In recent years, world polyamide consumption has grown at a rate of 7% p.a. No end to this trend is in sight. The high versatility of the polymers and the possibility of modifying them with fillers, elastomers and additives ensure that polyamides will continue to have a high innovation potential. Among engineering plastics, polyamides are therefore number one in terms of volume. The main fields of application are automotive engineering, electrics and electronics and packaging.

Manufacturers and Capacities

Table 1 lists the biggest polyamide manufacturers in Western Europe, and the monomers they respectively produce. Taking into account the relevant monomer capacities, with the exception of BASF, none of the polyamide manufacturers is completely vertically integrated. The market leader for PA 6 in Europe is BASF, followed by Lanxess and DSM. DuPont is the market leader in PA 66, followed by BASF and Rhodia.

Polyamide base polymers can be used in the fibres and engineering plastics segments. It is therefore not reliable to classify production capacities according to market segments.

In 2003, worldwide polymerisation capacity for PA 6 materials (injection moulding and extrusion) was about 1.3 million tonnes, and about 0.9 million tonnes for PA 66, corresponding to about a third of available world polymerisation capacity for polyamides, including fibres. Fig. 1 shows the regional distribution.

Figure 2 shows the total capacity of the various polyamide manufacturers in Europe. In addition to the possible shift from fibre products to engineering plastics, fibre waste and recyclates represent a further raw materials source for polyamide compounds in the low-price segment, with severe fluctuations in availability and quality in many cases.

No reliable figures are available for compounding capacities, either, since they are often multipurpose plant that
are used for various engineering plastics. However, the general trend can be seen that many suppliers have expanded their compounding capacity in recent years. This also applies to compounders, who now represent a market force with significant influence.

Consumption and Applications
Since the beginning of the commercial production of polyamide 6 and 66 over 60 years ago, demand for polyamides rose worldwide to 6 million tonnes in 2003. The major proportion of 4 million tonnes is used for the production of synthetic fibres for carpets, technical yarns, fabric and nonwovens, 2 million tonnes in the field of engineering plastics (injection moulding and extrusion). While in the early years, fibre markets grew very strongly, engineering plastics have since gained an increasing influence on the continued growth in sales.

In the period from 1993 to 2003, global market growth for engineering grew at an average of 6.5 % per annum, with a severe intermediate dip in 2001. Different regions developed at very different rates. Whereas Europe, the USA and, in particular South-East Asia, achieved very high percentage growth in many cases, the Japanese market lag significantly below the average. The USA and Europe are export regions, while Asian demand must be covered by additional imports. It can be assumed that the next five years will see a similar global growth scenario (Figures 3 and 4). The Asian markets, but also the Middle East European countries, with its so far comparatively low per capita consumption will be particularly important here.

Consumption of polyamide for materials in Western Europe was 700,000 tonnes in 2003 [1]. Of this, approx. 50 % is PA 6 and 40 % PA 66, and the remaining 10 % is divided between PA 11, PA 12 and other homo and copolyamides.

Fig. 5 shows the main application segments of polyamide materials; it is dominated by automotive engineering, electrics/electronics and packaging. PA 6, PA 66 and copolyamides are preferably used for these applications.

Partly-aromatic polyamides have become established in niche applications. These materials, which are capable of withstanding extreme mechanical, thermal and chemical loads, because of their excellent properties, are preferably used in applications where even the high standard of PA 66 is not entirely adequate.

Automotive Engineering
The application segment with the highest consumption of polyamide, at 36 %, is automotive engineering. Over several decades, polyamide successfully and continuously displaced metal in a large number of applications in interior trim, body parts and exterior applications, applications under the body, and vehicle electrical and electronic systems.

The causes for this impressive success are always the same: the advantages of PA design as a result of lower weight with increased functionality and significantly lower costs. The combination of plastics and metal results in hybrid parts that integrate numerous functions and therefore permit new manufacturing processes, such as modular design. But challenging design solutions in the engine compartment, such as the engine cover for eight-cylinder engines at BMW can be made entirely in polyamide (Title photo, manufacturer: IBS Brocke GmbH & Co. KG).

There is no end to this success story in sight. The share of polyamide in modern automotive, in particular as a substitute for metals in the engine compartment and in the body area, will therefore continue to increase strongly.

Electrical Engineering and Electronics
Polyamide components also play an important role in the modern electrical and electronics industry. In Western Europe in 2003, their share of consumption was 22 %. The average growth in this segment in recent years was about 4 % p. a. Responsibility for the sustained demand lies with the combination of advantageous properties in the event of fire, balanced mechanical properties and excellent thermal properties. Growing safety demands can often only be satisfied with specialty flame retardant additives. Halogen-free alternatives, such as red phosphorus or organo-nitrogen based flame retardants have proved their effectiveness over years in the market for applications in the field of industrial switch gear, domestic appliances, electrical installations, automotive electrics, terminal blocks, plug-and-socket connectors and electrical hand tools. Polyamide finds its way into applications wherever its technical performance offers higher functionality and a more attractive design with reduced costs.

Here, polyamide offers a replacement for thermostos (e.g. for power and current-operated circuit breakers) as well as metals (e.g. in arcing chambers).

Packaging
For packaging, PA is mainly used as a barrier layer in laminated film and containers. Pure PA applications are relatively rare. In composite and multilayer films, PA 6 and copolyamides with PA 6 as the

Fig. 1. Estimated polymerisation capacity for polyamide materials by region, 2003 and 2010

Fig. 2. Capacities of West European polyamide manufacturers (for 2003)
main component are used (PA 6/66, 6/11 and 6/12). The share of consumption in Western Europe was 12% in 2003. Increasing demand for printable polyamide special films in the packaging industry is predicted for the coming years, too [2]. This is due, not only to increasing demand from the threshold countries of Eastern Europe and Asia, but also to stricter requirements for the shelf life of foods, and an increasing trend towards lower raw materials costs, this trend is being driven by reduced manufacturing costs for friction-welded PA 6 intake manifolds, compared with fusible core cast intake manifolds of PA 66.

In the engine compartment, the temperature and stress limits are being pushed ever further. Examples of this are pioneering application developments, such as the first oil-filter module (series production Audi A6, 2003) or the manufacturing technologies such as injection moulding compounding (IMC) are opening up new possibilities for producing long glass fibre-reinforced parts from polyamide. The advantages of long glass-fibre compounds lie in their high stiffness and high energy absorption. Because of comparatively low manufacturing costs for large, planar parts, and good recyclability, IMC technology competes with established further developments in the automotive sector are targeted at fuel cells and the introduction of 42 V power systems, which pose particular demands on the plastics used here.

Electrical Engineering and Electronics. Development activities in Europe have partly been determined by the directives for waste electrical and electronic equipment (WEEE) and by the restriction of certain hazardous substances.

Product and Applications Development

Automotive. The main highlights of the developments in the automotive sector are in products and manufacturing processes for applications in the engine compartment. In materials for suction modules, a trend towards PA 6 can be observed. In addition to the first HGV oil sump (mass production for Mercedes-Benz Actros, 2003), in each case made of glass-fibre reinforced polyamide.

High modulus polyamides containing up to 70% glass fibre could replace high mechanical load-bearing plastics such as polyarylamide, polyphenylene sulphide or polyphenylamine in some applications [3].

For automotive electrics (sensors, housings), the rapid growth in part integration and miniaturisation is opening up opportunities for laser welding. This innovative joining technology has a number of advantages over conventional processes, such as gluing, riveting or friction welding, particularly as regards leak tightness and weld-seam strength. Various raw materials manufacturers have developed tailored, laser-transparent and absorbent materials based on PA 6 and PA 66 for laser welding in recent years [4].

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Water-assisted injection moulding, in which water is injected under pressure into the mould during mould filling, is a relatively simple way of producing injection moulded hollow articles with uniform, smooth interior surfaces of the channels. Compared with conventional processes, such as gas-assisted moulding, water, as a liquid, and therefore with a better cooling effect, results in a shorter cycle time together with lower residual wall thicknesses and large part diameters [6].

Further developments in the automotive sector are targeted at fuel cells and the introduction of 42 V power systems, which pose particular demands on the plastics used here.

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ment of a flame-retardant reinforced polyamide with the following combination of properties: easy processing, impressive mechanical strength, freedom of pigmentation and halogen-free flame resistance with the classification V0 according to UL 94.

On the other hand, increased safety requirements for electrical equipment, for example as a result of standardisation by the IEC (International Electrotechnical Commission) are posing new challenges to equipment and materials developers.

A technology that is gaining in popularity is the manufacture of three-dimensional moulded interconnect devices (3D-MID). Various methods are used to simultaneously integrate electronic and mechanical components (such as connecting elements and plugs) into an injection moulded housing, which serves as a circuit substrate, such as mobile phone shells [7]. The preferred material for this, because of the high soldering bath temperatures, is often a high-temperature (HT) polyamide.

Future product developments are aimed at more economical manufacture of parts with no loss in quality. The important general conditions for this are improved mould filling, rapid solidification and improved demoulding at high mould temperatures.

Outlook

In 2003, global market growth for PA materials was 5 %, with the market for PA 6 growing faster than the PA 66 market. In Europe, underutilised capacities and increasing raw materials costs have led to significant falls in margins for polymer producers. Stronger market growth is expected for 2004, though polyamide manufacturers will suffer from increasing costs for raw materials and energy.

These background conditions are forcing manufacturers to take radical measures to restructure their plastics businesses. Recent examples from the industry are the sale by DuPont of the polyamide fibre branch to a subsidiary of the Koch Group, BASF’s acquisition of the engineering plastics business from Honeywell, and Bayer’s float off of its PA business in Lanxess.

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REFERENCES