

# Change for the better – AP plasma ensures sustainable adhesive processes for LED lighting

Changing from an established industrial process to a completely new one is a huge step. One leading lighting manufacturer decided to radically change his pre-treatment process prior to bonding. Replacing wet chemical processes with atmospheric pressure plasma (AP plasma) is a very environmentally safe means of increasing the long-term stability of the adhesive bond.

As a manufacturer of energy-efficient safety lighting for illuminating production areas and advocate of one of the most successful manufacturing concepts in the industry, Herbert Waldmann GmbH & Co. KG can be considered a pioneer. 2001 heralded a new era in production for Waldmann employees with the introduction of the Japanese concept Kaizen, or 'change for the better', which saw the entire company convert to the Just-in-Time (JIT) system. The continuous improvement process now extends to all levels of the company and affects every step of production, from development to component production and finally to the end product.

## High requirements

Having the right lighting in the right place is a key factor in increasing productivity and worker motivation in industrial production. One of the company's specialist areas is the production of industrial lighting, especially LED surface-mounted machine lighting >>1. They are used to illuminate the interior of machines, especially those where the lighting housings have to withstand tough conditions: Metal chips fly from machine tools used for turning, drilling, milling and grinding. The lighting housing and covers are exposed to chemical substances such as cooling lubricants and oils. None of these contaminants should compromise the bonded joints in these lights, which is why the sealing requirements are extremely high. However, a strong, long-time stable bond invariably requires good pretreatment of the material surface.

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### Outmoded and obsolete

The use of wet-chemical substances that are harmful to the environment for the pretreatment of material surfaces is still one of the most widely used application methods in the industry. It was no different here. For years, an employee working in a separate room cleaned the adhesive surfaces manually using a cotton cloth soaked in solvent-based isopropanol and a plastic cleaner. He then inserted the parts in an automatic priming station, where they were treated first with an activator and then again with a chemical adhesion promoter using a felt applicator. The next step was to remove the parts and air-dry them, then finally transport them by trolley a distance of 10m to the bonding station.

The future-oriented company had long had a sense of unease about this treatment process. Not only was it harmful to the environment, the use of chemically reactive substances was associated with substantial additional costs for cleaning, materials and disposal. Other factors such as open times, shelf life and storage stability of the primer, as well as cleanliness of the rise cables in the station also had to be continuously monitored. The activator, adhesion promoter, spare parts, service and maintenance of the primer station alone incurred annual costs running into five figures. It was clear that the entire wet-chemical process should give way to a more efficient, environmentally friendly method. The only question was – which process was capable of replacing it and at the same time satisfying the stringent bonding requirements?

### Plasma instead of chemistry

The 180 degree turn that Waldman executed with the pretreatment of their lighting housings started with a study of modern methods of enhancing adhesion and resulted in the switch to Openair-Plasma technology. The process is based



>>1: Surface-mounted machine lighting must withstand tough conditions and the requirements for seal tightness are extremely high  
(Photo: Waldmann GmbH & Co. KG)



>>2: Environmentally friendly, adhesion-enhancing and harmless to electronics: Instead of wet chemicals, the machine lighting housing is now pretreated with Openair-Plasma before bonding (Photo: Plasmatreat GmbH)

on a plasma nozzles system >>2. Twenty years ago, the systems engineer succeeded in integrating a state of matter up till then scarcely used in industry into in-line production processes and so making plasma under normal pressure feasible on an industrial scale for the first time. The technology, now deployed throughout the world, lead to the creation of a pretreatment process requiring nothing other than compressed air as the process gas and electrical energy. This prevents the emission of VOCs (vola-

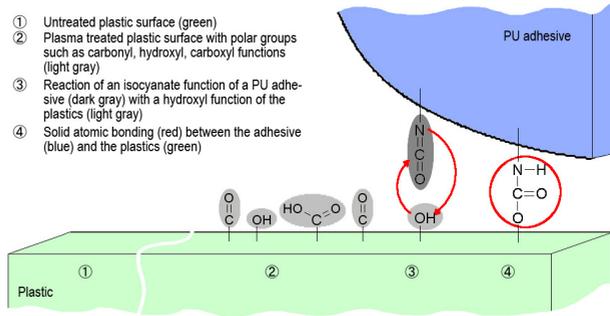
tile organic compounds) during production from the outset. The procedure is used mainly on materials such as plastics, metals, glass and ceramics.

When combined with fixed individual nozzles, this technology enables substrates to be transported through the plasma jet at speeds of several 100 m/min. The plasma system performs three operations in a single step lasting only a matter of seconds: It simultaneously brings about the microfine cleaning, electrostatic discharging and activation of a surface. The result is homogeneous wettability of the material surface and long-time stable adhesion of the adhesive bond or coating even under challenging load conditions.

This multiple effect outweighs conventional pretreatment systems. During cleaning the high energy level of the plasma fragments the structure of organic substances on the surface of the material and removes unwanted contamination even from sensitive surfaces. The high electrostatic discharge action of the free plasma beam has an added benefit for the user: Fine particles of airborne dust are no longer attracted to the surface. This effect is further reinforced by the very high outflow rate of the plasma, which ensures that even particles loosely adhering to the surface are removed.

Long-time stable adhesion is conditional on the material surface being ultra-clean and the surface energy ( $\text{mJ}/\text{m}^2$ ) of the solid material being higher than the surface tension ( $\text{mN}/\text{m}$ ) of the liquid adhesive. Plastics generally have a low surface energy of  $< 28$  to  $40 \text{ mJ}/\text{m}^2$ . But experience shows that only surface ener-

>>3: When the plasma hits a plastic surface, groups containing oxygen and nitrogen are incorporated into the mainly non-polar polymer matrix. This makes the non-polar substrate polar and so increases its surface energy (Photo: Plasmatreat GmbH)



gies above around  $42 \text{ mJ/m}^2$  offer the right conditions for adhesion, which means that the original energy state of the surface must be increased by activation. This is achieved through the chemical and physical interaction between the plasma and the substrate. When the atmospheric plasma hits a plastic surface, groups containing oxygen and nitrogen are incorporated into the mainly non-polar polymer matrix >>3. The area-selective plasma treatment renders the non-polar substrate polar at this place, thereby increasing its surface energy. Aluminum and glass have naturally polar surfaces, but this surface energy which gives them their adhesive characteristics can be compromised by layers of dust deposits, grease and oils or other contaminants. This is where the microfine cleaning action of the plasma comes into play, revealing once again the high level of surface energy already present in the substrate. Materials can be further processed immediately after cleaning and activation with AP plasma.

### Potential-free plasma

Apart from the clean and environmentally friendly nature of the process, those in charge were particularly impressed by its apparent high process reliability, accurate reproducibility and on-screen monitoring facility. Just one thing gave cause for concern. Since the electronics are pre-installed in the housing of some of the lights, any pretreatment process that conducts electrical potential could cause short-circuits, leading to the destruction of electronic components. But Openair-Plasma technology has a special feature to allay these fears: In recent years the company has developed special nozzles which discharge the electrical potential to such an extent that the plasma impinging on the material surface is virtually potential-free. So it is now possible to pretreat even highly sensitive SMD



>>4: One plasma nozzle, three materials – cleaning and activation of the PMMA plastic panel (top), microfine plasma cleaning of the aluminum housing (middle) and Openair-Plasma treatment of the safety glass panel (bottom) (Photo: Plasmatreat GmbH)

assemblies and other delicate electronic components.

### The test phase

Changing from one industrial process to a completely different one is a huge step which calls for a willingness to take risks and a great deal of patience on the part of an entrepreneur. Especially when the requirements for tight bonds are so high and when – as is the case here – the switch to the new pretreatment process is also accompanied by the introduction of a new adhesive. And furthermore, the pretreatment and bonding process was to be tested on not just one, but three different materials >>4. The housing of the surface-mounted machine lights, which are up to 1.20m meters long, are made from anodized or hard-anodized aluminum. The panels protecting the electronics are made from ceramic-coated single pane safety glass or screen-printed PMMA (polymethyl methacrylate) plastic (acrylic glass). The overall stability achieved through the combination of AP plasma and the new 1C-PUR adhesive had to be tested on these different surfaces, i.e. the bond between the adhesive and the materials and the strength of the adhesive itself.

During the 18-month test phase, they explored the uppermost limits of what an adhesive bond subsequently exposed to challenging chemical load conditions would have to endure. The microfine cleaning and activation power of the plasma was easy to demonstrate: Test ink measurements carried out before plasma treatment revealed surface tensions of < 44 mN/m for aluminum, < 36 mN/m for

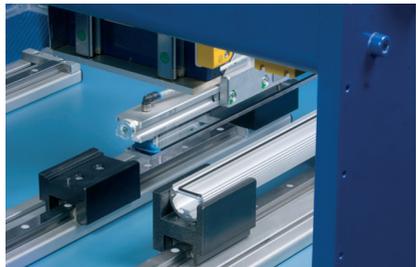
glass and 40 mN/m for plastic. After plasma activation, tension values ranging from > 56 mN/m to 72 mN/m were measured on all three substrates, which corresponds to the modified energy values (mJ/m<sup>2</sup>) of the material surfaces.

There then followed a series of tests including single-lap shear and tensile shear strength tests (DIN-EN 1465), constant humidity climate tests (DIN EN ISO 6270-2), climate cycling tests (BMW 308 KWT) and 1000-h storage of several adhesive samples at 30°C in different cooling lubricants and oils. But the critical adhesive test to confirm the long-term stability and safety of use of the adhesive bond was the caplasma test, the sole purpose of which is to destroy the entire adhesive bond. However, the accelerated ageing test simulated in the laboratory failed to achieve this objective. The plasma adhesive bond withstood even this.

### Summary: Kaizen and plasma

At the end of the eighteen-month test phase, the old primer station was dismantled, the space reconfigured and a plasma system controlled by a CNC-3-(xyz) axes portal and adjacent bonding station were installed.

In autumn 2015 the environmentally friendly process was integrated into series production. Its use has eliminated two entire process steps, and also dispensed with the need for drying times and interim storage. The plasma system equipped



>>5: Bonding the housing of surface-mounted machine lights – application of adhesive to the plasma-treated groove in the aluminum housing (top), a suction cup transports the plasma-treated glass panel to the adhesive bead (middle), the bonded housing (bottom) (Photo: Plasmatrete GmbH)



>>6: Openair-Plasma system (right) and bonding station (left) are immediately opposite one another. They were positioned in relation to the material flow to prevent any unnecessary steps, in other words they are fully integrated in the value stream. (Photo: Plasmamatreat GmbH)

with a potential-free rotary nozzle now operates continuously for eight to twelve hours a day and treats 1.000 lighting housings per week. The LED electronics in all the lights work perfectly and the high level of process reliability has been proven too. So not only has the plasma treatment created the ideal conditions for bonding, the process demonstrably improves the surface quality and long-term behavior of the adhesive bond as well >>5.

The use of Openair-Plasma technology and the associated rationalization and optimization of the pretreatment

process represents another milestone in the lighting manufacturer's process of continuous improvement. The plasma and bonding stations were positioned in relation to the material flow to prevent any unnecessary steps, in other words they are fully integrated in the value stream >>6. The climatic chamber where the bonded parts and adhesive are placed to cure is only 3m away. After a drying time of 12h, the lights are transported directly to the assembly station without any detours according to the flow principle. Change for the better – it has certainly paid off.