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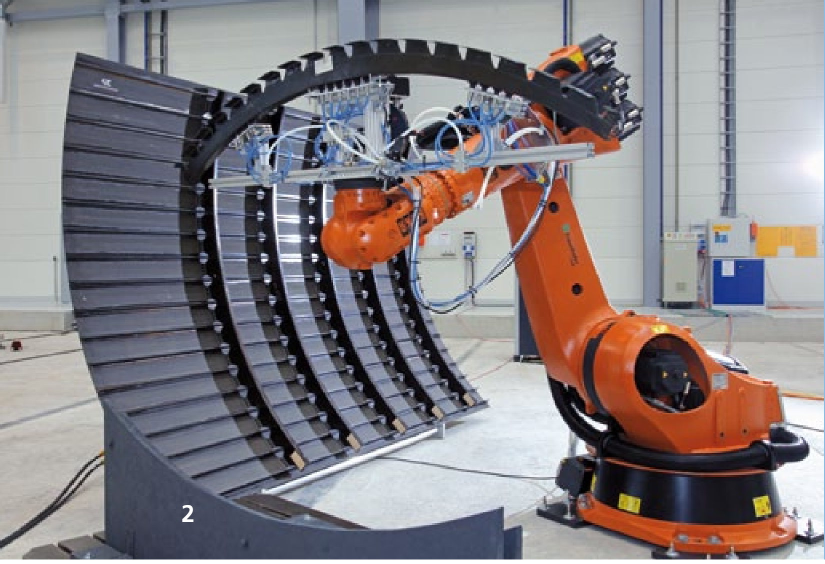
FASTER, LOWER COSTS, AND IMPROVED QUALITY: FRAUNHOFER IFAM ACCELERATES INDUSTRIAL PROCESSES

The Dubai Airshow in November 2011 was hugely successful for Airbus, the European aircraft manufacturer. The Airbus representatives were able to fill up their order books, with 175 new orders alone for the environmentally friendly A320neo model. This good news for the company also brings problems: Customers expect fast delivery and high demand stretches production to its limits. Up until now the aim of Airbus was to build 42 A320 aircraft per month up to the end of 2012. This plan has now to be revised in the light of the Dubai orders: John Leahy, Chief Operating Officer-Customers at Airbus, spoke of 50 aircraft per month now having to be produced.

Examples such as this from the aviation industry are also encountered in many other sectors of industry. When the general economic situation is favorable, companies receive lots of orders. This then stretches their production, with additional production capacity not possible to realize at short notice. Germany is a producer of many high-tech products, whilst mass-produced goods are today often made in countries that have lower labor costs. Additional investment in new production facilities is only undertaken cautiously: Facilities that are in full use one day can quickly fall into disuse if there is a recession and this can be a financial drain on the company. The solution for many companies is "process acceleration": Optimally harmonized materials and processing steps, an increased degree of automation, rising reproducibility, and improved quality monitoring – even during the production. Such approaches often allow manufacturers to quickly achieve significant gains in efficiency and profitability.

Accelerated processes also allow the problem of order surges, such as described at the beginning of this article, to be overcome. The Division of Adhesive Bonding Technology and Surfaces at Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM is the ideal partner here: The scientific work areas in this division have many years of experience working with industrial companies to optimize and accelerate production processes and getting excellent results. This may, for example, concern optimizing the use of adhesive bonding technology, new paint/lacquers and paint/lacquer methods, surface pre-treatment and coating, or the automation of processing and assembly steps. The Fraunhofer IFAM, Europe's largest independent R&D organization in the area of adhesive bonding technology, offers industry solutions for making production processes faster, more efficient, and cheaper – usually also with improved quality and higher reliability of production.

1 *Airbus A350 XWB (Xtra Wide Body; Source: AIRBUS S.A.S. 2010 – Computer Rendering by FIXON – GWLNSD).*



Joining and assembly: Previously manual tasks, today automated

In the area of machining, processing, joining, and assembly, the Fraunhofer IFAM has been involved in many successful projects concerned with replacing manual steps with automated processes. Nowadays robots and machines are often used for work which was previously carried out by people, such as complex surface pre-treatment, quality monitoring, adhesive application, drilling, milling, and joining. The robots and machines carry out the work 24/7 and their efficiency and precision are often far superior to what people could achieve. An example from the aircraft manufacturing industry is used to highlight the potential acceleration of production that could be achieved in the future via automation. That industry is using more carbon fiber reinforced plastics (CFRPs) than ever before, as evidenced by the new A350 XWB (Xtra Wide Body; Fig. 1).

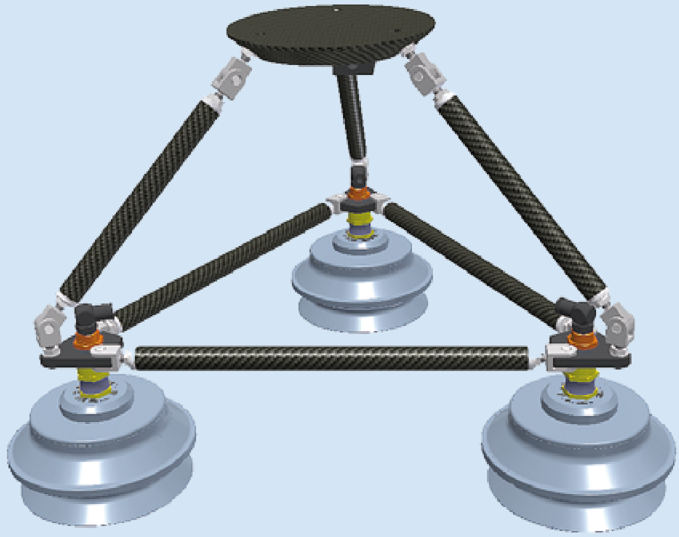
Joining two load-transmitting CFRP components has up until now been undertaken using traditional rivets. The adhesive here only acts as a shim. The shim material fills the space between the components. As these are irregular and as no more shim material than absolutely necessary must be used for reasons of weight, the current shim process involving in some cases several manual measurement and adjustment steps is extremely demanding on time and resources. In Bremen and in the research center CFK Nord (CFRP North) in Stade, a novel gap filling method has been developed by the experts of Fraunhofer IFAM in collaboration with aircraft manufacturers. This method can measure large components using advanced laser technology so accurately that the 3D gap geometry is known to fractions of a millimeter prior to joining and in addition deformation due to the joining pressure can be taken into account. The advantage: The shim material can be applied with perfect fit in an automated process. The result is an enormous acceleration of the production process (Fig. 2).

The use of laser measurement methods also allows manual, tactile steps to be replaced in other processes. For drilling, milling, and joining large structures, self-orienting robot systems now have an accuracy equal or superior to that of conventional manual processes (Fig. 3). The unavoidable shape deviations of large components are a special challenge. These deviations do not allow the robots to be programmed for fixed machining paths, as is the practice, – for example, in the car manufacturing industry. Contactless measurement methods and monitoring by optical, force, and torque sensors nowadays even allow large flexible components to be correctly and quickly positioned and formed, whereas previously this required a complex, manual step-by-step approach. Processes which hitherto have been carried out in sequence can now be undertaken in parallel, for example using several robots to simultaneously carry out different processing steps at the same workplace, such as surface pre-treatment of one component and joining of the other components.

The Fraunhofer IFAM has in-depth expertise developing such automated process steps. In the area of machining and robotics there is close collaboration with the Institute for Production Management and Technology IPMT of the Technical University of Hamburg-Harburg. The experts of Fraunhofer IFAM work continuously on developing processes for faster curing of adhesives and shims. More rapid curing means that there is no need to use the fixation aids that are necessary when curing is slower. This cuts out a whole manual work step, so benefiting the speed of the process.

2 *Automated adhesive bonding of a frame onto a CFRP aircraft fuselage.*

3 *Automated high-precision milling of the window opening on a CFRP aircraft fuselage.*



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At a different level, more flexible design of production plants also allows acceleration of processes. The Fraunhofer IFAM is working, for example, on solutions for using production plants for a diverse range of component geometries. This will avoid the time-consuming and costly refitting or even new installation of production lines when there is a change of product model, as it happened a lot in the past. Modern sensors and actuators make it possible for machine-driven manipulating arms or robots with their tools to be reprogrammed for other tasks and different geometries, materials, and processing steps. With the focus on aircraft manufacture, the Fraunhofer Project Group Joining and Assembly FFM of the Fraunhofer IFAM at CFK Nord in Stade has, for example, developed a carbon fiber reinforced plastic manipulator that can readily hold or pick up aircraft components having different geometries (Fig. 4). It adapts to the various fuselage of differing curvature that are used to build an aircraft. This is achieved by using movable suction cups arranged on a lightweight frame girder structure.

Surface pre-treatment:
In-line processes with multiple applications

Fraunhofer IFAM is also developing surface pre-treatment steps which make processes faster and less complex. This has mainly been achieved by carrying out the pre-treatment steps during the actual production process, and not separately as previously. In many industries, for example the aircraft manufacturing industry, materials and components often have to be cleaned using complex manual procedures and then pre-treated prior to bonding or paint/lacquering, before finally being transferred to the actual production process. The goal for competitive and economical processes must, however, be to directly integrate the pre-treatment steps into process lines using automatically controlled methods adapted to specific needs. If, for example, the substrate must be grit-blasted prior to bonding, then various techniques can be used to carry this out reliably and efficiently, even for mass production (see Page 84; “Cleaning and activation prior to painting/lacquering and bonding: Surfaces are the key issue for fiber composite materials”).

Another example of the R&D activities of the experts of Plasma Technology and Surfaces – PLATO – at Fraunhofer IFAM involves so-called transfer films for manufacturing molded components. These are web materials that are inserted into molds and can adapt to the geometry of the mold. The web material not only has a “releasing” effect, which allows the component to be easily removed from the mold, it is simultaneously able to give the component surface other functions. For example, effective scratch protection can be provided by a plasma polymer transfer coating on the transfer film. Whereas the conventional process for an injection molded component

4 *Modular carbon fiber reinforced plastic lightweight structure manipulator which can pick up and manipulate aircraft components – developed by the Fraunhofer Project Group Joining and Assembly FFM.*

involves three steps – namely the molding of the component, the removal of release agent residues, and the application of a scratch protection coating – the process developed at Fraunhofer IFAM allows a component to be manufactured in a single step. Here, the film remains on the manufactured component for protection right to the end of the process or even up to delivery to the end customer, potentially saving further processing costs and work steps.

These "in-mold processes" can also be integrated with other functions, such as the lacquering/painting of CFRP components. The molded component is then completely finished when it comes out of the molding press because the desired lacquer/paint has been applied to the release layer in advance. The transfer films developed by the Fraunhofer IFAM can also prevent contamination of the manufactured components. The customer then simply removes the film prior to use. The films also prevent damage during further processing steps and therefore ensure high product quality (Fig. 5).

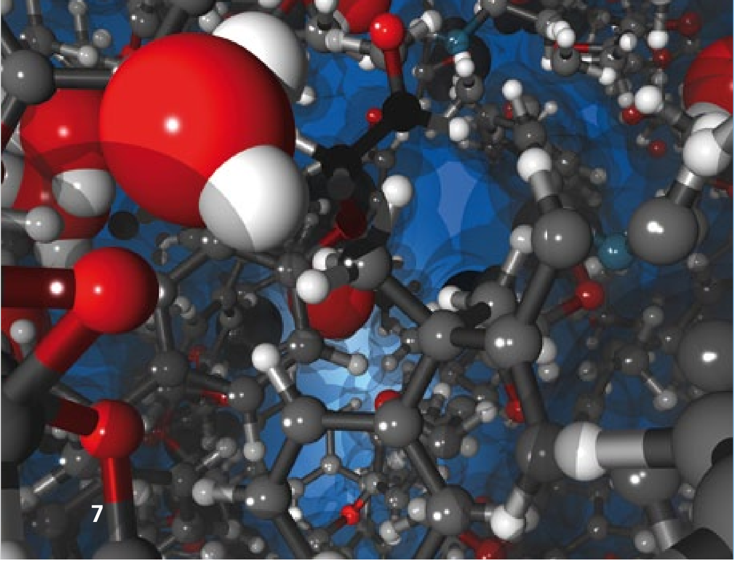
PLATO is also elaborating in-line plasma coating processes which allow targeted local coating using plasma nozzles (Fig. 6). These are being optimized for the needs of customers. A process was, for example, developed for a company in the automotive sector which allowed precise application of a corrosion protection coating on relevant areas of the servo gearboxes. At an interval of just a few seconds, one plasma nozzle cleans the material before another nozzle applies the protective coating. Just a few years ago, such a procedure would have required time-consuming wet-chemical treatment along with subsequent drying and expensive disposal of environmentally hazardous chemicals. Nowadays the procedure is carried out in a fraction of that time and with guaranteed quality, meaning not only that process costs are significantly reduced but also making Germany an increasingly attractive production location.

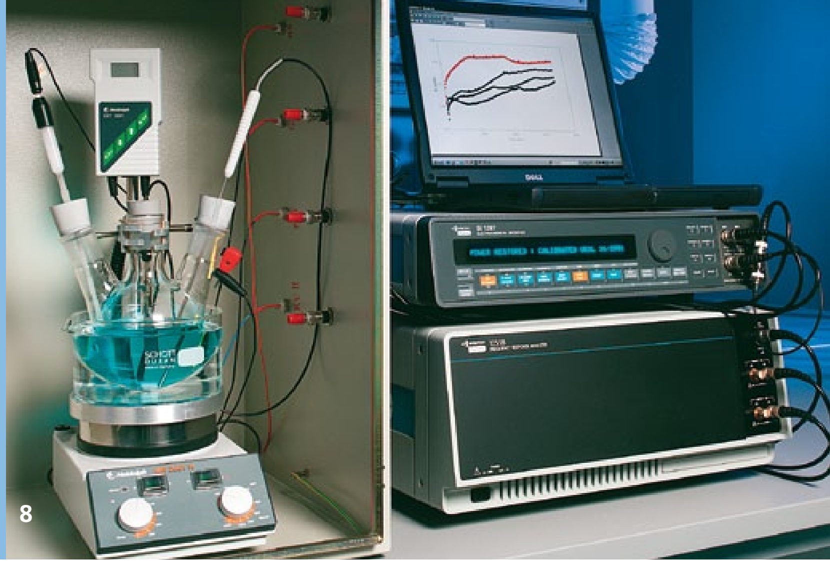
The Plato scientists have also undertaken similar development work on functional atmospheric pressure (AP) plasma coatings for the solar energy sector. These make the surfaces of the materials and components tougher and improve their aging properties, at the same time requiring less maintenance and prologing their functional effectiveness and service life. For solar modules this highly efficient coating reduces the corrosion and increases the service life by up to 20 percent. Compared to earlier methods that used low pressure (LP) plasma, coating at atmospheric pressure considerably accelerates the production. Also here, the coating can be applied fully automatically – and also selectively. The process can be readily integrated into existing production processes. This development is not restricted to solar modules. Indeed, all materials including metals, ceramics, glass, and polymers can be provided with AP plasma protective coatings. For this application with its high innovation potential Dr. Uwe Lommatzsch and Dr. Jörg Ihde of the Fraunhofer IFAM received the German High Tech Champions Award 2011 in the area of solar energy/photovoltaic technology (see page 108 – People and awards; "GHTC Award for Dr. Uwe Lommatzsch and Dr. Jörg Ihde in Boston for the plasma-polymer protection layer for solar modules").

PLATO has also developed a novel highly efficient process for pre-treating carbon nanotubes (CNTs), namely materials that have experienced a boom in industry in recent years. The plasma pre-treatment at atmospheric pressure takes just a few seconds, compared to the former wet-chemical pre-treatment in acids that took over 24 hours. This eco-friendly process has significantly improved the marketability of CNTs.

5 *Removal, transfer, and protection of molded components using Flex$^{Plas®}$ technology from the Fraunhofer IFAM.*

6 *Localized, suitable for in-line application, and environmentally friendly: Atmospheric pressure plasma coatings for adhesion promotion and corrosion protection.*





In the area of low pressure plasma coatings, the PLATO experts have also been successful in considerably accelerating the application of functional coatings. The lower time requirement for this means higher production rates and lower production costs. For example, anti-abrasion layers, which only have an effect for layer thicknesses greater than one micron, can be competitively applied at favorable cost.

Adhesion and interface research:
Small dimensions, large effect

The scientists at Fraunhofer IFAM are not only involved in projects which accelerate the actual production processes – they also ensure that the development of new materials and components and even the "design" are undertaken in as short a time as possible. For example, the experts of Adhesion and Interface Research have built up in-depth expertise in recent years in the area of computer simulation. Simulation of the chemical properties or aging of materials helps, for example, to considerably shorten the traditionally employed empirical test procedures. Numerical simulation allows a great deal of information to be acquired in a short time for which, a few years ago, test methods with longer procedure were required (Fig. 7). Simulation cannot completely replace testing work, rather it helps to streamline development processes and so accelerate them. One example of experimental simulation is accelerated corrosion testing of more materials. Test methods are being developed at Fraunhofer IFAM which allow conclusions to be drawn about corrosion behavior within a few hours or days (Fig. 8). Conventional test methods require up to a few months for this. When developing new corrosion protection paints/lacquers, for example, this means an enormous time saving for companies.

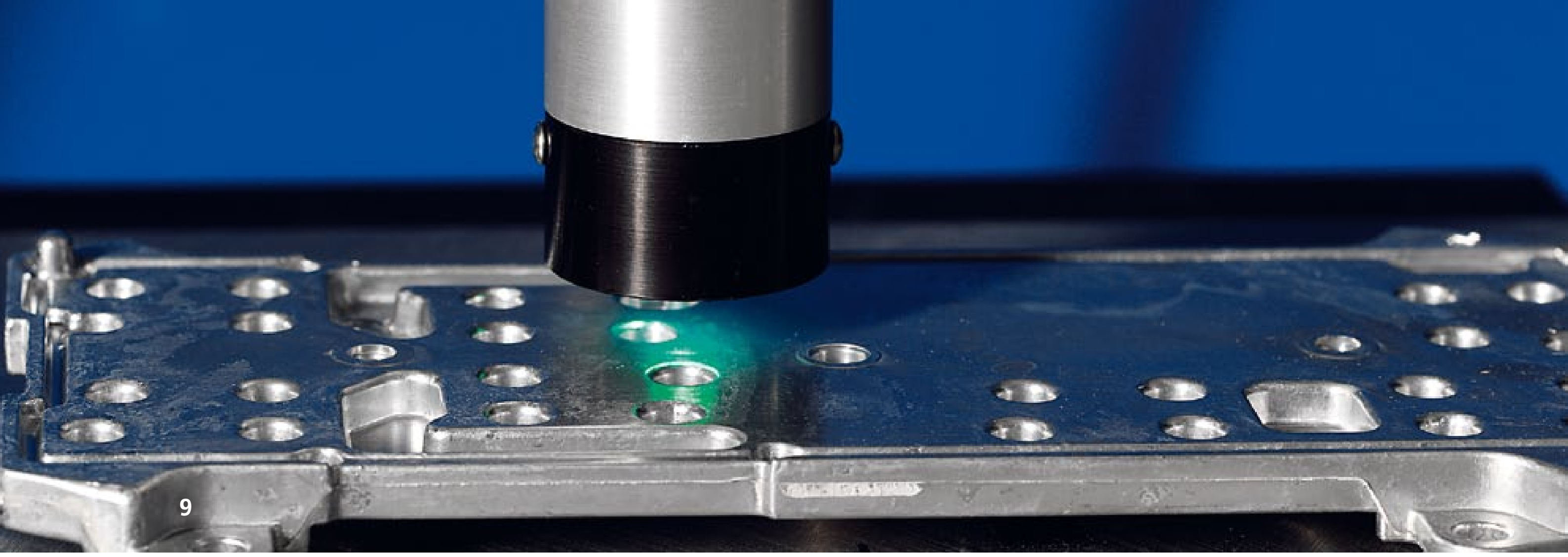
Although companies strive to minimize elaboration times when changing products or models, increasing emphasis is being put on effective simulation. In the automobile industry, structures must nowadays be able to be readily simulated in order, for example, to demonstrate the crash behavior by computer simulation and so minimize the number of expensive "real" crash tests. The scientists of Materials Science and Mechanical Engineering at Fraunhofer IFAM are largely responsible for this simulation, whilst Adhesion and Interface Research experts are primarily involved with the technical effects of the material properties at the microscopic and molecular level.

Adhesion and Interface Research is also involved with developments to accelerate production processes. One example is the development of chromate-free wet-chemical pretreatment methods for lightweight metals. These methods pre-treat metal structures to provide corrosion protection and simultaneously improve the adhesion for subsequent primer or adhesive application. The scientists of Adhesion and Interface Research thus guaranteed that despite the adjustments to new processes and the shorter treatment time, produced materials have equivalent or even better quality than those produced using conventional processes. In such development work the key is always to quickly transfer the results from the laboratory scale to industrial production. To achieve this, Fraunhofer IFAM constantly adapts its laboratory and small pilot plant equipment to this development work.

One discovery made by Adhesion and Interface Research to improve the rate of curing of adhesives and paint/lacquer systems concerned microscopically small capsules down to the nanometer range. These contain active agents which, when commanded – for example by a temperature impulse – are released, so causing rapid curing of the adhesive. For this,

7 *Simulation of the uptake of a water molecule (red-white; top left) into a polymer network.*

8 *Electrochemical tests to evaluate corrosion protection layers.*



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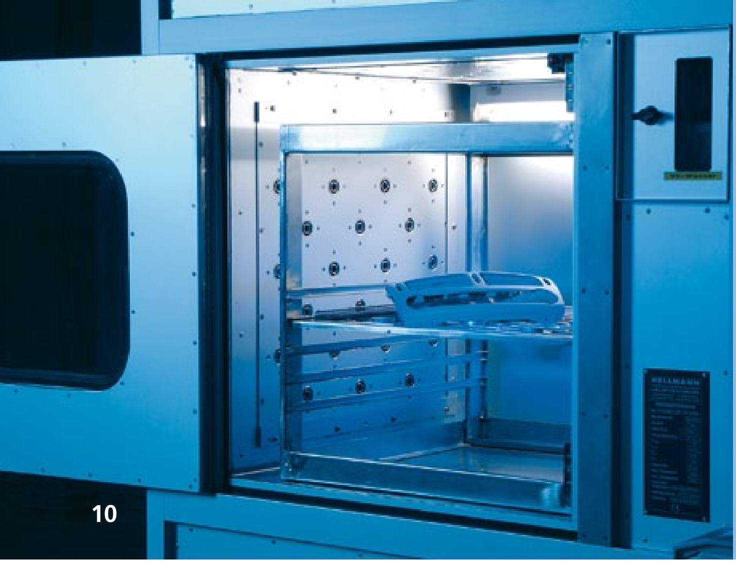
curing reagents are being incorporated at the molecular level into the voids of nano-zeolites. After the scientists had obtained excellent results using simulation, it was possible for a project partner to design suitable zeolite cage structures on the basis of these calculations. Other potential applications of the capsules are for the self-healing of paint/lacquer and for corrosion protection. Here the capsules with active agents only open when the surface is damaged. An example application: For offshore wind turbines such self-healing coatings could prolong the service lives of key components.

The considerable acceleration of production processes also requires a variety of approaches for in-line quality assurance. Adhesion and Interface Research is actively involved in this work. The aim here is to monitor the various stages of production processes involving bonding and painting/lacquering. The quality of the substrate surface or coated material is monitored here directly after the processing step (Fig. 9). The advantage: In-line monitoring of every process step means that there is no need to monitor the finished component. In most cases this was hitherto not possible to carry out in a non-destructive way and hence was only carried out on random samples. In-line monitoring primarily involves measuring the chemical state or roughness and structure of a component surface. Monitoring the chemical state not only involves detecting contaminants but also checking whether the pre-treatment was successful. Various techniques, customized for a particular application, are used for this, and these include, e. g. spectroscopic and optical methods.

Optical methods are very suitable for determining the wetting properties of surfaces. The scientists at Fraunhofer IFAM have optimized this application of in-line monitoring in a project concerned with bonding windscreens. This involved the application of primers which could not be checked with the naked eye. The method developed by Fraunhofer IFAM for this is so advanced that it is suitable for quality assurance.

Another example is the detection of release agent residues or production material residues on carbon fiber reinforced plastics (CFRPs). Even tiny, invisible amounts of contaminants can lead to significant impairment of the adhesion properties. Adhesion and Interface Research has developed laser spectroscopy methods with high proof of accuracy that can detect very small amounts of contaminants. These methods can be directly integrated into the production to monitor large surfaces and also small localized areas. In general, the main challenge is to develop methods which allow rapid detection in a production environment and have high proof of accuracy. However, they must also be very robust. Production cycle times must not be lengthened due to the use of in-line methods.

9 *Identification of residual contamination on an aluminum pressure-cast component using Optically Stimulated Electron Emission (OSEE).*



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Paint technology:
From more rapid drying to color matching

Fraunhofer IFAM has also developed various solutions in the area of paint/lacquer technology for accelerating these important processes. A good example concerns a solution developed in a research project funded by the Federal Ministry of Education and Research (BMBF). Working together with various industrial partners – including paint manufacturers, painting and drying plant manufacturers, and end users – the paint/lacquer experts at Fraunhofer IFAM elaborated a rapid drying process for lacquered/painted plastic parts in the automobile industry. This involves the use of ultraviolet radiation for rapid curing of painted/lacquered parts.

This work was carried out in close collaboration with Adhesion and Interface Research. By using computer simulation it was possible to customize formulations for this application. The correlation between theoretical and practical findings quickly resulted in concrete improvements in the industrial production process. Conventional lacquering/painting processes for mirrors, bumpers, and interior parts require the parts to be cured for between 20 and 60 minutes in the oven after application of the lacquer/paint. The R&D work at Fraunhofer IFAM allowed the drying time with UV curing to be reduced to less than five minutes. This not only means a huge time saving, but also a significant reduction in the energy requirement.

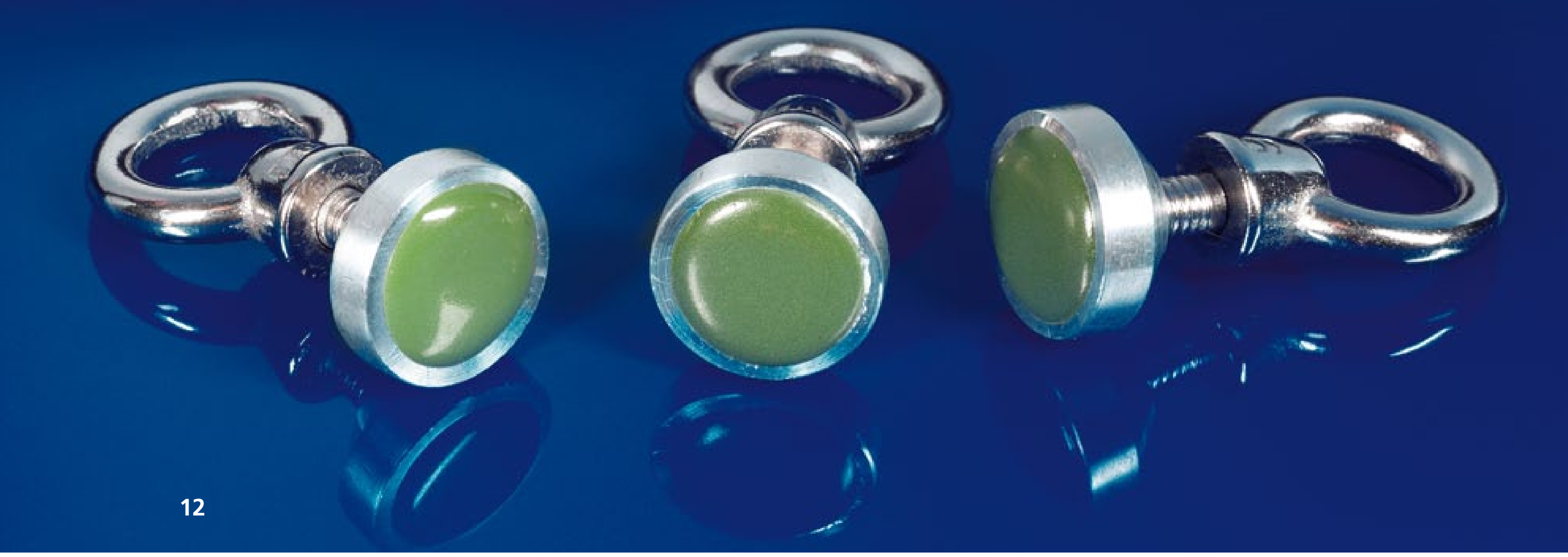
Another approach being developed by Paint/Lacquer Technology at Fraunhofer IFAM for industrial application is the so-called "cold drying" (Fig. 10). In contrast to drying with warm air, involving heating the component and curing of the paint/lacquer due to the increased temperature, cold drying involves cold, dry air. If a component covered with water-based paint is exposed to this air, the dry air takes up moisture – and so dries the paint on the component. This process is not only efficient, but saves energy because there is no need for heating and cooling the component. Energy is solely required to remove moisture from the air. Due to the technological process improvements made at Fraunhofer IFAM, this long-known process has recently been made very efficient. The drying of a painted/lacquered component only takes a few minutes.

A further example of process acceleration involves the use of infrared drying, which in particular allows large lacquered components to be dried in a much shorter time. Whereas aircraft components, rail vehicles, and wind turbine rotor blades traditionally have to be dried for between six and twelve hours after lacquering/painting, this time is reduced to 30 minutes by infrared drying. Paint/Lacquer Technology is highly involved in designing effective processes in this area – from selection of suitable IR emitters to specification of wavelengths and qualification of the relevant paints/lacquers and materials.

Automobile technology is benefiting from a new, faster color matching method designed and developed by Fraunhofer IFAM. Color matching allows time-consuming processes in everyday production in the automotive sector to be considerably reduced. Vehicle bodies are painted in the factory, as are many other components – but with different batches of paint – while other parts are painted by suppliers. In particular for special effect colors such as metallic paints, it was common for supposedly the same colors not to exactly match one another after assembly. In order to avoid this, a complex color matching procedure was undertaken at the different paint users: Specimens were painted by the

10 *Laboratory unit for effective and energy-efficient drying of water-based paints using cold, dry air.*

11 *Improved color matching, even for "difficult paints", allows optimal matching of vehicle bodies and components painted at different locations.*



paint manufacturer and individual users and these were exchanged by post and evaluated. Paint/Lacquer Technology at Fraunhofer IFAM successfully accelerated this process: They developed an electronic system that can measure colors and convert them into electronic data – itself not a novelty because this procedure was already known. However, the solution of the experts of Paint/Lacquer Technology also integrated other aspects into the evaluation, for example the coarseness of the effect paint and the degree of gloss (Fig. 11). This made it possible to measure "difficult paints", to define suitable tolerances, to virtually compare the paint colors, to adapt the colors, and finally to release the colors for production at the respective user.

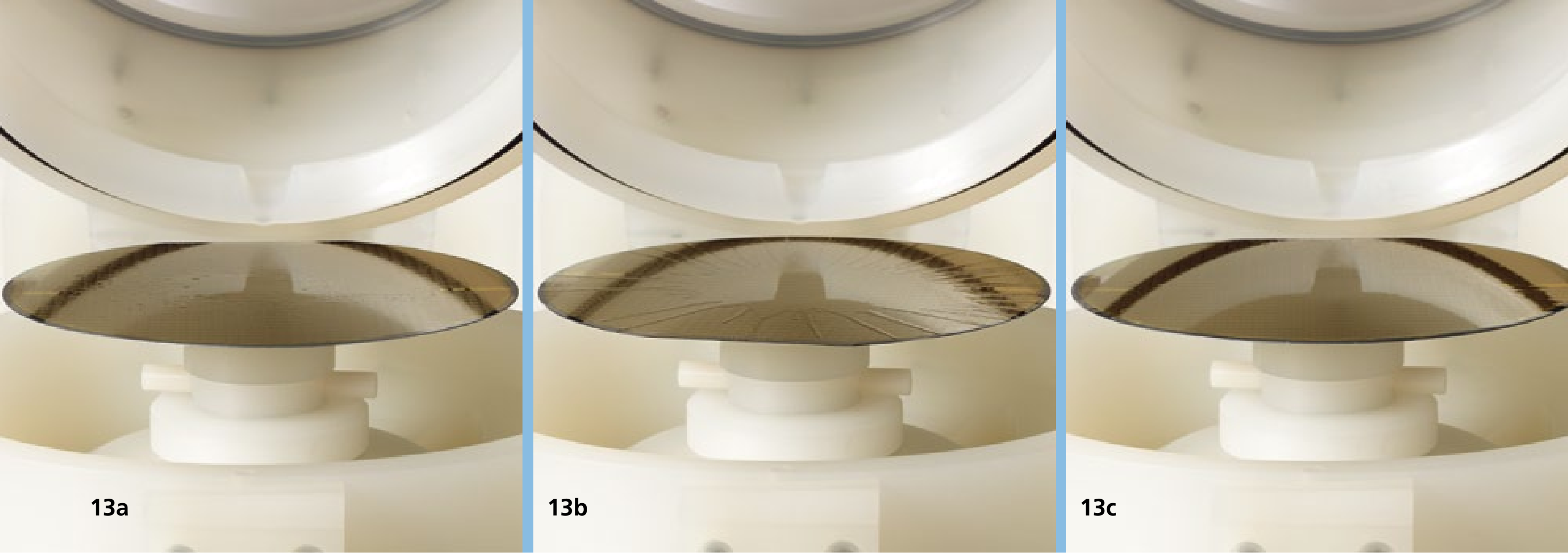
Adhesive bonding technology: Faster production using pre-applicable adhesives PASA®

New developments at Fraunhofer IFAM in the field of Adhesives and Polymer Chemistry are also making industrial processes considerably faster. For adhesive development, one aspect that has to be taken into account is optimized suitability for machine-based mass production at high cycle rates: The adhesives are customized so that they can be effectively used in production lines operating at ever higher rates. Another aspect is the curing rate: Faster curing processes mean significantly faster production.

Rapid curing processes are nowadays essential if companies want to achieve higher cycle rates. Whereas two-component adhesives from the building center take 24 hours to attain their final strength, industry uses adhesives that fully cure in a few seconds. This is the case, for example, with adhesives which cure when exposed to ultraviolet radiation (UV). As the strength of these bonds is not overly high, however, this method cannot be used in the automobile industry. UV curing is though highly suitable for electronic components and for bonding canulas in disposable syringes.

A groundbreaking development from Fraunhofer IFAM concerns Pre-Applicable Structural Adhesives (PASA®; Fig. 12). The PASA® adhesive is applied to the component and then partially pre-cured so that the component is not tacky. The advantage: The components – for example adhesive-covered fastening bolts which are used in the automobile industry as anchor points for the interior furnishing of the vehicle – can be stored for a long period of fluctuating temperatures in boxes without sticking to each other. To be used, the pre-applied adhesive, which is still chemically reactive, is activated

12 *Pre-applicable adhesive PASA® on metal fasteners.*



by a magnetic field in a matter of seconds. The magnetic field heats the "solid" pre-applied adhesive film for a short period, making it a liquid and so initiating its adhesive effect. This principle is similar to towel hooks whose adhesive films are covered by protective paper. The paper is only removed shortly before the hooks are bonded into position. In the case of adhesive-covered fastening bolts, the rapid activation allows them to be used in mass production.

Pre-applicable adhesives have the advantage that they are not applied to the components in sensitive areas of the production facility. They are applied at another location and ideally not by the end user but by upstream service suppliers. In situations where many small components have to be covered with adhesive, this can even be undertaken in a single step – for example for chips. Indeed, even at the wafer level these can be coated with adhesive (Fig. 13 a–c). These adhesive coatings were developed by the Adhesive Bonding Technology scientists at Fraunhofer IFAM using the example of transponders with radio frequency identification, so-called RFIDs. Whereas up until now chips have been bonded into plastic packaging with hot curing adhesives, the use of pre-applicable adhesives allows the adhesive application to be carried out away from the production line and allows the temperatures to be reduced. The result is significantly increased cycle rates with lower production complexity (see page 90; "Development of new adhesives: Making impossible property combinations possible").

13a–c *Applying a pre-applicable adhesive to a processed wafer via spin-coating.*

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