IFAM

**Fraunhofer** Institut
Fertigungstechnik
Materialforschung

# Annual Report 2003

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

Annual Report 2003

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# A year of transition

The year 2003 was a year of transition for IFAM. The new linkway from the main institute building to the new extension is symbolic of an eventful year.

On 1 April 2003 Professor Otto-Diedrich Hennemann took over as general manager of IFAM. At the same time, Professor Matthias Busse was appointed a director of IFAM. A thematic reorganisation took place in the “Near Net-Shape Production Technologies” department, consolidating the know-how and expertise of our employees. The new name “Shaping and Functional Materials” characterises this change.

There was also a change in the IFAM committee. Mr Arnd Picker has taken over the chairmanship from Dr. Dietrich Zeyfang. We would like to take this opportunity to thank the latter for his long term of office.

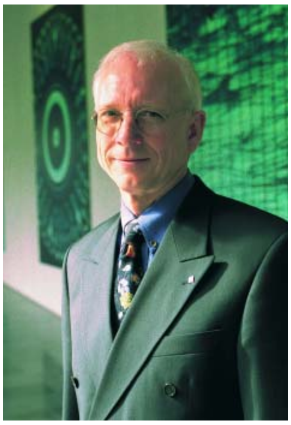
Looking back on the past year, we would like to make it clear that the success and changes have only been made possible by the efforts of our employees and the trust of our customers and partners. We are grateful to all concerned.

Bremen, March 2004

O.-D. Hennemann

M. Busse

*"We are carrying out services for industry that are even required in a recessionary climate"*



Professor Dr. Hennemann

Professor Otto-Diedrich Hennemann reflects on a positive year 2003 for the Adhesive Bonding Technology and Surfaces department and is delighted with the new IFAM extension which will create new opportunities in many areas of IFAM's work and will allow expansion of the range of services offered to industry.

Professor Hennemann, on 1 April 2003 you became general manager of IFAM and you are also director of the Adhesive Bonding Technology and Surfaces department. How big a challenge will this be?

From both technical and organisational points of view, the work of the Adhesive Bonding Technology and Surfaces department was already a major challenge. Taking on the role of general manager of the whole institute will now be an added challenge. My main task is to effectively position my department in the marketplace in the current economic climate. As general manager of the whole institute, I must above all represent the IFAM externally on for example matters such as how IFAM portrays itself to industry and commerce in our region.

In 2003 your department had to position itself in a difficult economic climate. Was this successful?

I think we were, because of our flexibility. The economic stagnation in Germany meant that high flexibility was imperative. In all areas of manufacturing technology there has been an ever growing demand for innovation and optimisation that can be rapidly brought into practice and so stop the economic decline. These market dynamics are increasingly becoming science-based, because it is solely new knowledge that can bring about new innovation. The Adhesive Bonding Technology and Surfaces department also had to follow this development. We have adjusted our work activities in rapid tempo and have opened new business fields. Although industry as a whole is cutting back on contracting out research, we have positioned ourselves so well that we have a balanced budget and have even been able to create eleven new jobs. This is testimony that our areas of work and way of working are suitably aligned with industry. We are carrying out services for industry that are even required in a recessionary climate.

What are currently the main areas of development work in your department?

First of all paint technology, because adhesive bonding processes also play a role when painting. Included here are the material properties of paint and its manufacture and processing. For example, we have developed virtual production processes which we will realise in practice in our new extension building. This will allow development work to be completed for industry within shorter spaces of time. Offshore wind energy is another challenge. This is highly complicated because, compared to plants on land, very different requirements have to be met. When one is involved with masts which are some 90 metres in height, rotor blades which are 70 metres long and machine housings weighing 200 to 400 tonnes – and all out at sea – then one realises what a challenge this presents.

Collaboration with industry is very important for you. Are you satisfied with IFAM's current level of collaborative work?

I am not dissatisfied. However, much can still be improved. Collaboration with industry is very exciting. In days gone by, R&D projects that did not wholly produce the intended result were nevertheless successful in the eyes of the researchers because they had led to new knowledge. This is not the case naturally with industrial projects. There it is necessary to concentrate on the matters that are important for industry and to work on them until a usable result is achieved. This also has consequences for us: Our employees are trained as researchers, but now as service providers they have to adapt to another way of thinking and also adapt their work and way of working. We have learned a great deal. The result for us is greater acceptance by industry. For example, we now have a greater degree of collaboration with the aircraft and aerospace industry in northern Germany and indeed there is a big demand for our services in this field.

**IFAM is the leader when it comes to training personnel in adhesive bonding technology. What importance is put on training?**

The already mentioned high dynamism of R&D means that new knowledge must be transferred to production in as short a time period as possible. This process must become even faster – the time factor here is absolutely decisive. We have investigated how we can intensify and accelerate qualified training courses and have developed new teaching concepts. In principle, our training courses are a transfer of knowledge at two levels. On the one side we introduce companies to new technologies and also train their employees. On the other side, in places where adhesive bonding technology is already used, we can constantly introduce the latest knowledge by means of follow-up training courses.

**As of 1 April 2003 a new colleague, Professor Busse, is director of the institute's other department. How will you work together?**

IFAM will benefit a great deal from the industrial experience that Mr Busse has brought with him. We have had interesting discussions about the main areas of work his department will concentrate on. In these discussions I have tried to introduce ideas from my own perspective and from that of the Fraunhofer-Gesellschaft. With our different experiences, we have started a dialogue that has been beneficial for both sides. I am optimistic that future collaboration will be fruitful.

**The new IFAM building will be brought into use in 2004. What new opportunities will the extra space bring for your department?**

New and important areas such as paint technology, manufacturing technology and training will finally have space to expand. For example, we have a new painting booth which allows us to offer companies the latest technologies in paint processing and paint development. Up until now, the manufacturing technology group could only show virtual simulations on the computer, but now we have the opportunity to turn this into practice in a real production line. For training, we have developed a new concept for knowledge transfer in which the teaching is at the centre and is not separate from the practical assignments (which take place in the same room). All this is only possible with the extra space.

**Collaboration with other partners is very important for you …**

I have already mentioned our contacts with industry. We also have contacts with other institutes which allow us to take on larger industrial projects than would be impossible for a single institute to handle. These alliances are important in order to be able to provide system solutions. We are, for example, a member of an alliance of eleven Fraunhofer institutes that collaborate in the area of materials and components. In addition there are thematic alliances such as POLO which carries out work on Polymer Surfaces and does not solely comprise Fraunhofer Institutes. Another alliance focuses on nano-technologies. The aim here is also to create synergies which in the future will allow us to more rapidly meet industry's requirements. Nowadays, projects are usually too complex to be solely carried out by a single institute.

**What would you like to see realised by the end of 2004?**

I would like the bringing into use of our new extension to be a success. One of the events planned in this connection has the motto "Research and Training". We want to hold a symposium on this and want if possible to make a clear contribution – both as an institute and as part of the Fraunhofer-Gesellschaft – to creating awareness for the very high importance of research and training. To this end, I naturally hope that we can rapidly build up and operate our new business fields so that we can quickly move from the learning phase to the knowledge-generating phase. I am convinced this can be achieved with the excellent motivation of our employees.

*"We have reorganised our work activities and created seven new areas of expertise"*

Professor Dr.-Ing. Busse

**The main focus of Professor Matthias Busse's first few months as managing director of the department of "Shaping and Functional Materials" were consolidation of the existing business and reorganisation for the future. With a new name, new fields of expertise and new projects – the year 2003 was a year of change for the department.**

**Professor Busse, after spending almost 10 years in R&D at Volkswagen you took over the position of general manager of the department of Shaping and Functional Materials at IFAM on 1 April 2003, linked to a professorship at the University of Bremen. What attracted you to this position?**

During my time at VW I learned about the requirements industry put on applied research. From this I learnt what optimal collaboration entails. My switch to the Fraunhofer means I now myself have the opportunity to shape that collaboration in a decisive way. The scope for adaptation here is greater than in industry because in the latter one is restricted to a greater extent and more confined by company concepts and regulations. This freedom excited me. Another attractive point for me was the combination of working for the Fraunhofer and the University of Bremen. My professorship means that I can collaborate with young people and will certainly be able to attract new scientific talent to the institute.

**Up until mid 2003 your department was still named "Near Net-Shape Production Technologies". Why the change to "Shaping and Functional Materials"?**

Shortly after my move to IFAM I initiated a strategic reorganisation. The new name is an inwardly and outwardly visible sign of the change process that has been initiated. In addition, although the name "Near Net-Shape Production Technologies" was clear to technical people, anyone who was not an insider did not know exactly what that name meant. The name "Shaping and Functional Materials" is more self-explanatory and helps towards the objective of further improving the way we represent ourselves externally. In the area of Functional Materials we plan in the future to look at new subject areas and concentrate on interesting developments. We naturally also want to manufacture materials in specific shapes using new technological approaches and advanced processes, hence the term "Shaping". The renaming hence also characterises the expansion of the scope of our work.

**At the outset you had to acquire an overview but have already made a few key directional changes …**

I would first like to stress that everyone has received me in a very open and friendly way – quite rightly with expectations but without any reservations and with a very positive attitude. I would like to thank all employees once again for this. On first taking stock of the situation I realised that our current situation, although not very simple, did however present opportunities. On the one hand, the national economic situation has an effect on us; on the other hand we currently find ourselves in a period of upheaval. We have asked ourselves: Where are we and which route must we take in the future in order to successfully operate in the marketplace? There are three facets to all this: Expansion of the scope of our work with new subjects and new projects, reorganisation of our internal structure and finally the matter of internationalisation. I am a great advocate of the latter because I believe international orientation is of fundamentally importance. That having being said, in 2003 we had to make the decision to stop operating our external facility in the US state of Delaware under our own direct responsibility and to consider an independent form of operation. The reason is that we currently want to concentrate fully on the stabilisation and reorganisation of the business here in Germany. We will naturally support the employees in Delaware in taking steps towards independence.

**What structural reorganisation have you undertaken?**

I must first of all mention that our Dresden site is not directly affected by the reorganisation. The situation there is stable and the positioning in the marketplace is good. In Bremen, we have created seven fields of expertise in order to be able to portray our thematic reorganisation externally in an effective way. Previously there were two departments, but now we have deliberately changed our structure. I have considered at length with colleagues the form this could take and the main focus of the work. Estimating potential markets naturally also plays a key role in these considerations. With the new fields of expertise should also come a new culture of collaboration – the seven fields will not be separate departments! Moreover, at the interfaces of these fields there will be valuable new work areas of interest and these will present new opportunities for cross-field collaboration. As part of the reorganisation I have appointed young, motivated employees from our own ranks to responsible positions and hence spread the responsibility onto many pairs of shoulders. This should create a climate that guarantees collaboration beyond the borders of the fields of expertise. Indeed, the first successes were achieved just a few months after the reorganisation. More details of the individual fields of expertise are given elsewhere in this annual report (see page 55).

### The new building means that you will acquire several hundred square metres of additional floor space in 2004. How will you use this extra space and what new opportunities will this allow?

It is naturally nice for me to have this additional space to add to the other good facilities. We are, for example, acquiring a new large hall. This will be used for foundry technology, for setting up industrial-scale plants. A further main area which we want to work on more closely with industry is metallic foams. We have undertaken development work in this area for several years but up until now only on a laboratory scale. The new space will allow us to be a more effective partner for industry, carrying out work from the development stage right through to industry-scale production.

### In the short time that you have been at IFAM, what has been your experience of the collaboration with the "Adhesive Bonding Technology and Surfaces" department?

My experience has been extremely positive. The openness of Professor Hennemann and his colleagues has been exemplary. We can build on this good working climate and collaborate in some work areas in a more intense way than was previously the case. There will certainly be closer collaboration because the scope of "Joining Technology" covers many aspects which overlap the activities of the two institute departments.

### You came to the Fraunhofer-Gesellschaft after working in industry. What are the differences?

The differences are not so great. The Fraunhofer-Gesellschaft is dedicated to application-orientated R&D and hence works very closely with industry. It would be different working in an establishment that solely undertook fundamental R&D work. One difference to industry is the much broader range of subjects being worked on at the Fraunhofer. Here, unlike in industry, the whole wealth of scientific and engineering knowledge is available. This makes the situation very exciting. Fortunately, the key aspect of customer-orientation also has high priority at the Fraunhofer: What can I do to get the best for the customer? Besides efficient collaboration in partnership, I believe flexibility and speed of reaction towards the customer are high in importance.

### During the winter term 2003/2004 you started your lectures on production technology at the University of Bremen. What knowledge do you want to pass on to the next generation of engineers?

Besides passing on technical knowledge concerning IFAM technologies, I can naturally also give the students an insight into the way of thought in the car manufacturing industry. I would also like to pass on information to the students about foundry technology, and its considerable relevance to the work of the institute. For would-be engineers, I also believe non-technical knowledge is important – matters such as vision, strategy, change management, etc. are often encountered more quickly than expected by engineers in responsible positions requiring leadership qualities. I would also like to inform students about the wonderful opportunities there are for engineers and how significant their influence can be on shaping our future environment.

### What do you want to achieve by the end of 2004?

Firstly I want to further stabilise the overall economic situation of the department. I want to complete the strategic reorganisation so that we have a clearly defined and easily discernible portfolio of expertise available. Associated with this will be a well-organised, motivated workforce all pulling in one direction, and improved external representation with a clear profile. Finally, greater dovetailing with the Dresden facility is important and so too is greater collaboration with the University of Bremen in order to train our own future talent. If clear progress is made in all these areas by the end of 2004 then I will be very satisfied.

View of the new extension building. From the left: Foundry hall, linkway between the buildings, offices and façade of the new auditorium.

# A profile of the institute

# A profile of the institute

The Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) undertakes R&D work in the area of:

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

The Adhesive Bonding Technology and Surfaces department at IFAM offers industry qualified development work as application-orientated system solutions for multifunctional products.

The objectives include the miniaturisation of optical and electronic products as well as the development of the required micro-production processes, lightweight structures, concepts for corrosion protection, surface modification for adhesive bonding and paint technology, and adhesive formulation.

Another main area of work is certified training in the area of adhesive bonding technology. Following the successful introduction in German-speaking countries of the concept of training qualifications in adhesive bonding technology, a new objective is to provide these training courses in other countries. Pilot courses in English have already been given.

The work groups in the Adhesive Bonding Technology and Surfaces department collaborate in an interdisciplinary way and form project teams. This ensures that all the knowledge that is present is available to all customers.

The Adhesive Bonding Technology business field is split into the following work groups: polymer chemistry, protein-based materials, application technology, manufacturing technology, adhesive bonding in micro-production, materials and construction methods, personnel qualification and technology transfer.

The Surfaces business field is divided into the following work groups: low pressure plasma technology, atmospheric pressure plasma technology and paint/lacquer technology.

These two business fields are complemented by the Applied Surface and Interfacial Analysis business field that comprises the work groups: interface research, electrochemistry and molecular modelling.

The Shaping and Functional Materials department, that up until 2002 was known by the name "Near Net-Shape Production Technologies", has facilities in Bremen and Dresden and carries out R&D work on the manufacture of metallic elements and components in a near final geometric shape using powder metallurgical and casting technology.

The scope of the work extends from market research via feasibility studies, pilot series production, know-how transfer, special turnkey plants, employee training and advice on the construction of production plants right through to the provision of support at the start of actual production.

In our pilot plants and application centres, the whole production chain from component development right through to pre-series production is available. Production processes for component manufacture are supported by computer simulation.

The Cellular Materials and Lightweight Structures business fields undertake R&D work on metallic foams and hollow metal sphere structures. Processes and materials for integrating functions into components are developed.

Problem-orientated and customer-orientated results are achieved in the following business fields:
- Powder technology/powder metallurgy
- Micro-production
- Lightweight structures
- Foundry technology
- Rapid product development
- Functional structures
- Component characterisation and analysis.

The primary objectives are minimisation of material and energy usage as well as complete solutions from the starting materials right through to the final component.

In addition to these technical objectives, the IFAM sites in Bremen and Dresden are striving for further integration and collaboration with regional industry in order to exploit innovation.

# 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 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 organisations throughout Germany at over 40 different locations. Some 12,700 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 2003 the total IFAM budget amounted to about 20 million euros. The workforce comprised some 267 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 2003 comprised the budgets of the IFAM sites in Bremen and Dresden.

**The provisional budget result was in total 19.6 million euros. The results for the two individual sites are shown below.**

**Operating budget, own income and business income**

**Adhesive Bonding Technology and Surfaces Bremen (2804)**

| | |
|---|---|
| Operating budget | 9.3 million euros |
| Own income including | 7.4 million euros |
| Business income | 5.1 million euros |
| Federal/state/EU/other | 2.3 million euros |
| Investment budget | 1.6 million euros |

**Shaping and Functional Materials Bremen (2801)**

| | |
|---|---|
| Operating budget | 5.4 million euros |
| Own income including | 2.3 million euros |
| Business income | 1.4 million euros |
| Federal/state/EU/other | 0.9 million euros |
| Investment budget | 0.2 million euros |

**Shaping and Functional Materials Dresden (EPW 52)**

| | |
|---|---|
| Operating budget | 2.7 million euros |
| Own income including | 2.3 million euros |
| Business income | 1.2 million euros |
| Federal/state/EU/other | 1.1 million euros |
| Investment budget | 0.4 million euros |

**Investments**

During 2003, IFAM investments amounted to 2.2 million euros, split as shown below. The most important acquisitions are indicated.

**Adhesive Bonding Technology and Surfaces Bremen (2804) (1.6 million euros)**
- Universal testing machines
- Paint booth for temperature and humidity simulation
- Scanning Kelvin probe
- Ellipsometer
- Microwave calorimeter
- Laser Acoustic (LA-Wave) measuring unit

**Shaping and Functional Materials Bremen (2801) (0.2 million euros)**
- CIP cold isostatic press

**Shaping and Functional Materials Dresden (EPW 52) (0.4 million euros)**
- NARA hybridisation system
- Selective debonding oven

Figs. 1 and 2 show how IFAM's budget and income have changed over the period 1999 – 2003.

## Workforce

On 31 December 2003 IFAM employed a total of 267 people (88 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 2003

| | |
|---|---|
| Scientists | 102 |
| Technical employees | 64 |
| Administration/internal services and work placement students | 28 |
| Ph.D. students, trainees and auxiliary staff | 73 |

The growth in the workforce over the period 1999 – 2003 is depicted in Fig. 3.

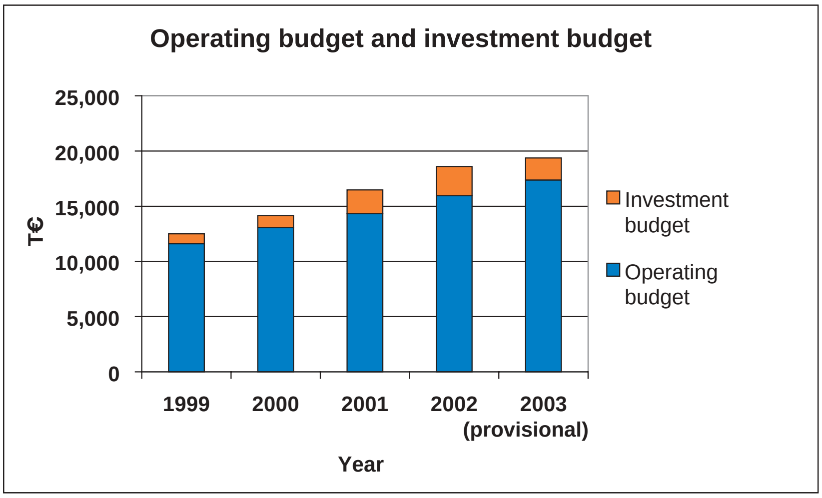



**Fig. 1**: Total expenditure (operating budget and investment budget) of IFAM.

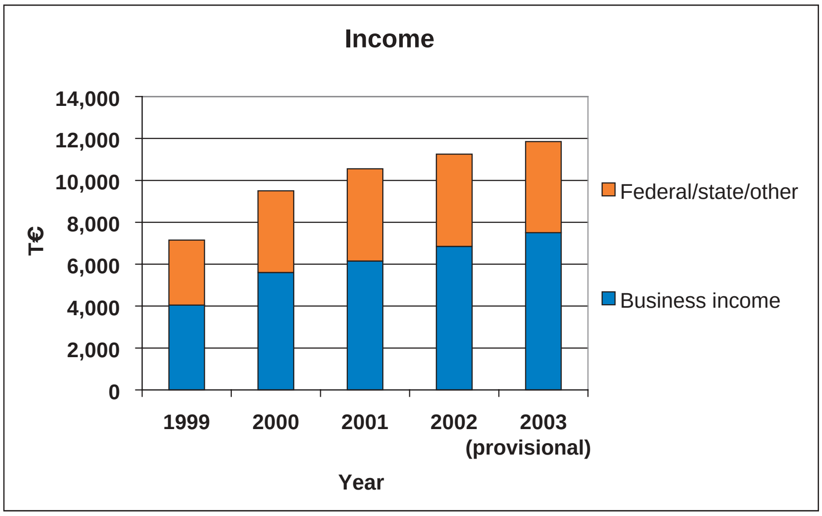



**Fig. 2**: Total income of IFAM.

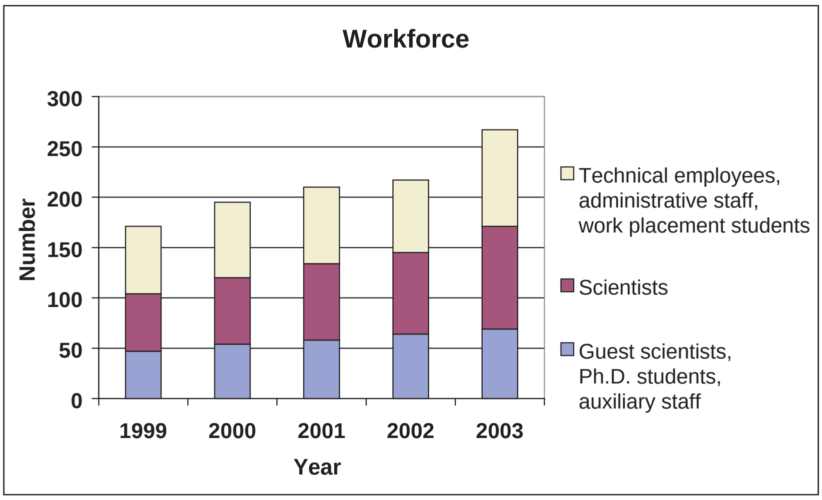



**Fig. 3**: Total number of employees at IFAM.

# The IFAM committee

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

- **Dr. H. Friedrich**
  Deputy chairman
  Volkswagen AG
  Wolfsburg

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

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

- **Dr.-Ing. F.-J. Floßdorf**
  Studiengesellschaft Stahlanwendung e.V.
  Düsseldorf

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

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

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

- **Dr.-Ing. W. Mörsdorf**
  The Budd Company
  A Thyssen Krupp Automotive Company
  Troy, Minnesota, USA

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

- **Prof. Dr.-Ing. K. V. Steiner**
  University of Delaware
  Delaware Biotechnology Institute
  Newark, Delaware, USA

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

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

- **Christoph Weiss**
  BEGO Bremer Goldschlägerei
  Bremen

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

- **Dr. D. Zeyfang**
  Bremen

- Permanent guest
  **Prof. Dr. Gerd Müller**
  Fraunhofer-Institut für Silicatforschung
  Würzburg

# Well-equipped for the future

The Fraunhofer IFAM is well equipped for the future and in 2003 a few essential steps were taken in this regard. The “Near Net-Shape Production Technologies” department was not only renamed to “Shaping and Functional Materials” but also underwent a strategic reorientation and new areas of expertise were defined. This has created a future-orientated base and made this area more attractive for external partners.

The new impressive extension building is by and large finished. This substantial investment, which also raises the profile of our training activities in the area of Adhesive Bonding Technology onto an exemplary and indeed unique platform, underlines the acceptance and attractiveness of IFAM.

IFAM has contributed several important aspects to the ongoing discussion in political, scientific and commercial circles on the topic of “Innovation and the elite”: The sustainability of research can only be guaranteed by innovation if this innovation can be utilised by industry and society. By virtue of its strong orientation towards customers and specific utilisation of new technologies and systems, IFAM has in the past been an excellent example of how a theoretical/political idea can be turned into a successful and enterprising institute within the Fraunhofer-Gesellschaft.

The committee, with members from the worlds of science, politics and commerce, oversees IFAM’s work with great enthusiasm and ever increasing involvement. The opportunity is taken here to wish all employees further success. IFAM’s customers can continue to rely on innovation and ideas from Bremen.

Arnd Picker, Henkel KGaA, Düsseldorf
Chairman of the committee

# New extension buildings

**New extension buildings for the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research in Bremen and Dresden.**

Over recent years, and in particular with the bringing into use of the buildings in the Technology Park of the University of Bremen and in the Fraunhofer Centre in Winterbergstrasse in Dresden, the Fraunhofer IFAM has expanded considerably. This has already been reported in the Annual Reports 2001 and 2002. Further building extension work in Bremen started in April 2002 once full approval had been granted. The shell of the building was in place by October 2002.

The severe frost in December 2002 only slightly affected the second building phase and the handover of the completed building to the institute took place in September 2003.

A noteworthy aspect of this new building is the foundry hall having a surface area of 440 $m^2$ and height of 10 metres, with the working height being limited by a crane level of 7 metres height.

In the lightweight construction hall (210 $m^2$), a multifunctional painting booth has been installed which utilises the full 6.35 metre height of this area.

The space devoted to "Training in Adhesive Bonding Technology" covers a total area of about 400 $m^2$, with the specially equipped training room taking up 250 $m^2$ of this. In the centre of this room there is a teaching platform and this is surrounded by laboratory equipment, testing machinery and other learning aids.

The building also houses additional office space (almost 400 $m^2$) for employees.

The technical facilities have to some degree determined the outer appearance of the building, with there being a tall, narrow flue for exhaust air from the paint technology area. On the roof there are several air feed and exhaust air systems, two cooling towers, a cold water cooling unit, a compressed air system for an extensive compressed air network and piping for the building. Between the buildings there is a near 7 metre high gas tank for liquid nitrogen.

**Fig. 1**: South side of the foundry hall in Bremen.

The new extension building and its technical facilities have increased the opportunities for the institute.

For the large foundry machinery there is now an additional area of some 400 $m^2$. This means that the prototype and near-industrial production processes no longer have to be carried out on a laboratory scale.

In 1996 a new laboratory and office building was opened in the Fraunhofer Centre in Winterbergstrasse in Dresden.

The planned construction of the second building was reported in the Annual Report 2001. In Spring 2002 further building work also started in Dresden at the other three Fraunhofer institutes (IWS, IKTS and FEP) that are situated in the Fraunhofer Centre in Winterbergstrasse.

The building work, which started in March 2002, went according to plan and the roof was present by October 2002.

Once the shell was complete the construction work concentrated on the façade and the interior. The completion date and the bringing into use of the new building are planned for the first half of 2004. The opening of the building will take place at the same time as the opening of the other building extensions in the Fraunhofer Centre in Dresden in June 2004.

**Fig. 2**: South-west side of the new extension building in Bremen.

**Fig. 3**: West side of the new extension building in Dresden.

# The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration. The organisation also accepts commissions and funding from German federal and "Länder" ministries and government departments to participate in future-oriented research projects with the aim of finding innovative solutions to issues concerning the industrial economy and society in general.

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

As an employer, the Fraunhofer-Gesellschaft offers a platform that enables its staff 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 roughly 80 research units, including 58 Fraunhofer Institutes, at over 40 different locations in Germany. A staff of some 12,700, predominantly qualified scientists and engineers, 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, 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 centres and representative offices in Europe, the USA and Asia provide contact with the regions of greatest importance to future scientific progress and economic development.

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

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

# The Fraunhofer 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 characterisation 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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## POLO Alliance for Polymer Surfaces

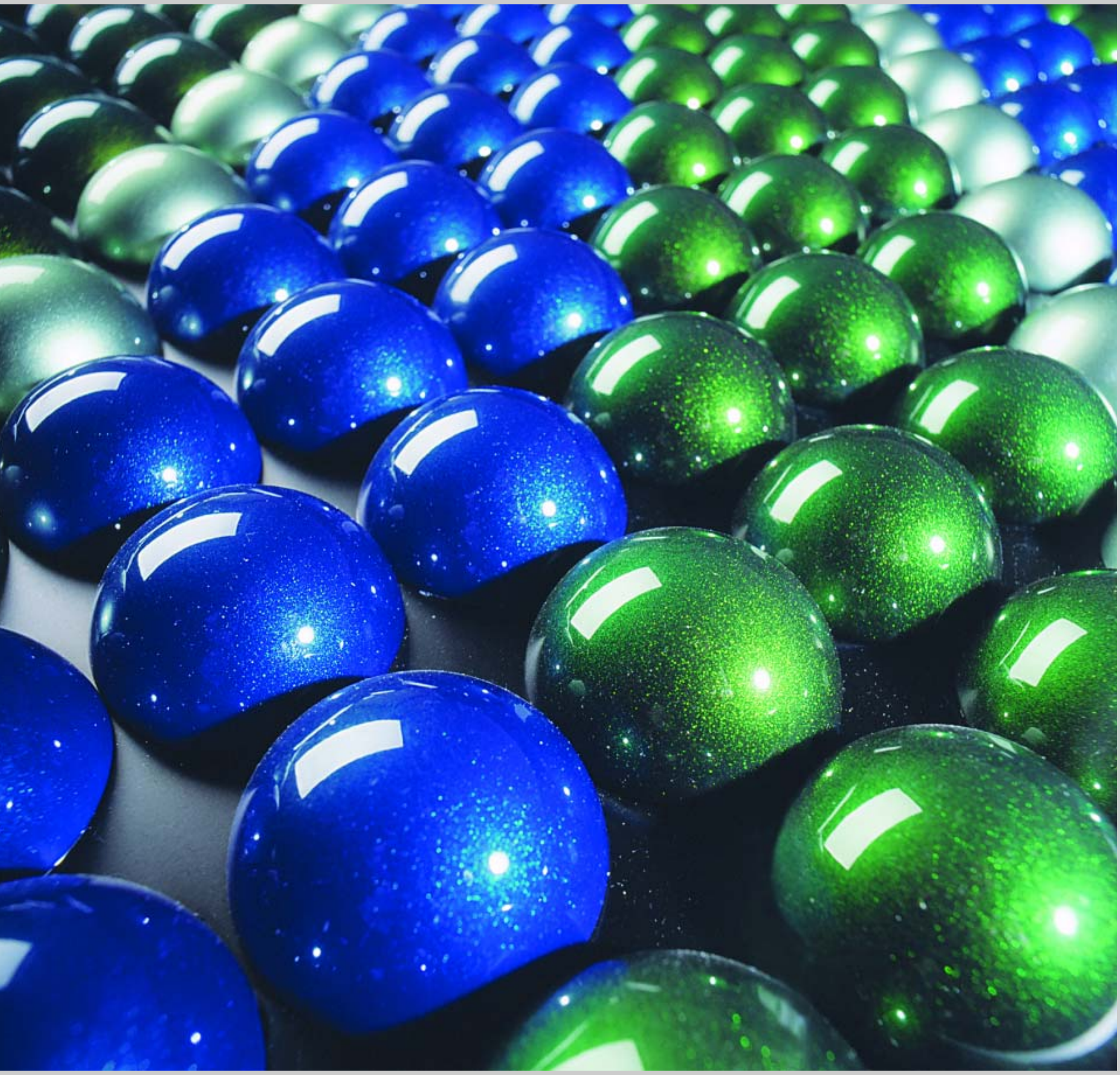
The POLO Alliance for Polymer Surfaces is an alliance of seven Fraunhofer Institutes whose objective is to develop innovative products from functionalised materials and semi-finished products.

The key expertise of POLO lies on the following areas:

- Molecular design, characterisation of polymer structures
- Formation and dissolution of molecules
- Process technology for polymers: flat products, manufacture of composite materials and laminates, surface modification
- Coating processes for web materials from roll to roll, for high-area flat substrates and 3-D components
- Scale-up, reliability and automation of treatment and coating processes

# Department of Adhesive Bonding Technology and Surfaces

Results   Applications   Perspectives



# Expertise and know-how

The Adhesive Bonding Technology and Surfaces department 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 100 employees are actively engaged in R&D work in this area. 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 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, micro-production and in the packaging, textile and electrical industries.

The Adhesive Bonding Technology area is primarily concerned with the development and characterisation of adhesives, the design of adhesive bonded joints and their realisation and qualification. A further main area of focus is certified training courses in adhesive bonding technology because the effective and appropriate training of staff is becoming ever more important for technology transfer. The Surfaces area is split into the sub-areas Plasma Technology and Paint Technology. These areas are concerned with pretreating the surfaces of materials to give them additional properties, so making them suitable for new applications. One topic covered by both these areas is Surface and Interface Analysis. The base knowledge required here guarantees the reliability of adhesive 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 Centre for Adhesive Bonding Technology is recognised following DIN EN 45013 as a certification organisation for providing training in adhesive bonding technology.

**Figure opposite:** Plasma pretreated polypropylene spheres coated with decorative paint.

## Perspectives

Technology trends must recognise medium to long term needs and must initiate development work. The aim is to utilise technological potential and to develop future technologies. Cross-field technologies are of particular importance for providing solutions in key areas such as communication, transport, energy, the home, the environment, etc. They hence benefit society and industry in a sustainable way.

The Adhesive Bonding Technology and Surfaces department is contributing to this and is developing new technologies and methods which allow companies to manufacture innovative products and successfully bring them to the marketplace. The manufacturing technologies play a key role here because high quality and reproducible manufacturing processes are preconditions for market success.

The digitalisation of processes (process simulation) is being increasingly used. The areas of hybrid joining (namely adhesive bonding and mechanical joining) and adhesive bonding in micro-production are two examples where process simulation is opening new, innovative opportunities.

The long term stability of adhesive bonded joints and coatings with respect to their adhesion properties and corrosion resistance has up until now only been able to be predicted to a limited extent. The use of various spectroscopic, microscopic and electrochemical techniques is giving new insight into degradation and corrosion processes in materials and components. These instrumental tests and accompanying simulation calculations are providing IFAM with new knowledge which the empirical test methods based on standardised aging and corrosion tests does not give.

Industrial sectors that put high requirements on surface technology such as the aircraft and car manufacturing industries can only maintain their high level of technological know-how by calling on external expertise. It is for that reason that IFAM collaborates with leading companies in these sectors to offer solutions for the development of innovative products. The combined expertise of the Surface Analysis, Plasma Technology and Paint Technology work areas is allowing new and highly promising routes to be pursued.

For example, combining innovative paint systems (characterised by their high scratch resistance and chemical resistance) and plasma technology (to clean, activate and functionalise the surfaces) has led to completely new solutions for old problems.

In the area of nano-technology, opportunities are being investigated and methods developed to deposit nanometre thin films on surfaces using atmospheric pressure plasma and low pressure plasma. This innovative technology is allowing materials and consumer goods with new properties to be produced and new applications to be found.

Multi-scale simulation involving molecular dynamics, meso-scale simulation and macro-scale simulation is also a trend-setting approach and is actively undertaken at IFAM. The institute is collaborating with other institutes in a Fraunhofer MAVO.

System development in the area of protein-based materials is futuristic but IFAM is already devoting effort to this area. One of the questions that is being asked is: Where and how is adhesive bonding achieved in nature? Studies are being carried out on a variety of topics from the mechanism of bio-adhesion at a molecular level right through to macroscopic adhesives made from proteins.

The employee training courses in adhesive bonding technology are being internationalised for world-wide use. Over the coming years this area will become a main area of activity at IFAM.

Main areas of work

- Formulation and testing of polymers for adhesives, laminating/casting resins, right through to industrial introduction
- Development of additives (nano-fillers, initiators, etc.) for adhesives
- Formulation of polymers with superstructures and biopolymers
- Computer-aided material development using quantum mechanical and molecular methods
- Introduction of 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 (adhesive bonding, hybrid joining)
- Application of adhesives/sealants, filling compounds (mixing, dosing, application)
- Adhesive bonding in micro-production (e.g. electronics, optics, adaptronics)
- Computer-aided production planning
- Economic aspects of adhesive bonding technology/hybrid joining
- Constructional design of adhesive 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 adhesive 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
- Testing physical-mechanical properties
- Determination of key parameters, alternating fatigue strength and operating strength of adhesive 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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**Manufacturing technology**

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**Materials and construction methods**

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**Training and follow-up training**

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**Work groups**

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**Atmospheric pressure plasma technology**

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**Work groups**

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# Equipment/facilities

**Department of Adhesive Bonding Technology and Surfaces**

- Low pressure plasma unit for 3-D components, bulk products and web materials up to 3 $m^3$ (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 adhesive bonded joints
- sgi Origin 3400
- Linux PC system with 64 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, 3,000 mm
- 1C piston dosing system SCA SYS 3000/Sys 300 Air
- 1C/2C 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
- 2C 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)

**Fig. 1**: Unit for drying paint/lacquer with moisture-free air (cold dryer).

**Fig. 2**: Low pressure plasma unit.

**Fig. 3**: Close-up of the scanning Kelvin probe.

# Manufacturing Technology: From the initial idea right through to the practical application

Adhesive bonding is establishing itself as a proven joining technique alongside other techniques such as welding, brazing, riveting and screwing and the question arises as to how this key technology can best be used for everyday industrial applications. As an advanced technology, adhesive bonding technology puts high demands on the production and these demands make precise planning and execution of the complex processes indispensable. The Fraunhofer IFAM has built up appropriate resources to this end over recent years: The Manufacturing Technology work group develops solutions that are tailored to customers' requirements for technically and economically advantageous integration of adhesive bonding technology into actual production processes.

The Manufacturing Technology work group is integrated into the Institute's extensive activities in the field of adhesive bonding technology and utilises resources that are available in other work groups. In that way, know-how for example about adhesive development is shared and passed on as is knowledge about surface modification and constructional component design. The Institute is thus in a position to be able to provide a spectrum of services that is unique amongst European R&D institutions. This is so for adhesive bonding, as an individual joining technique, and also for hybrid joining, namely a combination of adhesive bonding and other joining techniques. Integration of adhesive bonding technology into production processes is only successful if all aspects of the total system are harmonised with each other. This is a service that IFAM offers its customers.

## Requirement profile

The first step involves the Manufacturing Technology work group determining the exact requirements for a customer's particular situation. This includes taking into account a series of boundary conditions.

## Selection of the adhesive

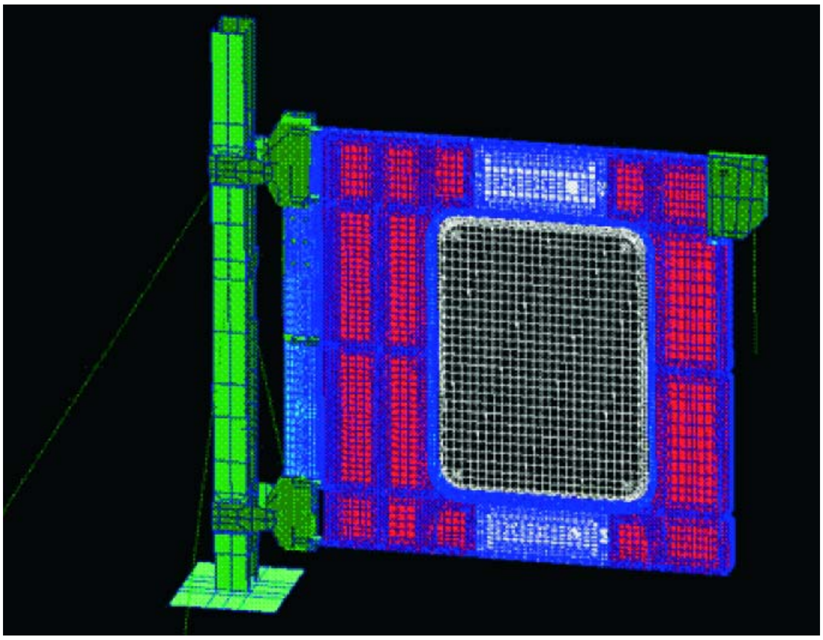
The search for a suitable adhesive initially focuses on commercially available systems. If there is no commercial adhesive available for a particular application then IFAM can if necessary develop or formulate an appropriate adhesive. It may sometimes be possible for example to modify adhesive products that are commercially available. However, if this approach does not offer promise then a totally new adhesive can be developed. Sound knowledge of surface chemistry and in-depth experience of practical applications ensure that a practically viable solution is found.

## Surface pretreatment

Adhesive bonded joints that are subjected to high loads often necessitate components being pretreated. The substrates to be bonded are cleaned by material-specific means and the surfaces are activated and modified in a customised way. In addition to improving the conditions for adhesion, other effects are realised such as improved corrosion protection. An example of this is the pretreatment of aluminium materials for the aircraft construction industry.

## Bond-specific design

The design of adhesive bonded joints is not merely concerned with the transfer of forces. Besides the mechanical load, the long-term stability of the joint must be investigated. Environmental and media influences reduce the load level that can be endured. Computer simulations and accompanying series of tests on standard samples give information about the optimum geometric design of a adhesive bonded joint. Load tests on actual component-like samples are used to verify the simulation results.



**Figs. 1 and 2**: (left) Setup for a mechanical component test, (right) mesh for FE-simulation.

## Central aspect: the design

Once this preliminary work has been undertaken the next stage is the actual introduction of this adhesive bonded joint into the production. This work is carried out in close collaboration with the customer. The central aspect of this integration into the production is optimum design of the bonding equipment for the process. This guarantees the customer a production unit that actually functions in practice. IFAM's position as an independent research and development institute within the Fraunhofer-Gesellschaft also means that the final result is not geared to outside commercial interests.

The joining process must be compatible with upstream and downstream manufacturing steps. The handling of the substrates here is just as important as customised application technology: feeding, dosing, mixing and application. This means for example that a detailed evaluation is carried out at the production planning stage as to how the adhesive can be applied to the components to give the greatest benefits: with an adhesive nozzle moved by robot or with a fixed nozzle (external TCP) under which the components are moved. Alternatives are assessed, taking into account technical and commercial aspects, in order to find an optimum customised solution. The time period up to the final investment decision is hence considerably shortened.

**Fig. 3**: Precision dosing unit for automatic application of 2-component adhesives from twin cartridges (IFAM development).

## Selecting the best components

Once the boundary conditions for the production process are known then decisions have to be made about the optimum combination of application techniques, machinery, dosing units, robots and other parameters. Considering dosing units by way of example, there are many different individual components. The specific processing properties of the adhesives such as shear sensitivity, reduction of the thixotropy, etc. must be taken into account, as must pump capacities adapted to the required flow volume. These factors are taken into consideration when seeking an optimum solution. Based on the parameters for the process and adhesive, IFAM selects the most appropriate plant components – for example mixing systems, pumps and drives. This selection is then practically tested under conditions that resemble those found in industry. IFAM also offers customised modular designs.

For designing the workplace, IFAM uses amongst other things computer-aided 3-D simulation tools. Additional modules with user-specific functions can be developed for this. This allows adhesive bonding-specific parameters to be considered to a greater degree in the robot simulations and so yields more realistic results than other hitherto used approaches. Instead of time-consuming series of trials, a variety of scenarios can be tested in a more cost-effective way. The use of robots, component movements, cycle time changes, accessibility and the risk of collision can be studied and evaluated over a whole range of scenarios. Possible shortcomings can hence be identified at a very early stage, so reducing the costs for start-up and subsequent modifications. This approach significantly reduces the time required up to actual implementation.

At the end of the planning process the solution is discussed with the customer. All proposals made by the Manufacturing Technology work group cover not only technical matters but also highlight the economicalness of the various alternatives. IFAM is developing a computer-based parameter system for economic evaluation of the use of adhesive bonding technology. This system visualises the effects of different decisions.

## Extensive small pilot-plant facilities

The solution that is proposed can be tested in practice in the new, ultra-modern small pilot-plant facilities at IFAM. IFAM possess an extremely flexible manufacturing unit. The heart of this is an industrial robot whose work range is extended by means of an additional linear axis. A unique modular dosing facility allows 1-component and 2-component adhesives to be processed. Feed units for various containers, ranging from 320 ml Euro-cartridges up to 200 l drums, can be freely combined with dosing pumps (piston pumps, gear-driven pumps and eccentric screw pumps), static or dynamic mixing heads as well as applicators for bead-spray and vortex-spray application. The dosing technique can be ideally adapted to the relevant conditions – something which up until now could not be tested. The surface pretreatment is carried out with amongst other things an atmospheric pressure (AP) plasma unit that permits continuous in-line operation with high processing rates. In addition, "cold" hybrid techniques are possible by combining this with mechanical joining methods such as clinching or riveting. The actual integration is dovetailed with computer-aided simulation work. This allows different variants to be tested and improved. The final result can hence be developed to meet the desires of customers.

## Micro-production

IFAM also develops innovative solutions for micro-production. For adhesive bonding on a scale of just a few microns, the key to success is perfect harmonisation of the production processes. Matters such as positioning, fixing and alignment at the microscopic level are just as important as correct application of the adhesives on a scale of just billionths of a litre. Typical changes of the adhesive during for example curing are taken into account at the selection and characterisation stage. The reproducibility of adhesive bonding processes in small and large series production is evaluated in close collaboration with the customer.

The Manufacturing Technology work group provides "adhesive bonding" solutions to a variety of different industrial sectors: In addition to serving the microelectronics, precision engineering, micro-system technology, communication technology and optics sectors, IFAM also has customers in the car manufacturing industry, accessory sector including suppliers and medical engineering sector. Numerous co-operative projects with leading industrial companies demonstrate what high interest there now is for this technology. A bright future awaits.

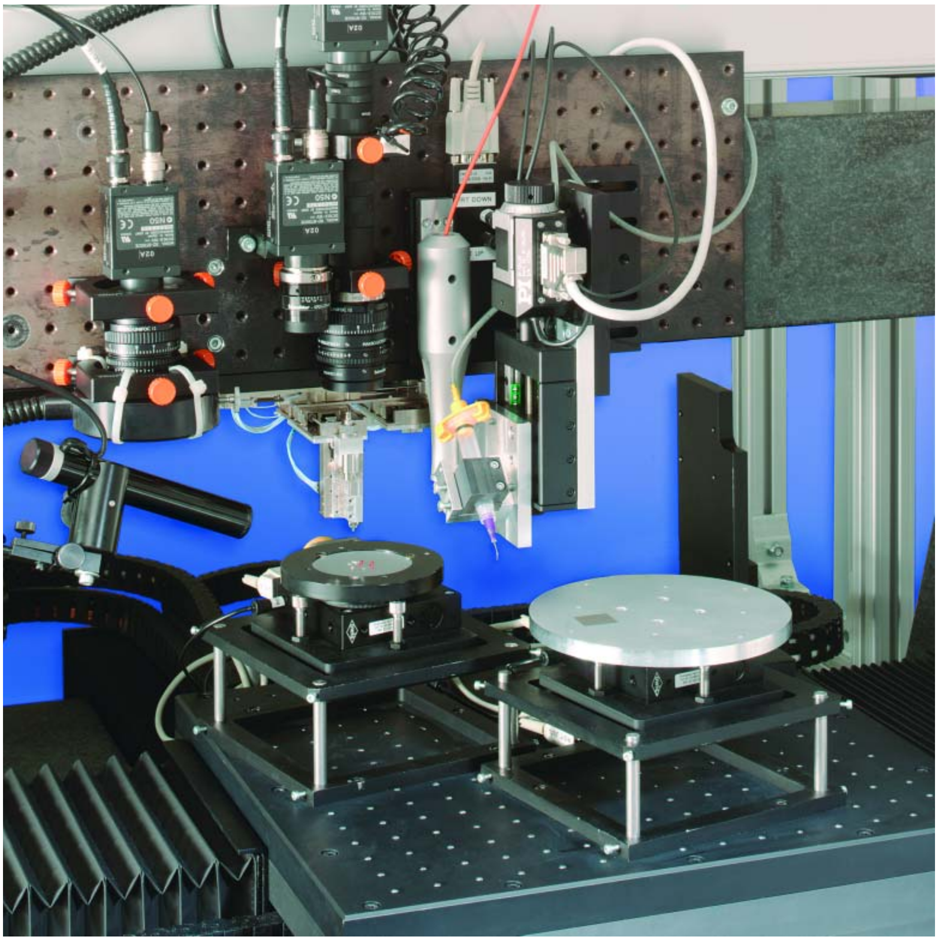


**Fig. 4**: Micro-production at IFAM: 12-axis nano-robot unit with sub-μm reproducibility (Manufacturer: Klocke, Aachen).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# Corrosion in the spotlight: From fundamental research to application-ready systems for corrosion protection

Corrosion has become one of the chief areas of work of the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM). Within IFAM's Department of Adhesive Bonding Technology and Surfaces, various working groups and organisational units have carried out extensive research over recent years on processes and technologies for protecting surfaces. Very considerable investment has been made in equipment and personnel in order to create the platform for future work: The damage caused by corrosion and the mechanisms involved are being researched and efficient and favorable-cost corrosion protection systems are being developed by various working groups, in particular the electrochemistry group but also by the interfacial analysis, metallography, paint technology and molecular modelling groups.

This sound basis and the wealth of know-how possessed by IFAM in this field provide the platform for high-quality fundamental research. The interdisciplinary collaborative work of the various groups at IFAM allows in-depth understanding of corrosion processes and degradation. A unique aspect of this within the context of research in Germany is that innovative systems for corrosion protection are being directly developed by IFAM from this acquired knowledge. Close collaboration between the above-mentioned working groups allows further development of these systems right through to application-ready technologies. IFAM is also linked to the "corrosion community" via AG Elektrochemie and the Institute is a member of the Gesellschaft für Korrosionsschutz e.V. (GfKORR).

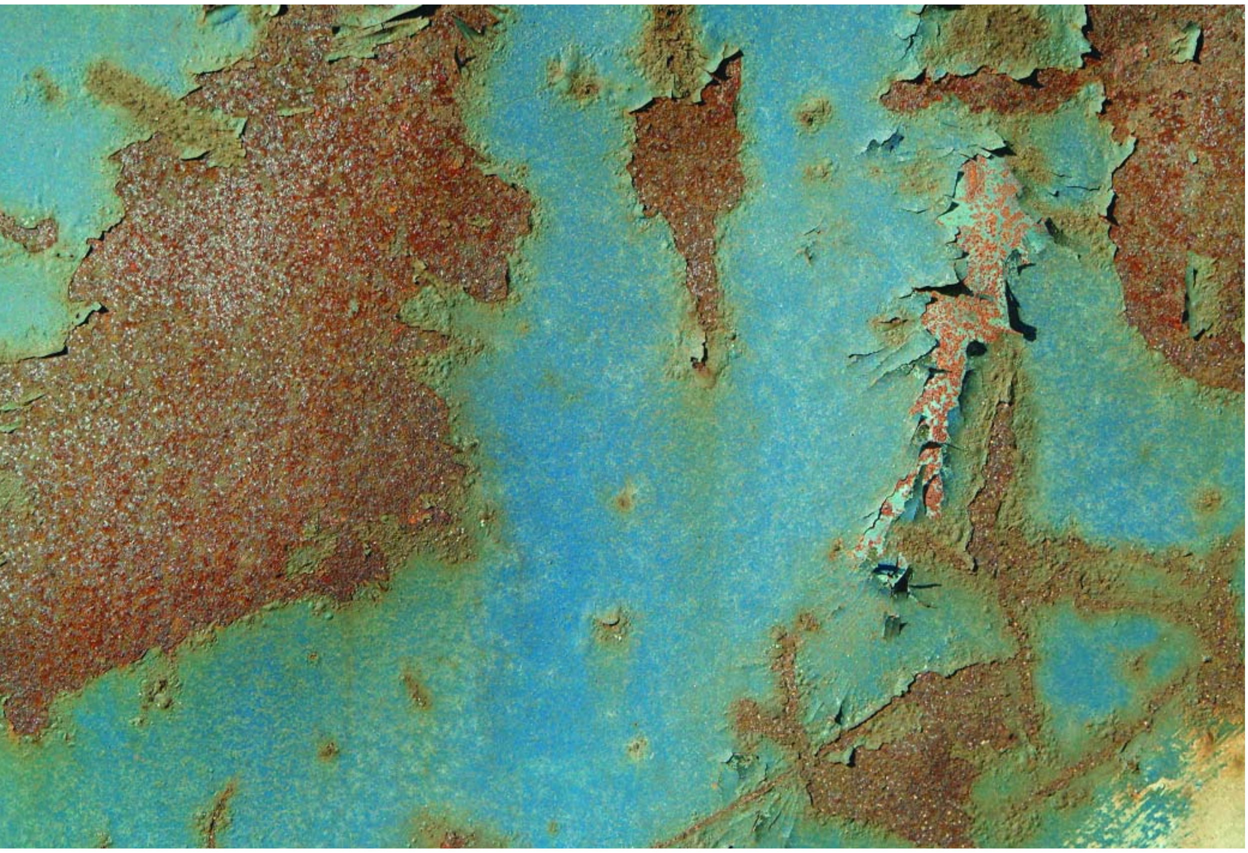

Fig. 1:
Improper application and incorrect choice of coating material can have catastrophic consequences.

## Corrosion is costly

Over recent years corrosion has been increasingly in the spotlight. Way back in 1991 the direct and indirect costs due to corrosion were estimated to be 110 billion marks – and this was just for the former West Germany! This amount, which is close to 5 per cent of the gross domestic product, demonstrates the enormous scale of corrosion damage. The prevention of corrosion and repairing damage caused by corrosion hence also costs a great deal of money, but also brings large potential savings: the better the corrosion protection, the lower the costs.

There has certainly been greater public awareness of the issue of corrosion since the collapse of the Berlin Congress Hall ("Schwangere Auster") in May 1980 as a result of corrosion damage to support sections of the building. Corrosion is however an everyday issue for the chemical industry, power stations, bridges, the oil-producing industry and the construction sector. This is also increasingly so in process engineering because new developments are putting ever higher requirements on materials: Higher pressures, higher temperatures and flow rates and more aggressive contaminants mean that there is a need for modern, user-friendly corrosion protection. Even in microelectronics, where even minimal corrosion damage – for example to conductor tracks – can result in total failure of systems, there is a need for intelligent, practical solutions. For example: In the latest generation of high-tech cars almost half of all incidences of damage to the electronics are due to corrosion. The ever growing awareness of environmental and health protection issues is also placing greater and more complex requirements on the materials.

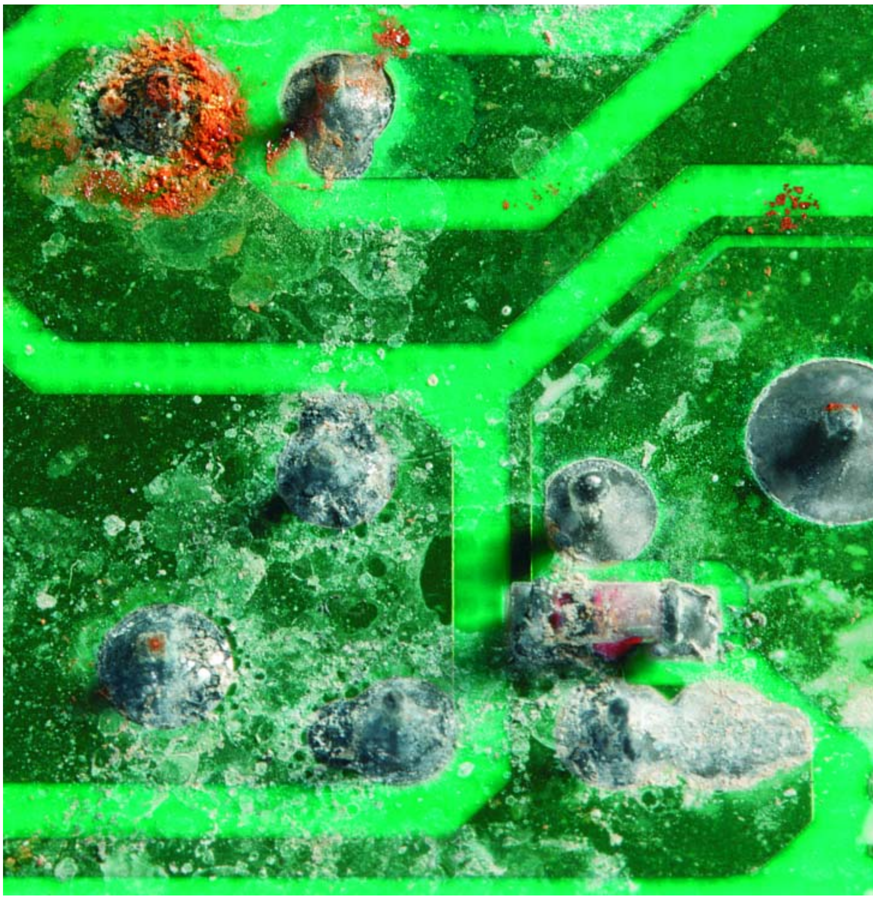

Fig. 2: A corroded printed circuit board.

## IFAM – centre of expertise

In order to able to provide customised solutions for corrosion protection, detailed knowledge of the degradation processes is required. IFAM has become established as a centre of expertise. AG Elektrochemie, that was founded in October 2001 within the Department of Adhesive Bonding Technology and Surfaces, is primarily involved with elucidating electrochemical mechanisms that lead to corrosion of metals. The ageing and degradation of coatings and adhesive bonded joints are also being researched. The available analytical instrumentation can be optimally coupled, so allowing any challenge to be tackled. Besides having instruments for conventional electrochemical techniques (potentiometry, amperometry, linear sweep voltammetry and cyclic voltammetry), there are also facilities for electrochemical impedance spectroscopy, test units for determining electrochemical noise, high voltage potentiostats for anodisation and a Scanning Kelvin Probe.

The collaborative work at IFAM results in a very successful blend of fundamental research and development of application-ready systems for corrosion protection. One of the main thrusts of the internal cross-discipline collaboration at IFAM is investigation of the mechanisms of alternative inhibitors to replace chromate use in the aircraft manufacturing industry. The various issues involved here are being jointly researched by the electrochemistry, interfacial analysis, polymer chemistry and molecular modelling working groups. Within the individual specialised groups, corrosion is constantly a key aspect of the work. For example, projects are currently being undertaken by the polymer chemistry and interfacial analysis working groups to develop new corrosion inhibitors based on organic and organometallic materials and to develop binder systems with intrinsic corrosion inhibition for paints and adhesives.

## Close collaboration with industry

We naturally work in close partnership with industry, including the aircraft construction industry, energy technology, car manufacturing sector, steel construction, offshore wind energy technology and the microelectronics sector. The relevant working groups are engaged in a variety of projects on actual corrosion issues. For example, the electrochemistry and paint technology working groups are developing and testing corrosion protection systems for offshore wind farms in conjunction with Mühlhan. This work is being funded by the Land Bremen. Anodisation layers are also currently being evaluated and tested for the aircraft manufacturer Airbus. We have contacts with numerous other leading companies such as Bosch and DaimlerChrysler.

Our research and development work in the field of corrosion protection is reaching an ever wider audience. In 2003 a well-attended workshop was held on "Corrosion protection for offshore wind farms". On 14 to 16 April 2004 a workshop entitled "Anodisation in the aircraft manufacturing industry" is planned with international participation.

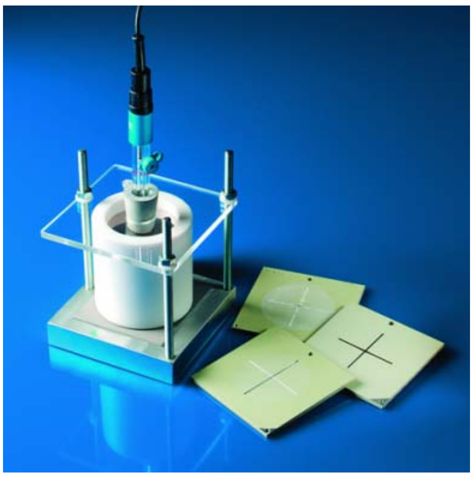

**Fig. 3**: Test cell for carrying out electrochemical measurements on coated surfaces.


**Fig. 4**: Scanning Kelvin Probe.


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# Bondship

**Adhesive bonding of lightweight materials for cost-effective production of high speed craft and passenger ships.**

EU 5. Framework programme,
Growth GRD1-1999-11012 (2000 – 2003)

## Background

Adhesive bonding is becoming an ever more important technology in shipbuilding. Adhesive bonding technology allows new hybrid construction methods to be realised and also permits new lightweight construction methods to be used – also in combination with other joining techniques. Lightweight construction is important in shipbuilding. Up until now, the full potential of adhesive bonding technology has often not been utilised in shipbuilding because of the production conditions, uncertainty about the long-term stability and a lack of approval guidelines. Adhesive bonding technology is interesting for shipbuilding in situations where different materials, for example aluminium and steel or steel and fibre-reinforced composite materials have to be joined. The components to be bonded can be smaller components but can also be several metres long and/or wide. In the modular construction methods used for constructing large passenger ships, which are executed simultaneously on different parts of a ship and in virtually all construction phases, adhesive bonding technology allows joining to be carried out with low heat input in areas where welding would be a fire hazard. This also includes joining finished painted components. A further requirement is the tolerance of the components, with often adhesive layer thicknesses and thickness changes of only a few millimetres being stipulated.

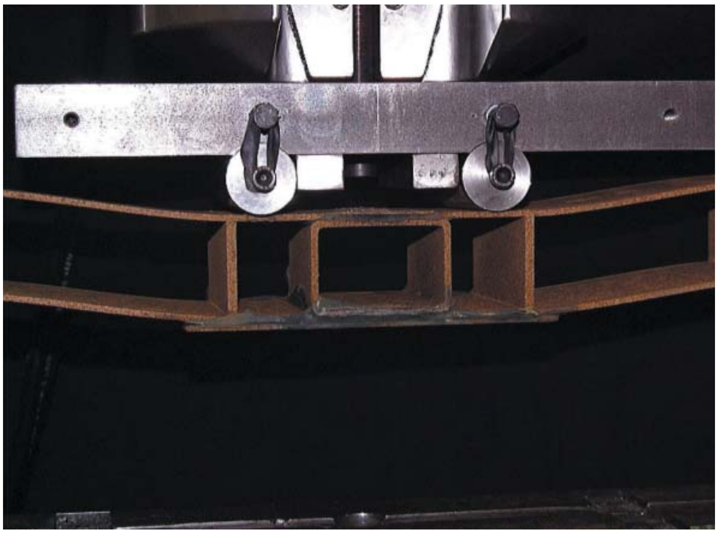

**Fig. 2**: Mechanical testing of an aged adhesive bonded joint.

**Fig. 1**: Adhesive bonded swimming pool.

## Task

The focus of the three-year project was to test several applications of adhesive bonding technology in the construction of high-speed ferries and passenger ships. The aim of the project was to evaluate construction methods, taking into account the long-term stability. The project results were also intended to form a basis for approval guidelines. Joining techniques should be qualified for specific applications.

## Results

In order to develop a process that mirrors reality, the participating shipyards were given specific applications for adhesive bonding technology in shipbuilding. Requirement profiles were determined for these specific applications. These profiles included specific data about geometry and loads, production, assembly, operating conditions and other aspects of the product development and product lifecycle.

A range of adhesives were used – high-strength epoxy and methyl methacrylate adhesives as well as elastic, flexible adhesives based on polyurethane. The adhesive bonded joints were made on both treated metal surfaces as well as on coated surfaces and on finished painted surfaces. For the constructive design and parameter determination, the surfaces and states of the surfaces under shipyard conditions had to be taken into account.

In accordance with the particular shipbuilding requirements on the substrate surfaces, adhesive layer thicknesses and ageing conditions, a pre-selection of adhesive and surface combinations was made from small samples, in particular from shear-tension samples. For this qualification, tests were carried out on the mechanical properties and also especially the specific electrical resistance of the adhesive bonded joint for estimating the contact corrosion properties and the pH value of the cured adhesive in demineralised water for rough estimation of the corrosion behaviour on aluminium surfaces. In addition, the compatibility between the adhesives and the polymers in the coating systems was evaluated.

In collaboration with the other project partners, the specific applications were tested at the shipyards in demonstration units. Demonstration units were constructed at each shipyard. In addition to the experience gained with 1:1 components, key component tests were carried out that were especially useful for verification of the design methods. Component tests for selected applications under fatigue loads and combined fatigue and corrosive loads in the laboratory and under free weathering conditions completed the data set.

**Fig. 3**: Ageing with seawater.

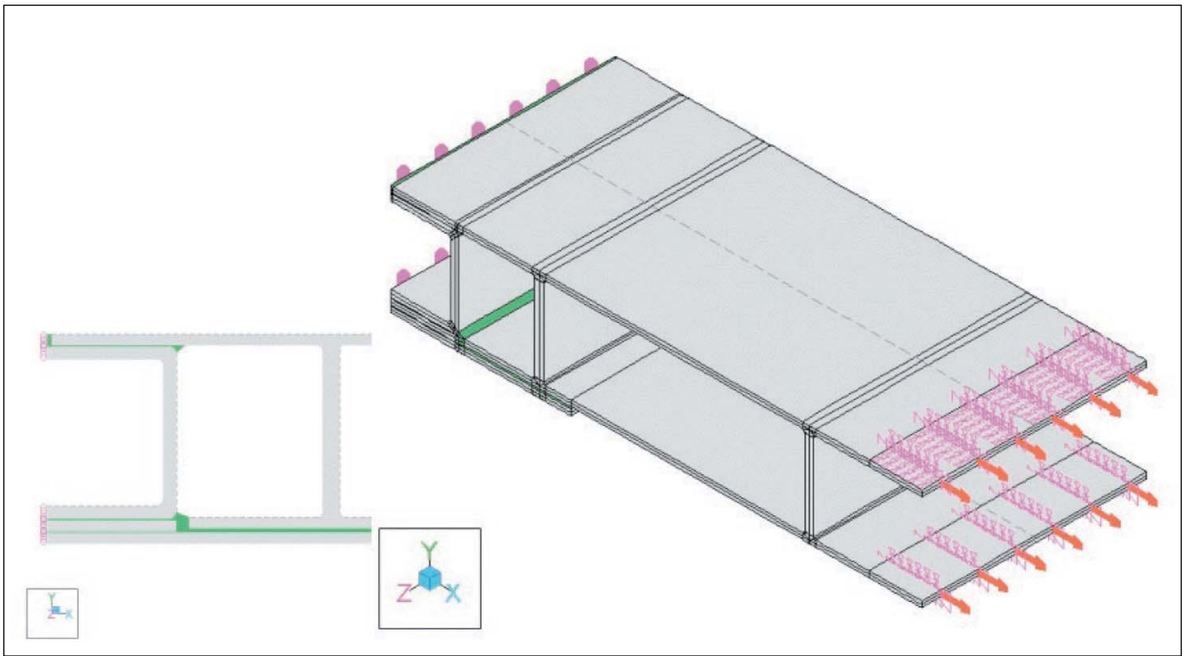


**Fig. 4**: FE-model of a steel sandwich joint.

The shipbuilding sector is demanding simple methods for the design of adhesive bonded joints. If at all possible they would like the constructional design to be based on a few simple formulae. This project has shown that such "simple" solutions do not exist. In shipbuilding it will in general not be possible to design all joints in such a way that the loads are transferred into shear. In addition to the variable adhesive layer thickness, local buckling behaviour, moments and transverse forces generate states of stress in the adhesive bonded joints that are difficult to quantify. It has been shown that in these cases parameterisable FE-models with linear-elastic approximation provide the "simplest" means of evaluating adhesive bonded joints. Experimentally based evaluation criteria can be generated which, although not allowing 100 per cent evaluation of the potential of the adhesive bonded joint, do allow a conservative estimate to be made.

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# Reproducible dispensing of sub-nanolitre quantities of electrically conducting adhesives with short cycle-times

## Background

Electrically isotropically conducting adhesives are already firmly established for many applications. Dispensing has proved to be a flexible application technique and can also be effectively used for non-level substrates and for later assembly. Compared to the current state of technology, applications in the future will require a significant reduction in the adhesive volume that can be reliably dispensed and in the diameter of the adhesive dots. The obvious way to solve this by using dispensing capillaries of smaller diameter does, for a variety of reasons, not result in immediate success.

## Aim of the project

The primary aim of the project was defined by the Supervisory Project Committee as follows: To dispense a filled, electrically conducting adhesive with a processing reliability of 4 $\sigma$ (corresponds to a maximum of one missing dot per 10,000 adhesive dots) and with a diameter of the adhesive dots of ca. 180 µm at a cycle-time < 1 s. As a concrete example, the Supervisory Project Committee chose a tolerance band of – 50 per cent / + 20 for the diameter. In addition, a favorable cost, easy to manage, non-destructive test (for goods receipt) for the adhesives was to be designed and trialled. The purpose of this was to allow evaluation of the ability of adhesives to be dispensed in small volumes.

## Key parameters

The reasons for the unsatisfactory reproducibility when dispensing small volumes of adhesive were first of all determined. The following parameters were investigated: conducting adhesives, dispensing techniques, dispensing accessories and process management (Fig. 1).

## Adhesives

A survey amongst adhesive manufacturers showed that potentially suitable conducting adhesives (100 per cent of the fillers < 20 µm, inhomogeneities in the adhesive – e.g. gas bubbles or regions poor in filler < 10 µm, etc.) were virtually unavailable commercially. Initial optimisation work carried out by the three

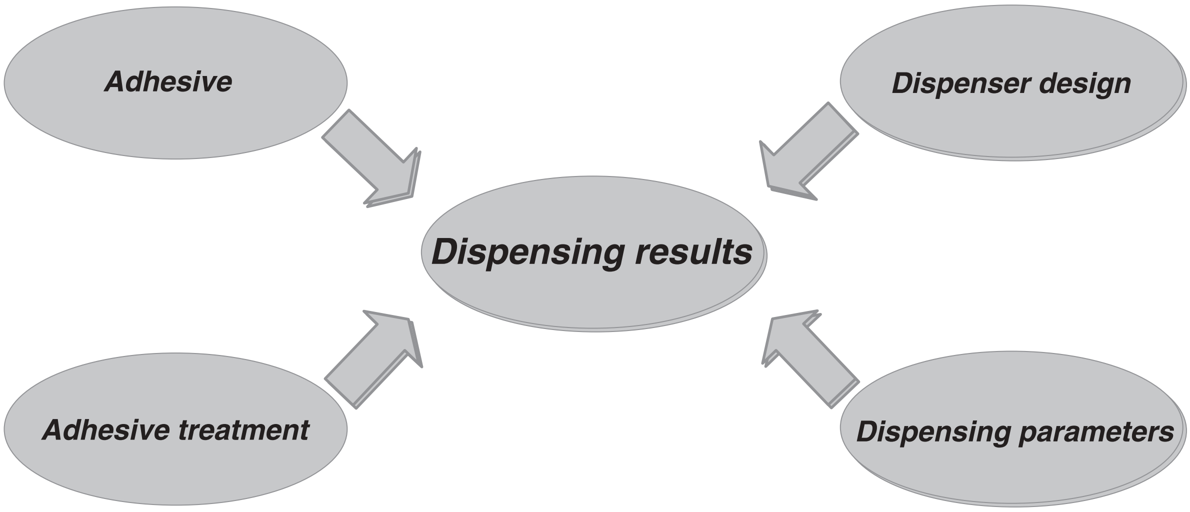


**Fig. 1**: Parameters influencing the dispensing results.

manufacturers out of the Supervisory Project Committee resulted in adhesives having properties that approached the requirements that were laid down at the outset. Non-destructive tests essentially confirmed the findings regarding the generally unsatisfactory starting quality of the conducting adhesives.

## Dispensing techniques

A number of commercial dispensers, modified dispensers and self-designed dispensing units were available. These functioned by various dispensing principles, namely pressure-time, "positive displacement", screw and piston. At the start the good reproducibility of pressure-time dispenser's delivery pulses was proved (those of the "positive displacement" dispenser were classified uncritically anyhow). The adhesives were available in commercial cartouches onto which commercial Luer-Lock dispensing capillaries were screwed. The entire flow path of the adhesive was examined and the flow of the adhesive could be monitored in real-time. For commercial cartouches and capillaries, the flow path is however deemed unsuitable for nano-dispensing from a flow-mechanics point of view. Potential solutions for this have been investigated. The capillary tubes have considerable manufacturing variation but are however generally free of burrs and other contaminants. The roughness $R_A$ of the inner surfaces of the capillaries possibly causes agglomeration of the filler particles. Plasma polymer coatings did not induce the desired poorer wetting of the capillary face surface by the adhesive.

## Dispensing experiments

The dispensing experiments involved preparing samples having up to 50,000 dots on 4" Si-wafers. There was 100 per cent control regarding missing dots. Dot volumes were measured in 5 measuring fields of 1,000 dots. In total, samples with ca. 4 million adhesive dots were produced and evaluated. Samples were produced by varying either the adhesive, dispensing technique or process management parameters. In each case the aim was to determine the minimum attainable dot volumes whilst maintaining the above-mentioned processing reliability and tolerance limits. Eight characteristic types of defects were catalogued in order to carry out defect type frequency-analyses and draw up cause-effect correlations. Application-related parameters were studied by varying the management of the process, for example the duration of storage of the adhesive at room temperature, different travel distances/waiting times and different sizes of needle gaps.

## Dispensing results under optimised conditions

Optimum samples were finally produced using an optimal combination of adhesive, dispensing technique and process management. Using the optimised parameters, reliable adhesive dots were dispensed. The so attained minimum dot diameters were 170 – 179 µm (in each case the arithmetic mean of a sample of 50,000 dots). Fig. 2 shows part of such a sample. The electrical conductivity of the dots was qualitatively proven. With regard to the adhesive volume, these dot samples are a factor of 3 better than the current commercial technology. By undertaking "provisional processability analysis", the stability of the process was determined using quality control cards, quality assurance-parameters and processability-indices.

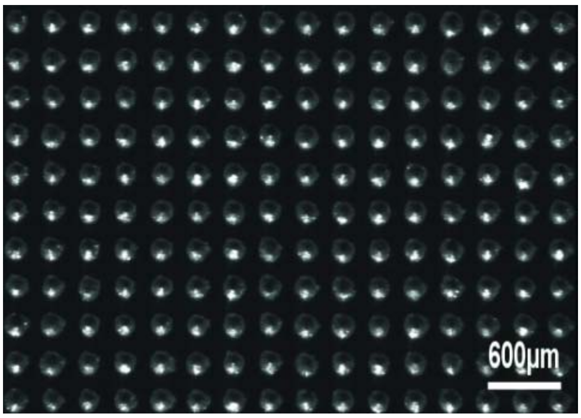


**Fig. 2**: Section of an optimised dispensed sample.

The process that was developed was used successfully for an industrial demonstration application. This was the precision application of an electrically conducting adhesive on a radar sensor for cars with connection pads of 0.15 x 0.36 $mm^2$ (Fig. 3).

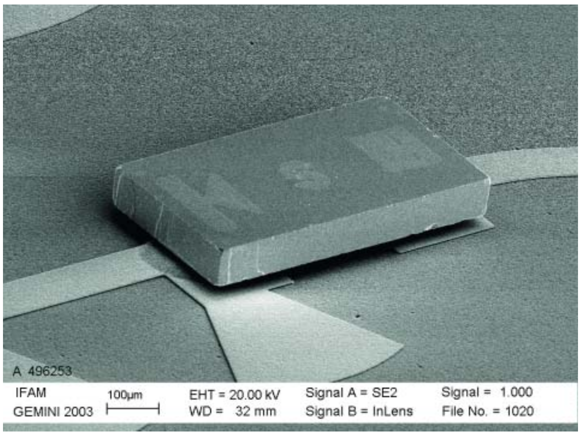


Fig. 3: Precision bonding with an electrically conducting adhesive.

## Non-destructive quality control

Non-destructive quality control carried out by the Fraunhofer IZFP involved characterising dispensed adhesive dots using complementary test methods. Also, a concept for a goods receipt test for adhesives was drawn up and trialled (Fig. 4). This was based on ultra-sound propagation time measurements and was correlated with x-ray absorption measurements. Theoretical estimates were made with regard to the sensitivity of the test to micro-bubbles responsible for flaws and too small dots in the dispensing process. It can detect in advance one missing dot per 2,000 adhesive dots. The duration of the test is less than 20 s per adhesive cartouche. The cost of suitable commercial test equipment is estimated to be about €20,000.

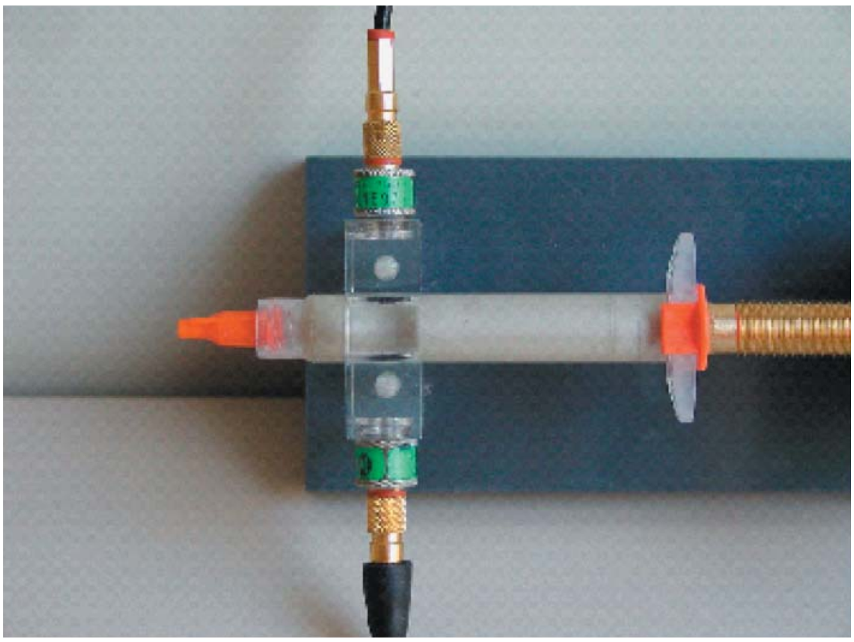

Fig. 4: Non-destructive quality control of a cartouche of adhesive.

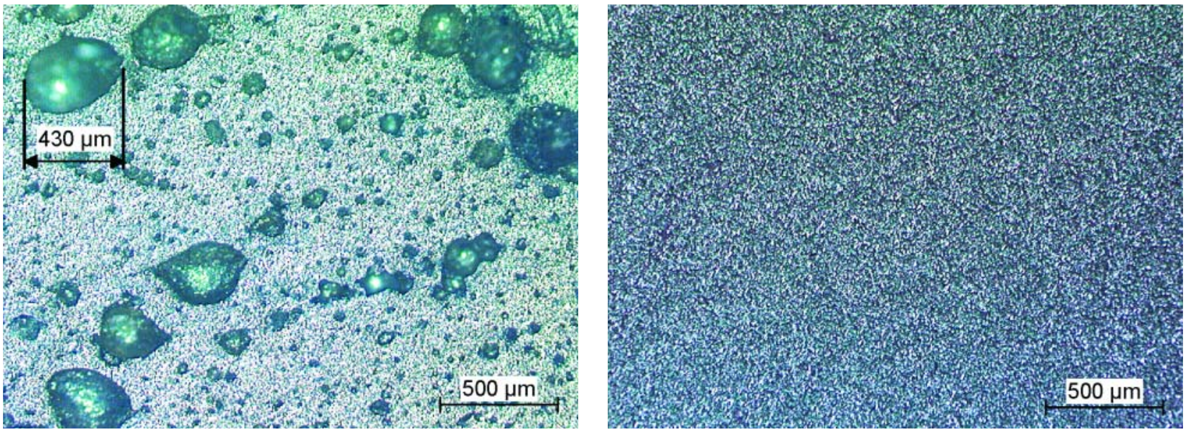


**Fig. 5**: A commercial conducting adhesive before (left) and after (right) degassing.

## Outlook

Of the parameters that were investigated, the quality of commercially available isotropicall electrically conducting adhesives is currently the limiting factor for reproducibly dispensing sub-nanolitre quantities of adhesive. As part of Ph.D. coached by IFAM and carried out at BOSCH, a process for degassing electrically conducting adhesives was developed and patented. This allows significant improvement of the quality of the adhesives (Fig. 5).


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# An integrated computer-aided system for optimising the application of adhesive on high-area structural components

## Background

In the transport construction sector, weight minimisation is a key criterion for successful product development. In order to implement lightweight construction methods, a key role is often played by new materials and innovative manufacturing technologies. Adhesive bonding technology, in particular, is of central importance here due to the range of advantages it offers.

Carbon-fibre reinforced plastics (CFPs) are being increasingly used in aircraft assembly as an alternative to aluminium. Due to the complex process management during the manufacture of individual components, high-area structural components have geometric tolerances that often do not allow planar assembly of the elements without additional work being carried out. In order to form high-quality connections it is therefore necessary to measure the gaps that develop between the components being joined and to fill them with paste-like adhesives and/or solid support materials. This procedure, which is often referred to as a "shimming process", is carried out manually and generally involves considerable time and cost due to the non-deterministic spread of geometric deviations.

## Task

The objective of the research project described below was to introduce an integrated system to optimise the process chain from the measuring stage via the gap determination right through to initiation of appropriate production measures. From a user perspective we use the term optimisation here to essentially mean simplification of the "measuring" and "fit analysis" processing steps. From an economic point of view optimisation also means the shortening of cycle-times with simultaneously reproducibly high product quality.

## Description of the project

A central aspect of the project is digital processing of the geometry data. This allows all the results from different functional areas (e.g. design, production) to be made available in a flexible way and with a high degree of automation. The demonstration object chosen for the tests was the outer aircraft landing flap. Based on this, an integrated reference model was developed that consisted of the four modules: measuring, automatic fit analysis, robot coding and data management (Fig. 1). The verification of the prototype was carried out with the lower

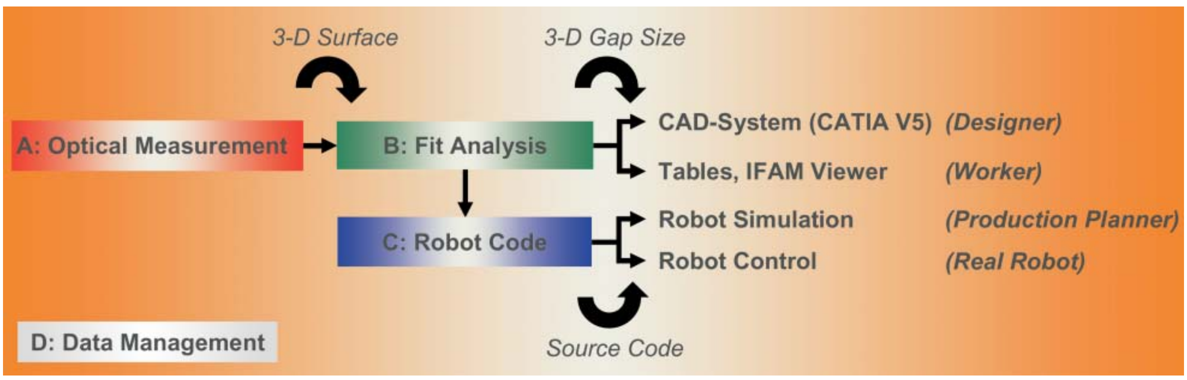


**Fig. 1**: The integrated computer-aided system for digital fit analysis.

CFRP-panel and a laminated fin into which systematically defined gaps were incorporated. In the actual production, the paste-like adhesive (shim) is applied to the fin and then pressed flat onto the covering in a stroking motion.

The measurements were taken using an optical method based on laser triangulation, with a distance accuracy of a few micrometres. A mobile measuring head can be passed across the surfaces to be measured in a few seconds and the position of the manual unit is determined by IR-diodes and a static module comprising three cameras (Fig. 2). The measurement data is processed using special software that must guarantee digital representation of the surface with small amount of data. After measuring the components to be joined, a software module, developed as part of the project, is able to automatically determine the position and orientation of the digital surfaces with respect to defined reference points. This status is the starting point for the subsequent gap size determination. The key advantage of the last step is that components now no longer actually have to be present or aligned for the gap to be determined. For complex and large components this can save time and money.

After global transfer of the data, the automatic fit analysis can then be carried out distant from the place of measurement. In order to realise this, a sequence of interpolation points is automatically calculated on the aligned component in the computer to which adhesive is to be applied, with the relevant distance vectors along freely definable application paths. This is then graphically displayed. This data is used for offline programming for mechanical application of the adhesive, using for example an industrial robot.

The "robot coding" module was developed in such a way that appropriate orientation of the TCP along the application strips can automati-

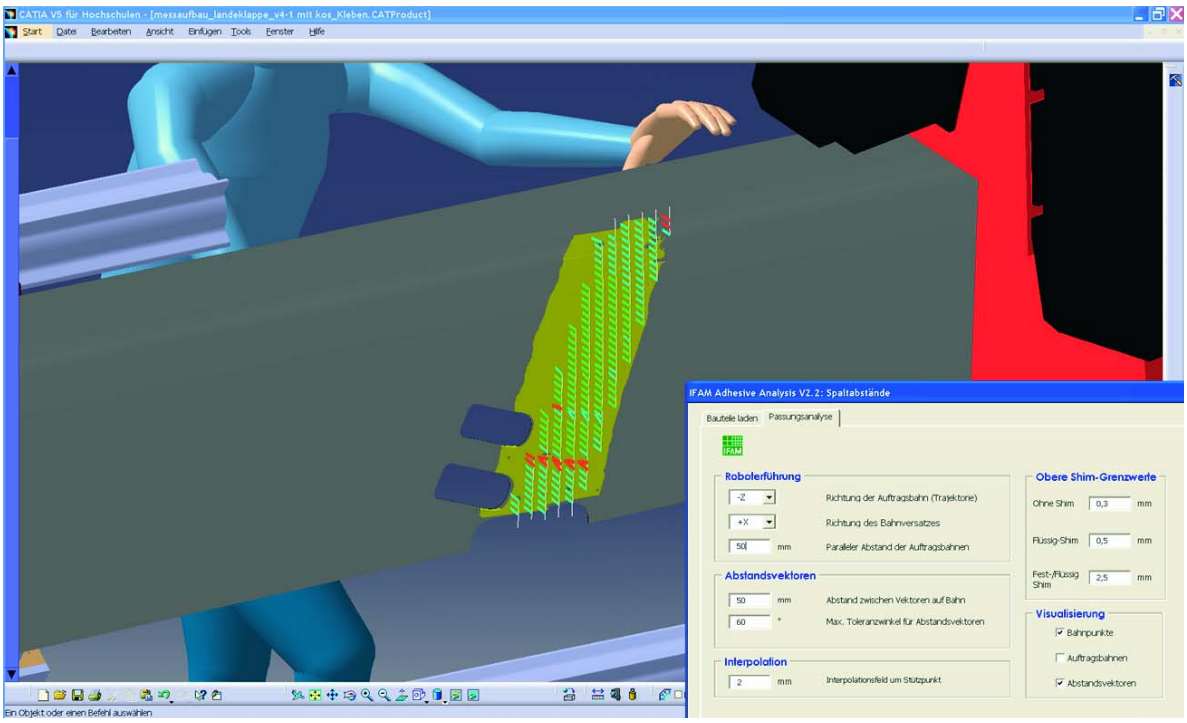


**Fig. 2**: Real measuring unit with subsequent digital gap size determination in the small pilot-plant of the Fraunhofer IFAM.

cally be determined after robot model referencing. When uploading the program into a robot simulation system the motion can be monitored or modified in a clear way (Fig. 3).

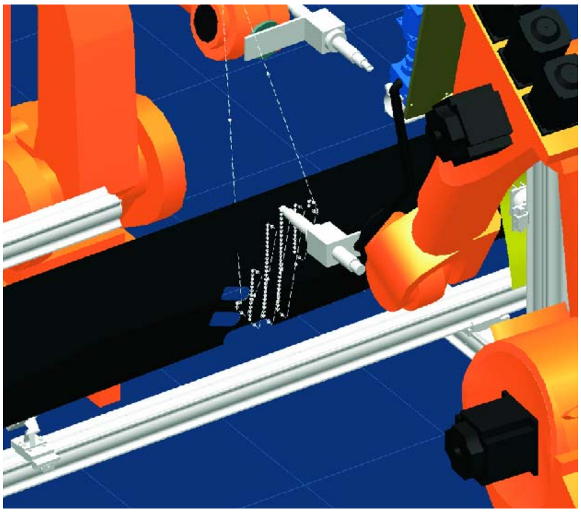

Fig. 3: Automatic determination and graphical testing of a robot program on the basis of the geometric gap size.

Alternatively, the fit analysis allows the calculated gap to be visualised in a CAD-system (CATIA V5), so that comparisons can be made with the design drawings. Using programs for table calculation, the output can be used for statistical tests and also provides additional information for manual production.

Another important functional module of the total system is systematic management of the data. The data transfer and database structure for this were designed in accordance with the client-server principle. Key features of the client program (front-end) are the unambiguous assignment of the measurement, gap determination and robot coding as well as function-orientated navigation. This means that depending on the task in hand the user is in an assigned area (Fig. 4). As each user in the process chain has the client program installed locally on his/her

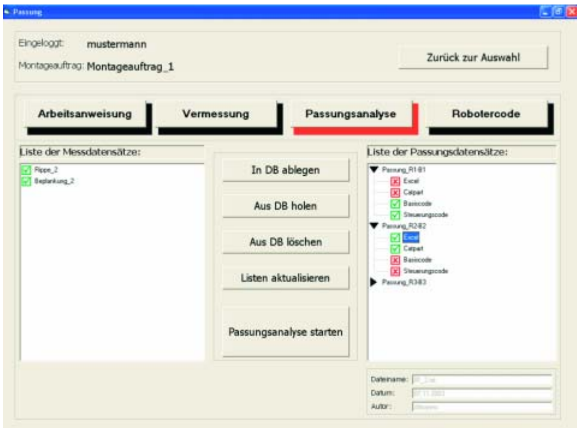


Fig. 4: Client program for transparent management of the data.

computer and can automatically monitor the completeness of the data on the server, this functions as the central management tool for the project.

## Results and benefits

A prototype is available that represents an integrated total system for optical measurement, automatic gap size determination and offline programming of an industrial robot for adhesive application on components having tolerance deviations. The management of the data is carried out via a customised database and a self-developed client-program.

Key benefits of the system are as follows:
- Reduced time and effort required for the measuring step and gap determination because the components no longer have to be physically aligned into the assembly position in the device.
- Gap determination is now carried out digitally, meaning that before the actual final assembly geometry deviations can be determined and suitable measures undertaken.
- Efficient reduction in the amount of measurement data, enabling digital gap determination.
- Control of the production harmonised to the tolerance deviations leads amongst other things to precise application of materials and hence less material usage than when constant material thickness is applied (too long-winded). As a result, the pressure forces during assembly can be reduced.
- Flexible data processing, so that measures can be taken in the design, production planning and operational assembly areas.
- A universal total system in which users do not have to process the data between the applications.
- Global data management.

## Outlook

Future work will involve actual assembly to produce a prototype component. IFAM will start work on this shortly. The automation of the adhesive application using industrial robots and dispensing equipment will bring major benefits. To achieve this there must be synchronisation of the subsystems – material, machine technology und software.

### Client

Bremer Innovations-Agentur – BIA GmbH
as part of the fundamental research project AMST 008:
"Computer-aided methods for the virtual assembly of complex technical systems"

### Dates

Start of project: May 2002
End of project: May 2004

### Definitions

AMST = Airbus Material and System Technology
CAD = Computer Aided Design
TCP = Tool Centre Point


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# Development of pretreatment processes for plastic films using atmospheric pressure plasma

## Background

Polypropylene films have a wide variety of industrial and domestic uses, for example in the electronics industry and for packaging foods and boxes of cigarettes. In order to guarantee good printing and bonding on such films, the surface energy and hence the number of polar groups on the film surface must be increased. This activation is currently often carried out by so-called flame treatment, which involves subjecting the surface to a gas flame, or by corona treatment, a process which involves plasma treatment under atmospheric pressure. These activation methods do however yield surfaces having poor long-term stability and in addition the corona treatment sometimes activates both sides of the film, resulting in an increased number of rejected films during the production.

Besides having many years of experience with low pressure plasmas, IFAM has for some time now been developing atmospheric pressure plasma technology. This is relatively new technology compared to other plasma techniques such as corona and barrier discharge and uses plasma nozzles. An arc discharge is generated in an ionisation gas in these nozzles. The ionised gas flows through the nozzle at high speed and acts on the substrate.

## Task

The aim is to implement a novel pretreatment technique in an industrial plant for manufacturing polypropylene films as an in-line process. The basis for this implementation will be laboratory experiments and small pilot-plant trials. This novel process will provide more effective treatment than is currently possible and will at the same time provide good long-term stability and temperature stability as well as not causing activation of the reverse side of films. In addition, the good sealing properties of the films will be maintained.

## Manufacture and pretreatment of the films

A polypropylene film was made from a granulate. The granulate was melted and mixed in an extruder, forced out of a wide slit and passed as a web over several rollers.

The film was first stretched lengthways as a result of the differing speeds of revolution of the rollers. In a further process step with renewed incipient melting the films was stretched broadways and then wound up. Pretreatment of the film can be carried out either immediately after the extruder, after the lengthways stretching or

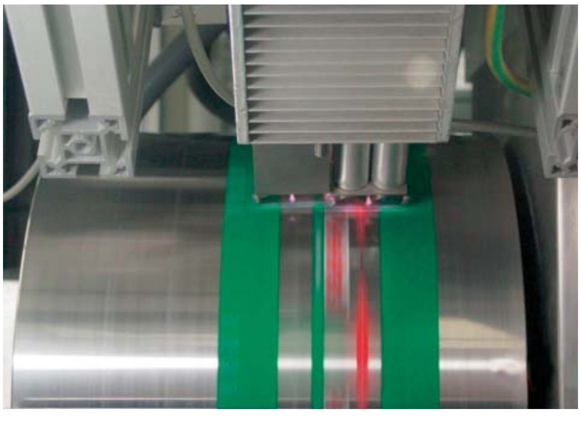

**Fig. 1**: Pretreatment of a film web with the plasma nozzle assembly.

after the broadways stretching. Configuring this processing step after the broadways stretching requires a homogeneous treatment covering a width of 4 to 10 metres. This is difficult to achieve and leads to high costs. It was hence decided to configure the plasma pretreatment before this step, meaning a web width of up to one metre. To achieve this, a plasma assembly manufactured by PlasmaTreat (Steinhagen) was used that allows a substrate to be treated homogenously (Fig. 1).

A problem with this configuration is the loss of surface energy due to the effect of heat. With the pretreatment step before the broadways stretching, the pretreated film loses much of the effect induced by the pretreatment due to the temperature increase necessary for the stretching. The polar groups on the surface turn into the material and it is this which causes the lowering of the surface energy. This is the reason why pretreatment is currently mostly carried out after the broadways stretching process. The consequence of this, however, is higher plant costs and major problems with the homogeneity of the pretreatment.

Due to the more effective albeit hotter pretreatment in our process compared to corona pretreatment, there is effective activation of the PP films and good long-term stability is simultaneously achieved. Surface energies are attained which, in contrast to conventionally treated surfaces, even allow printing of the films with water-based coating systems. In addition, undesired double-sided pretreatment of the films is avoided in this process due to the potential-free nature of the plasma-beam on the substrate.

Pretreating the films using the plasma nozzles enables a surface energy of 72 mN/m to be attained. This was measured with a test ink. This allows wetting with water. Far higher surface energies can hence be realised than when using conventional methods (Fig. 2).

XPS measurements show that the oxygen content increases from zero to ca. 20 per cent by atom. At the same time it can be shown that there are a greater number of different oxygen-containing functional groups on the surface. Small amounts of nitrogen (from 1 to 2 per cent by atom) are also incorporated into the surface.

Fig. 3 shows two films to which a water-based coating has been applied. After drying, an adhesive strip was applied with a defined force and then removed again. On the film on the left that was not pretreated, there is complete removal of the coating. On the film on the right that was pretreated, the coating is almost completely intact after removal of the adhesive strip.

Higher film temperatures during the broadways stretching process do however cause loss of these high surface energies. IFAM is currently carrying out work using a special method of plasma polymerisation that provides stabilisation of the surface energy after being subjected to heat. Here, a special precursor is fed into the plasma. This forms radicals and binds to the

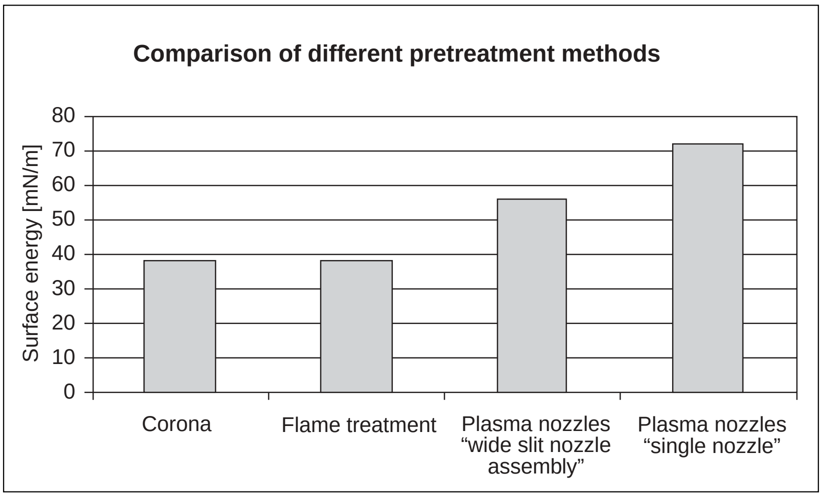


Fig. 2: Comparison of the surface energy that can be achieved with different pretreatment methods (The "wide slit nozzle assembly" is shown in Fig. 1).

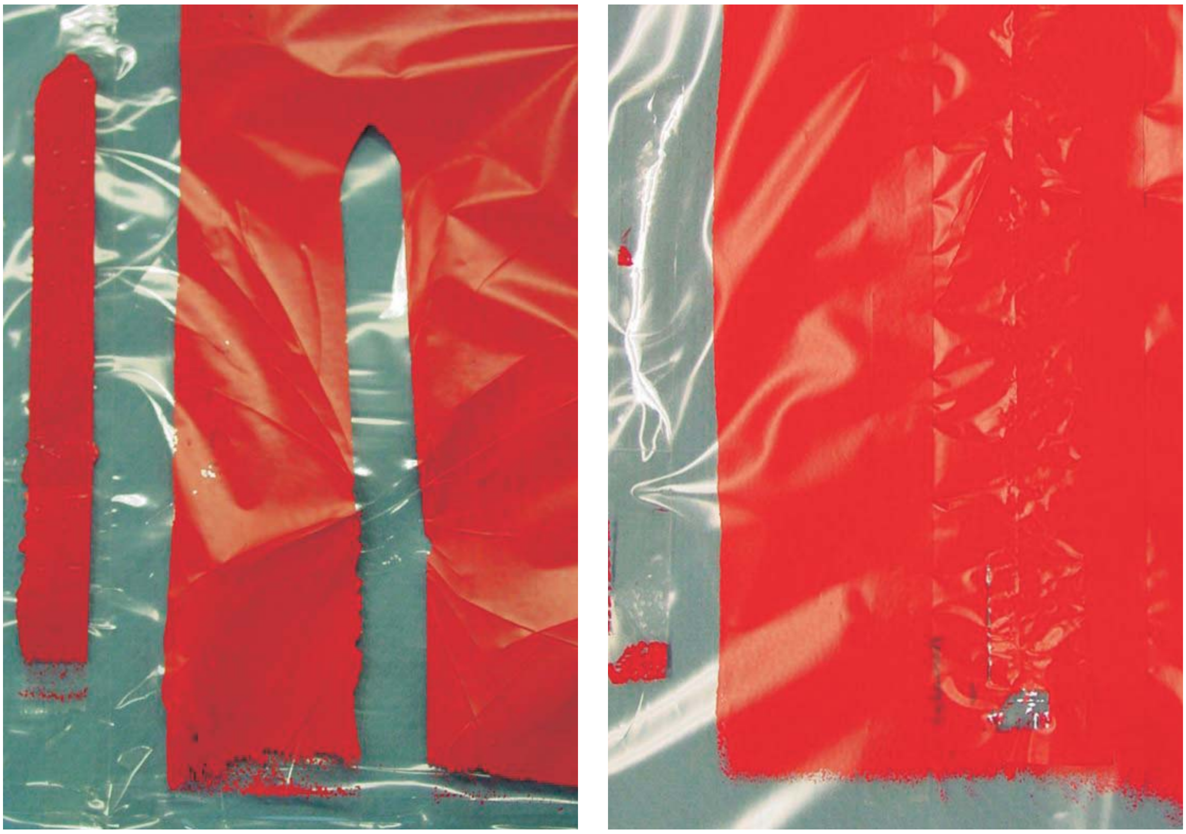

**Fig. 3**: Water-based coating system on PP films. Left: pretreated without "wide slit" nozzle.
Right: pretreated with "wide slit" nozzle.

surface, so preventing the polar groups turning inwards. The first laboratory experiments have been very promising and further development of this method is ongoing.

Another key property is the ability of a film to be sealed. To investigate this, it is tested whether two films can be lastingly fused with each other. In practice this occurs when sealing plastic bags for foods, e.g. potato crisps.

In order to test the strength of a sealed joint, two films are joined to each other under the influence of temperature and pressure using special equipment. They are then pulled apart at an angle of 180°, measuring the necessary force to do this.

Tests at IFAM have shown that the sealing temperature of the pretreated film does not increase and that the force required to break the seal is somewhat reduced as a result of the pretreatment. All the forces that were recorded do however represent tear values, namely the film splits before the join breaks. The strength of the sealed joint is thus certainly satisfactory.

## Outlook

Future work will focus on scaling up the small pilot-plant results to an industrial plant. In addition, the above-described method for stabilising the surface energy will be further developed and integrated into the existing assembly. Successful conclusion of this work will provide a serious alternative to conventional pretreatment techniques.

**Fig. 4**: Atmospheric pressure plasma unit. The nozzle assemblies are configured for simultaneous activation of several separate treatment tracks.


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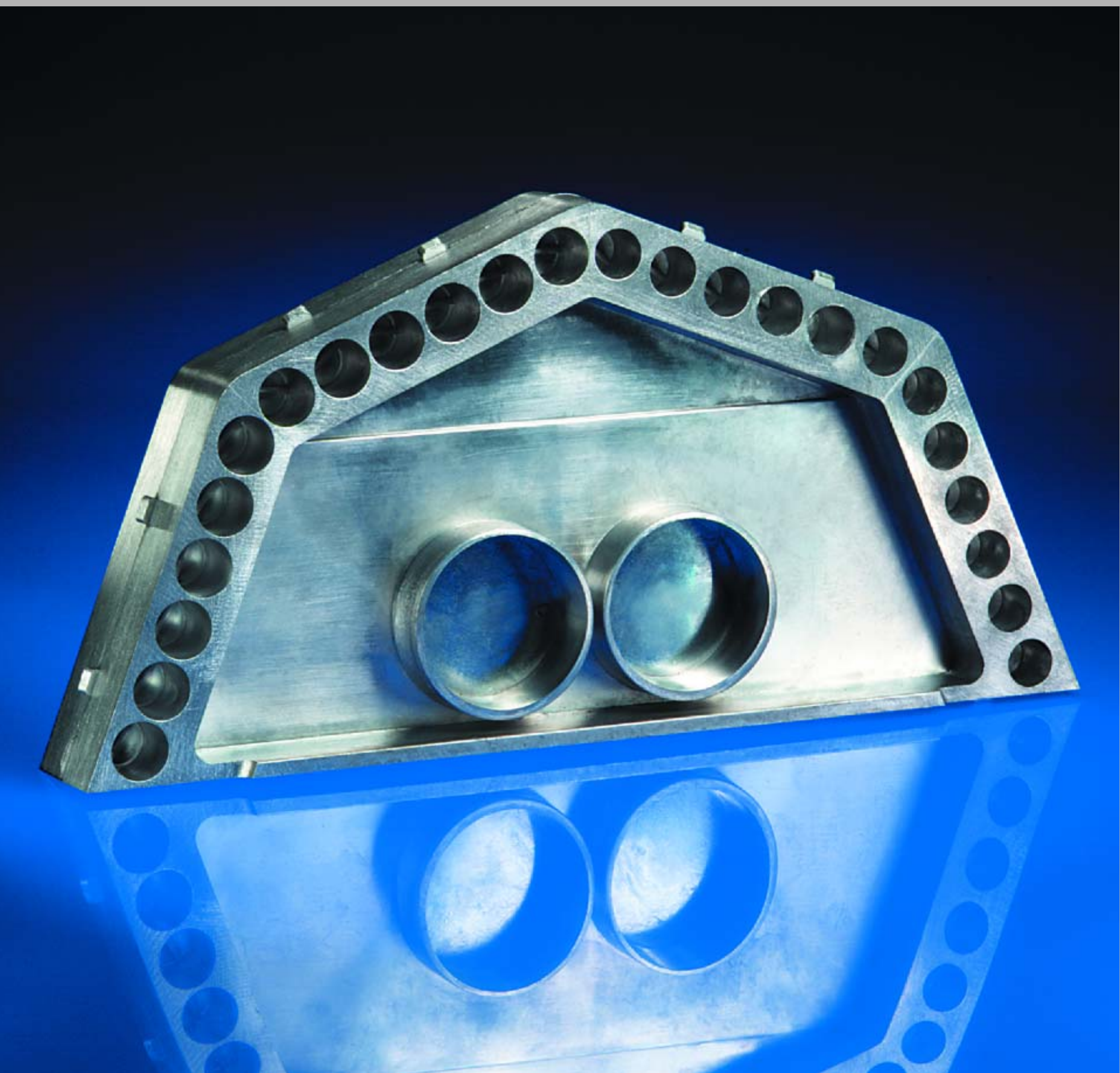
# Department of Shaping and Functional Materials

Results Applications Perspectives



# Strategic reorganisation of the department of "Shaping and Functional Materials"

In April 2003 Professor Busse assumed responsibility for the department previously known as "Near Net-Shape Production Technologies". After an initial orientation phase, a process of strategic reorganisation was started in order to stabilise the overall position of the department and open up new business fields for the future. The renaming to "Shaping and Functional Materials" was part of the ongoing change process and indicates the full scope of the work activities.

Internal and external networking considerations played a major role in the restructuring of the "Shaping and Functional Materials" department at IFAM. Expertise that was available was concentrated into fields of expertise and new fields of expertise were set up. At the interfaces of the individual fields of expertise new ideas can crystallise and interdisciplinary projects can be undertaken. The strategic reorganisation has hence created a matrix of fields of expertise which connects the IFAM technological expertise with cross-field processes, e.g. component development and function integration (Fig. 1).

The institute's Dresden facility is largely unaffected by the strategic reorganisation. Its present "Cellular metallic materials" and "Sintered and composite materials" already makes a key contribution to the total portfolio of expertise of IFAM (see green-coloured section in Fig. 1).

With regard to the institute's Bremen facility, seven fields of expertise have been formed, some with new or expanded thematic scope. Four of these (marked in grey in Fig. 1) are mentioned here first of all because these all represent technologies for manufacturing components.

The "Powder technology" field of expertise covers topical issues relating to materials and technology for manufacturing components using

**Figure opposite**: Al pressure casting sandwich component.

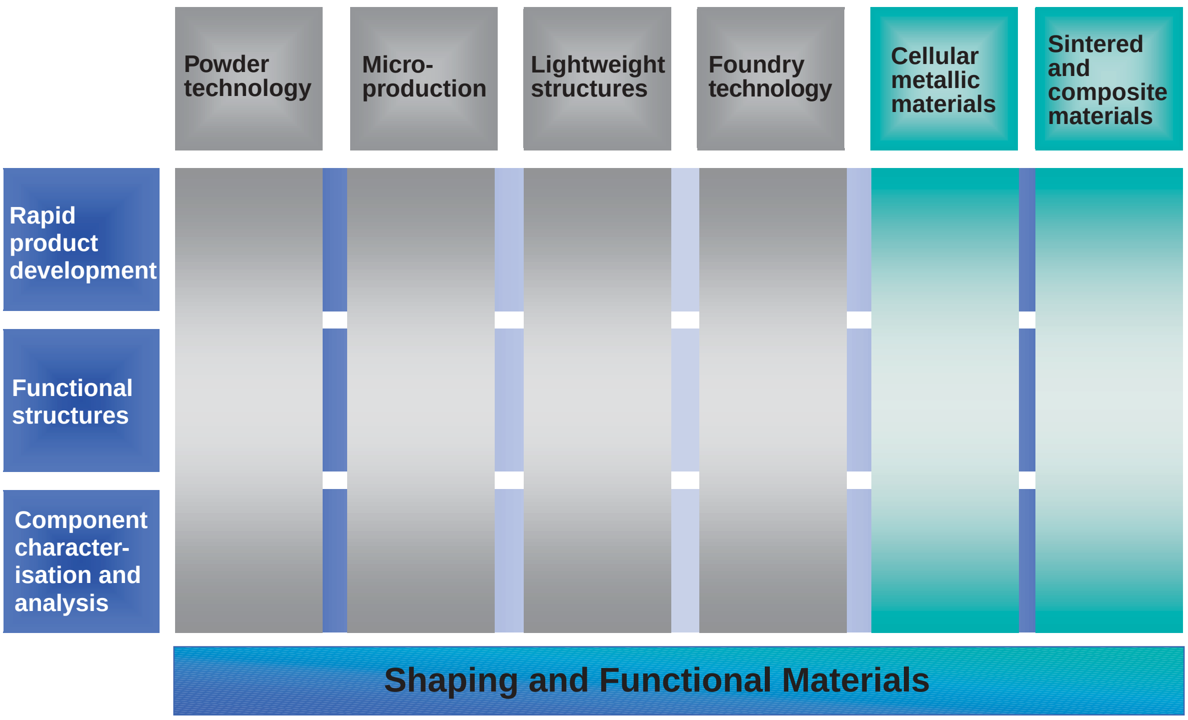



**Fig. 1**: Fields of expertise of the Shaping and Functional Materials department at IFAM.

powder technology. The new "Micro-production" field of expertise carries out work on materials and processes that allow sub-millimetre metallic structures to be manufactured or microstructures in components. The "Lightweight structures" field of expertise is chiefly concerned with issues related to the mass production and quality of components made from metallic foams. Cast components made of light metal, including the associated manufacturing processes and material-related aspects, are covered in the fourth field of expertise "Foundry technology".

In addition to these four fields of expertise, a further three fields of expertise (marked in blue in Fig. 1) have a cross-field character and so span the matrix of fields of expertise.

The "Rapid product development" field of expertise deals with the processes for constructing a component via, calculation, simulation and optimisation right through to prototyping and rapid tooling. The "Functional structures" field of expertise combines technologies by means of which additional functionality such as gradient structures, sensory properties or properties based on nano-structures can be generated in-situ in components. The "Component characterisation and analysis" field of expertise concentrates the know-how and experience in subjects ranging from material analysis, metallography and electron microscopy and makes this available to all the other fields of expertise at IFAM.

Fundamental research projects in subjects that overlap the fields of expertise are being carried out in order to lay a sound scientific basis for the IFAM reorganisation. It is indeed at the interfaces of fields of expertise that many promising new developments are taking place. Increased effort to strengthen collaboration within the Fraunhofer organisation and also in bodies, networks and industrial work groups will ensure that fruitful areas are identified for future-orientated development work.

In addition, our collaboration with the University of Bremen is being intensified, whereby the technical area represented by Professor Busse is being expanded and will harmonise more closely with the Production Technology area. In this way, fundamental scientific is strengthened, students have closer links with IFAM and the basis is so created for a stream of potential future scientific talent to IFAM.

The strategic reorganisation is seen as a dynamic process as far as adapting the areas of work and spectrum of services to the market is concerned. Continuous monitoring of potential R&D markets and ongoing detailed discussions with customers and partners from industry are important aspects of this. The change process that has been started has thus created the basis for future-orientated positioning of the "Shaping and Functional Materials" department at IFAM in the marketplace.

## Expertise and know-how

The "Shaping and Functional Materials" department of the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research investigates issues relating to the manufacture of metallic components and composite materials from powder-form or molten starting materials.

Customised to the respective material and to the complexity and desired number of components, manufacturing technologies are further developed and made reliable from a processing point of view.

In addition, fundamental studies on powder preparation, powder sintering, solidification of melts and the behaviour of metallic materials under the simulated production conditions are also undertaken.

The spectrum of applications is broad and covers different sectors, with the main focus being in the car manufacturing industry, medical technology and micro-technology.

## Perspectives

The observed trend towards rapid and flexible production of ready-to-assemble parts and components will create increased demand in the medium and long term in the area of "Shaping and Functional Materials".

Function integration is playing an increasingly important role in this regard. This is especially so for micro-component production because the high functionality means the complexity of system assembly can be reduced.

New development areas must be defined on the basis of shorter development times, reduced capital expenditure by manufacturing industry and sustainable use of resources for materials and energy. These challenges can be very suitably tackled with rapid tooling concepts.

Widespread and rapid product development necessitates the creation of databases in company-wide intranets in order to be able to apply computer-aided engineering more efficiently.

New lightweight construction methods, which are especially important for the transport sector, can be realised by sandwich constructions and the use of cellular materials.

Technological progress is also closely related to the availability of suitable materials, customised for the respective manufacturing technology. For example, for laser sintering and powder metallurgical production of micro-components, specially conditioned metal powders are necessary which must be custom-developed for the application.

The production of functional nano-structures is often closely connected to the development of processes that integrate the synthesis and processing of nano-scale powders and particles and so allow high production rates with a reduced number of processing steps.

Future work will also concentrate on the transferability of the processes that are developed into continuous processes on a small pilot plant scale (scale-up).

## 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, thixo-casting 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.

# Business fields and contact persons

### Powder technology

Powder-metal shaping, heat compaction for manufacturing high-density sintered components, metal powder injection moulding, 2-component injection moulding, process and material development, rapid manufacturing.

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E-mail fp@ifam.fraunhofer.de

### Powder metallurgy

Powder-metallurgical materials and components, high temperature materials, fibre metallurgy, gradient materials, metal matrix composite materials, metallic filter systems, sinter theory.

Univ.-Prof. Dr.-Ing. Bernd Kieback
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### Lightweight structures

Cellular lightweight components, functional porous metal foam structures, aluminium foam sandwich structures, production processes for metal foam components.

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### Foundry technology

Aluminium/magnesium pressure casting, thixo-casting, design of pressure casting moulds.

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### Rapid product development

FEM simulation for powder compaction, solidification, component optimisation, implementation of material legislation, tele-engineering.

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### Micro-production

Micro injection moulding for metals and plastics, microstructures, series production of miniature components, 2-component injection moulding for micro-components, micro reaction technology, micro-fluidics.

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### Functional structures

Nano-powders, gradient structures, function integration, ink-jet printing, special plant/equipment.

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### Application centre for metal powder injection moulding

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# Equipment/facilities

## Department of Shaping and Functional Materials

- Complete production chain for the manufacture of small, complex bulk components using metal powder injection moulding (MIM)
- Real-time controlled hot and cold chamber pressure casting machine (pressure 300 t and 600 t respectively)
- Mg melting and dosing furnace
- Application centre for rapid prototyping with laser sintering, multiphase jet solidification (MJS), stereo-lithography and 3-D printing
- Powder press for heat compaction for pressing forces up to 125 t;
  various furnaces for foaming metals and heat treatment and sintering under vacuum, inert gas and reducing atmospheres
- 5-MN extruding press
- Hot press
- Melt extraction unit (inert gas/vacuum) for manufacturing metal fibres and metal particles directly from the melt
- Instruments for structure analysis and physical-chemical characterisation of materials and components such as x-ray diffraction, metallography, REM/EDX, trace analysis (C,N,O,S), thermal analysis, etc.
- X-ray fine structure analysis
- Measuring units for analysing the electrical properties of powders, layers and components
- Measuring unit for density determination (g-Densomat)
- X-ray radioscopy
- Emission spectrometer
- Heating unit for thixo-casting
- Unit for measuring friction and wear
- Test unit for measuring high temperature oxidation (up to 1,600 °C/air)


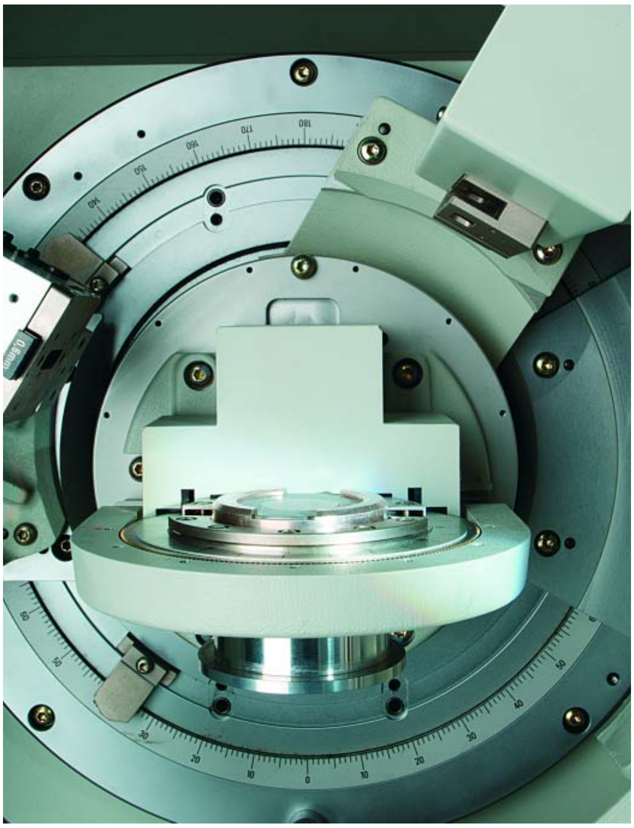

**Fig. (above)**: Powder press.

**Fig. (below)**: X-ray fine structure analysis.

# New development trends in aluminium foam technology

## Background

Over recent years there has been growing interest in all sectors of industry in lightweight constructions and structures. Besides there being environmental reasons for this, with legislation playing a part here, there are also economic and technical reasons for this trend. Metallic foams have experienced a renaissance, starting back in the early 1990s with the progress made at the Fraunhofer IFAM in the area of materials and process development (Fraunhofer Process). From a technological viewpoint, aluminium foam in particular is now a recognised alternative material wherever one or a combination of its characteristic properties is required – for example low density, excellent energy absorption capacity, integral vibration damping and high long-term thermal stability. Applications in rail vehicles, small-series car manufacture as well as in the area of sport and recreation now utilise these advantages.

## Shortcomings

A large number of feasibility studies have shown that the use of aluminium foam permits technically advantageous design solutions for a wide range of products. Implementation in series production is however often a non-starter due to component costs. A further shortcoming is the range of variation in the pore morphology of the foams. From a technical point of view this has only a limited effect, however the perception of customers is otherwise, leading to uncertainty about component quality.

Component costs are currently largely determined by the price of the starting materials. This is particularly so for medium and large batch quantities. The established process for manufacturing the foamable starting material on a small scale is extrusion of cold-isostatically precompacted powder mixtures. Shortcomings of this process are the non-negligible material losses, a certain variation in material quality and very limited suitability for continuous mass production.

It is known from customers that they desire quality improvement. The primary way of achieving this is to reduce the observed variation in the material properties. One way of achieving this in practice is to take measures to get a more homogeneous pore structure. Reducing the variation in the properties has direct economic implications because with precisely defined material properties less work is required for quality assurance and at the same time fewer safety reserves have to be introduced into the construction design.

## Remedy

One way to remedy the above-mentioned problems is to remove the economic barriers (cost reduction). This would open up many new fields of application and hence make a key contribution to the implementation and further establishment of this technology.

This development will go hand in hand with a greater need for research. At the same time, the scope of services demanded by industry will increase. The construction and dimensioning of metal foam components will gain importance. In addition, the optimisation of the foaming process will essentially lose its largely academic character by giving the market an increasing number of manufacturers of metallic foams a basis for existence.

The Fraunhofer IFAM can significantly support this development. In order to benefit from this development, it is necessary for the work and services offered by the Institute to reflect the production chain from the idea stage right through to the final product. This includes the constructive design of components and also control of the manufacturing process for semi-finished products and the ability to develop, demonstrate and implement (in pre-series, etc.) foaming processes in plants that closely resemble series production.

## Potential for research/realisation

In the past year a comprehensive evaluation was made of both established processes and new approaches for manufacturing foamable semi-finished products. As a result of this evaluation and the follow-up development work, IFAM Bremen focusses on a novel processing route based on cold-pressing of the powder mixture followed by thermal treatment. Despite the simplified process chain, the flexibility of the classical Fraunhofer Process regarding the choice of matrix alloy is maintained. The aim is to manufacture the material in the form of large blocks of several 100 kg weight. After rolling to suitable thicknesses, these can be used for manufacturing aluminium foam components. Alternatively, they also offer the possibility for roll-cladding from the coil and hence efficient manufacture of sandwich pre-materials.

A reduction of the variation in the material properties by a having more homogeneous pore structure can be achieved independently of the process used for manufacturing the semi-finished products by altering the foam formation. Approaches for doing this include altering the foaming process and gas-developing agent and measures related to the alloy. Utilisation of granulated semi-finished products in conjunction with cost-effective processes for manufacturing the same also seems very promising. In addition, the cutting of the semi-finished products required for complex component geometries would be avoided and this would be a major step towards automated dosing of the semi-finished product.


**Fig. 1**: Foamable aluminium semi-finished product (coil) manufactured by cold-isostatic pressing, sintering and rolling.

## Realisation

The selected process variants are being investigated within the framework of internal research projects and have already been patented. The current state of the development work allows the manufacture of foamable semi-finished products at IFAM Bremen at prices that, even for charges of just a few kilograms, are equivalent to externally available materials. This new opportunity has already benefited the first projects. It reduces the dependence on external suppliers, increases the flexibility regarding new materials and delivery times and puts control of the quality completely in IFAM's hands.

The work to use granulated semi-finished products for component manufacture is part of the BMBF "ULMA" project (see project report). Here first initial experiments on the foaming behaviour of foamable granulate particles and bulks of foamable granulate have been carried out.

The next step is to scale up both process routes for larger charges and hence to realise the cost advantages compared to conventionally produced materials. This represents a significant step on the way to providing a comprehensive range of services directed at the future needs of metal foam users and manufacturers. In tune with the current requirements of these customers, IFAM Bremen is focussing its efforts on manufacturing of semi-finished products at favorable cost and making available reliable production technologies.


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# ecoMold – A new concept for the rapid-tooling of large mould inserts for injection moulding

## Background

Due to low construction rates, the application of the laser sintering process (DMLS) has up to now been limited to the manufacturing of small mould inserts for injection moulding and Al die casting. The aim of this project was to expand the technology of rapid-tooling to larger mould inserts.

The basic idea was the splitting of the mould insert into modules and the manufacturing of these separate modules. Each module comprises a base geometry and a shape geometry. The base geometry represents the volume of regions of the mould insert that contain no shape-determining parts. In order to considerably reduce the required construction times, these base geometries can be manufactured at favorable cost as standard base modules for example by milling. The shape-determining geometries of the insert can then be sintered onto the base modules using the laser sintering process. The various modules are finally assembled to make the finished mould insert. The concept behind the project is schematically shown in Fig. 1.

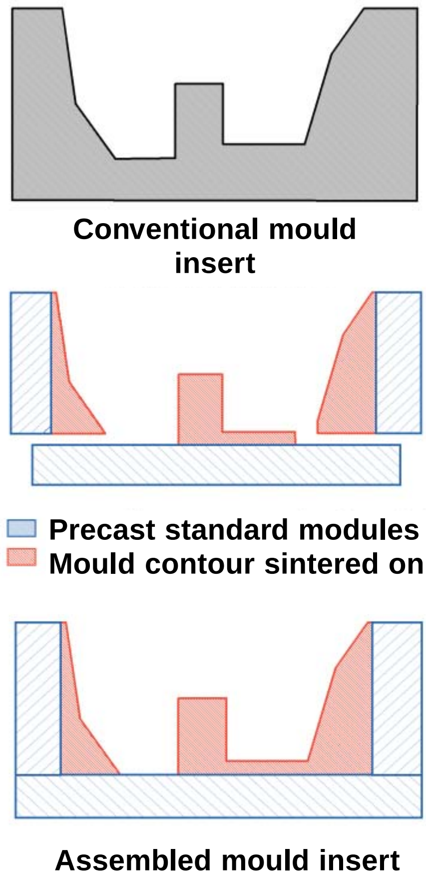


**Fig. 1**: Concept behind the ecoMold project.

## Task

The following tasks had to be fulfilled by the Fraunhofer IFAM and the other partners in the project:

- Testing different mould steels for their suitability for sintering onto the mould geometry
- Development of a software-tool for fully automatic calculation, positioning and alignment of the standard elements in a preset volume of a mould insert
- Development of a precision tensioning and positioning system for the laser sintering unit
- Realisation and testing of a reference mould for injection moulding.

## Description of the project

A key prerequisite for the efficient manufacture of a mould insert using the above-described approach is fully automatic data generation. In order to achieve this, the first part of the project involved the development of a software-tool, which generates these data. This development was done by the Fraunhofer IFAM, Department CAE. Based on the STL data set for the entire mould insert, this software-tool determines all standard elements and automatically positiones them in such a way that as large a volume as possible is filled by the standard elements in order to minimise the residual volume of the mould geometry that has to be sintered. For each standard element, the software calculates the residual geometry to be sintered on and generates the corresponding STL data set, which can then be used for directly controlling the laser sintering unit. Fig. 2 shows the data set for the ecoMold reference mould insert with the automatically positioned standard elements and a representative sinter geometry.

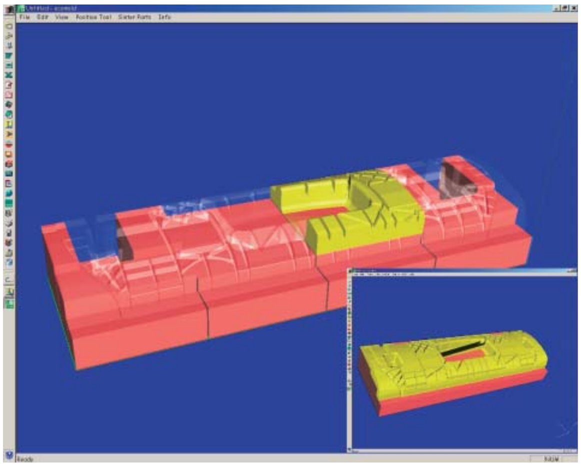

**Fig. 2**: ecoMold software-tool.

For precise construction of the individual modules it is also necessary that there is a tensioning and positioning system. Using these systems, the sinter geometries can be sintered directly onto the standard elements with, in an ideal case, zero tolerance margin. The development of this positioning system was the central aspect of the second part of the project. Fig. 3 shows the system mounted onto the platform of the laser sintering unit. The same positioning system, of similar construction, can also be mounted onto the milling machine, so that touching the same positioning of the elements as on the laser sintering unit is guaranteed.

In order to test the tooling concept that had been developed, an injection moulding reference tool was manufactured and tested in the last part of the project. This work was carried out in collaboration with all project partners. The reference component chosen was the cover of a car glove compartment. Fig. 4 shows all the construction elements for this reference mould. The whole mould insert consisted of 10 standard modules and 14 sinter modules. These were assembled to build up the final mould insert shown in Fig. 5. Finally the polished mould insert had the dimension of 420 x 140 x 75 $mm^3$. Fig. 6 shows the glove compartment cover made of ABS that was successfully moulded from the reference mould insert (size ca. 380 x 110 x 40 $mm^3$).

The system that has been described represents a new manufacturing concept, involving a combination of laser sintering and milling that allows the laser sintering process to also be used for rapid-tooling applications for larger components. First experiences and calculations indicate that compared to conventionally manufactured mould inserts the costs can be reduced by about 35 per cent and the required construction times can be decreasd by about 30 per cent.

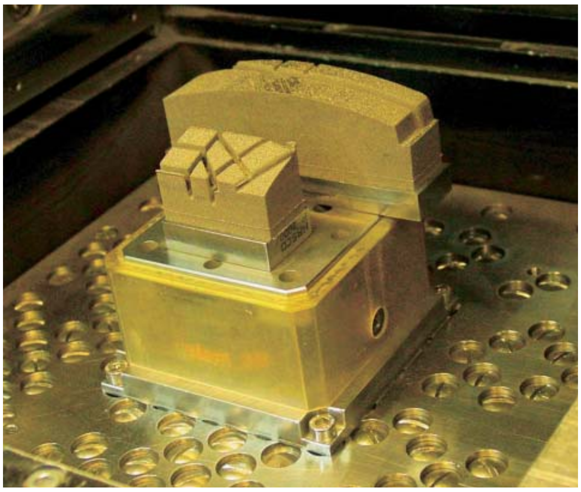

Fig. 3: ecoMold positioning system.

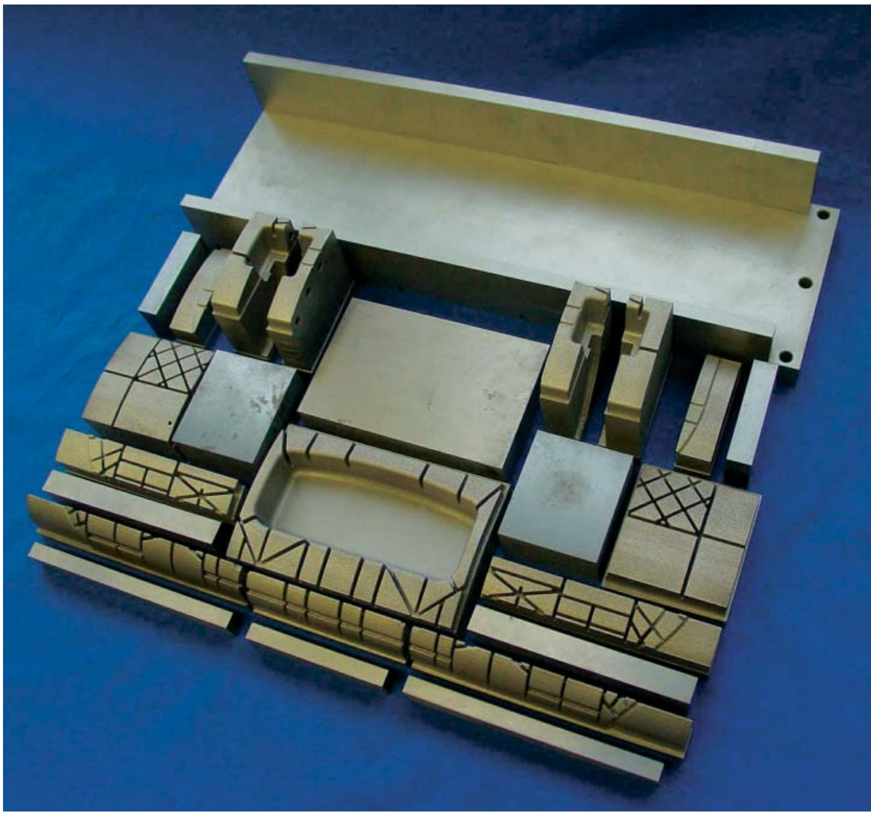

Fig. 4: Standard and sinter modules of the ecoMold reference mould.

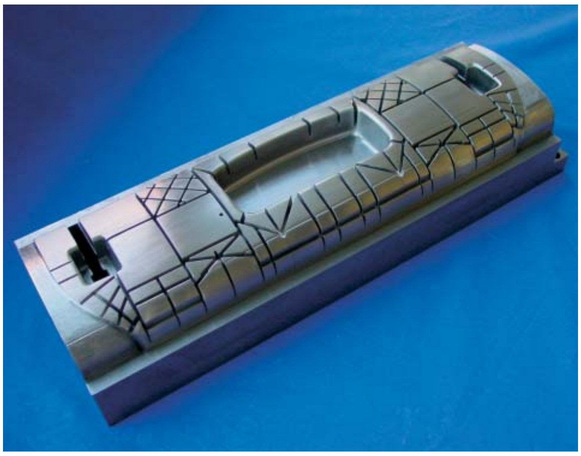

Fig. 5: ecoMold reference mould (420 x 140 x 75 $mm^3$).

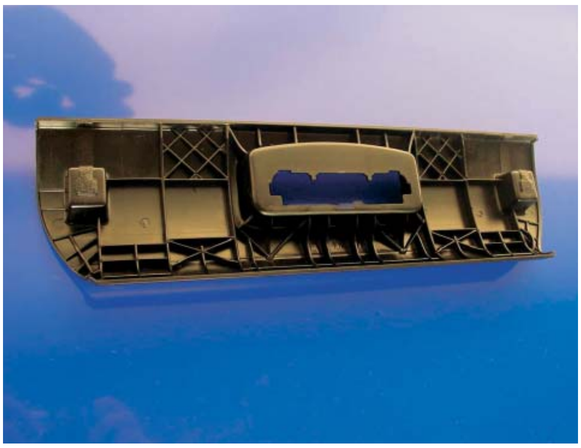

Fig. 6: ecoMold reference component (380 x 110 x 40 $mm^3$).


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Client

European Community, CRAFT Programme (1998-2002)

Project partners

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Polyline S.A., Greece
Legazpi Moldes Lda., Portugal
Cybamatic Ltd., England


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# IFAM Spin-off
# "Bio-Gate Bioinnovative Materials GmbH"

The development of highly porous silver powders ("nano-powders") by evaporation and condensation in noble gases ("IGV process") has been successfully carried out at IFAM for more than 15 years. A recently installed plant now allows customers to be supplied with even larger quantities up to several 100 kg. In addition to the good conductivity and corrosion resistance of conducting adhesives for bonded joints that are subject to high thermomechanical loads, the anti-bacterial action of products made from organic materials dosed with these highly dispersed silver metal particles has proved to be particularly advantageous: This very pure filler – manufactured via physical processes – has a high specific surface area and can be added to a wide variety of different paint systems, polymers and adhesives. The desired effect is especially good in anion-free (Cl-, K-, Na-) material systems.

Ways to market these developments have been sought – and found: Contact with Bio-Gate GmbH, located in Nürnberg, allowed direct access to a rapid method for testing the anti-bacterial effectiveness of the developed materials. With this patented method was the reason "Bio-Gate GmbH" came into being out of an institute of the University Hospital Erlangen/Nürnberg about 5 years ago.

The expanded business plan of the newly founded "Bio-Gate Bioinnovative Materials GmbH" now also includes own production of anti-bacterial materials, utilising the resources available at IFAM (process development and plant technology) for manufacturing silver-containing polymer matrix composite materials.

The basis for the long-term collaboration is a know-how/licensing contract in conjunction with a supply contract that controls the exclusive commercialisation of the silver powders made at IFAM – restricted to materials for life science applications and in the area of medical technology. This enables to provide Bio-Gate customers with samples of certifiable products at a very early stage. As a countermove the Fraunhofer-Gesellschaft holds a 5 per cent stake in Bio-Gate Bioinnovative Materials GmbH. This agreement was negotiated by the Fraunhofer Venture Group and does not obstruct the execution of other R&D projects in these application areas.

The business plan covers the development and manufacture of anti-bacterial materials and products that allow control and/or suppression of the adhesion and growth of micro-organisms on surfaces. The main aim is to prevent infection in medical environments, an increasing problem in hospitals. Due to the greater resistance of certain strains of bacteria to antibiotics, there has been an increased number of so-called "nosocomial infections" – after surgery or after long-term use of tube catheters. The proliferation of bacteria on surfaces must also be minimised or totally suppressed in some technical products (where "biocorrosion" occurs) and in the food industry (packaging foils/packaging machinery).

In addition to possessing good adhesion to the substrate, suitable anti-bacterial coatings must also be compatible with human tissue: Surfaces must have anti-bacterial properties but must have no cytotoxic effects. The application of highly dispersed metallic silver in a suitably modified form is often the simplest and most cost-effective solution to such problems.

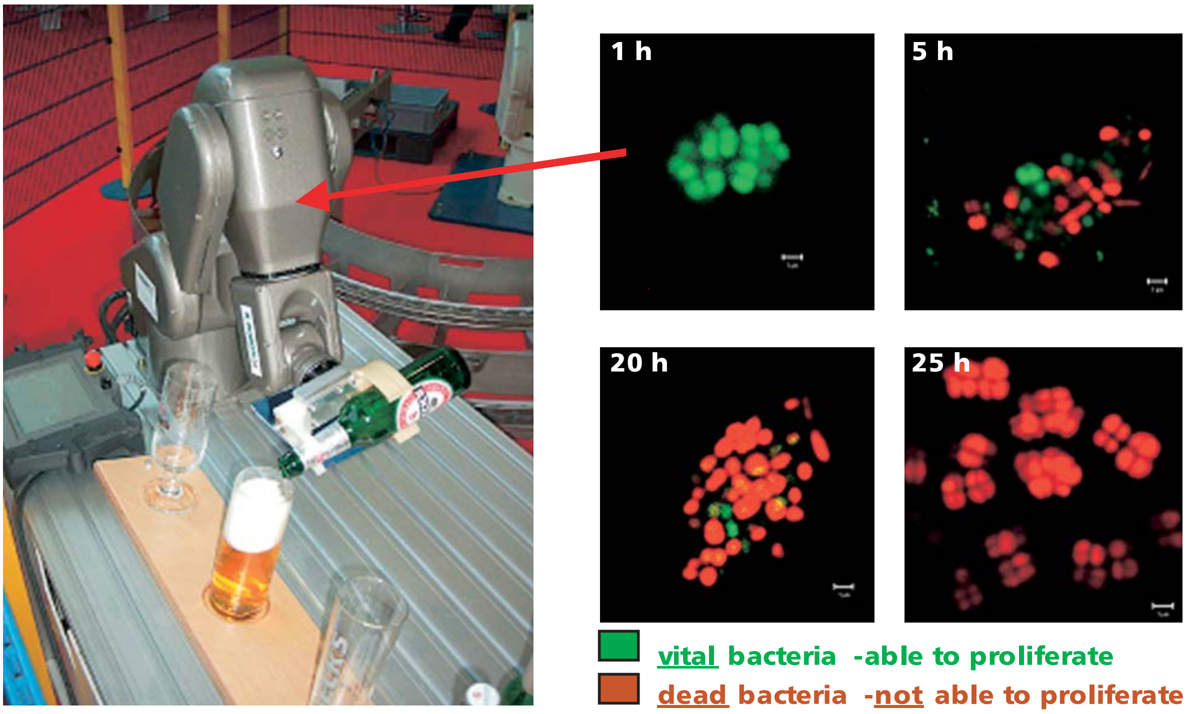


Fig. 1: A robot used in the food industry (left) is coated with a paint having an Ag-filler. The anti-bacterial effectiveness could be proven using a biotechnological test method (right).

Applications are found in the following sectors of industry:

- Medical technology and pharmaceutical industry – catheters and bandages,
- Food industry – packaging foils/packaging machinery,
- Coating industry – paints and sealant materials,
- Sanitary technology – fittings and ceramics,
- Clean room technology – filters,
- Biotechnology.

By way of example, the Fig. 1 shows a small robot used in the food industry that is coated with an anti-bacterial paint.

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# Studies on the manufacture and applications of granulates made from foamable materials

## Background

A great deal of research work is currently being carried out all over the world on new materials for lightweight construction. Such materials should ideally possess a range of characteristic properties such as excellent energy absorption properties, high rigidity per unit weight and good mechanical and acoustic damping. This desired spectrum of properties is essentially fulfilled by foamed metals. Aluminium foam in particular is for that reason being intensively researched for applications in the area of transport engineering.

In addition to the manufacture of prototype components as part of feasibility studies, industrial projects and publicly funded projects, a central aspect of IFAM's work is also process optimisation – namely efficient production at favorable cost.

The objective of the BMBF project ULMA (Ultralightweight construction for mobile machinery) is to significantly improve the functionality of such machinery by increasing the operability, namely by increasing the reach and adjustment speed, by increasing the positioning accuracy as well as by increasing the bearing load with simultaneous improvement of the dynamic positional stability and the ease of mobility. Reduced material input and usage with a target weight reduction of > 20 per cent should prevent axle loads being exceeded with simultaneous utilisation of the extended work functions of mobile machinery.

An aim of the IFAM sub-project (funding reference 02PP2494) is to prepare prototype components and test them under conditions close to reality. The other project partners will carry out practical trials with these components. The demonstration items selected included the distributor boom of a concrete pump and a quick-changer for excavators (Fig. 1). In order to make hollow foam components, a key aspect of the work is to manufacture and test granulates made of foamable aluminium materials. The aim is to optimise the production technologies. In this way, the need to cut the foamable material to size and the material losses resulting from this are avoided. In addition, simple dosing of the granulates represents a further step towards automation of the foaming process.

## Task

When foam components are produced by conventional manufacturing methods, the foamable aluminium must be made into the required geometrical form. To achieve this, the material is rolled down to the desired thickness and then cut to size. In order to avoid these steps, the use of granulate made of foamable material represents an interesting alternative. In this procedure, a defined amount of the granulates – e.g. as a free-flowing product – is simply filled into the cavity of the foaming mould and then foamed by heating.

A prerequisite for the success of this method is that the individual expanding granulate particles bind to one another well, so producing a homogenous foam component without internal interfaces.

In this regard, suitable granulating methods had first of all to be identified. In addition, different granulate particle sizes had to be tested. A number of cutting techniques came into consideration for this, depending on the required granulate particle size.

The granulates that were produced and the foam components that were made had to be characterised. This involved measuring the bulk density of the granulates and the densities of the foams that were produced.

## Results

Granulates of different size and shape were produced from foamable sheet material by sawing, cutting (metal-cutting shears), punching and nibbling. The punching produced circular, tablet-shaped granulates and nibbling produced half-moon shaped particles. The particle volumes were calculated as an average from the weight of 50 individual particles. The particle volume of the granulate was between 0.00015 and 1.0 $cm^3$.

The foaming behaviour of the granulates that were made from foamable materials in this way were characterised in both the expandometer and in free foaming experiments. The results of the free foaming experiments are shown in Figs. 2 and 3. Fig. 4 shows examples of different granulates and the foam objects made from them.


**Fig. 1**: Demonstrator object: "Quick-changer" (left: principle, right: in actual use).

**Fig. 2**: Nibbled and punched granulate particles, before and after foaming.

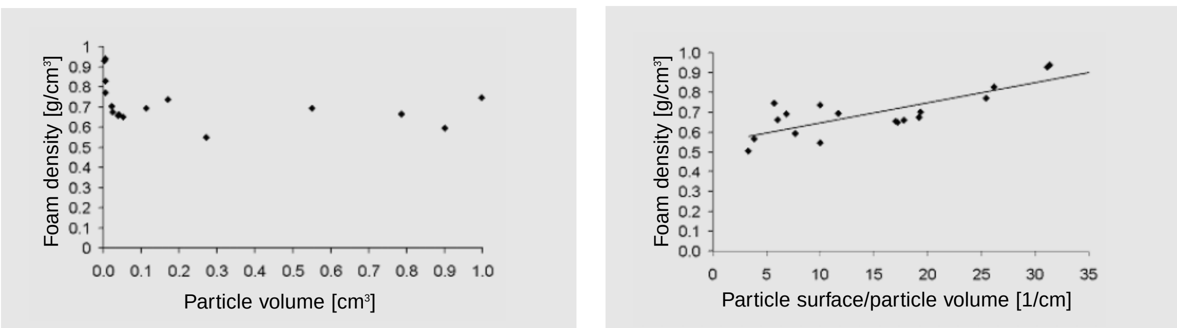


**Fig. 3**: Effect of the particle volume and the particle surface area/volume ratio on the foam density that can be attained.

The results can be summarised as follows:

- When granulate was foamed in a foaming mould, good mould-filling could be achieved.
- The granulate particles fuse into each other during the expansion process.
- The larger the surface area/volume ratio, the higher the density that can be achieved.
- Even for very small granulate particles with a volume of less than 0.02 $cm^3$, density values of less than 1 $g/cm^3$ can be attained.
- For very large mould volumes and for granulates having a low bulk density, the simultaneous heat flow into all granulate particles can cause problems (inhomogeneous foam structure).

Fig. 4: Examples of different granulates and the foam objects made from them.


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# Trends in powder metallurgy: "Lightweight" and "nano-structure" materials

## Introduction

Powder metallurgy allows attractively priced precision components to be produced, special joints to be created and defined porosities to be generated. These advantages have led to a broad range of powder-metallurgical processes and resulting materials and components. A particular feature of developments over the last three decades has been work aimed at increasing the shape diversity of components, improving material specifications in the individual sinter material groups and hence expanding the markets for products manufactured using powder-metallurgical processes. Only to a very limited extent were new materials and potential new areas of application the focus of research and development work in this period.

As a result of commercial developments and environmental requirements, the trend in powder metallurgy during the 1990s was towards lightweight construction and increased functionalisation of systems. This trend has gained further pace since the dawn of the new millennium. The research efforts of the IFAM facility in Dresden, whose core activity is the development of new and improved sinter materials, are currently chiefly targeted at functional applications and reducing the weight of components. Specific research areas include light high-porosity cellular metallic structures, sinter materials made from lightweight metals for room temperature and high temperature applications and composite materials with customised thermal properties for electronic components.

## Lightweight materials via powder metallurgy

In principle, lighter components can be produced in 3 ways:

1. By using materials of lower density having the same mechanical properties;
2. By substantially improving the mechanical properties of materials, at constant density;
3. Structural lightweight construction, i.e. load-specific material distribution in the design.

Combinations of these three options are naturally also possible. Options 1 and 3 are the most interesting and bring the greatest benefits.

## Sinter materials of lower density

### Aluminium

Of all the common lightweight metals, aluminium is used to the greatest extent in industry. Its use in powder metallurgy does however cause problems for the processing chain – powder manufacture, moulding and sintering – because thin layers of oxide are very stable and adversely affect the sintering. Ways to remedy this problem, whilst simultaneously generating the material properties required for a specific application, are currently the focus of a number of projects. The addition of magnesium and liquid phases during the sintering breaks down the oxide skin. High silicon concentrations (14 – 25 per cent) increase the wear resistance and the rigidity of the material and decrease the coefficient of expansion. In industry, all companies that are involved with PM are currently introducing PM-aluminium, largely to replace sintered steel components. In the future, interesting research topics in the area of powder metallurgy will be component-specific alloys, dense Al sinter materials via powder forging, high velocity compaction, solid-liquid forming as well as rapid-setting, nano-dispersion reinforced and quasi-crystalline materials.

## Titanium

The main drawback of using titanium in powder metallurgy is still the high price of titanium powder. New routes for metal recovery aimed at reducing costs are being researched at various establishments throughout the world. Of interest in this regard is the work on electrolytic reduction that was started at Cambridge University and continued by Quinetic. Also noteworthy is the work of ITP on continuous reduction of titanium tetrachloride. New studies on the HDH-process in China may also lead to cost reduction. Research work has been started at IFAM on applications for the new grades of powders. Over the next few years it is expected that the above-mentioned metallurgical processing routes will yield attractively priced titanium powders that open up new perspectives for press-and-sinter components as well as for MIM. The result will be a market for PM titanium and titanium alloys with potential applications in the car industry, recreation sector and medical engineering (Fig. 1).

Attractively priced Ti-powders are also interesting for research that was started several years ago on sinter materials based on the TiAl intermetallic phase. The reaction sintering of the elemental starting powders, which are transformed by mill treatment into a state that can be readily sintered, offers a favorable-cost means of manufacturing complex shaped components from materials that are difficult to work. As a follow-up to earlier work that focussed on customising the sintering process to the milling technique, the alloys are now being optimised. Using internal oxygen scavengers, room temperature bending strengths of 1,000 MPa and low plastic deformation have already be achieved. This has created the basis for the development of customised engine components (Fig. 2).

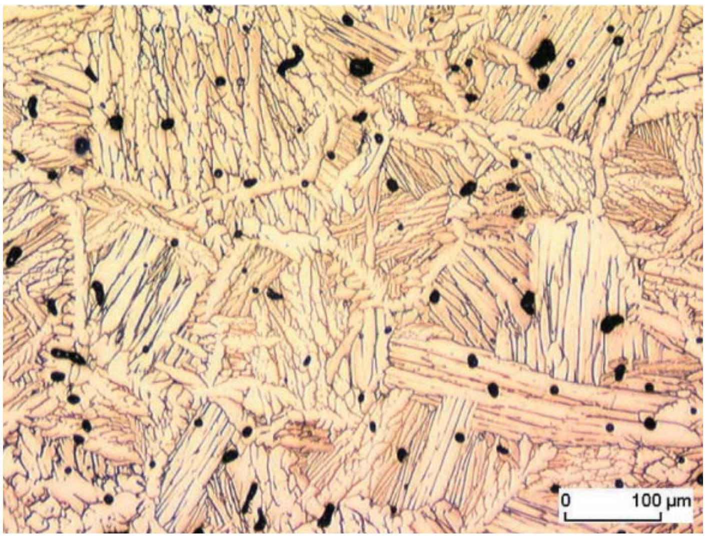


**Fig. 1**: Micrograph of a sintered TiAl6V4 sample made from a powder mixture.

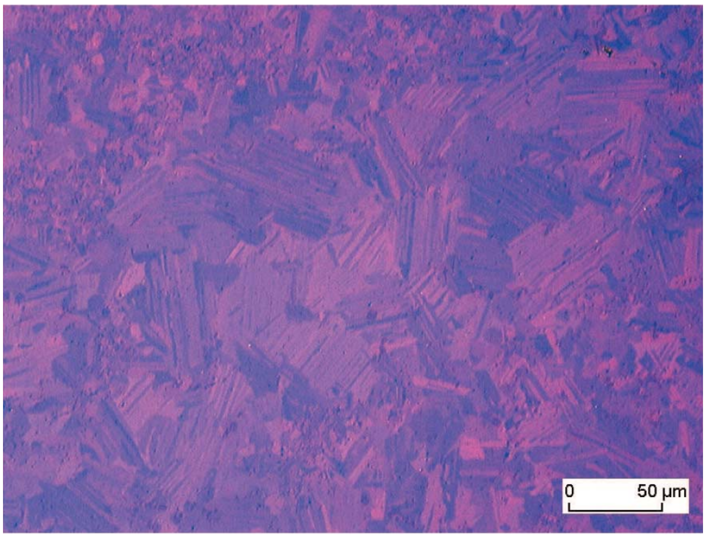


**Fig. 2**: Microstructure of a Nd-containing TiAl sample with Nd oxide segregations.

## Cellular metallic materials

Ever since metallic foams demonstrated their potential as high porosity metallic materials in the 1990s, alternative manufacturing processes have been sought. A highly interesting method is the manufacture of hollow spheres and hollow sphere structures. This interest stems from the low manufacturing costs, the universal choice of materials and the broad variation of densities and pore structures which can be tailored for different applications. By powder-coating spherical styrofoam supports, hollow metallic spheres are obtained after sintering. By including a shaping step in the green state, cellular mouldings or semi-finished products are obtained after sintering. In both cases the porosity is distributed in very defined cells and can attain values of more than 95 per cent. The method allows the cell size to be chosen, the selection of (virtually) any desired wall strength, the use of a broad range of metal and alloy powders and material and component manufacture using various means of joining the hollow sphere building blocks (bonding, brazing, sintering). In addition to applications for lightweight construction, current development activities include work on the functional properties for noise damping, heat insulation, catalyst and filter applications and energy absorption. Fundamental research is also being carried out in this area to deepen understanding of structure-property relationships. IFAM's Dresden facility is also undertaking exploratory research on further technologies for manufacturing cellular metallic materials and components. The opening of our building extension in 2004 will create a Demonstration Centre for Cellular Materials. Preparations for industrial-scale manufacture of metallic hollow spheres and hollow sphere structures at partner companies are already well advanced (Fig. 3).

**Fig. 3**: Regular cellular metal structure manufactured via hollow sphere technology.

## Powder-metallurgical routes to nano-structure materials

Started as a topic of fundamental research back in the 1980s, nano-structure materials are now used in industrial applications. In addition to the process for nano-powder manufacture that was introduced at an early stage at IFAM Bremen, high-energy milling methods are particularly suitable for producing nano-dispersion reinforced materials and nano-composites. Applications for high-temperature components, electrical contacts and wear-resistant materials are already known. The current research work being carried out at IFAM's Dresden facility is directed at composite materials with carbon nano-tubes and nano-laminates based on Ti3SiC2. (Fig. 4).

The international trend in powder metallurgy research is also towards nano-structure materials. Interesting fields of work are in particular hard metals with carbide grain sizes <100 nm, hard and soft magnetic materials and also hydrogen storage alloys. With its methods for mechanical alloying and microwave and pressure-aided sintering methods suitable for nanostructures, IFAM's Dresden facility has already created a solid platform for future research work.

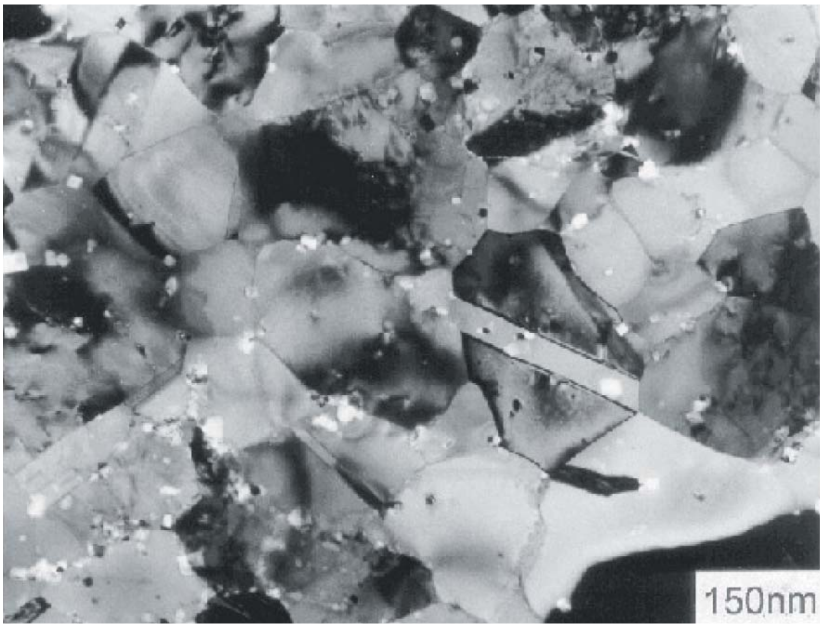


**Fig. 4**: TEM micrograph of Cu-3 vol.%. Formation of dispersoids due to reaction, $d_{TiC}$=10-30 nm, $d_{Cu}\approx$200 nm.


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# Development of new materials for abrasive seals in gas turbines

## Background

Abrasive seals, also known as "contact seals", have the task of sealing the gap between the rotating turbine blades and the turbine housing. During operation, the blades become longer due to heat expansion and creep behaviour and there is often considerable bending of the shaft as a result of take-off and landing operations. As a result, the seals must abrasively wear on contact with the blade tips, without subjecting the blade tips to too high loads. At the same time, the seals must provide an optimum sealing effect because this is of major importance for engine efficiency.

Up until now, the sealing function has been achieved using honeycombs made of nickel superalloy. The upper temperature limit of these honeycombs is however ca. 1,050 °C. Work has been carried out within the consortium to improve the honeycombs in order to raise the temperature at which they can be used to near 1,200 °C. This would considerably increase the turbine efficiency.

## Task

The special task of IFAM is to develop alternatives for honeycombs in the form of fibre and hollow-sphere structures. The client stipulated at any early stage that iron-chromium-aluminium should be used as the base material (e.g. material no. 1.4767, "Aluchrom YHf"). Due to their pore structures, cellular metals can be expected to have good abrasive properties. The hollow spheres should naturally have the better sealing properties, whilst the fibre structures should have much superior high temperature resistance. The latter is due to the fact that the metal fibres are made by melt-extraction and permit virtually unrestricted alloy design.

**Fig. 1**: Test sample of sintered Aluchrom YHf fibres.

## Results

Fibre and hollow-sphere structures having a porosity of ca. 80 per cent were developed. These were provided in suitable geometries for different tests.

The most important application-related tests that were carried out were tests on the abrasive behaviour and oxidation resistance. For the latter, test samples were tested under simulated turbine conditions up to 1,200 °C.

For testing the abrasive behaviour, the contact-behaviour is simulated under conditions close to reality. This involves passing the tip of a rotating blade into the sample at relative velocities of up to 305 m/s. Both the hollow-spheres and fibre structures showed very low blade abrasion and generally much superior abrasion properties to the honeycombs.

**Fig. 2**: Hollow-sphere structure after the abrasion test.

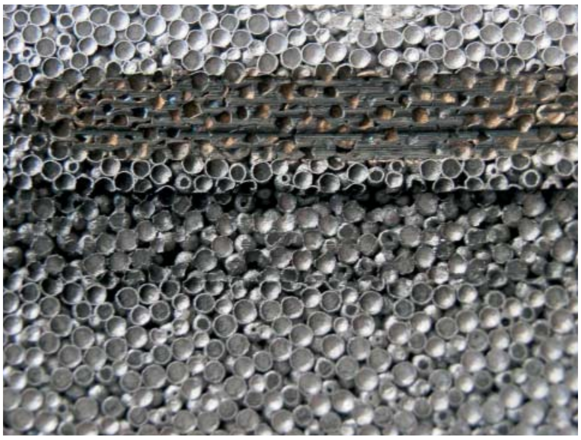

**Fig. 3**: Detailed hollow-sphere structure after the abrasion test.

The testing of the oxidation properties was made more difficult by the fact that attachment to the so-called backplates was by brazed joints. This showed that there is currently no high temperature solution for bonding nickel-based superalloys to Aluchrom. This was a problem with both the new materials and the Aluchrom honeycombs, resulting in regular failure of the structures at the brazed joints. A definitive statement is therefore not possible at the present time, but nevertheless the following conclusions can be drawn:

The fibre structures have excellent oxidation resistance, even at the highest temperatures. However the joining problem is very difficult to remedy. In addition, the fibre structures showed poor resistance against the abrasive effects of particles in the gas stream. Without taking further measures, the sealing effect is deemed to be unsatisfactory and for that reason the application of fibre structures is at present deemed less likely.

The hollow-sphere structures still currently possess a lack of oxidation resistance above 1,100 °C. This is due to the micropores in the sphere walls and the too high residual carbon content. The excellent resistance to the abrasive effects of particles in the gas stream, the good sealing effect that is expected and the protection of the brazed joints by the essentially gas-impermeable, insulating sphere structure do however justify that further development work be undertaken.

It is hence planned to carry out tests on hollow-sphere structures in the project period that remains. The practical suitability of these materials will be tested at moderate operating temperatures of ca. 1,050 °C in a test turbine.

## Description of the project

Under the central leadership of MTU, work was carried out to investigate the potential for improving abrasive turbine seals within the framework of the "ADSEALS" project (Investigation of Advanced High Temperature Seals, Project No. GRD1-1999-10608 as part of the "Competitive and Sustainable Growth Programme" of the EU). In this regard, IFAM Dresden has been developing "New Materials" since May 1, 2000 in work commissioned by MTU. Other members of the consortium for this project are Fiat Avio, Alstom Power UK Ltd., Neomet Ltd., Ecole Centrale de Lyon, Rolls Royce plc. and Rolls Royce Deutschland GmbH. The project term is 4 years and this will end on April 30, 2004.


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# Development of high-temperature resistant and corrosion resistant nickel aluminide and Inconel foams

## Background

Metallic foam materials already currently have a wide range of uses. These include applications in lightweight construction (Al) and applications as battery materials (Ni). The most cost-favorable manufacturing methods are however limited to specific materials and in general permit no manufacture of foams from complex high-temperature alloy materials.

Using the carbonyl process, Inco Special Products (Canada) manufactures large quantities of Ni-foam in different qualities for use in batteries.

## Task

The aim of the project was to modify the available Ni-foams so that these structures can be used at high temperatures and under oxidative and/or corrosive conditions. In order to successfully demarcate this work economically from already existing methods such as CVD-coatings on Ni-foam, priority was put on high cost-efficiency from the very outset of the development work. In addition, the developed process should be universally applicable, flexible and require little equipment as well as allowing later scale-up.

The main application areas for high-temperature resistant and corrosion resistant Ni-based foams are high temperature filtration (e.g. diesel soot filter), catalysis (catalyst supports) and also energy generation and energy conversion. The process to be developed should hence include moulding of the foams into structural components prior to conversion to the high-temperature stable phase that is difficult to work.

## Description of the project

Based on the required property profile, a metal powder process was developed that allows the conversion of Ni-foams into high-temperature resistant Ni-based foams. The most important material parameters, namely the final composition, the specific surface area and the porosity of the foam, were varied in order to achieve optimum flexibility for the respective applications. Fig. 1 shows the patented manufacturing process.

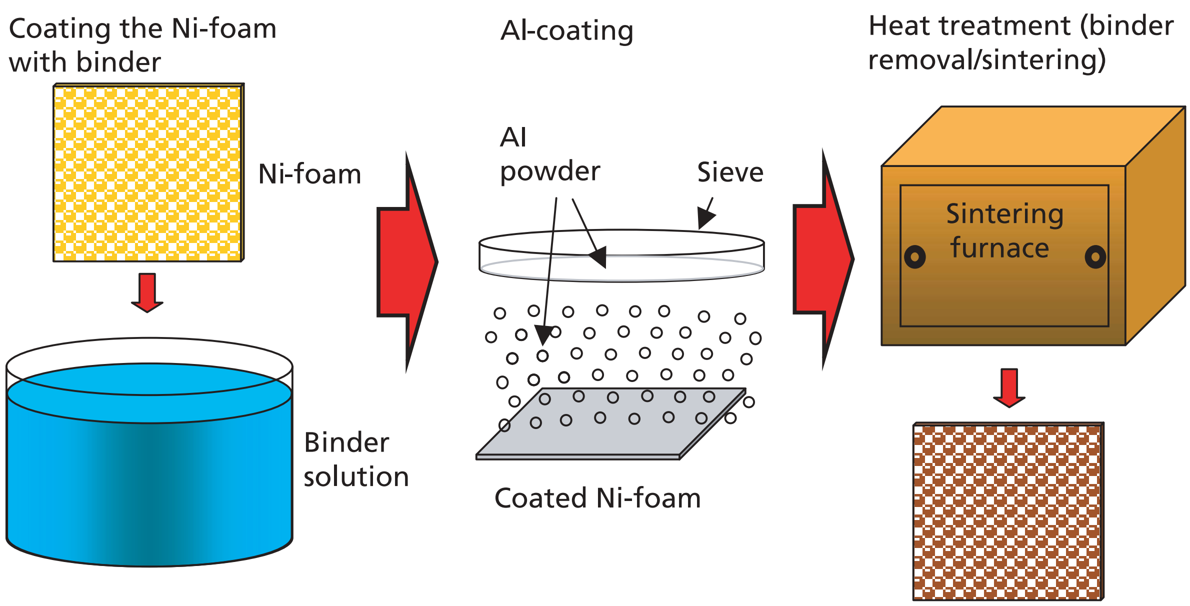


**Fig.1**: Manufacturing process for NiAl-foam (schematic).

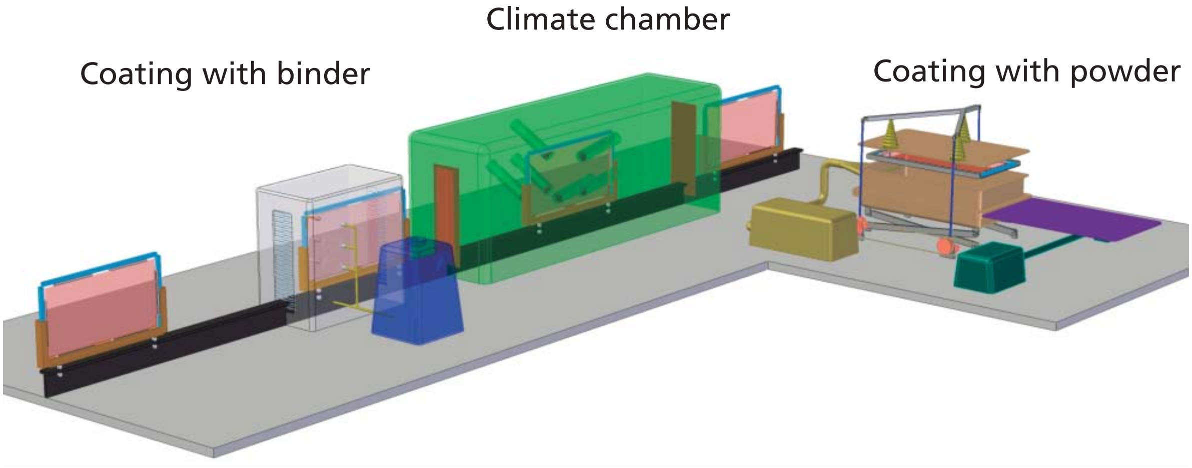


**Fig. 2**: Equipment design concept (in collaboration with MSM).

The first step of the manufacturing process involves coating the Ni-foam with a binder solution. This can be carried out using an immersion or spraying process. The foam is then coated with the desired powder (e.g. 50 wt.per cent Al for manufacturing NiAl-foam). During the subsequent sintering step, the final composition of the foam and its specific surface area and porosity can be adjusted as desired. The process also allows coating of the base substrate with multi-phase composite powders and is hence also suitable for manufacturing complex alloy compositions. Fig. 2 shows the first concept design for laboratory-scale equipment.

The good workability of the Ni base foam allows manufacture of the final geometry of the component after application of the coating – but before the sintering. In this way, complex components made of materials that are difficult to work are also easy to manufacture (Fig. 3).

**Fig. 3**: Worked foam structures made of NiAl.

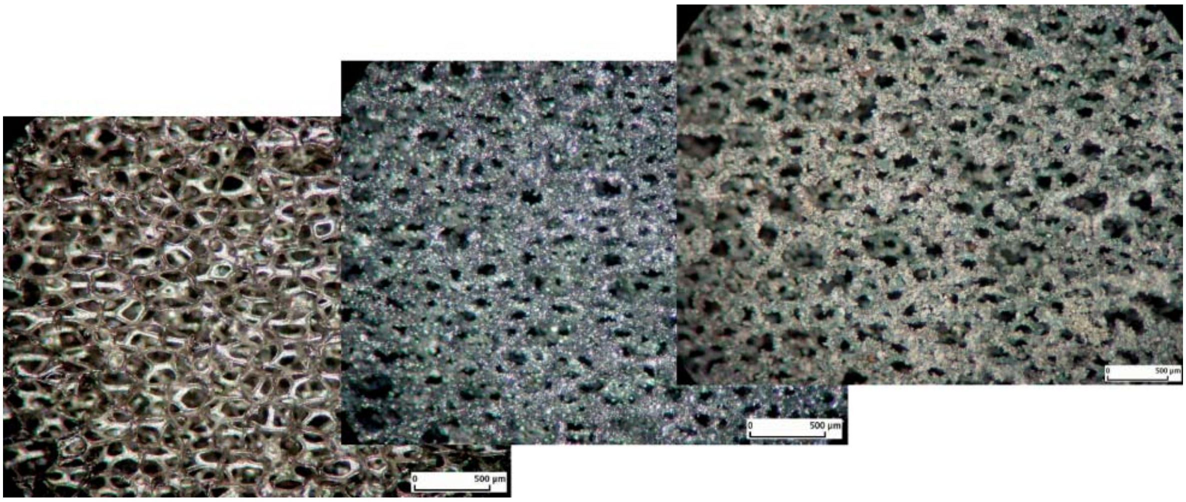

**Fig. 4**: Comparison of states of the coating (from left to right: Ni base foam, coated foam, reacted NiAl-foam).

One main objective of the project was that the final material be as homogenous as possible. This was achieved by optimally coating the base substrate with binder and then with composite powders. Fig. 4 compares the individual states of the coating from the base foam right through to the reacted NiAl final product. The specific example shown demonstrates how the specific surface area was increased in a customised way using composite powders.

The novel materials have good homogeneity, excellent oxidation and corrosion resistance and superior mechanical properties and open up a series of new fields of application in high-temperature filtration and catalysis. Initial application-related tests have confirmed the high promise of these novel foam structures (Fig. 5).

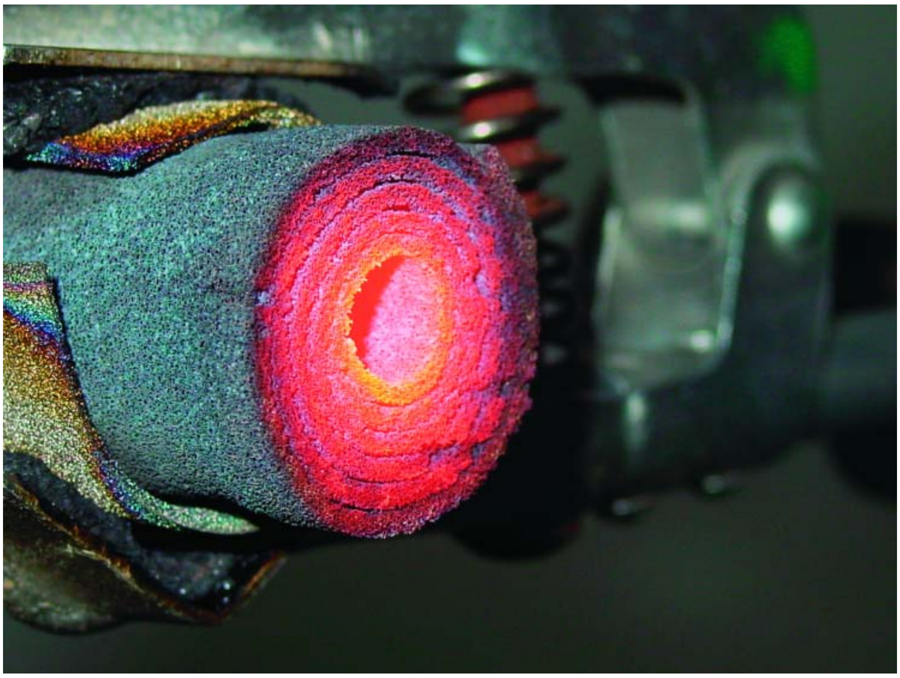

**Fig. 5**: Test on a NiAl structure at 1,050 °C (air).


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