Polyamides: Electromobility and Sustainability Boost Developments

Dual Change with Polyamides

In various respects, the polyamide market is in upheaval. Due to the climate change, new fields of development and sustainability topics have come into focus along the added-value chain. In addition, the ownership of several manufacturers in the polyamide sector has changed.

Polyamide continues to be one of the most important technical plastics in the automotive sector, where it enjoys widespread use. This not only applies for classical internal combustion vehicles, but in terms of volume will also be the case for electric vehicles.

Global production of polyamide 6 (PA6) and PA66 reached a volume of 8.4 million t in 2021. This means that the level of 2018/19 and thereby the pre-pandemic level was reached. The global market portions of PA6 and PA66 are 75 % and 25 % respectively. In 2021, 60 % of global PA66 was used in compounds. The remaining volume was limited exclusively to fiber production. In the same year, global PA6 sales of 6.4 million t were divided in ratios of about 65, 10, and 25 % respectively for fiber production, film production, and the compound business. In summary, that makes about 2.7 million t of PA6 and PA66, which were processed into 3.6 million t of PA6 and PA66 compounds in 2021.

With a portion of more than 50 %, the automotive industry is the major consumer of PA6 and PA66 compounds, followed by the increasingly important electrical and electronics industry (E&E). The Asia-Pacific region accounted for about half of worldwide sales of PA6 and PA66 compounds in 2021. With more than one third, the People's Republic of China is the largest consumer, and according to current evaluation, will even become the primary growth driver for PA6 and PA66 compounds in future (**Fig. 1**).

Unprepared Supply Chains and Flagging Auto Industry

At the start of the Covid pandemic, all industries prepared for a multi-year crisis, after demand reached a low point in the second quarter of 2020. Consequently, the unexpected and strong recovery of demand at the end of 2020 was confronted with unprepared PA supply chains. The attempt of producers to raise the low stocks to the higher demand level resulted in an additional raw material demand. In turn – due to shortages in resources, transport, and raw materials – the global PA market was dominated by bottlenecks and force-majeure situations. In the automotive industry, the worldwide shortage of semiconductors and the associated lack of chips in 2021 resulted in a drop in demand. This was intensified by the Russian invasion of the Ukraine early in 2022 and the associated crisis in the supply of wiring harnesses.

Since the middle of 2020, prices for PA6 and PA66 have rocketed worldwide and now remain at a high level. In Europe, they have more than doubled between June 2020 and May 2022. Since early 2022, rapidly rising energy costs on the continent have resulted in additional price increases for PA. For purchasers of PA6 and PA66 compounds, this is an economic challenge.

Growth Continues

Because of further catch-up effects after the crisis, a short-time global volume growth of 6 to 7 % for PA6 and PA66 compounds is expected. But for the time after 2024, an annual growth of about 3 % is assumed.

Sustainability and electromobility present new challenges for PA, but simultaneously also open up opportunities. Automotive trends such as reduced emissions, electromobility and autonomous driving require high-grade ma-

terials with precisely matched properties. High demands in terms of flame proofing, color stability, mechanics, and electric insulation are dominant. In addition, weight and installation space are to be reduced without impairing safety. In future, PA compounds will play an even greater role, because they contribute significantly to the solution of coming mega trends.

In order to meet the continuously growing market demand, PA producers react with capacity expansions. Early in 2022, Lanxess commissioned a new compounding plant at their Krefeld-Uerdingen site in Germany. In 2022, also BASF opened a new compounding plant in the south Chinese city of Zhanjiang, an annual capacity of 60,000 t (**Fig. 2**). In general, most of the present capacity extensions are found in Asia.

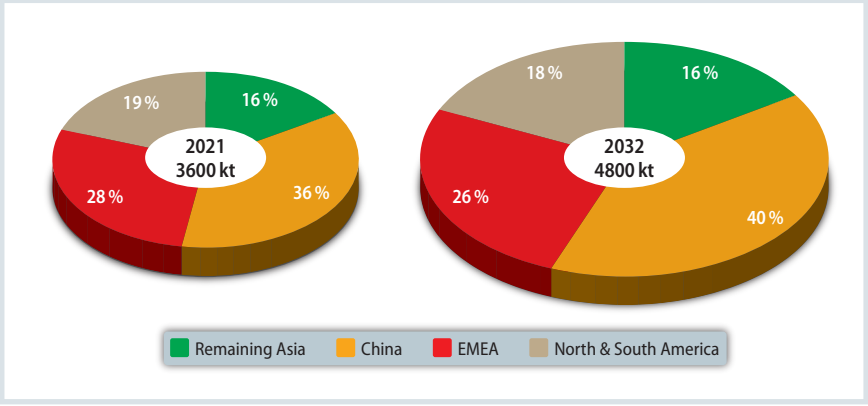

Fig. 1. Market growth for PA6 and PA66 compounds according to regions: By 2032, this market is expected to grow by one third. However, distribution of the overall market according to the different world regions will remain practically the same. Source: Wood Mackenzie Yellowbook 2022–04; graphic: © Hanser

Investments also in PA Precursors

Furthermore, investments are being made in the corresponding precursor stages. For example, starting in 2022, BASF will expand its PA66 polymerization in Freiburg, Germany, and is building a new hexamethylenediamine (HMD) plant in Chalampé, France. Presumably in 2024, it will increase BASF's annual HMD production capacity to 260,000 t. At the same time, Invista is investing in a new plant for adiponitrile (ADN) in China, with a capacity of at least 300,000 t. With a planned start of production in 2023, it will address the global structural supply problem within the PA66 added-value chain.

Currently, the plastics market is in a consolidation phase (**Table**). Following the sale of Solvay's PA business to BASF and Domo Chemicals in 2020, two other »

Fig. 2. BASF has commissioned its first compound production plant at the Zhanjiang/China site. After completion, it will be BASF's third-largest plant. © BASF

major plastics producers (DuPont and DSM) have offered their respective plastics business for sale. Early in 2022, Celanese purchased the corresponding mobility & materials division from DuPont. Later that year, Lanxess and finance investor Advent took over the engineering materials business from DSM. Already in 2021, Lanxess had announced to outsource its technical plastics business to an independent company. Now, a joint venture is merging this company with the purchased DSM activity, whereby Advent will take over leadership and 60 % of the shares.

Innovations Aimed at Electric Vehicles

The transition in the automotive industry from internal combustion engines to electromobility is also mirrored in recent innovations from plastics producers. Although new products for classical internal combustion (IC) engine applications continue to be marketed, many of the new developments involve fields such as surface quality, metal replacement, and E&E.

For example, Lanxess presented Durethan AKV320ZXTS2 – a blow-moldable PA66 – as a further development of Durethan AKV320ZH2.0 previously introduced to the market. The product is designed specifically for IC engines with high specific power outputs, as it withstands continuous service temperatures up to 230 °C. Also for high temperature requirements, Akro-Plastic has developed Akromid C28 GFM 10/20 5 XTC black (7367) in cooperation with Audi's material quality assurance. The material is a PA66/PA6 blend containing 10 % glass and 20 % mineral for particularly good heat stabilization, and will be used in the engine compartment of future high-performance Audi models.

2019	2024
BASF	BASF
Solvay	Domo Chemicals
Domo Chemicals	
DuPont	Celanese
Celanese	
DSM	Lanxess + Advent Int.
Lanxess	

Table. Consolidation of the polyamide market between 2019 and 2024. Source: BASF

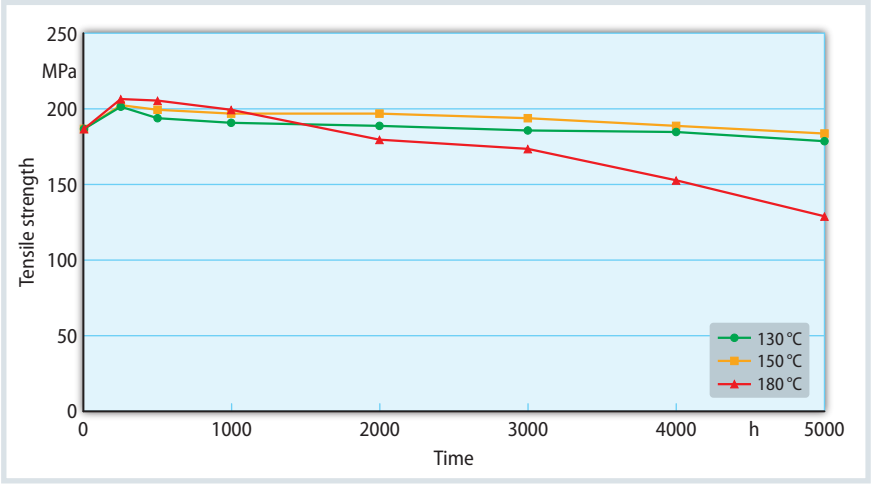

Fig. 3. Thanks to the newly developed P-stabilization, Ultramid B3PG6 BK23238 exhibits good thermal stability with a lifetime of up to 5000 h. Source: BASF; graphic: © Hanser

With the development of its heat stabilized PA6-GF30 Ultramid B3PG6 BK23238, BASF moves in a similar direction. The new P-stabilization provides thermal resistance up to 190 °C, and thanks to the halogenide and metal-free stabilization, it prevents galvanic corrosion of electric components (**Fig. 3**). With very good weld line strength for vibration and hot gas welding, the material offers excellent prerequisites for IC engine applications and also for hybrid or electric vehicles.

PA for Different Welding Processes

In the past years, laser welding has become one of the most cost-effective deep welding processes for polymer components in the automotive industry, and is used mainly for manufacturing complex parts. In order to comply with this trend, Domo has introduced the PA66 Technyl Star AF 219 V30 black LT with a high light transmission at a wavelength of 940 nm. It is suitable for applications with up to 3 mm wall thickness, and permits fast laser welding operations.

High Surface Quality also Required for PA

Especially for vehicle interiors, the subject of high-gloss surfaces has increased in importance during in the past years. In view of this trend, BASF has introduced Ultramid B3E2G6 SI BK23353 and Ultramid B3E2G10 SI BK23353 – a new generation of surface-improved structural materials (**Fig. 4**). Based on PA6, the glass fiber-reinforced types exhibit very low emission values and good UV stability, and are therefore ideally suited for visible functional parts in the vehicle interior with premium surface quality. In this way, structural components with smooth, matt, or textured surfaces can be produced in just one processing step, eliminating the need for additional painting to upgrade the surface.

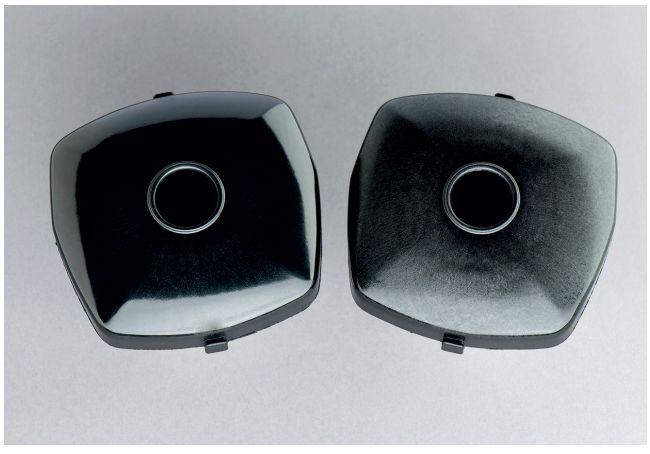

Fig. 4. High-gloss surfaces are in high demand for automobile interiors. For this field, BASF has developed two glass fiber-reinforced types, which provide very high-quality surfaces without the need for subsequent lacquering. © BASF

Fig. 5. The semi-aromatic PA of the Leona SG range from Asahi Kasei permits high-quality surfaces to be achieved without special treatment. © Asahi Kasei

Also the Japanese manufacturer Asahi Kasei has launched Leona SG on the European market, a range of semi-aromatic PA grades with which a high-quality surface appearance is possible without additional surface treatment (**Fig. 5**). Apart from high mechanical strength after humidity absorption, other features of the product line are improved flowability and shorter cycle times during injection molding.

With the introduction of various Grivory GV products, EMS Chemie has combined the wish for high-gloss surfaces with the prevailing subject of metal replacement. For example, glass fiber-reinforced Grivory G7V was developed for metal replacement applications, which require good surface quality. It combines high stiffness and strength – also after humidity absorption – with the high surface quality of a lower or unreinforced PA. On the other hand, Grivory G5V addresses classical metal replacement for applications in temperature ranges up to 100 °C. One special feature is stiffness in the conditioned state, which is 45 % higher at 80 °C than for well-known Grivory GV. One reason is that humidity absorption could be reduced, which also results in improved dimensional stability.

Special Challenges for E-Mobility

Regarding material requirements in electromobility, high-voltage wiring harnesses belong to the most complex components, because they must be flame retardant, mechanically robust, and provide high electrical insulation. In addition, their numerous connectors must have different colors for easier distinction during installation and maintenance, whereby the colors must remain stable during the vehicle's entire service life. Conventional PAs usually have a tendency for large color variations and/or for yellowing with thermal aging. Therefore, Lanxess developed Macrolex Orange HT, a soluble, organic colorant for PA for the automotive industry, where the orange color RAL 2003 is in high demand. It features high color strength, high thermal stability, and good weather resistance. In addition there is the PA6 product Durethan BKV30FN04 for connector applications, which features high flame retardancy. In the UL 94 flammability test, it achieved Classification V-0 with a specimen thickness of 0.75 mm, and CTI value of 600 V.

For the same applications, BASF has introduced Ultramid A3U44G6 DC OR, a flame retardant PA66 that ensures color stability with orange RAL 2003 (**Fig. 6**). For the first time, this product fulfills all the criteria for color stability and thermal aging, thereby permitting long-term color coding, which is safety-relevant e.g. in the sensitive high-voltage field. Moreover, it features high electric insulation with a tracking resistance of CTI 600. By dispensing with halide-containing additives, the material also counteracts electro-corrosion, which represents a challenge particularly in humid and warm environments.

Difficulties with PA Recycling

Due to the increasingly visible climate change effects, social demands for action are increasing greatly. Therefore, the subject of sustainability has been given more and more attention along the entire added-value chain of plastics in the past years, which has also resulted in the development of new recycling methods. Basically, a distinction is made between material and chemical procedures. The former are based on physical processes that do not modify the polymer chains during recycling. One example of this is mechan-

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All market data are based on own surveys and estimates by BASF. All additional information on innovations and sustainability originates from press releases of the named companies.

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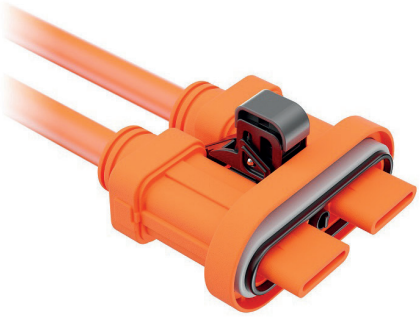

Fig. 6. High-voltage connector made of Ultramid A3U44G6 DC OR for e-mobility applications: the material from BASF was developed specially for electric vehicles, and for the first time meets all criteria regarding color stability and heat aging resistance. © BASF

ical recycling, which can be described as a thermal re-melting operation. In contrast, chemical recycling either uses a catalytic process to decompose the polymer basis into the corresponding monomers, or conversion into hydrocarbons by means of thermal processes.

In general, several hurdles must be overcome when recycling PA. One difficulty is that PA waste usually comes in the shape of glass fiber-reinforced compounds, or as multi-material systems used primarily in the packaging business. Another handicap is that in terms of quantity, PA compounds used in fields such as the automotive industry only represent a small portion of all the plastic materials used. For cost and time reasons, there is no disassembly into individual parts at the end of a vehicle's life. Therefore, only very limited material flows for simple mechanical recycling are presently available. However, plastics manufacturers are already using the available flows successfully, to offer their customers corresponding PA compounds with a high share of recycle.

For example, Domo uses recycled airbag fabric waste as basis for its Technyl4Earth product line. A similar approach is used by Celanese as well as Akro-Plastic. The Ecomid products from Celanese are PIR-based (post industrial recycle) PA materials, whose recycle portion consists of high-quality PA fiber and textile wastes. For its Akromid-Eco portfolio, Akro-Plastic generally uses non-processed PIR raw materials.

Various Producers Offer Recycling Compounds

With its product range Omnix ReCycle, Solvay introduced an extension of its PA-HT portfolio (high-temperature PA) to the market. The new compounds exhibit a recycle content of at least 33 %. They are based on PCR (post consumer recycle) and PIR material flows, and according to the manufacturer, this results in a significantly reduced CO_2 footprint compared with virgin material – as with all recycled PA compounds available on the market. Also the RadiciGroup has invested in sustainable products. With the takeover of the recycling company Zeta Polimeri, the Group has secured an easier access to PIR and PCR material flows. The resulting recycled PA compounds »

Fig. 7. In its Chemcycling project, BASF also works with the New Energy company, who supplies pyrolysis oil from chemically recycled scrap tires to BASF.
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have been launched under the trade name Renycle.

Also DSM has announced a PCR-PA6 product line under the name of Akulon RePurposed. The product's properties are said to be close to those of comparable virgin materials. Discarded fishing nets are processed as raw material source.

By offering PA6 compounds with recycled glass fibers, Lanxess has opted for a different approach to sustainable products. For this, PIR waste from their own glass fiber production is collected, subsequently used for producing new glass fibers, and assigned to the Durethan-Eco product line according to the mass balance principle. As a further development in this approach, at least 50 % of circular raw materials are used additionally for producing the PA matrix of the Scopeblue range. Hereby, some of the feedstock for synthesis of the PA6 monomer ε-Caprolactam is bio-based or chemically recycled cyclohexane.

When Classical Recycling Is Not Adequate

Mechanical recycling has the charm that the waste material flows used can frequently be compounded to new materials without great additional energy input, thereby conserving resources. However, the necessary waste material flows must be as pure as possible, and have a good, uniform quality. Because this cannot be ensured completely, the recyclate compounds based on this material usually have a lower property level compared with corresponding virgin material. As these pure-grade material flows only account for a small part of the accumulated PA waste, the plastics processing industry has developed further methods to increase the quantities and raw material quality of the PA recyclates.

With a modification of mechanical recycling, the APK company has developed a solvent-based recycling process called Newcycling. Hereby, the PE-PA multi-material systems are dissociated into respective pure-grade basic PE and

PA polymers, and sold as granulates. Consequently, the process offers an alternative to direct mechanical recycling of co-extruded PE-PA multi-layer films. According to a study by BASF in cooperation with Institut cyclos-HTP, also this material can be reused very well.

PA Based on Pyrolysis Oil

Apart from the described physical recycling process, also chemical recovery needs further development. For example, the Aquafil company has developed a re-monomerizing process, with which new PA fibers based on pure-grade PA6 recycled material flows can be produced. However, the depolymerization of mixed PA waste, whereby the waste is catalytically dissociated into its initial monomers, is not yet marketable.

Considerably further are thermolytic processes, in which olefinic raw material wastes are converted into pyrolysis oils under the exclusion of oxygen at temperatures above 300 °C. For example, BASF cooperates with Quantafuel, who operates a pyrolysis and cleaning plant with a capacity of about 16,000 t/a. In the plant, the company converts mixed post-consumer plastic waste – which otherwise would be incinerated – into a pyrolysis oil. Moreover, BASF cooperates with the Pyrum and New Energy companies. They produce pyrolysis oil from scrap tires, which otherwise are very difficult to recycle (**Fig. 7**). These oils are introduced into BASF's Production Verbund at the beginning of the added-value chain, which saves fossil resources. By means of an independently audited mass-balance approach, the quantity of recycled material used for Ccycled products is determined. Independently certified, they can also be used for PA compounds of the Ultramid range (**Fig. 8**), and accordingly, their properties are identical to those of comparable virgin materials. ■

Fig. 8. PA with a content of chemically recycled raw material is presently used e.g. by Jaguar Land Rover for their vehicles. For example, the prototype of a plastic cross-member for the electric I-Pace SUV was made of Ultramid B3WG6 Ccycled SW00564. © BASF