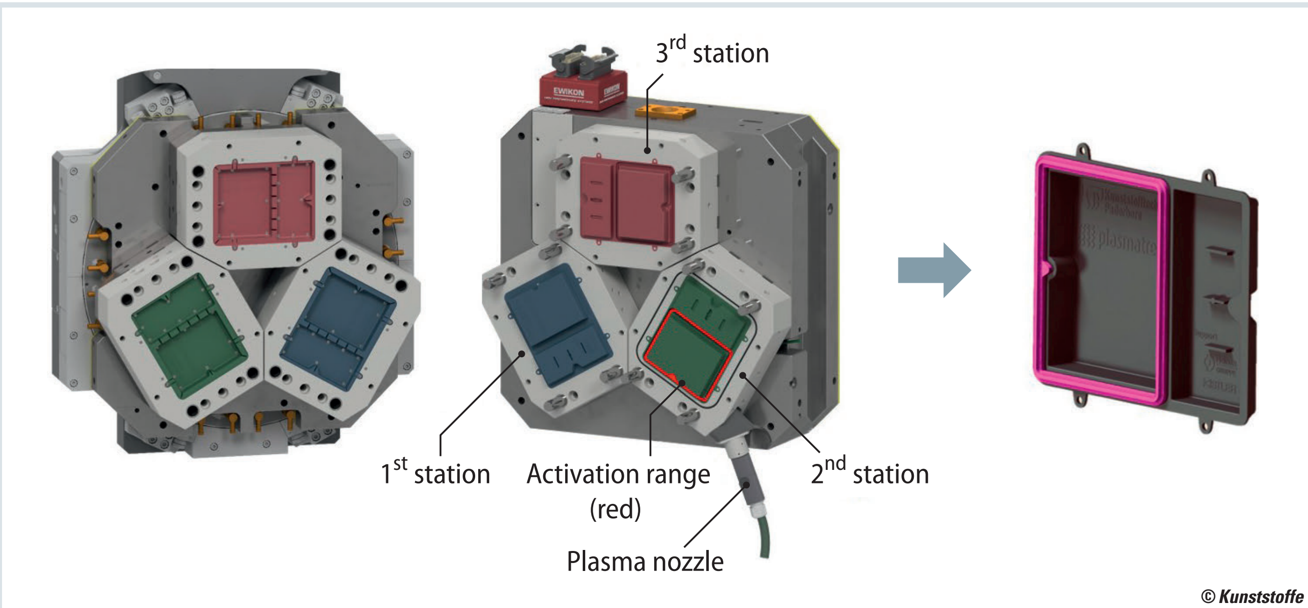
More Material Combinations, Lower Costs

InMould-Plasma Streamlines the 2-Component Process and Expands the Material Spectrum

Increasing demands on component functionality and the need for efficient manufacturing processes are keeping multi-component injection molding squarely in the focus of plastics processing. Not all materials can be processed reliably in the desired combination. The new InMould-Plasma process, which is fully integrated into the injection molding process, facilitates more-efficient production and paves the way for completely new material combinations.



Demonstration mold for the production of a housing cover by the InMould plasma process (© Kunststofftechnik Paderborn)

The InMould-Plasma process was developed as part of a research project between Plasmatreat GmbH, Steinhagen, Germany, and Kunststofftechnik Paderborn (KTP) of Paderborn University, Germany. Up to now, standard plasma processes have tended to treat the plastic surface in a separate step. The new process is based on conventional plasma technology conducted at atmospheric pressure (AP), but performs the activation step directly inside the injection mold and is an integral part of multi-component injection molding. This simplifies the manufacturing process and makes it more cost efficient.

New Properties for Surfaces

Plasma is created by coupling energy into gas. The atoms of the gas release electrons, and the gas becomes ionized and acquires new properties, such as electrical conductivity [1, 2]. Plasma is thus regarded as the fourth state of matter (**Fig. 1**).

The plasma is generated continuously at atmospheric pressure in a plasma nozzle. The process gas, usually oil-free compressed air, is passed through a discharge zone where an arc is generated by a high-voltage discharge [3]. The gas is then converted into the plasma state. As it emerges from the nozzle, the relaxing plasma is bundled together to form a beam. The Openair-Plasma nozzle from Plasmatreat [4, 5] is also based on this design principle (**Fig. 2**).

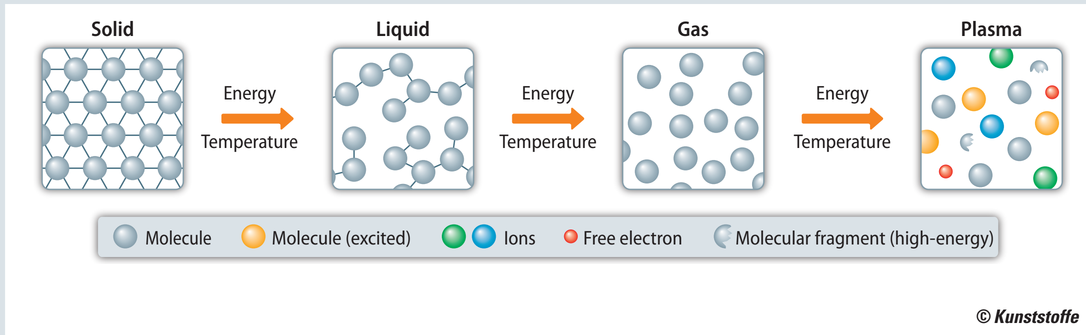


Fig. 1. Plasma – the fourth state of matter (source: Plasmatreat)

In conventional AP plasma processes, the plasma nozzle ensures uniform surface activation by maintaining a constant distance from the substrate surface. When the plasma comes into contact with a plastic surface, functionalization occurs because the excited molecules and ions in the plasma have enough energy to rupture the bonds between the atoms of the polymer chains [4–9]. These bonds are often carbon-carbon or carbon-hydrogen types.

InMould-Plasma is Protected against Reactions with Atmospheric Oxygen

The resulting radicals react with the excited molecules and ions of the plasma or with molecules from the surrounding air. This raises the surface energy and the polarity of the treated surfaces and improves the wettability of the treated plastic [5, 10–12].

During AP plasma treatment, contact between the plasma and the air gives rise to recombination reactions, leading to a reduction in the number of excited molecules in the plasma and to energy loss. This makes the plasma comparatively short-lived.

The InMould-Plasma process features a newly developed plasma nozzle from Plasmatreat that is flanged direct to the injection mold. In the closed mold cavity there is a free area above the plastic surface to be treated (**Fig. 3**).

Before the plasma cycle begins, the treatment channel is flooded with pure nitrogen via an inlet for one second to ensure complete gas exchange and to suppress recombination processes with atmospheric oxygen. Introduction of the nitrogen is followed by igniting the plasma nozzle for a pre-defined plasma-treatment time. Nitrogen is then flushed through the channel again and extracted through the outlet. This ensures that the plasma passes along the full length of the channel and that the plastic surface is activated uniformly enough. In trials, channel lengths of over 850 mm were reliably activated.

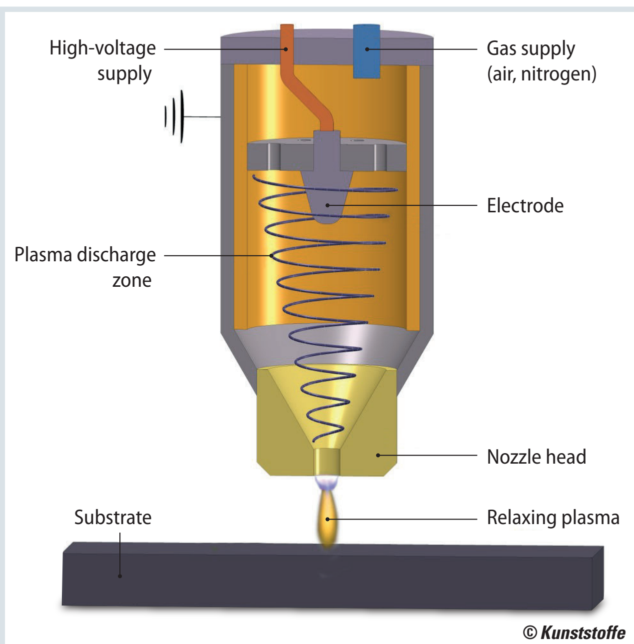


Fig. 2. Structure of an Openair plasma generator (source: Plasmatreat)

Case Study: Gasket for the Bottom Module of a Laundry Dryer

The development partners used the bottom module of a laundry dryer to investigate whether and how the InMould-Plasma process might be implemented industrially [13]. The module has an integrated gasket which must offer permanent media resistance at a temperature of 40 °C and a relative humidity of 100 %. In addition, the gasket is subjected to mechanical forces and must lend itself to repeated assembly in the event of repairs.

Up to now, the gasket has been made from foamed polyurethane (PU) which is applied to the polypropylene (PP) floor module by the formed in-place foam gasket (FIPFG) process. A CNC robot applies an even bead of sealant accurately into a groove in the floor module. To form a strong bond between the PU and the non-polar PP, AP plasma activation is required. Without it, the bond between the PP base module and the foamed soft component would be too weak and the two polymers could not be processed.

This production process can be optimized by InMould-Plasma treatment in the injection mold and switching to a thermoplastic polyurethane (TPU) for the gasket system. The outcome is a shorter cycle time and the elimination of the need for CNC robot and other ancillary equipment.

Proof of Aging Resistance

In order to prove that the InMould-Plasma process creates a lasting bond between the molded-on TPU gasket and the PP bottom module, the KTP studied hard/soft peel-test specimens made from PP filled with 40 wt. % talcum (PP-T40) and TPU (type: Hostacom HBC 386L grey/Desmopan 481; manufacturer: Lyondell- »

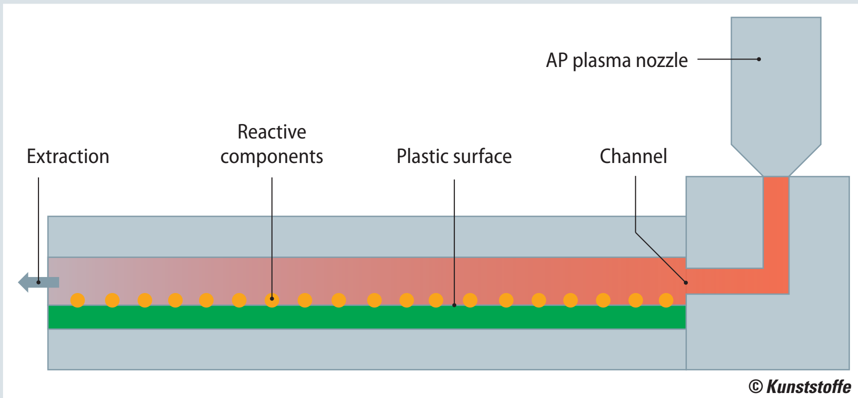


Fig. 3. Schematic representation of the InMould plasma process. The process takes place within a closed mold cavity (source: Kunststofftechnik Paderborn)

Basell Industries Holdings B.V. and Covestro AG). These were manufactured in a modular, three-station 2-component injection mold with integrated plasma nozzle by Plasmatreat (**Fig. 4**).

At the first station of the sliding table mold, a square panel is molded, which remains in the nozzle side of the mold. The second station (plasma station) is then moved in front of the molded panel. Surface activation now proceeds partly by guiding the channeled plasma in the free areas in a meandering pattern to simulate the process idea of an 850-mm activation channel. After reopening of the mold, in the third station, the soft component is molded onto the functionalized contact surfaces of the base panel. The geometry of the resulting three test specimens produced in a single shot is based on guideline VDI 2019 for the determination of peel resistance [14].

High-Strength PP/TPU Bond

The activation was performed with a plasma nozzle (type: PFW30-LT) in conjunction with an FG 5005 plasma generator and an HTR12 transformer from Plasmatreat; later studies were carried out with a newer system solution composing the FG 5005S plasma generator and a plasma control unit (PCU). The treatment time was set at 1 s. A universal testing machine from ZwickRoell GmbH & Co. KG, Ulm, Germany, was used for conducting the subsequent peel test as per the VDI 2019 standard. For this, the TPU component molded onto the PP-T40 was peeled off at an angle of 90° to the joining plane [14].

The peel strength reached a maximum value of 4.2 N/mm after 1 s of plasma treatment. This result was remarkable because PP and TPU do not bond with each other in the untreated state and so have a peel strength of 0 N/mm in the absence of InMould-Plasma treatment. A high bond strength is hard to obtain owing to the use of talcum as an additive to the PP. For another PP/TPU combination (type: Moplen HP500N/Elastollan E 1185 A10; manufacturers: LyondellBasell and BASF SE), peel strengths of up to 16 N/mm were determined.

Application-Specific Loading of the Test Specimens

The adhesive strength of the 2-component test specimens produced in the InMould-Plasma process underwent an aging resistance test [13]. For this, the

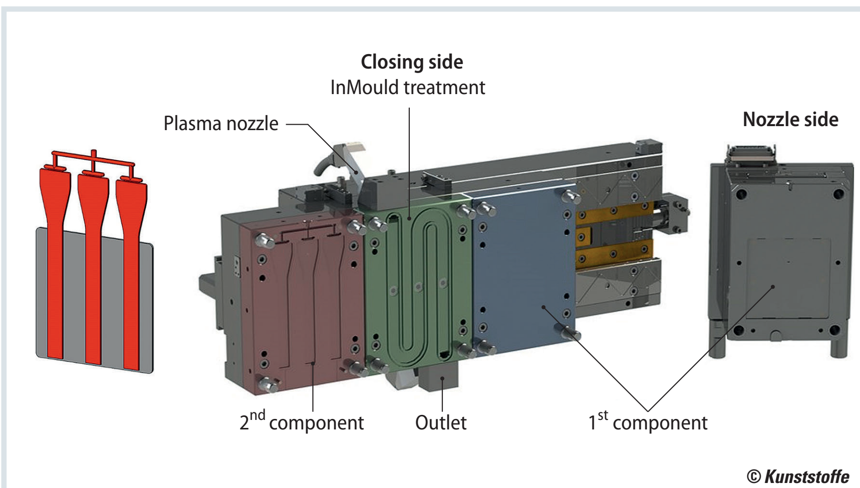


Fig. 4. Two-component overmolding tool with adapted plasma nozzle for the production of three hard/soft peel test specimens (source: Kunststofftechnik Paderborn)

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References & Digital Version

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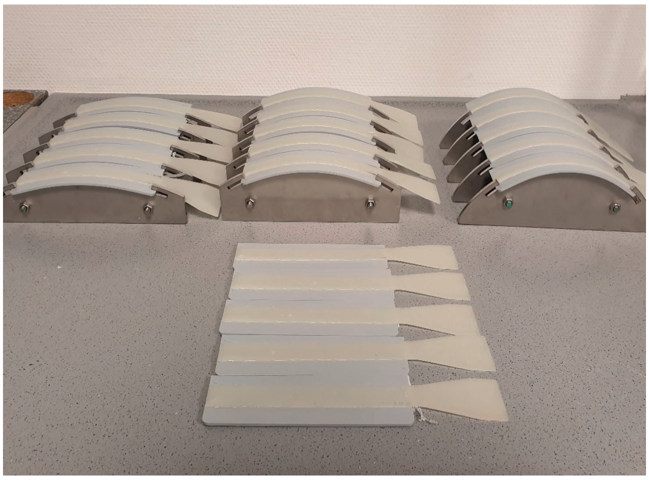

Fig. 5. Conditioning of the 2-component specimens of different bending radii. The outer fiber strain (ε_{RF}) is 0 %, 0.8 %, 1.3 % and 2 % (© [13], J. Braun)

specimens were subjected to an alternating condensation test based on ISO 6270–2: condensation (in-cabinet exposure with heated water reservoir). The cycle duration was 24 h, with a loading phase of 8 h and a resting phase of 16 h.

During the loading phase in a vapor-tight chamber, the air temperature was set to 40 °C and a relative humidity of 100 %. During the resting phase, it reached a standard climate of 23 °C and 50 % relative air humidity. After 7, 14 and 28 cycles in the alternating climate test, the specimen's peel strength was determined and compared with a reference that had not undergone this cycle.

To better assign the influence of aging induced by alternating climate stress, the samples were additionally aged under the standard climate. The bent strip method of ISO 22088–3 was also used to determine possible interactions between thermal and mechanical stresses. This entailed clamping the test specimens in bending templates of different bending radii (**Fig. 5**).

Bond Remains Fully Intact

No deterioration in the bond strength between the TPU and the PP-T40 was observed in the tests performed (**Figs. 6 and 7**). Nor was the peel strength significantly reduced by either the flexural load or the conditioning. Thus, 2-component injection molding of a TPU gasket onto a PP substrate may be regarded as an alternative to the separate activation step with AP plasma followed by application of the reactive PU system.

The realization of this manufacturing principle was illustrated with a 3-station turntable mold at K 2019 in Düsseldorf Germany, where a TPU seal was molded onto a PP base housing in a cycle-neutral process. Plasma activation took place in the area marked in red (**Title figure**).

Conclusion

The InMould-Plasma process is ideally suited to the industrial production of compatible polymer composites from incompatible hard/soft material combinations by 2-component injection molding. Production in a 2-component injection molding machine with cycle-neutral, integrated plasma activation yields cost advantages over the separate production of the components in two injection-molding machines with downstream assembly process or the separate application of a PU bead by a CNC robot. In addition, more cost-effective commodity polymers can be used as the base materials.

While the emphasis has been on combinations based on TPU and PP, the adhesive strength of many other material combinations can also be boosted considerably. Examples are thermoplastic elastomers, such as thermoplastic styrene block copolymers (TPS) on polybutylene terephthalate (PBT), polymethyl methacrylate (PMMA) and polycarbonate (PC). TPUs are characterized by their good scratch and oil resistance and low melt viscosity, which gives them high molding accuracy and flowability. This opens up numerous application areas for InMould-Plasma, ranging from polyurethane flow-coating of A and B columns for automotive interiors, to gaskets in housings through to shoe soles. ■

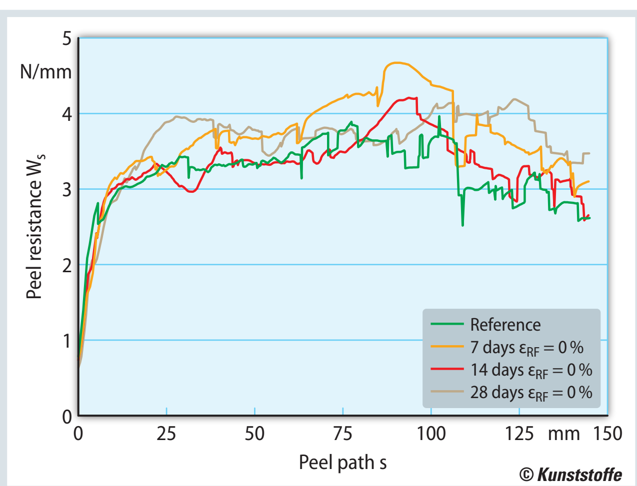

Fig. 6. Peel resistance for different periods of storage, without mechanical loading (source: [13], J. Braun)

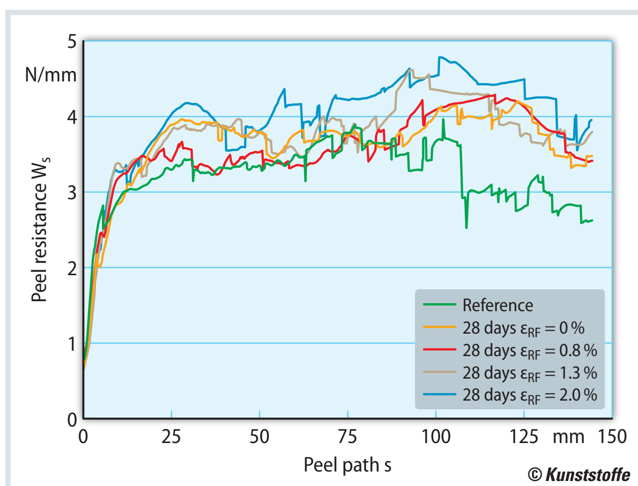

Fig. 7. Peel resistance at varying degrees of outer fiber strain (ε_{RF}) after 28 days of storage. Storage under load does not reduce the peel strength (source: [13], J. Braun)