Short Cycle Times and High Productivity for Smart Components

Direct Coating with Polyurethane Coatings Creates Opportunities in Design and Functionality

Classic coating techniques such as spray painting are reaching their limits in the production of functionally highly integrated and elegantly decorated plastic parts. In contrast, the process chain of the direct coating process has now been optimized. Self-healing, fast-curing PU casting coatings and polycarbonate compounds that adhere firmly to each other even after aging are now available for this manufacturing process.

The trends of e-mobility, connectivity, and autonomous driving are inspiring a new design language in vehicle construction. For example, exterior components for passenger cars with glass-like surfaces in which numerous sensor elements are integrated, as well as lighting elements, are in demand. In the automotive interior, large-scale decorative parts with multi-functional, seamlessly integrated display, control, and ambient lighting elements are gaining ground. As a result, there is an increasing demand for smart plastic parts that feature a high degree of functional integration in addition to a high-quality design.

Direct Coating (DC) with polyurethane (PU) coating systems is particularly suitable for manufacturing the newly requested components. Compared with the subsequent painting of plastic parts, it has the benefit that it can be used not only for surface finishing but also for integrating highly complex functional component properties. It combines two technologies that have been established in large-scale production for decades in a single process: the injection molding of thermoplastics and reaction injection molding (RIM) of PU systems.

The PU-coated component is created in a mold that combines injection molding and RIM technology. First, the thermoplastic substrate is produced in the first cavity and then transferred to a second cavity, which is enlarged by the thickness of the coating layer. The PU system is then injected onto the substrate through a RIM mixing head. The result is a component with a PU layer that can be from approx. 200 µm to several millimeters thick. If a turntable or turning plate mold is used, the next substrate can already be produced in the first cavity while the PU system is still curing in the second cavity. This ensures short cycle times and high productivity. In addition, the DC process has many advantages in terms of sustainability and economy (**Box**).

The DC process makes it easier and faster to produce sophisticated-looking components with integrated sensors and light elements © Covestro

Great Freedom of Design for Surfaces

PU coating systems offer an unusually wide scope for designing the surface of components. These can be produced to be transparent, translucent, or solid-colored and with high resistance to abrasion and chemical media such as oily skin creams. Leather-like soft-touch haptics can be created as well as hard, scratch-resistant optics with a brilliant deep gloss. A key benefit of the DC process with PU over spray painting is that detailed surface structures can be precisely molded with the RIM cavity. Macroscopically, these can be tactile supports and design elements such as edges. Microscopically, very fine grains up to nanostructures can be mapped for special effects such as anti-reflection properties. High-gloss areas can be directly adjacent to matte structures. This design option in particular can only be implemented with great effort using conventional coating methods and is therefore a unique feature of the DC process.

Specially Adapted Materials for the DC Process

Rühl Puromer GmbH and Leverkusen/Germany-based polymer manufacturer Covestro are one of the pioneers of the

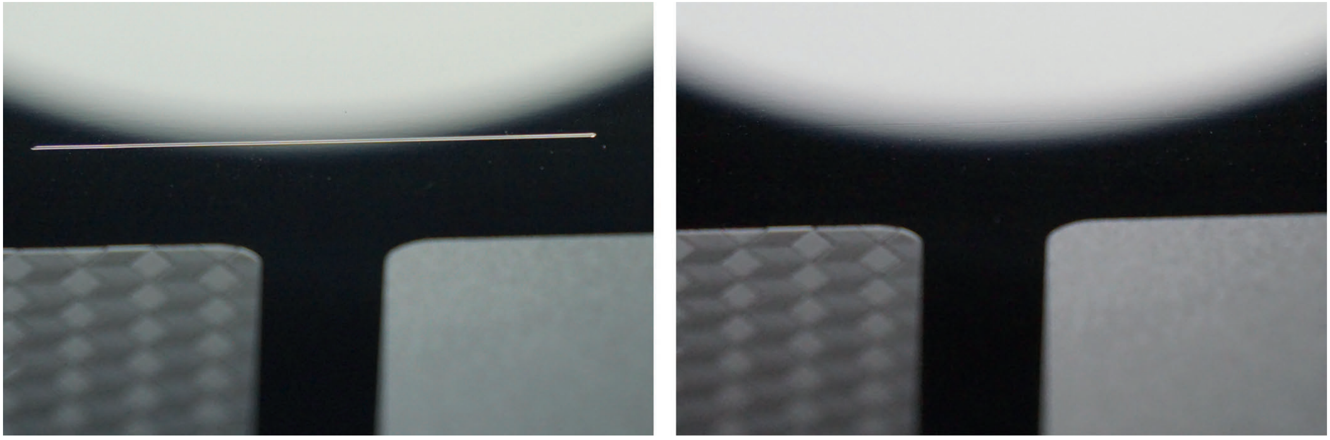

Fig. 1. White light interferograms of a scratch mark: after 48 hours, the scratch is no longer visible due to the self-healing effect © Rühl Puromer

DC process. Independently of each other and in part also jointly, they have developed important fundamentals of this manufacturing technology in terms of material formulation, component design, mold design and technology, machine equipment, and process simulation, among other things, and have often cooperated with machine and mold manufacturers in the process. Processing methods and raw material systems for the thermoplastic substrate and the PU coating were precisely adapted to each other by the two companies.

With Puroclear, Rühl offers light- and color-stable two-component PU coating systems based on aliphatic isocyanates, e.g. for wood and piano black trim parts. For the DC process, the reactivity of the product family was optimized for the shortest possible curing times, resulting in RIM cycle times at least equal to those of injection molding. Therefore, economical manufacturing is a given. The systems are also self-releasing with an "internal release function" integrated into the material, which has been tested in series production many times. The mold therefore does not need to be sprayed with release agent, nor does it require dedicated coatings. This also contributes to short cycle times and a simpler process flow. The great benefit of these self-releasing PU systems is that they allow for the mold-free production of components with brilliant surfaces without the need for post-processing. Separate release agents, on the other hand, prevent the direct formation of high-gloss surfaces.

Self-Healing Surfaces

The Puroclear range also includes variants that are self-healing, i.e. have the so-called reflow effect. Superficial scratches in the coatings – caused by vehicle keys or stone chips, for example – close themselves after a short period of time (**Fig. 1**). Components thus retain their high-quality appearance and function for »

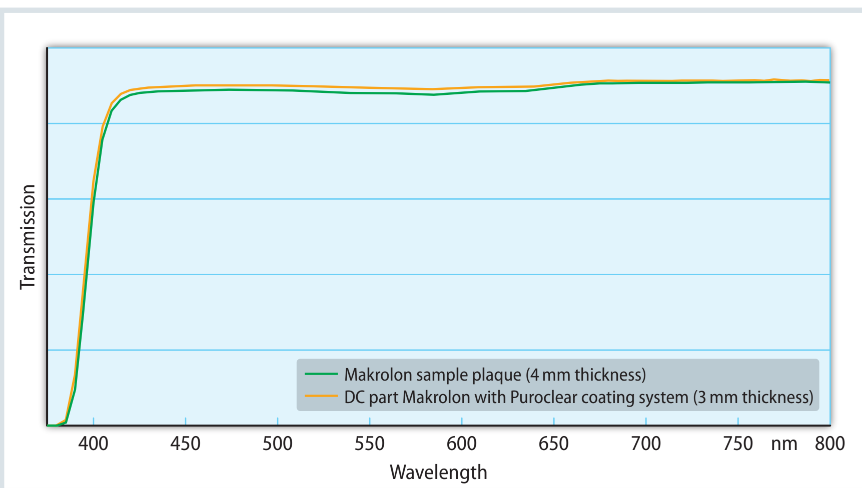

Fig. 2. Transparency in combination: comparative transmission measurements show that Makrolon and Puroclear ideally complement each other with their respective high transparency

Source: Covestro, Rühl Puromer; graphic: © Hanser

The Authors

Christoph Bontenackels is a CAE engineer in the Global Digital Engineering Team of the Engineering Plastics segment at Covestro; christoph.bontenackels@covestro.com

Dr. Ulrich Fehrenbacher is head of Development at Rühl Puromer GmbH and has worked for the company since 2014; ulrich.Fehrenbacher@ruehl-ag.com

Dr. Ingo Kleba is Managing Director of Rühl Puromer GmbH and has been with the Friedrichsdorf/Germany-based company since 2009; ingo.kleba@ruehl-ag.com

Dr. Markus Mechtel is Senior Manager in Industrial Marketing Automotive of Covestro's Coatings and Adhesives segment; markus.mechtel@covestro.com

Dr. Olaf Zöllner is head of Application Development Europe in the Engineering Plastics segment at Covestro; olaf.zoellner@covestro.com

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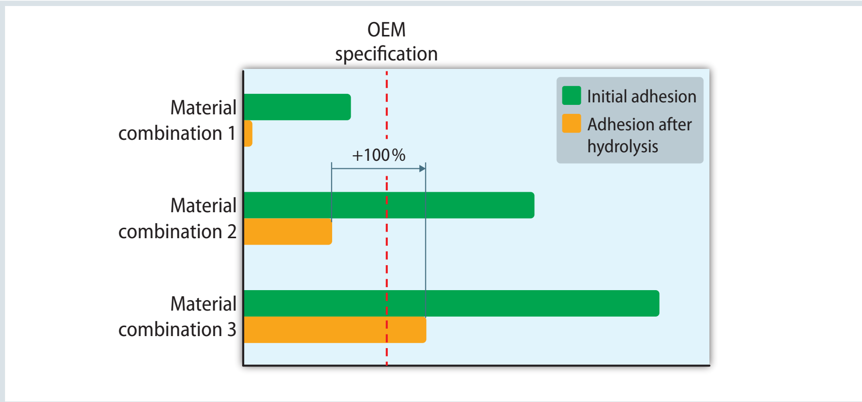

Fig. 3. Results obtained in the POSI adhesion test for the combination of a standard PC and PU coating (1) and for the combination of a Makrolon Class A product type with a puroclear standard coating (2) and with a puroclear coating system optimized for PC (3) (hydrolytic storage for 72 h at 90 °C and 95 % humidity) Source: Covestro; graphic: © Hanser

longer. The abrasion resistance of these PU RIM coatings also contributes to this high suitability for everyday use. The purely physically based self-healing effect is based on a special network structure. In addition to chemical crosslinking sites, this also contains physical crosslinking sites, so-called hard segment domains, which are based on hydrogen bonds. The latter form again as reversible bonds after damage to the surface, which, together with the resilience of the polymer network, the memory effect, leads to the disappearance of the scratches.

High Transparency Allows for the Integration of Light and Sensors

Covestro has developed special polycarbonate (PC) and PC blend compounds from its Makrolon, Bayblend and Makroblend product lines for the DC process, as well as an extensive modular range of coating raw materials without solvent additives for PU coatings, such as special isocyanate crosslinkers from the Desmodur series and polyols from the Desmophen series. Among the thermoplastic DC materials, one focus is on PC. The polymer's very good mechanical properties and high transparency meet the requirements of current design ideas in automotive interiors, for example, for ambient lighting and large, seamless control panels. In the exterior, it simplifies the integration of display functions for communication with other road users and of sensor elements for driver assistance systems based on radar and lidar frequencies. Suitable for such applications, Rühl has developed PU RIM coatings that exhibit very high transparency even at greater film thicknesses without sacrificing other automotive-relevant properties. They are therefore ideal synergy partners and offer good protection for transparent PC substrates (**Fig. 2**).

Ensuring the Adhesive Strength between PU and PC

Generally, the bond strength between PC and PU is considered challenging, especially under the influence of aging. It is true that Makrolon and transparent Puroclear grades have good adhesion properties in themselves. Nevertheless, the development partners Rühl and Covestro have further enhanced the adhesive strength

Fig. 4. The demonstrator for the control panel of a center console with inductive button functions was produced in the DC process using back injection molding of a printed Makrofol PC film, and the surface was finished with a puroclear-based deep gloss © Covestro, Rühl Puromer

with regard to long-term stability after aging. For this purpose, several material combinations were optimized and their adhesive strengths evaluated in the POSI pull-off test (according to ISO 4624). As a result, even specimens subjected to hydrolytic aging due to prolonged storage in hot-humid environments were found to meet automotive OEM adhesion specifications (**Fig. 3**). Further investigations also showed that the internal release function in the PU systems performs its intended task – easy demolding – and does not negatively affect the adhesion between PU and substrate.

Furthermore, both companies are working on incorporating the film insert molding (FIM) of films into the DC process. The deformed and decor-printed films not only considerably broaden the possibilities in component design, but are also very important for functional integration. For example, they can be used to represent inductive key functions by printing them with conductor paths and circuit diagrams that can be backlit (**Fig. 4**). The injection molding step can also be designed as a 2-component process.

Covestro and Rühl support project partners throughout the entire development chain of a DC component with a comprehensive application technology support. The focus is on process-oriented component design and mold technology and the simulation of the DC process and component properties. The precise simulation of the PU filling and warpage is essential, for example, to implement large, seamless PC decorative trim with glass effects, lighting elements, and touch sensors for automotive interiors. Components of this type must have a flawless aesthetic appeal with widely varying thicknesses of the PU layer. They can also tend to warp due to their size and the varying shrinkage of the PC substrate and the PU system. As a matter of principle, the PU filling process and warpage should be simulated at an early stage of the project in order to design the component and mold correctly from the outset and avoid subsequent expensive adjustments.

Tools for Filling Simulation

Covestro has developed corresponding calculation and simulation tools. A new calculation method based on a two-phase CFD (computational fluid dy-

Advances at a Glance

- No investment in separate painting systems
- No cleanroom conditions necessary
- No paint loss due to overspray
- No pre-treatment, e.g. by primer or corona treatment
- No common coating problems such as orange peel or coating build-up
- Less logistical effort in handling the parts
- Reduced space and resource requirements
- Fewer rejects due to coating defects (e.g. dust, runs)
- Hardly any emissions thanks to PU systems without solvent additives
- Lower energy consumption compared to separate injection molding and painting

namics) simulation is available for the filling simulation. In contrast to conventional methods for injection molding simulation, this considers the air displaced from the mold during PU filling not as a vacuum, but as a separate phase. In contrast to previous conventual simulation methods, this makes it possible to determine precisely where air bubbles form, where they migrate, and whether they remain in the component or reach the vent, depending on the structure in the coating and in the substrate (**Fig. 5**).

For the warpage simulation, a calculation method was developed that describes the material behavior of the coating systems with regard to shrinkage and warpage. The PU systems shrink more during molding than the thermoplastic substrates. Therefore, when designing a component, 3D structures with larger wall thickness increments should generally be placed in the substrate in order to keep the layer thickness of the PU system uniform and distortion low. However, in most applications, this is only possible in the ideal case. Simulation therefore helps to find an optimum layer thickness ratio at which the warpage and also the cycle times are minimal (**Fig. 6**).

Automotive Industry Appreciates the DC Process

Currently, the application focus of the DC process is on passenger car interiors. However, it is also increasingly being used for exterior components such as pillar trim with touch panels for entering codes to open and close the interior. Other potential exterior applications include highly integrated spoiler elements, radar covers, and front panels reminiscent of radiator grilles (**Title figure**). The latter primarily serve as a brand-defining design element in electric vehicles, with or without the integration of light and sensor substrates. Generally, the automotive industry increasingly appreciates the DC process as an efficient alternative to other manufacturing concepts for high-volume production because it offers increased component performance and freedom of design. Medical, equipment, IT, and communications technology are now also discovering the benefits of the process. ■

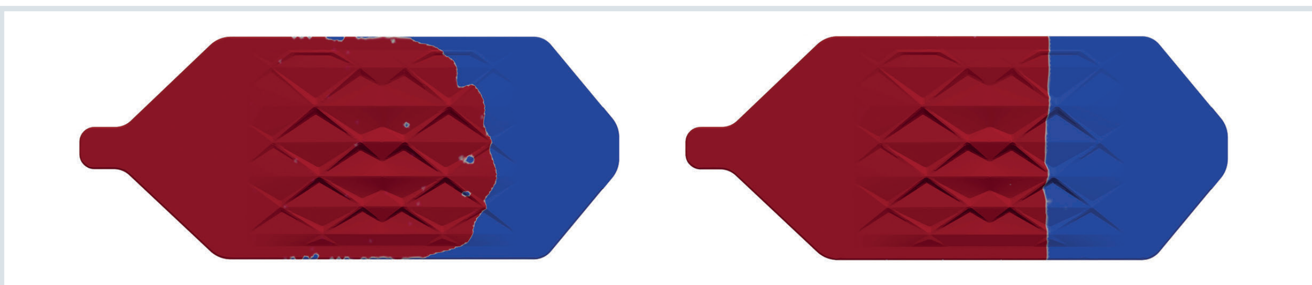

Fig. 5. Simulation of DC mold filling using the example of a sample board (red = PU coating, blue = air): if surface structures are integrated into the PU coating, air pockets can form in the coating as a result of the coating being advanced in thicker areas (left). If, on the other hand, the surface structures are in the PC substrate, no air pockets are formed in the PU coating due to the uniform wall thickness and flow front (right) © Covestro

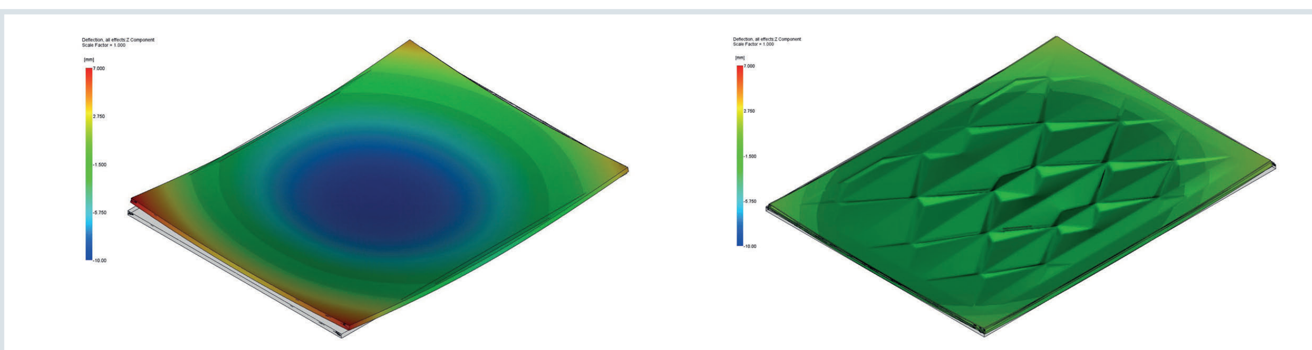

Fig. 6. Simulation of warpage using the example of a sample panel: if the surface structures are in the PU coating, increased warpage can occur due to the greater shrinkage potential in the thicker PU coating areas (left). However, warpage is largely avoidable if the surface structures are incorporated into the PC substrate and thus the PU wall thickness is homogeneous and low (right) © Covestro