Technical Synopsis of Plasma Surface Treatments

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Abstract

Surface treatment technology delves into some of the most advanced equipment in the packaging industry. This will explore into the cutting-edge methods of plasma treatment used to create the best polymer surface for inks, paints, and coatings to adhere to. The types of tests used to measure the degree of surface adhesion will also be explored however; the main focus will be on different types of plasma treatments as well as the most effective applications.

Introduction

Plasma surface treatment is a process that raises the surface energy of many materials so as to improve the bonding characteristics. One form of plasma treatment is also commonly known as a corona treatment, which was invented by Danish engineer Verner Eisby in the 1950s. In many cases this process is the standard treatment for materials such as: plastic polymers, papers, films, glass, and even metals.

Plasma technology is inclusive of many different purposes for surface treatment such as: cleaning, coating, printing, painting, and adhesive bonding. Plasma technology has come to encompass so many different applications that it is now one of the top methods in surface treatment, especially in industries which rely heavily on packaging. There are numerous industrial and packaging solutions created all the time due to the wide versatility in which plasma treatments can be applied. This technology is even heavily used in the automobile and aircraft industries. Plasma treatment also yields very high quality products in basically every applicable field while still being an environmentally friendly process. There is no doubt that plasma treatment is one of the top contenders in surface treatment methods, but which form of plasma treatment is the best? Some of the types, benefits, and shortcomings of different forms of plasma treatment will be explored to determine if any particular treatment types pose significant benefits in comparison to the others.

Background

Plasma is a fairly simple concept which refers to the fourth chemical state of matter. When enough energy is added to each state it changes in sequence from solid to liquid and from liquid to gas. Once in the gas phase if additional energy is forced into the system, then the gas becomes ionized and reaches the plasma state. When the plasma comes into contact with the material surface it transfers the additional energy from the plasma to allow for subsequent reactions to take place on the material surface. The altered surface properties on most materials are ideal for printing, painting, or adhesive bonding; which are used in some form in almost every industry whether plasma treatment is used or not.

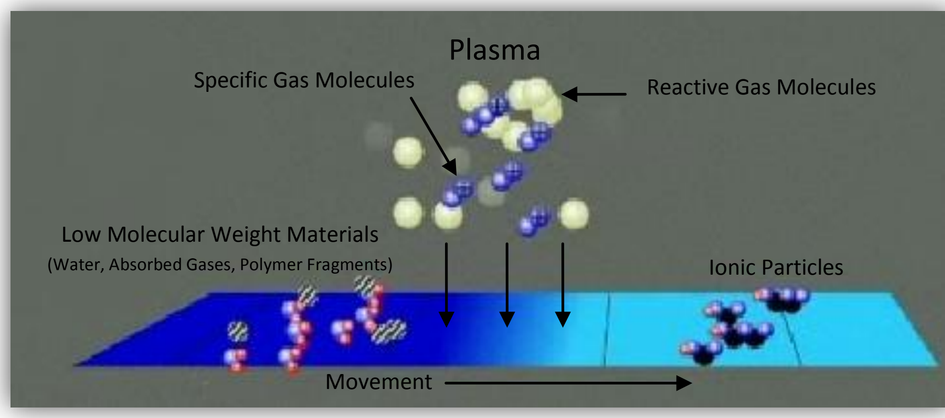

Figure 1 - Surface chemical structure when exposed to plasma

Surface Tension

Every surface has a specific surface tension varying greatly depending on the material. Furthermore; each ink, paint, and adhesive has its own unique properties which greatly affect its surface tension on different materials. The surface tension is increased by pre-treating with plasma to reach an optimum surface tension in which the ink or adhesive will bond. Figure 2 below indicates some of the

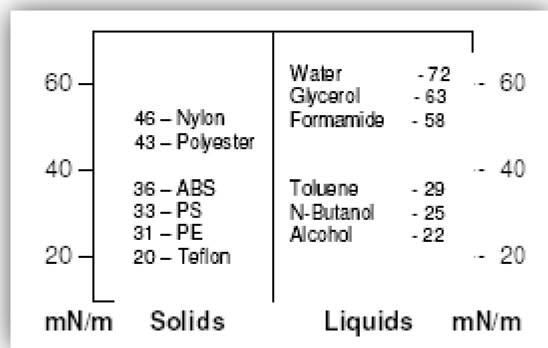

Figure 2 - Surface Energy of Solid Materials vs. Surface Tension of Liquids

There are ink kits used to measure the surface tension of a material, and each pen has a different wettability rating. The dyne is the unit of force equal to the force that imparts an acceleration of 1cm/sec/sec to a mass of 1 gram. 1 dyne (mN/m) = 0.00001 Newtons, or = $1gm/sec^2$, or 1 Newton = 100,000 dynes (8). Through utilization of these techniques the higher the rating yields a greater surface wettability.

Figure 3 - Dyne Test Inks (7)

In general plastics have fairly low surface tensions (less than 28 mN/m). The surface tensions of plastics, metals, and glass can be measured to find the wettability easily by using test inks. There are a variety of different inks used to print on materials which require different tension levels to maintain adhesion. Solvent-based inks require greater than 40 mN/m, UV-drying requires over 56 mN/m, and water-based ink requires a surface tension greater than 72 mN/m (1). Wettability is dependent upon the surface energy of the substrate or material. In order to obtain a decent wettability it is recommended that the surface energy of the substrate exceeds the surface tension by 10 mN/m (8). The wettability is also affected by the angle between the tangent line at the contact point and the horizontal line of the substrate surface.

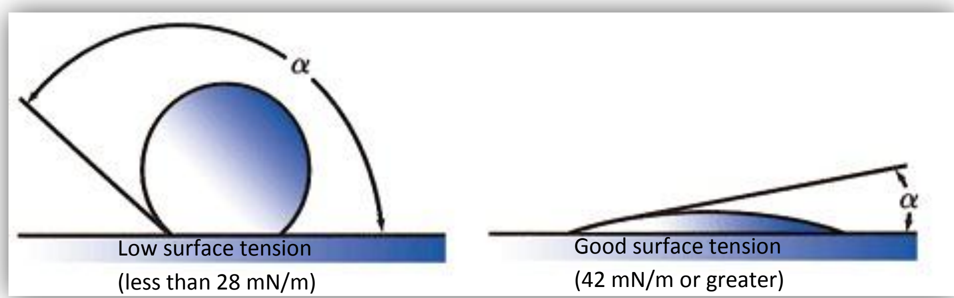

Figure 4 - Surface Tension for Adhesion (5)

Another practice commonly used to assess plasma surface treatment is a wetting angle test using a contact goniometer. Table 1 below shows how most angles typically vary between 60-100 degrees prior to treatment which are drastically reduced after undergoing an oxygen plasma surface treatment.

Hydrocarbons	Before	After
Polypropylene	87°	22°
Polyethylene	87°	22°
Polyamide (nylon)	73°	15°
Polyimide	79°	10°
Polycarbonate	75°	33°

Table 1 - Typical Wetting Angles Before and After Oxygen Plasma Surface Treatment (4)

Pretreatment

The pretreatment process consists of three segments: cleaning, activation, and surface bonding. These steps are an extremely important part of plasma treatment because it directly affects the quality of the surface in which ink or adhesive will later be applied. Cleaning the substrate surface can be done using a plasma system to remove even the finest particles of dust. The plasma actually consumes many of the particles through the surface reaction and completely removes them from the environment. No mechanical damage is done to the surface when this process is done with a dry plasma treatment, which also emits no harmful waste and is therefore an environmentally friendly process.

Plastics are made of long polymer chains which have a non-polar surface and are fairly difficult to bond and coat. When the surface is activated the plasma actually changes the chemical structure and polarity of the substrate. When properly activated with plasma plastics as well as many other materials have improved adhesive properties, increased surface wettability, and in many cases improved durability of adhesive joints.

The bond strength is in many cases the final step through the plasma treatment process. It is very important when applying adhesive that the surface has been thoroughly cleaned and activated so the adhesive can perform at its optimum level. Once the bond is made it is permanent and does not degrade over time. There are an increasing number of industrial applications of this treatment process used on plastics, glass, metal, fabrics, and films. Each individual process utilizes a different combination of cleaning, activating, and bonding steps where different plasma systems have been developed and tailored to each application.

Machinery

The most important components of the plasma system are the plasma jets and generators (6). Plasma is generated through a high-voltage discharge from within the jet. In blown ion systems, oxygen and sometimes other gases such as nitrogen are typically directed through the discharge which detaches part of the plasma and forces it through the diaphragm to the material being treated (6). The diaphragm also limits what is released; mainly any part of the plasma stream containing a charge, which is vital to the process of properly treating a surface.

Depending on the surface being treated, a normal/small plasma beam has a typical treatment width around 25mm and can treat at speeds of 6-600 mm/minute. There are also rotary systems available which consist of numerous plasma jets rotating at extremely high speeds to treat large areas. These systems if properly tuned can treat surfaces up to 2,000mm wide in a single pass.

Figure 5 – Industrial Rotary Plasma Treatment

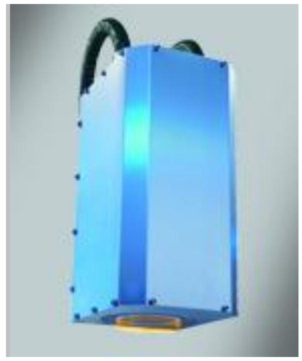

Figure 6 - Plasma Jet for Large Treatment Widths

Figure 7 - Open-air Plasma Jet for Various Applications (6)

Some of the basic forms of plasma treatment systems include: atmospheric/air plasma (dry), flame plasma, and atmospheric chemical plasma. There are various companies which offer numerous in-line solutions that can be custom tailored to almost any application from automobile headlight housings and windshields to reducing the glare on instrument panels in aircrafts.

Air plasma systems utilize either blown ion or blown arc technology. The main difference between these two is that the blown ion method is effective with both conductive and non-conductive surfaces (10). The chemical interaction of oxygen based plasma systems also create strong covalent carbon-oxygen bonds which are of greater polarity than the initial carbon-hydrogen bonds (9).

Blown ion systems are one of the most commonly used plasma treatment methods. The discharge occurs inside of the chamber making this method different from most other forms of plasma treatment. Pressurized air is forced past a single electrode inside of the chamber; electrons then become excited and create positively charged ions. The pressurized air forces these positively charged ions out of the tip and onto the surface of the substrate. The new positively charged surface is now much more receptive to inks and adhesives (10).

Similar to the blown ion, the blown arc system forces air past two high-voltage electrodes positively charging ion particles (10). This has a much larger surface area than the blown ion method, but operates using the same basic concept. The Dyne-A-Mite HP produced by Enercon is a form of blown arc treatment. The specifications claim that it is capable of treating polyethylene, polypropylene, polyethylene terephthalate, nylon, vinyl, polystyrene, polycarbonate, polyvinyl chloride, and all other types of thermoformed plastics (13). Figure 8 shows a wide variety of applications suitable for blown arc treatment.

Figure 8 - Air Plasma Treatment Applications (13)

Flame plasma systems combine compressed air and a flammable gas which is combusted to create a large blue flame. The material surface only has to be exposed to the flame for a brief period of time to become polarized through oxidation. This process also leaves behind other chemicals on the surface that allow for a greater surface adhesion in comparison to an air plasma treatment. The only setback is the heat level required for this treatment. It is typically used to treat injection and blow-molded products because in most cases their thickness can withstand the heat (11). Figure 9 below depicts some more of the typical flame plasma treatment applications.

Figure 9 - Flame Plasma Treatment Applications (13)

Atmospheric chemical plasma treatment systems are able to treat materials which would previously be deemed untreatable. This method is considered a phenomenal breakthrough simply because it is ideal for virtually any surface despite how rough or delicate it may be. The plasma used is formed similarly to that of both the air plasma and flame plasma treatment methods, but at low temperatures. Oxygen and acetylene reactive gases are introduced to an electrically charged atmosphere with a proprietary electrode, which produces a high density glow discharge. The resulting plasma sends a bombardment of ions and electrons to the surface of the material. Low molecular weight materials such as water vapor, carbon dioxide, and other non-toxic gases are removed to expose a fresh new surface. While these contaminants are being removed a fraction of the reactive components in the plasma and chemicals create a chemically altered surface by depositing polar functional groups ready for adhesion. Utilization of an atmospheric chemical plasma treatment creates a better surface tension than air plasma systems, but similar in quality to that of a flame plasma treatment.

Conclusion

There are numerous applications in almost any industry where some form of plasma treatment can be of benefit. Almost all international automotive manufacturers have used plasma treatments for bonding headlight housings, seats, and even windshields since 1995 (15). Modern aircraft construction even utilizes plasma treatment before any paint is applied to ensure it is of the highest quality. Not to mention all of the instrument displays have a plasma coating to prevent reflection (15).

All of the different plasma treatment systems have their specific benefits. Air plasma can treat most types of plastics as well as some other materials with few limitations. Flame plasma is a fast process due to the high temperatures; however it cannot treat as wide a variety of materials for the same reason. Atmospheric chemical plasma is an incredible break-through because it removes any previous limitations created by previous methods of surface treatment.

Within the packaging industry treatments have to be homogenous and consistent in every way imaginable. Plasma facilitates a method of surface treatment so advanced that it does not matter whether the process is to print on a glass bottle, a plastic grocery bag, or the side of an airplane. Plasma technology has enabled us to create an optimum surface anywhere.

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