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Adhesive processes: Pretreatment of aluminum lights with atmospheric pressure plasma

Groundbreaking decision: Adhesion without primers

Just a few years ago, lighting manufacturer Waldmann based in Swabia in Southern Germany decided to radically change his pretreatment process prior to bonding. Instead of wet chemicals, atmospheric pressure plasma achieves the high level of adhesion required for the thousands of aluminum lighting housings produced each year.

One of the company's specialist areas is the production of industrial lighting, especially LED surface-mounted machine lighting. Since these lights are designed to illuminate machine interiors, their housings and covers are frequently exposed to high mechanical loads (e.g. flying chips) and in particular, to chemical substances such as cooling lubricants and oil (Fig. 1). None of this should compromise the tightness of these luminaires, which is why the requirements for the bonded joints of the housing are extremely high. An especially effective pretreatment of the material surface is invariably required to produce a strong, long-time stable bond.

In search of an alternative

The use of wet-chemical substances is still one of the most widely used pretreatment methods in the industry. It was no different at Waldmann. For years, an employee working in a separate pretreatment booth cleaned the adhesive surfaces by hand using a cotton cloth soaked in solvents. 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 fourth step was to remove the parts and air-dry them, then finally transport them by trolley a distance of ten meters to the bonding station.

Waldmann had been looking for an alternative to this method for a very long time. 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.

Photo: Herbert Waldmann GmbH & Co. KG

Fig. 1: Installed inside the machines, the lights have to withstand high mechanical and chemical stresses. Good pretreatment is essential to ensure that bonded joints of the housing are long-time stable.

Plasma instead of solvents

Waldmann's rethinking of the pretreatment of its luminaire housings was put into concrete terms by a seminar held by the adhesive manufacturer Rampf, which, among other topics, dealt with the environmentally friendly pretreatment of material surfaces using atmospheric pressure plasma (AD plasma).More precisely, the Openair-Plasma technology (Fig. 2) from Plasmatreat.

The process is known for its use of plasma nozzles. The environmentally friendly technology used worldwide requires only compressed air as process gas and electrical energy for the operation of the nozzles. As a result, VOC emissions (volatile organic compounds) are avoided during production from the outset. The highly effective process is used mainly on materials such as plastics, metals, glass and ceramics.

The plasma nozzles perform three operations in a single step lasting only a matter of seconds: Dry microfine cleaning, electrostatic discharging and simultaneous activation of the 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. During cleaning, the high energy level of the AP plasma fragments the structure of organic substances on the surface of the material and removes unwanted contamination even from sensitive surfaces. Furthermore, the very high outflow rate of the plasma ensures that particles loosely adhering to the surface are removed.

Surface activation means modifying a surface at molecular level in order to optimize adhesive characteristics for downstream processes such as bonding or coating, for example. Plasma nozzles are area-selective, in other words the plasma is applied with pinpoint precision only where pretreatment is required. Long-time stable adhesion is conditional on the material surface being ultraclean and the surface energy (mJm^2) of the solid material being higher than the surface tension (mN/m) of the liquid adhesive. The aim of activation is to increase the surface energy sufficiently to ensure homogenous wettability.

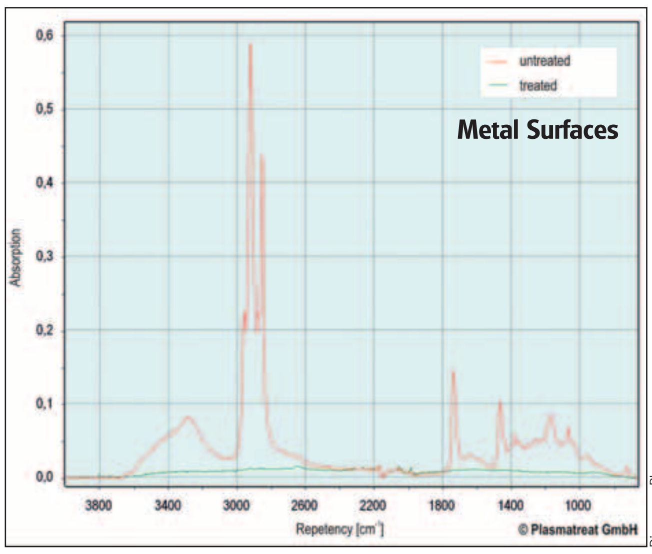

Diagram: Plasmatreat

Fig. 3: Infrared spectroscopic measurement: During the microfine cleaning of metal surfaces, Openair-Plasma removes all impurities and organic contaminants such as grease, oils and water adhering to the boundary layer.

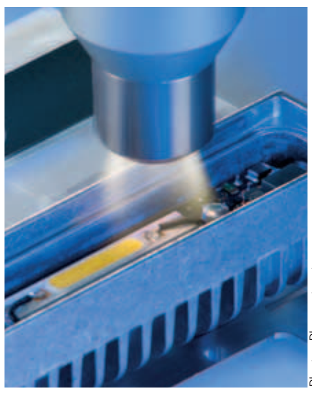

Photo: Plasmatreat

Fig. 4: Potential-free plasma pretreatment: Special rotary nozzle heads dissipate the electrical potential in the plasma, making it possible to pretreat even highly sensitive SMD assemblies and other delicate electronic components without damaging them.

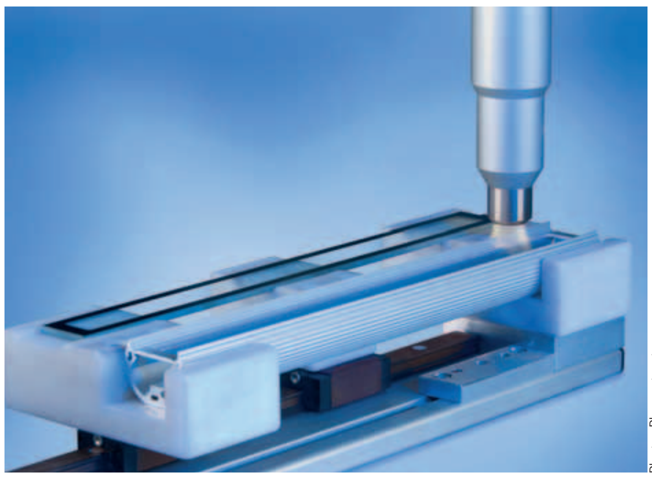

Photo: Plasmatreat

Fig. 2: Clean and environmentally friendly: Nowadays Waldmann uses Openair-Plasma instead of solvent-based primers to clean the aluminum housings of the surface-mounted LED machine lights to a microfine level and activate them before bonding.

A significant rise in the surface energy occurs during activation due to the chemical and physical interaction of the plasma with the substrate. The effect is particularly pronounced with non-polar plastics. Aluminum and glass have inherently good surface energy, but this energy which gives them their adhesive characteristics is often compromised by layers of dust deposits, grease and oils or other contaminants. This is where the high microfine cleaning action of the plasma (Fig. 3) comes into play, revealing once again the surface energy already present in the substrate. The entire pretreatment process takes only seconds and the materials can be further processed immediately after cleaning and activation.

Safe for electronic components

Waldmann was particularly impressed by the high process reliability and accurate reproducibility of the environmentally friendly plasma process, as well as its speed and efficiency. But they still had some reservations: Would the electrical potential in the plasma beam damage the sensitive LED components? Since the electronics are pre-installed in some of Waldmann's lighting housings, they feared that the electrical potential present in the plasma could cause short-circuits, leading to the destruction of electronic components. Plasmatreat confirmed that although these concerns were justified in principle, the Openair-Plasma technology had a special feature: In recent years the company had developed special nozzle heads which discharged the electrical potential to such an extent that the plasma impinging on the material surface was virtually potential-free. This now made it possible to pretreat even highly sensitive SMD assemblies and other delicate electronic components (Fig. 4). Suitably reassured, Waldmann decided to implement the technology immediately.

Trial phase on three materials

Changing from one industrial process to a completely different one is a huge step which calls for a great deal of patience. 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 if that were not enough, the pretreatment and bonding process was to be tested on not just one, but three different materials. The housings of the surface-mounted machine lights, which are up to 1.2 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, or acrylic glass as it is also known. The overall stability achieved through the combination of AP plasma and the new adhesive had to be tested on these different surfaces, i.e. the adhesion of the adhesive to the materials and the stability of the adhesive itself.

During the 18-month test phase, Waldmann 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 dyne for aluminum, ‹ 36 dyne for glass and 40 dyne for plastic. After plasma activation, values ranging from › 56 dyne to 72 dyne were measured on all three substrates, which corresponds to the modified energy values 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-hour storage of several adhesive samples at 30°C in different cooling lubricants and oils. But the all-important adhesive test to confirm the long-term stability and safety of use of the adhesive bond was the cataplasma test, the sole purpose of which is to destroy an adhesive bond. The plasma-pretreated adhesive bond withstood even this test.

Integrated into the process chain

The plasma technology was integrated into series production in autumn 2015. This new pretreatment process has eliminated two entire process steps, and also dispensed with the need for drying times and interim storage. Equipped with a potential-free rotary nozzle and controlled by a CNC-3-(xyz) axes portal, the plasma system now operates for eight to twelve hours a day in a continuous process and treats 1000 lighting housings per week. Bonding now takes place immediately after pretreatment in a new bonding station situated directly opposite the plasma system (Fig. 5). The LED electronics in all the lights function perfectly and the high level of process reliability has long since been proven too. According to Waldmann, 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.

Autor: Inès A. Melamies, specialized journalist, Facts4You.de press agency

i www.plasmatreat.de
www.waldmann.com

Photo: Plasmatreat

Fig. 5: *Advanced restructuring: Plasma system and bonding station facing one another. The components can be bonded and further processed immediately after pretreatment.*