Modifying thermoplastic polyolefin surfaces by gas-phase methods – relevance to adhesion for waterborne coatings in automotive applications

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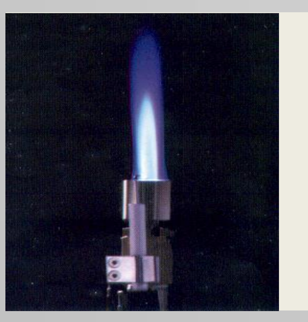
Motivation

Thermoplastic polyolefins (TPO) are widely used in the automotive industry for the manufacturing of bumpers. For esthetic and protective reasons, the decorative painting of bumpers is desirable. The low surface free energy and the lack of polar functional groups of these materials are the reasons for their poor paintability. Effective surface modification techniques are, therefore, needed to improve the adhesion properties of TPO.

It was the *aim of this work* to compare the modification effects of three gas-phase methods (flame, plasma jet treatment, gas phase fluorination), especially with regard to a better understanding of the interplay between chemical composition, surface energetic properties and surface morphology of the pretreated TPO on the one hand and the adhesion of waterborne coating systems on the other hand.

Methods and Materials



Flame treatment

air/ propane (22:1); variation of exposure time, burner capacity, and flame distance

additionally: flame treatments under industrial conditions in a paint line for plastic parts

Plasma jet treatment

static and rotating nozzles; variation of nozzle distance and exposure time

Gas phase fluorination

tunnel machine using a gas mixture of F_2/ N_2/ O_2 (oxyfluorination); batch process using a mixture of F_2/ N_2; variation of fluorine concentration and time of exposure

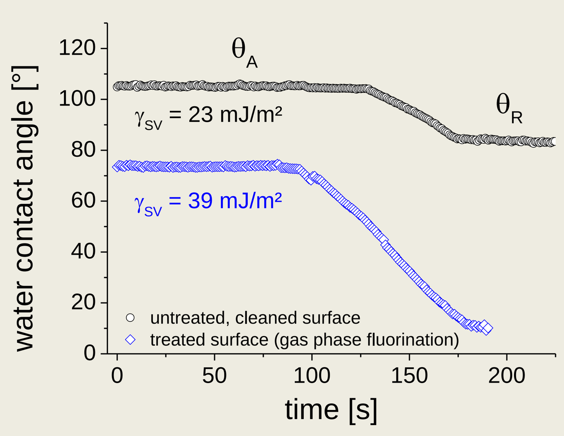
Materials

TPO: commercially available from Basell, Total, Borealis, Sabic; blends: polypropylene (PP), ethylene propylene diene monomer rubber (EPDM), additives, talc (10%, 20%, 30%)

Automotive coating system: 2K hydroprimer (15-25 µm), metallic base coat (10-14 µm), 2K clear coat (25-35 µm) provided by Wörwag

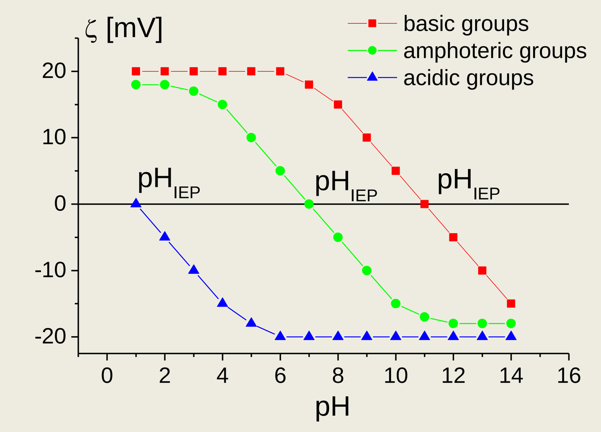
Complementary surface characterization techniques

Contact angle



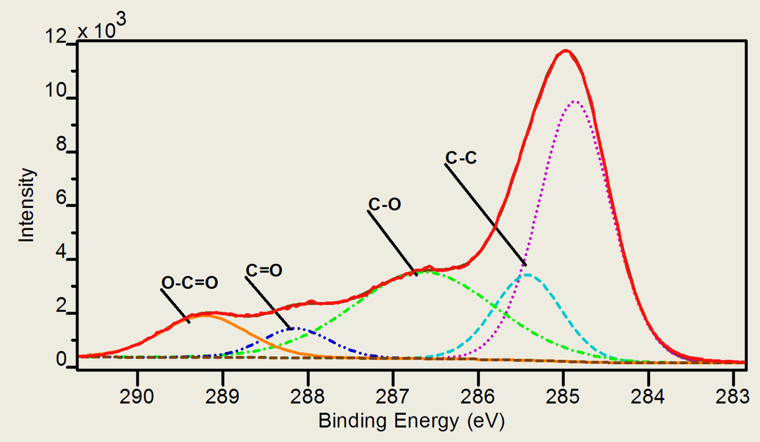
Surface free energy

Zeta potential



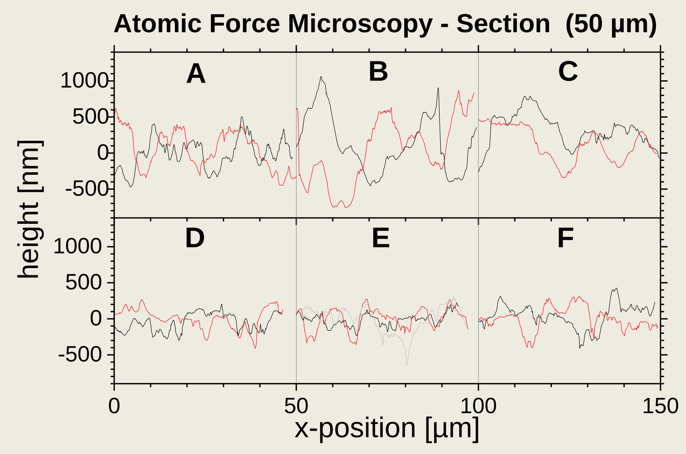
Acid-base characteristics

XPS

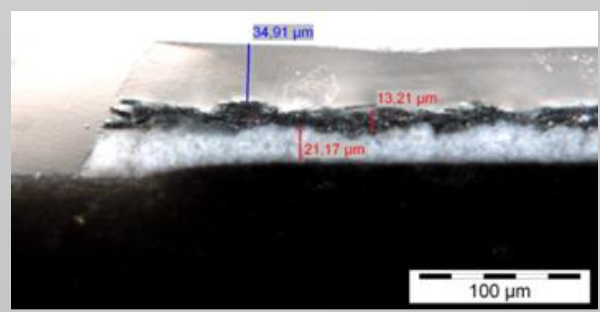


XPS high-resolution spectra of the C1s peak after plasma jet pretreatment

AFM, confocal light microscopy



Section analysis of different TPO-materials

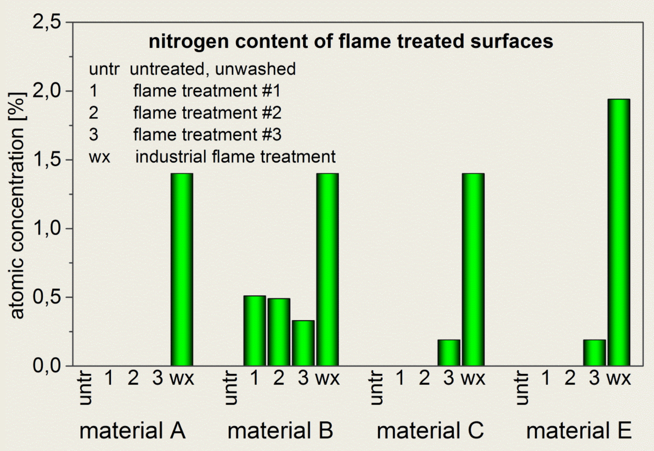


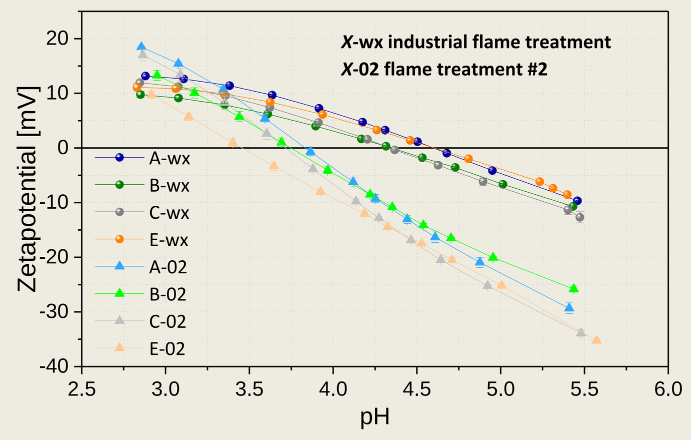
Estimation of paint adhesion

Vapor jet test (DIN 55662): after conditioning (7 day at 23°C and 50% rel. humidity) and after TWT test (3 cycles each with 15h, 105°C, 30 min RT, 8h -40°C, 30 min RT); coated test panels contained a cross-cut, adhesion level was assessed by a number between 0 and 5

Comparison of modification effects

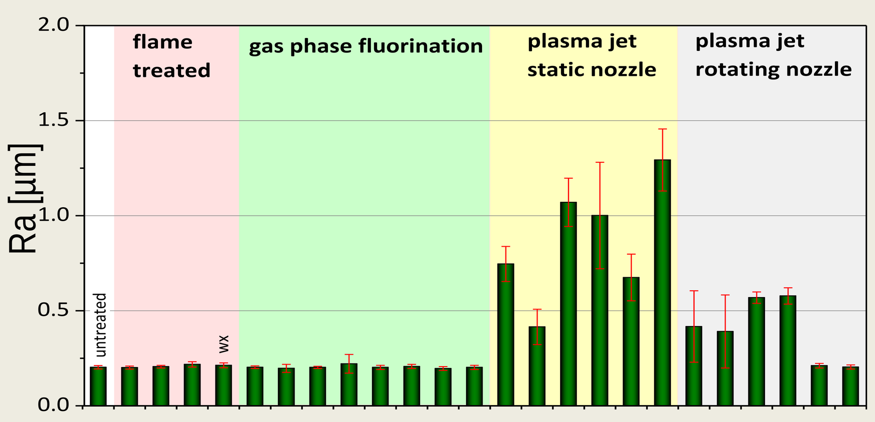
Effect of different flame procedures



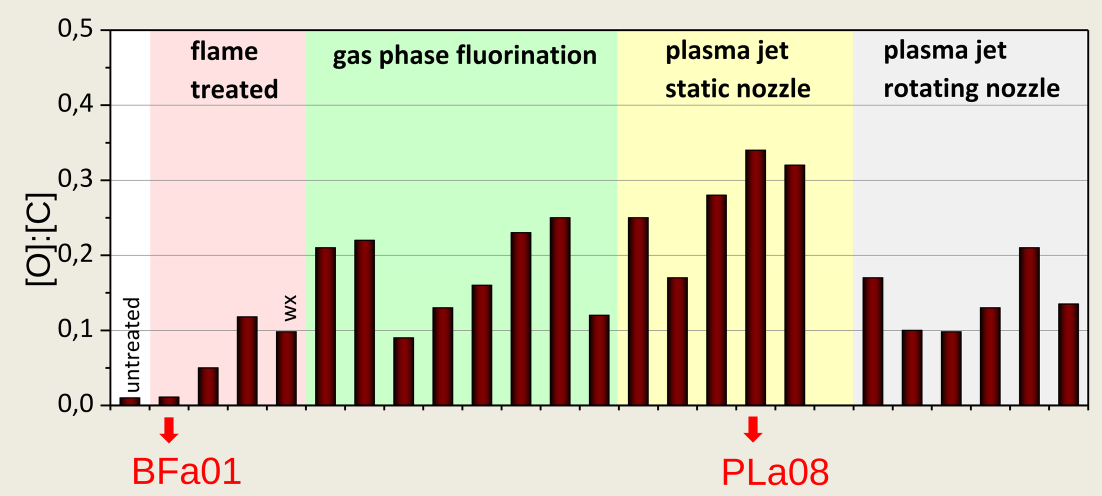


TPO surfaces treated in a paint line contained higher amounts of nitrogen resulting in a change of the acid-base properties

Effect of different gas-phase methods



Plasma jet treatment: surface roughness and heterogeneity were dramatically increased depending on the treatment parameters

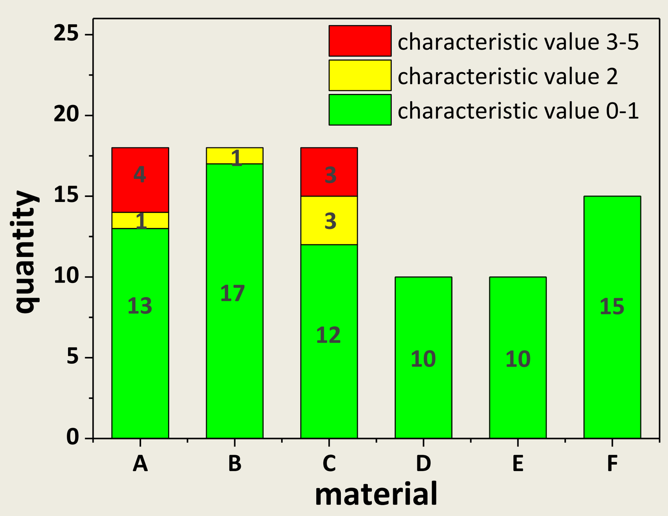


High fluctuations in the oxygen content of the outermost surface region

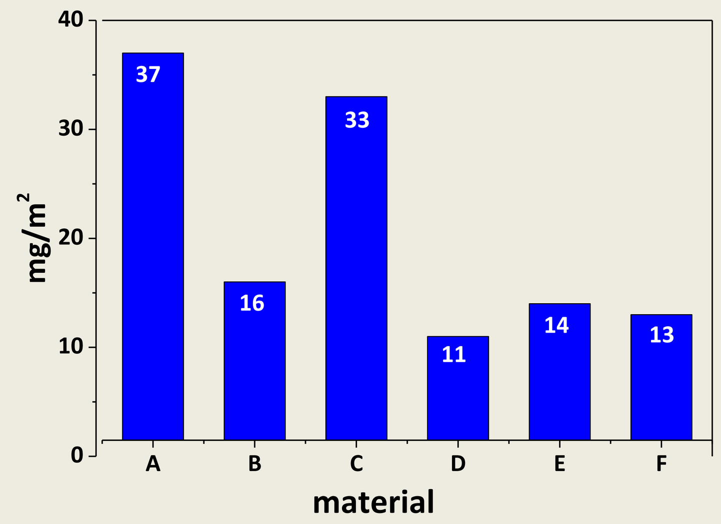
Relation between oxygen content and adhesion ?

Impact on paint adhesion

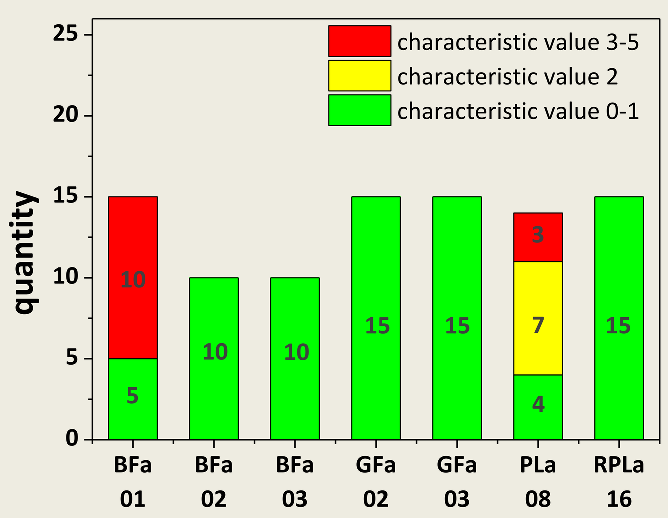
Adhesion of a waterborne paint system on pretreated materials



TPO materials A and C: destruction of the lacquer layer

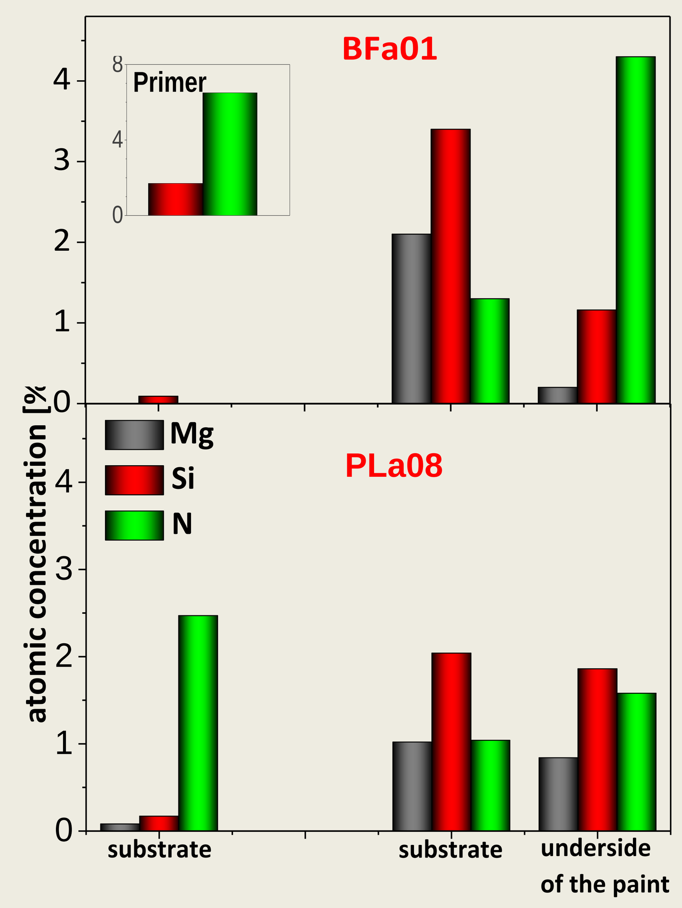


Insufficient adhesion of the paint correlates with higher amounts of soluble additives in the surface region of the different types of TPO materials



For the lowest and the highest oxygen content in the surface region of TPO, adhesion was insufficient

XPS analysis of the fracture surfaces



Flame treatment – small modification effect –

Plasma jet treatment – overtreatment –

Conclusions

- Flame treatment and gas phase fluorination had only a minor influence on surface roughness and heterogeneity of TPO materials. A dramatic increase in roughness and heterogeneity was observed after plasma jet treatments. But, by optimizing the treatment conditions surface roughness could be kept unaltered.
- Depending on the treatment conditions oxygen and nitrogen containing functional surface groups are introduced. In this way, it is possible to adjust the acid-base surface characteristics (influence on paint adhesion is expected).
- Higher amounts of additives in the surface region of TPO materials caused insufficient paint adhesion.
- A relation between the lowest and highest oxygen content in the surface region and paint adhesion was found. From XPS analysis of the fracture surfaces, it can be concluded that interfacial failure predominated when the modification effect was too small. Cohesive failure in the TPO material was observed when the surface was over-treated.

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