PC-based films enable attractive designs in automobile interiors. Electroplated real metal surfaces with touch sensors are a real eye-catcher, no matter whether the backlighting is switched on or off. © BIA

Polycarbonate (PC): Functional Integration and New Specialties

Growth Driver China

A large proportion of the world's polycarbonate is processed in Asia, especially in China. This is why capacity expansions are mainly taking place there. Outside Asia, manufacturers are increasingly focusing on specialties and products for new production technologies, such as functional integration in components. In the coming years, sustainability will also be the defining issue for all manufacturers.

Polycarbonate (PC) is marketed in the form of granules and granule compounds as well as film, sheet and composite semi-finished products. As a result of the coronavirus pandemic, the global PC market slumped slightly in 2020. However, it recovered to the 2019 level as early as 2021. According to Covestro estimates, global demand for the thermoplastic, including the PC content for blends, was over 4.5 million t in 2021. In the medium term, it is expected to grow by around 4 % per year. It is impossible, however, to reliably forecast how sales will develop in the near future on account of the war in Ukraine and the current disruption of supply chains worldwide due to occurrences such as the coronavirus pandemic.

The largest consumers of the polymer in 2021 were the electrical and electronics industry and household appliance manufacturers, accounting for around 35 %. Automotive producers accounted for about 20 % of sales, followed by the construction and consumer goods industries with about 15 % and nearly 10 %, respectively.

Over 60 % of Sales in Asia

As in the previous years, China consumed the largest share of PCs in the world. The Middle Kingdom accounted for over 40 % of global sales in 2021. The entire Asia-Pacific region (APAC), including China, accounted for over 60 %. The Europe, Middle East and Africa (EMEA) region and the NAFTA region (USA, Canada and Mexico) followed at a considerable distance, with shares of almost 25 % and 15 % respectively.

The largest PC manufacturers are Covestro and Saudi Basic Industries Corporation (Sabic). Together, the two companies have about half of the world's capacity. Other major players are Mitsubishi, Lotte Chemical and Teijin. The ranking behind the two leading PC manufacturers will, however, change in the medium term due to new Chinese producers.

At a predicted 5 to 6 %, PC sales in China will grow much faster in the next few years than in other regions of the world. Consequently, almost all investment in new capacity is concentrated in the country. Ten years ago, only four PC manufacturers were active in China. By the beginning of 2022, the number had grown to a total of 16. Covestro expects around 50 % of global PC capacity to be located in China by 2025/2026. The country is now able to meet almost all of its demands itself, as plants with a total nominal capacity of more than 2 million t have been built in recent years. In the next five years, China is expected to add another 2 million t of

PC capacities. As a result, among other things, global PC capacities are expected to rise from 6.5 million t in 2021 to over 9 million t in 2025/2026.

Capacity Expansion in China Continues Undiminished

In China, capacity is being expanded by globally active producers, but also increasingly by local producers, some of whom are new to the market. These investments are mostly in the expansion of existing plants. For example, PC manufacturers Luxi Chemical and Wanhua Chemicals, which have been active in China for some time, are planning to successively expand their plants in Liaocheng and Yantai, respectively, in Shandong Province. In the mid-term, Cangzhou Dahua also aims to double the capacity of its plant in Cangzhou, Hebei province, which was opened at the end of 2020, to 200,000 t/a. Zhejiang Petroleum & Chemical plans to add a stage of equal capacity to its 260,000 t/a producing plant that came on stream in 2021 at Zhoushan in Zhejiang province by 2023/2024. Pingmei Shenma Group also intends to significantly expand its newly built capacity of currently 100,000 t/a at Pingdingshan in Henan province in several stages over the coming years. Likewise, the capacity of the Hainan Huasheng plant in Dongfang in Hainan Province, which only went into operation at the beginning of 2022, is to be doubled to 520,000 t/a by 2024/2025.

Fig. 1. Covestro has expanded the capacity for specialty PC films at its Dormagen site. New applications in the automotive sector, for example, increase demand. © Covestro

Yet completely new plants have also been and are still being constructed in China. Sinopec Sabic Tianjin Petrochemical (SSTPC), a joint venture between Sinopec and Sabic, for example, completed a new plant with a capacity of 260,000 t/a in Dagang in Tianjin Province towards the end of 2021. Chimei of Taiwan is planning to commission a first plant in China in 2025 at Zhangzhou in Fujian province with 180,000 t/a capacity. A joint venture involving Sabic and Fujian Petrochemical is also expected to start up a 290,000 t/a capacity plant in Gulei, also in Fujian province, in the same year.

Focus on Specialties

A number of major PC manufacturers are also strategically focusing their activities more closely on the requirements of the market. One of the goals here is to benefit disproportionately »

Fig. 2. The PC filament Polymaker PC-r for 3D printing consists of a plastic recyclate made from used water bottles from Chinese manufacturer Nongfu Spring. © Covestro

from business with higher-value and faster-growing applications. Covestro has established two new segments for this purpose: "Performance Materials" bundles, among other things, the business with standard materials such as PC for water bottles, for which reliable supply at competitive market prices is particularly important. "Solutions and Specialties" places the focus on complex plastics production with high innovation speed, coupled with application technology services for the customer. For instance, this includes the business with PC compounds, for example for electromobility and medical technology, or with PC composites for lightweight construction. According to Covestro's estimates, sales of these materials will grow by 7 % annually in the mid-term, and thus at significantly higher rates than standard PC. The company therefore plans to expand its compounding capacities by 230,000 t/a in the next few years. The two further compounding lines that recently went into operation at the Greater Nodia plant near New Delhi in India are already making a first contribution to this.

Trinseo has also split its "Performance Plastics" segment. In addition to the "Base Plastics" segment, the "Engineered Materials" segment has been established. It combines the business with compounds and blends for demanding applications, for example in consumer electronics. Sabic plans to stock-list its Specialty Chemicals business, which includes PC-based copolymers and compounds. The aim is to restructure this business in order to better exploit the growth potential of the materials.

Backward Integration More in Demand

Currently, some Japanese PC manufacturers are also reorganizing. Mitsubishi Chemical, for example, pulled out of its joint venture with Sinopec, based in Yanshan in Beijing province, at the end of October 2021 as part of a portfolio reorganization. Mitsubishi Chemical plans to transfer half of its share in the 50:50 joint venture Mitsubishi Engineering Plastics to its partner Mitsubishi Gas Chemical in April 2023 as part of a restructuring of its plastics activities.

There is an increasing trend towards backward integration, especially among Asian producers, in some cases as far as phenol and acetone. Apart from the limited availability of raw materials, the underlying reason for this was probably the fact that the prices for bisphenol A in particular, one of the main raw materials for PC, have been very volatile in the last two years and have reached levels not seen for a long time. As a result, some Asian manufacturers who were not backward integrated had to reduce capacities or temporarily shut down plants.

In addition to PC base resin, capacities for films, sheets and composites are also being expanded worldwide. For example, Covestro commissioned additional production lines for high-quality specialty films at its Dormagen site in 2021 (**Fig. 1**). The focus is on multi-layer flat films, which are used for example in medical technology, the electrical industry, in automotive interiors and exteriors or for security features in identity documents. This project is part of a global initiative to expand the company's film capacities.

Building Circular Material Flows

Climate change, resource scarcity and the global waste problem with plastics have led virtually all PC manufacturers to adopt circular products and consider entry into the circular economy as the key to climate neutrality, resource conservation and environmental protection. Covestro, for example, is fully aligning its corporate vision towards a circular economy and aims to become climate-neutral by 2035. To achieve this, greenhouse gas emissions from its own production, external energy sources and upstream and downstream processes in the value chain (scopes 1, 2 and 3) are to be reduced.

The alignment of material cycles leads PC manufacturers to switch their production of compounds, films, sheets and composites to alternative raw material sources such as recyclates and bio-based materials. Production sites and products are being certified in order to demonstrate the sustain- »

Fig. 3. The use of quality-assured PC recyclates reduces CO_2 emissions in the production of the smartphone Fairphone 4 compared to conventional, purely fossil materials by 30 %. © Fairphone

Fig. 4. The distinctive front panel for the BMW iX is made of Makrolon AG. Camera technology, radar functions and other sensors for the driver assistance system are elegantly integrated into the large-scale component. © BMW

ability of these raw materials to customers. So far, the ISCC-Plus standard (International Sustainablility and Carbon Certification), an international system for the sustainability certification of biomass and bioenergy, among other things, has been particularly successful. Trinseo, Sabic, Lotte Chemical and LG Chem have announced they have received ISCC certifications. Covestro has had production at its Shanghai (China), Map Ta Phut (Thailand), Antwerp (Belgium), Krefeld-Uerdingen (Germany), Leverkusen (Germany) and Dormagen (Germany) sites certified to the standard.

More and More Materials Comply with the ISCC-Plus Standard

The ISCC-Plus standard is associated with mass balancing during production. This chain-of-custody method allows fossil and alternative raw materials to be mixed in production but separated in accounting. As a result, materials can be tracked through value chains and raw materials can be allocated to selected end products.

Fig. 5. Film technology makes it possible: the Nighthawk demonstrator from TactoTek and Covestro contains touch functions, a display and lighting elements and is only 3.5 mm thin. © Covestro

The mass-balanced raw materials are identical to their fossil counterparts and as such can be integrated into existing production processes as a drop-in solution.

One example of a switch to alternative raw materials in PC production is an agreement entered into by Covestro and Mitsui Chemicals. The Japanese chemical company will supply Covestro with the PC raw materials acetone and phenol from ISCC Plus-certified mass-balanced sources at its sites in Shanghai and Map Ta Phut, Thailand.

Climate-Neutral PC Materials

Virtually all major manufacturers of PC now offer products certified to the standard as part of their product range. For instance, Sabic launched renewable-based PC compounds in 2019 as part of its Trucircle initiative, and more recently film and sheet products (product name: Lexan). Covestro has recently unveiled the world's first carbon-neutral PC compounds under the name Makrolon RE. They are derived from biowaste and residual materials and are produced in part using renewable electricity. The designation "climate neutral" is the result of an assessment of a section of the entire product life cycle. The section from resource extraction (cradle) to Covestro's factory gate was considered. The assessment is based on ISO standard 14040 and was checked for plausibility by TÜV Rheinland. The assessment takes into account biogenic carbon sequestration based on preliminary data from the supply chain and the use of renewable electricity in the production process. Electricity was apportioned on the basis of so-called "Guarantee of Origin" certificates. Compensation certificates were not applied.

Alongside other PC compounds of the brand, ISCC-Plus certified RE product ranges are also in the process of being developed for the heat-resistant copolycarbonates Apec and the PC blends Bayblend and Makroblend. They are of particular interest for new-mobility, E&E and medical technology components. The company will also launch accordingly certified PC films from its Makrofol product range at the end of 2022.

Initial applications for Makrolon RE will include charging stations for electric cars. One example is EVBox, a Dutch full-service provider for electric vehicle

charging, which plans to use the sustainable PC compounds in the manufacture of charging stations. The aim is to conserve resources and minimize the stations' CO_2 footprint.

Recycling Cooperation

To build up material cycles in recyclates, PC manufacturers are now taking a look at the entire plastics value chain. In China, for example, Covestro is cooperating with beverage distributor Nongfu Spring and reprocessor Ausell to recycle 5-gallon (19-liter) water bottles made of PC. Among other things, the recyclate is used to produce filaments for 3D printing of components for consumer electronics (**Fig. 2**). Earlier this year, Trinseo acquired the Dutch company Heathland, a European recycler of post-consumer (PCR) and post-industrial plastic (PIR) waste.

One use case for quality-assured PC recyclates is the easy-to-repair Fairphone 4 from the Dutch company Fairphone. The back cover of the device, the middle frame and the wireless charger of the smartphone are made, among other things, from PC with a PCR content of 30 to 50 % (**Fig. 3**).

In the automotive industry, new growth opportunities for PC are arising from the transition to electromobility and the trend towards driver assistance systems and autonomous driving. The classic radiator grille, for example, is now a thing of the past due to the elimination of the internal combustion engine. Instead, new freedom of design is emerging at the front of electric vehicles, exploited by seamless and decorated exterior parts made of transparent plastic. The BMW iX, for example, features a kidney-shaped, multicolored front panel with a glass-like 3D deep gloss (**Fig. 4**). Whereas the vehicle's radar sensor is seamlessly concealed behind the front panel, it incorporates a virtually invisible heating film for the sensor. This keeps the sensor free of ice.

The Electromobility Growth Market

In production, a preformed 3D film insert made of Makrofol with a heating func- »

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Data Basis and Sources

All market data is based on surveys and assessments by Covestro. Any additional information on investments and technical developments also comes from Covestro or from press releases issued by the companies mentioned.

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tion is back-molded with the transparent PC Makrolon AG in an injection compression mold. The result is a thermoplastic part with an integrated partial film area, which is then coated with a transparent, scratch-resistant and self-healing polyurethane coating system (PUR) in the same mold using a RIM mixing head (Reaction Injection Molding). The component was developed jointly by BMW, Covestro as well as other partners. The hub for this was Covestro's Leverkusen technical center, where several development tools were tested and optimized for the project. This was supported by the plastics manufacturer's expertise in simulating the rheological behavior of both the injection compression molding material and the PUR reaction system during mold filling.

The trend for assisted driving will transform the car interior into a mobile working and living environment with radically new requirements in terms of functionality and comfort. The interior will be characterized by displays and infotainment, décor and elegant design, thus creating new applications for PC-based films as surface materials – for example in combination with "real" materials such as wood, metal or crystal. To this end, virtually all PC film manufacturers are working on new films. One such example is Covestro's translucent PC+ABS films for electroplated real-metal surfaces, combining cool touch with touch sensors and backlighting effects (**Title figure**). For displays, PC and PC+PMMA films with enhanced optical properties are in the process of being developed.

More Lightweight and Functionally Integrated Components

In-Mold Structural Electronics (IMSE) technology is a new and growing area of application for PC-based films. It enables interconnected electronic functions and components applied to films to be integrated directly into freely molded plastic housings. This involves printing films with decor and electronic functions such as circuits, sensors, control surfaces and lighting elements, and then forming and back-injecting them. The result is very thin, space-saving and lightweight components with smart, largely seamless surfaces that have a significantly lower number of individual electronic components. The potential of the technology is demonstrated by an IMSE display demonstrator from Covestro and TactoTek that is just 3.5 mm thin. In addition to capacitive touch control functions and an OLED display, it also integrates functional lighting elements and ambient lighting (**Fig. 5**).

IMSE technology offers tremendous potential for applications in optical bilayer surfaces, both in automotive interiors and in charging stations for electric vehicles, as well as in consumer and industrial electronics. Film development for this technology centers, among other things, on more scratch-resistant products. For this purpose, a coating layer is applied directly to the film in a roll-to-roll process and cured after the film has been formed. Alternatively, films can also be equipped with functional layers using coextrusion or lamination processes. This yields component surfaces with good scratch resistance and chemical resistance that have an aesthetic, velvet-matte look with a pleasant feel.

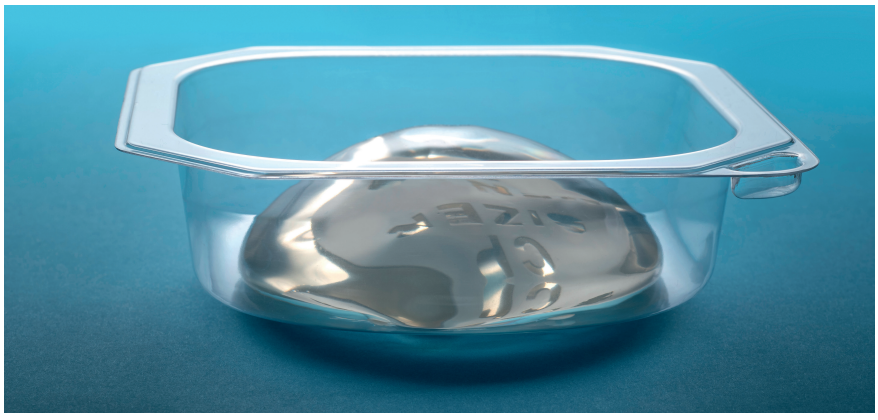

Fig. 7. Packaging for breast implants made from PC film. The robust outer layer protects the implant from impact. © Covestro

The Medical Technology Growth Field

Medical technology is becoming an attractive growth area, particularly for PC specialties. Here, too, sustainability and the Circular Economy continue to play an increasingly important role. One focus area, for instance, is the recycling-friendly design of medical devices for the reuse of discarded plastic parts. One example is the design study of an autoinjector for self-administration of medication (**Fig. 6**). In contrast to common designs, it does not consist of a mix of chemically mostly incompatible plastics, but exclusively of PC and blends. The injector can be assembled without fasteners and quickly disassembled. This means that the non-contaminated parts can be sorted by material at the end of use and the recovered materials can be used in a closed-loop recycling process to produce the original components. However, the parts can also be processed into a quality-assured PC material mix that can be used in other applications in the sense of open-loop recycling. Overall, this results in hardly any waste. The CO_2 footprint of the injector can be significantly reduced by using climate-neutral PC materials – such as the Makrolon RE series. Films made from PC are being used increasingly for the safe packaging of high-quality medical goods such as artificial breast implants. The latter, for example, are transported and stored in Makrofol MA507, a film that is particularly impact-resistant and can be sterilized by steam sterilization at high temperatures (**Fig. 7**). ■

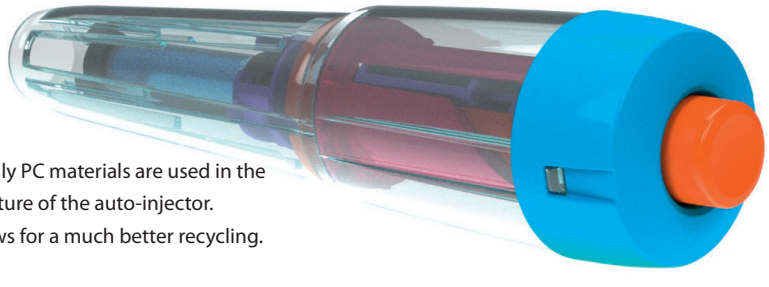

Fig. 6. Only PC materials are used in the manufacture of the auto-injector. This allows for a much better recycling. © Covestro