Right on target and eco-safe – Corrosion protection with atmospheric pressure plasma

The use of wet-chemicals for the pretreatment of aluminum surfaces prior to bonding is still one of the most widely used application methods in the industry. But alternatives have long since been available. A particularly cost-effective, energy-saving and environmentally friendly method is the area-selective pretreatment of adhesive and sealing surfaces with atmospheric pressure plasma.

Plasma jet technologies allow conventional pretreatments prior to bonding aluminum surfaces to be dispensed with entirely in many production processes. Unlike wet-chemical pretreatment methods, this approach makes drying and interim storage unnecessary, so components can be processed downstream immediately after plasma cleaning, activation and coating. This eliminates process steps, reduces energy consumption and operating costs and increases throughput and product quality. Users also benefit from the high process reliability and accurate reproducibility of the plasma processes, as demonstrated by their use in aluminum profiles, aircraft manufacturing and electronics.

Whether applied by hand, dipping bath or by other wet-chemical processes, there is a growing desire to avoid or at least minimize the use of solvents and toxic substances in the pretreatment of material surfaces – as well as excessive amounts of energy. This wish was granted over 20 years ago with the development of an inline atmospheric pressure plasma (AP plasma) jet technology by systems engineer Plasmatreat from Steinhagen in Westphalia. Now used throughout the world in virtually every sector of industry, the Openair-Plasma technology created by the company provides one of the most effective and at the same time most environmentally friendly methods for the area-selective microfine cleaning and activation of material surfaces (*Fig. 1*). Atmospheric pressure plasma can completely replace pretreatment methods that are harmful to the environment or to health and dramatically reduce energy consumption and operating costs.

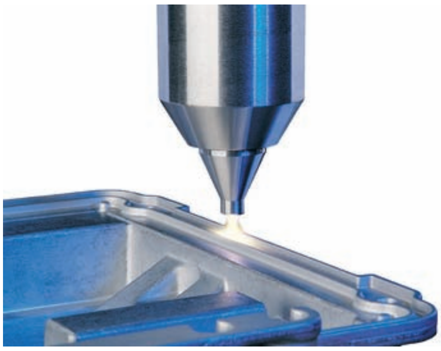

Fig. 1: Atmospheric pressure plasma is one of the most effective and at the same time most environmentally friendly methods for the area-selective microfine cleaning and activation of material surfaces (Photo: Plasmatreat)

Conventional cleaning methods

Aluminum surfaces must be completely clean to achieve an effective bond, but in practice this is rarely the case. Instead the metal surface is often contaminated with undefined oxide layers, wafer-thin layers of dust or traces of residue from the production process such as release agents, lubricants, cutting oils and drawing grease. These impurities diminish the effectiveness of the surface energy naturally present in the aluminum which largely determines the strength of an adhesive bond. Microfine cleaning of the substrate is therefore essential.

Even in modern industry, it is still common practice to clean aluminum components by hand prior to bonding. This often involves a worker spending several hours each day in a separate pretreatment chamber cleaning the designated adhesive surfaces of hundreds of parts by hand with a cloth, frequently using hazardous solvents such as isopropyl alcohol. The method is unstable and even poses a potential health risk to the operator. It is also astonishing, given that a manual cleaning process can never produce consistent, reliable results.

The wet-chemicals used as adhesion promoters or corrosion protection for these adhesive surfaces are often applied far too liberally. Components are fully immersed in the solvent-based media, despite the fact that in most cases the adhesive surface that actually requires this type of pretreatment makes up only a small fraction of their overall surface. Dipping processes are associated with high setup and disposal costs as well as costly protection measures and furthermore, if heat drying is required, they can make the pretreatment of a component an extremely energy-intensive process.

Sustainable alternatives

AP plasma can solve all the above-mentioned difficulties. In simple terms, its mechanism is based on the oxidizing ability of the plasma. The process is dry, environmentally friendly and fast. The nozzles run entirely on compressed air, high-voltage and a process gas if required. The plasma beam impinging on the surface removes all organic impurities from the metal (*Fig. 2*). The high outflow rate of the plasma also ensures that any dust particles loosely adhering to the surface are completely removed. The pretreatment is contact-free and area-selective, in other words it targets only those areas where it is actually needed. The surface is cleaned to a

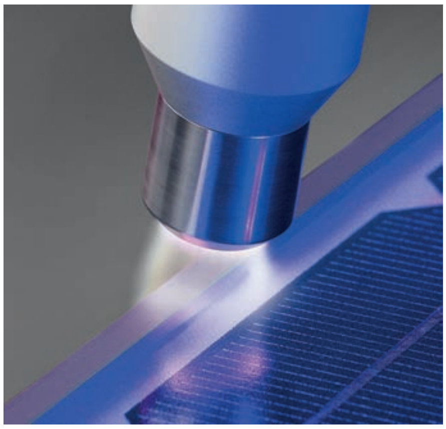

Fig. 2: The Openair-Plasma beam impinging on the surface at high speed removes all organic impurities from the metal and restores its surface energy (Photo: Plasmatreat)

microfine level and simultaneously activated in a singe step.

In the case of aluminum and other metals, the surface energy present in the substrate is restored by intensive plasma cleaning to ensure complete and homogenous wettability of the treated surface with the adhesive, paint or printing ink. If the oxide layer that has formed on the aluminum is stubbornly adhesive, the Openair-Plasma technology enables the plasma to be combined with a laser jet to create a hybrid technology for the targeted removal of the layer. The Plasmatreat systems designed for fully automated, continuous production processes are computer-controlled, screen-monitored and fully compatible with robotic applications. The processes themselves are robust and reproducible.

Area-selective plasma coating

To prevent moisture and other corrosive media migrating beneath the adhesive bonds when bonding aluminum, both an adhesion-promoting layer and corrosion protection must be additionally applied to the adhesive surfaces of many components. Conventional chromate-coating processes treat the entire component. Areas which do not require coating must be masked, or alternatively the coating must be removed from these areas in a subsequent step. Since in most cases only a small area of the component comes into contact with any adhesive, a locally selective and sustainable pretreatment would be of particular interest to these aluminum processors.

With the development of the PlasmaPlus technology in 2006, the plasma specialists from Steinhagen working closely with the Fraunhofer IFAM succeeded for the first time in making plasma coating processes which had previously been the reserve of low-pressure plasma (vacuum chamber) feasible under atmospheric pressure, i.e. under normal production conditions, on an industrial scale and integrating them into series production. For aluminum alloys in particular, the coating not only serves as an excellent adhesive substrate; by acting as a barrier against corrosive electrolytes it also provides exceptional corrosion protection (*Fig. 3*). The inline process which enables plasma-polymer nanocoatings to be deposited with pinpoint precision in continuous production processes is mainly used today in the electronics, solar technology and automotive engineering industries. With this technology, product-specific multifunctional coatings can be generated and deposited in precisely defined areas in a matter of seconds, where they form a covalent bond with the substrate material (*Fig. 4*).

Using atmospheric pressure plasma

The automotive industry is the main area of application for the pretreatment of aluminum parts using the plasma technologies described here. For example, in the construction of car engines, battery manufacturing or for cleaning and subsequently applying anti-corrosion coatings to die-cast aluminum electronics housings. The solar industry uses the PlasmaPlus process to obtain stable corrosion protection for the aluminum profiles of solar modules. The plasma technology from Westphalia is also used in other branches of industry:

Wrapped aluminum profiles

Aluminum trims and profiles such as windowsills and fence posts are often foil-wrapped. However, since aluminum tends to form oxides at the surface, bonding to aluminum is particularly challenging. The oxides migrate beneath the adhesive bond, eventually causing the film to delaminate on exposure to the effects of weather and fluctuating temperatures. For this reason, an adhesion-promoting and if necessary, anti-corrosion primer must be applied before bonding. The standard industrial process is based on up to ten dipping operations, including chromium baths, which generate contaminated wastewater that is expensive to treat.

However, with the aid of the two plasma technologies, the entire pretreatment process can be completed in a fraction of the time and in an environmentally friendly and far more cost-effective way (*Fig. 5*). And since the plasma nozzles are easy to integrate,

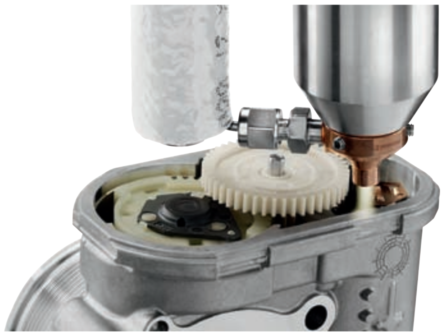

Fig. 4: Applying PlasmaPlus coating to a die-cast aluminum prior to bonding: This inline technology can be used to generate product-specific multifunctional coatings and deposit them in precisely defined areas in a matter of seconds (Photo: Plasmatreat)

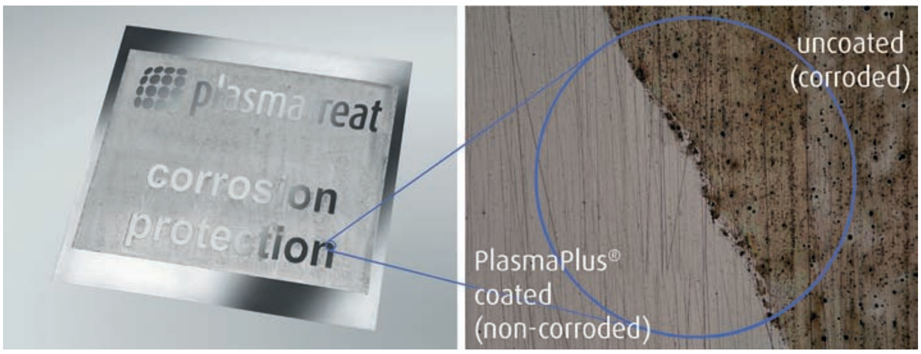

Fig. 3: The plasma-polymer coating not only serves as an excellent adhesive substrate; by acting as a barrier against corrosive electrolytes it also provides exceptional corrosion protection (Photo: Plasmatreat)

Fig. 5: Wrapping of aluminum trims: Pretreatment using AP plasma jet technology is not only much faster than dipping processes, it is also environmentally friendly and far more cost-effective (Photo: Plasmatreat)

cleaning and activation of the aluminum surface can take place directly inside the wrapping machine. The nozzles are positioned in relation to the surface so that the plasma beams overlap to ensure highly effective pretreatment, especially for profiles used in interiors. For components exposed to tougher environmental and temperature-related influences, the atmospheric plasma-polymer coating would be applied immediately afterwards to provide an optimum substrate for the wrapping adhesive and at the same time protect the surface from corrosion.

Aircraft manufacturing

Although restrictive measures regarding the use of *substances of very high concern* (SVHCs) in aircraft paint are already in force, intensive research into environmentally friendly solutions is still continuing apace. The issue is with chromium-based paint systems, which still remain indispensable even in the most up-to-date aircraft. The aircraft industry still applies anti-corrosion, chromium-based primers to the interior surfaces of fuselages, reinforced wing structures and mounting parts prior to painting to satisfy the extremely rigorous standards in aircraft manufacturing. According to the manufacturer, the PlasmaPlus process allows these primers to be replaced with non-toxic, dry-chemical plasma polymerization in a wide variety of components.

Joining elements can also benefit from plasma jet technology. Rivets made from titanium or aluminum alloys are subject to extremely tough corrosion protection requirements due to high air humidity and large temperature fluctuations. Flush-riveted metal assembles are often difficult to clean and pretreat. The edges of the rivets are susceptible to damage, providing an ideal entry point for corrosion. Since the process of applying plasma is contact-free, reliable coating adhesion can be achieved without damaging these very small, corrosion-prone areas (*Fig. 6*).

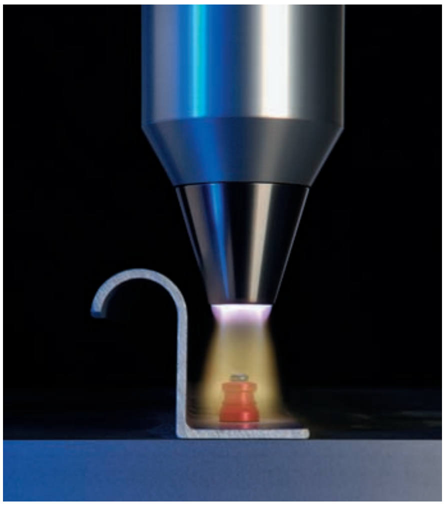

Fig. 6: Aircraft manufacturing: The edges of the tiny rivets are susceptible to damage and corrosion. With contact-free plasma, they can be pretreated without risk of damage (Photo: Plasmatreat)

Electronic components

Electronic components must be protected from corrosion wherever they come into contact with moisture. Almost half of all defects in modern cars can be attributed to climatically driven ageing and corrosion of electronic components. Wafer-thin, transparent and insulating plasma-polymer anti-ageing coatings can be deposited with the PlasmaPlus process to protect targeted areas of electronic assemblies, especially circuit boards, from corrosive influences and extreme climatic loads. The thin coatings act as an effective barrier which can increase the lifespan and product safety of the electronic component and significantly reduce costs compared with conventional coating methods.

Conclusion

The plasma jet technologies described here allow conventional pretreatments applied prior to bonding aluminum surfaces to be dispensed with entirely in many production processes. Unlike wet-chemical pretreatment methods, this approach renders drying and interim storage unnecessary, so components can be processed downstream immediately after plasma cleaning, activation and coating. This eliminates process steps, reduces energy consumption and operating costs and increases throughput and product quality. Users also benefit from the high process reliability and accurate reproducibility of the plasma processes – which are environmentally benign into the bargain.

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