

# Pre-treatment by means of plasma at atmospheric pressure

by Dr. Uwe Lommatsch, IFAM Bremen

**It has recently become possible to use plasma processes at atmospheric pressure for activating materials. In doing this high bonding strengths and surface energies are achieved. At the same time it is possible to run the process continuously.**

Pre-treatment is generally necessary for bonding and painting polymers and metals. In the last few years plasma processes operating at atmospheric pressure (AP) have been added to the list of physical pre-treatment methods used for this purpose. The individual processes differ from one another essentially in the way the plasma is generated (discharge characteristics) and the different surface modifications associated with this. In contrast with the corona technique, which is also essentially a



Figure 1: Plasma jet assembly

plasma process, these new processes produce a more homogeneous and more intensive treatment.

## Plasma from a jet

For AP plasma pre-treatment a system from the company PlasmaTreat<sup>®</sup> GmbH (Openair<sup>®</sup> Plasma) is employed. This system generates the plasma inside a jet by means of specially designed electrodes. Dry, oil-free compressed air, for example, can be used as the process gas. The beam of plasma is then ejected through the jet opening onto the material to be treated (see Fig 1). When this happens substrates can be moved at speeds of up to 400 m/min by the plasma flame. Due to the special design of the jet the actual treatment space on the surface

of the substrate remains almost free of electric potential. As a result it is possible without difficulty to activate not only plastics but also metals or recycled polymeric materials containing metal. Chemical and physical interactions of the plasma with the substrate cause activation of the surface. The pre-treatment method can be applied to workpieces of any shape. It can be readily integrated into in-line processes, can be carried out by robots and imposes only slight demands on industrial safety.

## Surface tension and bonding strength

The pre-treatment effects brought about by the AP plasma were investigated on the nonpolar plastics PP and HDPE, on the polar plastics PET and PA12 as well as on the aluminium alloy AlMgSi1. Prior to activation the materials were cleaned for 30 s in isopropanol in an ultrasonic bath. The specimens were then activated with the aid of

the AP plasma. In all of the materials a dramatic increase in surface tension was found, values ranging up to 60 mN/m (see Fig 2). The increase in surface tension facilitates wetting by adhesives and is sufficient for printing onto or colouring the corresponding materials. The low surface tension of untreated aluminium arises from contamination of the surface during production. Thus, treatment with AP plasma also cleans the surface of the metal as revealed by the increase in surface tension.

The improvement in bonding strength was investigated by bonding the test specimens in the activated as well as in the untreated state. In doing this the five materials identified above and a two-pack polyurethane adhesive (two-pack epoxide adhesive for aluminium) were used. The bonding strength was determined in accordance with DIN EN 1465 (tensile shear test). By comparison with the untreated test pieces, after activation a marked

increase in bonding strength is observed in all cases (see Fig 3). This is associated with a change in fracture behaviour. In the case of the untreated specimens the failure to bond is caused by the poor adhesion of the adhesive to the surface of the substrate (adhesion failure). In the case of the activated test specimens, however, cohesion failure or joined part failure is observed. Thus, due to activation, bonding strengths in the region of the structural strength of the joined part or of the adhesive are attained. Accordingly, the adhesion between the adhesive and the joined part is no longer the strength-limiting factor in bonding. This is the highest result that a pre-treatment process can possibly achieve.

### Practical aspects

Activation can be adjusted selectively by means of a series of treatment parameters. These parameters include in particular:

- the duration of treatment (typically between 1 and 1000 ms);
- the spacing of the substrate and the plasma jet (typically between 3 and 20 mm);
- the plasma parameters: type of gas, gas flow rate and excitation voltage.

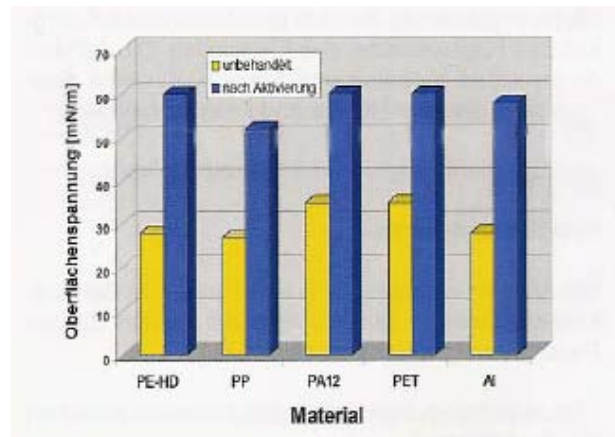


Figure 2: **Surface tension**  
Vertical axis: Surface tension [mN/m]  
Horizontal axis: Material  
Legend: Untreated (yellow)  
After activation (blue)

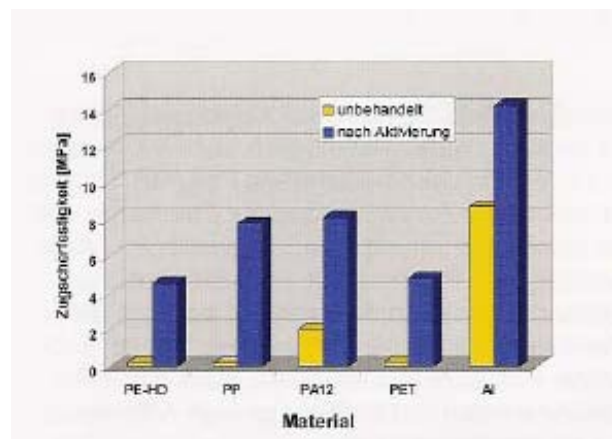


Figure 3: **Bonding strength**  
Vertical axis: Tensile shear strength [MPa]  
Horizontal axis: Material  
Legend: Untreated (yellow)  
After activation (blue)

Figure 4 shows the effect of the treatment spacing on the resultant activation with reference to the example of HDPE. For this purpose test pieces made of HDPE were activated at different spacings with respect to the plasma jet and then bonded. Reducing the treatment spacing results in an increase in bonding strength. Thus, by appropriate choice of spacing a desired degree of activation can be set. At even smaller spacings a visual modification of the substrate occurs (brown colour) and the bonding strength is not further improved or even deteriorates

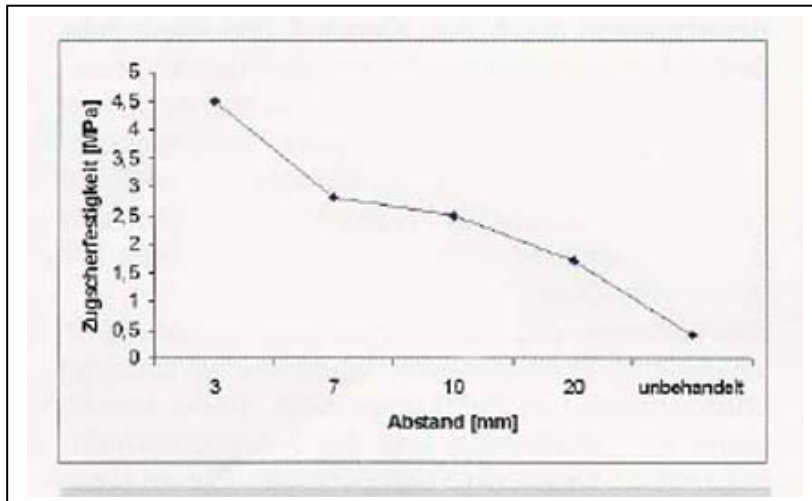


Figure 4: **Variation of spacing**  
 Vertical axis: Tensile shear strength [MPa]  
 Horizontal axis: Spacing [mm] (untreated)

the bonding strength is not further improved or even deteriorates (overactivation). Apart from the spacing, the duration of treatment in particular also has a great effect on the resultant activation. In comparison the other parameters are less important. Due to the different properties of the materials the sets of parameters are specific to each material. Thus, they need to be determined afresh each time a different material is used.

### Activation mechanism

The cause of activation by the AP plasma is to be found in the modification of the surface of the substrate. When this happens the reactive constituents of the plasma essentially cause the incorporation of oxygen in the surface. This results in the formation of different functional groups containing oxygen, e.g. acid, keto and alcohol groups. In some cases an increase in the oxygen concentration close to the surface of up to 30 at% is observed. Due to the thermal component of the plasma a change in surface topology also occurs. In the case of PET the change in appearance of the surface is shown by the complete loss of the initial structures. This behaviour depends, however, on the initial roughness of the surface of the substrate. The positive effect of this change in topology is presumably based essentially on the formation of a uniform surface, but one with roughness in the nanometer range.

Both effects, the chemical as well as the topological modification, are the cause of the good activating action of the AP plasma on plastics and metals.

*Dr. Uwe Lommatzsch [sic] is a staff member of the Fraunhofer Institut für Fertigungstechnik und Angewandte Materialforschung IFAM (Institute of Production Technology and Applied Materials Research) in Bremen. As part of his activities there Dr. Lommatzsch works with an atmospheric plasma system manufactured by the company Plasmatreat.*

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