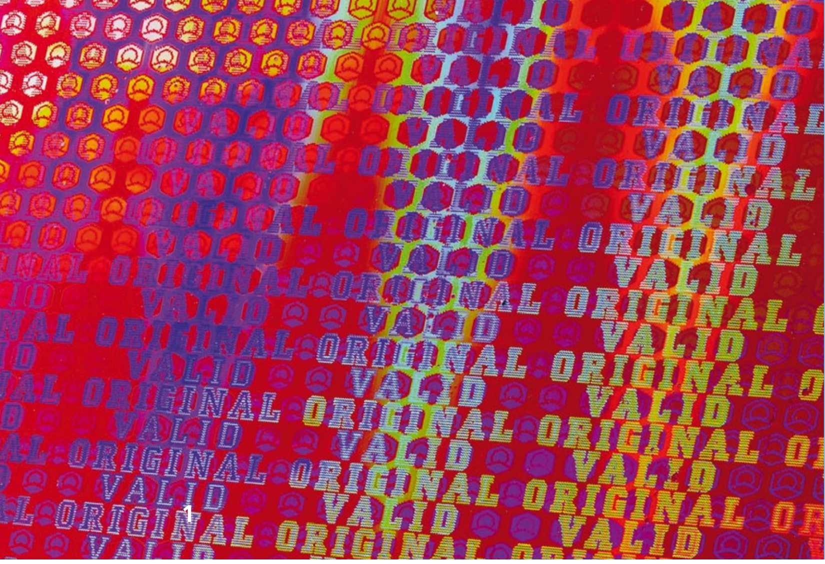


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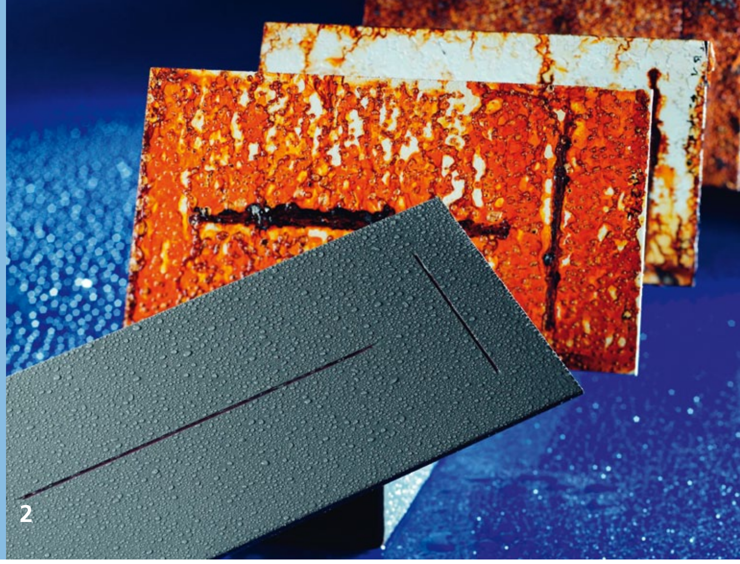

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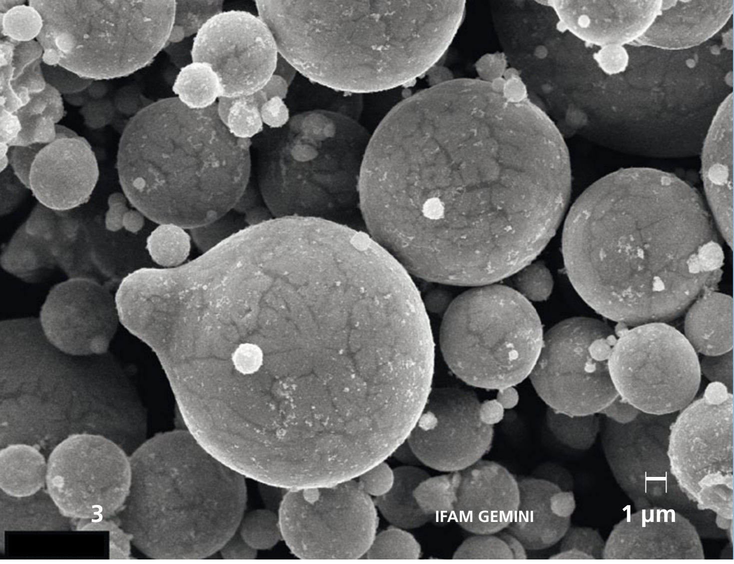
# FRAUNHOFER IFAM IN THE SPOTLIGHT AFTER SUCCESSFUL R&D WORK ON FUNCTIONAL COATINGS

They sound futuristic, but are already here: Functional surfaces (Fig. 1). They have a variety of functions, such as reducing the drag of aircraft and ships, and preventing ice adhesion, contamination, erosion, abrasion, as well as corrosion. There are even self-healing coatings which have repairing effects. The Paint/Lacquer Technology section of Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM has achieved impressive results in recent years in the field of functional coatings. Its work, in collaboration with other groups of the Fraunhofer IFAM, has made many existing applications for coatings more efficient and has also opened up completely new applications for coatings. Furthermore, the section has extensive knowledge of industrial coating and the latest technologies. The experts at Fraunhofer IFAM in Bremen are a valued partner of the paint and coating industry as a result of their successful development work, huge experience, and synergistic collaboration with other sections in the Adhesive Bonding Technology and Surfaces department of Fraunhofer IFAM.

Regardless of whether the work concerns coatings for aircraft, ships, wind turbines, heat exchangers, or other sensitive components: almost all the work is geared towards extending repair and maintenance intervals, prolonging the service life of components, increasing effectiveness, or saving energy. The industrial services offered by the section are varied and include work that has led to the industry changing over from solvent-based coatings systems to more environmentally friendly water-based systems. Currently the section's experts are helping industry to optimize coating applications, for example the prevention of cavitation and the prevention of dirt inclusion during coating processes. A further focus is on more efficient coating methods, for instance new methods for paint application and improved methods for drying paint.

**"Holistic" solutions guaranteed – for example innovative corrosion protection concepts**

When carrying out work for customers, the Paint/Lacquer Technology section collaborates closely with other specialists of Fraunhofer IFAM and is thus able to offer "holistic" solutions. On matters relating to defect avoidance during the application of coatings, the expertise of the Adhesion and Interface Research section is called upon. When drawing up concepts for corrosion protection, the researchers of Fraunhofer IFAM also benefit from close internal, interdisciplinary collaboration. For example, collaboration between the Paint/Lacquer Technology section and the Electrochemistry/Corrosion Protection work group (which falls under Adhesion and Interface Research) and the Casting Technology section of Fraunhofer IFAM resulted in the development of a new corrosion protection pigment.





The reason for carrying out this work was the fact that most damage to metal components is caused by corrosion. This is why metal components are often coated with anti-corrosion layers (Fig. 2). In most cases special coatings are used for this purpose. The anti-corrosion coatings often contain pigments which actively suppress corrosion of the component. Chromate-containing pigments were commonly used in the past for this, but these have environmental and health drawbacks. The search for alternatives, in particular for the aluminum alloys used in aircraft manufacture, has long proved difficult.

Within an internal Fraunhofer-project, aimed at assisting small and medium-sized companies (MEF), Fraunhofer IFAM finally succeeded in developing cathodically active metal pigments consisting of intermetallic magnesium-zinc phases which provide effective corrosion protection (Fig. 3). The electrochemical properties of the pigments mean that the corrosion of steel and aluminum alloys is significantly reduced. They also have the major advantage that they are not harmful to health or the environment. Effective, easy-to-apply corrosion protection coatings were then developed using these pigments.

Solvent-containing anti-corrosion primers demonstrated that the pigments developed at Fraunhofer IFAM were very efficient. For example, substrates made of very corrosion-sensitive aluminum alloys showed no corrosion after more than 10,000 hours in the salt spray test in the accredited corrosion testing laboratory of Fraunhofer IFAM – not even when the coating layer which was applied for experimental purposes was seriously damaged.

However, the researchers were still not totally satisfied. Further work was undertaken to develop pigments not only for solvent-based systems but also for water-based coatings, and so benefit the environment even further. As these pigments, due to their mechanism of action, are very reactive to water, a special stabilization system had to be developed for water-based coatings (Fig. 4): The stabilization system isolates the pigments in the liquid coating from the surrounding water, but becomes ineffective as soon as the coating is present as a cured layer. The initial corrosion tests showed that good protection was provided by the water-based coating containing stabilized pigments.

The stabilization of corrosion protection pigments in water-based coating systems was the topic of an article written by Anja Zockoll (Electrochemistry/Corrosion Protection) and Andreas Brinkmann (Paint/Lacquer Technology) in the technical magazine FARBE UND LACK. For this article the authors received an award for the best technical article of 2010 (see page 94).

### Sharkskin coatings reduce drag

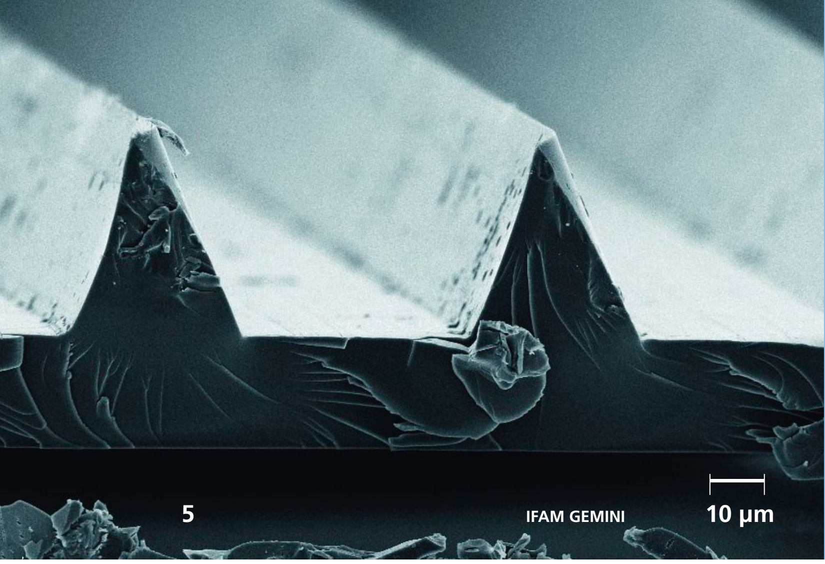
Also worthy of an award in 2010 was a development of the Paint/Lacquer Technology and Adhesive Bonding Technology sections at Fraunhofer IFAM which had been many years in the making: A coating system that significantly reduces the drag of large components. Dr. Volkmar Stenzel and Yvonne Wilke – both members of the Paint/Lacquer Technology section – and Manfred Peschka – a member of the Adhesive Bonding Technology section – received the Joseph von Fraunhofer Award in 2010 for this innovative work (see page 90). Since 1978 the Fraunhofer-Gesellschaft has presented this

1 *Example of functional surfaces: The nanostructuring of the coating, visible as a hologram, is used for product and brand protection.*

2 *Testing corrosion resistance: Coated test specimens after exposure in the salt spray chamber at Fraunhofer IFAM.*

3 *Scanning electron micrograph of magnesium-zinc pigments: Corrosion protection without risk to health or the environment.*

4 *Non-stabilized magnesium-zinc pigment (left) and stabilized magnesium-zinc pigment (right) on contact with water.*



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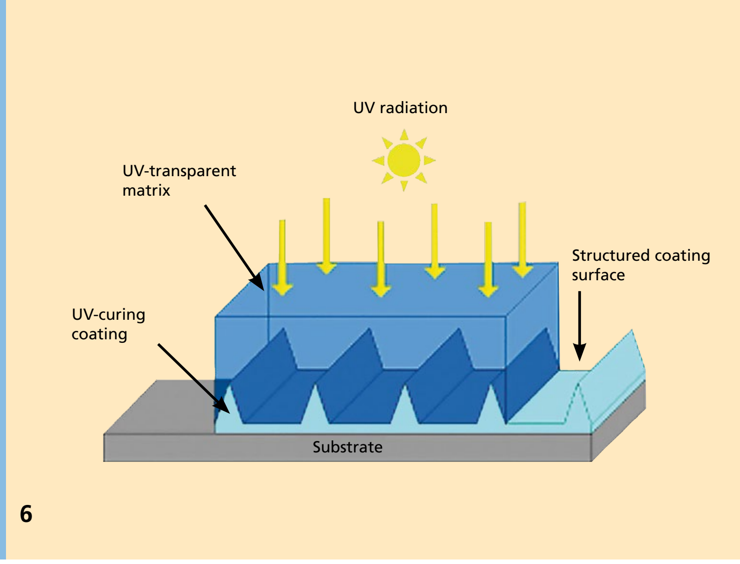

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award in recognition of excellent scientific work to solve application-related problems. The new coating of the Fraunhofer IFAM team helps to meet the demands of the European Commission to perceptibly lower the fuel consumption by aircraft and ships. From 2012 the shipbuilding and aircraft manufacturing industries will be incorporated into the emissions trading scheme. This will bring added pressure to reduce carbon dioxide emissions within the industries.

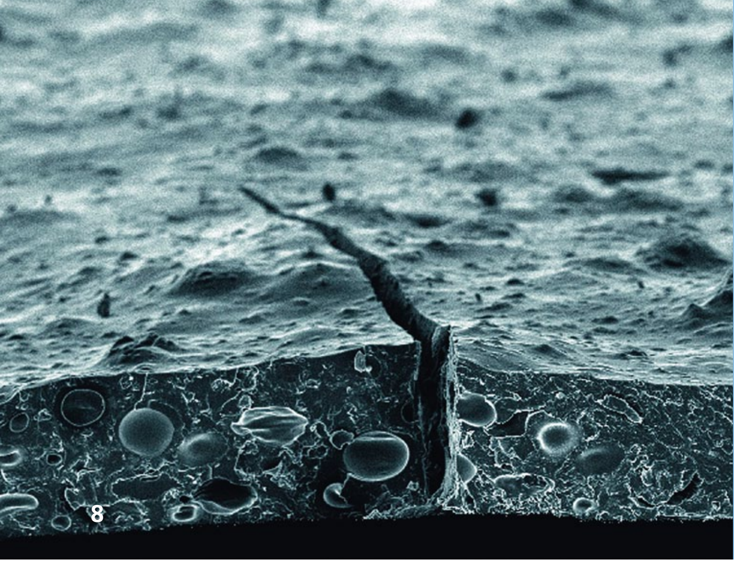
The structure of the coating system developed at Fraunhofer IFAM was based on what is found in nature. The scales of fast-swimming sharks have microscopic grooves, so-called riblets, in the longitudinal direction. These considerably reduce the drag of sharks in water. The Fraunhofer IFAM scientists transferred this concept to a coating (Fig. 5) which met the exacting requirements of the aircraft manufacturing industry – such as resistance to extraordinarily high temperature fluctuations from –55 to +70 degrees Celsius, aggressive ultraviolet radiation, and very high speeds. Nanoparticles are a key component of the riblet coating. They are the reason why the coating can withstand extreme conditions permanently. The advantages of the coating are enormous: In order to make fuel savings of about two percent, the only requirement is investment in the coating technology. Indeed, aircraft and ships always have to be coated and the application of a riblet coating is therefore essentially cost and weight neutral for users. Besides having low-drag, the coating has other advantages: It repels dirt and the nanoparticles make the coating highly resistant to abrasion and erosion.

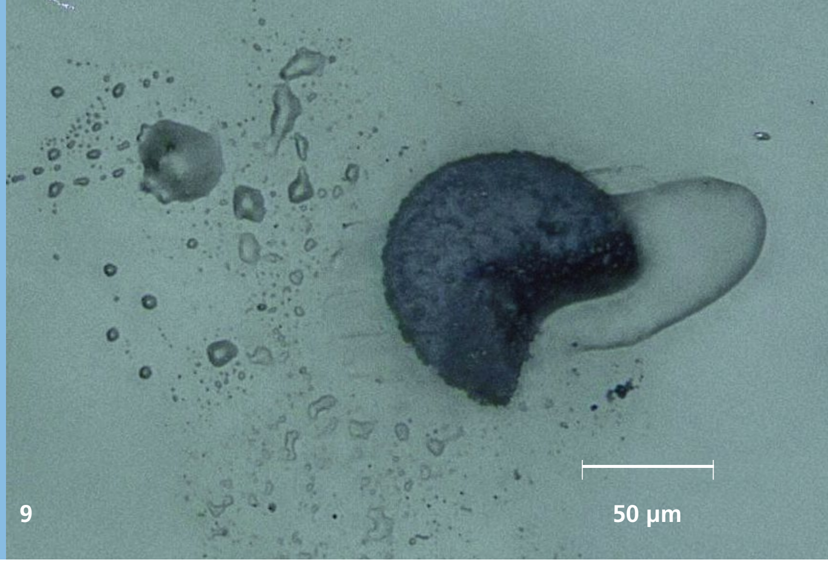
The "sharkskin coating" can be readily applied to three-dimensional curved surfaces, and this was not the case for previously tested systems involving structured foils. Indeed, the researchers of the Fraunhofer IFAM have simultaneously developed a suitable application system. This involves using a patented roller applicator to apply and structure the nanoparticle-containing coating with riblets. The coating is then partially cured by UV light and partially via chemical reactions (Fig. 6 + 7). The process can be operated automatically using a robot.

## Cracks which repair themselves

Also of great promise is a development of the Paint/Lacquer Technology section which involves coatings that have self-healing functionality. Coatings are frequently exposed to extreme stresses and this often leads to cracking of coatings. Such cracks ultimately mean a weakening of the component. Wind turbines, for example, are exposed to both environmental influences and very high dynamic loads, and this often gives rise to surface damage. In this sector – and in particular for offshore wind turbines – maintenance work is very expensive, and self-healing coatings would represent major progress. However, such coatings also have benefits for other steel structures such as large bridges and other capital goods which have to withstand high stresses. They are also desirable for "repairing" scratches on decorative coating systems such as car paints.

The self-healing system developed by the Paint/Lacquer Technology section of Fraunhofer IFAM contains microcapsules of active agents which are incorporated into the coating. If the coating is damaged, the microcapsules at this location are broken apart. They contain a healing reagent which immediately closes the cracks (Fig. 8 + 9). Untreated cracks normally quickly become deeper and bigger, soon causing material damage. The microcapsules prevent this. These coating systems would allow longer maintenance intervals and the less frequent repairs would result in perceptible cost savings. This would increase the economic viability of plants in various sectors. Of course, the demands on the microcapsules are very complex: They must be resistant to solvents and must be able to be dispersed, namely they must be able to be incorporated intact into the coatings. Simultaneously, it is vital that the microcapsules remain intact during the coating application with spray guns. Indeed, they must form a composite system with the matrix and must be stable in the coating for a long time. When needed, the microcapsules must effectively break apart and then seal the crack. In order to meet these requirements



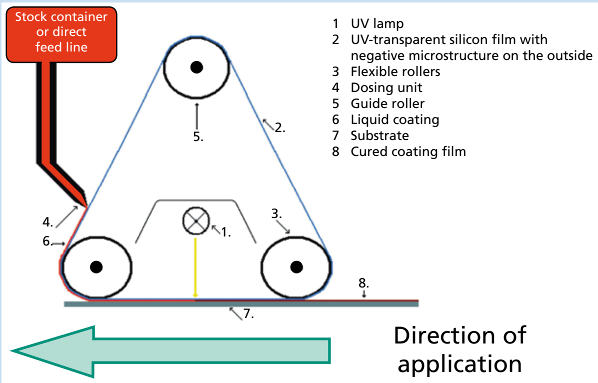




*Fig. 7: Riblet coating: Principle of the applicator for continuous application of the coating.*

for different applications, the microcapsules are "customized" by the Fraunhofer IFAM for specific coating systems and they are then thoroughly tested for their functionality.

## Strategies against icing

The work of the Paint/Lacquer Technology section on anti-icing coatings is also of much interest for commerce and industry. Complete prevention of ice formation on surfaces, or even partial reduction, is attractive for many sectors of industry because ice formation incurs high costs. The best known example is the deicing of aircraft. Passengers only see this when the plane is on the ground but deicing is also carried out during a flight if ice crystals form on the aircraft wings at high altitude. Ice formation on electricity pylons or wind turbines can lead to irreparable damage, and in particular under extreme weather conditions as exemplified in Münsterland in November 2005 when pylons collapsed. Also, ice on wind turbine rotor blades lowers the energy production and falling ice can be a danger. Ice formation is also a huge problem for rail vehicles, ships, cars, refrigerator systems, and roller shutters.

Common to all these areas is that downtimes, maintenance periods, and complex repairs add up to a considerable extra financial impact.

The Paint/Lacquer Technology section of Fraunhofer IFAM is currently working on a variety of strategies for minimizing ice formation. An icing chamber has been developed which can mimic virtually any icing scenario on surfaces and coatings – with different air and substrate temperatures, air humidity, rain and wind simulation, and much more (Fig. 10). In addition, outdoor weathering is carried out under real conditions on an icing test stand located 1141 meters above sea level on the Brocken in the Harz Mountains. The main tests used by researchers at the Fraunhofer IFAM are the rime adhesion test for simulating rime formation (Fig. 11), the ice rain test for simulating ice formation from rainwater, and the so-called runback ice test on models of wing sections (Fig. 12).

The objective of the scientists is to minimize or prevent ice formation using a variety of strategies. Their in-depth knowledge of surface pre-treatment, coating development, and testing are utilized here. The research work includes, for example, extremely water-repellant coatings which effectively prevent adhesion of water – and ice cannot form where there is no water. Another approach is the development of biomimetic anti-icing surfaces based on antifreeze proteins. Nature shows the way here: There are insects, fish, and plants which contain proteins for frost protection. They are able to withstand temperatures as low as –60 degrees Celsius without freezing. The Paint/Lacquer Technology section is working together with the Adhesives and Polymer Chemistry section on functionalizing

5 *Scanning electron micrograph of a riblet-structured coating surface.*
6 *Riblet coating: Principle of the application.*
8 *Damaged coating with microcapsules of healing agents.*
9 *Healing agent is released from a broken microcapsule.*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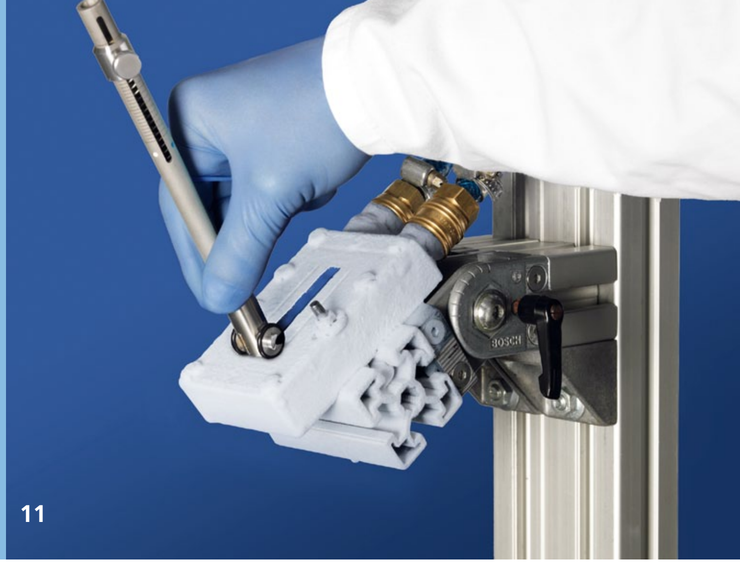
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technical coating surfaces with synthetic antifreeze proteins. A further approach concerns surfaces with microscopic structures which prevent the adhesion of ice.

The work of the Paint/Lacquer Technology section also involves collaboration with the Adhesion and Interface Research section of Fraunhofer IFAM: Customized studies on the mechanisms of ice formation and ice adhesion on different surfaces and computer-aided simulation work by the Applied Computational Chemistry work group support and accelerate the research work.

**Dirt-repellant surfaces**

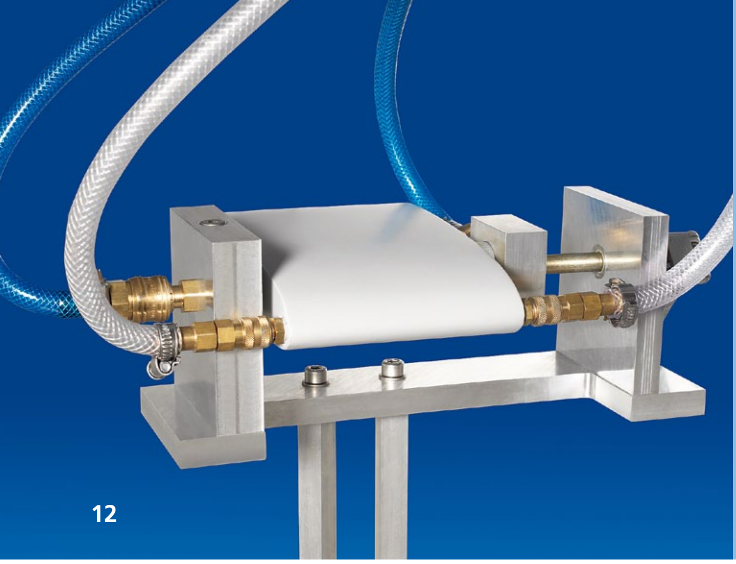
It is not only ice and rime that are problematic to industry. Contamination of surfaces is also often undesired. Indeed, regular cleaning is often required to maintain the full efficiency of plants and this brings with it considerable costs. Wind turbines are used once again as an example: Contamination due to insect residues in the summer months decreases the efficiency by up to five percent, and even more at certain wind speeds. The reason for this is the change in the aerodynamic profile caused by the insect residues. The Paint/Lacquer Technology section is using a variety of strategies to develop coatings which effectively prevent residues sticking to the surfaces.

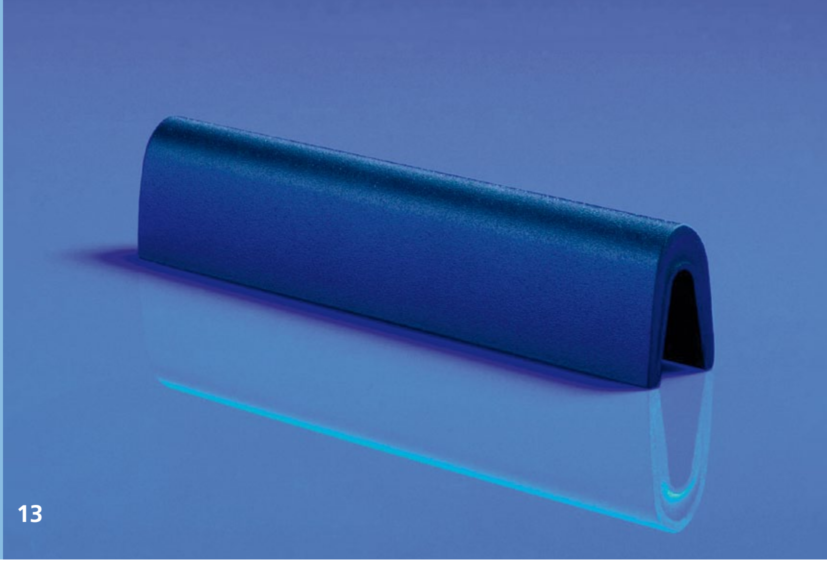
**Surfaces becoming more resistant**

A further challenge is to develop coatings which are resistant to erosion and abrasion. Over a period of time sand and rain damage the surface of components – the effect is like treating them with sandpaper. The same applies where two component surfaces rub each other – this abrasion shortens the service life of components and increases the maintenance as well as repair times. The Paint/Lacquer Technology section is using various approaches to significantly increase the resistance of surfaces and to develop coatings which provide components with greater resistance to erosion and abrasion (Fig. 13).

The load on surfaces differs widely depending on the application, so tailored solutions need to be developed: Surface protection for aircraft requires a different solution to surface protection for wind turbines. The experts of the Paint/Lacquer Technology are developing novel, highly erosion-resistant coatings containing inorganic and organic reinforcing fillers – for example nanoparticles – and systems already in use are being modified with this functionality (Fig. 14). To combat frictional loads, high-strength coatings having minimum frictional resistance are being developed. These have special slip and antiblocking properties. The Paint/Lacquer Technology section possesses state-of-the-art testing and analytical facilities in order to realize optimum solutions for each specific requirement.

The in-depth knowledge of the section on both everyday coating issues and the very latest technologies makes the Fraunhofer IFAM a valued partner of the paint/lacquer industry. The latter manufactures and processes more than 2.5 million metric tons of paints, lacquers, and printing inks in Germany each year. Its importance to society is considerable, because paints and coatings provide surfaces with customized surface protection. They protect materials worth many billions of euros, which otherwise would go into decline due to corrosion as well as wear and would have to be regularly renewed. And this surface protection is getting ever better. The work of the Paint/Lacquer Technology section in Bremen is making a significant contribution here.

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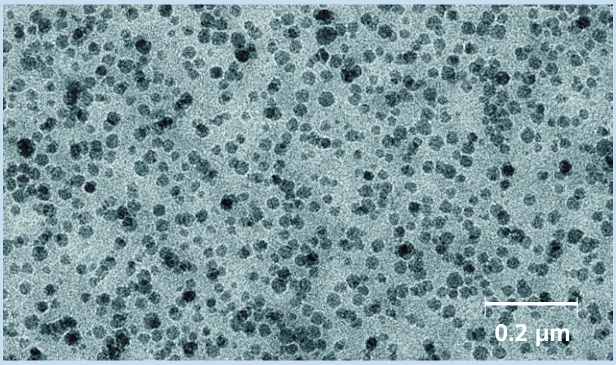


*Fig. 14: Silicon nanoparticle in a dual-cure coating to increase the abrasion resistance.*

10 *Icing chamber developed at Fraunhofer IFAM for testing anti-icing coatings.*
11 *Evaluation of rime adhesion using the rime adhesion test developed at Fraunhofer IFAM.*
12 *Test device developed at Fraunhofer IFAM for carrying out the runback ice test on wing profiles.*
13 *Erosion-resistant elastomer coating on a front wing profile.*