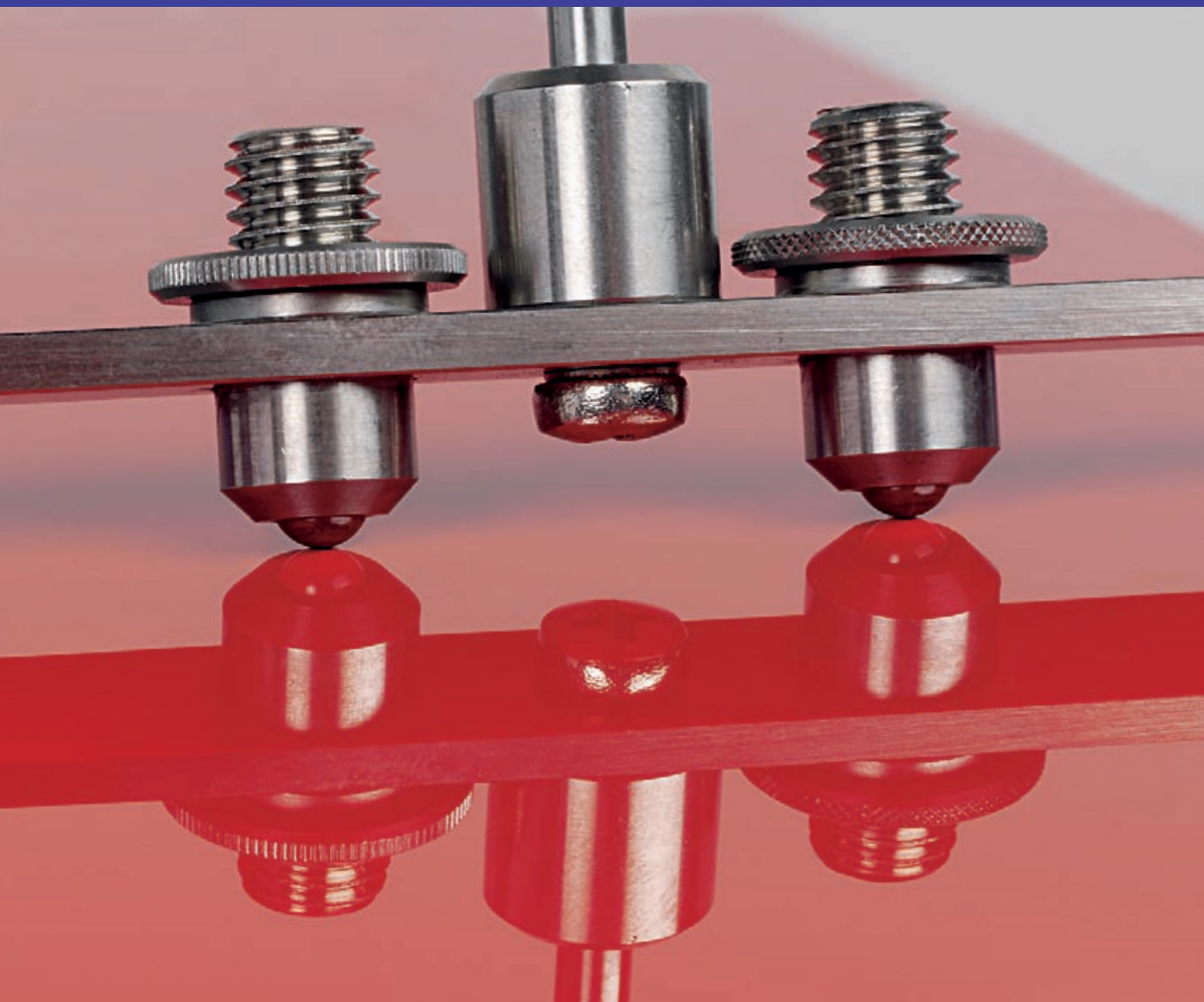
Fraunhofer
IFAM

FRAUNHOFER-INSTITUT FÜR FERTIGUNGSTECHNIK UND ANGEWANDTE MATERIALFORSCHUNG IFAM

PAINT / LACQUER TECHNOLOGY – FROM COLOR TO FUNCTION



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Figure, cover page: Testing a coating developed at the Fraunhofer IFAM.

Fraunhofer-Gesellschaft

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains more than 80 research units in Germany, including 59 Fraunhofer Institutes. The majority of the 17,000 staff are qualified scientists and engineers, who work with an annual research budget of €1.6 billion. Of this sum, more than €1.3 billion is generated through contract research. Two thirds of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Only one third is contributed by the German federal and *Länder* governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe.

Fraunhofer IFAM – Adhesive Bonding Technology and Surfaces – Expertise and know-how

The Department of Adhesive Bonding Technology and Surfaces at the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research is the largest independent research group in Europe working in the area of industrial adhesive bonding technology and has a workforce of more than 210 employees. The R&D activities focus on adhesive bonding technology, as well as plasma technology and paint/lacquer technology. The objective is to supply industry with application-oriented system solutions.

Multifunctional products, lightweight design, and miniaturization – achieved via the intelligent combination of materials and joining techniques – are opening up new opportunities which are being exploited by the Fraunhofer IFAM. The activities range from fundamental research through to production and the market introduction of new products. Industrial applications are mainly found in car, rail vehicle, ship and aircraft manufacture, plant construction, energy technology, packaging sector, textile industry, electronics industry, microsystem engineering, and medical technology. The work in the Adhesive Bonding Technology business unit involves the development and characterization of adhesives, the design and simulation of bonded, riveted, and hybrid joints, as well as the characterization, testing, and qualification of such joints. The planning and automation of industrial adhesive bonding applications are also undertaken. Further services include process reviews and certified training courses in adhesive bonding technology and fiber composite materials.

The work of the Surfaces business unit is subdivided into plasma technology and paint/lacquer technology. Customized surface modification – for example surface pretreatment prior to bonding/coating and functional coatings – considerably expand the industrial uses of many materials.

The Adhesion and Interface Research business unit is engaged, amongst other things, with the early detection of degradation phenomena, the validation of aging tests, and inline surface monitoring.

The Fraunhofer Project Group Joining and Assembly FFM of the Fraunhofer IFAM is carrying out ground-breaking work on large carbon fiber reinforced plastic structures and is able to join, assemble, process, repair, and carry out non-destructive tests on large 1:1 scale CFRP structures. Thus closing the gap between the laboratory/small pilot-plant scale and industrial scale in the area of CFRP technology.

The Department of Adhesive Bonding Technology and Surfaces is certified according to DIN EN ISO 9001, while the Materials Testing Laboratory and the Corrosion Testing Laboratory are also certified according to DIN EN ISO/IEC 17025. The Center for Adhesive Bonding Technology is accredited via DVS-PersZert® in accordance with DIN EN ISO/IEC 17024 as a training establishment for giving courses in adhesive bonding technology and has an international reputation. Like the Plastics Competence Center, it is also accredited in accordance with the German quality standard for further training, AZWV.

www.ifam.fraunhofer.de

INNOVATIVE, EXTENSIVE AND FOCUSED KNOW-HOW

Paints, lacquers, and functional coatings are becoming ever more important for a wide range of industrial applications. The special demands and increasing requirements being put on the quality of surfaces and coatings of surfaces are constantly presenting R&D experts, manufacturers, and users with new challenges. At the same time, the external applied R&D work for the development of advanced industrial coating systems has become an indispensable service.

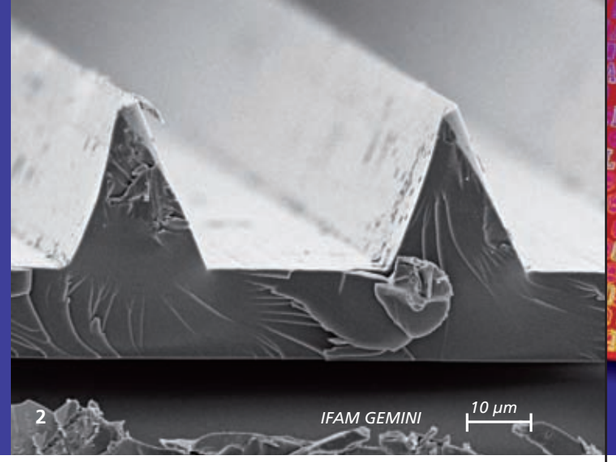
The Paint/Lacquer Technology work group of the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM is taking on these challenges and provides services on all issues concerning raw materials for paints/lacquers, the development of new paints, lacquers and functional coatings, and process engineering.

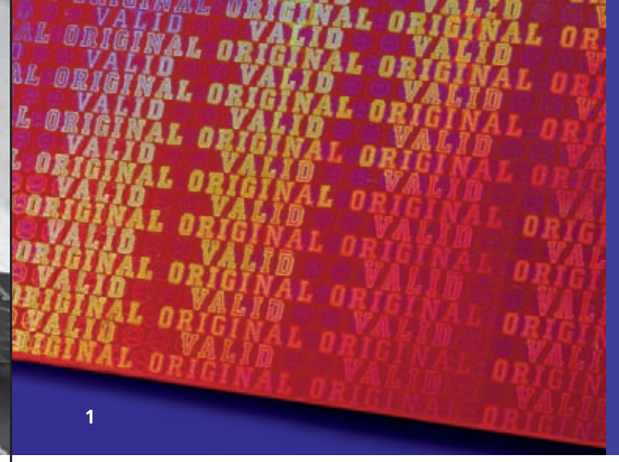
The range of services of the Paint/Lacquer Technology work group also includes the development of guide formulations, the qualification of coating materials and processes, and support for the application of the materials.

A feature of the Paint/Lacquer Technology work group of the Fraunhofer IFAM is the high number of scientists who work there. These specialists work in collaboration with customers to achieve optimal results. The practical focus of the work and the in-depth scientific know-how coupled with extensive, state-of-the-art equipment and facilities guarantee that project tasks are understood, evaluated and translated into practical, favorable-cost solutions.

The internal networking of the Paint/Lacquer Technology work group with other related areas of expertise at the Fraunhofer IFAM – such as adhesion and interface research, electrochemistry and corrosion protection, plasma technology and surfaces, material science and mechanical engineering, adhesives and polymer chemistry, and adhesive bonding technology – provides ideal conditions for being able to comprehensively support raw material manufacturers, paint/lacquer producers, and users.

1 *Plasma-pretreated polypropylene spheres coated with special-effect paint.*





RESEARCH – DEVELOPMENT – APPLICATION

The Paint/Lacquer Technology work group of the Fraunhofer IFAM offers a full spectrum of scientific and technical services for practical matters ranging from paint manufacture to paint application. These cover product development, functionalization, application and process engineering, test methods, quality assurance, and failure analysis. Below there is a brief description of some of our activities:

Product development

The focus of our work is the formulation of new systems and optimization of existing systems for practical applications. The development of a new, innovative coating requires extensive knowledge not only of the raw materials but also of the current state of technology in R&D and industry.

Resistance of products

The work of the Paint/Lacquer Technology work group includes, amongst other things, improving the **chemical and scratch resistance of coating systems**. Components employed for this allow, for example, a high polymer network density. These properties can also be introduced by the addition of inorganic nanoparticles. In order to combine the advantages of different curing mechanisms, so-called dual-cure coating systems, involving two different curing mechanisms, are increasingly being used.

Functionalization

Users of modern coating systems are demanding the customized integration of functions and in some cases multifunctionality. Of special importance here is the transfer of promising, economically viable surface coating systems that have been manufactured in the laboratory to large scale applications. For this reason, another main R&D area of the Paint/Lacquer Technology group of the Fraunhofer IFAM is the functionalization of surfaces and coatings. A few examples of this are described below:

Micro-structuring and nano-structuring

Micro-structuring and nano-structuring are promising methods for the surface functionalization of coatings. Microstructures, derived from the skin structure of sharks, can be transferred to paint surfaces as so-called riblet structures and contribute reduce the drag of ships, aircraft, rotor blades (wind turbines), and pipelines. The production and testing of such surface structures on large components is the topic of a number of current research projects at the Fraunhofer IFAM. Other uses for microstructures and nanostructures include applications for holograms and for anti-reflection.

Self-repairing coatings

The functionality of a coating does not always have to be at the surface itself. An example of this is our development work on self-repairing coatings. In these materials the active functional agent is encapsulated in the coating. Only if there is mechanical damage to the system the active agent is released and a repair reaction triggered. Self-repairing surfaces are of particular interest for corrosion protection and for prolonging the lifetime of components which are subjected to high loads/stresses.

Anti-icing

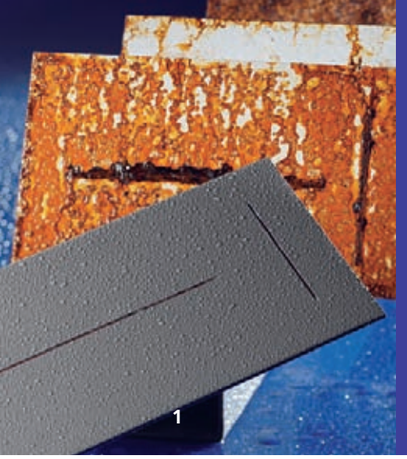
A further research field is the development of ice-repelling coatings. The focus here is on high abrasion-resistance coatings which reduce the adhesion of ice or reduce the tendency of ice to form. These systems are of great interest for the aircraft manufacturing industry and wind energy industry. Such coatings are also promising for the area of refrigeration engineering: heat-exchangers which, for example, provide low temperatures in fridges and refrigerated rooms often ice up and have to be thawed by a considerable input of energy.

Reduced growth/fouling

The development of **anti-fouling coatings** is another main development activity. The objective is, for example, to reduce or at least significantly hinder the growth of algae and mollusks on surfaces that are in constant contact with water. This is a challenge for the ship industry due to the ever stricter regulations being put on the raw materials which can be used for coatings. In line with the EU Biocidal Products Directive, the Paint/Lacquer Technology work group of the Fraunhofer IFAM is developing formulations for **fouling-release coatings** which reduce growth and are at the same time harmless from a toxicological point of view. A further area of development work related to this is the prevention of microbial growth and microbe-induced corrosion.

1 *High scratch-resistance coatings for customer-specific requirements.*
2 *Scanning electron micrographs of a riblet-structured coating surface.*

1 *The nano-structuring of the coating, visible as a hologram, is used for product and trademark protection.*
2 *Barnacles on the surface of a coating.*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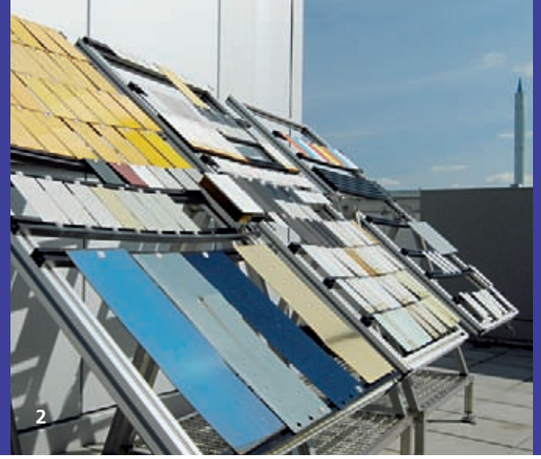
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APPLICATION TECHNOLOGY AND PROCESS ENGINEERING

The Paint/Lacquer Technology work group offers application-oriented technical assistance in the area of application technology and process engineering. The inter-group collaboration at the Fraunhofer IFAM ensures that favorable-cost solutions are developed in a timely way.

According to a guiding principle of the paint/lacquer industry, a coating is only as good as the pretreatment of the surface to be coated. This is especially true for plastics. Due to the very low surface energy of most plastics there are often wetting problems for coatings. In order to achieve the best possible coating results, process optimization is carried out in collaboration with the Plasma Technology and Surfaces – PLATO – group of the Fraunhofer IFAM. This process optimization involves adapting the pretreatment and coating processes directly to each other.

Test methods

Standardized suitability tests for coatings are required for new product developments in order to characterize the coating system as accurately as possible. Besides the tests on liquid coatings such as measurement of the flow properties and determination of the non-volatile fraction, the properties of hardened coatings must also be measured. The coatings are subjected to various loads/stresses depending on the application. This involves a large spectrum of practical test methods such as elasticity measurement, color management, and resistance to weathering and chemicals.

Aging tests

A variety of aging tests are essential in order to be able to assess the long-term resistance of coatings. Test chambers are available at the Fraunhofer IFAM for carrying out salt-spray tests, alternating climate tests, filiform corrosion tests, and artificial aging tests. There is also the facility for exposing coatings to natural outside weathering. For this the Fraunhofer IFAM has special weathering stands at the Bremen site, on the North Sea coast and on the Brocken (1141 m), the highest peak in the Harz Mountains in Germany.

1 *Determination of the resistance to corrosion: Test specimen after exposure in the salt-spray chamber.*
2 *Natural outside weathering gives information about the resistance of a coating to light and the weather.*
3 *Testing the adhesion of coatings via the cross-cut test.*


1


2


3

The theoretical methods and surface-analytical methods of interface research allow detailed information to be obtained about the long-term stability of materials and aging due to corrosion. The interdisciplinary exchange of information at the Fraunhofer IFAM between the Paint/Lacquer Technology work group and the Electrochemistry and Corrosion Protection work group of the Adhesion and Interface Research business unit allows innovative concepts for corrosion protection to be developed and tested for a wide range of requirements and materials.

Special test methods

Specific applications require customized test methods. The Fraunhofer IFAM hence develops application-oriented test methods adapted to customer requirements.

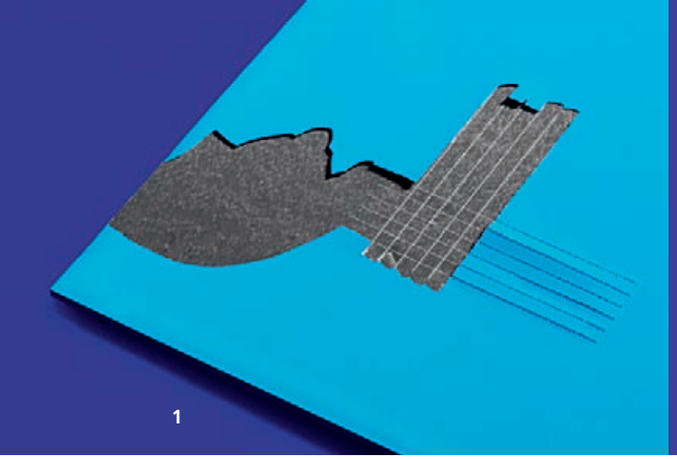
In shipbuilding, for example, there are many regions of ballast water tanks which are exposed to effects such as the sea swell, temperature, and also salt content and which are therefore particularly prone to corrosion. For this reason, a chamber was constructed for simulating the effects in order to allow the behavior of ship coatings, in particular, to be tested. There are only a few of these so-called wave tank simulation chambers in the world according to the guidelines of the International Maritime Organization (IMO). The largest of these is at the Fraunhofer IFAM in Bremen.

For developing anti-icing coatings the Fraunhofer IFAM possesses an icing chamber in which the effectiveness of the coatings is measured under suitable practical conditions. Various environmental parameters such as temperature, humidity, and wind speed can be varied and hence their effects examined more closely.

When developing a new coating and qualifying this for release it must be ensured that the coating has adequate resistance to the stresses experienced in standard coating ring lines. The stresses can be mimicked in the test ring line which is available at the Fraunhofer IFAM.

The carrying out of tests in conventional test ring lines is time-consuming and costly, and wasteful from a materials point of view. For these reasons, the Fraunhofer IFAM has also developed an environmentally-friendly miniature ring line in collaboration with the Fraunhofer UMSICHT in order to characterize the shear behavior of coatings and simulate the flow.

1 *Wave tank simulation chamber for testing coatings in ballast water tanks on ships; tank volume 2000 liters.*
2 *Icing chamber for studying anti-icing coatings.*
3 *Resource-friendly miniature test loop for determining the shear and flow behavior of coatings; volume about one liter.*



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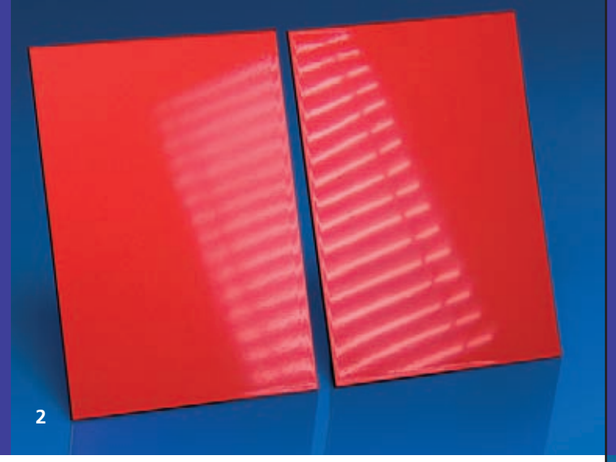

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Quality management and failure analysis

The increasing demands on coatings as well as the realization of quality objectives and the improvement of existing processes and products require the use of surface analytical techniques. For example, the causes of problems in production processes – such as the origin of particles or film residues – can be appraised and hence avoided in the future.

In both quality assurance and failure analysis the causes of failure and their origins must be systematically recorded, limited and, if necessary, adjustments must be made. Failure analysis involves the technical assessment of cases of failure and adjustment of processes. With the help of the extensive analytical facilities at the Fraunhofer IFAM the causes of failure can be verified and appraised.

1 *Poor coating adhesion to a CFRP specimen caused by inadequate surface pretreatment.*
2 *Left: defective coating – orange peel formation on a paint surface; right: defect-free coating.*

EQUIPMENT / FACILITIES OF PAINT / LACQUER TECHNOLOGY

In addition to the standard facilities for paint/coating manufacture and testing, other equipment held by the Paint/Lacquer Technology work group of the Fraunhofer IFAM includes:

- **Crockmeter / shear resistance** for determining the mechanical load limit
- **QUV test** for testing the color and gloss stability, and resistance to weathering
- **Alternating climate test** for simulating different climatic conditions
- **Soiling chamber** for studying the tendency of surfaces to soil
- **Test unit for coating using the ink-jet method** for horizontal and vertical printing of work pieces
- **Refrigeration dryer** for analyzing drying parameters for water-based coatings
- **Painting booth** in which all climatic conditions relevant for industry can be simulated
- **Automatic coating machine** – can be used for coating work to eliminate the effect of the individual person carrying out the spray painting on the coating result
- **Powder painting booth** for the application of powder paints
- **Electrostatic wet application** for reducing overspray (in compliance with VOC guidelines)
- **2-C plant** for evaluating 2-component coatings
- **Wave tank simulation chamber** for simulating the effects in the region of the ballast water tanks on ships (see page 5)
- **Icing chamber** for determining the effectiveness of anti-icing coatings (see page 5)
- **Test ring lines** for measuring the stability of coatings to shear forces (see page 5)

The automatic painting machine and climate-controlled booth guarantee reproducible coating quality.

COMPETENCE NETWORK ADHESIVE BONDING TECHNOLOGY AND SURFACES

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Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM

Adhesive Bonding Technology
Dipl.-Ing. Manfred Peschka
Phone +49 421 2246-524
manfred.peschka@ifam.fraunhofer.de
Production planning; dosing and application technology; automation; hybrid joining; production of prototypes; selection, characterization and qualification of adhesives, sealants and coatings; failure analysis; electrically/optically conductive contacts; adaptive microsystems; dosing ultra small quantities; properties of polymers in thin films; production concepts.

- Microsystem technology and medical technology
- Adhesives and analysis
- Process development and simulation
- Application methods

Plasma Technology and Surfaces – PLATO –
Dr. Ralph Wilken
Phone +49 421 2246-448
ralph.wilken@ifam.fraunhofer.de
Surface modification (cleaning and activation for bonding, printing, painting/lacquering) and functional layers (e. g. adhesion promotion, corrosion protection, scratch protection, antimicrobial effect, easy-to-clean layers, release layers, permeation barriers) for 3-D components, bulk products, web materials; plant concepts and pilot plant construction.

- Low pressure plasma technology
- Atmospheric pressure plasma technology
- Plant technology/Plant construction

Adhesives and Polymer Chemistry
Priv.-Doz. Dr. Andreas Hartwig
Phone +49 421 2246-470
andreas.hartwig@ifam.fraunhofer.de
Development and characterization of polymers; nanocomposites; network polymers; formulation of adhesives and functional polymers; chemical and physical analysis; peptide and protein chemistry; peptide-polymer hybrids; bonding in medicine; surfaces functionalized with peptides; marine protein adhesives.

- Synthetic materials
- Protein materials

Paint / Lacquer Technology
Dr. Volkmar Stenzel
Phone +49 421 2246-407
volkmar.stenzel@ifam.fraunhofer.de
Development of functional coatings, e. g. anti-icing paints, anti-fouling systems, dirt-repellant systems, self-repairing protective coatings, coatings with favorable flow properties; formulation optimization; raw material testing; development of guide formulations; characterization and qualification of paint/lacquer systems and raw materials; release of products; color management; optimization of coating plants; qualification of coating plants (pretreatment, application, drying); failure analysis; application-related method development.

- Development of coating materials
- Application technology and process engineering

Adhesion and Interface Research
Dr. Stefan Dieckhoff
Phone +49 421 2246-469
stefan.dieckhoff@ifam.fraunhofer.de
Surface, interface and film analysis; analysis of adhesion, release and degradation mechanisms; analysis of reactive interactions at material surfaces; damage analysis; quality assurance via in-line analyses of component surfaces; development of concepts for adhesive, paint/lacquer and surface applications; corrosion on metals, under coatings and in bonded joints; analysis of anodization layers; electrolytic metal deposition; accredited corrosion testing laboratory; modeling of molecular mechanisms of adhesion and degradation; structure formation at interfaces; concentration and transport processes in adhesives and coatings.

- Surface and nanostructure analysis
- Applied computational chemistry
- Electrochemistry/Corrosion protection
- Quality assurance of surfaces

Material Science and Mechanical Engineering
Dr. Markus Brede
Phone +49 421 2246-476
markus.brede@ifam.fraunhofer.de
Testing materials and components; crash and fatigue behavior of riveted and bonded; fiber composite components; lightweight and hybrid constructions; design and dimensioning of bonded joints; qualification of mechanical fasteners; optimization of mechanical joining processes; design and dimensioning of riveted joints.

- Structural calculations and numerical simulation
- Mechanical joining technology

Technology Transfer and Workforce Training
Prof. Dr. Andreas Groß
Phone +49 421 2246-437
andreas.gross@ifam.fraunhofer.de
www.bremen-bonding.com
www.kunststoff-in-bremen.de
Training courses for Adhesive Bonder, Adhesive Specialist and European Adhesive Engineer with Europe-wide certification via DVS®-EWF; In-house courses; consultancy; qualification of production processes; studies; health, safety and the environment; training course for Fiber Composite Technician.

- Center for Adhesive Bonding Technology
- Plastics Competence Center

Fraunhofer Project Group Joining and Assembly FFM
Dr. Dirk Niermann
Phone +49 421 2246-439
dirk.niermann@ifam.fraunhofer.de
Industrial assembly involving bonding, riveting and combinations thereof; adaptive precision machining; automated measuring and positioning processes; non-destructive tests on large fiber composite structures.

Business Field Development
Dr. Michael Wolf
Phone +49 421 2246-640
michael.wolf@ifam.fraunhofer.de

- Technology broker
- New research fields

Certification Body of the Federal Railway Authority in Accordance with DIN 6701-2
Dipl.-Ing. (FH) Andrea Paul
Phone +49 421 2246-520
andrea.paul@ifam.fraunhofer.de
Consultancy; testing and approval of rail vehicle manufacturing companies and their suppliers with regard to their ability to produce adhesive bonds in accordance with the requirements of DIN 6701.

Process Reviews
Dipl.-Ing. Manfred Peschka
Phone +49 421 2246-524
manfred.peschka@ifam.fraunhofer.de
Analysis of development and/or production processes taking into account adhesive bonding aspects and DVS® 3310; processing steps and interfaces; design; products; proof of usage safety, documentation; production environments.

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Fraunhofer Institute for Manufacturing Technology and Applied Materials Research IFAM
– Adhesive Bonding Technology and Surfaces –
Wiener Straße 12
28359 Bremen
Germany
Phone +49 421 2246-400
Fax +49 421 2246-430
ktinfo@ifam.fraunhofer.de

Paint / Lacquer Technology
Dr. Volkmar Stenzel
Phone +49 421 2246-407
volkmar.stenzel@ifam.fraunhofer.de

www.ifam.fraunhofer.de
For further information about
- Adhesive Bonding Technology
- Surfaces