteristic Si content at the moulding surface over a series of 10 mould removals (see Fig. 2). The results showed that there was only a very small (negligible) transfer of the release layer to the moulded component.

The permanence of the release layers was then tested in actual practice.

Fig. 1: Gradient structure of a permanent release layer.

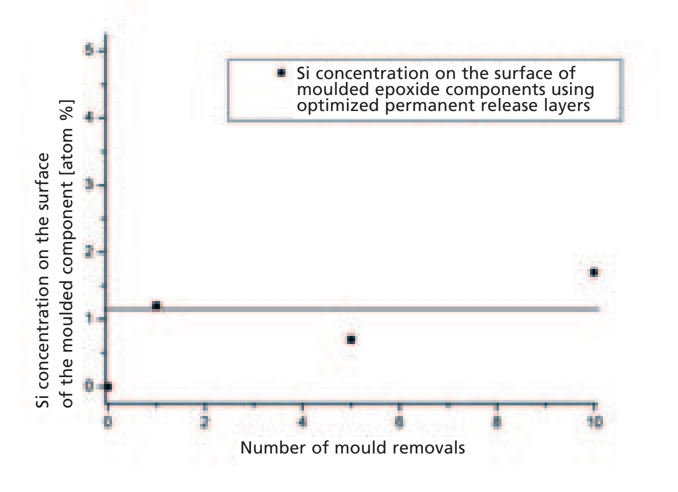

Fig. 2: Permanence of the release layers generated by plasma polymerisation.

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[1] ESCA = Electron Spectroscopy for Chemical Analysis

Permanent release layers on moulds use for processing plastics

Fig. 3 shows a small mould used to make a component for the car industry. Such moulds are used to process polyurethane foams and these foams put particularly high requirements on the release effect. The aim was to carry out between 1000 and 10,000 mould removals (depending on the application) with one coating. In work carried out to date, this has been achieved in some cases (1200 mould removals without worsening of the release effect). The application potential of these layers is hence clear and in addition larger plants (5 m^3) for coating larger moulds are also available. These can be used, for example, for coating moulds for manufacturing dashboards.

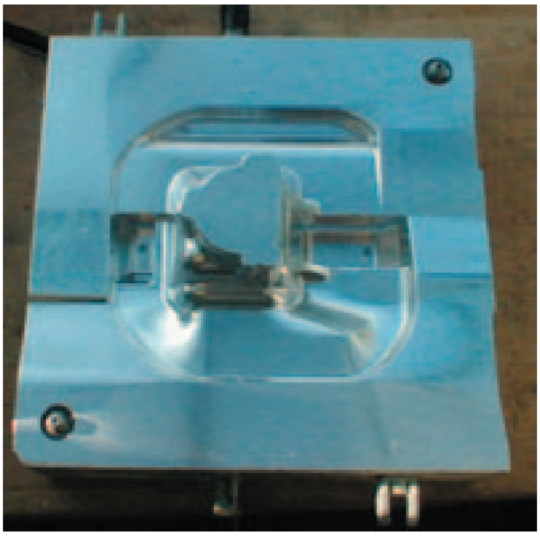

Fig. 3: Mould for foam materials for car wing-mirrors.

For other applications, for example moulded components for small series (several tens up to a few hundred components per year) in the aircraft manufacturing industry (CFRP components based on epoxide), the qualification procedure for implementation into the production is already underway. As part of this qualification procedure, 30 successful mould removals have already been carried out on larger aircraft components.

The LP plasma polymerisation technique is particularly suitable for generating gradient-layers. The plasma parameters (electrical power, precursor flow, etc.) can be varied during the deposition to allow customization of the chemical composition. Gradient-layers can hence be easily prepared in one plasma process.

Layer formation using atmospheric pressure (AP) plasma polymerisation

The application of atmospheric pressure (AP) plasma technology, which is available at IFAM as a plasma jet technology, which is an open air plasma technology, has the advantage over LP plasma technology that moulds which do not fit into a vacuum reactor can also be coated. The coating of complex 3-D moulds is however only possible using LP plasma technology.

Following the good results obtained with the permanent release layers generated using LP plasma, release layers were prepared using AP plasma. To carry this out, a special precursor feed system for the nozzles was first of all developed and built into the system. Detailed series of experiments produced layers whose atomic and functional group compositions (Fig. 4) were virtually identical to those of the layers generated using LP plasma.

For the mould removal tests a multilayer film was prepared, with the top layer containing the highest density of chemically repelling methyl groups and the bottom layer the highest degree of crosslinking. Fig. 5 schematically shows the entire release layer.

Permanent release layers on moulds for the aircraft manufacturing industry

In close collaboration with the aircraft manufacturing industry, a model metal mould for manufacturing a CFRP component was coated with a release layer (AP plasma). The epoxide resin that was used was pressed into the mould at a pressure of 6 bar and cured at a temperature of 180 °C. Despite these high thermal and mechanical loads, three successful mould removals have been carried out up until now without the layer being destroyed. There was no transfer of the layer to the moulded components.

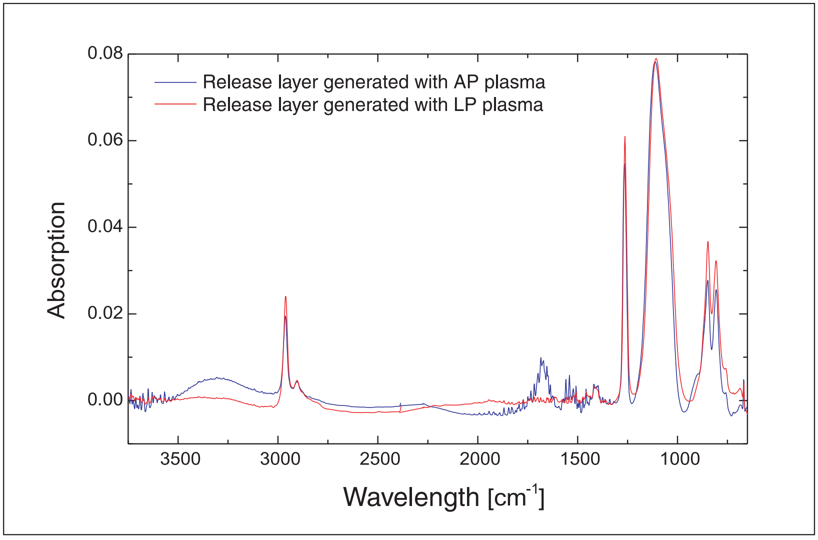

Fig. 4: Infrared spectrum of release layers generated using low pressure (LP) and atmospheric pressure (AP) plasmas.

Fig. 5: Multilayer structure of a permanent release layer produced using atmospheric pressure plasma.

Outlook

The permanent release layers made of epoxy resin and generated by LP plasma for the moulding of CFRP components are at an advanced stage of development and are currently undergoing qualification at an aircraft manufacturer with the aim of implementing this technology into the production. Also promising is the use of release layers for moulding polyurethane foams, which are very important materials in the car manufacturing industry. However, the release properties for the different foams must still be further tested and improved.

Regarding AP plasma technology, the present layer system must be transferred to larger moulds for viable use of these layers. A research project being jointly carried out with the aircraft manufacturing industry is investigating the use of release layers generated by AP plasma on non-metallic moulds.

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Adhesive and conductive – inkjettable nano-filled inks for use in microelectronics and microsystems technology

Current technology

Inkjet is an accepted technology for dispensing small volumes of material (50–500 picolitres). Traditional metal-filled conductive adhesives cannot be processed by inkjetting (owing to their large droplet size, ca. 150 µm). Electrically conductive inks are available on the market with metal particles ≤ 20 nm suspended in a solvent at 30–50%. After deposition, the solvent is eliminated and electrical conductivity is enabled by a high metal ratio in the residue. Some applications include a sintering step (Ref. Poulikakos et al). These nano-filled inks do not offer an adhesive function. Work reported here presents materials with both functions, adhesive and conductive.

Description

Generally speaking, inkjet nozzles have diameters ≤ 100 mm. It is widely accepted that the maximum silver filler particle size should not exceed 4 µm (with spherical morphology). Also, the viscosity of the loaded adhesive should be low, typically ≤ 100 mPas. Under these conditions, special care has to be taken to prevent agglomeration and sedimentation of the filler particles in the resin matrix: agglomeration results in large particles blocking the nozzle, sedimentation modifies the loading ratio of silver locally and may also obstruct the inkjet nozzle.

The present work demonstrates the feasibility of an inkjettable, isotropically conductive adhesive in the form of a silver loaded resin with a 2-step curing mechanism: In the first step, the adhesive is dispensed (jetted) and precured leaving a "dry" surface. The second step consists of assembly (wetting of the 2nd part) and final curing.

2-step curing mechanism – A combination of UV and thermal cure

The resin system was designed with a first UV-cure with radical mechanism. After deposition, the adhesive is partially cured by UV (Prepreg) and can be processed immediately or stored at ≤ 4°C. Because of its radical nature, the precure step has to be performed under an inert atmosphere. At this stage the adhesive surface is "dry", like a thermoplastic material with lateral epoxy functional groups. The second step involves heating of the adhesive (i.e. melting), followed by wetting of the 2nd part and crosslinking of the epoxy groups. Bonding of the 2nd part has to be performed under pressure. Final curing is achieved in a classical furnace/oven. The crosslinking ratio determines the mechanical properties and can be finetuned through the number of epoxy groups.

The 2-step cure is based on an Acrylate-Epoxy-Resin matrix with very low viscosity, i.e. 3 mPas of Newtonian properties. Spheroidal silver particles of high purity and a compatible organic coating with D_{90} of 4.1 µm have been loaded at 70% by weight (approx 20% by volume). As the metallic silver particles are not transparent to UV, special attention had to be paid to include various UV initiators. The present adhesive allows curing of layers up to 30 µm thickness. (To our knowledge, there are no commercially available conductive adhesives based on radical UV curing.)

The second, thermal curing step is promoted by imidazoles. A specific electrical resistance of 10^{-4} Ωcm and a bond strength of 10–15 N were achieved with SMD-resistors (case size 1206) on copper.

Jetting of the conductive adhesive

Inkjet dispensing was performed using an innovative design based on a glass capillary nozzle with a final opening of 30 µm, surrounded by a piezo-actuator. Under tension, the capillary contracts, pressure rises and generates a flow of adhesive which leaves the nozzle as a microdroplet. Droplet sizes of 30–100 µm have been achieved, depending on adhesive parameters and nozzle size.

The viscosities of the presented adhesives vary from (up to) 1 Pas at very low shear rate to 20–40 mPas at high shear rate. The shear rate occuring in the nozzle during jetting is estimated to reach 2500 s-^{1}. Under these drastic conditions, silver particles tend to agglomerate. Silver being a ductile metal with high tendency of cold welding its surface has to be coated for mechanical protection. However this protection does not remain functional in the cured material, otherwise it would prevent electrical conductivity.

Conclusions

This joint development of resin system, silver particles and inkjet device has opened the door for applying
the technology for electrically conductive joining in the microsystem and microelectronic fields.

Acknowledgement

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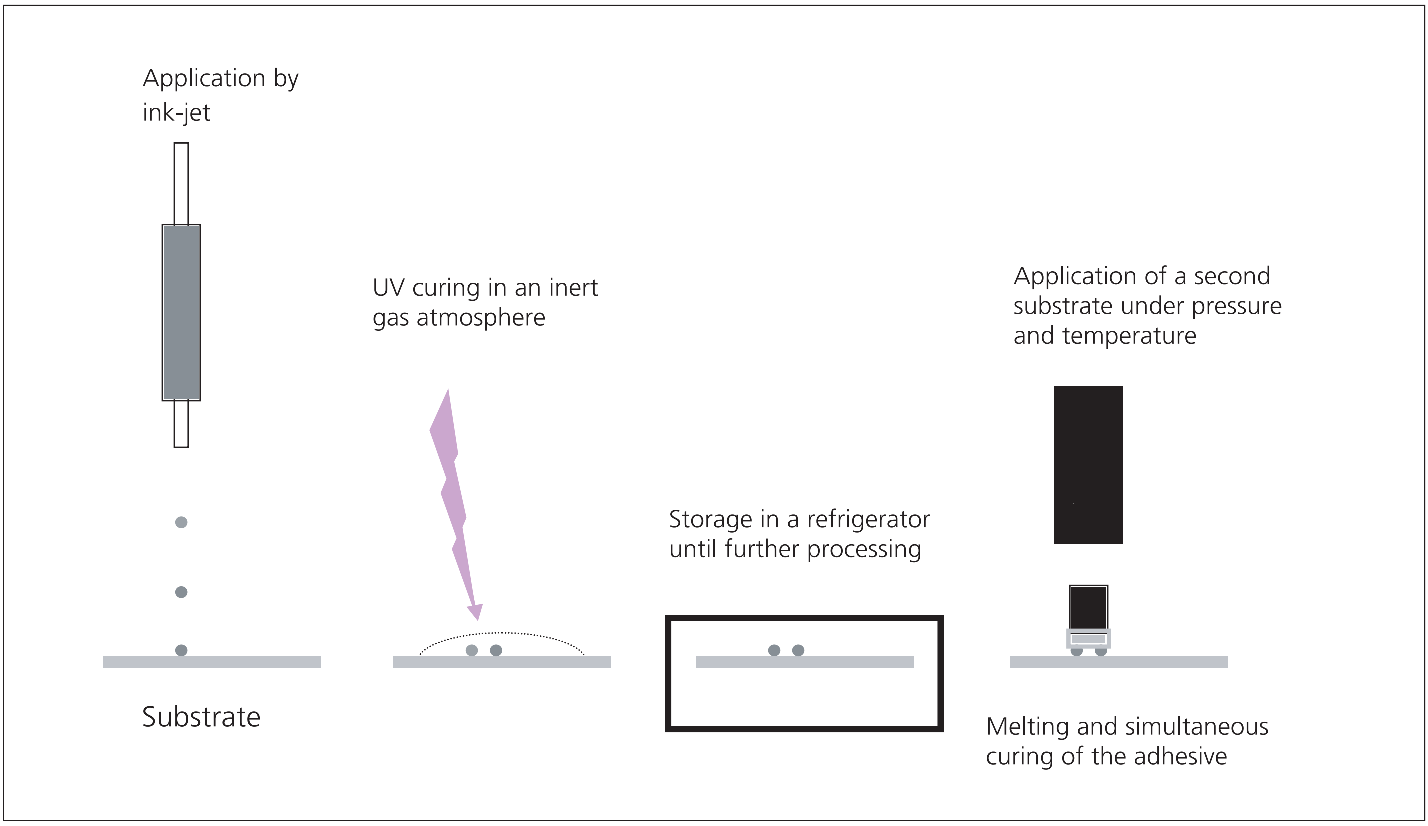
Fig. 1: Schematic representation of the production process.



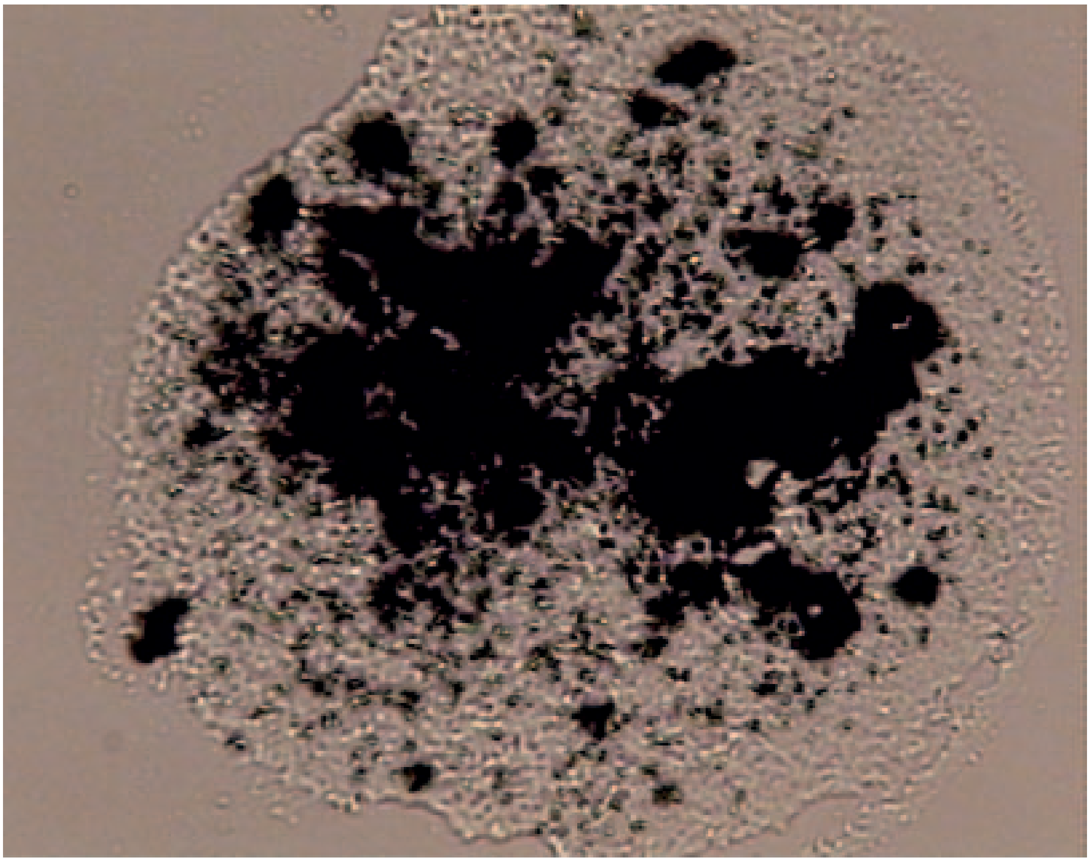
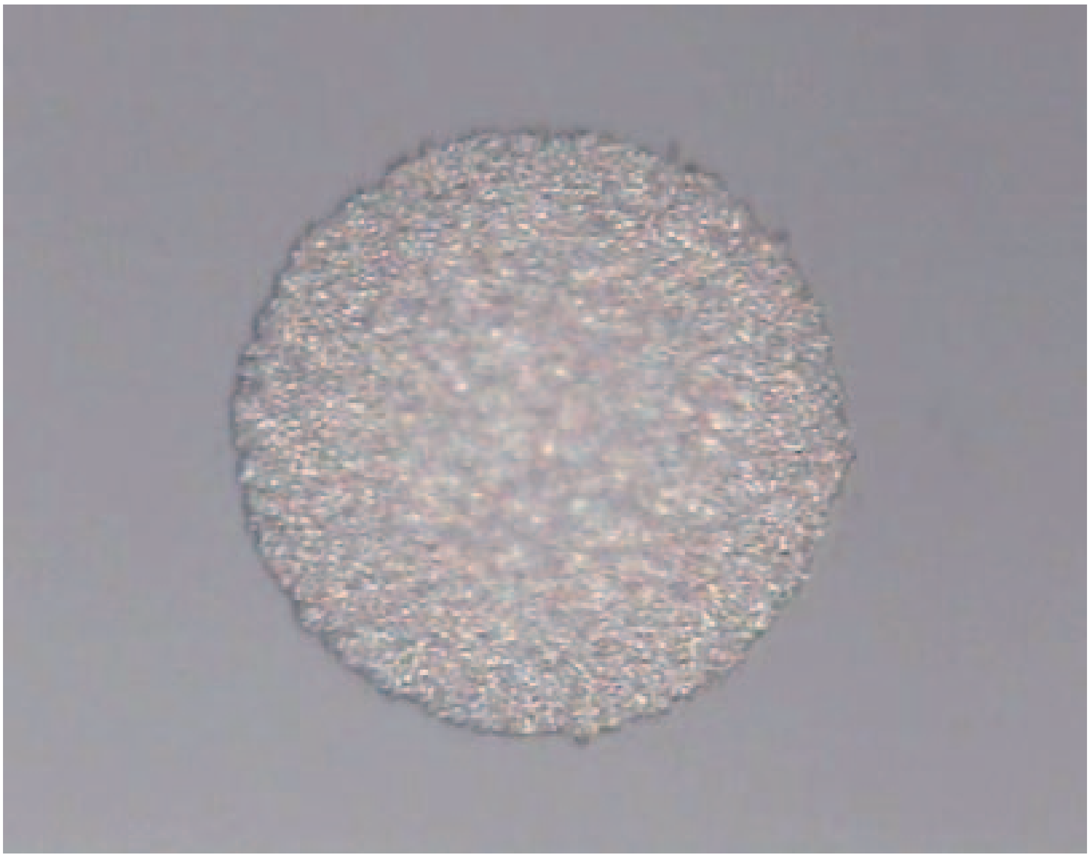


Fig. 2: Before (above): inhomogeneous distribution of silver particles after application.
After (bottom): homogeneous distribution.



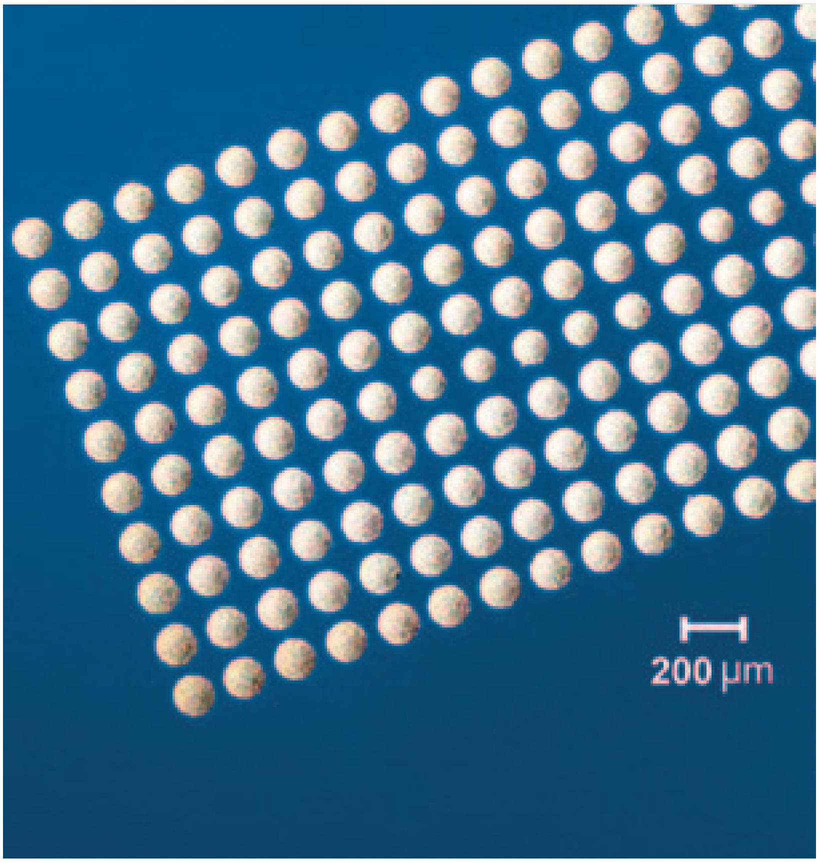
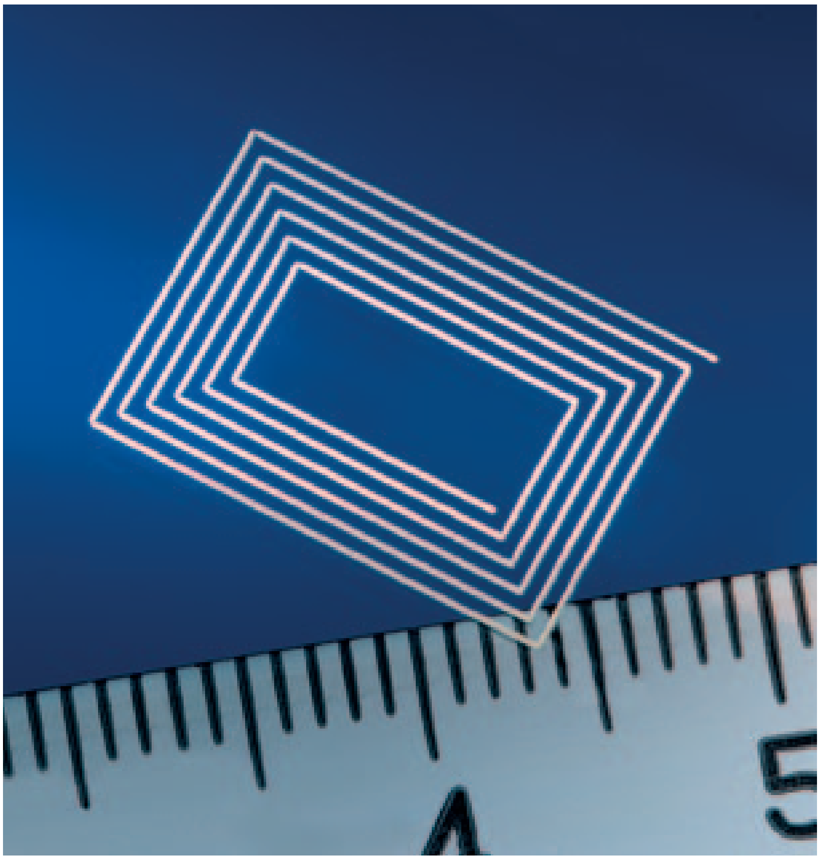


Fig. 3: Example applications.



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Characterization of heat transfer through thin adhesive films

Background

Developments in modern microelectronic components mean that electrical dissipation is taking place in ever smaller spaces and across ever smaller cross-sections. There is hence a greater risk of overheating and adverse effects on the lifetime and functional reliability of the components. Bonding technology is being increasingly used for joining these components. In addition to providing reliable attachment of the components and the reduction of mechanical stresses, the adhesive must also ensure there is effective dissipation of heat. For microelectronic applications, electrically and thermally conducting bonded joints usually involve an adhesive film thickness of 20–50 µm. There is, however, still a dearth of reliable heat conductivity data for this film thickness range because conventional instruments for measuring heat conductivity require samples having thicknesses of a few millimetres.

Project

A research project has been undertaken at IFAM to develop a procedure, using a commercially available instrument, which allows the heat conductivity of thin films of adhesive to be measured. Measurements on two adhesive systems typically used for microelectronic applications in film thicknesses of ca. 50–500 µm were carried out. Based on the results, a simple model for data fitting, extrapolating and predicting the heat conductivity of thin bonded joints was developed.

Heat conduction in thin adhesive films

It is generally assumed that the heat conductivity is a material-specific parameter that is independent of the size of the sample. However, when comparisons are made between the heat conductivity of an adhesive measured on a bulk sample with that in a bonded joint, considerable differences are often found. Usually the value for the bonded joint is lower than the bulk-value and the difference becomes greater the thinner the film of adhesive. This finding can be explained by the fact that the adhesive film does not have a totally homogenous structure, namely that in the vicinity of the adhesive-substrate interface the adhesive takes on different properties than in the bulk. For example, the heat flow from the substrate into the adhesive can be suppressed by surface layers on the substrate or by contact defects. As most heat conducting adhesives are highly filled systems, the concentration and orientation of the filler particles in the vicinity of the interface to the substrate also plays a role.

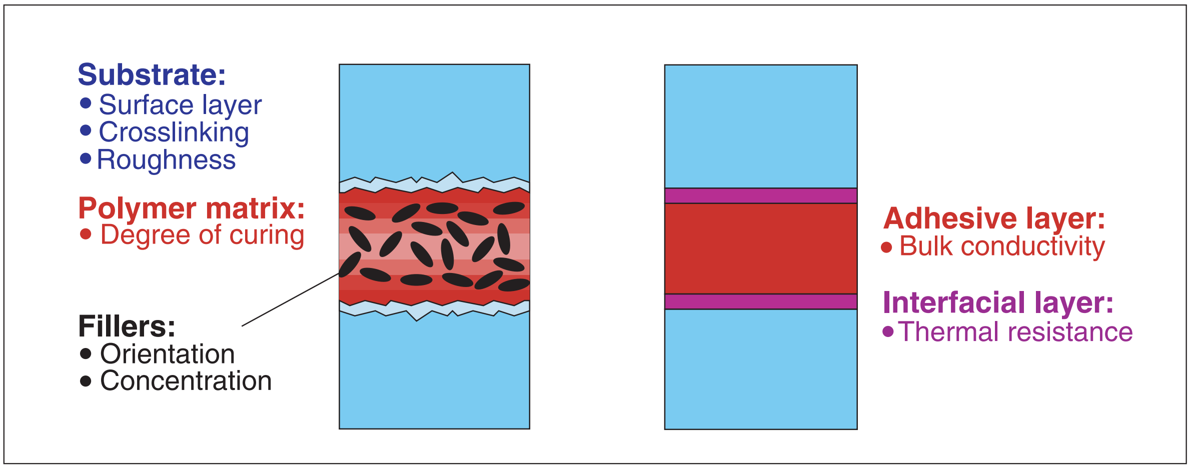

Fig. 1: Bonded joint: schematic (left) and in the model (right).

In order to develop a manageable model for heat conduction in bonded joints it is sensible to considerably simplify the above-mentioned relationships and the many factors which affect these relationships. It is hence assumed, as shown schematically in Fig. 1, that all "non-ideal" influences due to surface and orientation effects are concentrated in two thin interfacial layers. In between the two interfacial layers the adhesive possesses its bulk properties and has a heat conductivity which is the same as would be measured on a thick film of adhesive. In this model, the thermal resistance of the interfacial layer and bulk heat conductivity of the adhesive suffice to fully characterize the heat conductivity of bonded joints having different film thicknesses.

Techniques used for measuring the heat conductivity

The thermal resistance offered by a thin film of adhesive to a flow of heat is very small. Although this is desirable for technical applications, it does however make accurate experimental determination of the thermal properties more difficult. For this reason, a photoflash method, which is especially suited for measurements on thin samples having good heat conductivity, was selected. Photoflash methods, which are standardized in ASTM E 1461, involve thermal excitation via a short, intense pulse of light which heats the front side of a platelet-shaped sample. The time delay for the heat front to reach the back of the sample allows the heat conductivity of the material to be calculated. As the temperature on the back of the sample is also measured without contact, this eliminates a major source of error, namely the occurrence of thermal resistances at the contact points between the measuring instrument and the sample.

Further advantages of the photoflash method are the short measuring times and small amount of material required, namely the small sample size. As shown in Fig. 2, up to four samples can be tested simultaneously at temperatures up to 300°C.

For the accuracy of the overall measurement, it is vital that the thickness of the adhesive film can be manufactured with high precision (see Fig. 3). For example, an adhesive film having a thickness of 50 µm must be manufactured with a precision of 2.5 µm in order to prevent the measurement error for the heat conductivity increasing above 10%.

Results

The results of the heat conductivity measurements are illustrated using two typical adhesives: A ceramic-filled, thermally conducting adhesive (TCA) based on a silicone resin and a silver-filled, electrically conducting adhesive (ICA) based on an epoxy resin. The measurements were carried out on self-supporting adhesive films, semi-sand-

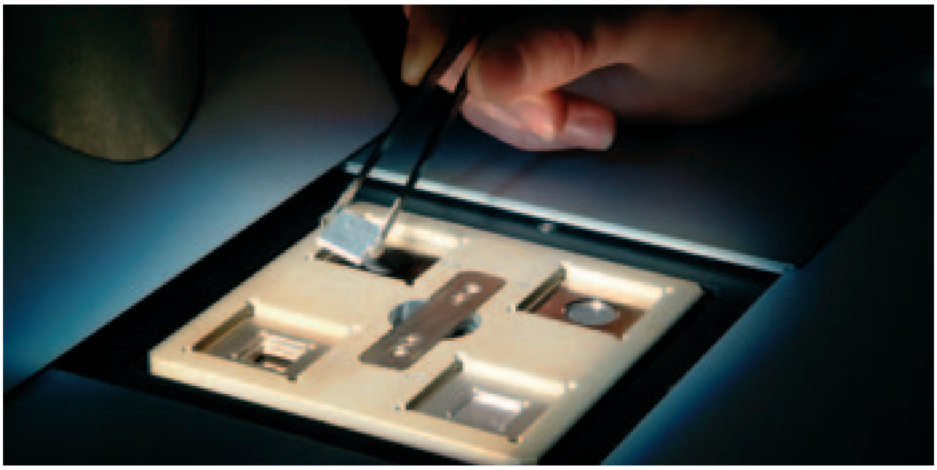

Fig. 2: Preparing the photoflash instrument for heat conductivity measurements.

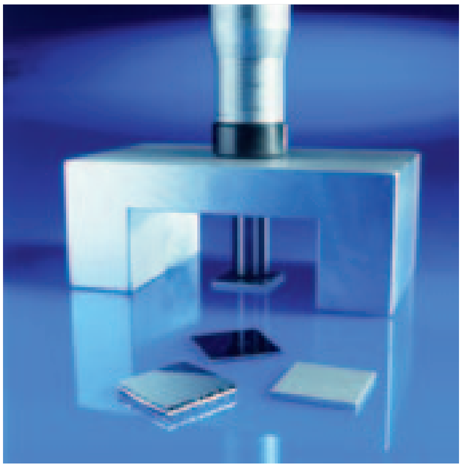

Fig. 3: Device for manufacturing bonded samples with a precisely defined adhesive film thickness.

wich constructions and sandwich constructions. The results showed that the heat conductivity also depends on the sample geometry. It can be assumed that the manufacturing process has an effect on the structure of the adhesive film and hence on its heat conductivity. The results described below focus on sandwich constructions of practical relevance.

Different aluminium alloys (Al99.5 and AlMgSi1) and silicon of various thicknesses were used as substrates for the sandwich samples. No dependence of the heat conductivity of the adhesive film on the type of substrate that was used was observed.

Fig. 4 shows the degree to which the heat conductivities of the two tested adhesives decrease with decreasing adhesive film thickness. For both adhesives we were able to accurately determine the bulk heat conductivity and the thermal resistance of the interface layer because there were a large number of measurement points covering a broad range of film thicknesses. The silver-filled epoxy resin has a very high bulk heat conductivity that was more than twice that of the ceramic-filled silicone. This is the reason why the thermal resistance of the interface layer of the ICA can be seen far more clearly from the decrease in the heat conductivity on reducing the thickness of the adhesive film than for the TCA, even though the thermal resistances of the interface layers of the two adhesives are almost the same.

The experiments also showed that the heat conductivity of an adhesive film depends not only on the composition of the adhesive and the film thickness but also on a range of other factors. These include the pore volume of the adhesive, possible production-related orientation of the fillers and the degree of curing of the polymer matrix, which in turn is highly influenced by the curing temperature. For the ICA, the heat conductivity of the adhesive film is high influenced by the orientation of the platelet-shaped silver particles. The degree of orientation in turn depends on the shear forces that are present when the bond is created. Fig. 5 shows how the curing temperature affects the degree of curing of the polymer matrix: A sample of the ICA cured at 130°C can be post-cured by heating to 150°C, resulting in a considerable increase in the heat conductivity after going through three temperature cycles.

Summary

The interplay between the thermal resistance of the interface layers and heat conductivity of the bulk material determines the heat conductivity of thin adhesive films. For materials having good heat conductivity, very small interface resistances

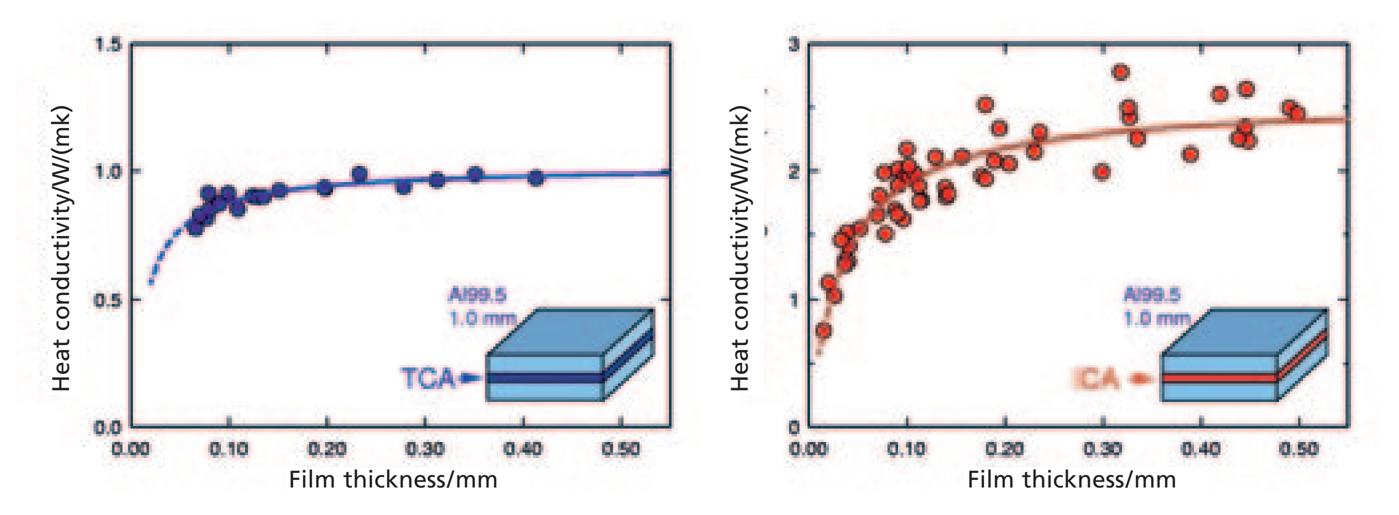

Fig. 4: Heat conductivity as a function of film thickness for the ceramic-filled silicone (TCA, left) and the silver-filled electrically conducting adhesive (ICA, right).

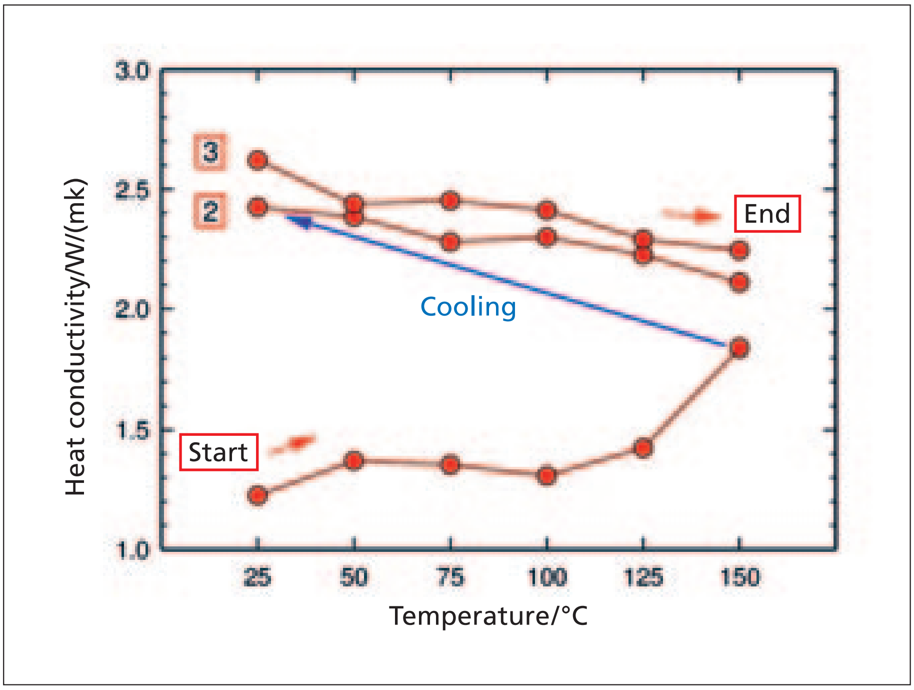

Fig. 5: Increase in the heat conductivity of the silver-filled conducting adhesive (ICA) by post-curing.

suffice to significantly reduce the heat conductivity of a thin bonded joint. Conversely, for adhesives having poorer heat conductivity, even higher interface resistances have far less effect.

Using the photoflash method, the heat conductivities of very thin adhesive films were successfully determined. The measurements show that the heat conductivities of adhesive films in the 30 µm thickness region, namely the region of importance for microelectronics, can fall to about a half of the bulk value.

All in all, the interface model adequately describes the experimental data. By fitting curves to the experimental data, the characteristic parameters for different adhesive systems, namely the bulk heat conductivity and the thermal resistance of the interface layer, can be determined. These parameters allow predictions to be made about how for example the adhesive behaves in very thin films and can be used as the basis for reliable computer simulation (FEM) of micro-scale bonded joints for developing electronic circuits with power elements.

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Ten years of training courses: Celebration on 22 June 2004

The 22 June 2004 was reason for celebration at the Fraunhofer IFAM and an opportunity to reflect on what has been achieved and the goals for the future. The milestone being celebrated was ten years of successful IFAM training courses in adhesive bonding technology. About 200 people were present at the Atlantic Hotel Universum and the speakers entertained everybody with their fascinating and enthusiastic talks. The event was chaired by Arnd Picker (Henkel KGaA), chairman of the IFAM committee.

When the first training course (DVS®,-Klebfachkraft; Adhesive Specialist) started on 31 January 1994 at the Fraunhofer IFAM, nobody imagined that the workforce training courses in Bremen would enjoy such success. Professor Otto-Diedrich Hennemann, managing director of the institute, recounted in his opening words that there was already an urgent need for such training courses at that time: “We had seen both euphoric and trying times for users as they endeavoured to develop adhesive bonding technology. Adhesive bonding technology offered undreamt of opportunities – but practical implementation was not always optimal. It became clear to us that workforce training was a key aspect if adhesive bonding technology was to realise its full potential.” Training was imperative for the development of markets for this modern joining technology. Against this background, the provision of training courses at the Fraunhofer IFAM immediately became a “key project”.

Arnd Picker
(Henkel KGaA, chairman of the IFAM committee)

Prof. Dr. Otto-Diedrich Hennemann (Managing director of the Fraunhofer IFAM)

Prof. Dr. Andreas Groß (Director of the Center for Adhesive Bonding Technology at the Fraunhofer IFAM)

The long road to success

The road to tangible success was long and difficult. Ultimately it was the richness of ideas and also persistence and flexibility that have allowed the Fraunhofer IFAM to train more than 1800 people over the past 10 years as Adhesive Engineers, Adhesive Specialists and Adhesive Bonders. Professor Andreas Groß was lauded as the main person responsible for this achievement. He is the director of the Center for Adhesive Bonding Technology at the Fraunhofer IFAM and along with Prof. Hennemann is the “father” of the workforce training courses. Professor Groß in turn praised his dedicated team and presented a fascinating talk: “How it all started and – more importantly – what the future holds” – something all those present wanted to know. Groß remembered the very first course and showed photos that were taken after the final examination. He gave an insight into how difficult it was at the outset when he said:

"I won't tell you whether it was the participants or the course tutors who were most relieved at the end of that course."

Andreas Groß also mentioned the difficult phase prior to the start in 1994: This involved many years of preparations, intensive discussions and formulation of teaching plans and guidelines. Groß mentioned the great support that was received from the Deutscher Verband für Schweißen und verwandte Verfahren e.V. (DVS), whose successful welding technology training system served as a model. Industrieverband Klebstoffe e.V. (IVK), the *Land* Bremen, the European Union and the Fraunhofer-Gesellschaft also helped us to realise our goal. The concept was clear: "It was our opinion that the knowledge transfer had three requirements in order to be successful: The very latest findings must be integrated immediately into training courses, the training must focus on work processes and the training must be designed from the start to be cross-hierarchal." Groß went to say: "What use is it if an engineer develops an exciting process if the person who then has to carry the work out in practice does not know that that he should not use silicone oil?" He added further that the matter of "how" to pass on knowledge also plays a major role. Modern didactic concepts and an interdisciplinary approach were employed from the start.

Training course model is expanded

Andreas Groß went on to stress the challenges for the future. The collaboration with schools is being constantly improved via the "TheoPrax" project. Bonding in the handicrafts sector is a "huge market and a big opportunity to further develop technology – with new means of knowledge transfer such as online learning". A further key area in the coming years will be internationalisation, with the first Adhesive Specialist training course in English soon to be held in the USA. Finally, having had so much success at IFAM with workforce training courses in the area of adhesive bonding technology, there is now the desire to expand this model to Lacquer/Paint Technology, Surface Technology and Quality Standardisation – as part of a "Center for Technology Transfer and Training". This approach could also be used a model for the entire Fraunhofer-Gesellschaft. "An attractive thought would be to have "Trained by Fraunhofer," as a trade name for a Fraunhofer Technology Academy", said Andreas Groß.

The invaluable organizations that have funded and supported the training courses were not only present at the celebration – key persons from those organizations also had the opportunity to say a few words. From their differing positions, they explained their motivation for involvement in the training courses in adhesive bonding technology. Ansgar van Halteren, the secretary of the Industrieverband Klebstoffe e.V. (IVK), pointed out the high importance to the national economy of the German adhesives industry. "Our aim is very clear: market expansion. Applications for adhesives are ever increasing and new markets are opening. Innovative composite materials require new systems and legislative requirements can be met with new adhesives", he said. In order to realise these opportunities, he went on to say that the training of users is one of the four cornerstones of the strategy of the IVK: "Training is one of

Ansgar van Halteren (Secretary of the Industrieverband Klebstoffe e.V. – IVK) the keys for qualified market expansion." That is why the German adhesives industry is also a partner in the Fraunhofer project "Internationalisation of certified training courses in adhesive bonding technology". Ansgar van Halteren made it clear how serious the IVK is by saying: "We are contributing a six-figure sum!"

DVS wishes to intensify co-operation with IFAM

The director of the Deutscher Verband für Schweißen und verwandte Verfahren e.V., Professor Detlef von Hofe, is pleased that training courses in adhesive bonding technology are integrated into his institution. "The DVS represents all joining technologies, including adhesive bonding technology. Sometimes these joining technologies are in competition with each other, sometimes they complement one another. Ultimately all technologies benefit because competition induces innovation." He went on to say that a result of this competition is the successful combining of joining techniques, for example spot welding and bonding. That good training is one of the base elements for the success of a technology is shown by welding and bonding to the same degree. "It is always economically better to produce quality rather than to test quality", believes von Hofe. For many years the DVS has had an active strategy for involvement with adhesive bonding technology. "We believe that the co-operation can be even closer – also with IFAM, which we believe to be a leading organization in the field of adhesive bonding technology!" Reflecting on the future of training courses, the DVS director hoped for further specialisation and modularisation, "because this is what industry and the handicrafts sector are demanding!"

Prof. Dr.-Ing. Detlef von Hofe
(Director of the Deutscher Verband für Schweißen und verwandte Verfahren e.V. – DVS)

Dr. Dirk-Meints Polter
(Member of the board of the Fraunhofer-Gesellschaft)

Dirk-Meints Polter, a member of the board of the Fraunhofer-Gesellschaft (FHG), pointed out that the FHG views adhesive bonding technology as a key technology. He said that the activities of IFAM were very positive. Polter was fascinated by adhesive bonding technology and mentioned many examples of adhesive applications. He was impressed that companies are now booking complete courses and that international courses are soon to take place.

Political world content with their decision to fund certified training courses

A guest at IFAM for the first time was Dr. Arnold Knigge, advisor to the Senator für Arbeit, Frauen, Gesundheit, Jugend und Soziales des *Landes* Bremen. He was the person ten years ago who helped the IFAM on their way with the necessary start-up funding from the *Land* for the provision of training courses. "We are very glad

Dr. Arnold Knigge
(Advisor to the Senator für Arbeit, Frauen, Gesundheit, Jugend und Soziales, Bremen)

that this decision has proved to be future-orientated”, says Knigge. “The Center for Adhesive Bonding Technology is now a splendid example of successful technology funding by the *Land* – an example that can also be seen in a Europe-wide context!” He went on to say: “With the new project ‘Online learning: adhesive bonding technology for the handicrafts sector’ being once again funded by the *Land*, the Fraunhofer IFAM is furthering its successful work.”

There was also an official presentation on the actual anniversary day. “Adult training today” was the topic of a talk given by Professor Rolf Arnold (University of Kaiserslautern), a renowned specialist in this area. The talk contained much interesting information and included the latest findings in the methodology and didactics of adult training. Time only allowed a brief insight into the latest studies – but it was clear that the Center for Adhesive bonding technology is on the right road with its teaching approach. As the start of “3. Bremer Klebtage” followed the end of the celebration, Arnold had to shorten his talk but he and the Fraunhofer IFAM intend to remain in contact.

Prof. Dr. Rolf Arnold
(University of Kaiserslautern)

Department of Shaping and Functional Materials

Results Applications Perspectives


IFAM

Department of Shaping and Functional Materials

Expertise and know-how

Following its strategic restructuring, the Department of Shaping and Functional Materials of the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) aims to be the first organization in Europe to offer R&D services for complex and intelligent metal components which extend from the initial raw material stage right through to the final application. Intelligent components have integrated properties which allow operating and ambient conditions to be recorded, processed and communicated. The spectrum of our R&D work extends from fundamental, application-orientated research right through to product realisation and support with implementation into production processes.

Our three core areas of expertise are:

- Powder technology and sintering technology
- Foundry technology and light metal technology
- Micro-technology and nano-technology

The expertise and know-how of IFAM staff coupled with our interdisciplinary approach ensure that innovative solutions are found for our industrial customers. The consolidation and extension of these core areas of expertise is a continuous process, dictated by creativity and strongly orientated towards the needs of the commercial marketplace.

Figure (opposite page): High-grade steel designer sphere produced via 3-D printing

Fig. 1: Gearwheels produced by hot pressing and sintering.

IFAM's many years of successful collaboration with industry in the area of powder metallurgy and powder technology have made IFAM renowned in Europe as a center of excellence. New sintered and composite materials, cellular materials and shaping methods such as metal powder injection moulding, hot pressing and laser sintering are mentioned here as examples of our activities.

Building on our know-how in the area of powder technology, micro-production has become an established field of expertise at IFAM. In addition to developing new mass production processes for miniature components and micro-structured components, new interdisciplinary work is being carried out in micro-reaction technology and in cell growth management and surface structuring.

Regarding the technological realisation of function-integration, further development of the ink-jet printing technology is being pursued using functional inks and the formulation and processing of pastes. This builds on our knowledge of nano-powder processing and the formulation and interaction of powders with organic substances.

The development of modern lightweight construction materials for a variety of applications covers the manufacture of these materials, the development of viable industrial production technologies and the complete development of components.

A state-of-the-art foundry plant and ultra-modern analytical equipment coupled with in-depth know-how of aluminium and magnesium alloy processing via pressure casting have enabled IFAM to assume an enviable position in the marketplace. Besides optimising casting processes for complex components, other examples of our work activities include the casting of sensors and actuators, the development of porous, lightweight core materials and simulating the filling behaviour of complex cast components.

Perspectives

It is imperative that our service portfolio is continually adapted to the needs of the market. Equally important in these considerations are product innovation under strict industrial boundary conditions and the contributions of the solutions to improving the quality of life and sustainable development in the areas of transport, energy, medicine and the environment.

Precision metal components are being integrated into systems in virtually all sectors of industry. The diversity of the products is opening up huge opportunities for further performance increase and cost reduction. An area in which we are often asked to carry out work for a variety of different sectors of industry is the development of precision metal components which can be manufactured using powder-metallurgical or casting processes. The most important development work concerns shaping processes for highly complex components which must be

Fig. 2: Gearwheel with metal foam ring for noise damping.

optimized under industrial boundary conditions. Pattern formation and simulation of the shaping processes play an important role here.

Future areas of work are the development of innovative solutions using new materials for the miniaturisation of components and new solutions for micro-reaction technology. The advantages of metal micro-reactors, compared to glass and silicon, that directly act as catalysts should ultimately mean improved management for processes in, for example, biotechnology, the chemical industry and also medical technology.

Materials are a key technology and are hence a major factor governing the success or not of innovative products. The market for materials is growing due to the increasing complexity of products. Material properties and technologies for structural and functional applications are customized and characterized. High performance materials, composite materials, gradient materials and smart materials are being developed and production technologies for integrating the properties into components are being evaluated. Customized combinations of materials to introduce sensory functions into components will be further developed. The potential savings in manufacturing costs and the combination of various sensory and actuator functions is opening up totally new application areas for these intelligent components.

Technology platforms such as “Functional printing” are allowing product development work to be undertaken with key customers from different sectors of industry and are opening up new applications. For example, miniaturisation applications have been developed which are currently impossible to achieve using conventional components or tools. Telematic integration and permanent monitoring of operations using intelligent components allow the design and dimensions of elements to be optimized, so enabling weight reduction (lightweight construction) and improved operating reliability of function groups.

Lightweight construction materials and components, as well as processes to produce them, are topical issues in the car manufacturing and transport industries. IFAM collaborates here with leading companies to find customized solutions for lightweight construction.

Fig. 3: Porous aluminium foam.

These solutions are based on light metals such as aluminium alloys, cellular materials and components with optimized structures and there is then transfer into components and systems using for example modern casting technologies. To complement casting processes using long-life moulds, the total process chain of the Lost Foam method is being integrated at IFAM.

A regional, BMBF funded alliance and the Demonstration Center for cellular Materials in Dresden are key cornerstones for making the full application potential of porous structures available to companies, including 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 utilization 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, development work in the areas of medical technology and bio-materials will be furthered. Our activities here involve production processes and materials for components for medical technology and specially developed materials for nano-structured and micro-structured systems. Close collaboration in networks with other institutes having complementary expertise and with companies and clinical partners is desired. Key challenges are antimicrobial surfaces and bio-compatible materials and also the customized micro-structuring of surfaces for cell growth management.

In order to enable rapid realisation of this strategy, investments are being made in simulation software, in further machinery for shaping and in analytical equipment.

Main areas of work

- Powder metallurgical shaping via powder pressing/sintering
- Heat compaction and metal powder injection moulding
- Lightweight structures from metal foams, especially those made from aluminium, aluminium alloys, steels and titanium
- CAD supported rapid prototyping for mould design
- Conditioning of metal powders for laser sintering and 3-D printing (rapid prototyping)
- Manufacture and processing of ultra-fine and nano-scale metal powders under inert conditions
- Process development for materials and components made of metal fibres and hollow metal spheres, especially for filters and lightweight components
- Process development for the manufacture of gradient materials
- Shaping of lightweight metal alloys using casting technology (pressure casting, thixocasting and squeeze casting)
- Development of computer-aided production processes to increase process reliability (CAE)
- Production of micro-components from metal powders and suspensions
- Rapid tooling for injection moulding and pressure casting

Shaping and Functional Materials
Fields of expertise and contact persons
Managing director Prof. Dr.-Ing. Matthias Busse

Bremen site

Powder Technology

Powder-metallurgical shaping; warm compaction for manufacturing highly dense sintered components; metal powder injection moulding; 2-component injection moulding; process and material development; rapid manufacturing; laser sintering; screen-printing; simulation.

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Functional Structures

Nanopowders; gradient structures; nanoporous layers; functional integration; inkjet-printing; special plants.

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Micro Engineering

Micro injection moulding for metals and plastics; micro-structuring; series production of miniature components; 2-component injection moulding for micro components; microreaction technology; microfluidics.

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Lightweight Structures and Analysis

Cellular lightweight construction materials; functional, open porous metal foam structures; aluminium foam sandwich structures; production processes for metal foam components.

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Casting Technology

Zinc, aluminium and magnesium pressure casting; thixocasting; pressure casting moulds; lost-foam processes; sand casting; simulation.

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Cellular Metallic Materials

Fibre metallurgy; high porosity structures; metallic hollow sphere structures; open cell PM foams; screen-print structures; applications for e.g. lightweight structures; crash-absorbers; heat exchangers; catalyst support materials.

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Sintered and Composite Materials

High temperature materials; aluminides (NiAl-foam); nano-crystalline materials; materials for tribological exposure; sputter targets; modification of powders.

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Equipment/facilities

Department Shaping and Functional Materials

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

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

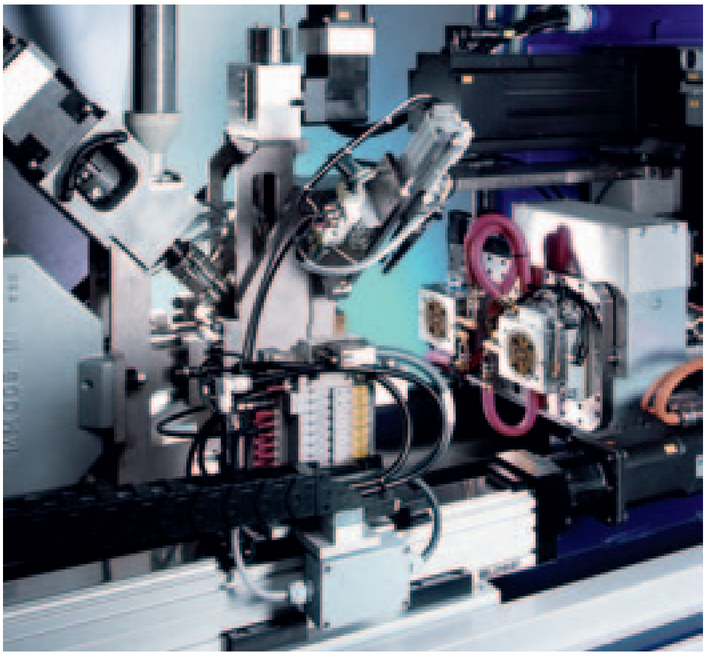
- Induction furnace for metal foams
- Plants for manufacturing gradient materials (sedimentation, wet powder injection)
- Plants for manufacturing metallic nano-powders and nano-suspensions
- Test rig for characterising functional inks for the ink-jet printing method
- 3-D ink-jet printer RX-1 (PROMETAL)
- Melt extraction unit (metal fibres)
- Centrifugal mill for high energy milling of metallic and ceramic powders (5–10 kg, also inert gas, vacuum)
- Air classifier for classifying powders

Analytical equipment

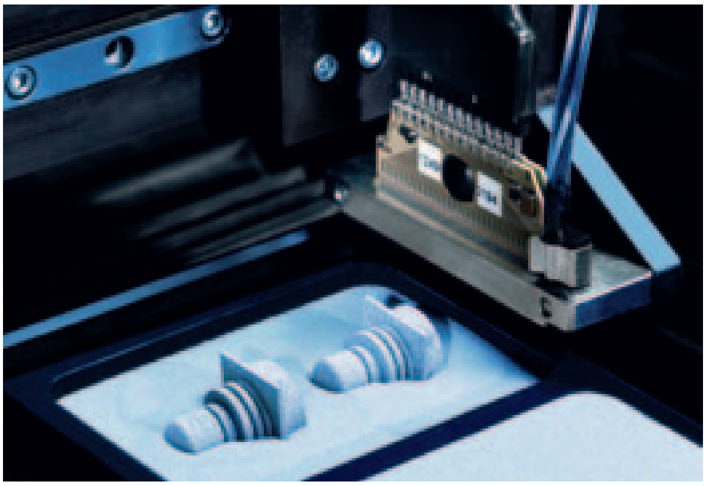
- FEM scanning electron microscope with EDX
- X-ray fine structure analysis
- Insulation resistance
- Thermal analysis (DSC, DTA, TGA)
- Sinter/alpha dilatometry (accredited laboratory)
- Powder analysis with BET surface area and laser granulometry
- Rheometry
- Trace element analysis (C, N, O, S)
-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

Computer equipment

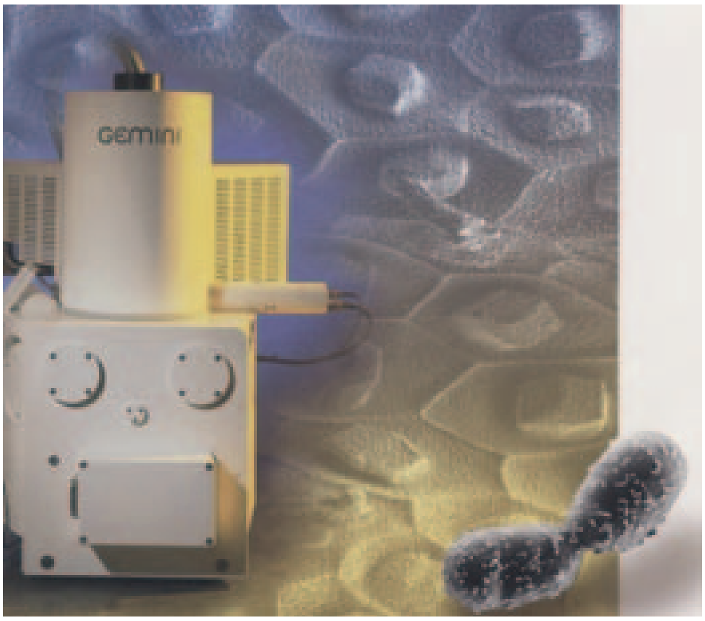
- High-performance work stations with software for non-linear finite element analysis, for simulating mould filling and solidification and for component optimisation



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



3-D ink-jet printer RX-1 (PROMETAL).



High-resolution FEM scanning electron microscope.

Functionalisation using micro and nano technologies

Over recent years the miniaturisation of components and systems has gained increasing importance. During the 1990s micro-scale components and systems experienced enormous growth, in particular in the microelectronics market. The trend now, however, is moving towards the nano-scale, namely a billionth of a metre. New possibilities for combining a wide range of materials are opening up a broad spectrum of new applications.

The individual components are becoming ever smaller, and at the same time are having to fulfil ever more functions. Function-integration is often possible via micro-structuring and nano-structuring. The Fraunhofer IFAM is strengthening this core area of expertise of the Shaping and Functional Materials department with two other fields of expertise, namely Micro-Production and Functional Structures. The micro-production group at the Fraunhofer IFAM is primarily involved in the manufacture of metallic micro-functional components and the development of functionalized micro-structured surfaces. The focus here is on shaping processes (embossing, micro injection moulding) which allow favourable-cost series production of complex surface-structured components using a variety of materials. The emphasis is on metallic materials, but work is also carried out on polymers. The micro-production group can lend on the many years of experience of IFAM in standard injection moulding techniques and in the processing of metal powders and polymers. It is now using this knowledge to developing micro-systems technology. The functional structures field of expertise is utilising knowledge gained in previous IFM work on the manufacture of nano-scale metallic powders and suspensions to develop processes suitable for implementation by industry. New functional materials such as nano-powders, nano-suspensions and functional inks for inkjet techniques are being developed. In addition to a variety of technologies such as rapid-prototyping, inkjet printing and various sputtering techniques, the implementation of function-integration into production processes is also making use of plants for compounding nano-scale materials into nano-composites. Accompanying work on developing special plants is enabling the functional structures field of expertise to transfer its technology and is hence making a direct contribution to the value-increase of many products.

The micro-structuring and macro-structuring core area of expertise has grown continuously over recent years. This is because micro and macro technologies allow products for medical applications, the aircraft and aerospace industries, the car industry right through to the chemical industry to be produced. New components for microelectronics, materials for the antibacterial design of medical equipment and customized cell growth via microstructuring are just some of the applications our work is focussing on. The micro-structuring and macro-structuring areas of expertise hence complement each other in an ideal way. These interactions are resulting in trend-setting concepts for production.

Micro metal powder injection moulding (Micro MIM)

The Fraunhofer IFAM has been carrying out R&D work in metal powder injection moulding (MIM) for more than 10 years. This process combines the freedom of shaping of plastic injection moulding with the material diversity of powder metallurgy and so allows series production of complex shaped components made from a wide variety of metallic materials. The production of very small miniature metallic components and components with micro-structured surfaces requires the standard MIM process to be modified. The principles of micro MIM were hence developed at IFAM. This process uses average particle sizes of about 2 µm and smaller in order to mould complicated fine structures. These powders are mixed with a specially developed, high-strength binder system and then injected into a mould or mould insert. Mould inserts that can be reused many times are manufactured by using micro-production technologies such as silicon etching, micro-shaping, micro-machining, laser-structuring and LIGA technology. The injection moulding itself is carried out in a production chamber especially designed for micro-components. The handling, optical monitoring and positioning of the components for injection moulding is carried out automatically. Miniature components with an edge length of 300 µm and minimum structure sizes of 10 µm with an aspect ratio (height/width) of 16 can be produced. New binder-removal and sintering steps, which are possible due to the very small size of components and the use of special powders and binders, are being developed for a broad range of materials. Dense metal components in a variety of high-alloy steels, iron (iron alloys), hard metals, copper and tungsten-copper can be produced. Micro powder injection moulding can in principle be transferred to all materials that are available in a suitable powder form. The process can considerably extend the range of materials on offer for micro and precision applications.

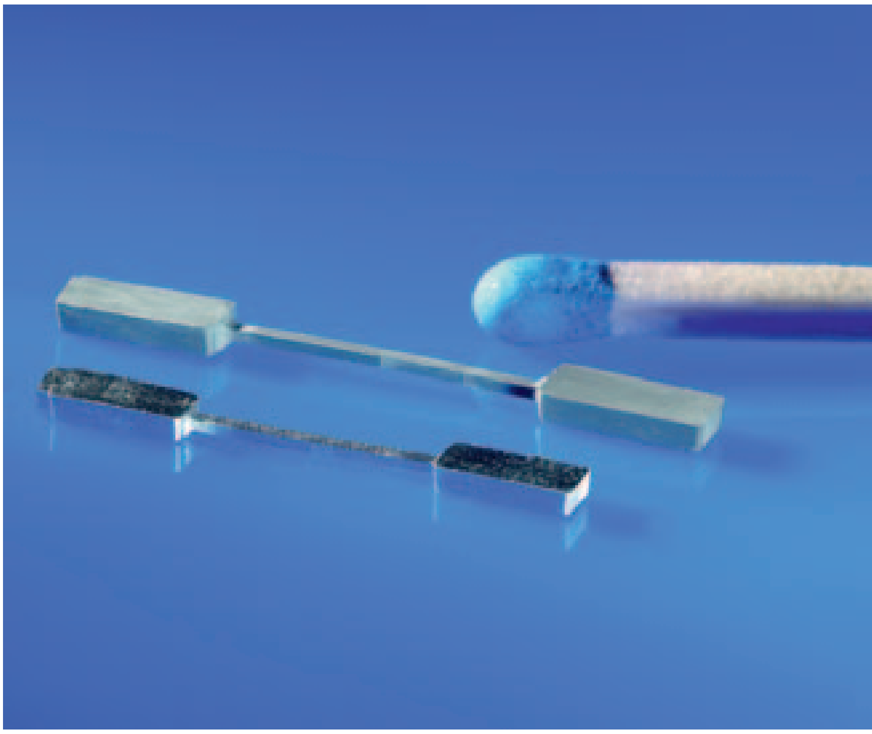


Fig. 1: 2C micro tensile test sample (non-sintered and sintered component).

Multifunctional micro-components via two-component powder injection moulding (2C micro-PIM)

Two-component powder injection moulding (2C PIM) is a powder-metallurgical process for manufacturing components from two materials having different mechanical or physical properties in a single production step. The process was developed as part of a 3-year BMBF project, which will shortly end, entitled “Multifunctional materials for micro-components via multi-component powder injection moulding”. It was developed in conjunction with the Research Center Karlsruhe. The objective of the work was to produce micro-components and components having different local functions. IFAM carried out work to combine a magnetic steel (17-4PH) with non-magnetic steel (316L), whilst the Research Center Karlsruhe concerned itself with developing a material containing ceramic materials of differing conductivity.

In 2C micro-PIM the metal and ceramic powders are injected into a mould, either at the same time or after one another, such that a composite of good integrity forms between the materials. There is simultaneous shaping and joining, without other assembly steps being necessary. The binder required for the injection moulding and removing the micro-components from the moulds is then removed by suitable heat treatment. The resulting components made of different materials are then sintered to form a completely dense metallic component. Careful choice of mould sizes, the size of the powder particles and the sintering process allow crack-free boundaries with good adhesion to be realised. The function-integration in micro-components that can be realised here relatively easily would otherwise only be achievable via complicated assembly and joining technologies.

Fig. 1 shows the geometry of a 2-component micro tensile test specimen for the combination 316L/17-4PH, in the non-sintered and sintered state, as used for mechanically testing the quality of the composite. Fig. 2 shows a 2-component position-indicator made at IFAM consisting of a non-magnetic section (high-alloy steel 316L) with two soft-magnetic ends (high-alloy steel 17-4PH). Using a suitable Hall sensor, movement of the micro-component causes a voltage change and this can be translated into a corresponding positional change. The image of the section shows a crack-free boundary of high strength after sintering. By customising the process the magnetic properties of the 17-4PH steel can be optimized.

The 2C micro metal powder injection moulding process can be used to create a host of combinations of properties and integrated functions with metallic or ceramic materials. Examples of possible combinations are fine/coarse, dense/porous and conducting/insulating.

Micro-structured surfaces for microfluidics

Functional micro-fluidic surfaces are being used in interesting applications in the chemical industry, biotechnology and medical technology. Joint development work by biologists, chemists and engineers are opening up very promising, trend-setting areas of application. For example, micro-reactors are being increasingly used for the synthesis of fine chemicals and for analysis and diagnostics (lab on a chip). A key aspect here is the opportunity to use shaping processes to process a wide variety of different reactor materials that are customized to the specific chemical or biochemical reactions.

For the micro reactor system FAMOS, that was developed by several Fraunhofer institutes, a T-mixer with a meander-shaped outlet section was designed as an integrated component and produced in rust-free steel (see Fig. 3). The FAMOS reactor system is constructed in accordance with the modular principle and can be adapted to the requirements of different chemical/pharmaceutical syntheses.

Other work being carried out at IFAM is involved with designing micro-fluidic reactors for water treatment and producing these via micro injection moulding. The reactors are then photo-catalytically coated (TiO_2) and fitted with a glass cover (see Fig. 4). This photo-catalytic effect enables this system to be used for sterilising water with the aid of UV radiation. The 200 µm wide channels increase the surface area of the water and hence the active surface for light. By connecting a large number of reactors in parallel, large amounts of water can be treated. The effectiveness for sterilising used water or drinking water is determined by the residence time. In initial experiments carried out in conjunction with the Institute for Environmental Process Engineering (IUV) at the University of Bremen the activity of the photo-catalytic coating was tested by monitoring the decolorisation of water mixed with methylene blue. Up to 80% decolorisation was achieved.

Another area of application is the use of micro-fluidic components in novel analysis systems for testing for and quantifying for example pathogenic germs such as bacteria, viruses or yeasts. For this the surface of the reactors is designed such that biological ligands can couple to the surface. This application is focussing on several mass markets that can be served by a favourable-cost and easy to use analysis system. Possible applications of these systems are early detection of resistant strains of bacteria/viruses in hospitals, the analysis of foods for pathogenic germs and/or their metabolic products and the monitoring of drinking water quality.

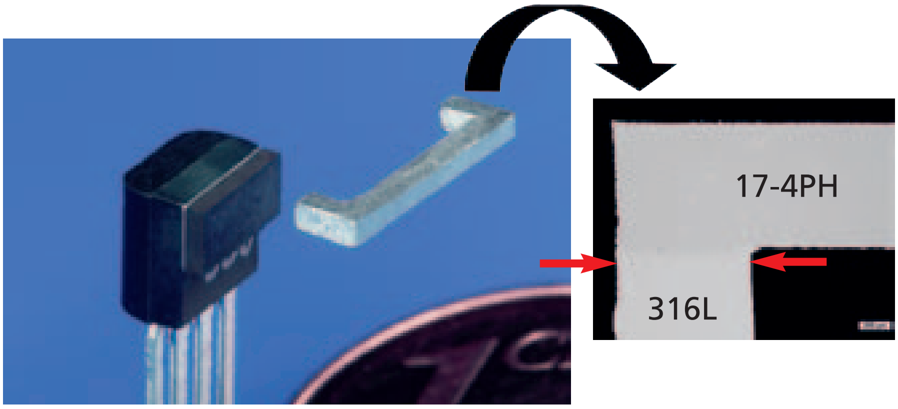


Fig. 2: 2C Position-indicator, section of the boundary.

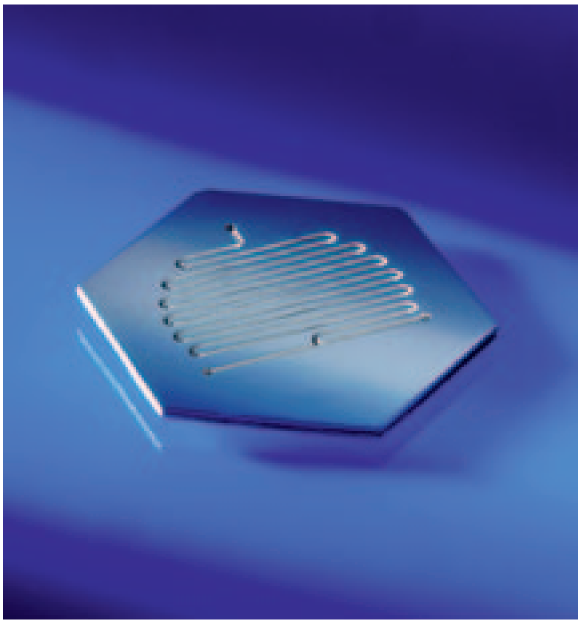


Fig. 3: T-mixer with meander-shaped outlet section.

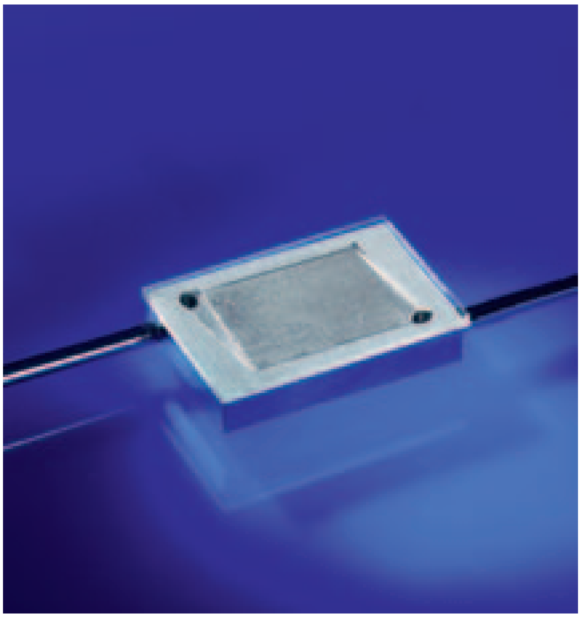


Fig. 4: Fluidic photo-reactors for sterilising water.

Bioactive surface-structuring

Customized micro-structuring of the surface (roughness and/or specific structures) can be used to improve the biointegration of implants or, if desired, can be used to prevent the growth of cell layers. A multidisciplinary project at the Fraunhofer IFAM has been involved in developing a variety of micro-structured surfaces. The adhesion of cells to these surfaces has been tested by project partners. Surface roughness values of about 1 µm allowed the growth of human fibroblasts on the micro-structured silicone surface. The cells showed their typical growth structure. Surfaces with greater roughness (R_a about 4 µm) resulted in lower growth of the fibroblasts, with their typical growth morphology being suppressed.

Specific structures such as arrays with columns (see Fig. 5) are particularly suitable for implants. The respective cell type can involve itself in a sort of “fastening process”. Growth can be accelerated and improved, and this makes a significant contribution to more rapid healing of patients.

The results achieved up until now show that surface micro-structuring looks for very promising for applications in cell growth management. It is also of interest for developing specialized cell culture dishes and for screening cells and bacteria. Shaping with other materials such as high-alloy steel, titanium and cobalt alloys is also possible.

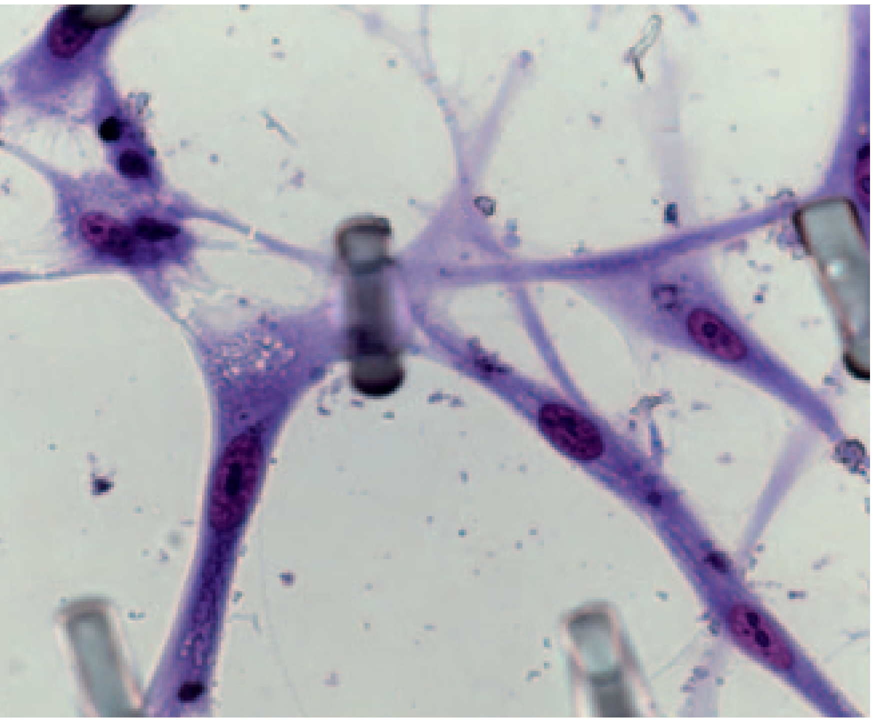


Fig. 5: Human fibroblasts integrate silicone columns into their growth.

Nano-scale functional materials

New materials concepts for manufacturing intelligent surfaces and components are increasingly based on nano-technology. Nano-particles having diameters below 100 nm often possess different properties to particles of the same material of larger diameter. As a result, they have been the subject of much research over recent years.

Nano-particles in particular open up the opportunity of realising novel properties in (classic) components, so increasing their value. Nowadays nano-particles play a key role in many technological products. Nano-particles have become established for so-called "self-cleaning surfaces", and also for medical equipment and medicines. The effectiveness of catalysts can be significantly improved by nano-structuring. The activities at the Fraunhofer IFAM are focusing on acquiring fundamental knowledge and also on developing new technologies for the manufacture and processing of nano-scale materials.

Nano-particles can be manufactured at the Fraunhofer IFAM using so-called IGV (inert gas evaporation) technology as highly porous powders in an inert gas atmosphere. They can then be immediately further processed. The dispersion of these nano-particles in for example polymers, followed by compounding (see Fig. 6), opens up the opportunity of converting the nano-particles into nano-composites. These functionalized materials can then, for example, be processed into electrically and thermally conducting adhesives.

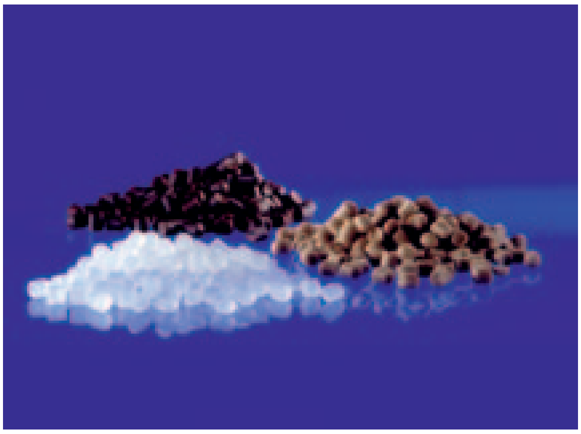


Fig. 6: Polymer nano-composite granulate.

The VERL (Vacuum Evaporation on Running Liquids) technology also offers the opportunity to use sputtering processes to introduce nano-scale particles into a liquid.

Such suspensions (see Fig. 7) can either be directly integrated into conventional processes or applied as fine structures to substrates or to components. The well-known inkjet printing method provides an ideal technology platform. Nano-scale suspensions, so-called "functional inks", can be applied to structures very accurately, quickly and easily and this is hence an attractive production technology for nano-structuring.

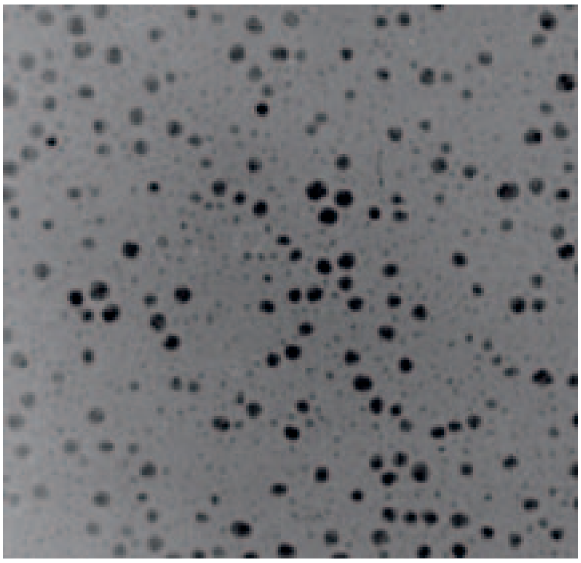


Fig. 7: TEM micrograph of an Ag nano-suspension.

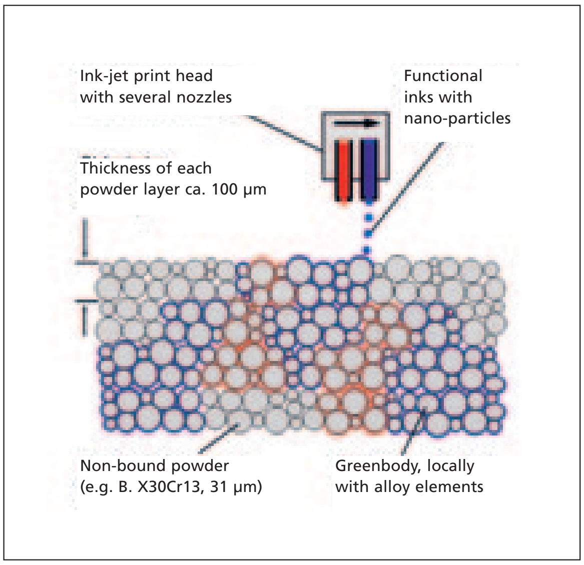


Fig. 8: Principle for manufacturing graded structures using 3D-printing.

Functional printing

A variety of inkjet printing technologies are available at the Fraunhofer IFAM for customized function-integration. Three-dimensional printing (3DP) allows for example geometrically complex gradient materials to be manufactured (see Fig. 8). Using the principle of an inkjet printer, nano-scale suspensions can be printed layer by layer using independent nozzles to form a powder bed. The printed nano-particles can then be subjected to a heat treatment step to form localized alloys with the matrix powder or to remain as specific phases in the component. The local material information is entered via CAD datasets and can then be selectively integrated into the component being manufactured.

The inks are characterized and optimized for their printability using a test stand via visualisation of the droplet formation.

In addition, sputtering technologies can also be used to manufacture nano-structured, functional layers (see Fig. 9). For example, catalytic layers are applied to filters and channels in micro-reactors using sputtering processes. The morphology of the nano-porous layer plays a key role.

In the Department of Shaping and Functional Materials at IFAM these technologies are summarized under the term "Functional printing". This area is complemented by so-called functional pastes, which can be applied to metallic components using sintering technologies. "Functional printing" hence represents a wide range of technologies for micro-structuring and nano-structuring.

This technology platform allows technological solutions for customized function-integration to be developed and allows favourable-cost utilization of the potential of nano-technology. The technologies allow a very wide range of mate-

Fig. 9: Structured, coated silicon wafer.

rials to be applied using printing technologies. In addition to metallic inks for conducting tracks, ceramic particles can also be printed. Biological molecules can also be printed using such technology (so-called "Tissue engineering"). "Functional printing" will be increasingly used in the future for making components and structures ever smaller, more multifunctional, more favourable in cost and more reliable to manufacture. "Functional Printing" hence fills the gap between nano-technological know-how and favourable-cost transfer to series production processes ("from smart materials to smart parts"). The technology transfer is accompanied by the development of special plants for manufacturing and integrating nano-scale materials into components and onto surfaces.

Value-increase via nano-technology

Nano-technology is already used today in a host of different products. For example, anti-soiling surfaces are due to nano-scale TiO_2 particles and silver-coated medical equipment keeps surfaces free of bacteria.

In addition to the technological advantages, of special interest to IFAM is the increasing debate about potential risks of nano-technology. To avoid inhalation of (nano-particles) particles, nano-scale suspensions are being manufactured. These liquids allow processing without risks and also bring technological benefits. The VERL process allows particles with highly active surfaces to be integrated into nano-composite materials in a customized way.

In the near future the printing of nano-structures and micro-structures will be increasingly used for the manufacture of electronic labels. They will improve the programmability and readability of the current RFID tags. Nano-technology will in the future give value-increase in the area of medical technology, car manufacturing and in the aircraft and aerospace industries. However, even the chemical industry and machine construction sector in general are already profiting today from new nano-technological concepts. The Fraunhofer IFAM is making a considerable contribution in this field.

Fig. 10: Printed structures made of resorbable bone material for implant applications.

Outlook

Potential of micro-structuring and nano-structuring

The Fraunhofer IFAM is functionalising surfaces and (miniature) components in a customized way using metallic powders (including nano-powders) and specific structuring. The resulting systems have increased value due for example to reduced wear, their antimicrobial design or their electrical conductivity. The technologies being used for this are being developed for industrial implementation and most are being integrated into existing processes. The Fraunhofer IFAM is hence making an important contribution to transferring micro-technology and nano-technology know-how into industrial production processes.

Future developments at the Fraunhofer IFAM in the area of micro-technology and nano-technology are becoming increasingly characterized by bionic issues. In addition to the expertise that is available for influencing cell growth and for antimicrobial surfaces, issues about the general self-organization of microstructures and nanostructures are being increasingly addressed.

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Materials for laser sintering

Background

Of the many laser-based, generative, near-net shape manufacturing processes, direct metal laser sintering (DMLS) is one of the most suitable rapid prototyping processes for the direct manufacture of powder-metallurgical components or mould inserts, so-called rapid tools, for plastic injection moulding and metal pressure casting. A disadvantage of this process is the limited range of materials that can be used. Up until now, only three powder materials have been commercially available for the DMLS process. These are multi-component powder mixtures based on bronze and steel having powder grain sizes between 20 and 50 microns.

Problem

The disadvantages of using these powders, in particular for toolmaking, are the high material costs and the susceptibility of steel-based laser sinter materials to cracking. Although extra effort with the data processing can reduce the probability of cracking, this is detrimental to the mechanical and thermal properties of the laser sintered components. Due to the composition of the alloys, there has up until now been no possibility of subjecting the laser sintered steel components to a heat treatment. Such a heat treatment would cure and temper the components to improve the mechanical properties.

Opportunity

Novel powder materials provide an opportunity to considerably reduce the product development time for P/M components and hence reduce the production costs. A precondition for cost and time savings is that the prototypes, test samples and series components are made of materials having identical properties. The aim is therefore to develop flexible material concepts for different production processes. For example, the first test samples can be made from a fine powder (particle size typically 20 µm) by laser sintering, so producing very high surface qualities. Pressing and sintering methods are chiefly used for the P/M production of large quantities of work pieces. For these processes, powders can be used which contain coarser particles but which otherwize have identical final properties.

Research potential/scale-up

It is known from the literature that a variety of different ferrous and non-ferrous powder materials can be processed by laser sintering. It has not however been hitherto possible to use conventional steel alloys, for example non-alloyed or low-alloy steels. By developing materials customized for the production process and subsequent areas of application, there was the opportunity to increase the range of materials for the rapid production of P/M components and at the same time to gain important knowledge about the laser sintering process and new potential materials.

The development of the novel materials for DMSL avoided polymeric or low melting point binder components which are present in the powder systems that have been commercially available up until now. This means that the good mechanical properties of the base steel material are not reduced by the lower strengths of the binder components (e.g. bronze). The role of the alloy elements carbon, phosphorus, copper, chromium, manganese and nickel on the density and microstructure after laser sintering was also investigated.

Further studies confirmed that post-sintering can completely eliminate the porosity of laser sintered structures and that heat treatment improves the strength and toughness. The mechanical properties were characterized in tensile and bending tests and by hardness measurements. The results showed that initially there is an inhomogeneous laser sintered structure composed of ferrite, martensite and bainitic microstructures. The laser sintered densities were 95–97% of the theoretical density. Post-sintering homogenized the microstructure and completely eliminated the residual pores. The high density of the components coupled with a low fraction of alloy elements in the steel guarantees high thermal conductivity for toolmaking.

Another key work area is improvement of the surface roughness. Approaches employed up until now have been based on optimization of the laser sintering parameters or the infiltration of porous structures, with in some cases lowering of the surface roughness. By using very fine starting powders, significantly better surface qualities can now be achieved. In addition, sintering in the semi-solid state is aided by customising the alloy composition. For example, very small quantities of liquid phase have been found to promote material rearrangement processes during the sintering.

The material development work has been customized for the direct laser sintering process for manufacturing moulds. However, the use of conventional powder-metallurgical powders also allows rapid, uncomplicated and favourably-priced manufacture of conventional P/M components in series production. The laser sintered structures are particularly suitable for use as mould inserts for plastic injection moulding and metal pressure casting as well as for the direct manufacture of individual components.

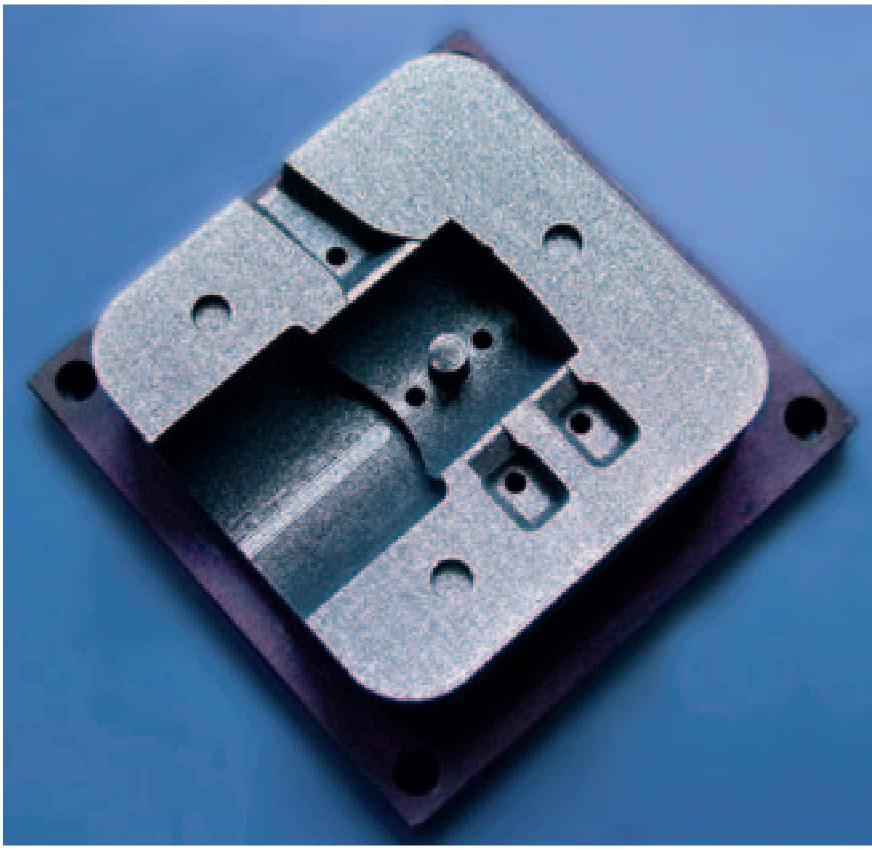

Fig. 1: Laser sintered component for pressure casting mould inserts.

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Vacuum SLS – laser sintering in the micro-range

Background

Selective laser sintering (SLS) is an established process for manufacturing components in a flexible way. Nevertheless, the use of this process does have its limitations: limited choice of materials, limited accuracy, long assembly times, post-treatment of components, internal stresses, heterogeneous microstructure, high degree of roughness and low structural resolution.

At the same time, there is a growing need in industry for micro-structured components. A modified SLS process for the micro-range would open up the possibility of manufacturing complex contoured components for micro-production. In micro-production the costs are largely dependent on the volume and the required resolution (number of layers), but not on the complexity of the components to be manufactured.

A project was carried out to investigate the suitability of selective laser sintering in a vacuum (Vacuum SLS) for manufacturing such components. By carrying out the SLS process in a vacuum it becomes possible to process micro and sub-micro sized powders. Until now no concepts for the selective laser sintering of sub-micro sized powders have been able to be implemented on an industrial scale. The use of considerably finer powders than has hitherto been possible allows the extension of the application of the SLS process for the manufacture of individual structures down to the micro-range. This should also allow surfaces and edges with a roughness in the micron region to be manufactured for the first time.

An SLS process for producing structures in the micro and miniature range should provide an effective means of manufacturing components which, due to their size and tolerances, are either impossible to manufacture using conventional processes or which can only be manufactured with difficulty.

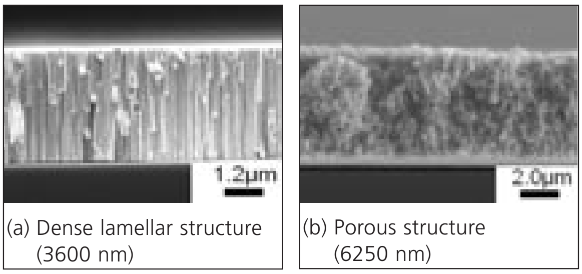
Project

In order to meet the demand for shorter product manufacturing times, the cost and quality of not only milling processes but also generative processes must be improved. Within the framework of this project, this will be achieved by developing a novel SLS process specially designed for the micro-range. The initial focus on small components allows the vacuum sintering process to be studied with only limited costs. Later scale-up of the process to large components is possible. Concepts for large building volumes in vacuum already exist.

The aim of this research project was to develop a novel technology for the generative manufacture of micro-structured components or moulds from metal and ceramic materials.

Project description/implementation

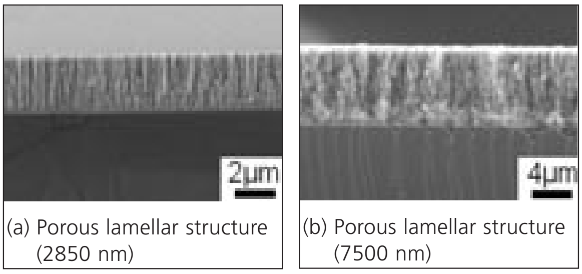
A joint project was carried out at IFAM to develop a novel concept for applying very thin layers of very fine powders (grain size smaller than 10 µm down to nano-scale powders). This project covered plant, material, software and process development activities. This process allows layer thicknesses in both the micron range and in the nanometre range to be realised. The application of the powder is not carried out by blade coating, but via a sputtering process. Various sputter targets were chosen. Depending on the parameters chosen for the sputtering, there were clear differences in the resulting morphological structures. The differing structures (dense and porous) obtained for sputtered gold layers are shown in Fig. 1.



(a) Dense lamellar structure (3600 nm)

(b) Porous structure (6250 nm)

Fig. 1: SEM micrographs of gold layers on silicon, sputtered under different argon pressures.



(a) Porous lamellar structure (2850 nm)

(b) Porous lamellar structure (7500 nm)

Fig. 2: SEM micrographs of tungsten/copper layers on silicon, sputtered under different argon pressures.

Laser sinter tests at one of our project partners, Hochschule Mittweida/Laserinstitut Mittelsachsen, showed that the porous powder-like layer shrank considerably on sintering. However, as this shrinkage is not refilled during the sputtering process, as is the case in the blade coating method, it is difficult to manufacture components that consist of several layers. For that reason, dense layers were usually applied by sputtering. These more dense layers shrank less during the laser sintering process; at any rate, the non laser-sintered material was much more difficult to remove.

Further experiments were carried out using tungsten/copper (W 80%, Cu 20%) as the sputter target (see Fig. 2). The experiments showed that layers of 100 nm can be applied by sputtering in a few seconds. The sputtered W/Cu layers are homogenous, the structure is in between an open porous powder layer and a solid layer. It hence shrinks much less during laser sintering than the porous gold layer and the non laser-sintered material can be removed correspondingly easier than the dense gold layer. As the surface of the sputtered W/Cu layer only has roughness of a few nanometres, the sputtering process with the W/Cu target is suitable for applying fine powder layers.

The sputtering process is hence an alternative to the blade coating of ultra-fine powders. Moreover, the sputtering process can be used to produce considerably thinner layers than is possible using the blade coating process. Layers of small thicknesses can be applied rapidly by sputtering. Another major advantage is that a wide variety of metal powders can be manufactured using the process and hence this obligates the need to purchase expensive ultra-fine special powders. Integration of the sputtering mechanism into the existing plant concept was not possible within the scope of this project.

The result of this joint project is an SLS process which allows ultra-fine metal and ceramic powders to be sintered, so enabling microcomponents to be produced of hitherto unattained resolution and quality.

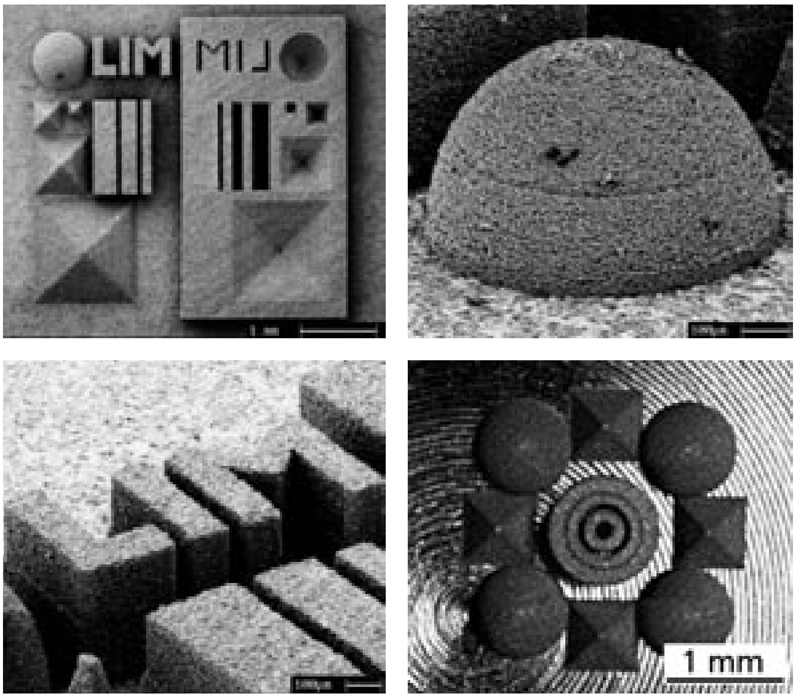


Fig. 3: Sample Structures.

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Project funding

BMBF framework programme “Production for tomorrow”
Joint project: Vacuum SLS

Project partners

Hochschule Mittweida/Laserinstitut Mittelsachsen
Fraunhofer IKTS, Dresden
Fraunhofer IWU, Chemnitz
3D-Micromac AG, Chemnitz
IVS Solutions AG, Chemnitz
EGT GmbH, Mittweida
Portec GmbH, Zella-Mehlis
MiLaSys GmbH, Stuttgart

The vacuum SLS process was awarded the silver EuroMold-AWARD 2004 at the EuroMold fair in Frankfurt.

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APM aluminium foam: reproducible properties, flexible to produce and easy to use

Foamed metals are being increasingly used for lightweight construction. The development of the second generation of metal foams has given rise to a new process which allows flexible and low cost production of components. Ideal conditions have been created for easy and rapid technology transfer to industry, and in particular to small and medium-sized companies.

Background

The powder metallurgical process for foaming metals was rediscovered some 15 years ago at the Fraunhofer IFAM in Bremen and developed into an application-ready technology. The process patented under the name FOAMINAL® for manufacturing complex, 3-dimensional, shaped metal foam components is excellently suited for large series production. Due to the near net shape component manufacture, finishing steps are either avoided or reduced to a minimum. The process was adopted by industry and today a variety of companies are able to offer users of metal foams a broad spectrum of services that range from component development right through to large series production. Currently first metal foam products are in production and use.

Process analysis and project

In order to promote and support these positive trends in metal foam technology, the Fraunhofer IFAM in Bremen operates a continuous process analysis. Based on the results, there is focussed further development of the total process and the individual steps.

There is a large market for aluminium foam as a lightweight core material for hollow structures (e.g. aluminium foam filling in structural body components). This demand is met in part by aluminium foam components manufactured using the FOAMINAL® process. From discussions with customers it became clear however that there is a need for optimization of the robustness, flexibility and cost of the process in order to be able to open up further market segments.

Solution

The Fraunhofer IFAM is able to provide a solution to the aforementioned issues by separating the two main steps of the near net shape process for manufacturing aluminium foam components.

In the Advanced Pore Morphology (APM) process the
- foam expansion and
- foam part shaping

steps are separated from each other and carried out asynchronously. An APM aluminium foam component consists of numerous small-volume foam elements which are connected to each other by a simple joining operation (e.g. adhesive bonding).

Fig. 1: Cross-section of an APM aluminium foam element.

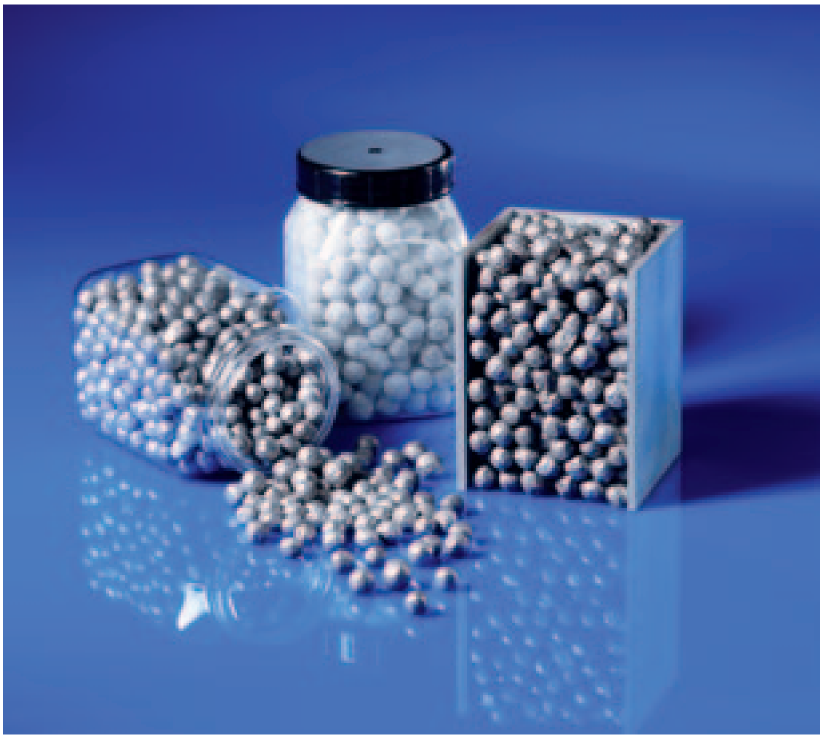

Fig. 2: APM aluminium foam elements (left) with adhesive coating (center) and a filled hollow section (right).

Fig. 3: Finished component.

An individual foam element is produced by expansion of a particle of granulated foamable precursor in a furnace. The expanded foam element can for example be coated with a thermoplastic adhesive in a subsequent process. If a number of such coated elements are placed in a mould or hollow structure and heated, the adhesive coating melts. The adhesive coating bonds at the contact surfaces of two adjacent elements, and after cooling a "bonded" foam element bed is achieved. This is the APM component or APM filled composite structure.

Results

The described process creates ideal conditions for easy and rapid technology transfer to industry, and in particular to small and medium-sized companies.

- Both main process steps are reduced to easy controlled processes which can be carried out under optimum conditions.
- Due to the good process control, the properties of the APM metal foam components show excellent reproducibility.
- APM aluminium foam has the same properties as FOAMINAL® at the same density.
- A production line for APM components can largely be constructed from commercially available standard components (handling equipment, belt furnace, etc.).
- Each type of foam element (matrix material, volume, shape, density) can be used for a variety of different applications and APM components.
- End-users do not necessarily have to acquire knowledge about metal foam expansion because they can manufacture metal foam components using a relatively simple joining operation (e.g. adhesive bonding).
- The universal applicability of standardized foam elements gives maximum production flexibility for short-term changes to component geometry.
- There is a significant increase in the overall efficiency and as a result a considerable reduction in costs.

Fig. 4: Design freedom with APM aluminium foam elements.

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Applications of foamed metals in mobile machinery

Background

New lightweight construction materials are currently the focus of a great deal of research and development work all over the world. Such materials should ideally have excellent energy absorption capacity, high rigidity per unit weight and good mechanical and acoustic damping properties. Foamed metals essentially possess such a spectrum of properties. This is the reason why intensive work is being carried out on the use of metal foams in vehicle technology, with particular attention here being on aluminium foams.

Fig. 1: Concrete pump with extended distribution mast.

The BMBF funded ULMA project (ultra lightweight construction of mobile machinery) aims to considerably extend the functionality of mobile machinery by increasing the reach, adjustment speed, positioning accuracy and bearing loads with simultaneous improvement of the dynamic positional stability and driving dynamics. Less usage and consumption of materials, with a target weight reduction of > 20%, should lead to compliance with axle load limits with simultaneous benefits from the extended working functions of the mobile machinery.

Project

One of the aims of the IFAM sub-project "Applications of foamed metals in mobile machinery" (funding reference 02PP2494) was to prepare prototype components for testing and practical trials by the other project partners. The selected demonstration objects included the distribution mast of a concrete pump (see Fig. 1). Such a distribution mast consists of hollow steel constructions which must be designed such that they do not buckle or kink when under maximum load. The use of aluminium foam components as strengthening elements for these masts was to be investigated.

Other work included carrying out the necessary component-related feasibility studies and further development of customized production technologies for manufacturing metal foams and creating metal foam joints. In addition, both the foamable and foamed materials were characterised and material parameters were determined.

Fig. 2: Demonstration object "concrete pump distribution mast" at the BAUMA 2004 fair (above: overview, below: close-up).

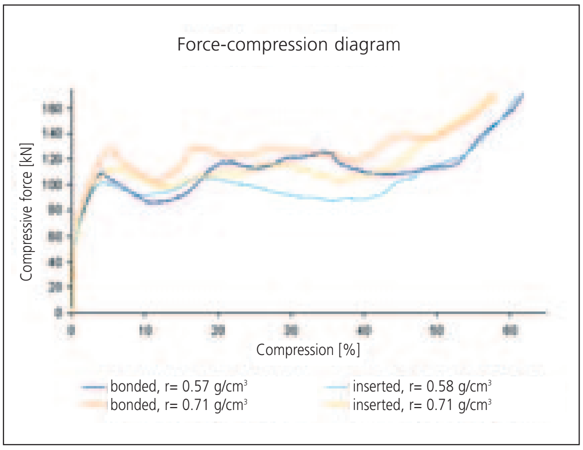

Fig. 3: Compression tests on foam-filled sections with bonded and inserted foam cores.

Results

In order to determine the mechanical properties of foam-filled steel components, two process variants were used: firstly direct foaming inside of the relevant component and secondly manufacture of a foam object in a suitable foaming mould with subsequent adhesive bonding of the foam core into the respective steel component as a strengthening element. The components were tested by the project partners. The mechanical tests were very encouraging, so the demonstration object was set up and exhibited at the BAUMA 2004 fair (see Fig. 2).

A synergistic effect was observed during the mechanical testing of the foam-filled hollow sections. In all cases the foam-filled structure showed a higher force level than the sum the individual components (foam and section) would correspond to, and always developed more folds during buckling. Comparison of bonded and inserted foam cores in the same aluminium sections showed that the bonded foam cores were always superior to the inserted cores (see Fig. 3).

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Mg chassis project

The main aim of the Mg chassis project is to develop alloys and a suitable manufacturing process for large series production of lightweight chassis components made of magnesium.

Background

Car manufacturers are increasingly using lightweight construction materials such as aluminium, magnesium and novel composite materials. Magnesium, in particular, holds much promise for weight reduction. Depending on the particular alloy, it has a specific weight of only 1.74 g/cm^3 and is hence the lightest metallic construction material. There is also a desire in other sectors to use more and more lightweight components, for example for laptops, mobile phones and recreational and sports equipment.

The importance of magnesium has increased considerably in recent years due to its very low density, high weight-strength ratio and ability to provide electrical-magnetic shielding. Magnesium is widely available and easy to recycle.

In order to meet the requirements for series production, a substantial amount of process development work and the development and testing of new magnesium alloys are necessary.

The mechanical properties of magnesium alloys that are currently commercially available mean these materials are not suitable for thick-walled components. Thick-walled components that are subject to high stress are preferably cast using the cold chamber process. The mould tempering, molten metal treatment and inert gas treatment in the currently used production method must also be improved in order to produce magnesium components of suitable quality.

Aim of the project

Besides undertaking specific work packages, the "Light metal casting" work group at Fraunhofer IFAM has also taken over the co-ordination of the EU project "Mg chassis". The aim of this project is to increase the industrial use of cast, thick-walled, chassis components made of magnesium.

The EU project "Mg chassis" involves 9 partners from industry and research in 4 countries and is addressing a variety of issues relating to the processing of magnesium alloys.

The aim of the project is to develop a cost-effective casting method for chassis components using novel alloys. The properties of the materials must be equivalent or superior to those of the commercially available AZ91 alloy. The project work covers the drawing up of design guidelines, alloy development, process development and process selection, corrosion studies and mechanical and component tests. The effect of the innovative post-treatment technologies Liquid Hipping and Flow Forming on the mechanical and physical properties of magnesium alloys is also being investigated in this project.

Using three demonstration components which are not subjected to high thermal loads (VW gear bracket, Opel engine bracket, Fiat engine bracket), the suitability of different casting processes will be evaluated.

Fig. 1: Gear bracket.

Results

AZ91, AM50 and four newly developed alloys with improved mechanical properties and corrosion resistance were cast by squeeze-casting and pressure casting.

One partner is working in the area of sand casting with an improved, commercial alloy for gravity die casting.

The demonstration objects were evaluated with regard to their ability to be cast, the mechanical properties of the samples and cast components, corrosion and cost. As improved joining techniques for magnesium components with other metals, and in particularly with aluminium and steel, are also a key objective, the demonstration components were tested for contact corrosion in combination with these metals.

The results of all casting experiments and tests are used to set up a database which is being developed as part of a separate work package.

The project will be concluded at the end of 2005 with a final report.

Project partners

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Fraunhofer LBF, Germany
Centro Ricerche Fiat, Italy
Magnesium Research Institute, Israel
Swedish Corrosion Institute, Sweden
Adam Opel AG, Germany
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Cellular metallic materials – state of technology and perspectives

Introduction

Cellular metallic materials (CMMs) are a new class of materials which have been the focus of numerous scientific studies over the past few years. The increasing interest in CMMs is principally due to the fact that the introduction of pores into the materials significantly lowers the density. These highly porous materials also possess combinations of properties which are not possible to achieve with other materials. Besides the drastic weight and material savings that arise from the cell structure, there are also other application-specific benefits such as noise and energy absorption, heat insulation, mechanical damping, filtration effects and also catalytic properties. Cellular metallic materials are hence multi-functional lightweight construction materials.

Due to the increasing importance of weight-saving, in particular in the car manufacturing industry, in the aircraft and aerospace industries and for machine, plant and equipment construction, the last 20 years have seen a host of R&D programmes (DFG, EU, USA, Japan) to develop cellular metallic materials and these have also resulted in new methods for their manufacture.

In principle, CMMs can be manufactured from the gas, liquid or solid phases. Current the most advanced methods involve melt-metallurgical processes (see also the trend report on aluminium foam technology, IFAM annual report 2003, pages 60–62).

State of technology

IFAM (Dresden facility) is currently pursuing 4 different technologies for manufacturing CMMs (see Fig. 1):

- Hollow sphere structures;
- Fibre structures;
- Open-celled foam structures;
- Direct typing structures.

These technologies cover a wide range of cell sizes (5 µm–10 mm), porosities (50–97%) and materials enabling a broad spectrum of material properties to be produced and hence a wide range of potential applications to be explored.

Hollow sphere structures

Development work on hollow metallic spheres and hollow sphere structures has been carried out for the past 5 years. The three-step manufacturing process involves coating Styropor spheres with metal powder, a shaping step and a polymer-removal and sintering step. Features

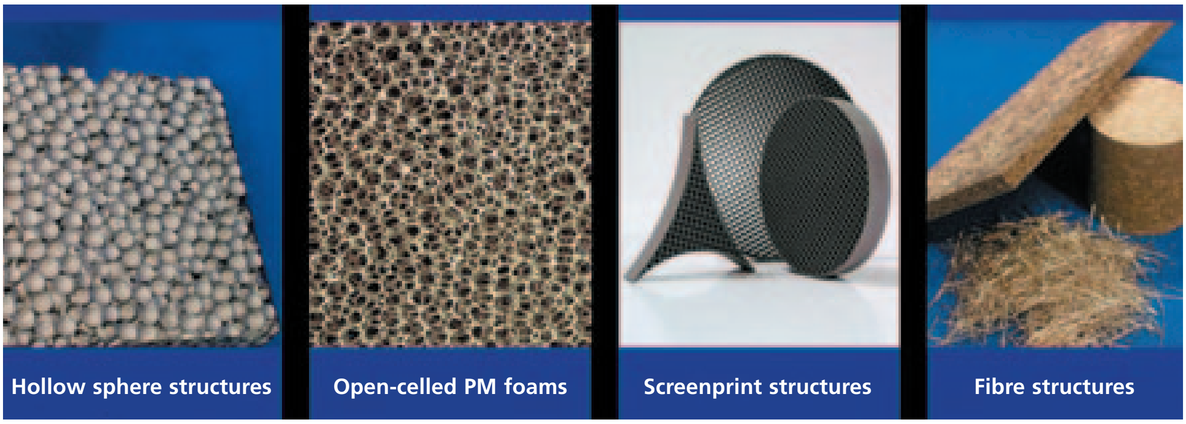

Fig. 1: Cellular metallic materials prepared at IFAM Dresden.

of the manufacturing process are its suitability for a wide range of materials and a broad cell size spectrum (0.5–10 mm). Our results show that hollow sphere structures have excellent energy absorption properties, very good noise absorption and good heat insulation capacity.

Due to the very good noise absorption properties of hollow sphere structures, work has been carried out with an industrial partner, Arvin Meritor Zeuna Stärker GmbH (Augsburg), to fit test cars (BMW, Skoda Oktavia) with hollow sphere silencers. Results obtained to date show equivalent or better noise absorption than a reference silencer (glass fibre), with at the same time a weight-saving of up to 30%!

Studies on the heat conduction properties of hollow molybdenum spheres (partner: Plansee AG) showed the spheres possessed only around 1% of the heat conduction capacity of compact molybdenum (see Fig. 2). This opens up new opportunities for high temperature insulation due to the "self-supporting" nature of the hollow sphere structures.

The advanced state of development work and the application opportunities for hollow metal sphere structures is such that industrial implementation is planned by our industrial partners Glatt GmbH und Plansee AG (→ hollomet®) in the next 2 years.

Fibre structures

High-porosity fibre structures have been a subject of development work at IFAM Dresden for more than 10 years. The focus has been on the manufacture of unique fibres using the melt-extraction principle. This involves extracting fibres from the melt bath surface being in a single processing step using a so-called melt-extraction wheel. The process-related rapid cooling (up to 10^5 K/s) of the fibres (fibre thickness 30–200 µm) allows unconventional fibre materials (e.g. nickel aluminides) having microcrystalline/amorphous structures to be prepared. The fibres that are recovered can be processed into a fibre-web using suitable processing technology. This is then sintered to give the final shape and material properties.

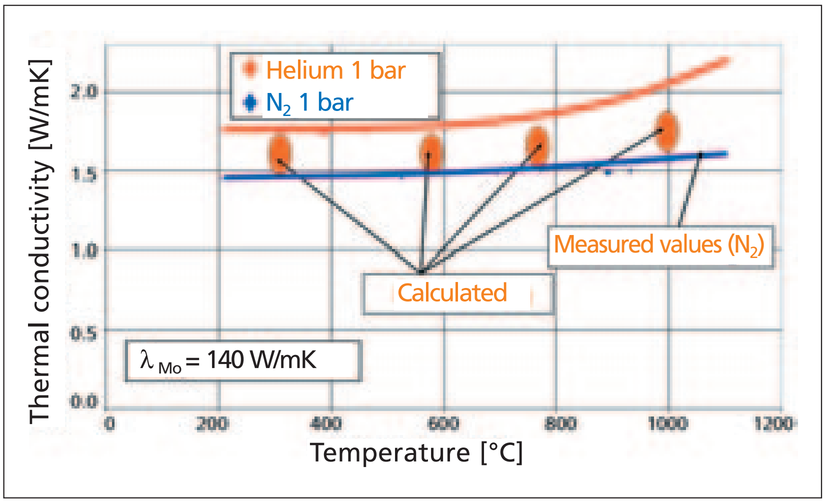

Fig. 2: Heat conductivity of hollow molybdenum spheres (sphere diameter 4 mm) of density 0.3 g/cm³ as a function of temperature.

Over the last 10 years R&D studies have been undertaken in the following fields of application:

- High temperature filtration;
- Catalyst support materials, particle filter for diesel engines;
- Heat exchangers;
- Fuel cells;
- Catalysts;
- Heat protection, flame protection;
- Explosion protection.

In particular, the fibre-based heat exchangers, fuel cells, catalysts and explosion protection materials (see Fig. 3) have proved very promising for industrial applications. IFAM hence intends to establish a business field in this area within the next 2 years (→ HIGHPOR®).

Open-celled foam structures

Development activities on open-celled, powder-metallurgical (PM) foam structures have been carried out for about 2 years in conjunction with the Fraunhofer Institute for Ceramic Technologies and Sintered Materials (IKTS). The latter already had a number of years experience manufacturing open-celled ceramic foam materials. In contrast to open-celled fibre structures (pore size 5–300 µm), pore sizes of ca. 0.2–5 mm can be achieved with PM-foams. As the process for manufacturing PM-foams involves powder-coating polyurethane (PU) foams, its suitability for a wide range of materials

Fig. 3: Explosion-proof element made of sintered fibre structures (in co-operation with KEK GmbH).

is guaranteed. In addition the PM coating technology of PU-foams allows the development and manufacturing of net shape components. Features of open-celled PM-foams are their high permeability (see Fig. 4), high specific surface area, good heat exchange properties and high noise absorption capacity. Due to the defined PU-foam structure, a high degree of reproducibility and homogeneity can be achieved.

Direct typing structures

The most recent CMM development work has involved the manufacture of high-porosity metallic direct typing structures. The base manufacturing process (patent rights held by Bauer RAD, Darmstadt) involves layer-wise build up of the structure by direct typing. The structuring itself is achieved by mask variation.

After layer-wise generation of the structure, a subsequent polymer-removal and sintering step is necessary. The advantages of the process are the large shape diversity (see Fig. 5), precise and dimensionally stable structures, whose properties can be calculated/predicted, and the development of real 3-D structures. Potential applications for such cellular structures are mainly in microsystems technology, micro-mechanics, heat exchangers, bio-implants, high-precision lightweight construction, catalyst support materials and fuel cells.

Joint development work is currently being carried out with Bauer RAD, which has granted IFAM exclusive permission to use the direct typing process for manufacturing metallic materials.

Perspectives

Cellular metallic materials are a relatively new class of materials. Currently there are very few products made of CMMs and applications of CMMs (Al-foam: Alulight (Ranshofen) and Cymat AG (Toronto); Alporas: Shinko Cuore (Japan); open-celled cast foam: m.pore (Dresden), ERG (Orlando)). The main reasons for this are the poor familiarity of people with CMMs and the high cost which has hitherto prevented large scale applications in for example the car manufacturing industry. A key objective of IFAM is hence to create greater awareness of the properties and uses of this class of materials amongst users. This will be achieved amongst other things by setting up a Demonstration Center for Cellular Metallic Materials at IFAM and work on this is currently underway.

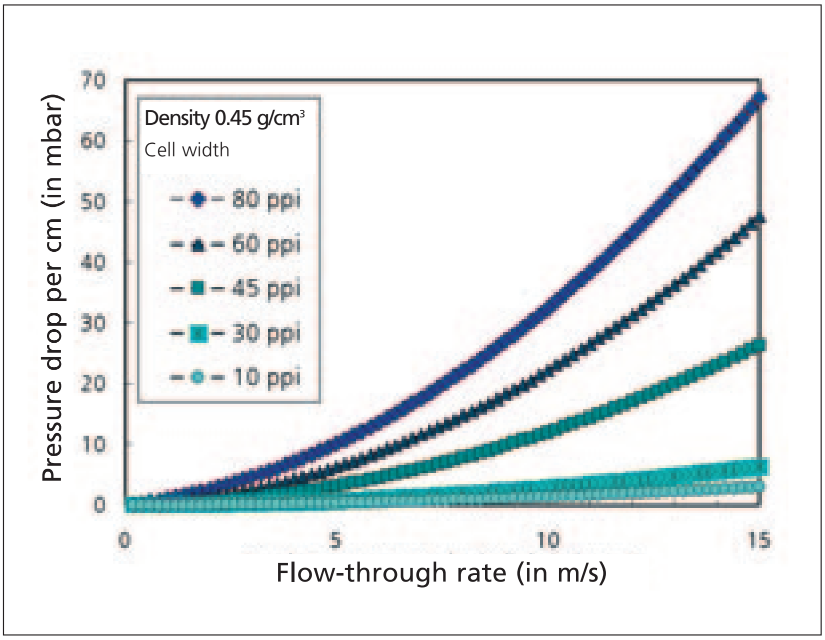

Fig. 4: Permeability of open-celled high-alloy steel foams (316L) as a function of the cell size, for a structure density of 0.45 g/cm^3.

The CMMs currently being developed at IFAM Dresden cover a wide range of materials and structures. Future R&D will focus on:

- The development of graded-structured hollow sphere, fibre and open-celled materials:
  - e.g. for optimum energy dissipation;
  - e.g. for filter elements, combined with catalytic properties.
- The development of closed-celled hollow sphere structures with optimized component properties.
- The development of composite materials made of hollow sphere/fibre/open-celled foams:
  - expansion of the property spectrum.
- The development of coated hollow sphere, fibre and open-celled foams using chemical, galvanic technologies or processes from the gas phase:
  - increasing the functionality;
  - cost-reduction by using favourable-cost support materials.
- The modelling and simulation of the material properties:
  - calculating/predicting the properties of CMMs.
- The design of components made of CMMs.
- Studies and R&D work on new manufacturing technologies, in particular for polymer-removal and sintering:
  - spark plasma sintering;
  - microwave sintering;

  as well as for the manufacture of 3-D net shape components from fibres:
  - wet webs.

Cellular metallic materials have a promising future. This is on the one side due to the demands of industry for weight-saving, particularly in the car manufacturing industry, which allows material and energy savings to be made and hence results in lower resource usage. In addition, the broad range of properties of CMMs should allow existing products to be improved and completely new products to be developed and manufactured, for example heat-resistant noise absorbers, filter elements with a combined catalytic function, bio-analogue materials for replacing bone and self-supporting high temperature insulation materials.

Fig. 5: Cellular direct typing structures made of high-alloy steel.

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Studies on the microwave sintering of powder-metallurgical materials

Background

Studies have already been carried out on the microwave sintering of a variety of powder-metallurgical systems such as PM-steel, bronze, copper and metal-ceramic materials. The general trend observed here is that microwave radiation allows lower sintering temperatures. In addition, so-called non-thermal contributions of the electromagnetic alternating field to the material transport (corona discharges, ionisation processes, etc.) often bring improvements to the mechanical properties (e.g. ductility). The increase of the electrical field strength in the pores of a powder-metallurgical component is independent of any simultaneous induction heating that takes place. As compact metals only have a small penetration depth for electromagnetic radiation with centimetre waves (in the region of µm), this effect is especially important for powder-metallurgical green bodies. Microwaves can also contribute to a mild and rapid binder removal from green bodies before the sintering. Due to the volume heating typical of microwaves, the temperature gradients in the work piece are reduced, meaning that the removal of the binder can take place more quickly.

On the basis of these very promising, albeit sometimes contradictory, evaluations of the microwave sintering of powder-metallurgical materials, IFAM designed and constructed a microwave sintering furnace. The design of the furnace and microwave technology was undertaken in close collaboration with Innovative Verfahrenstechnik InVerTec e.V., Bayreuth, and GERO Hochtemperaturöfen, Neuhausen. The plant was assembled and brought into operation at IFAM Dresden at the start of 2004.

Project

The aim of the project was to install the furnace and bring it into operation, to study the effect of MW radiation on selected PM materials and to optimize sintering procedures to produce high quality materials. In order to achieve these objectives, extensive work was carried out to calibrate the contact-free, pyrometric temperature measurement.

From a materials point of view, the main focus was on further tests on PM steel and Co-containing composite materials (e.g. Co/diamond cutting materials).

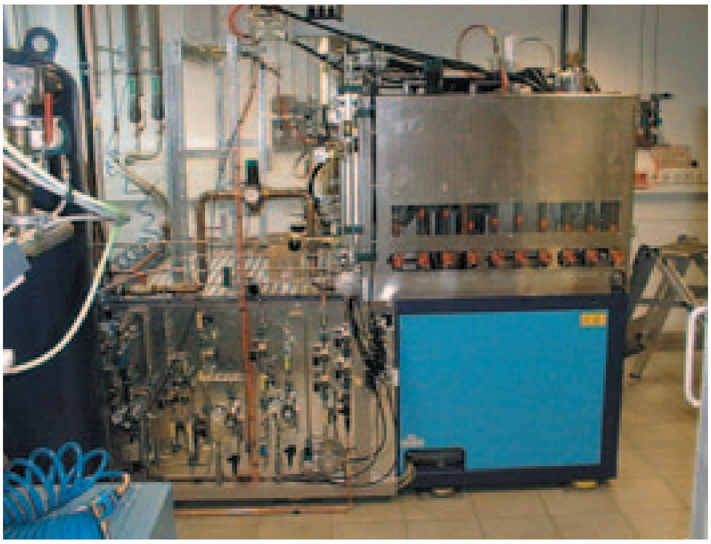

Fig. 1: The microwave hybrid chamber furnace MIHTK 60/17 Mo.

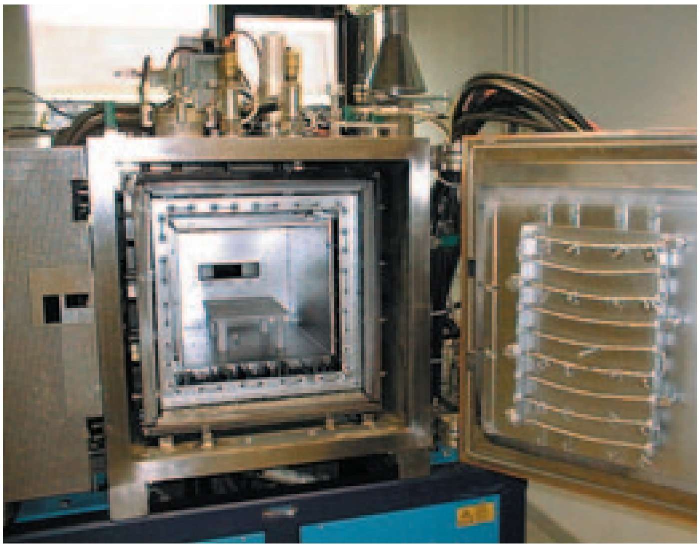

Fig. 2: View of the open resonator of the microwave sintering furnace with single charging stand made of hBN.

Description of the project

Based on existing data on the microwave sintering of metallic materials, a furnace design was chosen which allowed as wide as possible a spectrum of metallic materials and composite materials to be heated and sintered.

This comprized a cold wall – chamber furnace (type MIHTK 60/17 Mo, GERO Hochtemperaturöfen GmbH, Neuhausen) with a hot wall-multimode resonator (ca. 50 l useful volume) made of molybdenum (see Fig. 1 and Fig. 2). Conventional heating was achieved with Mo-heaters (150 kW) and the microwaves were generated by a 6 kW magnetron (2.45 GHz) via waveguide.

This design, with no ceramic insulating materials in the inner space, allows defined atmospheres to be set. Due to the explosion-proof design, binder removal and sintering of components in an inert gas, vacuum and also hydrogen is possible up to a temperature of 1700°C.

The pyrometric temperature measurement must be as accurate as possible, for both conventional heating and also for heating in a microwave field. Only then is there a guarantee of reproducibility and comparability between these heating processes. For that reason, for each material under test extensive calibration of the temperature measurements was carried out. The results showed that the emissivity of green bodies during the heat treatment fall to a limit value due to the increasing reflectivity. This value depends on other factors such as the green density (and hence the porosity of the surface) and the colour (see Fig. 3 and Fig. 4).

Various material systems were evaluated in preliminary experiments, usually in collaboration with partners from industry. In addition to PM steel and PM aluminium, soft and hard magnetic materials, high temperature materials and diamond/Co composite materials were tested.

Using the example of diamond /Co cutting materials, Fig. 5 shows the sinter density of materials sintered by conventional means and microwave-aided. Within the electromagnetic alternating field, the cutting attachments sinter considerably faster than when other methods

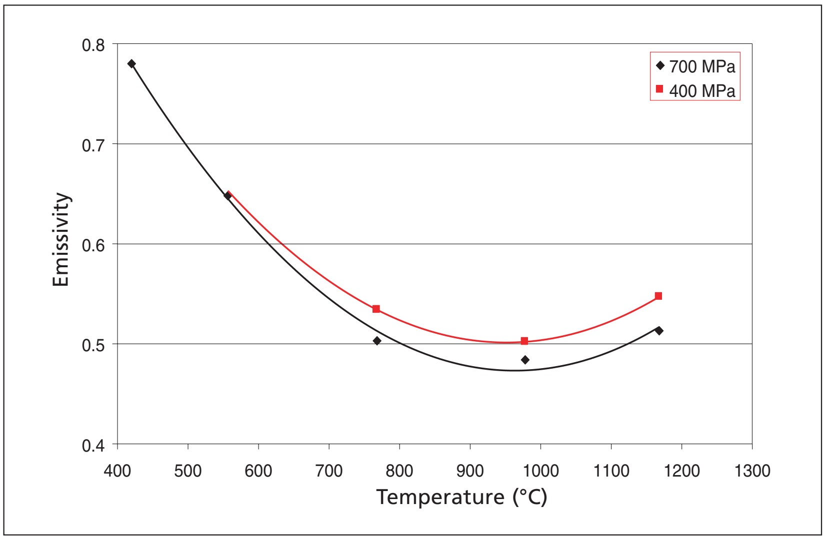

Fig. 3: Effect of temperature on the emission levels of PM steel (Distaloy AE + 0.5% C, Höganäs AB) for different mouldet densities.

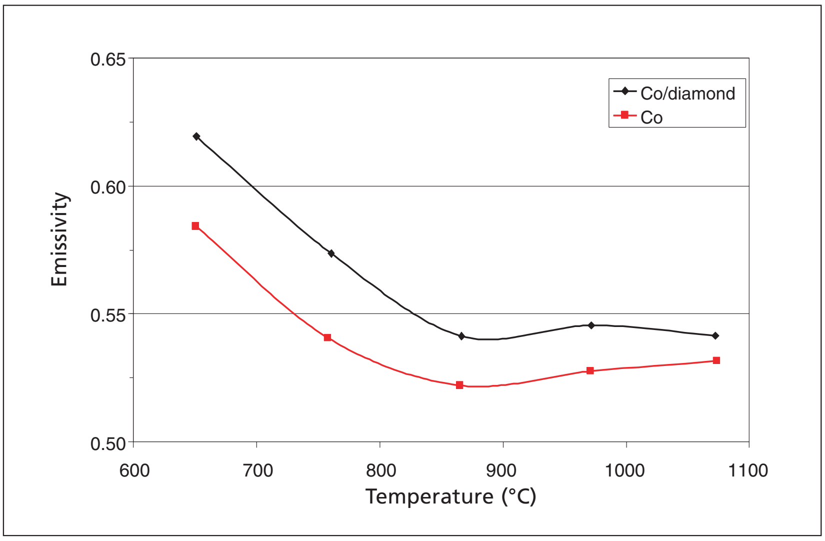

Fig. 4: Effect of temperature on the emission levels of pure Co and a Co/diamond composite having the same mouldet densities.

are used. For these materials, the focus is on rapid sintering at temperatures as low as possible in order to avoid damage to the diamond cutting phase.

In addition to testing other relevant material systems, future work will include the microwave sintering of cellular materials (e.g. hollow sphere structures). Due to their low green density and the associated high penetration depth for microwave sintering, it is expected that these materials will give interesting effects and results. The use of microwaves for removing binders from high-porosity materials holds the promise of considerably shortened processing times because it should be possible, due to the volume heating, to achieve complete binder removal without local temperature hotspots.

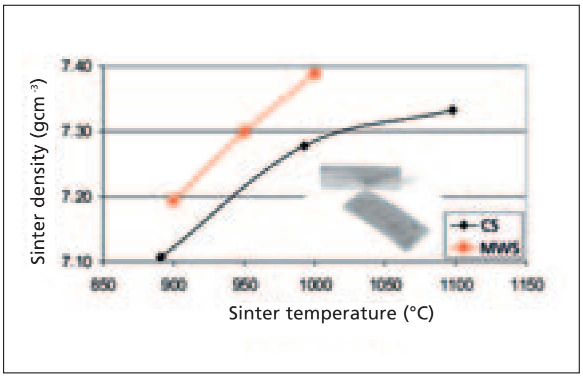

Fig. 5: Sinter density of a diamond/Co composite after 30 minutes sintering under conventional conditions and under microwave-aided conditions.

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Short metallic fibres as catalysts for oxidative dehydrogenation in the gas phase

Background

Propene is an important raw material for the chemical and plastics industries. The required quantities of propene are costly to produce and usually involve steam-cracking processes. Other processes that can be used include catalytic dehydrogenation and catalytic cracking. Oxidative dehydrogenation (ODH) of propane is in theory a favourably priced means of obtaining the necessary quantity of propene. However, up until now research to find suitable catalysts and reaction conditions has not resulted in a major breakthrough. The ODH of isopropanol to acetone serves as a model reaction for ODH reactions of higher alcohols.

Oxidative dehydrogenation of low molecular weight hydrocarbons and alcohols requires specific reaction conditions in order to prevent the oxidation reactions going to completion. It has proved beneficial to keep the oxygen concentration of the educt gas flow low. In addition, short residence times on the catalyst are required. This is achieved by using catalysts with a low specific surface area. The catalysts must also have a low pressure drop across their beds in order to allow rapid and uniform throughflow of the educt gas. Efficient heat removal from the catalyst bed is also advantageous in order to prevent localized hotspots.

Project

As part of a project funded by the BMBF, the effectiveness of ten different catalysts for oxidative dehydrogenation were tested. All the catalysts comprized short metallic fibres. The fibres gave a low pressure drop across the catalyst bed and they had low but adequate specific surface areas. The ability to vary the composition of the fibres to virtually any desired combination of catalytically active metals is beneficial.

The specific work of IFAM involved selection of the materials, manufacture of the short metallic fibres using the crucible melt extraction method and characterization of the materials before and after catalytic testing. The actual catalytic testing of the short fibres was carried out at the Institute for Technical Chemistry and Environmental Chemistry at the Friedrich Schiller-University, Jena, using suitable test equipment (see the article published in Chemie Ingenieur Technik 2004, 76, No. 6, 693-699). The selection of the alloy components for the fibres was based on known mixed oxide oxidation catalysts. However, in this work the active components in the catalysts were present in metallic form. From a materials science point of view it was also interesting to investigate the effect of the structure (crystalline, amorphous, quasi-crystalline) on the catalytic properties.

Results

The key results of this work are described here using selected materials (see Tab. 1). The catalysts made from Cu_3Sn and CuNiMnFe have a crystalline structure, the AlCuFe fibres are quasi-crystalline and the CuTiNiZrSn fibres have an amorphous base structure with crystalline segregations. In order to tailor the quasi-crystalline structure, the AlCuFe fibres were heat-treated at 720°C after the melt extraction.

Catalyst	Composition	Average fibre size		Specific surface area	Propane: ODH	Isopropanol: ODH
	[Wt. %]	Length [mm]	Diameter [µm]	[m²/g]		
Cu_3Sn	Cu 61.9 Sn 38.1	5.27	70.0	0.0103 (BET) 0.0061 (opt.)	-	++
CuTiNiZrSn	Cu 39.94 Ti 22.58 Ni 13.83 Zr 14.33 Sn 9.32	9.47	95.0	0.0277 (BET) 0.0052 (opt.)	+	++
AlCuFe	Al 42.40 Cu 40.75 Fe 16.85	10.26	138.0	0.0418 (BET) 0.0104 (opt.)	++	-
CuNiMnFe	Cu 64 Ni 28 Mn 7 Fe 1	10.30	81.6	0.007 (opt.)	+	++

Tab. 1: Composition of the fibre catalysts and their effectiveness for oxidative dehydrogenation of propane and isopropanol.

The specific surface areas of the fibres were determined by gas adsorption (BET method) and analytical evaluation of images of the cross-sections of the fibres (optical). The considerably higher BET value for the AlCuFe fibres is due to the finely structured porous surface of the quasi-crystalline fibres. SEM and EDX show there is a nanometre thin oxide layer on the surface (see Fig. 1). Fig. 2 shows the fibre surface after the catalytic testing and this shows the same finely structured surface as the starting material.

The quasi-crystalline AlCuFe fibres were particularly effective for the oxidative dehydrogenation of propane to propene, with high propene selectivities and simultaneously high conversions (see Fig. 3). The other Cu containing catalysts were also suitable for oxidative dehydrogenation, but gave considerably lower conversion.

The stability studies that were carried out and the characterization of the AlCuFe fibres after use showed that the catalyst has excellent stability and retains its high catalytic activity. Some of the catalysts showed excellent conversion and selectivity for the selective oxidation of isopropanol to acetone (see Tab. 1). Using these catalysts, virtually 100% conversion can be reached at 380°C with simultaneously high acetone selectivity, as exemplified in Fig. 4 for the CuTiNiZrSn fibres.

It is believed that the melt-extracted short metallic fibres have high potential as catalysts for typical industrial processes for oxidative dehydrogenation due to the ability to customize the composition of the alloys and hence optimize their structure, surface morphology and specific surface area.

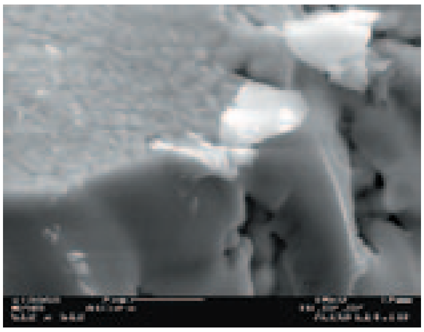

Fig. 1: SEM micrograph of the fracture surface of an AlCuFe fibre before the catalytic reaction.

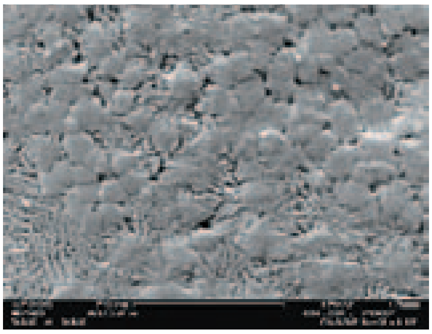

Fig. 2: SEM micrograph of the surface of an AlCuFe fibre after 5 test cycles (ODH of propane).

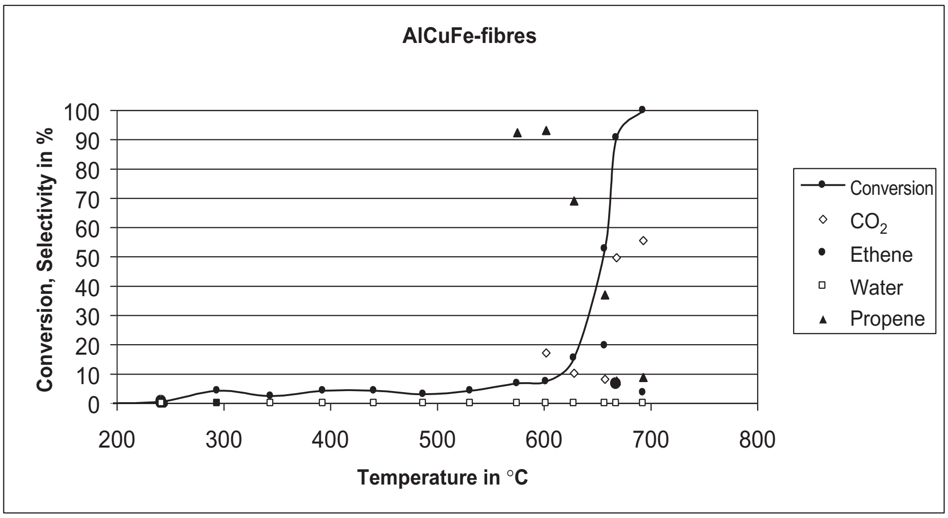

Fig 3: Conversion and selectivity as a function of temperature for gas-phase ODH of propane on AlCuFe fibres.

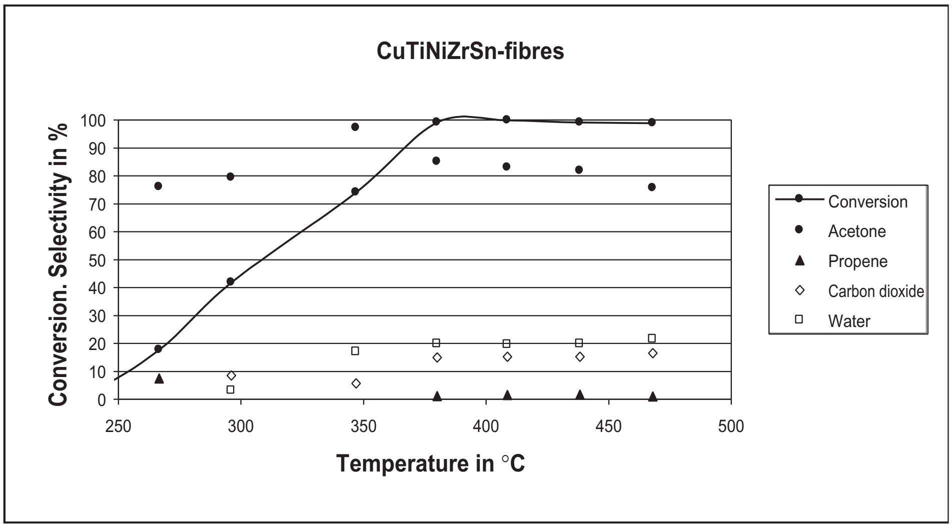

Fig 4: Conversion and selectivity as a function of temperature for gas-phase ODH of isopropanol on CuTiNiZrSn fibres.

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