Abstract

Corona and flame treatment are a well established methods to improve adhesion on film, foil and paperboard. For a given adhesion problem the question arises: Which method is best suited? This mainly depends on the material and the application process. Considering treatment effects as well as economical aspects flame treatment may be more convincing than Corona treatment applying high web speeds and large web widths. Latest developments include flaming with silane precursors.

Introduction

For decorating the surface with a paint, lacquer, glue or coating a good adhesion between surface and decorating fluid is necessary. Surface treatment is performed to increase the adhesion properties of surfaces. Among other methods physical treatment methods like corona, plasma or flame treatment are wide-spread. The advantages of these compact treatment units are that they can easily be integrated in the production line providing good treatment results even at high working speeds and that they do not produce any significant waste.

Which method is best-suited depends on the form of the part to be treated. Moulded parts are a domain for flame treatment. Small moulded parts or small working width are treated by atmospheric plasma devices. Corona treatment is mainly used for even surfaces like films and foils. In the following both methodes are described and compared to each other.

Treatment of films and foils

A typical Corona treater device for web material consists of a roller which is connected to electrical earth and an arrangement of electrodes around the roller at which the high voltage is applied. Electrical power needed and the shape and number of electrodes depend on the web material and web speed.

For single sided treatment there are three classical arrangements commonly used (fig.1,2):

- bare electrodes and insulated roller for non-conductive substrates. This system is the most effective Corona discharge system. It should be used whenever it is clear that only non-conductive films are to be treated.

Fig.2: Principle of Corona treatment of films
- electrodes insulated by ceramic and a bare roller. To avoid short circuits the electrodes have to be insulated e.g. by putting a conductive tube into a ceramic tube. This arrangement also allows the treatment of non-conductive substrates. So this device can be considered as a good "allround solution".
- insulated electrodes and insulated rollers for sensitive substrates e.g. foam. With this combination a very even and homogenous discharge is created which helps to avoid perforation (pin-holes) due to disruptive discharges. But on the other hand it is the most ineffective treatment system and should only be used if absolutely necessary.

It should be mentioned that, in many cases, you could not completely prevent a slight treatment of the back side of the substrates with this arrangement which is in some cases causes problems.

There is a number of applications, in which a double-sided treatment of the web is necessary. The best method to achieve this is an arrangement of two discharge units (fig.3). Such a system works very well but takes a lot of space to fit it onto a machine and often needs two Corona generators and high voltage transformators for operation. An alternative for double-sided treatment is the use of a contoured roller (fig.4).

If different web widths are processed in the same web machine an adjustment of the width of the discharge is possible when special robe electrodes are used.
Principle of flame treatment

For flame treatment of web material the typical arrangement consists of a burner which flames onto the web guided by a cooling roll. Besides web guiding near the flame the roller has the task to hold a defined distance between web and flame and to remove excess heat out of the system. For large web width the burners should be cooled, too. A housing built around the flame unit may be useful for removing the exhaust gas arising during the flaming (fig.5).

Besides cooling drum and exhauster the flame treating unit consists of an air/gas controller and special burners. The controller together with a special mixing chamber provides the air/gas mixture by controlling the air flow and the gas flow. A rather exact and fast measure of flow rates can be carried out by mass flow meters. These devices measure the mass flow instead of the volumetric flow which is independent on temperature and gas pressure.

The burners are connected to the controller unit by special gas hoses or pipes. Due to a special design the burners create a homogeneous flame even at large working widths up to several meters in length. To avoid heating up burners should be cooled. On the other hand the temperature of the cooling water should not be too low to prevent the formation of condensed water. So it is advisable to use a cooling/heating unit for the burners and the cooling drum.

Like Corona treatment, different flame widths due to processing of different web widths can be adjusted according to actual web width manually by an bare or automatically.

Results

In the following some treatment results obtained by flaming are discussed. The treatment effect can be measured by an increase in surface tension (surface energy) or wettability in case of polymer surfaces. For preliminary tests of the treatment effect it is suitable to use the test inks. These are fluids with known surface tensions. Dependent on the behaviour of a drop on the surface the surface tension can be estimated very quickly close to production. If the fluid which may be applied to the surface with a brush or a felt pen forms drops on the surface, surface tension of the ink is higher than that of the surface. On the other hand, if the ink spreads on the surface, surface tension is higher than the surface tension of the ink.
Best information on adhesion can be gained by performing an adhesion test. In any case this should be done for finally assessing the treatment result for all applications. High surface tension is necessary for a good contact between the surface and the coating material. But surface tension cannot guarantee a good chemical (or any other kind of) link between coating and surface. Both coating and surface material have to be matched with each other. If this has been done surface tension ensures good adhesion properties in most cases.

In fig. 7-8 you see the dependence of the surface tension on the flaming parameters. Varying the air/gas ratio (fig.7) the typical bell-shaped curve is obtained. Increasing air/gas ratio the treatment effect increases up to a maximum and drops when air/gas ratio is increased further (“over-treatment”). In principle the same behaviour occurs when increasing the heat power of the burner (fig.8).

![Surface tension for different mixing ratios](image1)

**Fig. 7: Dependence of the surface tension from air/gas mixing ratio**

![Treatment of PP-film](image2)

**Fig.8: Dependence of the treatment effect from the heat power of the burner in case of pp-film. Surface tension without treatment is 28 mN/m.**

The long-term behaviour of the treatment effect is shown in fig. 9. After some time depending on the material the treatment effect decreases. This can happen between several minutes and several month. Therefore it is best to do the treatment just before lamination, printing…In case of Aluminium foil the treatment effect keeps a high level up to several days at least.
Another application of flame treatment is the lamination of paperboards with a PE-film. Flaming of the paperboard is necessary for a good adhesion of the PE film. At low web speed low power is enough for good adhesion. Increasing the web speed more power is needed to get good adhesion as shown in fig. 10.

For an ideal flame treatment the flaming parameters should be adjusted properly to get good adhesion and to save energy. The ideal parameters have to be found out by trials. With best parameters a good adhesion together with a savings in energy consumption (gas consumption) can be achieved. A web speed-dependent power control flaming enables a start of the flaming at lower web speed thus reducing untreated web material.

Silicoating

Further improvements on adhesion may be achieved by the new silicoating technique. A silane precursor is mixed into the flame. The silane burns to silicate which is deposited on the surface forming a thin invisible silicate layer on the surface to be treated. The amorphous structured layers have thicknesses of about 20 nm. By the silicate layer the surface tension and the adhesion properties are improved. Specific requirements on adhesion can be fulfilled such as stability against moisture, protection against corrosion, diffusion barrier. Long time stability of the surface activation is improved.

Like conventional flaming the silane containing flame has be passed over the surface to be treated within the active region of the flame. Preliminary investigations of the treatment effect can be done by measuring the increase in surface tension with the test inks. Adhesion tests give more precise results.

Fig. 9: Longtime stability of the treatment effect on Al-foil with various thicknesses. Surface tension before treatment is 32mN/m.

Fig. 10: Adhesion of a paperboard-polymer composite. The drawing shows the dependence of the burner’s heat power from the working speed.
The silicoating method is used for dental applications since more than ten years. Up to now only small parts have been coated. Latest developments in burner technology and silane dosages made it possible to expand the applications to higher working width and working speeds. Systems with working widths up to one meter and more are available.

The silicoating flame treating device consists of a conventional flame treating system supplemented with a silane dosage. The silane dosage which evaporates the silane fluid is connected to the flame treater via a pipe. Typically the silane consumption is below 1% of the air consumption. Though, in principle, it is possible to use standard burners, special silane burners with special air/gas flow characteristic should be used to reduce the probability of burner contamination. Flame colour of the cover flame is changed from dark blue to slightly red colour which can be used for an optical proof of the presence of silane in the flame.

Applications of the silicoating method is conceivable in the area of film and foil treatment. Metal foils like copper, aluminium or steel could be coated for protection against corrosion as well as for improving adhesion. In case of copper the silicoated copper surface is protected against oxidation which could be demonstrated easily by flaming different parts of the surface with and without silane. The silicoated parts do not change colour at temperatures around 300 °C while the non-silicoated parts change colour to black indicating an oxidation of the surface. This effect can also be used for proofing the silicoating.

**Comparision between Corona and flame**

Now the question arise : Which method is best suitable for a given substrate? This question cannot be answered commonly. It strongly depends not only on the kind of substrate but also on the conditions of production (application, requirement on adhesion, substrate handling, speed of the production line and so on.).Therefore the best method should be determined by trials in the application technology.

From our experience we could say that the domain of Corona treatments are substrate with flat surfaces like films, foils, or thin sheets where a simple configuration of electrode and counterelectrode is possible. Also rotationally symmetrical parts like cups and tubes can be treated by Corona treatment.

Due to its larger working depth flame treatment is used for strongly structured moulded parts. For large web widths and web speed flame treatment could be an alternative to Corona treatment concerning treatment effects as well as economical aspects. If only one-side treatment is required, flame treatment should be applied. Furthermore flame treatment avoids the formation of "pin-holes" which may occur during Corona treatment owing to disruptive discharges. Often flame treated substrates show a better long-term behaviour of the treatment.

**Conclusion**

Corona- and flame treatments are well-established method for increasing surface tension and adhesion properties of moulded plastics as well as film, foil and paperboard. Further developments in technique and a better understanding of the processes ensure product quality and demands in future. The question which method is best suited for a given adhesion problem cannot be answered commonly. It has to be found out by trials as the composition of the base substrate e.g by additives in case of plastics. Silane precursors dosed into the flame may lead to further improvements of adhesion. In principle other precursors are conceivable creating layers with custom-designed properties.