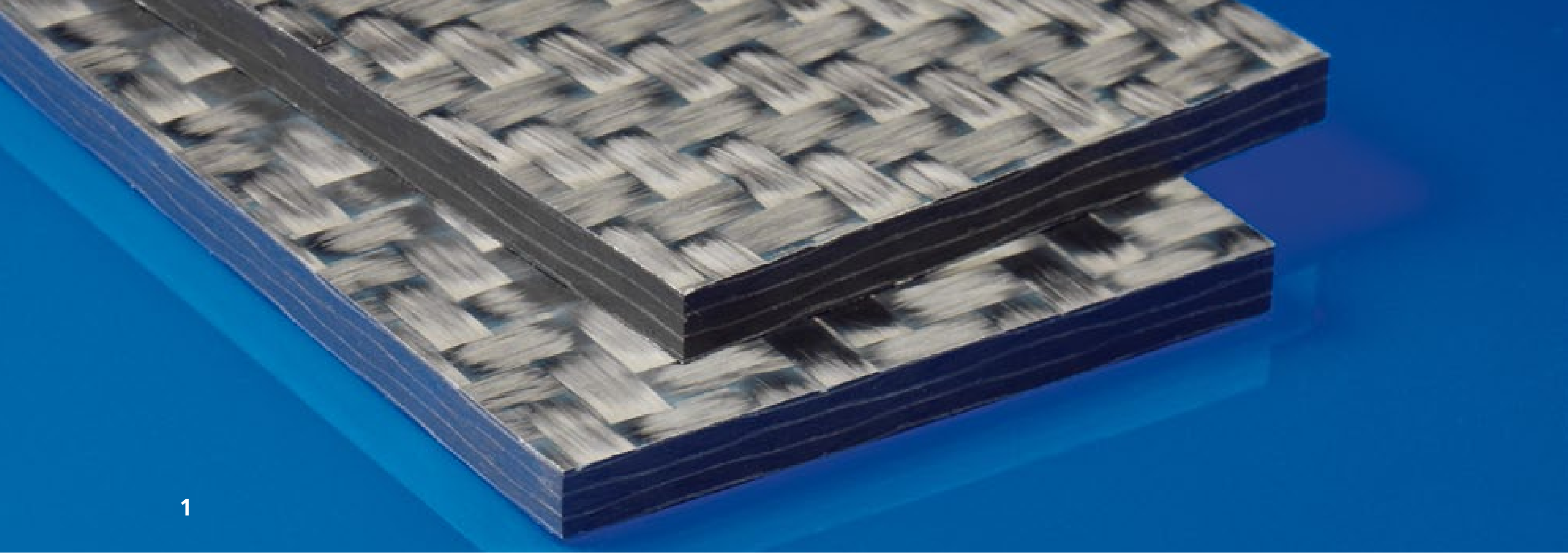

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CLEANING AND ACTIVATION PRIOR TO PAINTING/LACQUERING AND BONDING: SURFACES ARE THE KEY ISSUE FOR FIBER COMPOSITE MATERIALS

They are the reason for technological breakthroughs and totally new industrial applications: Carbon or glass fiber reinforced plastics have truly made their noteworthy mark over the last 25 years. Whenever low weight and high rigidity are required, it is fiber reinforced plastics (FRPs) – and in particular carbon fiber reinforced plastics (CFRP; Fig. 1) and glass fiber reinforced plastic (GFRP) – that are nowadays the likely choice. It is thanks to FRPs that lightweight design has taken off in major industries. These materials have made resource-friendly production and hence eco-friendly products possible.

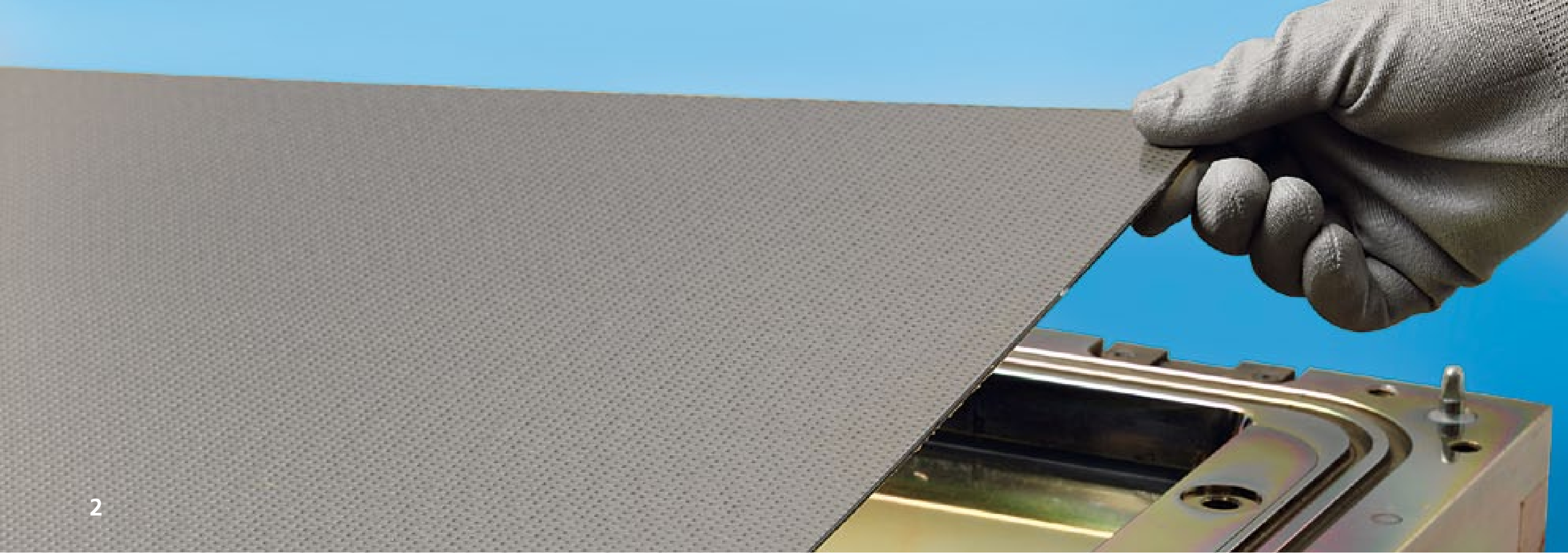
In the aviation sector, aircraft wing components and tailfins are made of CFRP, whilst GFRP components are commonly found in the automobile industry as roofs, trunk covers and are used for making rotor blades for wind turbines. The weight reduction has enormous benefits. For example, lightweight design improves efficiency and for means of transport it lowers fuel consumption and hence CO_2 emissions. Extremely hard, rigid, and yet light tennis racquets and bike frames have enhanced to aspired performance in sport as an optimal "tool" for maximum performance. In short: CFRPs have assumed an established place in modern industry – and have a very promising future. Soon, more than 50 percent of an aircraft will consist of CFRPs. New aircraft such as the Airbus A 350 and Boeing 787 are leading the way.

Although CFRPs have already made their breakthrough in the automobile and aircraft manufacturing industries, in many other sectors the use of these materials is still in its infancy, but offers enormous potential. Wherever FRPs are used, there is one key prerequisite in addition to meet the required mechanical properties: The application must be economically viable. This viability is often only achievable via automated mass production and processing of FRPs. High and efficient cycle rates are required in particular in the automobile manufacturing industry. And also in aircraft manufacture the trend, despite the size of the components, is to move from individual component manufacture to series production.

Contamination by release agents – a necessary evil?

There is a major innate challenge when manufacturing FRP components. Almost all FRP components are made in metal molds. They are cured in these molds to obtain their final

1 *Ideally suited for lightweight structures – carbon fiber reinforced plastic (CFRP).*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structure and stability. In order to prevent the components becoming stuck in the molds, so-called release agents are usually used to facilitate the removal of components, some of which can be several meters long, from their molds without being damaged. Nevertheless, residues of release agents are transferred to the components and this makes subsequent cleaning of the surfaces necessary. The nature, quantity, and method of application of the release agent determine the complexity of the cleaning step. The rule is: As much as necessary but as little as possible.

There have been a variety of developments in this area. In recent years, for example, internal release agents for FRP components have been developed to replace coating of the mold. In this case the components in effect have their own in-built release agent. The release agents are incorporated into the starting materials used to form the polymer matrix. However, in order here for the components to be easily removed from the mold, the release agents must act at the surface. This in turn means that the release agents must be made "harmless" prior to subsequent painting/lacquering or bonding.

Instead of release agents, alternative processes utilize permanent release layers (Fig. 2) or release films placed in the molds. This increases the work for preparing the molds, but the costs for post-treatment are considerably lower.

The experts of Plasma Technology and Surfaces – PLATO – at Fraunhofer IFAM have carried out much R&D work in this area in recent years. They have developed, for example, flexible deep-drawable release films which can totally replace release agents (see page 67; "Faster, lower costs, and improved quality: Fraunhofer IFAM accelerates industrial processes").

Surface pre-treatment for fiber reinforced plastics: Cleaning and activation

If it is not possible to do without release agents for FRP component manufacture, they must be removed prior to further processing. This cleaning process must be monitored. Only release agent free FRP components have good bonding and painting/lacquering properties. This is particularly important because adhesive bonding, and not mechanical riveting, is the ideal joining technique for FRPs. Mechanical joining methods require complex and costly holes to first of all be drilled in the FRP materials. This causes local structural damage to the FRP and substantial strength loss, as well as high wear to tools.

In contrast, adhesive bonding is ideally suited for joining these materials. It allows damage-free, planar transfer of forces and is more economical. In addition, for CFRPs there is complete prevention of contact corrosion between the carbon fibers and metallic rivets. Suitable surfaces are, however, required in order to utilize these benefits.

The PLATO scientists at Fraunhofer IFAM are also involved in this area. PLATO has broad expertise and has undertaken many projects in recent years to optimize FRPs and make their use possible.

The challenge is a demanding one: The surfaces of FRPs must be pre-treated in such a way that effective bonding and defect-free painting/lacquering are subsequently guaranteed. Time, cost, and quality are the parameters by which the use of FRPs is measured and which determine the pre-treatment of the materials. Up until now time-consuming manual work has often been used to clean components for aircraft and wind turbine manufacture, thus preparing them for bonding

2 *Release agent free removal of FRP components from molds using permanent plasma-polymer release layers.*

or painting/lacquering. This manual work includes sanding, cleaning with solvents and is sometimes assisted with laser beam cleaning which – like the manual work – brings the risk of defects and damage to sensitive materials.

The aim of PLATO is to automate the pre-treatment processes and so enhance the reliability and quality of FRP usage and reduce costs. Various pre-treatment processes can be used depending on what must happen to the FRP component in the next step of the processing. In collaboration with the customers, suitable solutions for the particular application can be identified. Of advantage here is that this work is also undertaken in close collaboration with other specialists at Fraunhofer IFAM – for example the adhesion and interface research, adhesive bonding technology, and paint/lacquer technology.

A further challenge is that there are thermoplastic CFRP materials which, even when clean, do not have good bonding or lacquering properties. The majority of CFRP components are still made with epoxides. However, there is a trend towards thermoplastic materials in the aircraft and car manufacturing industries. These CFRP-containing plastic sheets can be pressed into any desired shape under the effect of heat – just like metal sheets are for example pressed for car manufacture. The disadvantage is that thermoplastic materials are not ideal for coating and bonding. They have hydrophobic surfaces which, even when totally clean, are difficult to coat and bond. Besides being cleaned, the surfaces of these materials must therefore also be activated.

What pre-treatment is the most suitable?

What pre-treatment is best for what kind of contamination and for what kind of production process or production step? These are the key questions the PLATO experts are trying to answer. The ideal solution is in some cases to combine two pre-treatment processes and so have the best technical and economically viable solution. The pre-treatment must be adapted and safe – for the production, for the service life of the component, and for the customer.

CO_2 snow cleaning – gentle and thorough cleaning …

In situations where release agents cannot be avoided in the production, CO_2 snow cleaning has been used as successful cleaning method in recent times. This uses carbon dioxide (CO_2), a non-combustible colorless and odorless gas that is present in air and which can be isolated in an environmentally-friendly way. It is stored as a liquid in a tank and when being used is converted into small snow crystals by special nozzles. The snow crystals hit the component surface under high pressure (Fig. 3).

This cleans the surface of contaminants in a gentle and environmentally responsible way. As the snow crystals revert to the gaseous state and truly "dissolve in air", there are no residues. The process is very gentle for the surfaces yet cleans them thoroughly. Major automobile companies, such as BMW, already use CO_2 snow cleaning in their production prior to painting/lacquering plastic components. This obviates the need for time-consuming cleaning with water – and also means car manufacturers can be sure that the cleaned components meet the high requirements for painting/lacquering.

3 *Gentle, thorough, and residue-free – removal of release agents using CO_2 snow.*

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The big advantage of CO_2 snow cleaning is hence the cleaning effect. However, polymers that are often naturally hydrophobic cannot be effectively wetted with water after CO_2 snow cleaning.

… which in combination with atmospheric pressure plasma provides an optimum surface for bonding and painting/lacquering

The treatment with atmospheric pressure (AP) plasma can be used to make polymers easier to bond and coat (Fig. 4). Thermoplastic materials, such as polyphenylsulfide (PPS), which are difficult to paint/lacquer can be advantageously modified by AP plasma treatment. This incorporates oxygen into the surface of the material. This, however, is only sensible when there is minor contamination: Plasma can remove organic contaminants, e. g. thin oil film. If there is more major contamination then other pre-treatment methods must also be used in addition: For example a combination of CO_2 snow cleaning – to remove the coarse contamination – and AP plasma treatment – for fine cleaning and functionalization of the surface. Both processes can be automated and coupled to each other in series production lines.

Cleaning and activation with light – VUV excimer technology

A relatively new technology in the PLATO portfolio is the cleaning, activation, and coating of surfaces using vacuum ultra violet radiation, in short VUV radiation. Here, so-called "excimer lamps" emitting radiation at a wavelength of 172 nanometers are passed across a surface. The intense radiation removes release agent residues or converts them into adhesion promoters. PLATO is currently working on integrating VUV systems into production lines, so allowing high-precision and effective surface treatment (Fig. 5).

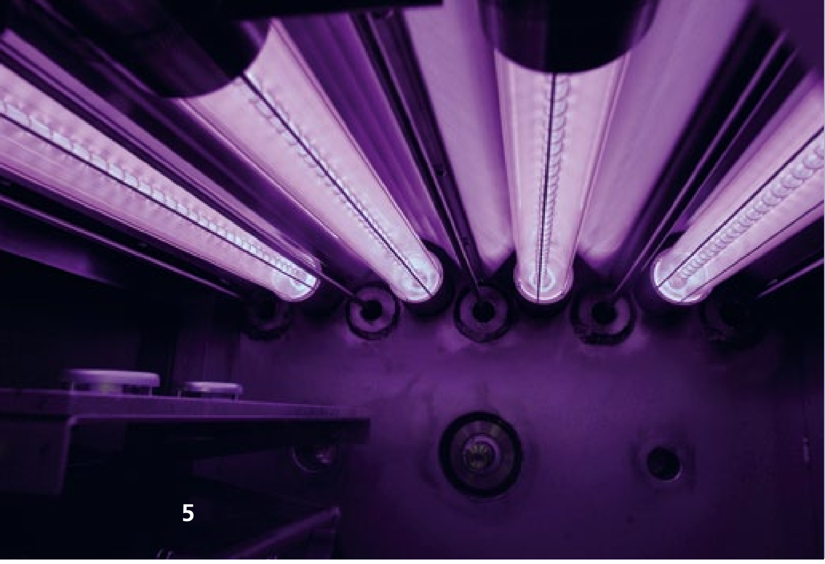
4 *Cleaning and activation of complex FRP surfaces using atmospheric pressure plasma.*

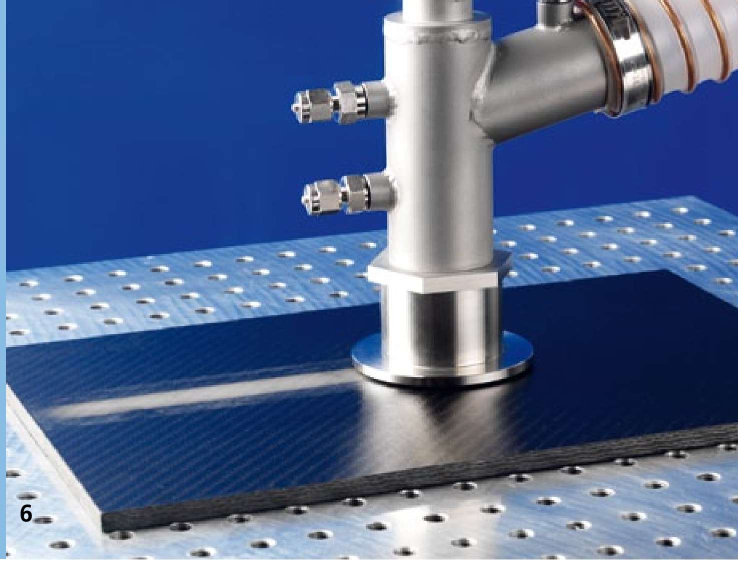
Vacuum suction blasting – a universal technique for cleaning and abrasion …

Another proven method for treating components prior to subsequent bonding and painting processes is jet cleaning with solid particles. In conventional compressed air blasting, solid particles hit the material surface at high speed and abrade the surface. The disadvantage is that the particles become airborne and that is why the method is usually carried out in blasting booths.

An alternative method to this is vacuum suction blasting in which the blasting is carried out under a bell which is connected to an industrial vacuum cleaner. So a differential pressure is produced, which accelerates the blasting medium towards the surface and removes the particles directly in the vacuum cleaner. The method is hence suitable in situations where the blasting and painting/lacquering have to be carried out in the same production area. It utilizes the effect of classical compressed air blasting but avoids contamination – and there is no need to transport components to blasting booths. It also allows very large components to be pre-treated directly in a production line. Any dust that forms is immediately extracted and this is also of benefit for the environment and workplace safety: The liberation of harmful epoxide dusts from FRP components can hence be efficiently negated.

In addition, the method which is adopted by Fraunhofer IFAM can also be used for localized application. In the vacuum suction blasting process, a nozzle travels across a surface and there is no contact with the surface; the particle beam roughens the surface in a defined way, for example for subsequent bonding. PLATO is developing vacuum suction blasting processes with effective extraction for industrial use – adapted to the specific applications of customers (Fig. 6).





… and with quality assurance

In collaboration with experts in the Adhesion and Interface Research, integrated in-line monitoring systems are being developed to allow process monitoring and if necessary adjustment of process parameters. The work involves the development of robust methods suitable for an industrial production environment, customized and optimized for specific applications in order to achieve the best as well as most economically favorable results (Fig. 7).

Customized combinations of surface pre-treatment

A combination of methods is often required in order to achieve the ideal solution for a specific application. For example, regions of components that need to be bonded can be roughened by laser beam treatment or vacuum suction blasting. The regions where a smooth CFRP surface is required for painting/lacquering can be realized by CO_2 snow cleaning or AP plasma treatment. In practice, the processing unit in a robot cell takes the tools it requires for the specific region. In series production this occurs in own stations for the various steps.

When manufacturing large aircraft components, it generally makes sense for a robot to clean the whole surface first with CO_2 snow and then to activate defined regions with a plasma nozzle or vacuum suction blasting nozzle. An example of such a procedure on aircraft is when small components – such as cable holders – have to be affixed at certain intervals. In conventional manufacturing these places are manually roughened and cleaned with solvent. In the future this work will be automated by targeted vacuum suction blasting.

Actively involved in European research projects

The expertise of PLATO is being utilized in European projects. For example, as a partner in the ABITAS project (Advanced Bonding Technologies for Aircraft Structures) with Airbus and other companies from all over Europe to lower the costs for the development of new aircraft by 20 to 50 percent in the medium to long term. The experts of Fraunhofer IFAM were mainly involved here with surface pre-treatment using atmospheric pressure plasma. Compared to other pre-treatment techniques it has been demonstrated that this technique can replace manual activation methods. PLATO tested various CFRP surfaces and pre-treated these with AP plasma. Different methods for removing components from molds and hence various types of contamination were considered in the studies. It was demonstrated that AP plasma pre-treatment is suitable for realizing bonded joints with good long-term stability for aircraft manufacture. The bonded joints were tested for their resistance to aging and excellent results were obtained.

A key R&D topic is also the repair of CFRP components. The more intense the usage of the material, the greater the probability of damage during everyday use. Repair processes for CFRPs must be understood and then developed for specific situations. PLATO is developing robust processes that are suitable for on-site environments – for example at the airport, where damage to the CFRP outer skin of an aircraft has to be repaired efficiently and with effective quality control but with as little complexity as possible. This does not concern components just "out of the production" but rather components that have already been under considerable stress, are contaminated, and have undergone aging. Here PLATO is also

5 *Cleaning and activation of surfaces with VUV radiation using excimer technology.*

6 *Contactless vacuum suction blasting of FRP components prior to bonding.*

highly engaged in a major European R&D project, CleanSky. Fraunhofer IFAM is developing potential processes for this in the SFWA sub-project (Smart Fixed Wing Aircraft) along with well-known players in the European aircraft manufacturing industry.

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7 *In-line quality assurance using thermography.*