General information on applications, processing and properties
With polymerization and compounding facilities for a range of polyamides, polyesters and polycarbonates, we serve our global customers base and assure a constant, reliable supply of products.

Recently, DSM completed major investments in the building of Akulon polyamide 6 polymerization plants both in the USA and in the Netherlands, as well as finalizing a joint venture with Xinhui in China for the production of polyamide 6 polymer. The capacity of the polymerization plant for Stanyl polyamide 46 in the Netherlands was increased by 30% to meet the high growth demand for this product. Access to polycarbonate was secured under a long term capacity sharing agreement with Dow Chemical.

All our compounding facilities in the world (in the Netherlands, Belgium, USA, Canada, China and India) are being expanded continuously to keep up with the growing demand.

As a result of a constant product innovation and creation process, DSM Engineering Plastics can offer a cohesive portfolio of high performing engineering plastics. Established trade names are:

- Akulon® (PA6 and PA66)
- Akulon® Ultraflow™ (high flow Akulon PA6)
- Akulon® XP (Xtreme Performance PA6 for film)
- Arnite® (PBT, PET)
- Arnitel® (TPE-E)
- Stamylan® UH (UHMWPE)
- Stanyl® PA46 (PA46)
- Stanyl PA46 High Flow™ (high flow PA46)
- Stapron® (PC-blends)
- Xantar® (PC)
- Yparex® (extrudable adhesive resins)

Complemented in some regions by products as:

- Electrafil® (conductive products)
- Fiberfil® (reinforced polypropylene)
- Nylatron® (PA66 specialties)
- Plaslube® (lubricated products)

These materials all have their specific properties, yet they share the same high quality, thanks to state-of-the-art production processes and quality systems, like Total Quality Management, ISO 9001 and QS 9000. It’s an approach to quality that can be found throughout the DSM organization:

- in relations with industry partners, working closely together in true co-makership, ready to meet any technical challenge
- in technical service and after sales, providing support to help customers optimize their processes
- in logistics and delivery, shipping products anywhere in the world, quickly and reliably.

From product concept, through processing, to final application DSM Engineering Plastics brings the portfolio, the skills and the global presence to help its industrial partners create world-class products and solutions.

It’s surprising what we can do together!

**Production sites**

**Europe**
- Emmen - Netherlands (polymerization and compounding)
- Geleen - Netherlands (polymerization)
- Genk - Belgium (compounding)
- Stade - Germany (polymerization)

**North America**
- Evansville - Indiana (compounding)
- Augusta - Georgia (polymerization)
- Stoney Creek - Ontario Canada (compounding)

**Asia Pacific**
- Jiangsu - China (compounding)
- Pune - India (compounding)
- Tokyo - Japan (M/S joint venture and toll compounding)
DSM has been involved in polyamides almost from its beginning. The company has a long history as a supplier of polyamides and a provider of polyamide know-how and technical service. DSM continues to invest in polymerization and compounding plants and technology. Today, DSM is one of the largest merchant caprolactam suppliers in the world and one of the largest global suppliers of polyamide resins and compounds.

The company’s caprolactam facilities are located close to its large PA6 polymerization and compounding plants in the US, Europe and Asia. DSM’s efforts to achieve full backward integration from monomer to compounded resins underscores its commitment to global engineering plastic supply. In addition, it demonstrates DSM’s focus on the continuing growth and quality of polyamides. DSM Engineering Plastics manufactures polyamide resins under the trade name Akulon, its largest product line.

The company’s vast expertise enables it to play a unique role as a resin producer and compounder.

**New plant.** In 2000 DSM Engineering Plastics started up a new state-of-the-art PA6 polymerization plant in Emmen, the Netherlands. Downstream of this polymerization unit is a large compounding plant. Another polymerization unit is located in Augusta (Georgia, US), with compounding facilities in Evansville (Indiana) and Stoney Creek (Canada). In Japan, the group has formed a joint venture with Japan Synthetic Rubber Co., Ltd. (Tokyo), and in China it has a strong foothold via a fully owned and strongly expanding compounding facility.

**New high-flow grades.** Another recent development is the introduction of a new family of high flow grades with undiminished mechanical properties: Akulon Ultraflow. This product line offers tangible advantages such as strongly improved flow, shorter cycle times, better surface appearance and less wear.

**Polyamide 6 versus polyamide 66**

Polyamide is the most common engineering thermoplastic in use today. Annual consumption of polyamide for engineering plastic applications exceeds 2000 ktons. Polyamides cover a broader range of applications than any other engineering plastic. The Akulon grades are suitable for all major processing techniques, such as injection moulding, blow moulding and extrusion.

The most important application areas are:
- automotive: air and fuel ducts, under-the-bonnet covers, door handles and trunk grips, power train, blow moulding and interior applications
- electrical/electronics: power distribution, industrial connectors, power tools and E&E components
- other industries: railway systems, furniture, castor wheels, sports goods, consumer durables, building products and industrial goods.

Polyamide has an excellent combination of properties:
- high stiffness and strength at elevated temperatures
- toughness at low temperatures
- excellent heat ageing resistance
- good abrasion and wear resistance
- chemical resistance
- excellent surface appearance.

These properties can be enhanced by the use of glass fibre and beads, minerals, flame retardants, toughening agents and other additives.
The most important polyamide 6 injection moulding grades in our portfolio are presented in Table 1 on this page. An overview of the available extrusion grades can be found on page 13. You will find a more detailed overview of our portfolio and the corresponding set of properties at the end of this brochure. The nomenclature is explained on page 29, Table 13.

**PA6 versus PA66.** The Akulon product line encompasses a range of polyamide compounds based on polyamide 6 and 66 types. However, given our backward integration, our core product line is Akulon PA6. This fits in with our vision that in most applications polyamide 6 outperforms polyamide 66 at temperatures up to 185 °C, since PA6 yields in comparison to PA66:

- higher toughness levels at low temperatures but comparable stiffness levels at elevated temperatures up to 185 °C
- better heat ageing resistance
- easier processability (broader processing window, the use of lower processing temperatures can lead to shorter cycle times)
- higher weld strength after various welding processes;
- better surface appearance of reinforced grades;
- the possibility of halogen-free flame retardancy in reinforced PA6 grades.

These advantages can lead to lower system costs and/or better safety margins in your applications. The high stiffness levels at elevated temperatures and higher absolute values for strength levels measured after heat ageing, imply savings in material costs (because wall thickness can be reduced) or a higher safety margin (at a certain wall thickness). Also, the broader processing window and lower melting point of polyamide 6 mean easier processing. Processing costs can be reduced as a result of lower energy costs and/or shorter cycle times. The higher toughness level leads to lower reject levels in production. The higher weld strength of polyamide 6 provides better safety margins in the applications, whilst its superior surface appearance leads to an improved image in the marketplace.

More details can be found in the technical chapter in the second part of this brochure.

There are many reasons to choose Akulon PA6 for your applications!

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**Table 1. The most important PA6 grades in our portfolio.**

<table>
<thead>
<tr>
<th>Type</th>
<th>Additive</th>
<th>Remark</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unreinforced</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low viscous</td>
<td></td>
<td>F223-D</td>
</tr>
<tr>
<td></td>
<td>High viscous</td>
<td></td>
<td>F130-B</td>
</tr>
<tr>
<td>Reinforced</td>
<td>Glass fibres</td>
<td>30% GF</td>
<td>K224-G6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30% GF, HS</td>
<td>K224-HG6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35% GF, HS</td>
<td>K224-HG7</td>
</tr>
<tr>
<td></td>
<td>Hybrid (glass fibres/minerals)</td>
<td>10% GF, 20% M, HS</td>
<td>K223-HGM24</td>
</tr>
<tr>
<td>Flame retardant</td>
<td>Glass fibres</td>
<td>20% GF, halogen free</td>
<td>K222-KGV4⁹</td>
</tr>
<tr>
<td></td>
<td>Hybrid (glass fibres minerals)</td>
<td>5% GF, 20% M, halogen free</td>
<td>K222-KGMV14</td>
</tr>
</tbody>
</table>

1) K222-KGV4 and K222-KGMV14 are halogen free materials; HS = heat resistant.

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**Ski-bindings**

Akulon K224-TG9.
Automotive exterior

Door handles, radiator grilles. As an integral part of the vehicle's body, the door handles have many difficult requirements. They must have an excellent surface appearance, paint ability, and UV-resistance, but also good mechanical properties, like stiffness and toughness. DSM is one of the market leaders in these applications and offers a broad portfolio of tailor-made Akulon solutions for door handles, for painted and unpainted use. Akulon is easy to process, even in the most difficult processes for door handle applications, like gas-assisted technology or foaming.

Automotive interior

Airbag containers. The task of an airbag is to save the head of a human being from hitting a hard surface or component in an automobile within some milliseconds. The materials to enable the airbag to do its job have to fulfill the most stringent specifications. They must carry specific mechanical and thermal properties and a certain product consistency. The super toughened Akulon K224-HG6 and K224-PG8 (PA6 GF30 and GF40) withstand these challenging requirements. The polymer enables the system suppliers to design cost-effective and state-of-the-art airbag containers.

Table 2. Examples of automotive applications.

<table>
<thead>
<tr>
<th>Exterior</th>
<th>Interior</th>
<th>Electrical</th>
<th>Under the bonnet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Door handles</td>
<td>Ski flaps</td>
<td>Fuse boxes</td>
<td>Air-/fuel modules</td>
</tr>
<tr>
<td>Tailgate handles</td>
<td>Door openers</td>
<td>Stork switches</td>
<td>Airducts</td>
</tr>
<tr>
<td>Wheel trims</td>
<td>Airbag housings</td>
<td>Connectors</td>
<td>Valve-/engine covers</td>
</tr>
<tr>
<td>Body panels</td>
<td>Window winders</td>
<td>Relay boxes</td>
<td>Fans and shrouds</td>
</tr>
<tr>
<td>Radiator grilles</td>
<td>Headrest support</td>
<td>Sensors</td>
<td>Gear box consoles</td>
</tr>
</tbody>
</table>

DSM polyamides: first choice!

The demand for plastics of today’s automotive industry is very simple but tough. Cost effective, innovative solutions at benchmark quality, combined with global availability and recyclability. Therefore, DSM’s polyamides and especially Akulon PA6 are the first choice. With its unique property profile, Akulon PA6 can undoubtedly fulfill the requirement of the automotive industry for its most challenging applications, e.g. in the engine compartment, for powertrain applications, etcetera. And, when it comes to recycling of End of Live Vehicles (ELV’s), DSM is developing ways to chemically recycle ELV PA6 parts. DSM Engineering Plastics is in the position to offer post-consumer PA6 grades under the trade name Akulon Recap globally, partly coming from its depolymerization plant in Augusta.

Polyamides have been used for many years in the automotive industry. Due to their performance profile, they can offer the appropriate solution for many different applications. Akulon polyamides have been successfully applied in (see Table 2):

- automotive exterior;
- automotive interior;
- electrical and electronic applications;
- under-the-bonnet.
Electrical and electronic applications

**Relay boxes.** In automotive E&E-applications, Akulon PA6 plays an important role when it comes to relay boxes. Akulon K224-HGR24 (PA6 GF10 GB20) offers good mechanical properties and excellent weld line strength at elevated temperatures, combined with the required dimensional accuracy. Where higher stiffness combined with excellent flow characteristics is demanded, Akulon K-FHGM44 (PA6 GF20 M20) can do the job. That’s why many OEM’s rely on Akulon.

**Under-the-bonnet**

**Air intake manifolds and airducts.** ‘Fuel economy’ and ‘weight reduction’ are the main challenges of the automotive OEM’s and their suppliers of today. A big step towards these goals can be made by the integration of functions and replacements of aluminium and steel by plastics, e.g. for air intake components.

Akulon PA6 play an important role in this game, be it a standard Akulon K224-HG6/HG7, a burst pressure/welding optimized Akulon K230-HXG6 or even one of the blow moulding specialties for airducts, like Akulon K249-HG4. DSM Akulons are in the position to cover all of our customers’ needs in this important segment.

**Engine covers.** Also for this segment fit-for-use Akulon grades are available like K223-HGM24 (10% GF, 20% Mineral) and K220-HGM44 or K-FHGM44 (both 20% GF, 20% Mineral: highly flowable with superb surface appearance. These grades do offer the requested combination of high toughness and stiffness, of low warpage and good surface appearance, and of easy and speedy processability, which explains the many approvals at all major OEMS.
Polyamides are used in electrical or electronic applications: low voltage switch gears; connectors, bobbins and electromotor parts. Below the main emphasis will be directed towards low voltage switchgears and towards connectors. Information on the other applications can be obtained at our sales engineers or application development engineers.

**Low voltage switchgear**

The segment of ‘Low Voltage Switchgear’ can be sub-segmented into the following categories of applications (which are covered by the different IEC standards, quoted between brackets):
- miniature circuit breakers; domestic (IEC 898) or industrial (IEC 947)
- residual current devices (IEC 1008/1009)
- fuses (IEC 269)
- switches and relays (IEC 947-3)
- contactors (IEC 947-4)
- cabinets (IEC 439-5).

The main trends in these sub-segments are:
- thermo set replacement
- shift from halogen containing flame retardant systems towards halogen free and phosphorous free systems
- the integration of functions, miniaturization and designs with thinner wall thickness
- and the application of laser marking instead of printing.

These trends lead to more stringent requirements with respect to the thermoplastics used, especially due to trends in design. Comprehensive Tracking Index (CTI) requirements shift to ‘CTI ≥ 400 V’ and Relative Temperature Index (RTI) requirements towards ‘RTI electrical ≥ 130 °C’ and ‘RTI mechanical ≥ 120 °C’. All this preferably realized in a halogen free and phosphorous free system. Other requirements are:

**Minimum general requirements:**
- Glow Wire Flammability Index of 960 °C
- Ball Pressure >125 °C
- specific combinations of Flammability, Hot Wire Ignition and High Current Arc Ignition (according to IEC 947-1; see Table 3).

This set of requirements explains why PA6 (and specifically Akulon) is the preferred material for these applications:

**Miniature Circuit Breaker**


Other parts: Akulon K222-KGV4.
its melting point of 220 °C is sufficient to withstand the short-term temperature rises. Its stiffness is the same as that of PA66 up to 190 °C; with its high RTI values it can easily meet the long-term temperature requirements. Typically continuous temperatures seldom exceed 70-90 °C. There is however a trend to higher continuous temperature exposures; it is available in halogen free and phosphorous free flame retardant versions, which also comply with the CTI ≥ 400 V requirement; it is tough and easy process able.

Especially the halogen free and phosphorous free flame retardant requirement in combination with a CTI ≥ 400 V is difficult to be met by PBT or PA66. Other deficiencies of these materials are: too much warp age sensitivity, less stiffness and strength at elevated temperatures, less impact resistance in the case of PBT and more difficult process ability and limited electrical properties in the case of phosphorous based flame retardant PA66. Despite its moisture absorption, PA6 still easily manages to meet the various specifications with respect to dimensional stability and electrical requirements.

**Circuit breakers.** Circuit breakers protect wiring systems from over-current situations and protect equipment from short circuits. Ball pressure temperature and glow wire flammability index are important requirements for domestic applications (as laid down in IEC 898). Glow wire flammability index and comparative tracking index are requirements for industrial applications, as described in IEC 947-2. The devices have to exhibit high impact resistance (polyamide is preferred above polyester) and must pass cyclic thermal and mechanical endurance tests. Akulon PA6, in the standard colours such as electro-grey RAL7035 and black, is used as well for the enclosures as well for various internal parts.

**Contactors.** Contactors connect and interrupt electrical power. In general they are subject to higher currents than switches. They can be controlled remotely, or by an integrated switch, as for example in motor starters. The main material related requirements are described in IEC 947-4 and include a glow wire flammability index of 960 °C. Also the comparative tracking index is important here, because it is strongly related to the level of design freedom of these contactors.

**Table 4. The Akulon PA6 portfolio for the low voltage switchgear segment consists of:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>K225-KS</td>
<td>halogen free, unreinforced, UL94 V-0</td>
</tr>
<tr>
<td>K222-KGV4</td>
<td>halogen free, 20% glass fibre reinforced, GWFI 960 °C</td>
</tr>
<tr>
<td>K222-KGMV14</td>
<td>halogen free, 5% glass fibre reinforced, 20% mineral reinforced, GWFI 960 °C</td>
</tr>
<tr>
<td>K-FKGS6</td>
<td>halogen containing, 30% glass fibre reinforced, UL94 V-0</td>
</tr>
<tr>
<td>K222-KMV5</td>
<td>halogen free, 25% mineral reinforced, GWFI 960 °C</td>
</tr>
<tr>
<td>K223-KMV6</td>
<td>halogen containing, 30% mineral reinforced, GWFI 960 °C</td>
</tr>
</tbody>
</table>

(note: halogen free versions of the latter two are under development)

**Contactor**

Switches and relays for industrial applications. Switches connect or interrupt electrical power. There exists a wide range of switches, like rotary switches and push buttons. Their requirements are described in IEC 947-3. The main material-related requirement is again glow wire flammability Index. The CTI plays an important role in designing these devices. This because of its relation to environmental pollution requirements. If a compact design is needed, materials should have a CTI-value as high as possible (preferably > 600 V). In many cases additionally dimensional stability is required, while thermal requirements are often not as high compared with MCB’s or RCD’s.

Industrial connectors (CEE). The CEE-connectors (CEE = International Commission on Rules for Approval of Electrical Equipment) are found in industrial environments as devices for supplying and coupling of electrical power. Important requirements for this market are laid down by the industry standard EN 60309-1. It states that connector materials supporting current carrying parts must:
- exhibit resistance to chemicals and a ball pressure of at least 125 °C
- impact resistance also at -25 °C
- UL94 V-2 and resistance to ageing up to 100 °C.

Other, more or less customer specific requirements, are:
- high stiffness to prevent creep age and possible bad connections
- high ductility because of film hinges and dovetailing interconnections
- and good flow ability because of thin sections.

This set of requirements explains why PA6 (and especially Akulon) is preferred above PBT (which has a too low impact resistance, a limited flow ability and only UL94 HB in unreinforced version) and PA66 (which is too expensive). The main Akulon grades used are F223-D (unreinforced PA, V-2), K224-G0 (PA6, 50% GF) and K223-KMV6 (PA6, 30% mineral reinforced, V-2). Some are available in company specific colours as well as in signal (cadmium free) colours.

Connector applications

The segment of connectors can be sub-segmented into:
- automotive connectors
- PCB-connectors
- industrial connectors (CEE)
- terminal blocks
- wire-to-wire-connectors
- and various other type of connectors.

Below a special emphasis is given to the sub-segments of “industrial connectors” and “terminal blocks”. Information on the other sub-segments can be obtained via our sales engineers or application development engineers.

Terminal blocks. Terminal blocks are either modular or one-piece (multi-contact). They connect individual wires by means of a screw or spring contact. They are primarily found in industrial switch cabinets and on printed circuit boards (PCB’s) to provide the wire-to-board connection. Important requirements, as described in EN 60998 and EN 60947, are:
- high levels of CTI, HWI and HAI
- and in addition, resistance to soldering heat at 260 °C (pin-through-hole, wave soldering technique). A trend is observed towards surface-mount-technology. This implies: the necessity of the application of a high temperature resistant material as Stanyl (PA46).

Other requirements are:
- halogen and phosphorous free flame retardancy (UL94 V-0 at 0.4 mm) in combination with a CTI level > 600 V
- a high flowability, because of thin sections down to 0.2 mm
- a low corrosivity in injection moulding
- a high stiffness to prevent creep age and possible bad connections
- and a high ductility because of film hinges and dovetailing interconnections.

In the case of PCB terminal blocks are also required:
- a low warp age level (necessary for a good fit to the PCB)
- and high levels of stiffness and strength, combined with low creep levels (necessary for sufficient high levels of pin retention).

The main Akulon grade used here is S225-KS (unreinforced PA66, halogen free, UL94 V-0).
Application areas outside of automotive and electrical and electronic applications, include railway systems, chair bases and general furniture applications, castor wheels, sports applications, consumer durables, building and construction and industrial goods. This important market segment makes up about 40% of the polyamide injection moulding market. Our Akulon PA6 grades are eminently suitable for use in these applications.

**Railway systems**

Railway systems comprises in most cases the insulators or railway pads. For this application good mechanical properties are required. In most cases Akulon K224-G6 is the best choice.

**Power tools**

For many years polyamide 6 has been the dominant material for power tool housings because it is heat resistant, tough and processable. The heat of electric motors and the continued downsizing of units result in high operating temperatures in power tools. And as with lawn and garden, power tool manufacturers know the abuse their units might withstand. They want materials that can take impact without failure. In power tools colours and aesthetic appeal are important. Polyamide 6 delivers exceptional surface appearance with good colour stability.

**Castor wheels**

Polyamide 6 is also the preferred material for castor wheels, which in this case means everything between furniture wheels and heavy-duty industrial applications like air cargo container wheels. Material in use is essentially unreinforced polyamide; ranging from higher viscous material like F130-C for high impact and mechanical strength to Akulon F223-D for less demanding applications.

**Sports**

Polyamide 6 is also used in large applications in sport, like ski-bindings and inline skates. DSM Engineering Plastics has extensive experience with K224-TG9 for ski-bindings, because of its excellent fatigue properties. For inline skates, Akulon K224-PG6 is used, which provides high impact and mechanical strength.

**Consumer durables**

Consumer durables are an very broad area, which includes kitchen tools, consumer tools (like hammers and screwdrivers) and garden tools (like hedge cutters, axes and scissors). Akulon K224-G6 is used for these applications, but also materials like Akulon K224-PG6 or K224-PG8 are used if impact is required for the application. The latter material provides an excellent impact/stiffness balance.

**Building & construction**

Like consumer durables, this application area is fragmented but contains one large application: wall plugs. Usually pullout force and flexibility during mounting of plugs are key requirements. Akulon F223-D and K223-P2 meet these criteria.
Polyamide 6 and 66 can be used for extrusion processes in many different applications, due to its chemical and mechanical properties, which include:
- chemical and mechanical resistance
- high impact and creep resistance
- low oxygen permeability
- resilience
- temperature resistance
- fast processing.

**Film**

Akulon 6 is our range of polyamides 6 for extrusion and injection moulding. They are commonly used for the production of mono and multiplayer films and made by cast and blown film extrusion methods. These films are mostly used for food packaging applications. The films can be both thermoformed and bi-axially stretched.

Monolayer films are used primarily in sausage casings and sauce packaging pouches. Multiplayer films are used for cheese and meat packaging and medical applications. DSM’s polyamides have excellent mechanical properties, including very high puncture resistance.

<table>
<thead>
<tr>
<th>Polyamide type</th>
<th>Viscosity</th>
<th>Additives</th>
</tr>
</thead>
<tbody>
<tr>
<td>F = PA 6</td>
<td>1 = Extraction value/food contact approved</td>
<td>C = lubricated &amp; nucleated</td>
</tr>
<tr>
<td>S = PA66</td>
<td>2 = low extraction value, basic polymer suitable for all applications incl. food contact applications</td>
<td>E = lubricated &amp; nucleated</td>
</tr>
</tbody>
</table>

They feature good barrier resistance to oxygen, carbon dioxide and aromas. Additionally they have very high transparency. Akulon 6 also excels in critical properties like purity and low gel.

In food packaging, Akulon 6 is usually used with a polyolefine material (LDPE or LLDPE). A tie layer is needed to allow co-extrusion of these materials. DSM supplies Yparex, a very suitable C8 and C6 LLDPE-based-tie-layer material. The polyolefines can also be added to monolayer polyamide films by either lamination or extrusion coating.

More information about the crystallization, barrier properties, mechanical properties and processing of Akulon 6 is available in an extended brochure.

**Semi-finished materials (stock shapes)**

Stock shapes are semi-finished materials and extruded or cast rods, mandrels, thick-walled tubes, thick sheets and profiles. They are easily machined to make all kind of products. The excellent properties of engineering plastics give them very high strength and rigidity, dimension stability, low creep, very good tribological and electrical insulation properties.

Products made from engineering plastics include all kind of bearings, gear wheels, bushes, guide rolls, guide strips, pulleys, buffers, hammer heads, seals, scrapers and electrical insulation parts. The most important engineering plastics for stock shapes are PA6, PA66, POM and PET. DSM Engineering Plastics offers PA6, PA66 and PET.

Polyamide is frequently used in mono & multilayer films. In multilayer film for food packaging PA6 exhibits high mechanical protection due to an excellent puncture resistance, good barriers against $O_2$ and aroma’s, and a very high level of transparency.
The main characteristics of PA6 and PA66 are:
- high mechanical strength, rigidity, hardness and toughness
- good shock absorption
- good resistance to fatigue
- good sliding and bearing properties, both dry and lubricated
- excellent wear properties
- good electrical insulation properties.

**PA6.** The combination of mechanical strength and rigidity with wear resistance, together with an excellent electrical insulation and good chemical resistance, make PA6 an ideal ‘universal’ material for industrial and maintenance parts. It is also suitable for use in dirty or sandy environments, for example for bearings on agricultural equipment, or support rolls for tracks.

**PA66.** Compared with PA6, PA66 has slightly better tensile strength, rigidity, temperature resistance and wear behaviour. However, the mechanical extinction and the impact strength are moderately lower.

There is a more extended brochure on this subject available. This also includes PET and a comparison of DSM materials to POM.

**Convoluted tubes**

Akulon is an excellent material to use as tube for the protection of electrical wiring and cables. Due to its higher temperature resistance, flexibility and chemical resistance, these tubes are often used in under-the-bonnet applications in the automotive industry. The requirements for tubes in these segments, as well as in the electrical/electronic markets, are very strict, especially on the chemical and thermal properties of the material.

Still, in the machine construction market metal tubing is being used to a great extent. But due to its weight and better flexibility, there is a trend to use plastics more and more often. An emphasis on halogen free material and safety issues, like smoke density, levels direct material towards polyamide.

### Table 6: Film grades.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F126-C</td>
<td>Grade with low viscosity, applicable for multilayer film</td>
</tr>
<tr>
<td>F132-E</td>
<td>Grade with medium viscosity, nucleated for flat film</td>
</tr>
<tr>
<td>F136-C</td>
<td>Grade with high viscosity, applicable for flat and blown film</td>
</tr>
<tr>
<td>F136-E</td>
<td>Grade with high viscosity, nucleated for blown film</td>
</tr>
<tr>
<td>F136-EN</td>
<td>Grade with high viscosity, improved thermoformability</td>
</tr>
<tr>
<td>S240-C</td>
<td>Grade with high viscosity, applicable for blown film</td>
</tr>
</tbody>
</table>

### Table 7: Semi-finished grades.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F136-C</td>
<td>High viscosity PA6 grade for rods and sheet</td>
</tr>
<tr>
<td>F150-CZ</td>
<td>Very high viscosity PA6 grade for big rods and vacuum seized thick-walled tube</td>
</tr>
<tr>
<td>F160-Z</td>
<td>Highest viscosity PA6 grade for thick-walled vacuum seized tube</td>
</tr>
<tr>
<td>S240-C</td>
<td>High viscosity PA66 grade for rods and sheet</td>
</tr>
<tr>
<td>S245-C</td>
<td>Very high viscosity PA66 grade for big rods and thick-walled vacuum seized tube</td>
</tr>
</tbody>
</table>

### Table 8: Convoluted tube grade.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F136-DH</td>
<td>Heat stabilized grade for convoluted tubes.</td>
</tr>
</tbody>
</table>
Akulon polyamide 6 and 66 are semi-crystalline engineering thermoplastics. In their solid state they show regular crystalline structures dispersed in an amorphous phase. This basic characteristic is what determines how the products react to heat, chemical attack, glass reinforcement, or any number of other stimuli.

**Dimensions**

All thermoplastic materials shrink as they cool from their melt temperature. Crystalline materials like Akulon, tend to shrink much more than amorphous materials. The addition of filters and reinforcements to crystalline materials has a dramatic reducing effect on mould shrinkage (see Figure 1).

Unreinforced and mineral filled Akulon grades are largely isotropic with respect to shrinkage. Shrinkage in the direction of flow is more or less equal to shrinkage across flow. On the other hand, glass reinforced grades show anisotropic properties. Due to fibre orientation, shrinkage values in the direction of flow are often substantially smaller than shrinkage values across the direction of flow. This is the basic reason for the warpage which often occurs in parts moulded with glass reinforced crystalline materials.

Moisture absorption plays a major role in the prediction of dimensions in Akulon materials (see Figure 2). Moisture absorption is a time and humidity dependent, reversible process, which continues until equilibrium is reached. A change in the moisture content will result in different product dimensions. During the use of the product the designer should anticipate varying humidity conditions. The moisture absorption of reinforced grades differs from those of reinforced grades. Moisture also effects other important properties (however mainly at temperatures below 100 °C).
Yield stress, modulus of elasticity and hardness decrease with increasing moisture absorption. Toughness, or impact resistance, shows considerable increase.

**Surface appearance**

Some Akulon polyamides are capable of a high level of reproduction of the mould surface. In general, unreinforced grades offer the best reproduction and glass reinforced the worst. Mineral filled grades fall somewhere in between. Polyamide 6 will almost always reproduce a mould surface more accurately than polyamide 66. All these guidelines are particularly true of high gloss moulds. Often textures can be used to hide the surface imperfections inherent to moulding these products.

**Wall thickness**

Performance requirements determine the wall thickness of a given part. Wall thickness should be minimized to shorten moulding cycles, reduce part weight and optimise material usage. The minimum wall thickness, which can be used in injection moulding, depends on the size and geometry of the part and the materials flow behaviour. In general, Akulon type 6 grades flow easier than type 66 materials.

Uniform wall thickness assists consistent even filling of the mould and results in more predictable shrinkage. When varying wall thickness are unavoidable for reason or design, there should be gradual transitions.

**Corners and radii**

Sharp internal corners and the resulting stress risers are among the most common causes of structural plastic product failure. All polyamides are somewhat notch sensitive and glass reinforced versions are particularly susceptible. The stresses arising from internal corners can be minimized by the use of generous radii. In general, internal radii equal to one half the wall thickness best distributes the loads over the surface of the part. Smaller radii causes stress concentrations. Larger ones do not significantly help the situation. External corners should maintain a constant wall thickness around the radius of the internal corner. This reduces variations in wall thickness and helps prevent warpage and sinks.

**Ribbing**

Ribs provide a number of advantages to the part designer. They may increase strength and stiffness. They can reduce weight and shorten cycle times by eliminating heavy cross sections, which can substantially reduce costs. Ribs have their problems, however. Sink marks may appear on the surface opposite the ribs. Often these can be hidden by the strategic use of texture. If proper design rules are not followed, ribs may also cause stress at their intersection with the wall of the part. They can be helpful for the product designer if they are only used when they are necessary to provide the mechanical performance of the application.

**Assembly**

Akulon polyamides are suitable for a number of assembly techniques, including heat staking, sonic welding, moulded-in or post-mould-insertion threaded inserts and snap fits. While making allowances for any of these assembly methods, the designer should keep in mind the standard design rules for polyamides, i.e. avoiding notches or - in the case of snap fits - exceeding the strain limits of the material, etcetera.

While adhesive bonding of polyamides has been done successfully, the superior chemical resistance makes this a difficult option. For the best results, the recommendations of the adhesive manufacturer should be followed precisely.

Both heat staking and ultrasonic welding are used to stake or weld Akulon. Other welding techniques frequently used in combination with Akulon are vibration and laser welding. PA6 grades usually outperform PA grades with respect to the weld strength achieved after the welding process. Lower filler content grades typically perform better and cause fewer processing problems than highly reinforced versions do.

**Tailgate handle**

Akulon K224-HG6.
Machinery

Akulon polyamides can be processed on standard plastic processing equipment. Typically, general purpose screw designs (i.e. compression ratios of about 2.5:1) and sliding check rings work best. For unreinforced grades, polyamide or reverse taper nozzles work well, while reinforced grades typically do better with general purpose nozzles. These tend to reduce shear and provide better mechanical properties and, since the reinforcement inhibits drool, the reverse taper of a polyamide nozzle doesn’t add much benefit.

Tooling. Akulon polyamides need similar specific tooling requirements as other polyamide materials. For unreinforced Akulon, the gates and runners can be very small, to save material scrap and reduce cycle times. Larger parts and/or more highly reinforced materials require more generous gates and runners. However, sub-gates are the most common because of their automatic de-gating capability.

Most of the major hot manifold manufacturers have built manifolds which have been successfully used with Akulon polyamides.

Unreinforced materials use polyamide or long reversed tapered nozzles to reduce drool. Reinforced products generally work better with general purpose nozzles.

It is very difficult to accurately predict shrinkage for highly crystalline materials. Unreinforced polyamides tend to have very high shrinkage. In glass reinforced grades transverse shrinkage may be 50% to 100% more than the linear shrinkage value reported in most product data sheets. As a result, glass reinforced polyamide parts have a propensity to warp during the post-mould shrinkage phase. For precision parts with very tight dimensional tolerances, it is best to build a prototype mould. It requires the same gate type, size, location, etcetera as the production mould to predict shrinkage and warpage accurately.

Material handling

Akulon granules are supplied dry in airtight moisture proof packing. It is important to prevent moisture absorption before moulding, when working with polyamides. Akulon is hygroscopic and absorbs moisture from the air relatively quickly. Should this occur prior to moulding, there can be an adverse effect on the quality of the moulding. During storage, containers should be kept closed and undamaged.

During moulding the following measures are recommended:
- open the container just before filling the hopper
- close the container securely if all contents have not been used
- keep the hopper closed
- bring cold granules up to ambient temperature in the moulding shop while keeping the containers shut.

Every batch is tested for moisture content and viscosity level after production. A certificate with relevant lot data can be delivered with the materials.

Room-installation

Akulon K222-KGMV14, K223-HM6 and K225-KS.
All polyamides are hygroscopic and require special handling to prevent the absorption of moisture from the atmosphere. Akulon polyamides are packaged at a maximum level of 0.15% moisture content. Moisture levels above 0.2% will cause surface splay on the moulded parts.

In order to achieve the best appearance and performance Akulon polyamides should be dried to the recommended levels. The equipment for this task includes desiccant bed dryers, which are capable of holding the dew point of the circulating air to between -40 and -30 °C.

**Safety.** Under normal conditions, Akulon does not present a toxic hazard through skin contact or inhalation. During processing contact with the polymer and inhalation of fumes should be avoided. A material safety data sheet (MSDS) can be requested from your local DSM account manager.

**Cylinder temperatures.** Akulon polyamide 6 with a melting point of 220 °C, can be processed within a broad temperature range, for example 230-290 °C. The melting point of Akulon polyamide 66 is 260 °C. It can be processed at temperatures between 270 and 300 °C (see Figure 3 for recommended processing parameters). Keep in mind that these can vary depending on the specific grade and the size and condition of the moulding machine.

**Use of regrind.** Regrinding levels of 25% hardly influence short and/or long term properties of Akulon. They are therefore recommendable under the prerequisite that the regrind must be dry as moulded and free from dust and/or longs.

---

**Figure 3. Guideline for cylinder temperatures.**

<table>
<thead>
<tr>
<th>Akulon Polyamide 6</th>
<th>Mould</th>
<th>Melt</th>
<th>Nozzle</th>
<th>Front</th>
<th>Center</th>
<th>Rear</th>
<th>Drying</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass Reinforced</td>
<td>55-95</td>
<td>280-305</td>
<td>280-295</td>
<td>275-290</td>
<td>290-300</td>
<td>280-295</td>
<td>80</td>
</tr>
</tbody>
</table>

*Relay box*  
Akulon K224-HGR24.
Characteristics properties of Akulon (PA6 and PA66)

Positioning Akulon in the world of thermoplastics

Polyamides are characterized by the presence of amide-groups (-NH-CO-) in the main polymer chain. Chemically the aliphatic polyamides may be divided into two types:
- those based on diamines and diacids (like PA66 and PA46). PA66 is produced by a polycondensation reaction from hexamethylene diamine and adipic acid
- those based on amino acids or lactams (like PA6, PA11 and PA12). PA6 is produced in a ring-opening polymerization process starting from caprolactam.

Commercial use of the aliphatic polyamides is dominated by PA6 and PA66. They are characterized in Table 9.

The Akulon product line comprises both polyamide 6 (PA6) and polyamide 66 (PA66) grades. PA6 and PA66 belongs together with the polyesters PET and PET and the polyacetal POM to the segment of semi-crystalline engineering plastics. Semi-crystalline indicates that these materials contain a certain fraction of crystalline domains. They are to a large extent responsible for the excellent temperature and chemical resistance. The materials in this segment do yield a higher temperature resistance (short term as well as long term) than the commodity materials (like PE, PP, PS and PVC and the amorphous engineering plastics ABS, PC and ABS/PC). Only materials belonging to the high performance material segment (like PA46, PPS, PEI, PES and LCP) do exhibit an even higher temperature resistance.

Table 9: Characteristics of aliphatic polyamides.

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Tm (°C)</th>
<th>Tg (°C)</th>
<th>HDT* (°C)</th>
<th>Crystallinity Level/Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA6</td>
<td>220-225</td>
<td>60</td>
<td>210</td>
<td>30-50/medium-fast</td>
</tr>
<tr>
<td>PA66</td>
<td>260-265</td>
<td>65</td>
<td>255</td>
<td>50/fast</td>
</tr>
<tr>
<td>PA46</td>
<td>295</td>
<td>80</td>
<td>290</td>
<td>70/ultrafast</td>
</tr>
</tbody>
</table>

* for GF-contents > 30 %.

The main characteristics of Akulon PA6 and PA66 are:
- an excellent short term heat resistance due to the high melting points of 220 °C and 260 °C
- high stiffness and strength at elevated temperatures above 100 °C
- high creep resistance, especially at elevated temperatures
- good long-term heat resistance, especially when expressed in absolute stiffness/strength levels measured at elevated temperatures after the heat ageing exposure in air. This is called the Absolute Real Operating (ARO) value concept
- outstanding toughness behaviour, especially important at low temperatures (23 °C and -40 °C), excellent fatigue resistance behaviour
- good resistance against oils and chemicals
- fast cycling properties combined with an excellent flow behaviour at processing temperatures, without showing any signs of flash
- limited dimensional stability due to the absorption of moisture.

This combination of properties, which will be discussed more detailed in the following chapters, makes Akulon excellently suitable for high performance technical applications in the automotive, electrical/electornical and general, other industries. In the following sections PA6 and PA66, among themselves, are compared with the polyesters PBT and PET.

Temperature performance

The temperature performance of every engineering plastic can be described by:
- a peak temperature resistance or a short term temperature resistance, as indicated by a melting point, a Vicat or a Heat Distortion Temperature and/or a certain level of stiffness and strength at a certain elevated temperature
- resistance to long-term heat exposure and oxygen containing environment at higher temperatures in combination with or without an applied load

Power tool

- with load: creep resistance, respectively without load: Continuous Use Temperature or Absolute Real Operating-value.

**Short term heat performance.** In today’s high tech world the performance of engineering plastics over a wide temperature range is often of critical importance. An indication for the short-term temperature performance of a material is its stiffness and strength level at elevated temperatures. For instance, between 100 °C and 200 °C the stiffness/strength level should be considered as is the critical level to design for, since room temperature levels for stiffness/strength are much higher (even after moisture absorption) in general.

The shear modulus offers one of the means of measuring and comparing the variation of the *stiffness* of plastic materials with changing temperature. Its high level of crystallinity in combination with its high melting point enables Akulon to retain its stiffness to a high extent at elevated temperatures. This ensures either more safety margins for critical applications in comparison to other competitive materials like polyesters (see Figure 4). It also implements the possibility of the reduction of the wall thickness of the part. It also should be noted that up to 185 °C there is hardly any difference between the stiffness of PA6 and that of PA66. Only above 185 °C PA66 exhibits a clear advantage.

**Figure 4a. Stiffness versus temperature**

**Figure 4b. Stiffness versus temperature**

**Engine cover**
Akulon K220-HGM44.
Stanyl (PA46) of course outperforms both polyamides with respect to stiffness and strength at all elevated temperatures because of its higher crystallinity level.

Other indicators of the stiffness level are more suitable as a design criterion than the shear modulus (as used in Figure 4). Think of the elasticity and/or the flexural modulus. Polyamides properties like these and tensile or flexural strength merely depend on ambient temperatures, moisture contents, heat ageing exposures, reinforcements or other additives (lubricants, pigments) and moulding conditions. For an example see Table 10, where, by adding reinforcements, stiffness levels are increased significantly. The high stiffness of Akulon at elevated temperatures (especially above 100 °C) offers new opportunities for designing with thin walled parts thus achieving cost and weight reductions.

<table>
<thead>
<tr>
<th>Property</th>
<th>PA6</th>
<th>PA66</th>
<th>PA46</th>
<th>PBT</th>
<th>PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-modulus (MPa)</td>
<td>Unreinforced</td>
<td>Unreinforced</td>
<td>Unreinforced</td>
<td>Unreinforced</td>
<td>Unreinforced</td>
</tr>
<tr>
<td>23 °C – dam</td>
<td>3600</td>
<td>3300</td>
<td>3300</td>
<td>2700</td>
<td>2500</td>
</tr>
<tr>
<td>23 °C – 50% RH</td>
<td>1600</td>
<td>1600</td>
<td>400</td>
<td>2700</td>
<td>2500</td>
</tr>
<tr>
<td>150 °C</td>
<td>400</td>
<td>1000</td>
<td>700</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>E-modulus (MPa)</td>
<td>30% GF reinforced</td>
<td>30% GF reinforced</td>
<td>30% GF reinforced</td>
<td>30% GF reinforced</td>
<td>30% GF reinforced</td>
</tr>
<tr>
<td>23 °C – dam</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
<td>11000</td>
</tr>
<tr>
<td>23 °C – 50% RH</td>
<td>6000</td>
<td>6500</td>
<td>6500</td>
<td>10000</td>
<td>11000</td>
</tr>
<tr>
<td>150 °C</td>
<td>4000</td>
<td>4000</td>
<td>5000</td>
<td>2700</td>
<td>3000</td>
</tr>
<tr>
<td>170 °C</td>
<td>3500</td>
<td>3500</td>
<td>4700</td>
<td>2400</td>
<td>2700</td>
</tr>
<tr>
<td>E-modulus (MPa)</td>
<td>50% GF reinforced</td>
<td>50% GF reinforced</td>
<td>50% GF reinforced</td>
<td>50% GF reinforced</td>
<td>50% GF reinforced</td>
</tr>
<tr>
<td>23 °C – dam</td>
<td>16000</td>
<td>16500</td>
<td>17000</td>
<td>18000</td>
<td>18000</td>
</tr>
<tr>
<td>23 °C – 50% RH</td>
<td>10000</td>
<td>11000</td>
<td>10500</td>
<td>18000</td>
<td>18000</td>
</tr>
<tr>
<td>150 °C</td>
<td>5500</td>
<td>6000</td>
<td>8000</td>
<td>4000</td>
<td>5500</td>
</tr>
</tbody>
</table>
The melting point in combination with the Heat Distortion Temperature (HDT) gives another good impression of the peak temperature resistance under a certain load. The HDT is the temperature at which a test bar is deformed to a given extent. This is related to a certain level of stiffness at the elevated temperature. Because of its excellent retention of the stiffness at higher temperatures the HDT-rating of Akulon (210 °C for 30% glass fibre reinforced PA6 and 255 °C for PA66) is higher than that of other engineering plastics (PBT yields only 190 °C).

**Long Term Temperature Performance: creep Resistance at elevated temperatures.** For optimum performance and maximum lifetime engineering plastics, which are subjected to long-term loading, must have a high creep resistance (i.e. a low plastic deformation level under a certain applied load). Materials specifications for engineering parts therefore often include a creep modulus, defined as the ratio of a constant load and a time dependent deformation level, or a maximum allowable elongation. Exposure to higher temperatures results in lower levels of creep moduli. Akulon’s high level of crystallinity results in a high retention of the stiffness at elevated temperatures (above 100 °C). It therefore gives rise to a creep resistance that is superior to that of other engineering plastics. Again, up to certain temperatures and exposure times PA yields a similar performance as PA66 (see Figure 5).
Heat ageing resistance in air.
Designers must know the performance level of the material after exposure of thousands of hours to heat in an oxygen environment. The performance (the heat air ageing resistance) can be expressed in various ways. To monitor the performance after heat ageing over time, different parameters can be selected, like strength, stiffness, impact resistance, elongation at break measured either at room temperature (see Figure 6) or at the elevated temperature. Again, the results of these measurements can be displayed in various ways. In a relative way via retention levels or via relative characteristics like Continuous Use Temperature (CUT) and Relative Temperature Index (RTI), or in an absolute way like in the Absolute Real Operation Value concept (which shows the absolute value of strength measured for instance after ageing for 5000 hours at 150 °C).

The Continuous Use Temperature is frequently used in the automotive industry as a selection criterion. It is defined as the temperature at which a given mechanical property (usually tensile strength or impact resistance, since stiffness only increases after heat ageing and since tensile elongation shows a too sharp, non discriminating drop for all materials) of the material decreases by 50% within a certain period of time (usually 500, 1000, 5000, 10,000 of 20,000 hours). From Figure 7 and 8 it follows that the CUT of 30% glass fibre reinforced Akulon PA6 at 5000 hours is 185 °C (the drop in tensile strength is 50% after 5000 hours of aging at 185 °C). This result is higher than that of 30% glass fibre reinforced PA66, which shows a 50% drop already after 5000 hours at 170 °C.

The Relative Temperature Index as given by UL, frequently used in E&E, can be considered to a certain extent as a CUT for very long half lifetimes, ranging...
between 60,000 and 100,000 hours. Also here, the RTI of 140 °C for heat stabilized PA6 30% GF proves to be superior to the one of 130 °C for PA66.

**Absolute Real Operating Value** after heat ageing yields for designers more realistic comparisons between the various materials since it overcomes the major drawbacks of the CUT- and the RTI-concept: in these last concepts only retention of properties is considered and properties are only measured at room temperature after the heat ageing. Certain materials, starting at a very low level but retaining to a high degree, are better rated in CUT-terms than other materials that start at a higher level and show a stronger reduction. The latter however can in absolute values still outperform the former materials after the heat ageing exposure. Next to that, the CUT-concept is based on measurements of properties at room temperature, whilst the more critical design levels for stiffness and strength are to be expected in the elevated temperature range (as demonstrated in Short Term Heat Performance). The ARO-concept, the only true measure, is demonstrated in Figures 9 to 12, which show once more the superiority of PA6 to PA66 after heat ageing (see also Table 11). The ARO-performance of Akulon PA6 comes even close to that of various aromatic polyamides (PPA). Only Stanyl (PA46) outperforms PA6 and PPA in this respect. From the combination of these curves with curve 5 it follows that, despite the slight, non-significant difference in starting value for stiffness and strength, heat stabilized PA6 with 30% glass fibre easily can replace heat stabilized PA66 with 30% glass fibres!

**Table 11. Heat Ageing Resistance and Stiffness of various 30% GF reinforced polyamides.**

<table>
<thead>
<tr>
<th>Property</th>
<th>PA6</th>
<th>PA66</th>
<th>PA46</th>
<th>PPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARO 5000 hrs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength at high temp. (MPa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150 °C</td>
<td>80</td>
<td>70</td>
<td>110</td>
<td>90</td>
</tr>
<tr>
<td>170 °C</td>
<td>70</td>
<td>50</td>
<td>90</td>
<td>80</td>
</tr>
<tr>
<td>CUT 5000 hrs (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>185</td>
<td>185</td>
<td>130-170*</td>
<td>170</td>
<td>185</td>
</tr>
<tr>
<td>E-modulus (MPa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150 °C</td>
<td>4000</td>
<td>4000</td>
<td>5000</td>
<td>4000</td>
</tr>
<tr>
<td>170 °C</td>
<td>3500</td>
<td>3500</td>
<td>4700</td>
<td>3500</td>
</tr>
</tbody>
</table>

Note: ARO is the only true measure for heat ageing resistance.

**Clutch pedal**
Akulon K224-HG8.
Figure 9. Tensile strength (23 °C) after heat ageing at 150 °C.

Figure 10. Tensile strength (150 °C) after heat ageing at 150 °C.

Figure 11. Tensile strength (23 °C) after heat ageing at 170 °C.

Figure 12. Tensile strength (170 °C) after heat ageing at 170 °C.
**Toughness, fatigue and wear properties**

Whilst tensile and flexural stiffness and strength decrease with increasing temperatures (similar curves as tensile and flexural modulus), toughness levels (elongation at break, impact resistance) increase with increasing temperatures. The critical level to be designed for is therefore not the level at elevated temperatures, but the level at room temperature (23 °C) or lower (-30 or -40 °C). Even at temperatures below 0 °C the notched and unnotched impact resistance values of Akulon remain at a high level. As can be seen from Table 12 even in a dry-as-moulded (dam) state the polyamides outperform the polyesters, which facilitates production and assembly steps. Combined with an unequalled level of elongation at break Akulon offers an optimal solution for thin walled parts, snap fits, film hinges and insert mouldings. Table 12 also shows that **PA6 is again superior to PA66 and that the effect of different amounts of glass fibre reinforcement is different for both toughness parameters. The elongation at break level decreases, whilst the Charpy and Izod impact resistance increases with increasing the amount of glass fibres.**

Engineering parts are frequently subjected to dynamic loads and alternating stress levels. In order to predict the performance of plastic materials under these conditions the fatigue resistance is measured by plotting the stress level variation against the number of cycles till break endured under continuous prestress (the so called ‘Wöhler diagrams’). The high stiffness level in combination with the high toughness and the use of superior glass fibre qualities implies a superior fatigue resistance for Akulon in comparison to that of most other engineering plastics. **Akulon has an excellent abrasion (or wear) resistance.** It outperforms many other engineering plastics, like POM, under most conditions but especially at elevated temperature conditions. The friction coefficients of standard grades of these thermoplastics are quite similar, but Akulon can outperform these materials because of its higher PV-rating (see Figure 13).

It permits higher pressures or velocities to be used in combination with Akulon. Modified Akulon grades (unreinforced as well as glass fibre reinforced) are available with even better wear properties. They make external lubrication redundant. Its smooth and tough surface, combined with its stiffness at elevated temperatures, makes Akulon an ideal material for sliding parts.

---

**Table 12. Toughness at room temperature of polyamides (dam) versus polyesters.**

<table>
<thead>
<tr>
<th>Property</th>
<th>PA6 UF</th>
<th>PA66 UF</th>
<th>PBT UF</th>
<th>PET UF</th>
<th>PA6 30% GF</th>
<th>PA66 30% GF</th>
<th>PBT 30% GF</th>
<th>PET 30% GF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Elongation (%)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Charpy Notched (kJ/m²)</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Charpy Unnotched (kJ/m²)</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>22</td>
<td>17</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Tensile Elongation (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.5</td>
<td>3.0</td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td>- dry as moulded</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>- conditioned at 50% RH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>180</td>
<td>185</td>
<td>140</td>
<td>160</td>
</tr>
<tr>
<td>Tensile Strength (Mpa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Charpy Notched (kJ/m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.0</td>
<td>2.5</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>- dry as moulded</td>
<td></td>
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<td></td>
<td></td>
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<td>80</td>
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<tr>
<td>- conditioned at 50% RH</td>
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<td>Charpy Unnotched (kJ/m²)</td>
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<td></td>
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<td>17</td>
<td>11</td>
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<tr>
<td>Tensile Elongation (%)</td>
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<td></td>
<td>100</td>
<td>85</td>
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**Inline skate**
Water absorption and hydrolysis resistance

Like most polyamides, Akulon absorbs moisture reversibly from the environment until it reaches an equilibrium (see Figure 14). **PA6 absorbs more water than PA66**, especially under high humidity conditions. But the resulting **dimensional change is still of a similar order**. The use of polyamides is not recommended when dealing with applications with very tight tolerances. This with respect to dimensions. In this case polyesters could be considered. Although it should be checked whether their hydrolysis resistance level is appropriate, because the hydrolysis resistance of polyesters is rather poor. Polyamides are superior with respect to this. Note however, that for many applications the dimensional stability of polyamides is ‘good enough’!

Absorbed water acts as a plasticiser reducing strengths and moduli (see Table 10) and increasing the toughness of a plastic (see Table 12). Although at room temperature the stiffness and strength of PA6 is more reduced by the moisture uptake than those of PA66, this difference can be considered to be non-significant. This because Akulon is mainly being used in market segments, which have temperature requirements above 100 °C. This leads to the critical design level to be located at the elevated temperature (strength at 150 °C is still lower than the conditioned value at 23 °C) and thus rendering the influence of the water absorption on mechanical properties to be in general negligible.

Cable channels

Akulon K224-HLG3.
Polyamides are well known for their resistance to a wide range of chemicals. Especially, when expressed again via the ARO-concept, Akulon’s good resistance to different types of oil (see Figure 15) and greases makes it an ideal material for applications in the automotive industry - particularly under-the-bonnet - and for industrial applications in gears and bearings. Akulon is like other polyamides attacked by strong mineral acids and absorbs polar solvents.

Note: polyesters are attacked by strong base solvents and also by moisture (hydrolysis). On request, data concerning the resistance of Akulon to various chemicals and solvents are available from your local DSM sales office.

Electrical properties, flammability and UL-classifications

As most other engineering plastics Akulon exhibits similarly high levels of surface and volume resistivity, dielectric strength and comparative tracking resistance. The exact levels of these properties depend however on the specific grade, temperature and moisture content. In general, these levels will remain high enough in order to fulfil critical application requirements. This fact, in combination with its very high peak temperature resistance and its high toughness level, makes Akulon an excellent choice for electrical and electronical connectors, circuit breaker housings, electromotor parts, bobbins and switches.

A number of halogen free or halogen containing flame retardant grades of Akulon are available, rated according to the Underwriter Laboratories (UL) 94 classification, either V-0 or V-2 (GWFI of 960 °C at 1.6 mm). The unmodified, unreinforced Akulon grades are rated V-2 and the glass fibre reinforced grades without flame retarder are rated HB. Several other UL-classifications have been obtained for different Akulon grades as well (see UL File E 47960 Components Plastics at UL’s website data.ul.com). A complete overview of the total system rating and more detailed information concerning optimal processing with Akulon is available at your DSM Sales Office.

Power steering fluid tanks

Akulon F232-D.
After treatments

Plastic parts often have to undergo a finishing operation after the actual production step. This step can either be functional (machinging, gluing, wending, screwing or snap fitting) or decorative (vacuum metallization, electroplating, painting, printing or laser printing). In general, with respect to these after treatments the same recommendations as for the aliphatc polyamides are applicable for Akulon. Because of its relatively high polarity, the adhesion behaviour of Akulon usually will be quite good, especially when the finishing technique is applied on ‘dry as moulded’ parts. Welding (vibration, ultrasonic, laser) and/or snap fitting are the preferred bonding techniques for Akulon. Welding should be performed with ‘dry as moulded’ parts in order to achieve optimal weld strengths and to avoid blistering and severe polymer degradation. Note that PA6 grades offer in general a much higher weld strength, resulting in higher burst pressure levels, than corresponding PA66 grades. By its superb level of elongation at break - especially after moisture uptake - (see Table 12) snap fits designed in Akulon offer many advantages in comparison to the other joining techniques.

Decorative finishing techniques on Akulon are next to the decorative reason applied for reasons like product liability (printing and laser printing) or functionality (metallization). Due to the better surface appearance of reinforced grades, PA6 grades are preferred above the corresponding PA66 grades. More detailed information is available at your DSM Sales Office.

Basic comparison polyamides versus polyesters and PA6 versus PA66

In the previous sections PA6 and PA66 are compared with polyesters and among themselves. In this section and in Figure 16 a short positioning resume is presented.

Polyamides versus polyesters

Advantages of polyamides:
- higher stiffness and creep resistance at elevated temperatures (above 100 °C)
- better heat ageing resistance in terms of the ARO-values at elevated temperatures
- higher toughness at low temperatures;
- more fatigue resistance
- excellent wear resistance
- less sensitivity for hydrolysis in the applications and for moisture during processing
- halogen free flame retardancy in reinforced PA6 grades is possible.

Advantages of polyesters:
- better dimensional stability under humid conditions
- better retention of electrical properties as function of temperature and/or humidity
- more chemical resistance in acetic environments.

**Polyamide 6 versus polyamide 66**

Advantages of PA6:
- better heat ageing resistance in terms of the ARO-values at elevated temperatures
- higher toughness at low temperature
- easier process ability (broader processing window)
- higher weld strength after various welding processes
- better surface appearance for reinforced grades
- halogen flame retardancy in reinforced PA6 grades is possible.

Advantages of PA66:
- higher melting point
- more stiffness/strength only above 185 °C.

The advantages above can lead to substantially increased profit and/or safety margins in your applications. Higher stiffness levels at elevated temperatures and higher ARO-values imply for instance either savings on material costs, through the possibility to reduce the wall thickness of the application, or a higher safety margin, when keeping the wall thickness the same. An easier process ability (a broader processing window in combination with a lower melting point) leads to a possibility to achieve lower processing costs as a result of lower energy costs and/or lower cycle times (due to the lower melting point) or to a possibility to reduce wall thickness even further as a result of a better flowability of the material by using higher processing temperatures. Higher toughness levels leads to lower reject levels in production or like higher weld strengths to higher safety margins in the applications, whilst better surface appearance leads to an improved image in the market place.

Thus in summary, a lot of economical reasons to choose Akulon (especially the PA6 product line) as the most optimal material for most of your applications!
### DSM Engineering Plastics product portfolio

<table>
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<tr>
<th>Material</th>
<th>Description</th>
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<tr>
<td><strong>Akulon®</strong> polyamides</td>
<td>Polyamide 6 and 66 in both unreinforced and reinforced grades, including flame retardant products.</td>
</tr>
<tr>
<td><strong>Akulon® Ultraflow™</strong> polyamide</td>
<td>Polyamide 6 reinforced grades, easy flowing, lower processing temperatures, faster crystallization speed, shorter injection and holding time, reduced cycle time.</td>
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<tr>
<td><strong>Akulon® XP</strong> polyamide</td>
<td>Xtreme Performance PA6 for film</td>
</tr>
<tr>
<td><strong>Arnite®</strong> thermoplastic polyester</td>
<td>PBT and PET based materials, including unreinforced, reinforced, and flame retardant grades, offering excellent dimensional stability and low creep with good chemical resistance.</td>
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<tr>
<td><strong>Arnitel®</strong> copolyester elastomers</td>
<td>High performance elastomers based on polyester.</td>
</tr>
<tr>
<td><strong>Stamylan® UH</strong> ultra high molecular weight polyethylene</td>
<td>A high performance polymer having outstanding abrasion resistance in combination with excellent impact and chemical resistance, low coefficient of friction and very good electric and dielectric properties.</td>
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<tr>
<td><strong>Stanyl® PA46</strong> 46 polyamide</td>
<td>High temperature polyamide which bridges the price-performance gap between traditional polyamides and high-performance materials.</td>
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<tr>
<td><strong>Stanyl® PA46 High Flow™</strong> 46 polyamide</td>
<td>An innovative PA46 which combines excellent mechanical performance with (LCP-like) high flow and low warpage resulting in cost-savings for demanding high-end applications.</td>
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<td><strong>Stapron®</strong> PC/PET-blend</td>
<td>Unreinforced and reinforced PC-blends. Flame retardant grades based on halogen free systems.</td>
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<tr>
<td><strong>Xantar®</strong> polycarbonate</td>
<td>Unreinforced, reinforced, and flame retardant grades with outstanding impact resistance, dimensional stability, and high heat deflection temperature.</td>
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<td><strong>Xantar® C</strong> PC/ABS-blend</td>
<td>A new generation PC/ABS-blend providing improved flow, simultaneously increasing impact and stress-crack resistance, while optical appearance and stability are on a very high and consistent level.</td>
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<tr>
<td><strong>Yparex®</strong> adhesive resin</td>
<td>This family of extrudable adhesive resins consists of polyolefins with incorporated functional groups, which provide the necessary bond between polyolefins and polar materials (e.g. PA, EVOH, glass) or metals (e.g. steel, aluminium, brass, copper).</td>
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*Registered tradenames of DSM*
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