BASF Plastics
key to your success

Ultramid®

Polyamides (PA)

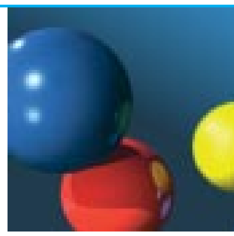
Applications
Product range
Properties
Processing

Advantage 4U

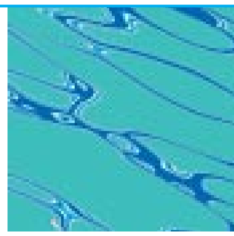
BASF

The Ultramid grades are polyamide molding compounds based on PA 6, PA 66 and various copolymers such as PA 6/66, PA 66/6 and partly aromatic polyamide. Due to their outstanding properties these materials have become indispensable in almost all fields of engineering for the most varied components and machine parts, as high-quality electrical insulating materials and for many special applications. Ultramid is exceptional for its high mechanical strength, rigidity and thermal stability. Moreover, Ultramid affords good impact resistance even at low temperatures, advantageous sliding friction properties and problem-free processing.

Ultramid, the material of choice ...

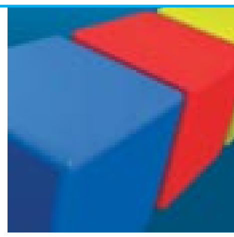


The properties of Ultramid



Ultramid in processing

General information



Ultramid, the material of choice...
...in today´s automotive sector

The very high demands on quality and safety in modern automotive engineering impose high requirements on the materials employed. Ultramid offers high thermal stability, dynamic strength, impact resistance and long-term performance. These engineering properties of Ultramid can be combined in exceptional manner with intelligent concepts in today´s automotive industry. Here, on account of its broadly based functionality Ultramid has great potential for the economically optimized production of structural components and modules. Further criteria such as lightweight construction, recyclability and integrated system solutions combining different materials demonstrate the superiority of Ultramid by comparison with conventional materials.

Accordingly, the use of engineering plastics such as Ultramid in the automotive industry will continue to rise significantly. Even today in some models, e.g. the 1998 model of the BMW 321i, up to 25 kg of polyamide are built in.

Typical Ultramid applications in automotive engineering

Parts in the engine block and in engine lubrication, e.g. camshaft timing gears, chain guides, toothed belt covers, air intake modules, engine covers, oil sumps, oil filter housings, valve bonnet and cylinder head covers.

Parts and housings for cooling and ventilation systems, e.g. radiator tanks and heat exchangers for heating purposes, water expansion tanks, hot-water control valves, thermostat housings, fans, fan cowls and frames.

Parts in the fuel supply system, e.g. fuel filter housings, fuel reservoirs and lines.

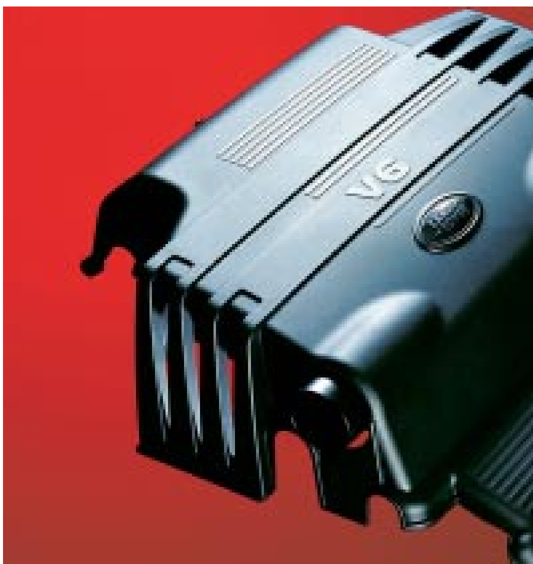
Parts in gears, clutches, clutch thrust bearings, gearshifts and speedometer drives, such as bearing cages, gearshift-lever housings, shift forks, shift links, speedometer drive pinions and gear thrust disks.

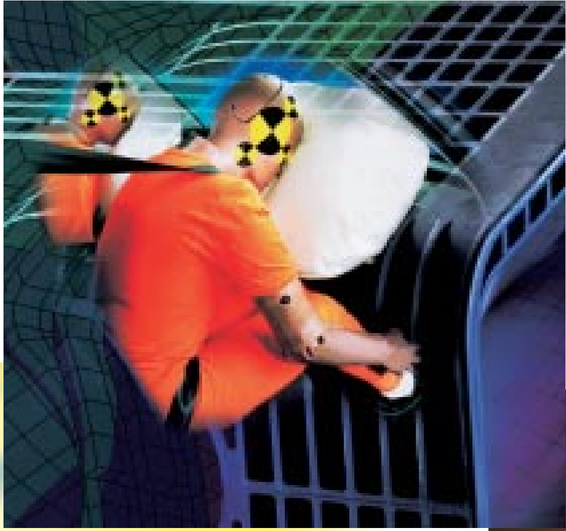
Chassis parts, e.g. steering wheels, steering column mountings, roller bearing cages and fastening clips.

Air intake manifold

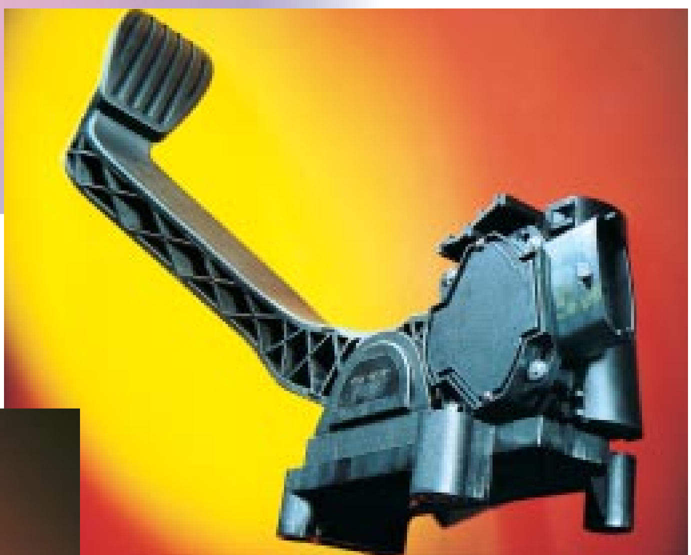
Exterior parts, e.g. spoilers, bumpers, singly or combined, door sills, radiator grills, exterior door handles, door-mirror housings and wheel covers.

Parts for the electrical fittings, e.g. cable harnesses, straps and connectors, headlamp housings, lamp holders and fuse boxes.





Airbag housing



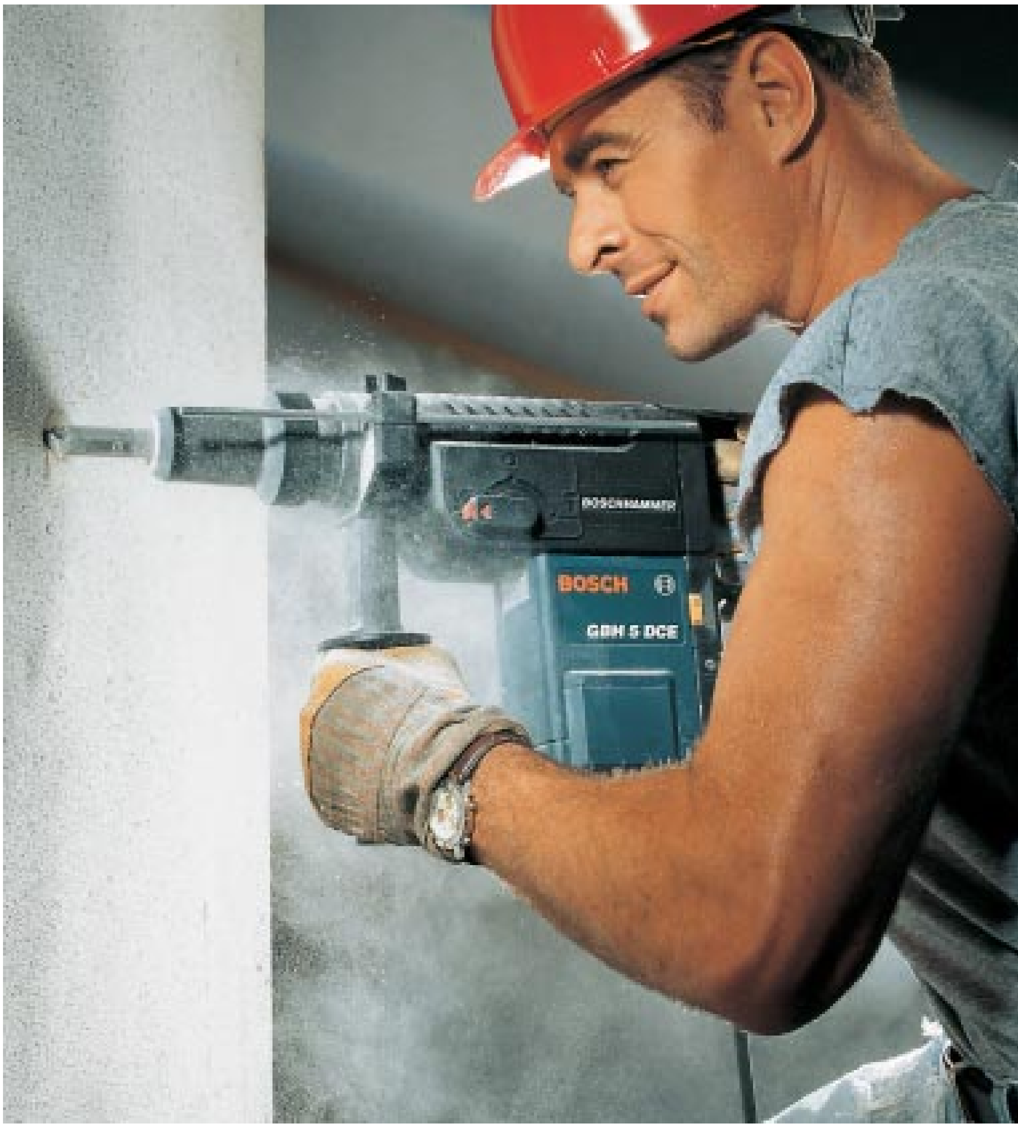
Clutch pedal

Housing for electronic components

Engine cover

... in power engineering and mechanical engineering

Its excellent electrical insulation properties, advantageous sliding friction characteristics and outstanding mechanical strength make Ultramid a material which is employed in almost all fields of power engineering and mechanical and chemical engineering.



Power engineering
High-tension insulated switch parts and housings, cable fastenings and ducts, terminal blocks and connectors, plug-in devices, coil formers, parts for domestic appliances such as instantaneous water heaters, solenoid valves, power tool housings and power circuit breakers.

General mechanical and chemical engineering
Bearings, gear wheels, transmissions, seals, housings, flanges, clamps, connectors, bolts, housings for air-pressure gages, housings for pumps at gas stations and nutting collars.

Materials-handling technology
Rollers, pulleys, bushings, transport containers, conveyor belts and chains.

Precision engineering
Control disks and cams, parts for counting mechanisms, lever and transmission links, daisy wheels for teletypewriters, mounting frame parts, control levers and sliding elements.

Plug connector

Hand grinder

Mouse sander

Motor starter combination

Vibrating grinder

Tension pulleys

In plumbing and sanitary engineering Ultramid is the material of choice in many products, especially for parts subject to high mechanical loading. Ultramid has likewise proved to be outstandingly effective in packaging materials for foods and cosmetics.

Plumbing, sanitation and household
Wall dowels and masonry anchors, fasteners, cable and pipe clamps.

Handles, fittings and fixtures, hammer shafts and fans.

Seating furniture, chair frames, furniture casters and cooking utensils.

Packaging
Composite films with polyolefins, primarily LDPE, for food packaging.

Composite and monolayer films for medical packaging (sterilized goods).

Monolayer films, e.g. for baking and roasting.

Multilayer blow moldings in composite with polyolefins for packaging goods containing solvents or cosmetics, packaging tapes.

Vapour barrier sheeting

Sausage skins

Door handle

Doorstop

Arm-rest

Socket

The properties of Ultramid

Ultramid is the tradename for polyamides supplied by BASF for injection molding and extrusion. The product range includes PA 6 grades (Ultramid B), PA 66 grades (Ultramid A), PA 6/6T grades (Ultramid T) as well as special grades based on copolyamides, e. g. PA 66/6.
Ultramid A is produced by condensation polymerization of hexamethylene diamine and adipic acid, Ultramid B by hydrolytic polymerization of caprolactam and the copolyamides by polycondensation or hydrolytic polymerization of caprolactam, hexamethylene diamine, adipic acid and terephthalic acid. Ultramid T is obtained by polycondensation of caprolactam, hexamethylene diamine and terephthalic acid. The most important starting materials, adipic acid, caprolactam, hexamethylene diamine and terephthalic acid are obtained from petrochemical feedstocks such as cyclohexane, benzene and toluene.

The most important characteristics of Ultramid are:

- High strength and rigidity
- Very good impact strength
- Good elastic properties
- Outstanding resistance to chemicals
- Dimensional stability
- Low tendency to creep
- Exceptional sliding friction properties
- Simple processing

Product range

Polyamides 6, 66 and 6T form the basis of the Ultramid B and A grades as well as the copolyamide grades. These are supplied in a variety of molecular weights or melt viscosities, have a range of additives and are reinforced with glass fibers or minerals. More detailed information on the individual products may be found in the range chart “Features, applications, typical values” and in the references (p. 73).

The Ultramid range comprises the following groups of products:

Ultramid B
PA 6 (unreinforced) is a tough, hard material affording parts with good damping characteristics and high shock resistance even in the dry state and at low temperatures. PA 6 is distinguished by particularly high impact resistance and ease of processing.

Ultramid A
Among the unreinforced polyamides, PA 66 along with Ultramid T is the material with greatest hardness, rigidity, abrasion resistance and thermostability. It is one of the preferred materials for parts subject to mechanical and thermal stresses in electrical, mechanical, automotive and chemical engineering.

Ultramid C
This is the name given to copolyamides made from PA 6 and PA 66 building blocks. They exhibit different properties according to their composition.

Ultramid T
This new class of partly aromatic copolyamides possesses very high thermostability (melting point 298 °C), rigidity, dimensional stability and constant mechanical properties under conditions of varying humidity.

Glass-fiber reinforced Ultramid B, Ultramid A and copolyamides
These materials are distinguished by high mechanical strength, hardness, rigidity, thermostability and resistance to hot lubricants and hot water. Parts made from them have particularly high dimensional stability and creep strength.

Glass-fiber reinforced Ultramid T is moreover exceptional for its extraordinarily high heat resistance (290 °C).

Ultramid A3WC4 reinforced with carbon fibers or Ultramid T KR 4370C6 combine very high rigidity and strength with outstanding sliding friction properties and low density.

Reinforced grades with flame retardants
Ultramid grades treated in this way including C3U, A3X2G5, A3X2G7, A3X2G10, B3UG4 and T KR4365G5 are particularly suitable for electrical parts required to meet enhanced specifications for fire safety and tracking current resistance.

Mineral-filled Ultramid B, Ultramid A and copolyamide Ultramid C3
The special advantages of these materials lie in increased rigidity, good dimensional stability, low tendency to warp, smooth surfaces and good flow characteristics.

Table 1 **Ultramid grades**

Ultramid		PA	Chemical structure	Melting point °C
B		6	polycaprolactam $-NH(CH_2)_5CO-$	220
A		66	poly(hexamethylene adipamide $-NH(CH_2)_6NHCO(CH_2)_4CO-$	260
C3 C35,C4	Copolyamides	66/6 6/66	copolymer of hexamethylene diamine adipic acid and caprolactam	243 196
T	Copolyamide	6/6T	copolymer of caprolactam hexamethylene diamine and terephthalic acid	298

Mechanical properties

The Ultramid product range includes grades with many combinations of mechanical properties.

One particular feature of the unreinforced grades is the ideal combination of moderate strength, rigidity and creep strength while impact resistance and sliding friction properties are excellent.

These advantages are attributable to the partially crystalline structure and the strong cohesive forces between molecules brought about by hydrogen bonding between neighboring amido groups in the molecular chains.

The reinforced grades offer high rigidity, high creep strength, hardness and dimensional stability while resistance to heat and heat aging are outstanding.

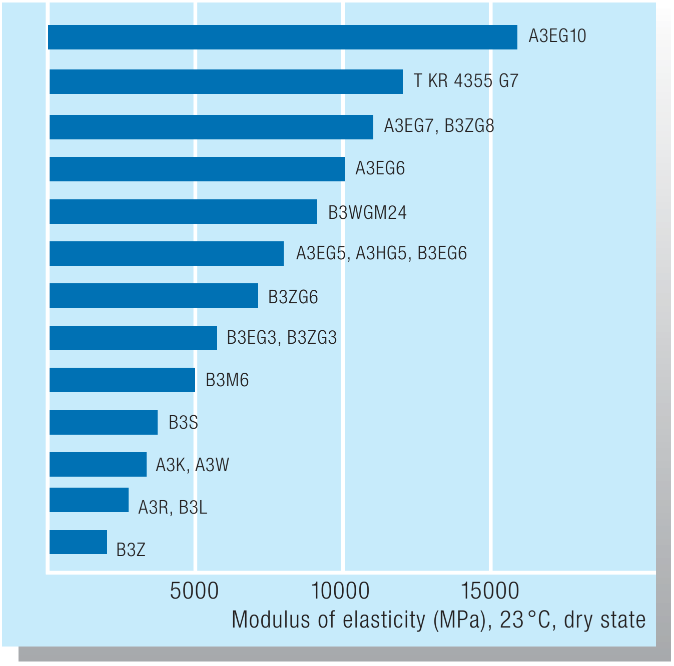


Fig. 2: Modulus of elasticity for selected Ultramid grades at 23 °C in the dry state (ISO 527)

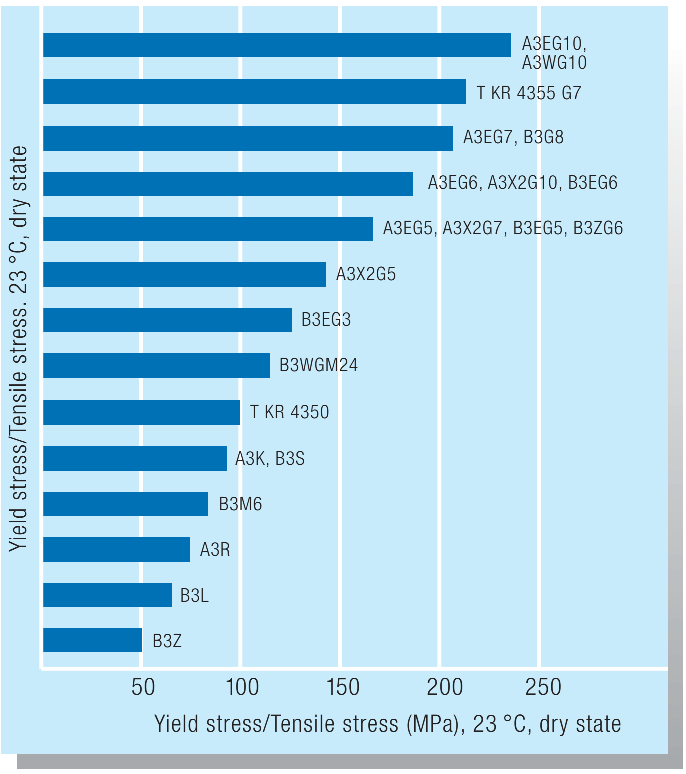


Fig. 1: Yield stress (tensile stress in the case of reinforced grades) for selected Ultramid grades at 23 °C in the dry state (ISO 527)

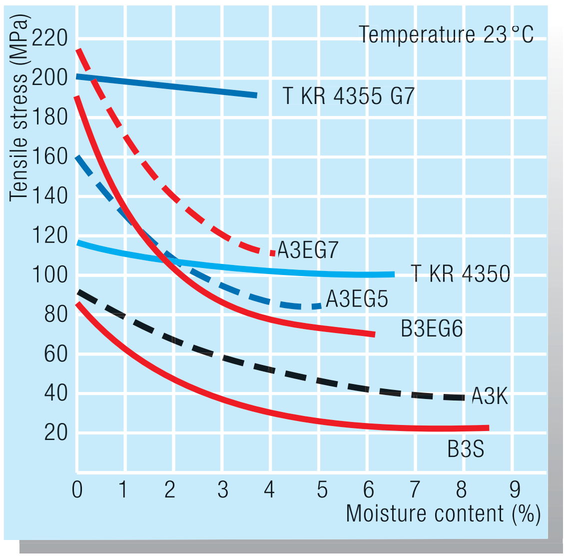


Fig. 3: Tensile stress (yield stress in the case of unreinforced grades) for Ultramid as a function of moisture content at 23 °C (ISO 527)

The product range can be broken down into seven groups according to the modulus of elasticity:

- impact-modified unreinforced grades 1,500 – 2,000 MPa
- unreinforced grades 2,700 – 3,500 MPa
- mineral-filled, impact-modified grades (+GF) 3,800 – 4,600 MPa
- mineral-filled grades (+GF) 3,800 - 9,300 MPa
- impact-modified, glass-fiber reinforced grades 5,200 - 11,200 MPa
- glass-fiber reinforced grades 5,000 - 16,800 MPa

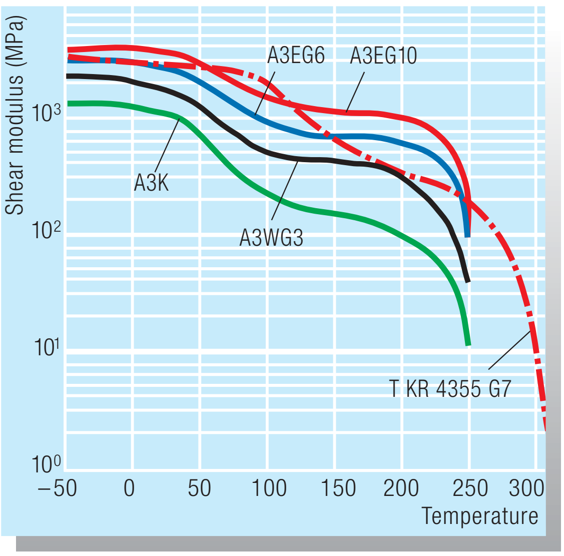


Fig 4: Shear modulus of Ultramid A and T grades as a function of temperature (DIN 53 445, dry)

The mechanical properties are affected by the temperature, time and moisture content and by the conditions under which the test specimens were prepared.

Ultramid T is exceptional here in that its mechanical properties are largely independent of variations in moisture content.

In the case of the reinforced grades additional factors having a significant effect on properties are, for example, the glass-fiber content, the orientation, average length and length distribution of the fibers, and the pigmentation.

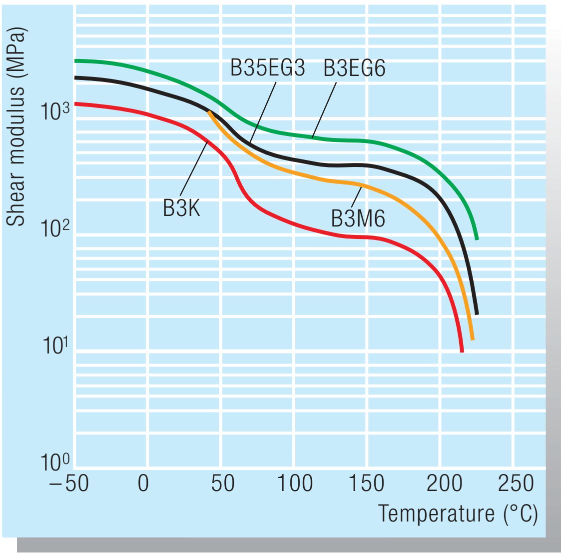


Fig 5: Shear modulus of Ultramid B grades as a function of temperature (DIN 53 445, dry)

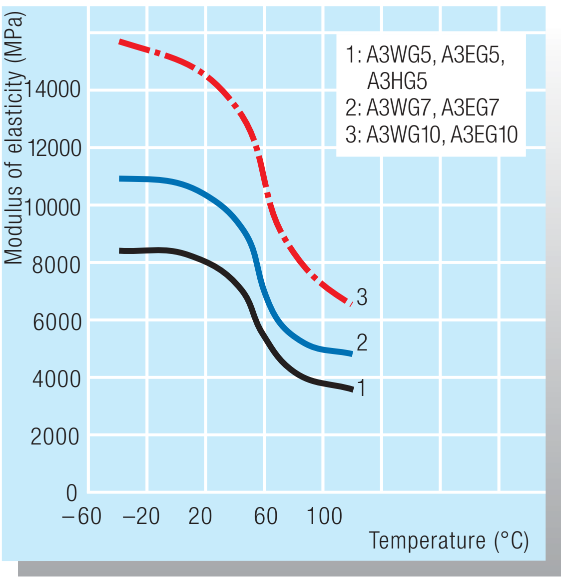


Fig 6: Modulus of elasticity of reinforced Ultramid A grades as a function of temperature (Flexural test ISO 178, dry)

The yield stress of dry, unreinforced Ultramid ranges from 70 to 110 MPa while that of the reinforced grades rises as high as 250 MPa. The behavior under short-term uniaxial tensile stress is presented as stress-strain diagrams (cf. Figs. 9 - 11) in which the effects of temperature, reinforcement and moisture content are illustrated.

High creep strength and low tendency to creep are also exhibited, especially in the reinforced grades.

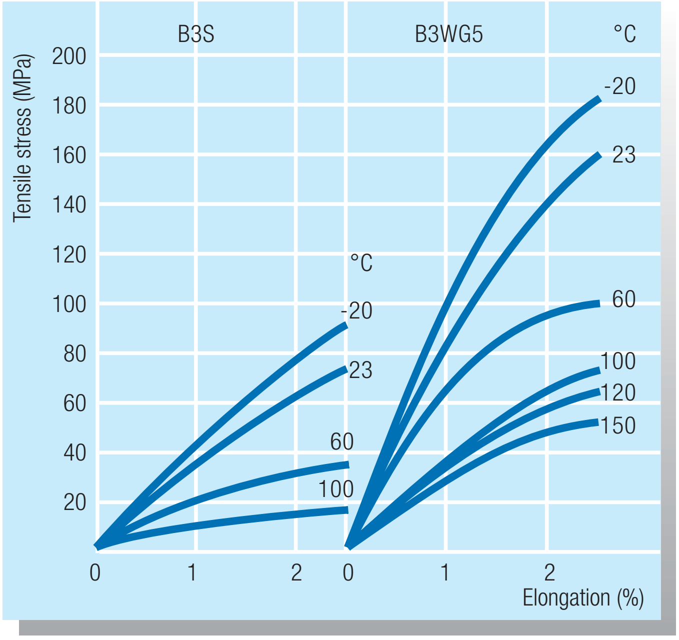


Fig. 9: Stress-strain diagrams for Ultramid B3S and B3WG5 (dry) in accordance with ISO 527 (test speed 2 mm/min)

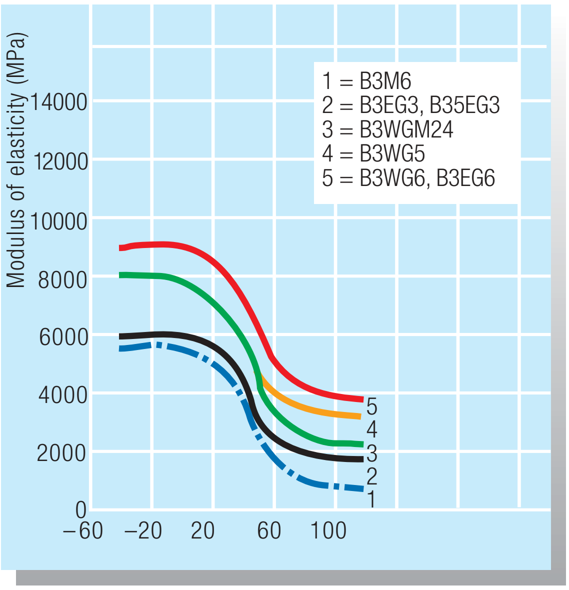


Fig 7: Modulus of elasticity of reinforced Ultramid B grades as a function of temperature (Flexural test ISO 178, dry)

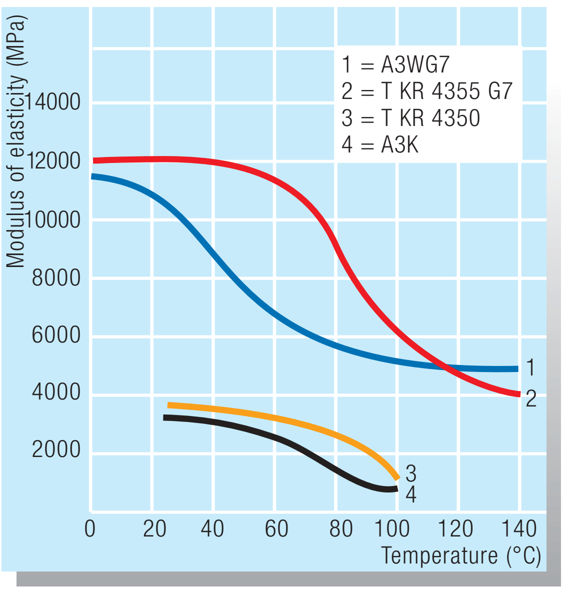


Fig 8: Tensile modulus of elasticity (ISO 527) of Ultramid T compared with that of Ultramid A as a function of temperature in the dry state

Contactor

Impact strength, low-temperature impact strength
Polyamides are considered to be very tough materials. They are suitable for parts required to exhibit high resistance to fracture. Standard test values generally determined under different conditions are used to characterize their impact behavior (cf. the range chart "Features, applications, typical values").

Although the values are not directly comparable with one another due to the differing test setups, test specimen dimensions and notch shapes, they do allow comparison of molding materials within the individual product groups.

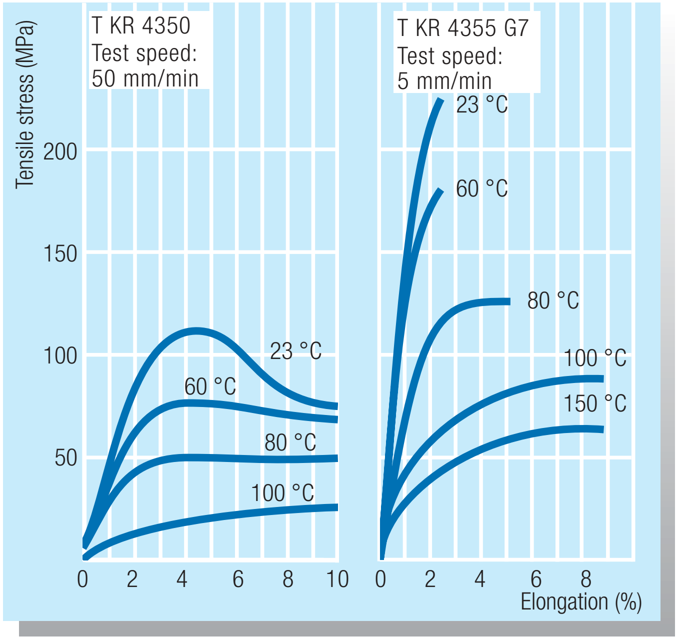


Fig 11: Stress-strain diagrams for Ultramid T, dry, in accordance with ISO 527

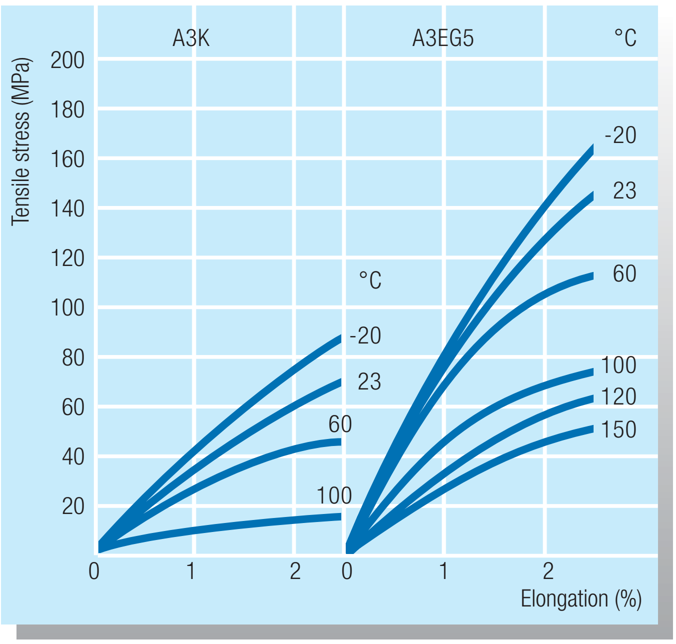


Fig. 10: Stess-strain diagrams for Ultramid A3K und A3EG5 (dry) in accordance with ISO 527 (test speed 2 mm/min)

Tests on finished parts are indispensable for the practical assessment of impact behavior. The falling weight test, for example, carried out on housings, sheets or test boxes (cf. Fig. 12) in conformity with DIN 53 443, Part 1, has proved to be effective for this purpose. The measure of toughness is the fracture energy W50 (J) at which 50 % of the parts tested fail. On this basis high-impact, unreinforced Ultramid grades even in the dry state at 23 °C, and sometimes even at low temperatures, attain values > 140 J, i.e. the parts do not break when, for example, a 10 kg weight is dropped on them from a height of 1.4 m (impact speed = 5.3 m/s).

However, the behavior of Ultramid when subjected to impact is affected by many factors, of which the most important are the shape of the part and the rigidity of the material.

As can be seen in Fig. 13 there are Ultramid grades with the most varied combinations of impact strength and rigidity.

Depending on application, requirements, design and processing, products which are unreinforced, of relatively high molecular weight, glass-fiber reinforced, mineral-filled or impact modified can be selected each having an optimum relationship between impact strength and rigidity.

The advice below should also be taken into account when choosing suitable materials.

Moisture promotes the toughness of Ultramid, even at low temperatures. In the case of glass-fiber reinforced grades the impact strength of finished parts decreases as the glass fiber content rises while strength and the values in the flexural impact test for standardized test specimens increase. This effect is due to differences in the orientation of the glass fibers.

Unreinforced products of high molecular weight have proved to be effective for thick-walled engineering parts required to exhibit high impact strength.

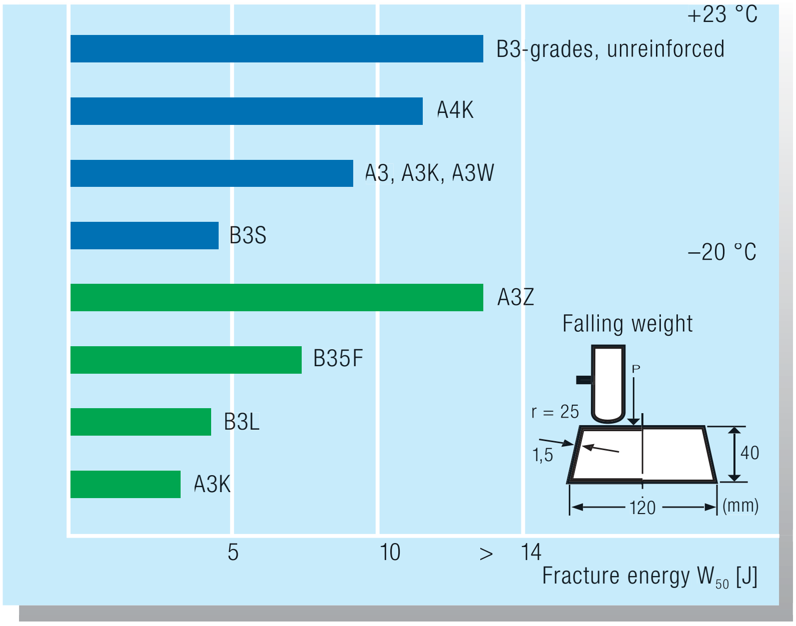


Fig. 12: Impact strength of reinforced Ultramid at +23 and -20 °C determined in the dry state as the fracture energy W50 in accordance with DIN 53 443, Part 1 (test box, wall thickness=1.5 mm, uncolored)

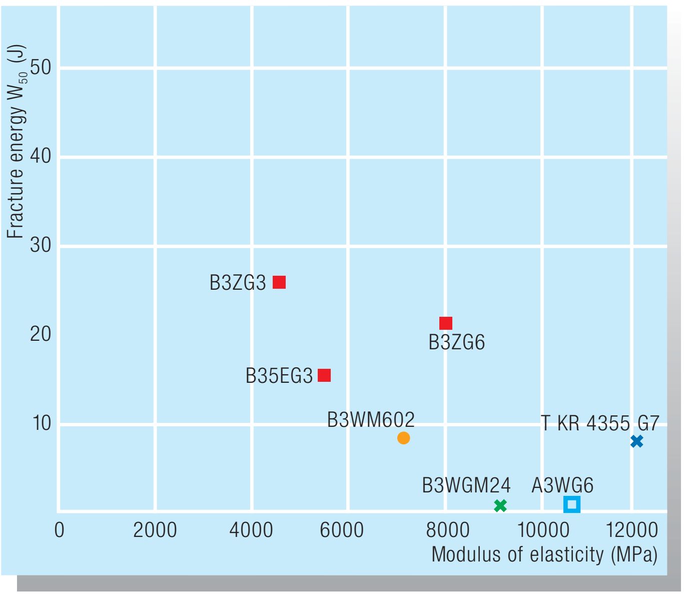


Fig. 13: Impact strength, determined as the fracture energy W_{50} in accordance with DIN 53 443, Part 1(cf. Fig. 12), and modulus of elasticity (ISO 527) of reinforced Ultramid at 23 °C in the dry state

Even in the dry state the impact-modified, unreinforced PA6-grades B3L, B3Z, and A3Z exhibit high impact strength. They are employed when conditioning or intermediate storage for absorption of moisture are uneconomic or when extremely high notched or low-temperature impact strength are called for. Apart from the particular processing conditions, the geometry of the molding – with the resultant moments of resistance – and especially the wall thicknesses and the notch radii also play a major role in determining the fracture energy. Even the speed and point of impact significantly affect the results.

Behavior under long-term static loading

The static loading of a material for relatively long periods is marked by a constant stress or strain. The tensile creep test in accordance with DIN 53 444 (ISO 899 –1993) and the stress relaxation test in accordance with DIN 53 441 provide information about extension, mechanical strength and stress relaxation behavior under sustained loading.

The results are presented as creep curves, creep modulus curves, creep stress curves and isochronous stress-strain curves (Figs. 14 – 15). The graphs for standard conditions (in accordance with DIN 50 014 – 23/50-2) reproduced here are just a selection from our extensive computer-based results.

Further values and diagrams for different temperature and atmospheric conditions can be requested from Ultra-Infopoint (p. 74) or found in the PC program "Campus" (see References p. 73). Design data obtained from uniaxial tensile loads can also be used to assess the behavior of a material under multiaxial loads.

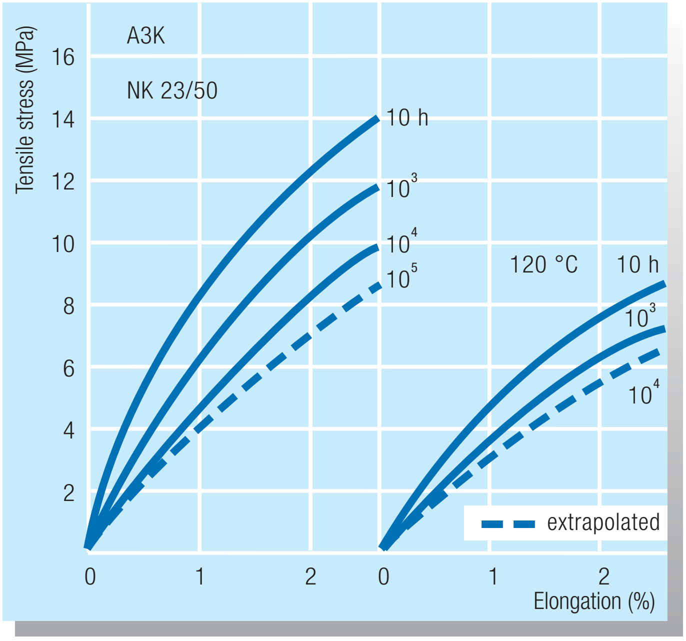


Fig. 14: Isochronous stress-strain curves for Ultramid A3K in accordance with DIN 53 444 under standard atmospheric conditions (23/50) and at 120 °C (in the dry state)

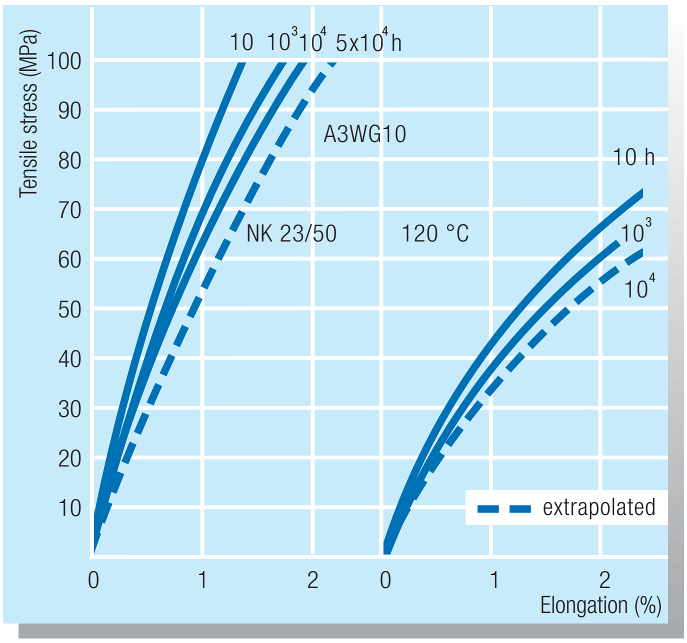


Fig. 15: Isochronous stress-strain curves for Ultramid A3WG10 in accordance with DIN 53 444 under standard atmospheric conditions (23/50) and at 120 °C (in the dry state)

Fan rotor

The PC programs “SNAPS”, “SCREWS” and “BEAMS” developed by BASF can be used for the calculation of structural elements such as snap and screw connections and flexurally loaded support beams respectively. The creep strength values determined for Ultramid pipes (Fig. 16) apply to conditions of multiaxial stress and the action of water on all sides.

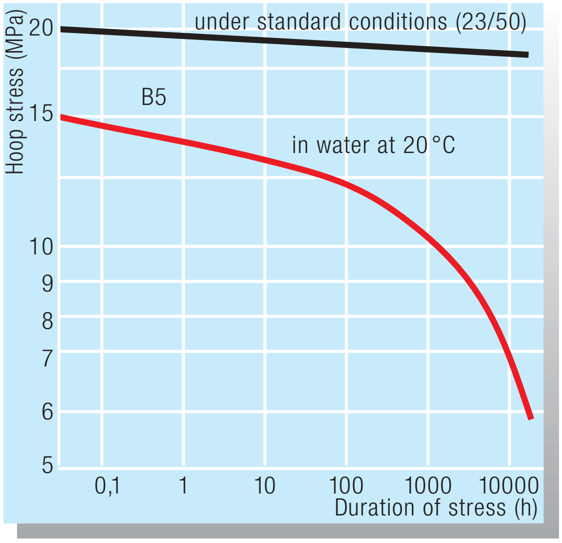


Fig. 16: Creep strength of Ultramid B5 (pipes, diameter 8 mm, wall thickness 1 mm)

Cable duct

Behavior under cyclic loads, flexural fatigue strength

Engineering parts are also frequently subjected to stress by dynamic forces, especially alternating or cyclic loads, which act periodically in the same manner on the structural part. The behavior of a material under such loads is determined in long-term tests using tensile and compressive loading (specimen shape in accordance with DIN 53 455, No. 3) alternating at up to very high load-cycle rates. In doing so the temperature of the specimen is maintained at exactly the temperature specified by controlling the frequency (BASF method). The results are presented in Woehler diagrams obtained by plotting the applied stress against the load-cycle rate achieved in each case (see Fig. 17).

When applying the test results in practice it has to be taken into account that at high load alternation frequencies the workpieces may heat up considerably due to internal friction. In such cases the curves measured at higher temperatures have to be used (Fig. 18).

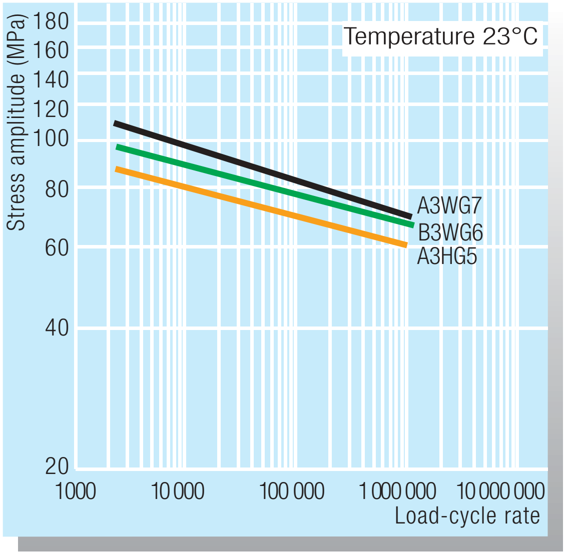


Fig. 17: Flexural fatigue strength of glass-fiber reinforced Ultramid A, B and T. Stress amplitude as a function of load-cycle rate at standard moisture content (standard conditions 23/50)

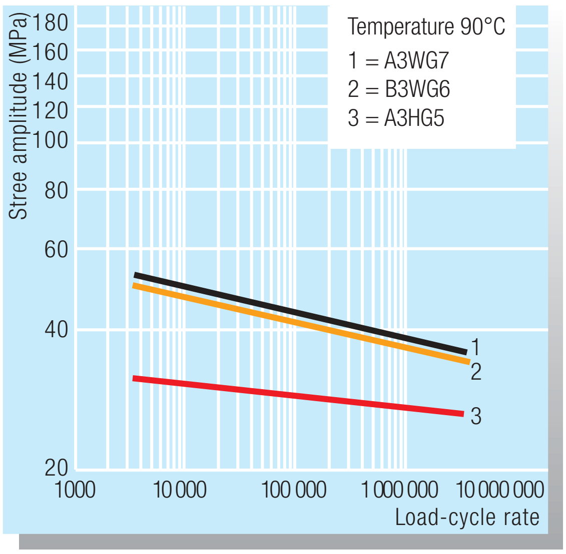


Fig. 18: Flexural fatigue strength of glass-fiber reinforced Ultramid A and B. Stress amplitude as a function of load-cycle rate (90 °C)

Mouse sanders

Tribological properties
A smooth, tough and hard surface, crystalline structure, high thermostability and resistance to lubricants, fuels and solvents make Ultramid and ideal material for parts subjected to sliding friction. Its good dry-running properties are worth pointing out. Whereas metallic materials tend to jam under dry-running conditions, pairings with Ultramid run satisfactorily even without lubrication.

Wear and friction are system properties which depend on many parameters, e.g. on the paired materials, surface texture and geometry of the sliding parts in contact, the intermediate medium (lubricant) and the stresses due to external factors such as pressure, speed and temperature.

<u>Wear due to sliding friction</u>
The most important factors determining the level of wear due to sliding friction and the magnitude of the coefficient of sliding friction are the hardness and surface roughness of the paired materials, the contact pressure, the distance traversed, the temperature of the sliding surfaces and the lubrication. Fig. 19 shows friction and wear values determined in a specific tribological system for different Ultramid grades having two degrees of surface roughness.

Ultramid A grades, especially A3R and the mineral-filled grades, are distinguished by a low coefficient of sliding friction and low rates of wear due to sliding friction (rate of wear S in µm/km).

<u>Drop erosion and cavitation</u>
Ultramid has proved to be superior to aluminum in withstanding wear stresses of this nature which play a significant role in water pumps for example.

<u>Jet erosion</u>
Fans and automobile spoilers for example are exposed to this type of stress which is caused by granular solids entrained in streams of air or liquid. The advantageous elastic behavior of Ultramid results in high resistance in this case.

Fig. 19: Coefficient of sliding friction and wear rates of unreinforced and fiber reinforced Ultramid.
Tribological system: pin-on-disk apparatus, p = 1 MPa, v = 0.5 m/s
Paired material: Cr 6/800 HV steel, technically dry

Oil sensor

Thermal properties

Ultramid has extraordinarily high melting temperatures:

Ultramid B	220 °C
Copolyamide C3	243 °C
Ultramid A	260 °C
Ultramid T	298 °C.

Due to its semicrystalline structure and strong hydrogen bonding Ultramid retains its shape even at elevated temperatures close to the melting range.

Ultramid stands out among other partially crystalline thermoplastics due to its low coefficients of linear expansion. The reinforced grades in particular exhibit high dimensional stability when exposed to temperature changes. In the case of the glass-fiber reinforced grades, however, linear expansion depends on the orientation of the fibers as is evident from Fig. 20.

Behavior on application of heat
Apart from its product-specific thermal properties the behavior of components made from Ultramid on exposure to heat also depends on the duration and mode of application of heat and on the loading. The design of the parts also has an effect. Accordingly, the thermostability of Ultramid parts cannot be estimated simply on the basis of the temperature values from the various standardized tests no matter how valuable the latter might be for guidance and comparisons.

The shear modulus and damping values measured as a function of temperature in torsion pendulum tests in accordance with DIN 53 445 afford valuable insight into the temperature behavior. Comparison of the shear modulus curves (Figs. 4 and 5, p. 12) provides information about the different thermomechanical effects at low deformation stresses and speeds. Based on practical experience the thermostability of parts produced in optimum manner is in good agreement with the temperature ranges determined in the torsion tests in which the start of softening becomes apparent.

Polishing machine

The test for heat resistance in accordance with VDE 0470, § 4b (ball indentation test), is usually specified for applications in electrical equipment. The requirements of this test at 125 °C for supports for voltage-carrying parts are met by finished parts made from all grades of Ultramid. The reinforced grades are recommended for this purpose.

Base for additional starter

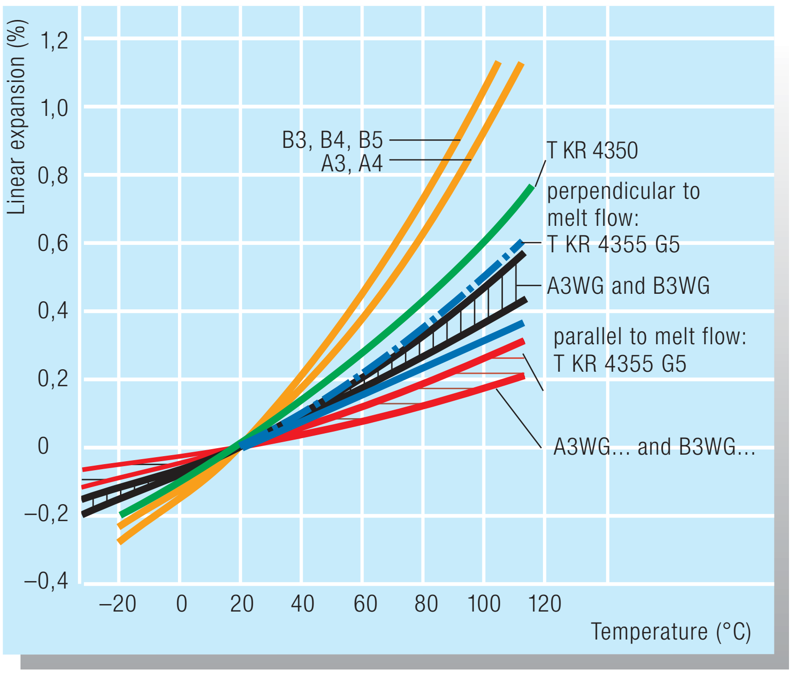


Fig. 20: Linear expansion of Ultramid grades as a function of temperature (in the dry state)

Heat aging resistance

Stabilized Ultramid grades with K, E, H or W as the second letter in their name are suitable for parts subjected to long-term-exposure to high temperature.

Table 2 sets out the characteristics and effectiveness of this stabilization with reference to the example of Ultramid A.

Two characteristics are suitable for comparing heat aging resistance, i.e. the response of the various Ultramid grades to the long-term action of heat. These are the temperature index (TI) for exposure to heat for 5,000 or 20,000 hours and the halving interval (HIC) in accordance with IEC 216. In the case of Ultramid the decline in tensile strength and impact strength to the limiting value (50 % of the initial value) are suitable evaluation criteria.

Diagrams of the thermal resistance, i.e. graphs of the times measured at different temperatures for the initial value to change to the limiting value, are reproduced by way of example in Fig. 21 for some unreinforced Ultramid grades. The TI values are also listed in the typical values table in the range chart.

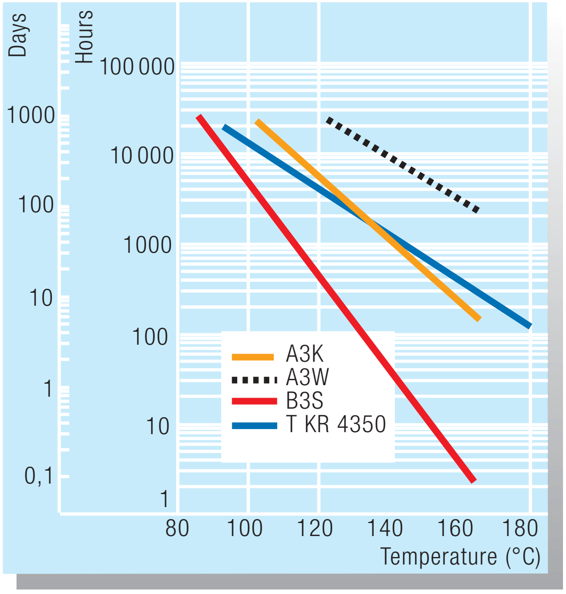


Fig. 21: Heat aging resistance of unreinforced Ultramid A under the action of heat (graphic temperature profile) in accordance with IEC 216-1; limiting value of property: 50 % tensile strength

Cable duct

Table 2	**Stabilized Ultramid A grades**				
Code		K	E	H	W
Example without GF		A3K			A3W
Example with GF			A3EG6	A3HG5	A3WG6
Natural color		colorless	colorless	brown	greenish
Effectiveness					
Time taken at 120 °C for initial tensile strengh to drop by 50 %					
without GF	days	200		700	1000
with GF	days		> 1500	> 2000	> 2000
Hot water Coolants			•	•	•
Outdoor exposure		•	•	•	•
Engine & transmission oils		•	•	••	•
Dielectric properties		•	•	•	(•)
Physiological harmlessness		•	•	–	(•)

••= particularly suitable • = suitable or favourable (•) = suitable, but with limitations – not recommended

<u>Heat aging resistance in hot lubricants, coolants and solvents</u>

The widespread application of Ultramid in engineering, especially in automotive engineering, e.g. in engine oil circuits and gearboxes, is based on its outstanding long-term resistance to hot lubricants, fuels and coolants and to solvents and cleaning agents. Fig. 22 shows how the flexural and impact strength of Ultramid A and T are affected by immersion in hot lubricants (120 °C) and coolants. H- and W-stabilized grades are particularly resistant to lubricants and hot coolants. A3HG6 HR has proved to be particularly successful in applications in automobile cooling circuits.

Information on the temperature limits for Ultramid exposed to the action of these and other chemicals is provided by the Technical Information leaflet “Resistance of Ultramid, Ultraform and Ultradur to chemicals” (see References p. 73).

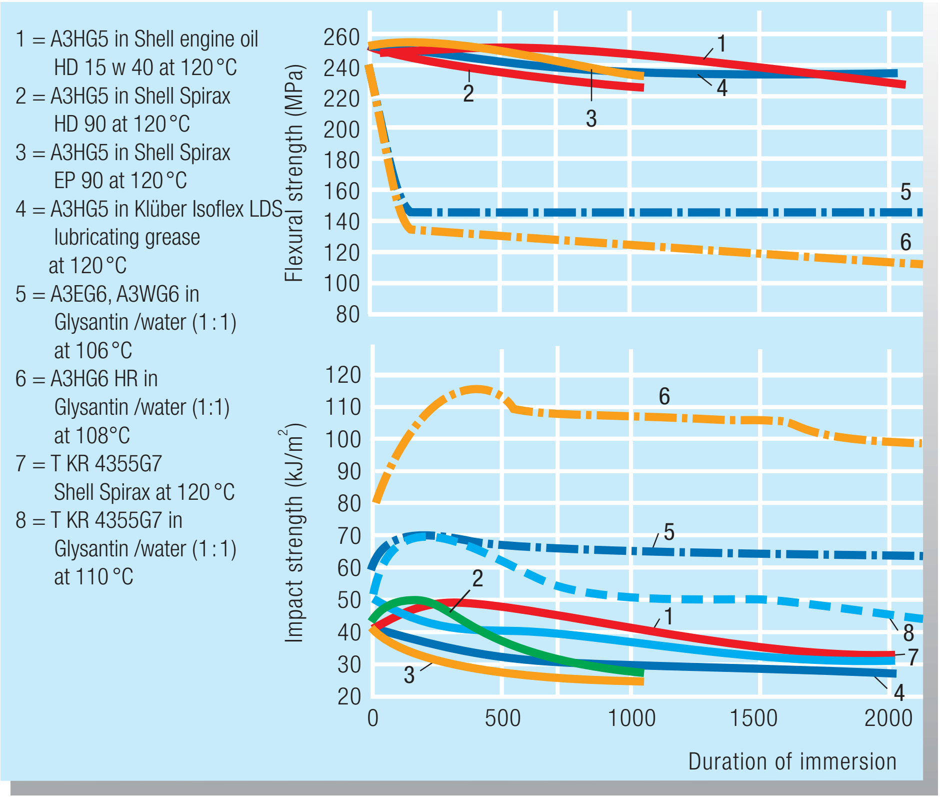
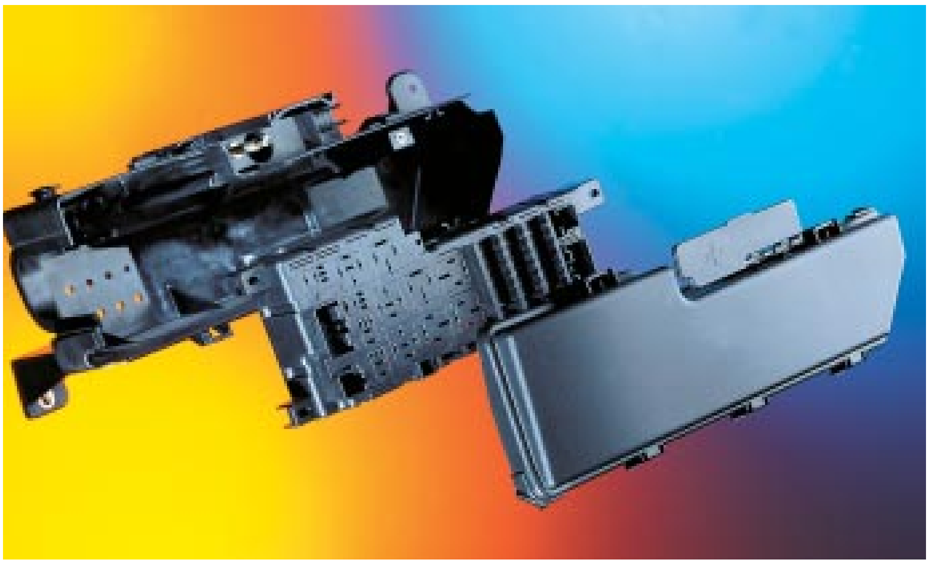


Fig. 22: Flexural strength (DIN 53 452) and impact strength (DIN 53 453) of Ultramid A3HG5, A3EG6, A3WG6 and T KR 4355 G7 in hot lubricants and coolants as a function of immersion temperature (measurements at 23 °C)



Housing for electronic components

Water absorption and dimensional stability

A special characteristic of polyamides in comparison with other thermoplastics is their water absorption. In water or in moist air depending on its relative humidity and dependant on time, temperature and wall thickness moldings absorb a certain quantity of water so that their dimensions increase slightly. The increase in weight on saturation depends on the Ultramid grade and is listed in the tables in the range chart. Fig. 23 shows how the absorption of moisture on saturation depends on the relative humidity.

Figs. 24 - 25 show the water absorption of Ultramid as a function of storage time under various test conditions. It is evident from these that in comparison with the PA 6 and PA 66 grades Ultramid T affords distinct advantages with respect to water absorption.

As can be seen from the table of properties water absorption results in increased impact strength, elongation at break and tendency to creep whereas strength, rigidity and hardness decrease.

Provided that the water is uniformly distributed in the molding, Ultramid A and B undergo a maximum increase in volume of about 0.9 % and a mean increase in length of 0.2 to 0.3 % per 1 percent (mass fraction) of absorbed water. The dimensional change of the glass-fiber reinforced grades amounts to less than 0.1% per 1% in the direction of flow (longitudinally). As a result of this the dimensions of these grades, like those of the mineral-filled grades, remain particularly constant when humidity varies.

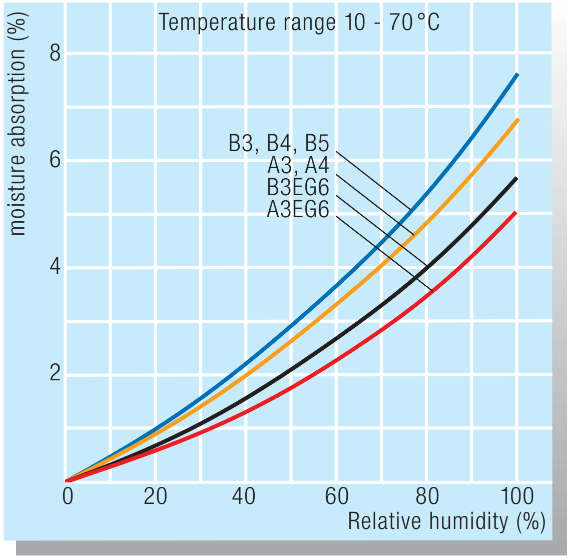


Fig. 23: Equilibrium moisture content of Ultramid as a function of relative humidity in the temperature range 10-70 °C (scatter: ±0,2 to 0,4% absolute)

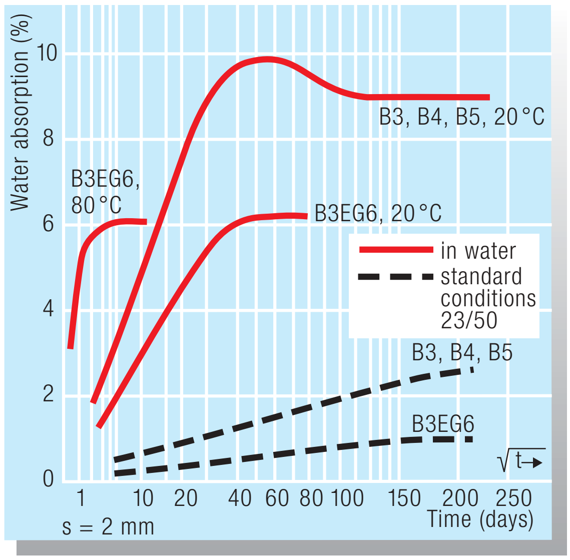


Fig. 24: Water absorption of Ultramid B as a function of storage time and the conditioning parameters (specimen thickness 2mm)

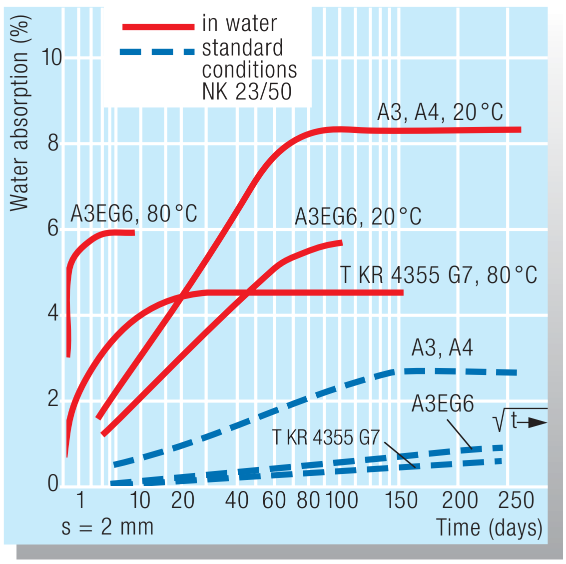


Fig. 25: Water absorption of Ultramid A and T as a function of storage time and the conditioning parameters (thickness of specimen 2 mm)

Electrical properties

The paramount importance of Ultramid in electrical engineering, especially for electrical insulating parts and housings in power engineering, is attributable to its good insulating properties (volume resistance and surface impedance) combined with its impact strength and creep strength as well as its advantageous properties in relation to heat and aging. As a result Ultramid is numbered among the high-performance insulating materials. You will find detailed information on the use of engineering plastics such as Ultramid in the brochure Technical Information for Experts ”Engineering plastics for electrical and electronical applications“ (see references p. 73).

Wherever there are high demands on fire properties the flame-retardant grades A3X2G...,.T KR 4365G5, C3U and B3UG4 are preferably used. The following points should be noted in relation to electrical properties.

- The products are characterized by a high tracking current resistance which is only slightly impaired by the moisture content of the material.
- The specific volume resistance and the surface impedance are very high; these values decline at elevated temperatures and also when the water content is relatively high.
- As for all electrical insulating materials when used in harsh conditions continual wetting due to condensation must be prevented by appropriate design measures.
- Unfavorable operating environments such as hot pockets combined with high air humidity, moist, warm conditions or poor ventilation can adversely affect the insulating properties.

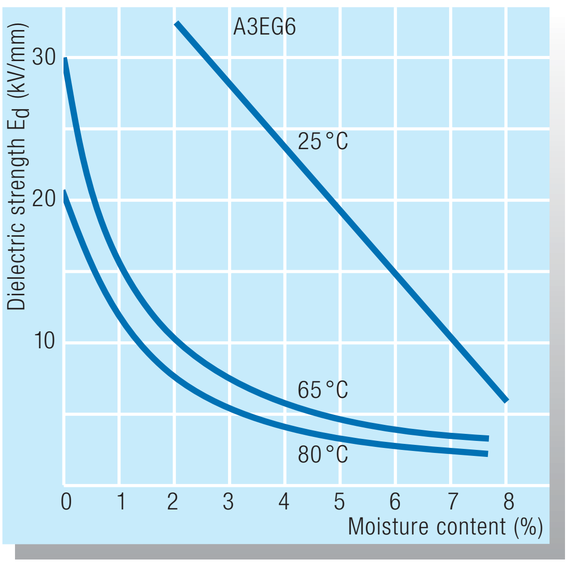


Fig. 26: Dielectric strength of Ultramid A3EG6 at different temperatures as a function of moisture content (DIN 53481; wall thickness 3 mm)

For the above reasons the performance of the components should be carefully checked for each application.

The values of the electrical properties are listed in the range chart.

Figs. 26 - 28 show the effect of temperature and moisture on the dielectric strength and specific volume resistivity of Ultramid A3X2G... and T KR 4355G7.

Insulating materials are tested for the production of deposits harmful to electrical contacts in accordance with the preliminary FTZ standard 547 PV1 (FTZ = Fernmeldetechnisches Zentralamt = German central telecommunications technology office). The change in resistance of relay contacts is measured after these together with the insulating material have been stored in a desiccator at a temperature of 70 °C. The Ultramid grades which on the basis of the results of this standard test are suitable for electrical engineering applications are rated as not harmful to electrical contacts.

The Ultramid grades A3X2G... and T KR 4365G5 contain a special stabilizer to prevent the formation of red phosphorus decomposition products which can occur some in polyamides with phosphorus-based flame retardants. As is the case with all insulators parts made from Ultramid, especially those intended for use under extreme conditions of heat and humidity, must be carefully designed and tested to ensure they operate reliably.

Overviews, tables and examples illustrating the use of Ultramid in electrical, power and telecommunications engineering are presented in the brochure “Halogen-free flame-resistant Ultramid grades” (see References p. 73).

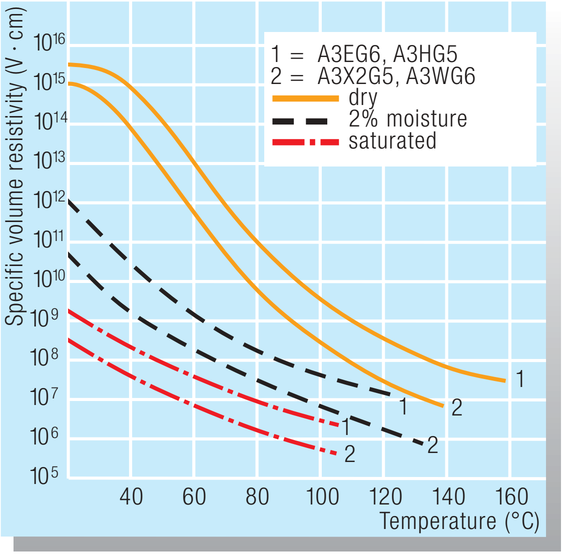


Fig. 27: Specific volume resistivity of glass-fiber reinforced Ultramid A having different moisture contents as a function of temperature (DIN 53 482)

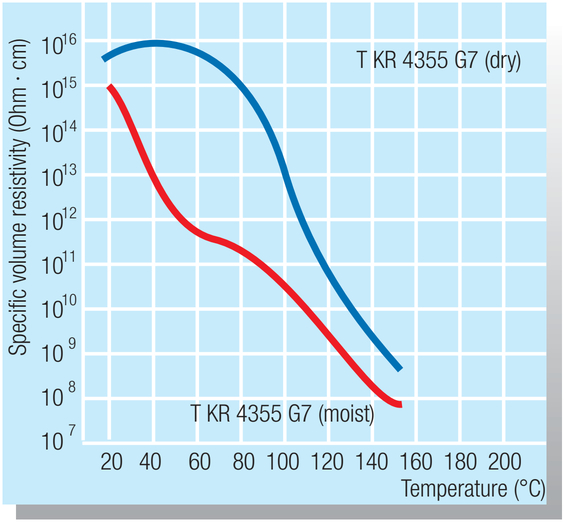


Fig. 28: Specific volume resistivity of glass-fiber reinforced Ultramid T in the dry state and following exposure to moist air (conditioned) as a function of temperature (IEC 93)

Bus system casing

Fire behavior

General notes

Above 300 °C Ultramid A and B grades slowly begin to decompose. In the case of Ultramid T this happens above 350 °C. In the temperature range of 450 to 500 °C flammable gases are given off which continue to burn after ignition. These processes are affected by many factors so that, as with all flammable solid materials, no definite flash point can be specified. The decomposition products have the odor of burnt horn. The decomposition products from charring and combustion are mainly carbon dioxide and water and depending on the supply of oxygen small amounts of carbon monoxide, nitrogen and small amounts of nitrogen-containing compounds. The decomposition products formed in the temperature range up to 400 °C have been shown in toxicological investigations to be less toxic than those produced under the same conditions from wood. At higher temperatures they are equally toxic. The calorific value Hu according to DIN 51 900 lies in the range of 29,000 to 32,000 kJ/kg (unreinforced grades).

Our brochure "Thermoplastics – Fire protection aspects" (see References p. 73) contains extensive details on the fire behavior of Ultramid.

Tests

Electrical engineering

Various material tests are carried out to assess the fire behavior of electrical insulating materials. In Europe the incandescent wire test in accordance with IEC 695 is often specified. Table 3 shows the classifications for Ultramid grades. A further test for rod-shaped samples is the rating in accordance with "UL 94 – Standard Tests for Flammability of Plastic Materials for Parts in Devices and Appliances" from the Underwriters Laboratory Inc./USA. On the basis of this test method almost all unreinforced grades fall into the UL 94V-2 class. The unreinforced, flame-retardant grade Ultramid C3U attains the rating UL 94V-0.

The reinforced grades require the incorporation of a flame retardant in order to achieve a correspondingly favorable rating. Examples include the Ultramid grades A3X2G... (with glass-fiber reinforcement), B3UG4 and Ultramid T KR 4365G5 as well as special mineralfilled grades. The fire-protection properties are summarized in Table 3.

Transportation

DIN 75 200 is the test method used in automotive engineering for determining the flammability of materials in the passenger compartment of automobiles. Sheet specimens arranged horizontally are tested with a Bunsen burner flame, a method which is largely equivalent to FMVSS 302 (USA). As can be seen in Table 3 Ultramid meets the requirements.

Engine protection switch

Table 3 **Fire performance**

Ultramid	UL 94	Incandescent wire test[1)]IEC 695 part 2-1	FMVSS 302 (d ≥ 1 mm)
A3 unreinforced	V-2 (1.6 mm)[2)]	960 °C	pass
B unreinforced	V-2 (3.2 mm)[3)]	850 °C[4)]	pass
A3EG... reinforced	HB	650 °C	pass
B3EG... reinforced	HB	650 °C	pass
A3X2G10	V-1 (1.6 mm)	960 °C	pass
A3X3G5/G7	V-0 (0.8 mm)	960 °C	pass
B3UG4	V-2 (0.8 mm)	960 °C	pass
C3U	V-0 (0.4 mm)	960 °C	pass
T KR 4365G5	V-0 (0.8 mm)	960 °C	–

1) Test carried out on test specimens 1 mm thick
2) A3R, UL 94 HB
3) B3L, UL 94 HB
4) B3L: 750°C

Construction industry
The testing of building materials for the construction industry is carried out in accordance with DIN 4102, Part 1, “Fire behavior of building materials and building parts”. Sheets of unreinforced and glass-fiber reinforced Ultramid (thickness ≥ 1 mm) are rated as normally flammable building materials[1]) in Building Materials Class B 2.

1) Designation in accordance with the building regulations in the Federal Republic of Germany.

Resistance to chemicals

Ultramid exhibits good resistance to lubricants, fuels, hydraulic fluids and coolants, refrigerants, dyes, paints, cleaners, degreasing agents, aliphatic and aromatic hydrocarbons and many other solvents even at elevated temperatures.

It is also resistant to aqueous solutions of many inorganic chemicals (salts and alkalis). Ultramid is therefore resistant to corrosion. A characteristic to be emphasized is its outstanding resistance to stress cracking. Media that are dangerous for certain polyethylene or polystyrene molding compounds, e.g. wetting agents, essential oils or certain solvents (alcohols) do not impair the creep performance of Ultramid.

Good resistance to chemicals is an important prerequisite for the use of Ultramid in automotive, aerospace and chemical engineering.

Ultramid is attacked by inorganic acids, even at low concentrations, and by certain oxidizing agents and chlorinated hydrocarbons especially at elevated temperatures. Note also has to be taken of its sensitivity to solutions of certain heavy metal salts, e.g. aqueous zinc chloride solution, and in the case of glass-fiber reinforced grades to alkalis because they attack glass fibers.

Table 4 summarizes Ultramid's resistance to the most important chemicals. Further detailed information based on immersion tests and practical trials is presented in our Technical Information leaflet “Resistance of Ultramid, Ultraform and Ultradur to chemicals” (see References p. 73).

When clearing the use of the material, especially for components subject to high stresses and possible exposure to corrosive chemicals, its chemical suitability should be verified. This may be done on the basis of experience with similar parts made of the same material in the same medium under comparable conditions or by testing parts under practical conditions.

Table 4 **Overview of the chemical resistance of Ultramid**

Rating			
Very good resistance	**Good resistance[1])**	**No resistance**	**Solvents**
Aliphatic hydrocarbons	Alcohols	Mineral acids	– At room temperature
Aromatic hydrocarbons	Chlorinated hydrocarbons	Certain organic acids	formic acid (> 60 %)
Alkalis	Water	Oxidizing agent solutions	fluorinated alcohols
Brake fluids	Aqueous solutions	Phenols	m-cresol
Esters, ethers		Zinc chloride solutions	sulfuric acid (96 %)
Fats			
Ketones			– At elevated Temperatures
Fuel (gasoline, diesel)			benzyl alcohol
Coolants			phenol
Paints			glycols
Solvents			formamide
Cleaning agents			
Lubricants (oils, greases)			
Detergents			

1) nevertheless marked changes occur in weight, dimensions and mechanical proporties (strength, impact resistance)

Behavior on exposure to weather

Ultramid is suitable for outdoor applications. Different grades come into consideration depending on requirements. The unreinforced, stabilized grades with K and H identifiers are highly resistant to weathering even when unpigmented. Suitable pigmentation increases outdoor performance still further, best results being achieved with carbon black.

The reinforced grades also exhibit good resistance to weathering. Stabilized grades, e.g. Ultramid B3EG5, can be relied upon to last for well over five years.

Since the glass fibers near the surface are attacked more severely, glass fiber reinforced grades may exhibit some surface texture and color changes with short exposures. After several years exposure abrasion of the surface layer by up to several tenths of a millimeter can be expected. However experience shows that this does not cause any appreciable impairment of the mechanical properties.

Specially UV-stabilized grades and products with a high carbon black content have proven to be very effective for outdoor applications, such as housings for door mirrors on automobiles, in which surface quality must not change even after several years use.

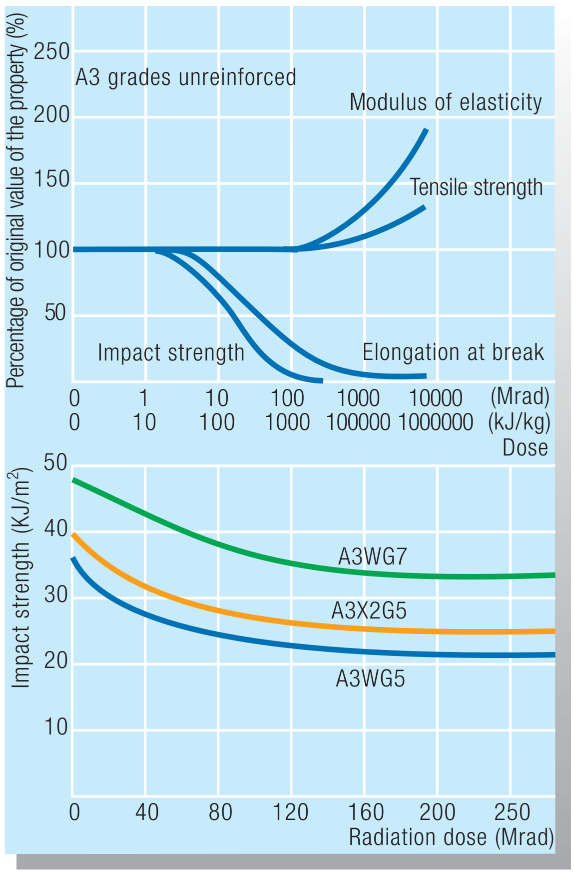


Fig. 29: Behavior of Ultramid on exposure to high-energy radiation. Impact strength (DIN 53 453), tensile strength, modulus of elasticity and elongation at break (DIN 53 455) as a function of the absorbed dose. Irradiation with 2 MeV electron beam, absorbed dose rate 0.5 Mrad/min

Behavior on exposure to high-energy radiation

In comparison with other thermoplastic materials unreinforced polyamide exhibits moderate resistance to radiation. The change in properties of unreinforced Ultramid resins due to high-energy radiation varies with the grade of resin exposed.

Some properties already change at low doses whereas others change scarcely at all even at high doses. Irradiation with a 2 MeV electron beam (high dose rate) gives rise to the changes in properties shown in Fig. 29 for Ultramid A3 grades as a function of the absorbed energy dose.

In the range up to 10,000 kJ/kg (1,000 Mrad) the electrical properties (dielectric constant, loss factor, tracking current resistance) are practically unaffected.

The glass-fiber reinforced grades, including those containing a flame retardant, are extraordinarily resistant to radiation. A radiation dose of 2,000 kJ/kg for example only results in a drop in impact strength of 15 to 30 %.

A gamma-ray dose of 25 kJ/kg has no adverse effects on the mechanical properties of Ultramid. Uncolored or white-pigmented parts assume a slight yellow tinge.

Viscometric and molecular data

The solution viscosity of polyamides can be determined by various standard methods using different solvents. Table 5 gives the viscosity numbers and other viscosity-related values as well as molecular data and melt viscosities for various standard Ultramid grades. The viscosity number and the melt volume flow rate MVR 275/5 or MVR 325/5 of the individual grades are given in the range chart.

Table 5 **Viscometric and molecular data for Ultramid B, A and T grades (typical values)**

	Unit	B3	B35	B36	B4	B5	A3	A4	T KR 4350
Viscosity number ISO 307 (sulfuric acid)	cm^3/g	150	195	217	250	320	150	205	130
Viscosity number ISO 307 (formic acid)	cm^3/g	143	187	220	250	325	134	196	–
Relative viscosity (c = 1 g/dl, sulfuric acid)	–	2.7	3.3	3.6	4.05	5.0	2.6	3.45	2.6
Number average molar mass M_n	–	18000	24000	28000	33000	42000	18000	26000	–
Number average degree of polymerization[1]	–	160	210	250	290	370	160	230	–
Melt viscosity at 250[2]/280[2] (shear rate = 1000 s^{-1})	Pa · s	140	280	340	400	520	130	210	175
MVR[3] („Melt-volume-rate") DIN-ISO 1133, procedure B; at 275°C/5 kg	$\frac{cm^3}{(10\ min)}$	130	40	30	16	8	150	40	30

[1] for Ultramid A grades, express as 1/2 basic molecule.
[2] Ultramid B grades at 250 °C, Ultramid A grades at 280 °C, Ultramid T at 320 °C
[3] Die L/D = 8.0/2.1 mm Ø, load 5 or 10 kg, moisture < 0.05 %, Ultramid T at 325 °C / 5 kg

Ultramid can be processed in principle by all methods known for thermoplastics. The main methods which come into consideration, however, are injection molding and extrusion. Complex moldings are economically manufactured in large numbers from Ultramid by injection molding. The extrusion method is used to produce films, semi-finished products, pipes, profiled parts, sheet and monofilaments. Semi-finished products are for the most part further machined by means of cutting tools to form finished molded parts.

Processing characteristics

Melting and setting behavior

The softening behavior of Ultramid on heating is shown by the shear modulus and damping values measured in accordance with DIN 53445 as a function of temperature (Figs. 4 and 5, p. 12). Pronounced softening only occurs just below the melting point, from about 270 °C for Ultramid T, 240 °C for Ultramid A and about 200 °C for Ultramid B. Glass fibers raise the softening point.

The melt also solidifies within a narrow temperature range which is about 20 to 40 °C below the melting point depending on the rate of cooling and the Ultramid grade in question. This range is identified by DSC as the temperature at which the rate of crystallization is a maximum. At the same time there is a contraction in volume of 3 to about 15 %. The total volumetric shrinkage can be read off from the PVT diagrams in Fig. 30.

Thermal properties

The relatively high enthalpy of Ultramid, shown as a function of temperature in Fig. 31, requires not only powerful heating elements, but also somewhat longer setting and cooling times which are proportional to the square of the wall thickness or diameter.

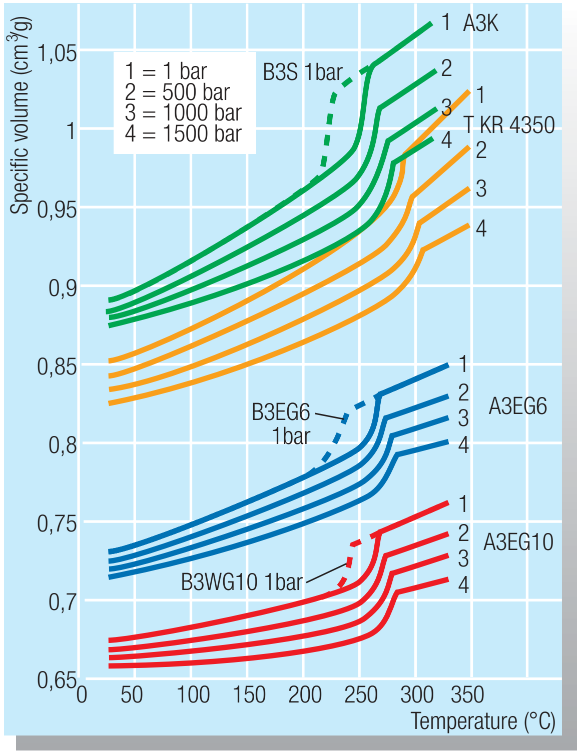


Fig. 30: PVT diagrams for Ultramid A, B and T

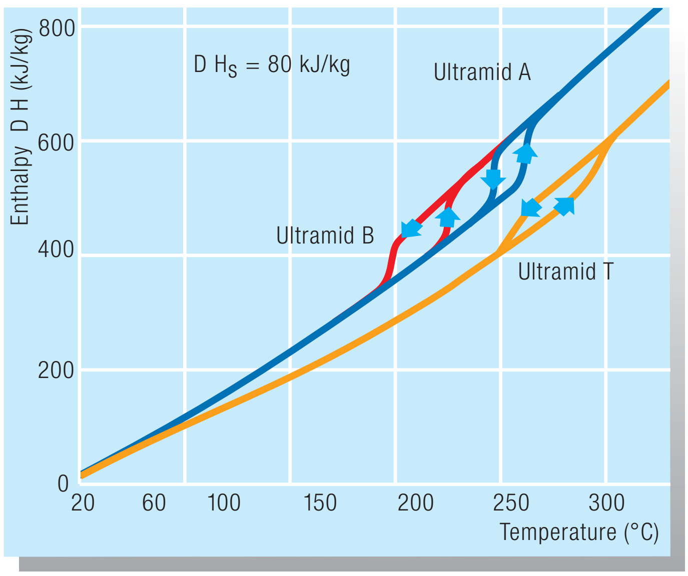


Fig. 31: Enthalpy of Ultramid A, B and T (unreinforced) as a function of temperature

Plug connector with film hinge

Melt viscosity

The rheological properties of Ultramid melts are evaluated on the basis of viscosity diagrams produced from measurements using a capillary rheometer or on the basis of injection-molding tests.

In the processing temperature range the Ultramid grades have a melt viscosity of 10 to 1,000 Pa · s, the actual value being highly dependent on temperature and shear rate. The higher the relative molar mass or the relative solution viscosity (given by the first digit in the name), the higher is the melt viscosity and the greater the resistance to flow (Fig. 32). In the case of Ultramid grades with mineral fillings or glass-fiber reinforcement the viscosity increases in proportion to the amount of reinforcing material incorporated.

The melt viscosity can change over time. A rapid drop in viscosity can occur for example when the melt is too moist, too hot or subjected to high mechanical shear forces. Oxidation can also cause the viscosity to fall. All these factors have an effect on mechanical properties and the heating aging resistance of the finished parts or the semi-finished products.

Thermostability of the melts

When correctly processed the thermostability of Ultramid melts is outstanding. Under normal processing conditions the material is not attacked or modified. Degradation in relative molar mass only occurs when the residence time is relatively long. The recommended melt temperatures for processing may be found in Tables 6 (p. 38), 12-14 (p. 56-57) and in the Ultramid range chart.

If the melt does not come into contact with oxygen no appreciable change in color occurs. In the presence of air, especially in the case of free-flow nozzles, the surface can become discolored after just a short time, e.g. during a temporary production stoppage.

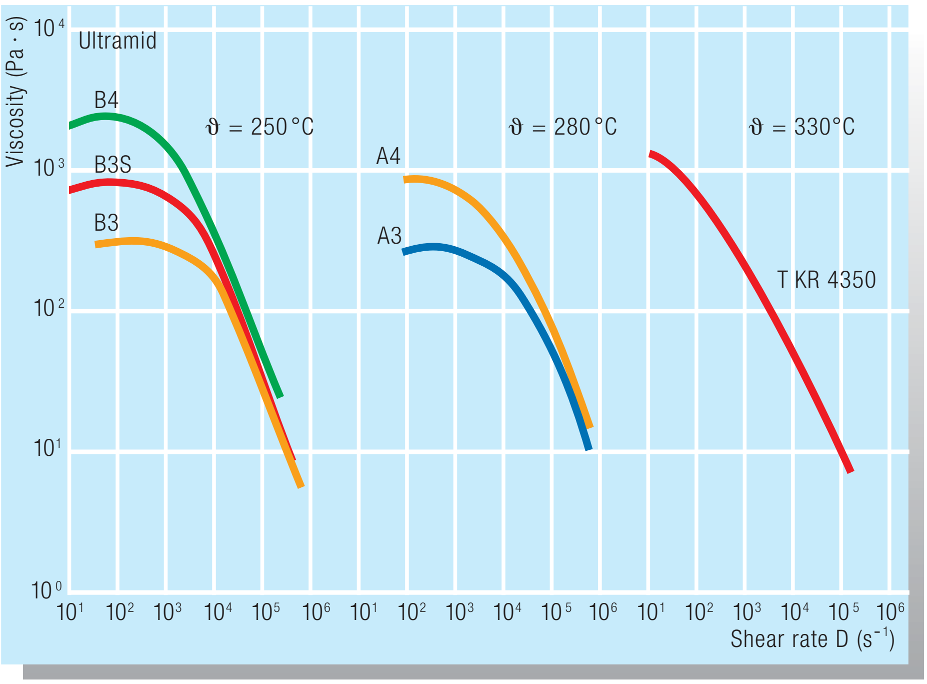


Fig. 32: Apparent viscosity of Ultramid A, B and T (unreinforced) as a function of shear rate

General notes on processing

Preliminary treatment, drying

(cf. "Storage", p. 64).
The flat or cylindrical pellets supplied in moisture-proof packaging can be processed without any special preliminary treatment. Following improper storage, e.g. in open containers, it is strongly advisable that the moist granules be dried in a dehumidifying or vacuum dryer. Dehumidifying dryers are the most efficient and reliable. The maximum permissible drying temperatures for Ultramid lie in the range of about 80 to 110 °C.

Pellets having pale colors sensitive to heat should be dried under mild conditions at temperatures not exceeding 80 °C in order to avoid yellowing or a change in shade.

The drying time depends on the moisture content. The maximum permissible moisture content for injection molding is 0.15 %. In the case of extrusion the limiting value is 0.1%. An excessively high moisture content can result in degradation and plate-out, especially in the case of flame-retardant grades. Fig. 33 presents the results of a drying trial using a dehumidifying dryer (with continuous drying of return air).

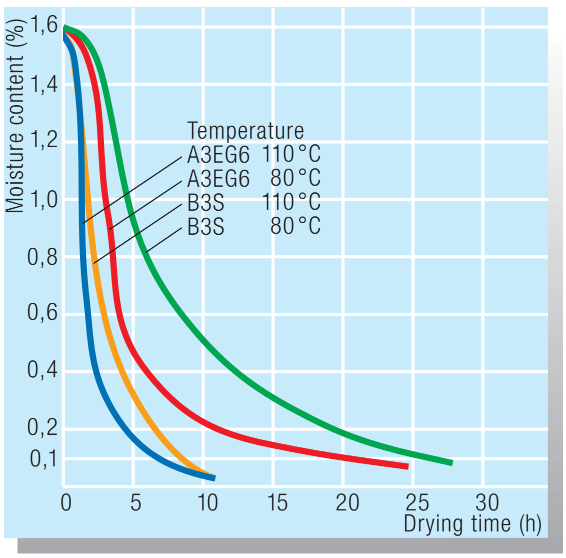


Fig. 33: Moisture content of Ultramid pellets as a function of drying time (measurement of moisture content in accordance with ISO 960)

Start-up and shutdown

The processing machine is started up in the usual manner for thermoplastics. The barrel and nozzle heaters are set to achieve the melt temperature required in each case (see Table 6, p. 38 for guide values). As a precaution the melt exposed to thermal stresses during the heating-up phase is pumped off. After this the optimum processing conditions have to be determined in trials. When there are relatively long work stoppages or when shutting the system down the machine should if possible be run until it is empty and the heaters switched off. On restarting, production can continue under the previously optimized processing conditions after a run-up phase.

When processing flameproofed grades it is recommended that the melt should not be pumped off but rather injected into the mold. If pumping off cannot be avoided an extraction device (hood) should be available and the melt cooled in the water bath (see "Safety notes - Safety precautions in processing", p. 61).

Compatibility of Ultramid grades among themselves and with other thermoplastics; Change of materials

The Ultramid A, B, C and T grades are compatible with one another within their own groups. Mixtures of Ultramid A, B or G with T have only limited stability due to the high processing temperatures and have to be checked with care. Ultramid A, B and C, however, are miscible with one another under certain conditions. For example a small amount of Ultramid B can be added to glass-fiber reinforced Ultramid A to facilitate processing. Due to the limited homogenizing action of most processing machinery excessive differences in viscosity in the components to be mixed should be avoided.

Ultramid is generally immiscible with most other thermoplastics including PS and ABS. Even small amounts of such extraneous materials usually have an interfering effect which becomes apparent, for example, in the form of a laminar structure, especially close to the gate, or in reduced impact strength.

When changing over to other thermoplastics and from other thermoplastics to Ultramid it is advisable to purge the barrel with PE or PP pellets of high molecular weight or with suitable cleaning compounds. Glass-fiber reinforced Ultramid grades also have a good cleaning action. If the screw has to be dismantled, e.g. when changing color or switching to high-temperature thermoplastics, it is advantageous to clean the barrel with PP as described above. After the screw has been dismantled the residual material can be drawn off while it is still warm in the form of a film or it can be readily removed with a wire brush. Further residues have to be removed by blasting with glass beads (diameter approx. 10 µm).

In-line coloring
In-line coloring of Ultramid by the converter is generally possible. In the case of Ultramid T, however, which is usually processed at temperatures in excess of 310 °C, we advise against in-line coloring due to its limited thermostability.

The properties of parts made from in-plant colored pellets, especially homogeneity, impact strength, fire and shrinkage characteristics, have to be checked carefully because they can be dramatically altered by the additives and the processing conditions in question.

In the case of three-section screws homogeneity can be improved by raising the back pressure. This measure, however, simultaneously increases the dissipation and hence the heat exposure of the melt. In addition the output rate may drop. The mixing action of the three-section screw is thus limited and for that reason in some exceptions it may be necessary to use screws having shearing and/or mixing parts. Barrier screws are equipped as standard with shearing and/or mixing parts and are therefore suitable for in-line coloring (see “Plasticating unit”, p. 34).

Flameproofed Ultramid grades should not be colored in-line because their good combination of properties (fire behavior, electrical insulating properties) may be severely impaired and no longer meet the UL flammability specification.

If in-line colored parts are used in food applications special provisions have to be observed (see “Food legislation”, p. 62).

Reprocessing and recovering of scrap
Ground sprue waste, reject parts and the like from the processing of Ultramid grades can be reused in limited amounts (up to about 10 %). They must not be dirty or have been damaged by heat in the prior processing. In ground form Ultramid is particularly sensitive to moisture. Even when the ground material has been stored in dry conditions it is advisable to dry it before processing. Moisture can give rise to molecular degradation during processing. For drying conditions see “General notes on processing“.

The addition of ground material to the original pellets can result in changes in feed and flow properties, ease of demolding and shrinkage behavior and especially may change mechanical properties.

Scrap produced in extrusion is generally not used again. The processing technique, machines and dies should be carefully checked, monitored and maintained so that at worst waste is produced only on start-up and shutdown of the installation.

Chain saw housing

Injection molding

Injection molding is the most important method for processing Ultramid. Ultramid can be processed on all commercial injection-molding machines provided that the plasticizing unit has been correctly designed.

Gas-assisted injection molding (GAM)

This method which is known by different names affords designers new possibilities in relation to the reduction of wall thicknesses and weight as well as optimization of strength. In most applications additional degrees of freedom in the design of moldings and in simpler mold construction are at the fore.

In principle both unreinforced and reinforced Ultramid grades can be processed by this method. Numerous applications from the most varied fields can already be implemented. However, special features with reference to conventional injection molding, such as e. g. shrinkage, warpage, gate design, gas injection, distribution of wall thicknesses, etc., should be clarified as early as possible.

Plasticating unit

Three-section screws

The single-flighted three-section screws usual for other engineering thermoplastics are suitable for the injection molding of Ultramid. In modern machines the effective screw length is 18 - 23 D and the pitch 1.0 D or in rare cases 0.8 D. The geometry of the three-section screw which has long proved effective is shown in Fig. 34.

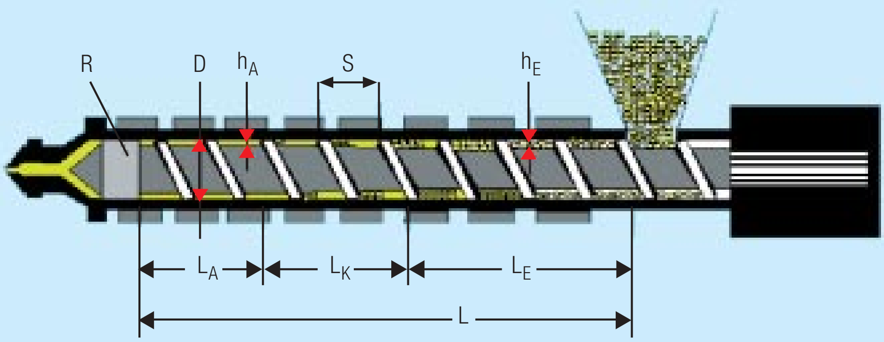
The feed behavior is substantially determined by the temperatures in the region of the hopper and by the flight depth in the feed section. Apart from the control of the cylinder temperature the dissipation is decisive for plastication. Recommended flight depths are shown in Fig. 35. These flight depths apply to standard and more shallow-flighted screws and afford a compression ratio of 1 to 2. When using shallow-flighted screws the output rate is lower than in the aforesaid standard designs, but in practice this is usually of secondary importance. Shallow-flighted screws convey less material than deep-flighted ones. The residence time of the melt in the cylinder is therefore shorter. This means that more gentle plasticization of the pellets and greater homogeneity of the melt are achieved. This is an advantage for the quality of injection-molded parts made from Ultramid.

Barrier screws

The characteristic feature of a barrier screw is the division of the screw channel into a channel for solid and a channel for melt which are separated by a barrier wall. The barrier wall has a greater gap width than the main divider and this has the effect that only fused material and particles smaller than the barrier wall can get into the melt channel. When the solids channel overflows into the melt channel the melt is exposed to additional shear stress. Since unfused material can be present at the end of the solids channel, barrier screws require shearing and/or mixing parts in order to ensure adequate homogeneity.

When the back pressure is low and metering strokes are short the barrier screw can exhibit advantages over the three-section screw. At higher back pressures the throughput rate drops markedly. Longer metering strokes can result in partial filling of the melt channel with solid if the remaining length of feed section is too short.

Due to the additional shear stress in the barrier wall together with shearing and mixing parts the barrier screw is not recommended for fiber reinforced and/or flameproofed Ultramid grades.



D	outer diameter of the screw		
L	effective screw length	18 - 22	D
L_E	length of feed section	0.5-0.55	L
L_K	length of compression section	0.25-0.3	L
L_A	length of metering section	0.2	L
h_A	flight depth in the metering section		
h_E	flight depth in the feed section	0.8-1.0	D
S	pitch		
R	non-return valve		

Fig. 34: Screw geometry - Terms and dimensions for three-section screws for injection molding machines

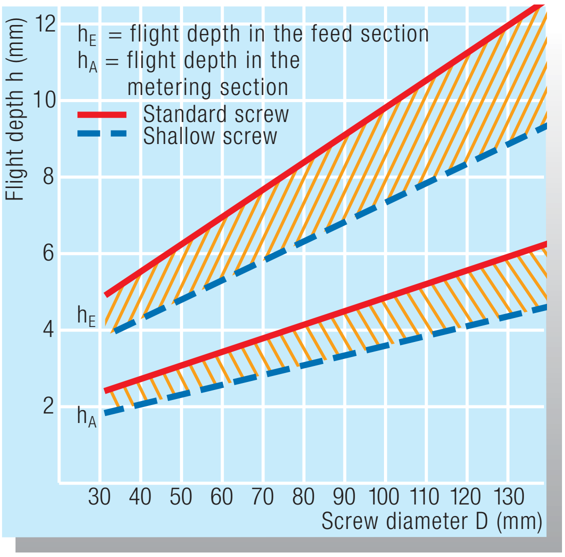


Fig. 35: Screw flight depths for three-section screws in injection molding machines

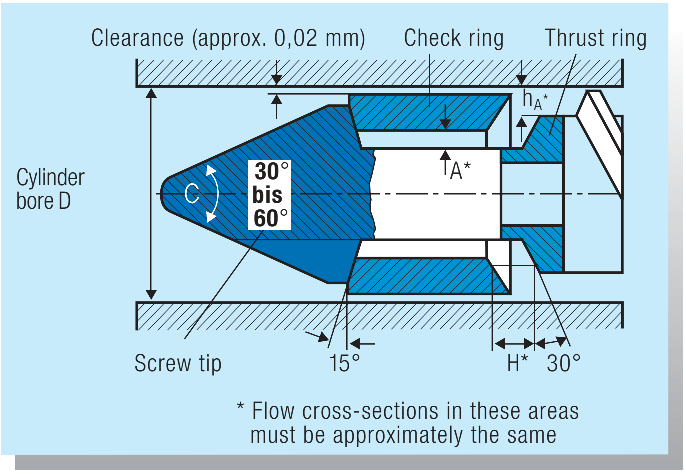


Fig. 36: Non-return valve

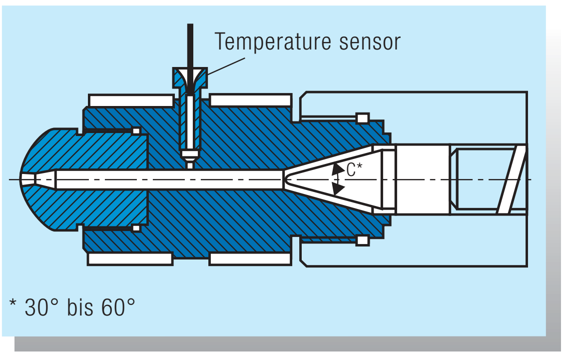


Fig. 37: Open nozzle with temperature sensor

Vented screws

Flameproofed Ultramid grades should not be processed in vented screws. Although vented machines may be used for the other Ultramid grades they are not necessary as the pellets are shipped dry and ready to use. The drying of pellets and ground material in vented machines is not recommended because it results in molecular degradation and hence in poorer quality of the finished parts, especially in the case of heat-sensitive products.

Screw tip, non-return valve

The design of the screw tip and the non-return valve are vital for the trouble-free flow of the melt into the plasticating unit. This prevents the melt from flowing backwards during injection and holding.

Stable melt cushions and long holding pressure times can only be achieved with non-return valves.

The clearance between cylinder and non-return valve should not be greater than 0.02 mm (Fig. 36).

The flow cross-sections in the various sections (A, h_A and H) should be of the same size, as shown in Fig. 36, in order to prevent return flow of the melt. It is recommended that the screw tip be designed (angle C in Fig. 36) in such a way that as little melt as possible can collect in the head of the cylinder or in the nozzle.

Machine nozzle

Open nozzles are preferred to shut-off nozzles because of their streamlined design and uniform heat transfer. This makes them advantageous in particular when changing from one color to another. The angle of the transition in the nozzle from the barrel to nozzle bore should correspond to the screw-tip angle.

To prevent the melt from escaping during the plasticizing phase, the nozzle should be right up against the mold. Afterwards, the screw is retracted by about 5 to 10 mm to depressurize the nozzle and the injection unit is pulled back from the mold. Cooling the nozzle is also conceivable to prevent the escape of melt. However, the melt must not be allowed to freeze. With glass-reinforced grades, for example, "cold slugs" are easily formed in the forward part of the nozzle, leading to poor quality moldings.

If the plasticizing unit is vertical and/or the melt viscosity is low, often nothing will prevent the escape of molten polymer from the nozzle. In such cases, shut-off nozzles are preferred to ensure uninterrupted production. These nozzles also prevent the melt from coming into contact with oxygen in the tip of the nozzle while the injection unit is being pulled back from the mold. Needle shut-off nozzles must be designed to ensure smooth and even flow. An example is shown in Figure 38.

Stoppages should be avoided if a shut-off nozzle is installed, since each additional heat-up phase exposes thermally sensitive materials to unnecessary thermal loading. This is especially true of Ultramid flame-retardant grades. It is much more difficult to purge thermally degraded material from a shut-off nozzle than from an open nozzle.

Frozen melt can be extracted more easily and cleanly from a shut-off nozzle than from an open nozzle. It is important that the plug of frozen material is completely removed from the nozzle orifice to avoid solid material entering the cavity with the next shot, where it could exert a notch effect or cause streaks or a flaw in the molding. The nozzle orifice must be conical to ensure troublefree extraction of the frozen plug (angle β in Figure 39).

Shut-off nozzles also enable the plasticizing unit to operate with a back pressure when it is retracted, resulting in better melt homogenization. This advantage should not be ignored when it comes to in-line coloration.

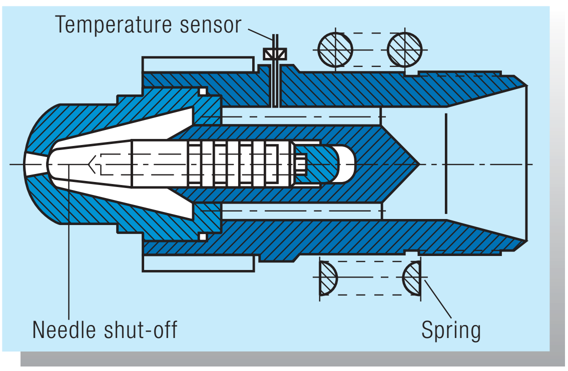


Fig. 38: Spring-loaded needle shut-off nozzle (plastic-service, Mannheim)

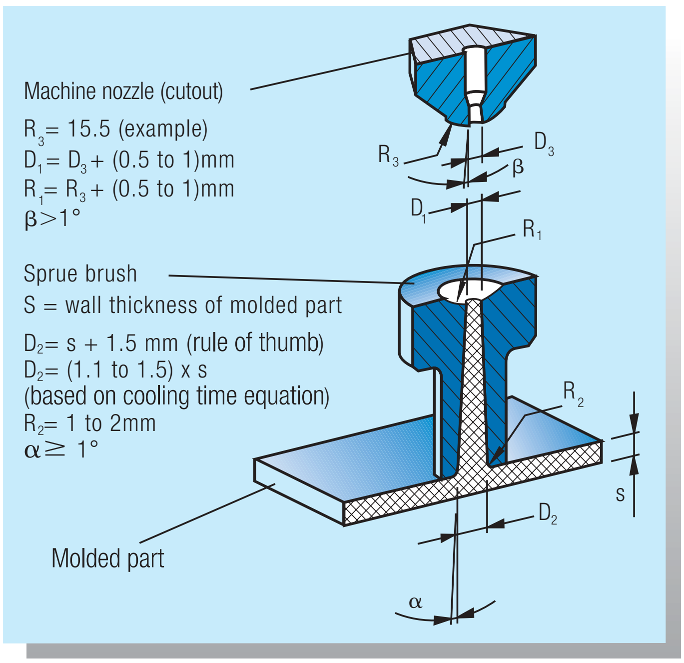


Fig. 39: Screw gate dimensioning

Protection against abrasion and wear
Plasticizing units with hard-wearing components, for example bimetal barrels and hardened screws, screw tips and non-return valves, are recommended for use with glass-reinforced Ultramid, as is the case with most other glass-reinforced thermoplastics.

Injection mold

Mold design

The mold design guidelines specified by VDI 2006 also apply to Ultramid grades.

The low melt viscosity of the unreinforced grades means that features on the mold surfaces are reproduced extremely accurately on the molded part; these surfaces must therefore be produced with the same degree of precision as is required on the subsequent part.

With the glass-reinforced grades, glass fiber content may cause the surface of the molded part to be of a somewhat duller appearance (glass fiber effect). This effect can be compensated by injecting at high speed and at the same time increasing the temperature of the mold (for example to 80-120 °C).

Draft and ejectors

As a rule, the draft on injection molds for Ultramid grades is 1 to 2°. With drafts of a lower angle there is a great increase in the demolding forces, making the ejector system an even more important consideration. For long and thin cores, high-strength steels should be used. To reduce demolding forces, it may be helpful to use a PVD (Physical Vapor Deposition) process to apply surface coatings such as TiN, or CrN when processing A3X2G... grades, and/or to make the surfaces smoother. The contact area of the ejector pins or stripper plates should be as large as possible to prevent the part being punctured or deformed during demolding. This particularly applies to moldings with undercuts and/or low-angle drafts, which require higher demolding forces. In some cases, large-area ejectors permit earlier demolding and thus shorten the cycle time.

Types of gating

In principle, all kinds of conventional gating, including hot runner systems, can be used for Ultramid. Problems may arise with self-insulating hot runner and ante-chamber systems, because of the risk of the melt freezing even during relatively short interruptions.

The feed system (runners and gates) must have large enough cross sections to avoid having to operate at unnecessarily high melt temperatures and pressures, and thus run the risk of streaks and burn marks on the surfaces of the molding. Premature freezing of the melt in the gate area will cause voids and sink marks because the holding pressure will be insufficient to compensate for volumetric shrinkage in the mold cavity.

In the case of fiber-reinforced grades, increased wear occurs in the gate area at relatively high output rates; this can be countered by selecting suitable types of steel and the use of interchangeable mold inserts.

Mold venting

With Ultramid, and the flame-retardant grades in particular, venting at the end of the flow path or at places where flow fronts meet is important. Slits of 0.015 to 0.02 mm should be machined to a length of 2 to 3 mm and then widened to about 1 mm before running out into the open (cf. Figure 40). In the case of free-flowing products, such as B3S for example, the slits must be made thinner in order to avoid flash. The optimum slit thickness depends on the mold and should be determined in processing tests, beginning at 0.005 mm.

Corrosion-resistant high-alloy steels (for example X42Cr13, DIN 1.2083) have proven suitable for A3X2G… grades.

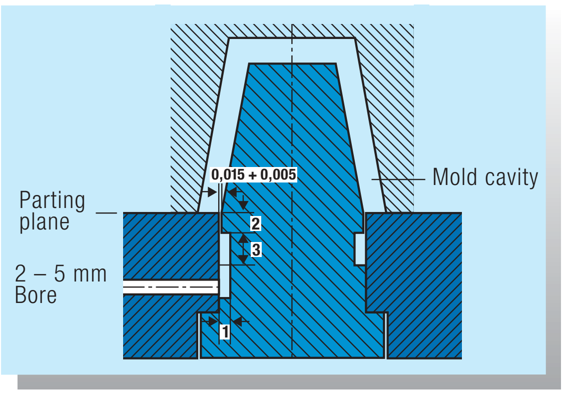


Fig. 40: Design diagram for mold venting

Table 6 **Typical values for the process temperature and molding shrinkage of injection-molded Ultramid**

Ultramid grades	**Melt temperature range (°C)**	**T_W - range(°C)**	**Molding shrinkage (%)** Melt temp. (°C)	**T_W (°C)**	**Test box[1] lengthwise**	**Sheet (2 mm thick)[2] lengthwise**	**crosswise**
A3K, A3W	280–300	40–60	290	60	0.85	1.35	1.45
B3S	250–270	40–60	260	60	0.55	0.6	0.75
B3L	250–270	40–60	260	60	0.65	0.9	1.15
C3U	250–270	40–60	270	60	0.80	1.0	0.9
A3HG5, A3EG5, A3WG.	280–300	80–90	290	80	0,55	0.45	1.1
A3X2G5	280–300	80–90	290	80	0.5	0.4	1.1
A3EG6, A3WG6	280–300	80–90	290	80	0.55	0.35	0.95
A3EG7, A3HG7, A3WG7	280–300	80–90	290	80	0.5	0.35	0.9
A3X2G7	280–300	80–90	290	80	0.45	0.3	0.9
A3EG10, A3WG10	290–310	80–90	300	80	0.45	0.3	0.8
A3X2G10	280–300	80–90	290	80	0.4	0.3	0.9
B3ZG3	270–290	80–90	280	80	0.5	0.45	0.65
B3WG5	270–290	80–90	280	80	0.35	0.25	0.7
B3EG6, B3WG6	270–290	80–90	280	80	0.4	0.25	0.7
B3ZG6	270–290	80–90	280	80	0.4	0.3	0.7
B3WG7	270–290	80–90	280	80	0.35	0.2	0.7
B35EG3	270–290	80–90	280	80	0.55	0.4	0.7
B3WGM24	270–290	80–90	280	80	0.4	0.3	0.6
B3M6	270–290	80–90	270	80	0.75	0.8	0.85
T KR 4350	310–340	60–80	330	80	0.65	0.95	1.4
T KR 4355 G5	320–350	70–90	330	80	0.4	0.27	0.75
T KR 4357 G6	320–350	70–90	330	80	0.4	0.26	0.7
T KR 4355 G7	320–350	70–90	330	80	0.35	0.25	0.78
T KR 4365 G5	310–330	70–90	310	80	0.4	0.31	0.76

Sheet: p_N = 500 bar TK (Test box): p_N = 800 bar

1) impeded shrinkage T_W = mold temperature
2) free shrinkage

Use of inserts

Metal inserts can be encapsulated without any trouble. In the case of large sizes, however, they should be preheated to 100 to 150 °C or at least to the mold temperature so that no excessive internal stresses occur in the molding. The metal parts must be degreased and should be knurled, grooved or similar to provide better anchorage. In addition the edges of the inserts should be well rounded.

Mold temperature control channels and devices

The quality of moldings is very highly dependent on the temperature conditions in the mold. Precise mold temperature control is possible only with a suitably designed system of temperature control channels in the mold together with temperature control devices of appropriate power. Frequently the two halves of the mold or certain parts of the mold must be maintained at different temperatures in order to achieve a uniform distribution of temperature or to counteract warpage in the moldings. The temperature control channels should therefore be laid out in as many separate circuits as possible some of which can be connected in series.

The mold temperatures required for Ultramid can be achieved with temperature control devices using water. Temperatures of up to 150 °C can also be attained with special devices (closed systems).

Air intake manifold

Processing temperatures and residence times

Melt temperatures
The melt temperature ranges listed in Table 6 for the various Ultramid grades are recommended. Tables 7 and 8 (see pp. 40 and 42) with examples of processing by injection molding provide further details.

The correct melt temperature within the specified ranges is dependent on the length of melt flow path and the thickness of the walls of the molding. Higher melt temperatures should be avoided due to the possibility of heat damage to the melt. Slight increases (+10 °C) are only permissible for extremely short production cycles or residence times of the melt in the cylinder (< 2 minutes).

Continuous measurement of the melt temperature is recommended, for example by means of a thermocouple installed in the region of the nozzle (see Figs. 40 and 41).

Mold temperatures
Unreinforced Ultramid is processed as a rule at mold temperatures of 40 to 60 °C. Reinforced Ultramid grades require higher temperatures. To achieve good surface qualities and moldings meeting high requirements for hardness and strength the mold wall temperatures should be 80 to 90 °C, and in special cases 120 to 140 °C (see also Table 6).

A good temperature control system coupled with the correct temperature in the mold is the prerequisite for high-quality injection-molded parts. The mold surface temperature affects the degree of crystallization, the surface quality, shrinkage, warpage, dimensional tolerances and the level of internal stresses.

Cylinder temperatures
When the melt has a long residence time in the cylinder gentle fusion is achieved by setting the temperatures of the cylinder heater bands so that they rise from the charging hopper towards the nozzle. In the case of short residence times flat temperature control on the cylinder can also be appropriate (see Fig. 41 for examples).

Barrier screws may require that the temperature profile falls from the charging hopper towards the nozzle.

The nozzle must be provided with at least one heater band with a heating power of 200 to 300 W because high heat losses due to radiation and conduction to the injection mold can occur and this in turn gives rise to the risk of the melt solidifying in the nozzle. It is recommended that the control of the heating bands be monitored. By giving early warning, e.g. of the failure of a heater band on the cylinder, this can provide protection against screw fracture. Feed behavior can often be improved by means of temperature control (approx. 80 °C) in the region of the hopper.

Residence time in the cylinder
The residence time of the plastic in the plasticating cylinder is a major factor determining the quality of the molding. Residence times which are too short can result in thermal inhomogeneity in the melt whereas if they are too long (> 10 min) they often produce heat damage. This in turn results in a loss in impact strength which is sometimes visible from discoloration, dark stripes or burnt particles of product on the injection moldings.

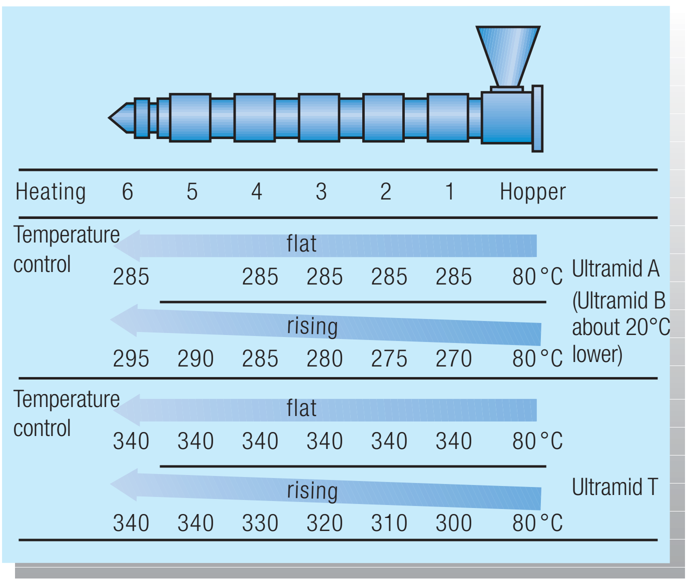


Fig. 41: Examples of cylinder temperature control

In a specific test, the dwell time can be determined by adding granules of a different color. When processing Ultramid grades of a light color, just a few dark-colored particles are sufficient for this. The dwell time is then the product of the cycle time and the number of cycles required before differences in color are evident on the molding. It is not possible to estimate the dwell time on the basis of the theoretically possible injection volume.

Figure 42 shows that the dwell time decreases with increasing metering stroke (assuming a constant metering volume and constant injection cycle); this dependence becomes less strong once metering strokes exceed 3D. In practice this means that the dwell time can often be reduced by using a smaller plasticizing unit. However, metering strokes > 3D may have the effect that the remaining effective screw length is too short, increasing the risk of air being drawn in and melt inhomogeneities (unmelted granules). Experience shows that a plasticizing stroke between 1 and 3D produces optimum injection processes.

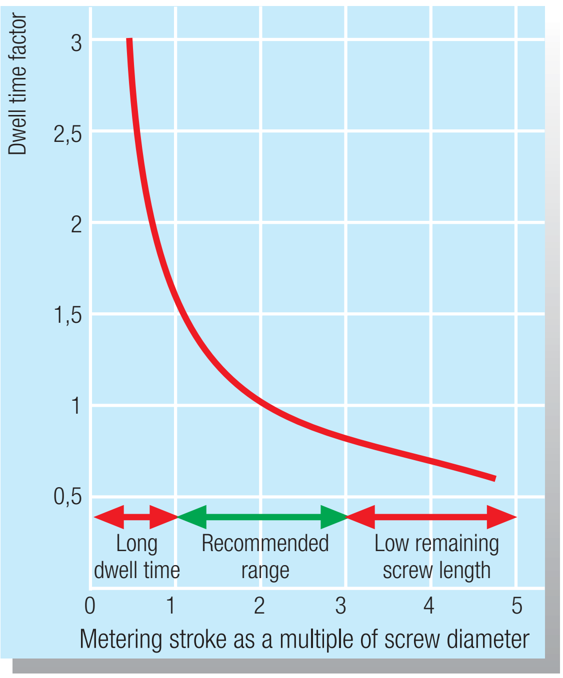


Fig. 42: Dwell time as a function of metering stroke

Processing characteristics

<u>Feeding</u>

With the screw designs described, Ultramid can be uniformly plasticized. However, the melting and feeding characteristics of the granules depend not only on the screw design but also on the temperature control of the barrel, the screw speed and the back pressure.

If premature melting of the granules is to be avoided, it is important that the temperature in the feed section (hopper zone HZ1) is not set too high. This could cause bridge formation (clogged screw flights), something which may occur if the processing temperatures and dwell times of the melt are very high.

Table 7 **Injection molding examples**

Ultramid		**B3S**	**B3EG7**	**A3K**
Description of molding		Wall plug	Power tool housing	Terminal block for electric switches
Dimensions of molding	mm	32 cavity 8 ∅; 40	170x170x35	2 cavity 55x35x8
Total/individual weight	g	43/1.3	436/200	20/8
Wall thickness	mm	0.9…3.5	1.2–6.5	1.3–2.5
Length of flowpath	mm	40	230	55
Type/size of gating system	mm	sprue; 2 pin gates	sprue; runner gate 5x2.5	gates 1.2 ∅
Michine data				
Swept volume (max.)	cm	235		56
Injection pressure (max.)	bar	1236		1200
Clamping force	kN	750		600
Screw diameter	mm	45		32
Heater temperatures (hopper...//nozzle)	°C	255/260//260	260/270/280	255/265/275//280
Melt temperature	°C	265	290	285
Mold temperature	°C	60	80	70
Cycle time	s	7	60	22.5
Injection time	s	0.7	3	1.5
Holding time	s	2.2	12	4.0
Cooling time	s	2.2	4	12
Plastification time	s	1.8	21	–
Injection pressure	bar	480	980	800
Holding pressure	bar	400	700	640
Back pressure	bar	0	210	0
Screw speed	rpm	260	80	60
Output	kg/h	–	26	3.2
Processing shrinkage V_s				
– Length of diameter	%	–	0.4–0.5	1.3
– width	%	–	–	–

Back pressure
Back pressure is often used in practice to maintain a constant plasticizing time, to avoid entrapped air, or to improve the homogenization of the melt. It is not absolutely essential for processing pre-colored Ultramid grades. An excessively high back pressure can cause the melt temperature to increase and lead to greater polymer degradation as well as a reduction in the average fiber length of fiber-reinforced products.

Screw speed
If possible, the screw speed should be set so as to fully utilize the time available for plasticizing within the molding cycle. For instance, a speed of 60 to 100 rpm (corresponding to a peripheral screw speed of 200 to 300 mm/s) is often adequate for a 50 mm diameter screw. Low screw speeds allow temperature rises due to frictional heating to be kept within acceptable limits.

On account of the relatively high torque, however, very low speeds may cause problems in the screw drive. If operating with long cycle times, plasticizing should be commenced shortly before the beginning of injection. This avoids melt staying for too long in the space in front of the screw; this is particularly important when processing at high temperatures.

A3EG7	**A3X2G5**	**A3WG6**	**B3M6**	**T KR 4355 G5**
Housing for domestic appliance	Lower part of contactor	Automobile radiator header tank	Wheel cover	housing
270x180x170	78x55x40 2 cavity	322x55x 65/38	400 ∅	107x47x1.5
960	94/45	190	300	39
3.5 – 7.5	0.8 – 2.2	2.4 – 4.0	2.2 – 2.6	1.5-4
360		345	150	90
sprue l6–10 ∅, l = 82	sprue 5 ∅, l = 35; tunnel 1.0 ∅	sprue 4.8–9.4 ∅, l = 81; film 30x1.0	hot canal; sprue 6 – 12 ∅	sprue 3-6 ∅
1630	186	380	820	38
1500	1800	1600	1880	1200
7000	1300	1750	7500	1200
95	42	60	40	
250/260/ 270…//280	275/280/ 285//285	290/290/ 290//300	250/270 270//270	300/320 330/330
285	290	288	275	330
90	40/90	68/40	80	80
110	35	58	38	28
1.6	1.2	1.9	4.3	0.3
18	8	10	8,0	10
60	20	30	20	18
–	–	9.5	6,5	-
1100	660	640	865	755
300	820	280	675	800
60	70	55	5,0	3
70	100	100	80	100
31.5	9.7	–	28	-
0.5	0.3–0.6	0.2–0.26	0.75–0.85	0.4
0.25	–	–	–	0.6

Plug connector

Mold filling

The speed at which the mold is filled affects the quality of the moldings. Rapid injection favors uniform solidification and the quality of the surface, especially in the case of parts made from glass-fiber reinforced Ultramid grades.

In the case of moldings with very thick walls a reduced injection rate can be appropriate depending on the gate type and position in order to achieve laminar flow rather than jetting. When the melt is injected the air in the mold cavity must be able to escape at suitable points so that scorch marks from compressed air are not produced (Diesel effect, see Mold venting).

In order to prevent sink marks and voids when material accumulates the holding pressure and the holding time must be selected in such a way that contractions in volume when the melt cools are compensated. The precondition for this is that the gate is sufficiently large so that in this region the melt does not solidify before the end of the holding pressure time and as a result prevents the holding pressure from acting on the still plastic molding in the interior.

Flow characteristics

Mold filling always depends on the flow characteristics of the melt. Flow characteristics can be assessed using a spiral-shaped mold on a standard commercial injection-molding machine. The length of path covered by the melt in this mold, as a function of temperature for example, is a measure of the flow characteristics.

Table 8 **Flow characteristic of Ultramid during injection molding: spiral length and flow path/wall thickness ratio (i)**

Product	T_M	T_W	Flow characteristics					
Ultramid			Spiral length/Spiral thickness					
			1 mm		1,5 mm		2,0 mm	
	°C	°C	mm	i	mm	i	mm	i
B3S	270	60	230	(230)	430	(285)	630	(315)
A3K	300	60	250	(250)	415	(275)	615	(310)
C3U	270	60	285	(285)	505	(235)	775	(390)
B3EG3	290	80	260	(260)	515	(345)	650	(325)
B3EG6	290	80	190	(190)	405	(270)	530	(265)
B3WGM24	280	80	210	(210)	320	(215)	490	(245)
B3ZG6	290	80	180	(180)	325	(215)	450	(225)
B3M6	290	80	170	(170)	335	(225)	440	(220)
A3EG5	300	80	280	(280)	465	(310)	620	(310)
A3EG6	300	80	270	(270)	450	(300)	580	(290)
A3WGM53	300	80	280	(280)	440	(295)	520	(260)
A3X2G5	300	80	180	(180)	290	(195)	460	(230)
A3EG10	310	80	300	(300)	500	(335)	590	(295)
T KR 4350	340	80	–	–	450	(300)	545	(270)
T KR 4355 G5	350	80	–	–	505	(335)	600	(300)
T KR 4357 G6	350	80	–	–	370	(245)	440	(220)
T KR 4355 G7	350	80	–	–	455	(300)	570	(285)

T_M = Melt temperature T_W = Mold surface temperature

The spiral flow lengths for some Ultramid grades are presented in Fig. 43. The maximum injection pressure in all cases was 1,000 bar and the mold surface temperature was 60 °C or 80 °C. In this test the spiral flow length achieved serves as a measure of the flow characteristics of a thermoplastic. From this the ratio of flow path to wall thickness is obtained. In this test the spiral thickness was 1.5 mm. Thinner spirals or molding walls yield smaller flow path to wall thickness ratios. These ratios (i) are given in Table 8 for spirals 1.5 and 2.0 mm thick. They have only limited application to actual moldings.

Apart from the flow properties of the plastic other factors which have a substantial effect on the ratio of the flow path to the wall thickness include the processing conditions, the injection capacity of the injection-molding machine and the wall thickness of the molding. A further method for evaluating flow characteristics is to find that pressure (injection pressure) which just fills the mold while the temperatures of the mold and the melt are kept constant.

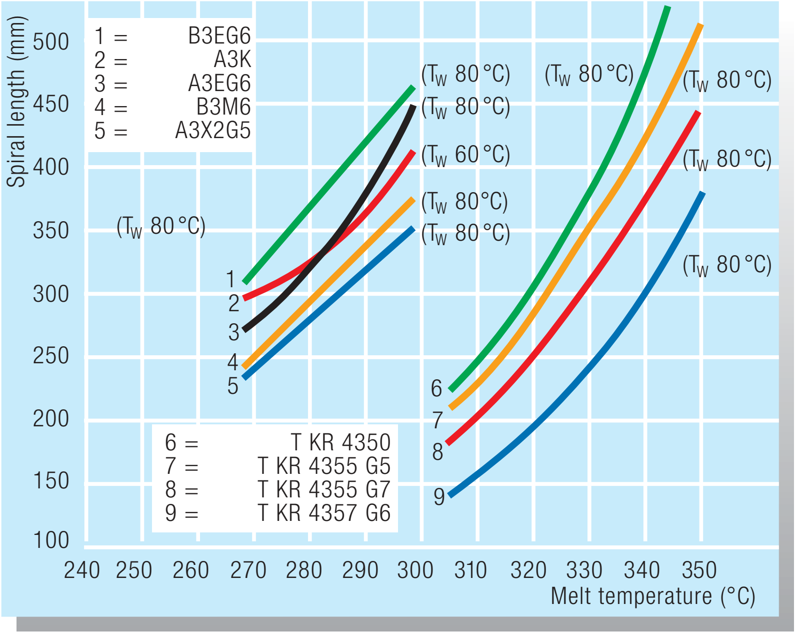


Fig. 43: Spiral flow length as a function of melt temperature; spiral thickness = 1.5 mm

Wall-mounted coatrack

In principle the injection pressure for a thermoplastic can be determined in this way using almost any mold. Of course the rheological values found can only be compared with one another under the same processing conditions and using the same type of mold and machinery. Fig. 44 shows a rectangular box which was used to determine the flow characteristics of some Ultramid grades by this method. Further details are presented in Fig. 45.

Demolding
Moldings made from Ultramid can be readily demolded. In injection molding Ultramid has no tendency to stick to contour-forming walls even in the case of hot molds.

Shrinkage and aftershrinkage
DIN 16901 defines the terms and test methods for shrinkage in processing. According to this, shrinkage is defined as the difference in the dimensions of the mold and those of the injection-molded part at room temperature. It results from the volumetric contraction of the molding compound in the injection mold due to cooling, change in the state of aggregation and crystallization. It is also determined by the geometry (free or impeded shrinkage, Fig. 46) and the wall thickness of the molding. In addition the position and size of the gate and the processing parameters (melt and mold temperature, holding pressure and holding pressure time) together with the storage time and storage temperature play a decisive role. The interaction of these various factors makes exact prediction of shrinkage very difficult.

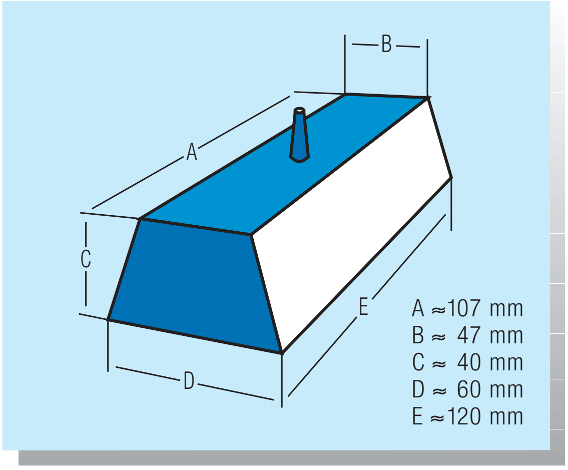


Fig. 44: Test box

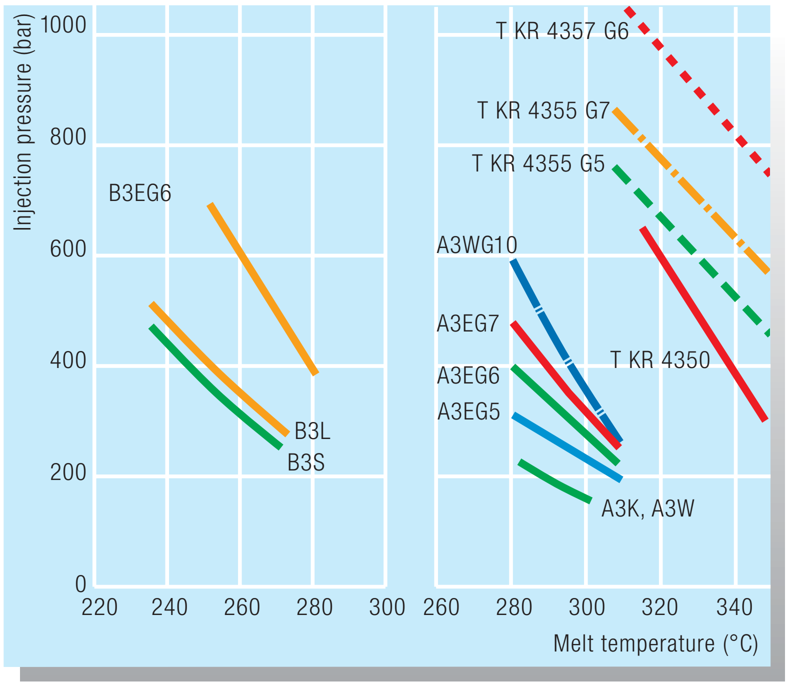


Fig. 45: Flowability of Ultramid grades in injection molding; injection pressure as a function of melt temperature in the production of test boxes. Test conditions as in Fig. 48 but with a mold surface temperature of 80 °C
Unreinforced Ultramid: $T_W = 60$°C
Reinforced Ultramid: $T_W = 80$°C

However, a prediction of the expected shrinkage as accurate as possible is important, especially for the mold maker. The mold dimensions have to be designed in such a way that moldings having the desired external dimensions are subsequently produced.

The free and impeded shrinkage (measured parallel and transverse to the melt flow direction) for some Ultramid grades is shown in Fig. 46. These shrinkage values determined under the same processing conditions reveal that relatively large differences between longitudinal and transverse shrinkage occur among the glass-fiber reinforced products. Dimensional requirements can usually be met by selective modification of the following variables. However, in order to adhere to narrower size tolerances it is essential to take after-shrinkage into account (see the section “Dimensional changes as a result of after-shrinkage”, p. 48).

Variable cam control

Fig. 46: Free and impeded shrinkage of Ultramid; sheet measuring 110 x 110 x 2 mm with film gate, holding pressure 500 bar, measured after storage for 1 h at 23 °C

Effect of holding pressure
The holding pressure and the holding time should as far as possible compensate for the volumetric contraction occurring on solidification and subsequent cooling. Polyamides undergo considerable thermal contraction (see Fig. 30, p. 30, PVT diagrams).

Thus selective changes in holding pressure are a particularly effective means for size correction (see Figs. 47 and 48). In many cases it is useful to drop the holding pressure in stepwise manner in order to avoid excessive internal stresses. For the same reason the holding pressure time should be limited in such a way that it is just long enough to prevent sink marks.

Effect of mold temperature
In this case the mold temperature is the mold surface temperature. As is evident from Figs. 49 and 50, shrinkage increases rapidly as the mold temperature rises. Dimensions can often be kept within the required tolerances by optimizing the mold temperature.

Effect of melt temperature and injection rate
The melt temperature and injection rate exercise only a small effect on shrinkage. Shrinkage increases slightly as the melt temperature (Figs. 51 and 52) rises and the injection rate falls.

Effect of wall thickness
Moldings with thick walls shrink more extensively than those with thin walls (see Figs. 53 to 56). In the case of moldings with highly variable wall thicknesses it is difficult to predict an exact value for shrinkage. In such cases, therefore, a mean wall thickness is taken as the starting point. Variable shrinkage due to differences in wall thickness are frequently the cause of warpage of the molding. Remedies include modification to the design of the part and seperate temperature control circuits in the different parts of the mold.

Effect of gate position and type
The effect of the holding pressure decreases with distance from the gate. Regions close to the gate shrink less than those remote from the gate. This is especially the case in relatively large and complicated moldings. The position of the gate determines the melt flow direction and also the orientation of the glass fibers in the case of the glass-fiber reinforced grades. As a result of the high degree of orientation as the glass fiber content increases, sheet injected via a film gate exhibits pronounced anisotropy of shrinkage (relative low longitudinal shrinkage in comparison with transverse shrinkage). On the other hand in the case of test boxes filled via a central sprue gate a mixed orientation becomes established. Thus shrinkage of the test box lies between the extreme values for longitudinal and transverse shrinkage found for the sheet produced using a film gate (see Figs. 53 to 56).

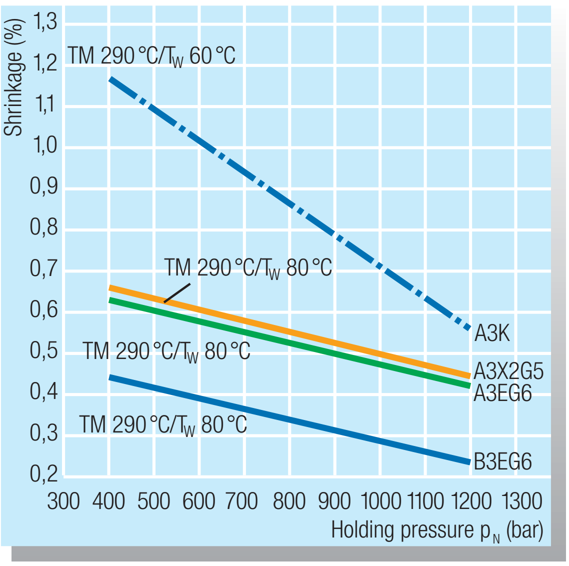


Fig. 47: Shrinkage of Ultramid A and B as a function of holding pressure (test box, 1.5 mm thick)

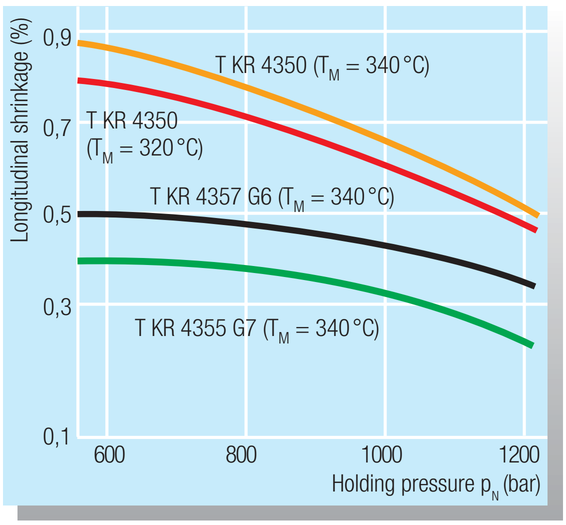


Fig. 48: Shrinkage of Ultramid T as a function of holding pressure (test box, 1.5 mm thick; T_W = 80 °C)

Ultramid can be processed using all types of gates. As polyamides readily flow pin and tunnel gates can be kept relatively small. In these cases it has to be kept in mind that the effective maximum holding pressure time decreases as the gate cross-section decreases. This can result in increased shrinkage. For very thick-walled parts, therefore, a sprue gate is advisable.

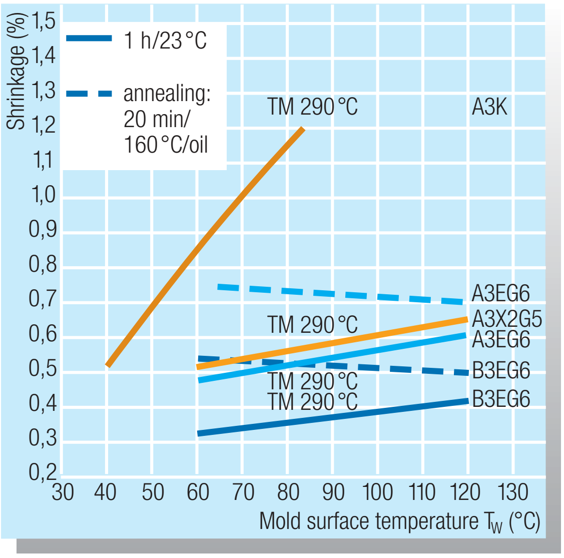


Fig. 49: Shrinkage of Ultramid A and B as a function of mold surface temperature and annealing (test box, 1.5 mm thick)

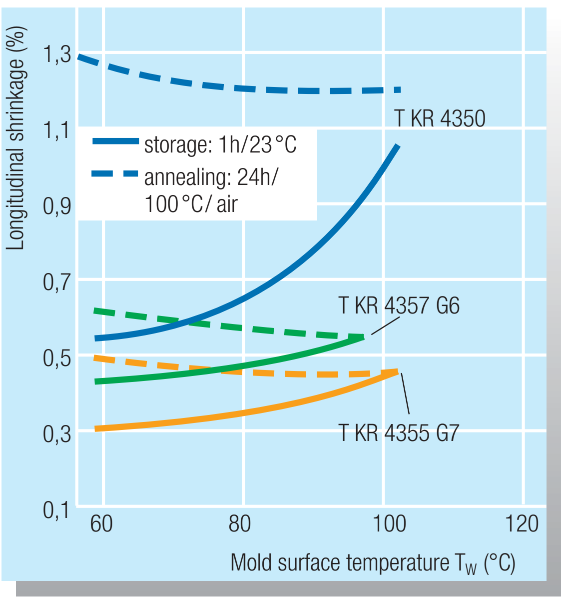


Fig. 50: Shrinkage of Ultramid T as a function of mold surface temperature and annealing (test box, 1.5 mm thick; holding pressure = 800 bar; T_M = 340 °C)

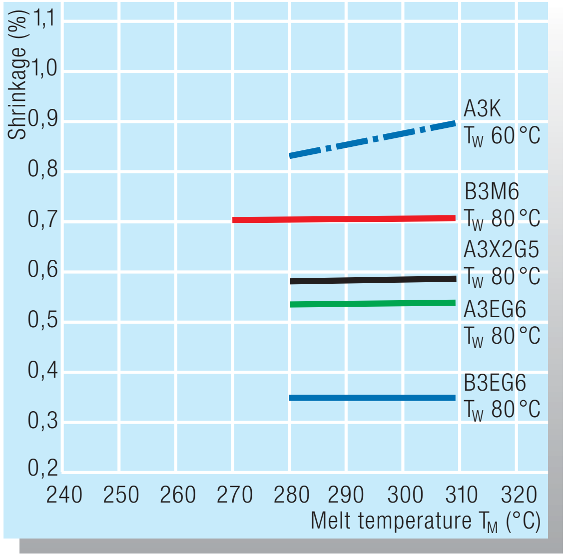


Fig. 51: Shrinkage of Ultramid A and B as a function of melt temperature (test box, 1.5 mm thick)

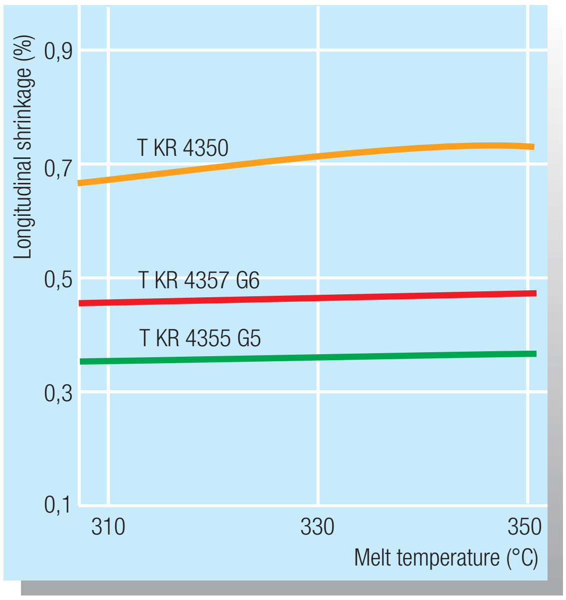


Fig. 52: Shrinkage of Ultramid T as a function of melt temperature (test box, 1.5 mm thick; holding pressure = 800 bar; T_W = 80 °C)

Dimensional changes resulting from aftershrinkage

The dimensions of moldings may change slightly over time as internal stresses and alignments break down and as time- and temperature-dependent postcrystallization occurs.

While aftershrinkage is relatively small at room temperature it can give rise to potentially significant changes in dimensions at higher temperatures. The process of aftershrinkage can be accelerated by annealing. High mold temperatures reduce aftershrinkage and can, therefore, act as a substitute for a subsequent annealing process (Figs. 49 and 50).

Warpage

Warpage in a molding is mainly brought about by differences in shrinkage in the melt flow direction and in the direction transverse to it. In addition it depends on the shape of the moldings, the distribution of wall thicknesses and on the processing conditions.

Figs. 53, 54:
Impeded shrinkage of diverse Ultramid grades as a function of wall thickness (sheet measuring 110 x 110 mm made using a film gate; p_N = 500 bar; ⊥ means perpendicular and II means parallel to the melt flow direction)

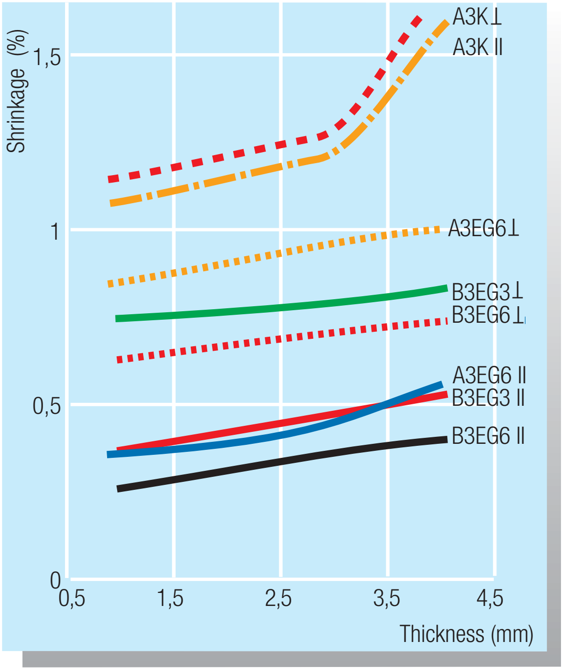


Fig. 53

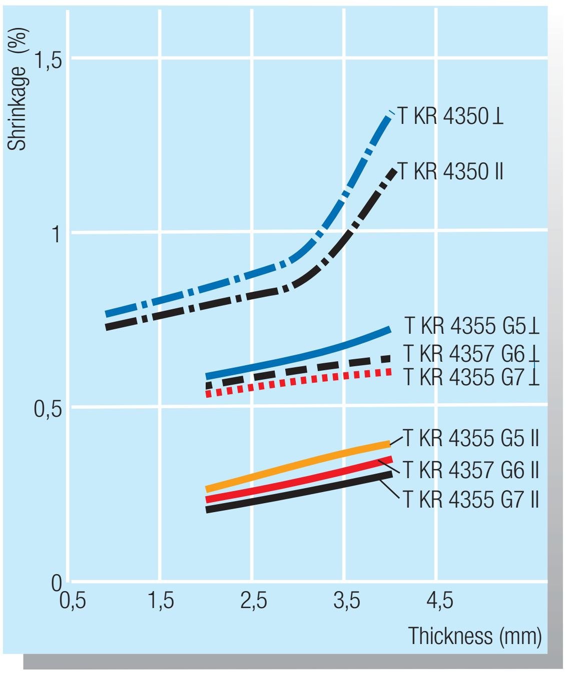


Fig. 54

Cable duct

Figs. 55, 56:
Impeded shrinkage of Ultramid as a function of the wall thickness of a test box (p_N = 600 bar)

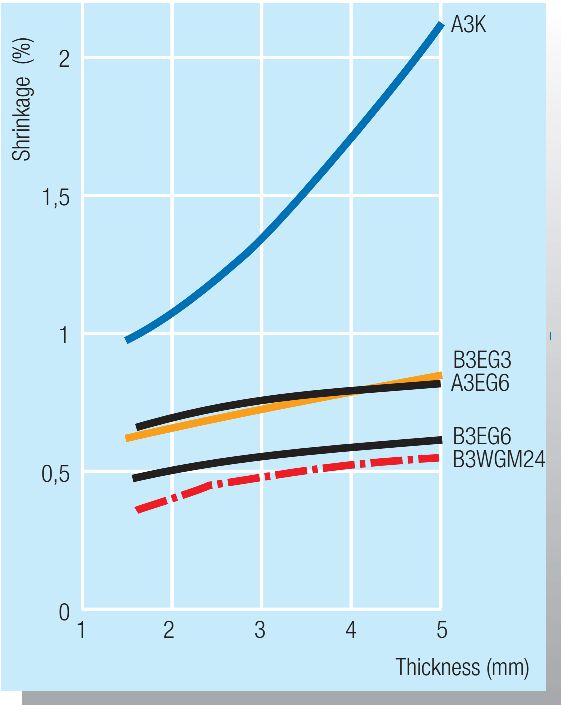


Fig. 55

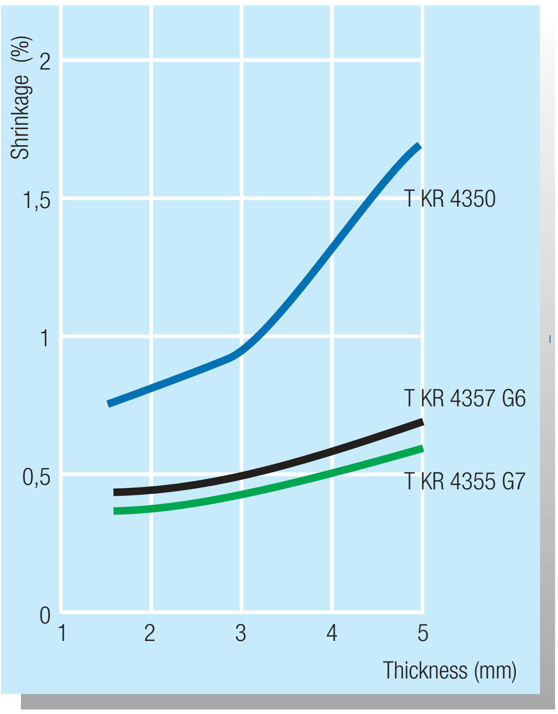


Fig. 56

In the case of unreinforced grades differential temperature control of individual parts of the mold (core and cavity plate) can allow the production of warp-free or low-warpage moldings. Thus for example inward warping of housing walls can be counteracted by means of low core and high cavity plate temperatures.

Due to its higher anisotropy of shrinkage glass-fiber reinforced Ultramid has a more marked tendency towards warpage than unreinforced grades.

The mineral-filled grades are distinguished by largely isotropic shrinkage. They are therefore preferred materials for warp-free moldings.

Oil sensor

Extrusion

Fundamentals, screw geometry and processing temperatures

In the main higher-viscosity (high molecular weight) grades, such as Ultramid A4, A5, B35, B36FN, B4, C35 and C4 for example together with the products based on them containing lubricants and nucleation agents, are suitable for extrusion. In special cases grades of low or normal viscosity such as Ultramid A3 and B3 are used. The melt viscosity required for the extrusion process in question is decisive for the choice of grade.

On the basis of present experience three-section screws having an overall length of 20 to 28 D and a constant pitch of 1 D are best suited to processing properties of Ultramid (cf. Table 9).

The flight depth ratio should be between 3:1 and 3.5:1 (Fig. 57). As indicated, the flight depths themselves are dependent on the screw diameter D and on the melt viscosity. At low melt viscosities the screw should have shallower flights. This applies equally to uncolored products and to grades containing lubricants and nucleation agents.

The screw play (radial clearance between the screw and barrel) should be 0.1 to 0.2 mm so that the leakage flow remains small.

In the case of large screws having diameters of 90 – 150 mm as used in film production we recommend that they are fitted with shear sections at positions 22 – 25 D, depending on the length of the screw. The radial screw clearance should be 0.6 – 0.8 mm. Recently, barrier screws have increasingly been used especially for constant throughput. More gentle fusion and transport at constant speed are possible for example in a narrow throughput range.

Screen packs having a mesh count of 400 to 3,600/cm^2 are usually essential for the required pressure build-up and good homogeneity.

Depending on the actual product and method, the processing temperature of Ultramid A grades is 270 to 290 °C, that of Ultramid B grades 240 to 270 °C and 210 to 235 °C for Ultramid C grades. Suitably powered heater bands and drives (e.g. 10 kW heater power and 60 kW drive power for an extruder having a screw diameter of 60 mm) with precise controllers for screw barrels, adapters and dies are required. The most favorable temperatures for a particular production run must be determined in each case through tests. Data on processing examples are assembled in Table 12 (p. 56). Lubricants and nucleation agents have no appreciable effect on the resultant melt temperature.

Table 9 **Guide values for screw geometry (extrusion)**

Length of sections		
Total length	L	20 – 28 D
Feed section	L_E	8 – 9 D
Transition section	$L_Ü$	4 – 6 D
Metering section	L_A	8 – 13 D[1)]

1) mit Scherteil, Länge 1 – 2 D

Extrusion of semi-finished products and profile sections

Thick-walled semi-finished products such as round-section, hollow and flat rods and other thick-walled profile sections are produced using cooled mold pipes under pressure (cooled-die extrusion method). Grades of medium and high viscosity are mainly used for this purpose. Uniform conveyance and hence constant pressure build-up and improved impact strength are important advantages of these products.

Ultramid B5 is employed when there are particularly high requirements for impact strength and fatigue strength in relation to dynamic stresses. Data on processing examples are assembled in Table 12. The dimensions of standard semi-finished parts made from polyamide and their quality requirements have been standardized as follows:

Technical delivery conditions	DIN 16985[1)]
Round-section rod	DIN 16980[1)]
Hollow rod	DIN 16983[1)]
Sheet	DIN 16984
Slab	DIN 16986[1)]

1) These DIN standards have been combined into European standard EN 1549

The requirements laid down in DIN 16985 are reliably fulfilled by Ultramid B4F and B5 provided they are correctly processed. Different cooling and solidification rates of the melt can give rise to internal stresses which may be compensated by subsequent heat treatment. In the case of thick-walled semi-finished products made from grades with a particularly high modulus of elasticity (Ultramid A and reinforced grades) such annealing, which also promotes dimensional stability, is essential.

Thin-walled profile section, e.g. for sliding rails, is extruded from Ultramid B5 using dies containing an appropriately designed flow channel. The extrudate is cooled in air or in a water bath or sized in a vacuum calibration unit located close to the die (cf. example in Table 12, p. 56).

Glass-fiber reinforced Ultramid A has proved to be effective for thermal insulation bridges in aluminum window profile. Specially adapted extrusion methods afford the necessary dimensional accuracy of the bridges. Apart from good mechanical and thermal properties, advantages include resistance to chemicals including cleaning agents for windows and anodizing baths, and the ability to finish them with stoving enamels.

Production of tubes
Tubes are manufactured from the high-viscosity grades Ultramid B5 or B5W mainly by the waterbath-vacuum calibration technique. They find extensive application in fuel and oil lines, pneumatic and hydraulic control lines, speedometer tubes and tubes for central lubrication systems, Bowden and other sheathed cables.

Sizes and quality requirements are standardized as follows:

Polyamide tubes for automobiles	DIN 73378
Polyamide tubes (sizes)	DIN 16982

The requirements of DIN 73378 can be reliably met using Ultramid B5 providing it has been properly processed.

In the extrusion of tubes by waterbath-vacuum calibration sizing plates arranged one behind the other or radially slotted or drilled calibration sleeves are used for shaping. In both cases, due to shrinkage, the bore of the sizing device should be selected to be about 2.5% greater than the desired external diameter of the tube. In order to exploit the available take-off speeds the ratio of the tube die diameter to the bore of the calibration tube should be approximately 2:1. In tubes having a diameter greater than 10 mm this ratio should be approximately 1.5:1. In the case of a tube diameter greater than 30 mm it can be reduced to 1.1:1.

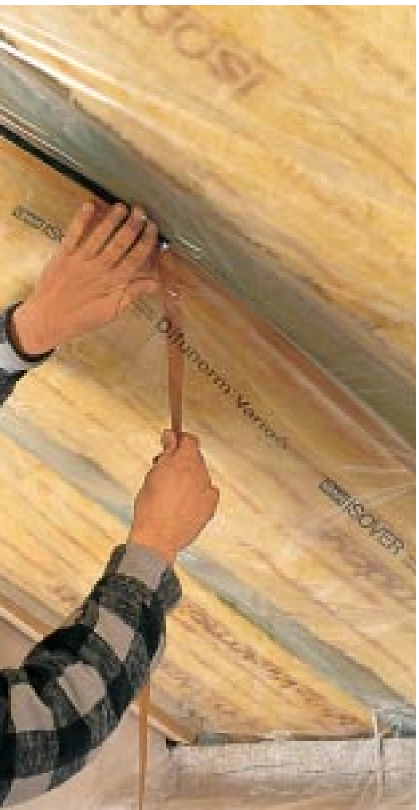
Proceeding from the desired wall thickness of the tube, the die gap width of the tube die must be enlarged in proportion to the selected die/calibrator ratio. Since the melt swells up the gap is additionally reduced by 10 % in each case.

The distance between the tube die and the sizing device should be kept small in order to ensure reliable sizing. The following waterbath maintained at about 20 °C has a length ranging from about 0.5 to 1.5 m depending on the thickness of the tube wall and take-off speed.

Tubes having diameters of up to 5 mm can be extruded from Ultramid B5 with satisfactory dimensional accuracy without sizing. In doing so the melt is drawn off with high take-off speed (up to 40 m/min) directly into a cooling bath which should be up to 3 m long depending on the actual take-off speed.

The ratio of the desired external diameter of the tube to the die diameter lies in the range of 1:1.5 to 1:2.

The same figure applies to the ratio of the desired wall thickness of the tube and the die gap to one another. Table 12 contains examples of the extrusion of tubes having wall thicknesses of 1 mm and 8 mm.


Vapour barrier sheeting

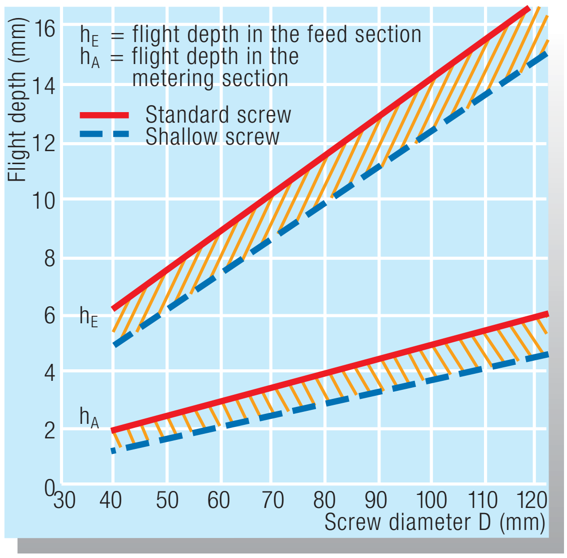


Fig. 57: Screw flight depths for three-section screws in extrusion machines

BASF has improved the waterbath-vacuum calibration process to enable thick-walled tubes to be produced with particularly high efficiency. The greatest advantages (5 – 10 times higher productivity) are yielded in the range of sizes which previously could only be produced as hollow rod by means of cooled-die extrusion (generally at low take-off speed).
Ultramid B5 can be extruded in this way in the diameter range of about 70 mm and with tube wall thicknesses of 10 to at least 15 mm at take-off speeds of 0.20 to 0.25 m/min and output rates of 50 – 60 kg/h.

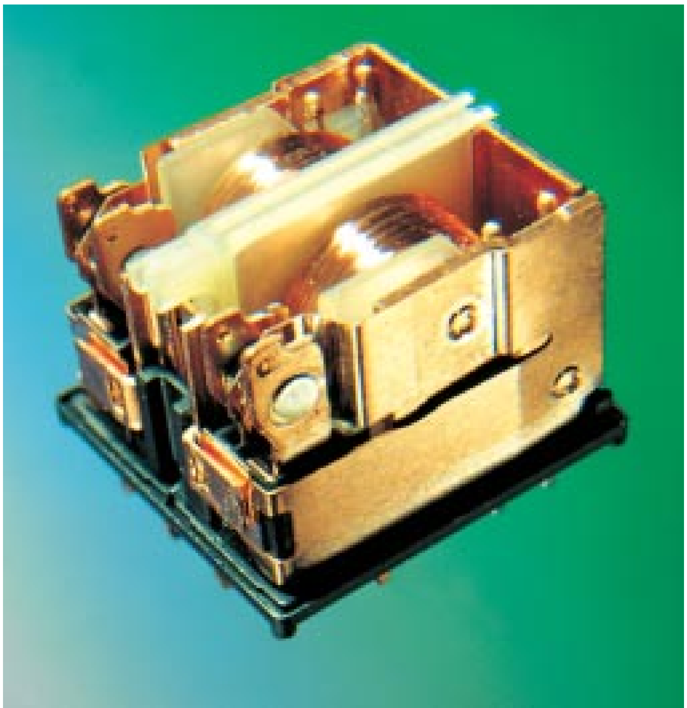
Use of this process substantially requires a high-performance extruder affording good control of the melt temperature (not higher than 240 °C) and an appropriately designed pipe die (including pressure build-up to 150 bar and a die land of adequate length). When designing the sizing device the increase in shrinkage as the wall thickness rises has to be taken into consideration. In the case of an external tube diameter of 70 mm and a wall thickness of 15 mm it amounts to approximately 4 %. Sizing tubes with radially offset slits and a length of at least 70 - 80 cm are recommended.

In addition, a cooling section (spray bath) of adequate length should be provided so that the tube has solidified sufficiently before entering the flying knife.

Production of sheet, tapes and special drive belts
Ultramid B5 is used to produce sheet. Relatively thin sheet and tapes (0.5 to 2 mm) can also be manufactured from Ultramid B4.

Sheet and tapes 0.5 to 1 mm thick may be produced on installations commonly used for flat film extrusion. Given appropriately low take-off rates and an enlarged die gap, roll temperatures of 90 to 150 °C depending on thickness are required to produce warp-free sheet or tapes having a smooth surface finish. Sheet ranging in thickness from about 2 to 8 mm is manufactured on the usual installations with a horizontally oriented sheet die, three-roll polishing stack and following take-off unit. The lips of the sheet extrusion die should extend as close as possible to the nip of the rolls. The temperatures of the rolls depend on the sheet thickness and in the case of Ultramid B5 range between 140 and 150 °C. Using this technique avoids premature solidification of the melt as well as internal stresses and warping of the sheet. Output and take-off speed are matched to one another in such a way that a bead of material spreads uniformly across the entire width of the roll. This produces narrow size tolerances and uniformly smooth surfaces.

Contactor



Production of film
Flat film (extruded sheeting) and tubular film (blown film) are extruded from medium- to high-viscosity Ultramid A, B and C grades. They are principally used for food packaging, usually in the form of composites with polyethylene. The Ultramid grades suitable for the extrusion of film are set out in Table 10 (see p. 54) and the properties of such films are described in Table 11 (see p. 54).

Blown monofilm is produced for example from the Ultramid B grades and from Ultramid A5. Standard commercial installations such as those generally known from the production of polyethylene film are suitable for this purpose. In this case the film bubble can be drawn upwards and downwards. The gap in the annular die should be 0.6 to at most 0.8 mm wide. The emerging molten tube has to be cooled with air or water. Take-off speeds of more than 30 m/min are achievable. Typical blow-up ratios (die/tube diameters) range from 1:1.1 to 1:3.

Food packaging

Collapsing should begin as close as possible to the frost line so that the film can be laid flat while it is still warm. Height-adjustable take-off units facilitate the matching of the layflat section to the take-off and cooling rate. The usual thicknesses of blown Ultramid film are 20 to 100 µm depending on the rate of cooling. Table 13 (see p. 56) provides an example of blown film extrusion.

For blown coextrusion of composite films, especially in the case of asymmetric three-layer structures (PE/tie resin/PA), copolyamides based on Ultramid C are preferred because under the special conditions of this method their processing properties approximate to those of PE. Ultramid C affords readily thermoformable and flexible composite films having high transparency and low tendency to curl. On the other hand in the case of a symmetrical five-layer composite (PE/tie resin/PA/tie resin/PE) where the PA layer is embedded, the somewhat more rigid Ultramid B grades can also be employed.

Flat film is extruded mainly from Ultramid B grades. They are normally drawn to a thickness of 20 to 100 µm from extrusion dies which can be 2,000 mm wide. The lip gap is 0.4 to 0.5 mm and take-off rates are 25 to 120 m/min. Extruders with 120 mm screws (length 25 to 28 D) are recommended for efficient production.

Apart from the choice of Ultramid grade, the quality of the film, i.e. its tolerances, dimensional stability, smooth passage through the machine, transparency and suitability for thermoforming, are largely determined by its previous thermal and mechanical history in the extruder and downstream equipment, but above all by the cooling and postcrystallization conditions.

Depending on film thickness and take-off speed, the temperatures of the chill rolls lie between 20 and 100 °C. The optimum temperature setting depends on design of the installation in question and the desired film properties. For a processing example see Table 13 (p. 57).

Oriented PA film

Biaxially oriented shrinkable blown or flat film (single layer or multilayer) is produced by rapid cooling of film made from Ultramid B or C grades followed by stretching. Stretching ratios for biaxially oriented tubular film are about 2.7 to 3.2 (longitudinally and transversely respectively). A thermofixation step can be included depending on the desired film properties.

Properties and applications of Ultramid film

The importance of Ultramid film in the packaging sector is attributable to its high strength, outstanding thermoformability, high heat resistance including resistance to sterilization, and very good barrier properties with respect to gases, especially oxygen and flavoring agents.

In composites with polyethylenes (LDPE, MDPE, VACPE), the main application of Ultramid film, a ideal, flexible film for the vacuum-packaging of foods sensitive to oxygen such as sausage, ham, cheese, fish, peanuts, and many others is created.

In these cases the good thermoformability of Ultramid film ensures suitably shaped, sales-promoting and hence effective packaging. Artificial sausage skins made from polyamide for boiling sausages can be produced in the conventional manner as well as by biaxial orientation, i.e. by stretching. PA 66, e.g. Ultramid A5, is used primarily for non-oriented film, and PA 6, e.g. Ultramid B35F, for oriented film. Artificial sausage skin made from polyamide is distinguished by a high oxygen barrier, ready acceptance of printing and gage accuracy. Biaxially oriented film is additionally characterized by defined shrinkage on boiling and very high strength. Biaxially oriented tubular film is frequently coextruded with polyolefins in order to attain the required barrier to water vapor.

Due to their special ranges of properties Ultramid films and Ultramid/PE composites even have some interesting packaging applications in the chemical industry.

Characteristic properties of films made from Ultramid are tabulated in Tables 11 and 13 (p. 57).

Table 10 **Ultramid film grades**

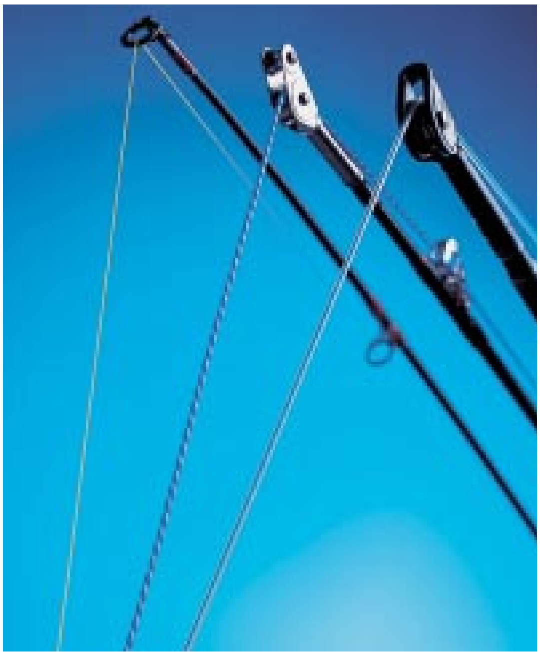
Ultramid	**Type**	**Viscosity number**	**Relative viscosity**	**Nucleation**	**Feed aid**	**Type of film**
B35F	PA 6	200	3.3	–	x	oriented film
						coextruded
B36FNQ99	PA 6	225	3.6	x (Batch)	x	cast, blown
B4F	PA 6	250	4.0	–	x	cast, blown
B4FNQ99	PA 6	250	4.0	x (Batch)	x	cast, blown
C35F	PA 6/66	195	3.2	–	x	blown, Coextrusion
C4Q42	PA 6/66	250	4	–	–	blown
A4	PA 66	195	3.2	–	–	cast

Table 11 **Properties of Ultramid film**[1)]

	Units	**B4F, B36FN Q99**	**C35 F**
Production method		Cast and blown film	Blown film
DSC Melting point	°C	218–220	195–197
	F	424–428	383–387
Density at 23 °C	g/cm^3	1,120–1,128	1,120–1,123
Stress at break parallel / perpendicular	N/mm^2	80–100 70–90	80–90 70–90
Strain at break parallel / perpendicular	%	350–450 400–500	500–600 500–600
Gas permeability at, 23 °C (DIN 53 380) Oxygen (40 % r.F.) / Carbon dioxyde (0 % r.h.	$\frac{cm^3 \cdot 25\ \mu m}{m^2 \cdot d \cdot bar}$	40 160	48 180
Water vapor transmission rate at 23°C, (DIN 53 122)	$\frac{g \cdot 25\ \mu m}{m^2 \cdot d}$	50	60

1) Film thicknesses 20 – 100 µm

Housing for door electronic



Fishing lines

Production of monofilaments
The following Ultramid grades are used for the production of stretched monofilaments such as industrial wires, fishing lines, tennis racket strings, lawn mower monofilaments, bristles and dolls' hair.

Ultramid B3, a polyamide 6 of low viscosity, is suitable on its own or blended with other Ultramid grades for the production of monofilaments having diameters of up to 0.7 mm. Applications include, e.g. artificial hair, fishing lines, monofilaments for fishing nets, bristles and fine monofilaments for industrial fabrics.

Ultramid B35F, a polyamide 6 of medium viscosity, is the general-purpose grade for the production of fine and medium gage monofilaments for the fisheries sector and industrial applications, such as filters, paper screening fabric and bristles. These monofilaments are stronger and more flexible than B3 monofilaments. Ultramid B35 is also outstandingly suitable for the production of artificial hair.

Ultramid B4F is particularly suitable for manufacturing stretched monofilaments having medium and relatively thick diameters of up to 5 mm and for bristles.

Ultramid A3 and A4 are used for relatively stiff bristles and monofilaments. Ultramid A4 is also used in blends with Ultramid B35F for making monofilaments for sewing.

Ultramid C35F and C4Q42 are suitable for the manufacture of high-grade sports angling lines, hook monofilaments, long lines of up to 2.0 mm and tennis racket strings.

Extrusion lines for monofilaments and bristles mainly consist of a single-screw extruder, spinning pump (precision gear pump), spinneret (multiple die), waterbath for cooling, roll stretching units, hot-water stretching bath and/or hot-air stretching channels. The ratio of the peripheral speeds of the roll stretching units, usually seven-roll sets, corresponds to the stretching ratio which is preferably in the range of 1:4 to 1:6. Depending on the type of monofilament stretching is done in one or more stages. The subsequent "shrinkage or relaxation" stage comprises a further hot-air channel and a set of three rolls which run at a lower peripheral speed depending on the percentage shrinkage (e.g. 5 to 10 %).

Special methods involving particular know-how are occasionally used for the production of monofilaments or wires having large diameters (> 3 mm).

Table 14 (see p. 57) provides examples of monofilament extrusion.

Production of blow moldings
Ultramid B5 is highly suitable for blow molding due to its high melt viscosity and the good dimensional stability of the melt associated with this.

Since parison sag is relatively small it is possible to produce blow moldings having volumes of up to 2 liters with satisfactory distribution of wall thicknesses by continuous extrusion (without melt accumulator). At extrusion speeds of 10 to 20 mm/s the length of the parison can be up to 400 mm. For the production of larger blow moldings requiring longer parisons it is necessary to use higher delivery rates, i.e. operate with a melt accumulator (accumulator head).

Multilayer blow moldings made from polyolefins in composites with Ultramid C35F or the impact-modified grade Ultramid B3Z are remarkable for their low permeability to gases and solvents. Ultramid B3Z (formerly Ultramid KR4430) is especially suitable as a barrier layer for large containers for crop protection agents. In addition blow-molded articles with an outer layer of Ultramid C35FN have a decorative, glossy surface.

Packaging (coextruded) for cosmetics

Example of Ultramid extrusion

Table 12 **Special extrusion**

Ultramid		**B4F**	**B5**	**B5**
Product		Round-section rod	Tube/ hollow rod	Sheet
Production technique		Extrusion, pressure controlled, with water-cooled sizing device double[3]	Vakuum calibration	Slot die sheet formed and solidified in nip
Dimensions[4]	mm	d=60	d=75 s=8	b=1050 s=2,5
Screw diameter D	mm	45	60	90
L/D		20	20	25[5]
Flight depths h_E/h_A	mm	606/2,5	9/2,75	14/4,5
screw sections[1]		6/6/8	7/6/7	6/6/13
Heater temperatures barrel adapter die	°C	 220...260 240 260	 230...260 250 240	 220...270 270 270
Melt tempereatures	°C	260		285
Melt pressure	bar			
Scew speed	min^{-1}		30	60
Type of die Dimensions	 mm		Pipe die[2] Die d = 82 Mandrel d = 70	Slot die 1100
Sizing/ cooling	mm			
Additional cooling				
Take-off/Stretching			Caterpiller take-off	
Take-off speed	m/min	0,022	0,15	0,80
Weight per unit length	g/m	3325	522	2980
Output	kg/h	8,4	20	140

Table 13 **Film extrusion**

B36FNQ99 B4F	**B36FNQ99 B4FNQ99**	**C35F**
cast film	Multilayer cast film	Multilayer cast film
Slot die metal chill and constant-tempe-rature rolls	Slot die metal chill and constant-tempe rature rolls	Coextrusion blow molding
s=0,0050 b=1,200	s=0,030 b=1200	b=810* s=0,030
90	90	60
25	25	24-25
12/14	12/14	8/2,5
9/4/12	9/4/12	9/4/12
240...270 260 250	240...270 270 260	230...240 240 240...235
275	270	240
180	110	150...200
80	50	45
Slot die (Flexlip) b = 1300 s=0,5	 b=1300 s=1,2	3- and 5-layer- d = 500 s = 1.2
Air knife Chill rolls 40 °C Vacuumbox	 80 °C	Air, Waterbath 50…60 °C
Center winder		Center winder
70	50	30
67	40	54
280	120	97

1) Length of feed / compression / metering sections as multiple of screw diameter D.
2) W. Mink, Grundzüge der Extrudertechnik, page 166 & 247, D (R. Zechner Verlag, Speyer, Germany, 1964)
3) Kunststoff-Handbuch, Vol. 6, Polyiamides, page 302 onwards (C. Hanser-Verlag, Munich, 1966)
4) s = thickness, d = diameter, b = width; for dimensions of roads and tubes see DIN 16980, 16983, 16982
5) With shear and mixing elements
6) After stretching

Table 14 **Monofilaments**		
B35F	**C35F**	**A4**
Monofilaments, bristles (general)	Monofilaments for fishing lines	Monofilaments, bristles (general)
Extrusion, water quenched, stretched between rolls		
d = 0.30	0.30	0.51
45	45	45
25	25	25
8,0/2,5	8,0/2,5	7,0/2,2
6/7/12	6/7/12	9/4/12
260/290/285/275 275 275	270/280/275/270 265 265	275/290/280/280 280 280
275	265	280
120	32	42
55	32	42
Die x 30 1.40 2.0 d	Die x 20 3.0 d	Die x 10
Waterbath 10–20 °C	Waterbath 35–40 °C	
7-roll set 7-roll/3-roll set Stretch ratio 1:4.0 Stretch temperature 210 °C	7-roll set 7-roll/3-roll set 1:5,7; 2-step 130°C/230 °C	7-roll set 7-roll/3-roll set 1:4.5 200 °C
25.0	20.0	20.0
0.0806 (stretched)	0.0806 (stretched)	0.232 (stretched)
16.8	10.3	10.8

Sausage skins

Machining

Semi-finished parts made from Ultramid can be machined and cut using all the usual machine tools. General rules which apply are that cutting speed should be high while the rate of advancement is low and care should be taken that tools are sharp.

Joining methods

Parts made from Ultramid can be joined at low cost by a variety of methods. They can be easily joined using screws which form their own threads (self-tapping screws). Ultramid parts can be connected without difficulty to one another or to parts made from other materials by means of rivets and bolts.

Threaded metal inserts have proved to be effective for screw connections subjected to high stresses and which frequently have to be loosened and retightened. These are encapsulated during molding or attached subsequently in prepared holes by means of ultrasound or hot embedding.

Snap-in and press-fit connections can also withstand high stresses. Ultramid's outstanding elasticity and strength, even at high temperatures, are particularly advantageous for this form of construction.

Practically all methods developed for welding thermoplastics are suitable for Ultramid. The following welding methods are employed for moldings:

- ultrasonic welding
- heating-element welding (thermal sealing, radiation welding)
- vibration welding (linear, biaxial)
- spin welding
- laser beam welding

All these methods have their own specific advantages and disadvantages (see Table 15). As a rule they require special joint geometries and configurations adapted to the welding technique so that the welding method should be chosen before the final design is drawn up.

The newly developed Ultramid A3WG6 LT black 23229 provides the user with a highly developed product for laser welding applications. Further information on the subject of laser welding can be found in our publication "Transmission laser-welding of thermoplastics" (see References p. 73)

Directions for design and choice of welding parameters can be found in the corresponding guidelines of the DVS (Deutscher Verband für Schweißtechnik, Düsseldorf = German association for welding technology).

Heat impulse welding, and high-frequency welding in the case of suitable formulations, are preferably used for film. However, laser-beam, heating-element and ultrasonic welding may also be used.

Adhesive solvents or varnishes are particularly suitable for bonding Ultramid. These may be based for example on phenol or resorcinol solutions, concentrated formic acid, solid adhesives with or without chemical crosslinking (reactive or two-component adhesives), e.g. for securing bearing bushings in metal structures, and on polymerizable, pressure-sensitive and contact adhesives.

Parts made from Ultramid grades, e.g. on rollers, can be bonded very securely to rubber, e.g. after surface treatment with special dispersions acting as bonding agents. This could take the form of a running ring in vulcanization.

Table 15 **Advantages and disadvantages of welding methods**

Method	**Advantages**	**Disadvantages**	**Applications**
Ultrasound	short cycle times; capable of integration in production lines	high mechanical stress due to vibrations, damage possible due to resonance	housings, devices, bearing cages, filters
Heating element, heat sealing	high strength; smooth coherent flash	long cycle times; adhesion of melt to heating element	containers
Radiation	high strength; smooth coherent flash	only slight warpage permissible or compensation in mold required; long cycle times	
Vibration	relatively short cycle times; high strength	high welding forces; stress due to vibration; grainy weld flash; wide joint	intake manifolds, containers, air lines
Spin	relatively short cycle times; high strength	rotationally symmetrical joint required	containers, connection pieces, lids, rigid frames, filter housings
Laser	flash-free; clean welded joint; stress-free welding; design freedom	adaptation of material required	housings, lids, filter medical devices

Printing, embossing, laser marking, surface coating, metallizing, surface coloring

Printing
Printing on Ultramid using conventional paper-printing methods requires no pretreatment. Injection-molded parts should be largely free of internal stresses and produced as far as possible without mold release agents, particularly those containing silicone. Special tried and tested inks are available for printing to Ultramid.

Hot embossing
Ultramid can be hot-embossed without difficulty using suitable embossing foils.

Laser marking
Marking Ultramid using lasers affords a series of advantages with respect to conventional methods, particularly when there are tough requirements for permanence, flexibility and speed.

General information on the subject of laser marking can be found in our publication "Laser marking of thermoplastics" (see References p. 73).

The following information is intended only to provide initial guidance. Our application support team will be happy to give more detailed advice, on the choice of Ultramid colors that are best suited to laser marking.

Nd-YAG lasers (wavelength 1064 nm)
Uncolored standard Ultramid grades are practically impossible to mark with Nd-YAG lasers due to very low absorption of energy. This also applies to glass-fiber reinforced and mineral-filled grades. Better markability for Ultramid grades can be achieved by using special additives. High-contrast lettering is obtained with certain black pigmentations.

Uncolored Ultramid A3X grades can be marked with good contrast but not in customary black colors.

The Ultramid LS range comprising unreinforced, reinforced and flameproofed grades was specially developed for marking using the Nd-YAG laser. We will be happy to send you an overview on request.

Frequency-doubled Nd-YAG lasers (wavelength 532 nm)
A frequency-doubled Nd-YAG laser can generally produce higher definition and higher contrast images on uncolored and brightly colored Ultramid grades than a conventional Nd-YAG laser. On the other hand there is no advantage in the case of black colors.

Excimer lasers (wavelength 175 - 483 nm)
Excimer lasers produce a higher definition and a better surface finish on Ultramid than do Nd-YAG devices. Good results are achieved especially for bright colors.

CO_2 lasers (wavelength 10640 nm)
Uncolored and colored Ultramid is practically impossible to mark with CO_2 lasers. At best there is only barely perceptible engraving of the surface without color change.

Surface coating
Due to its outstanding resistance to most solvents Ultramid can be coated in one or more layers with various paints which adhere well and have no adverse effects on mechanical properties. One- or two-component paints with binders matched to the substrate are suitable.

Metallizing
Parts made from the various Ultramid grades can be metallized in high vacuum following priming or by electroplating after suitable preliminary treatment. Excellent surface quality can be achieved for unreinforced and reinforced grades. Metallized Ultramid parts are being used increasingly in sanitary, electronic and automotive applications.

Coloring in dyebaths
Ultramid parts can be colored in the dyebath using water-dispersible dyes. White-pigmented injection-molded parts are especially suitable for this purpose, e.g. fashion items which can be colored in many shades with Palanil® dyes.

Laser-marked parts

Conditioning

Ultramid parts, especially those made from standard injection-molding grades, only achieve their optimum impact strength and constant dimensions after absorption of moisture. Conditioning, i.e. immersion in warm water or storage in warm, moist air is used for the rapid attainment of a moisture content of 1.5 to 3 %, the equilibrium content in normal moist air (cf. Fig. 23, p. 23 and individual values in the Ultramid range chart).

Practical conditioning method
Immersion in warm water at 40 to 90 °C is simple to carry out but it can result in water stains, deposits and, especially in the case of thin parts with internal stresses, in warpage. Additionally, in the case of the reinforced grades the quality of the surface can be impaired. Furthermore, conditioning of A3X grades in a waterbath at higher temperatures is not recommended. Accordingly, preference is generally given to the milder method of conditioning in humid air (e.g. at 40 °C and 90 % relative humidity or in 70/62 conditions for the accelerated conditioning of test specimens in accordance with ISO 1110). Here too the temperature should not exceed about 40 °C for parts made from Ultramid A3X grades.

As a simple method of conditioning, parts can also be stored in the warm in PE sacks containing 5 to 10 % of water with respect to the weight of the parts.

Duration of conditioning
The time required for conditioning to the normal moisture content (standard conditions 23/50) increases with the square of the wall thickness of the parts but decreases markedly with rising temperature. Table 16 gives the conditioning times needed for flat parts (sheet) made from Ultramid A and B grades as a function of wall thickness and conditioning conditions in either a moist atmosphere or in a waterbath. Conditioning in a moist atmosphere, e.g. 40 °C/90 % r.h., is generally recommended as a mild thermal treatment.

Our Technical Information leaflet “Conditioning Ultramid moldings” provides further details.

Annealing

Annealing, e.g. by heat treatment for 12 to 24 hours (ideally in an annealing liquid at 140 to 170 °C) can largely remove internal stresses occurring in thick-walled parts made from grades with a high modulus of elasticity (e.g. Ultramid A3EG7) or in extruded semi-finished parts. Annealing also results in postcrystallization of incompletely crystallized injection-molded parts (produced with a cold mold). On the one hand this causes an increase in density, abrasion resistance, rigidity and hardness and on the other hand it gives rise to slight after-shrinkage and sometimes a small amount of warpage.

Heat-resistant mineral, paraffin and silicone oils are excellent annealing liquids. The annealed parts must be cooled slowly.

Table 16 **Time required for Ultramid sheet to attain a moisture content corresponding to the equilibrium moisture content obtained in a standerd atmosphere (23 °C/50 % r.h.)1)**
(figures in bold type refer to days, non-bold to hours)

Ultramid	Equilibrium moisture content atmosphere NK 23/50 1) (%)	Conditions	Thickness mm	1	2	4	6	8	10
B grades									
unreinforced	3.0	Waterbath	40 °C	3.5	14	**2.5**	**5**	**10**	**16**
glas-fiber reinforced	1.5…2.6		60 °C	1	4	16	**1.5**	**3**	**4.5**
mineral-filled	2.0…2.4		80 °C	0.3	1	4	10	18	**1**
		Atmosphere	40 °C/90 %	15	**2.5**	**11**	**25**	**45**	**70**
			70 °C/62 %2)	10	**2**	**5**	**10**		
A grades									
unreinforced	2.8	Waterbath	40 °C	6	**1.3**	**4.5**	**10**	**20**	**28**
glas-fiber reinforced	1.2…2.2		60 °C	1.5	6	**1**	**2.5**	**5**	**8**
mineral-filled	1.4…1.5		80 °C	0.5	2	8	20	**1.5**	**2.5**
		Atmosphere	40 °C/90 %	**1**	**4**	**18**	**40**	**70**	**120**
			70 °C/62 %2)	15	**2.5**	**10**	**23**		

1) Values for individual grades are given in the Ultramid range chart.
2) Used in ISO 1110 – Polyamides – Accelerated conditioning of test specimens.

Safety notes

Safety precautions during processing
Ultramid melts are thermally stable at the usual temperature for A, B and C of ≤ 310 °C and ≤ 350 °C for T and do not give rise to hazards due to molecular degradation or the evolution of gases and vapors. Like all thermoplastic polymers Ultramid decomposes on exposure to excessive thermal load, e.g. when it is overheated or as a result of cleaning by burning off. In such cases gaseous decomposition products are formed. Decomposition accelerates above 310 °C (T> 350°) approximately, the initial products formed being mainly carbon monoxide and ammonia, and caprolactam too in the case of Ultramid B. At temperatures above about 350 °C (T>400°) small quantities of pungent smelling vapors of aldehydes, amines and other nitrogenous decomposition products are also formed.

When Ultramid is properly processed no harmful vapors are produced in the area of the processing machinery.

In the event of incorrect processing, e.g. high thermal stresses and/or long residence times in the processing machine, there is the risk of elimination of pungent-smelling vapors which can be a hazard to health. Such a failure additionally becomes apparent due to brownish burn marks on the moldings. This is remedied by ejection of the machine contents into the open air and reducing the cylinder temperature at the same time. Rapid cooling of the damaged material, e.g. in a waterbath, reduces nuisances caused by odors.

In general measures should be taken to ensure ventilation and venting of the work area, preferably by means of an extraction hood over the cylinder unit.

Ultramid A3X...G... grades
Incorrect processing of Ultramid grades such as A3X2G... or A3X3G... due to overheating or excessively long residence times in the cylinder can give rise to toxic vapors from the fire resistant additive based on red phosphorus which is present. For this reason adequate ventilation and venting of the work areas must be ensured.

For emptying the cylinder before shutting the machine down it is recommended in particular to inject the melt into the mold and to not to pump it off as it is usually done. If pumping off cannot be avoided an extraction device (hood) should be used.

Before changing materials the machine should be run with a similar material without flameproofing, e.g. Ultramid A3EG5, and then purged.

It has been shown that if the workplace is adequately ventilated the concentration of harmful gases (phosphine) will not exceed the maximum allowed concentration (0.1 ppm). Routine monitoring of the workplace with gas detection equipment fitted with a PR 830 (Auer) or CH 31101 (Dräger) test probe is recommended.

Biological action
No detrimental effects to people engaged in the processing of Ultramid have come to light when the material has been correctly processed and the work areas have been well ventilated.

Ultramid grades are not subject to the provisions of the German ordinance on protection against hazardous substances of September 19, 1994.

Table 17 **Test methods for goods inward inspection of Ultramid**

Test method[1]	Typical value given in Ultramid range chart	Test standards	Remarks
Identification		DIN 53 746	Simple methods of indentification by means of melting point, density, solubility
Melting point	●	ISO 3146-C ISO 3146-A	DSC technique (heating and cooling rates 20 °C/min) Capillary tube method
Density	●	ISO 1183, DIN 53 479	BASF simplified density titration method
Ash	●[2]	DIN-ISO 3451-4	To determine the content of reinforcing material
Viscosity number VZ	●	DIN 53 727, ISO 307	Solvent 96 % H_2SO_4, in the case of reinforced and modified products, a correction must be made to the amount weighed out
Melt volume rate MVR	●	DIN-ISO 1133	Preferred test conditons: 275 °C/5 kg load; material must contain less than 0.05 % water
Moisture content	●[3]	ISO 960 D ISO Draft	Vapor Pressure method (BASF) Computer controlled coulometric Karl Fischer titrator; fine determiation in microgram range possible (Mitsubishi method)

[1] All tests can be performed on the molding compound or on the molded part.
[2] Nominal values for the amount reinforcing material are given in the range chart.
[3] Ultramid resins are supplied ready for processing with moisture content of less than 0.15% (injection molding) or 0.1% (extrusion)

Food contact status

The "Monomers and Other Starting Substances" used in the manufacture of the Ultramid grades are listed in the Directive 90/128/EEC and its subsequent amendments (92/39/EEC, 93/9/EEC, 95/3/EEC, 96/11/EC, 99/91/EC and 01/62/EC) in annex 2, section A with the following specific restriction:

Ultramid A, C resp. T
Hexamethylene diamine: SML = 2,4 mg/kg

Ultramid B, C resp. T
Caprolactam: SML(T) = 15 mg/kg (itself or together with the natrium salt of caprolactam, calculated as caprolactam

Ultramid T
Terephthalic acid: SML = 7,5 mg/kg

The meanings of the used abbreviations are:
SML = specific migration limit in food or in food simulant

(T) = SML expressed as the sum of the specified substances or group of substances

The composition of the Ultramid grades designated by E and K (second letter in the name) comply with the requirements of the Bedarfsgegenständeverordnung (German ordinance) in the revised version of 23.12.1997 (Monomers and other starting substances) and the BgVV (former BGA) - Recommendation X. "Polyamid" of 01.06.1998. The products may not be used in contact with alcohol containing food.

Presuming appropriate processing the above mentioned Ultramid grades can be used in the Federal Republic of Germany for the production of food contact articles according to Sec. 5, 1st para, No. 1 of the Lebensmittel- und Bedarfsgegenständegesetz (Food and Food-contact Applications Law) in the revised version of September 9th, 1997 (LMBG). The glass fiber reinforced grades are suitable for repeated use applications only.

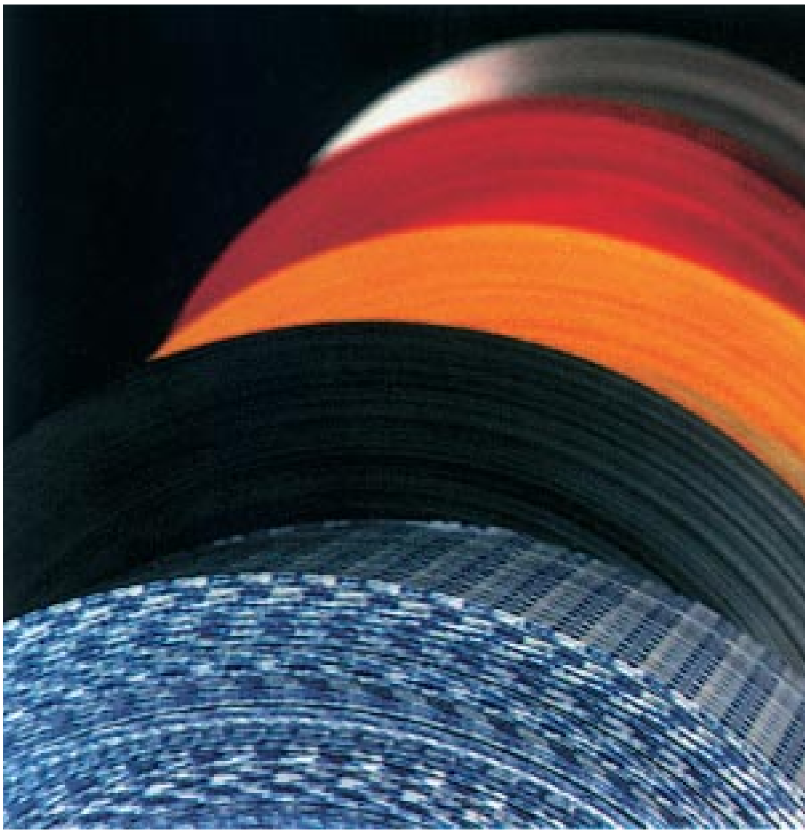
Compliance with the regulations of the LMBG, especially suitability of articles for the application and observance of any given limitations, must be ensured by the person who introduces the articles into circulation.

In that case, the food contact articles meet the requirements of Sec. 30 ("Verbote zum Schutz der Gesundheit" (Prohibitions for Health Protection)) and Sec. 31 ("Übergang von Stoffen auf Lebensmittel" (Migration of Materials to Food)) of the LMBG.

The data indicated above are the results of our product tests and refer to the state of the laws of august 2001.

Commercial grades designated by W, H, U and X are not recommended for food contact applications.

The confirmation above refers only to uncolored Ultramid grades. In case of colored products, other commercial grades or specialities please contact BASF Aktiengesellschaft for food contact status in each case. On request we will be happy to provide detailed information with respect to food contact regulations in force.



Sausage skins

Quality management

Quality management is a central component of BASF's corporate strategy. A major goal is customer satisfaction.

The Business Unit Engineering Plastics Europe of BASF Aktiengesellschaft has a quality assurance system in accordance with ISO 9001, QS 9000, VDA 6.1 certified by the German Association for the Certification of Quality Management Systems (DQS). The certification includes all services which the business unit provides in connection with the development, production and marketing of Ultraplasts: product and process development, production and customer service. Constant internal audits and training programs for staff ensure the continuing operational capability and steady development of the quality assurance system.

For customers who are themselves certified or wish to obtain certification Ultramid affords an ideal basis for their own seamless quality concept.

Quality assurance

Goods inward inspection at the converter

In most countries converters have a legal duty to carry out goods inward inspections. Such inspections are also essential because it is only in this way that the converter can obtain reliable knowledge as to the state of the goods at the time of their arrival.

Apart from a visual examination, depending on the product and requirements a goods inward inspection for Ultramid primarily covers the set of test methods set out in Table 17. Many other test methods suitable for Ultramid are presented in DIN 16 773, Part 2, or ISO 1874-2 "Polyamide molding compounds for injection molding and extrusion".

The values obtained from these test methods for the various Ultramid grades are given in the Ultramid range chart.

Quality assurance in the converting plant

Quality assurance is a component of every modern injection-molding operation because apart from effects arising from the product the quality of Ultramid moldings is primarily determined by the processing parameters. Unchanging processing conditions are the prerequisite for obtaining injection-molded parts of consistent quality. The most important process parameters are:

- melt temperature
- mold filling speed
- holding pressure and time, and
- mold surface temperature.

Modern injection-molding machines are equipped with process control devices by which the aforementioned variables can be kept constant within a narrow tolerance range. Narrow ranges from the process data, e.g. the variation of the internal pressure in the mold, can be set to limit the tolerances. Quality assurance can be facilitated by documenting the actual values.

Important quality criteria for Ultramid moldings are:

- dimensional stability (freedom from warpage) and
- surface finish.

A simple test on finished parts is to weigh them. Any inconstancy in a process can generally be observed through weight fluctuations. Surface finish is checked by visual examination.

Examples of typical surface faults include discoloration, flow lines, streaks, marks, grooves, sink marks, glass-fiber effects and warps.

Microscopic images of the structure of thin layers of injection-molded parts form an important criterion especially in the case of the unreinforced grades. Disruptions in crystalline structures and other irregularities in the interior of the parts can be rendered visible in this way and hence the quality of Ultramid moldings assessed and causes of faults analyzed (cf. Fig. 58).

Examination of the microstructure is also useful for determining the optimum processing conditions. It can also form part of continuous quality assurance procedures. Planned quality control tasks while production is in progress are essential for obtaining high-quality engineering parts from Ultramid. They can be carried out by means of sampling or if need be done on all parts. Computer assisted test devices reduce the workload for measurements and facilitate documentation, for example of the measured sizes.

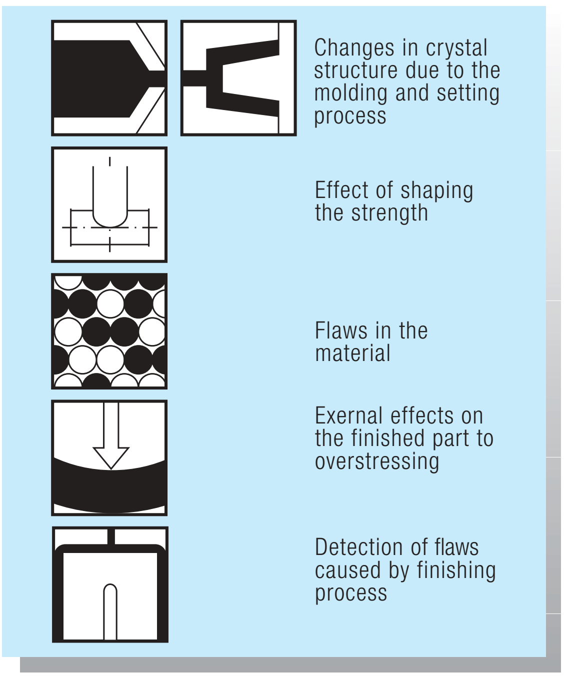


Fig. 58: Assessment criteria for optical microscopic examination of finished parts made from Ultramid

Form as supplied and storage

Ultramid is supplied dry and ready to use in moisture-proof packaging in the form of cylindrical or flat pellets. Its bulk density is about 0.7 g/cm^3.

Standard packs are the special 25 kg bag and the 1,000 kg octabin. Subject to agreement other forms of packaging and shipment in tankers by road or rail are also possible. All containers are tightly sealed and should be opened only immediately prior to processing.

To ensure that the perfectly dry material delivered cannot absorb moisture from the air the containers must be stored in dry rooms and always carefully sealed again after portions of material have been withdrawn. Ultramid can be kept indefinitely in the undamaged bags. Experience has shown that product supplied in IBCs can be stored for about 3 months without any adverse effects on processing properties due to moisture absorption. Containers stored in cold rooms should be allowed to equilibrate to normal temperature so that no condensation forms on the pellets.

Colors

Ultramid is supplied in both uncolored and colored forms. Uncolored Ultramid has a natural opaque white color. Individual grades are available in several standard colors and shades.

The H and W stabilized grades are exceptions which can only be supplied in black or natural because their natural color does not permit colored pigmentation to a specific shade. This is also the case for Ultramid A3X grades with fire resistant additive and Ultramid T (cf. colors in the range chart).

Cadmium-free colors
Constant improvements in the environmental compatibility of our products mean that we only supply colorants based on cadmium-free pigments.

Differences with respect to cadmium-based pigments can arise in processing and applications. This is especially the case with reference to heat resistance in processing, color constancy and light and weathering fastness.

Ultramid and the environment

Storage and transportation

Under normal conditions Ultramid can be stored indefinitely. Even at elevated temperatures, e.g. 40 °C in air, and under the action of sunlight and weather no decomposition reactions occur (cf. Sections "Form as supplied and storage" and "Behavior on exposure to weather", p.28).

Ultramid is not a hazardous material as defined by the German ordinance on hazardous materials of September 19, 1994 and hence is not a hazardous material for transportation (cf. Ultramid safety data sheet).

Ultramid is assigned to the German water pollution class WGK 0, i.e. Ultramid poses no risk to groundwater.

Waste disposal

Subject to local authority regulations Ultramid can be dumped or incinerated together with household garbage. The calorific value of unreinforced grades amounts to 29,000 to 32,000 kJ/kg (Hu according to DIN 51 900).

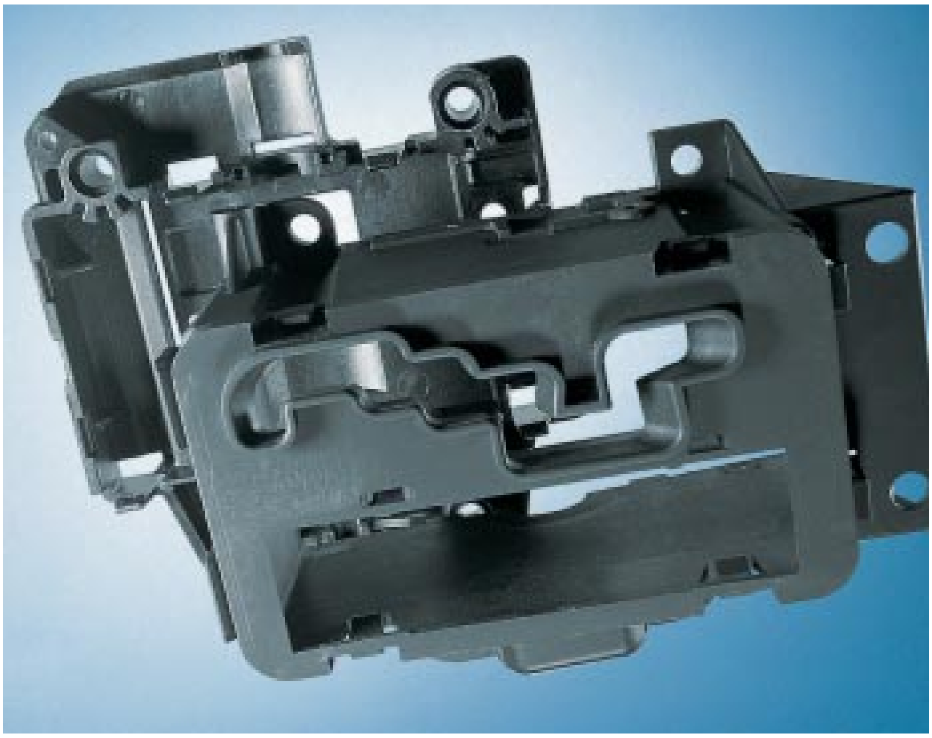
The burning behavior of Ultramid is described in detail in the Section "General information" and in the brochure "Thermoplastics - Fire protection aspects".

The complete combustion of Ultramid produces carbon dioxide, water and nitrogen. In incomplete combustion carbon monoxide is additionally formed. The combustion gases also contain traces of unburned primary decomposition products such as hydrocarbons, nitrogen-containing compounds and their oxidation products.

The toxicity of the combustion gases is determined primarily by their carbon monoxide content. Toxicological studies have shown that the decomposition products given off in the temperature range up to 400 °C are less toxic than those produced under the same conditions by wood. At higher temperatures they are equally toxic.

Recovery

Like other production wastes, sorted Ultramid waste materials, e.g. ground up injection-molded parts and the like, can be fed back to a certain extent into processing depending on the grade and the demands placed on it (cf. "Reprocessing and recovering of scrap", p. 33). In order to produce defect-free injection-molded parts containing regenerated material the ground material must be clean and dry (drying is usually necessary, cf. "General notes on processing: Preliminary treatment, drying", p. 32). It is also essential that no thermal degradation has occurred in the preceding processing. The maximum permissible amount of regrind that can be added should be determined in trials. It depends on the grade of Ultramid, the type of injection-molded part and on the requirements. The properties of the parts, e.g. impact and mechanical strength, and also processing behavior, such as flow properties, shrinkage and surface finish, can be markedly affected in some grades by even small amounts of reground material.



Gear lever housing

Product range

Characteristics	Ultramid B	Ultramid A	Ultramid T	Ultramid C copolyamides
Injection-molding grades (unreinforced)				
easy flowing, very fast processing high impact strength once conditioned	B3S			
easy flowing to medium viskosity, fast processing, high impact strength, even in dry state		A3K A4K KR 4206		
impact-modified to give very high impact strength even in dry state and low temperatures; fast processing	B3L			
high resistance to heat aging		A3W		
very high resistance to distortion and heat aging			KR 4350	
flame-retardant (UL 94 V-0)				C3U
dry-running material with improved tribological properties for unlubricated systems		A3R		

Injection-molding grades (reinforced) **glass-fiber reinforced (15 % to 50 %)**				
high-impact grades good heat-aging resistance and dielectric properties	B35EG3, B3EG3…6 B3G8	A3EG5…10		C3EG6
impact-modified to give enhanced notched impact strength and breaking strength	B3ZG3 B3ZG6		KR 4357 G6	
very high heat-aging resistance even in lubricants;		A3HG5		
very high heat-aging resistance	B3WG5 B3WG6	A3WG3…10		
with enhanced hydrolysis resistance		A3HG6HR		
very high resistance to distortion and heat aging			KR 4355 G5 KR 4355 G7	
flame-retardant and impact strength	B3UG4	A3XZG5…10	KR 4365 G5	
mineral-filled (15 % to 40 %)				
grades with very high rigidity and strength; low warpage	B3WM602			
grades with medium rigidity and strength; low warpage	B3M6			
glass-fiber and mineral-filled; glass-bead reinforced				
grades with medium rigidity and strength; low warpage	B3WGM24	A3WGM35		

Characteristics	Ultramid B	Ultramid A copolyamides	Ultramid C
Extrusion grades			
for film (cast and blown); medium to high viscosity B4F B4FNQ99	B35F B36FN Q99	A4	C35[1] F
for semi-finished stock, profile, tubes, sheet, tape; medium to high viscosity	B4F B5	A4	
for cable sheating medium viscosity	B35F		
for monofilaments; low to medium viscosity B35MF01	B3F B35F	A3 A4	C4 Q42
for moldings; high viscosity	B5 B5W		C35[1] F
for extrusion coating; low to medium viscosity	B3 B35F		
for insulation profile in aluminum window frames high viscosity, glass-fibre reinforced		PA66GV40[2]	

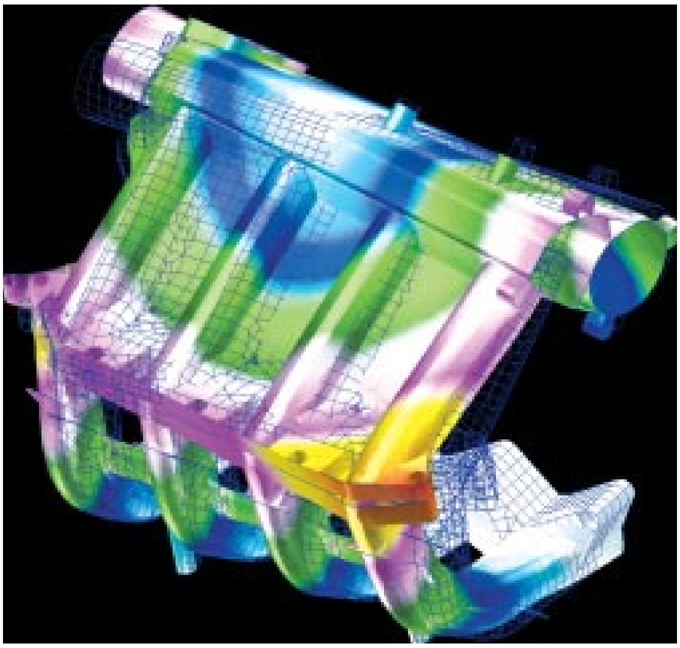
1) for multiplayer blow molding or film
2) special grade

Services provided by Thermoplastics Application Support

Our customers are constantly seeking ways of optimizing their processes. Since the material and the processing machines account for up to 80 % of the costs of producing a plastic part these are key factors for success. We help to optimize process parameters and the use of materials and hence to bring down the production costs to the lowest level conceivably possible.

Major elements of our range of services are computer-aided testing and optimization of parts together with damage analysis. Our many years of experience coupled with the latest test methods ensure a significant contribution to the speedy solution of your particular problems.

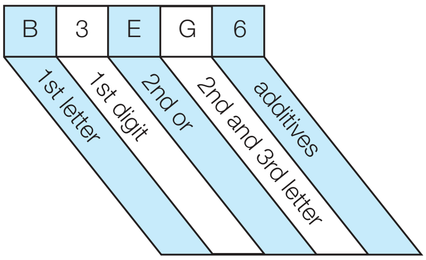
We will be happy to give you more detailed information at our Ultra-Infopoint (see p. 75).



Computer-aided optimization of components (acoustic properties) with reference to the example of a DaimlerChrysler intake manifold

Nomenclature

Ultramid commercial grades are uniformly designated by letters and digits which indicate chemical composition, melt viscosity, stabilization, glass fiber content and processing behavior.



1st letter

Type of PA

B = PA 6
A = PA 66
C3 = copolyamide 66/6 (melting point 243 °C)
C35 = copolyamide 6/66 (melting point 196 °C)
T = copolyamide 6/6T (melting point 298 °C)
KR = special order products

1st digit

Viscosity class

3 = easy flowing, low melt viscosity, mainly for injection molding (however Ultramid B3 without additives and reinforcement only for extruction),
35 = Low to medium viscosity, for injection molding and for extruding monofilaments and films.
36 = medium,viscosity, for film extrusion
4 = medium viscosity, for injection molding and extrusion
5 = high melt viscosity, for extrusion only

2nd or 2nd and 3rd letter

Type of stabilization

E, K = stabilized, light natural color, enhanced resistance to heat aging, weather and hot water, phsyologically harmless, dielectric properties remain unaffected (see Table 2)
H = stabilized enhanced resistance to heat aging, weather and hot water, only for enineering parts,electrical properties remain unaffected, natural color (see Table 2)
W = stabilized, high resistance to heat aging, only availabel uncolored and black, less suitable if high demands are placed on the part's electrical properties (see Table 2)

Special properties, additives

F = for flat film extrusion with enhanced feed performance characteristics
HR = enhanced hydrolysis resistance
L = impact - modified and stabilized, impact resistent when dry, easy flowing, for fast processing
N = for transparent films with improved clarity
R = PE-modified and stabilizes, for highly stressed, low noise, wear resistant, low - friction bearings
S = for rapid processing, very fine crystalline structure; for injection molding
U = contains phophorus - and halogen - free flame retardant
X2 = phosphorus-containing flame retardant
Z = impact modified and stabilized with very high low - temperature impact strength (unreinforced grades) or enhanced impact strength (reinforced grades)

Type of reinforcement

G (plus digit) = glass fiber reinforced
C (plus digit) = carbon glass fiber reinforced
K (plus digit) = glass bead reinforced, stabilized
M (plus digitl)= mineral - filled, stabilized; special product: M602 with 30 % special-silicate (enhanced ridiity)

Combinations available with glass fiber reinforcement:
GM (glass fibers/mineral)
GK (glass fibers/glass beads)

2nd or 2nd and 3rd digit

Content of reinforcing material
(mass fraction)

2 = 10 %
3 = 15 %
4 = 20 %
5 = 25 %
6 = 30 %
7 = 35 %
8 = 40 %
10 = 50 %

The amount of reinforcing materials for combinations of glass fibers (G), with mineral (M) or glass beats (K) indicated by 2 digits, e.g.:

GM 53 = 25 % glass fibers and 15 % mineral, stabilized
GK 24 = 10 % glas fibers and 20 % glass beads, stabilized

Example 1
Ultramid B3EG6
B = PA 6
3 = viscosity class 3 (low viscosity for injection molding)
E = stabilized, high long-term heat resistance, light natural color
G6 = 30 % glass fibers

Example 2
Ultramid A3WGM53
A = PA 66
3 = viscosity class 3 (low viscosity for injection molding)
W = stabilized, very high resistance to high aging
GM = Combination of glass fiber and mineral reinforcement
53 = 25% glass fiber and 15% mineral

Example 3
Ultramid A4
A = PA 66
4 = viscosity class 4 (medium viscosity for extrusion)

Example 4
Ultramid A3X2G10
A = PA 66
3 = viscosity class 3, (low viscosity for injection molding)
X2 = fire safety additive
G10 = 50 % glass fibers

Snowboard-binding

Subject Index

Explanation of symbols:
TI = Technical Information leaflet

References

BASF Publications

General

BASF competence in plastics	KST 0012 d, e
Plastic set the pace – Easy on resources, innovative, indispensable	KST 0011 d, e
Thermoplastics – Fire protection aspects	KTX 9700 d, e
Ultraplasts – Quality management	KTX 9701 d, e

Technical information for experts

Engineering plastics for electrical and electronical application	KTX 0009 d, e
Dimensioning integral hinges	KTX 9602 d, e
Transmission laser-welding of thermoplastics	KTX 0003 d, e
Warpage characteristics of fiber-reinforced injection-molded parts	KTX 9913 d, e
Life Cycle Assessment and Eco-Efficiency	KTX 9912 d, e
CAE Development Service for Plastics Processors and Users	KTX 9911 d, e
Screw designs in injection molding	KTX 9908 d, e
Acoustic optimization of plastic parts	KTX 9801 d, e
Laser Marking on Thermoplastics	KTX 9800 d, e
The quick way to optimal snap-fitting connections	KTX 9704 d, e
Screw design and optimization of grooved-barrel extruders	KTX 9703 d, e
Estimating in cooling times in injection molding	KTX 9702 d, e

Information on the Internet

Campus – with mechanical, electrical and thermal properties (single-point data), stress-strain diagrams (long-term and short-term), shear modulus, viscosity functions.

http://www.basf.de/en/produkte/kstoffe/kstoffe/werkst/campus.htm

Information on data media

Calculation programs:
Snaps (snap-in connections)
Beams (bending beams)
Screws (self-tapping screws)

Ultramid publications

Ultramid grades in film extrusion	KTUM 0002F d, e
Ultramid: Conditioning finished parts	TI KTU/AS 13 d, e
Resistance of Ultramid, Ultraform and Ultradur to chemicals	TI KTU/AS 28 d
Halogen-free flame-resistant Ultramid grades	KTUM 0003F d, e
Ultramid – Economy under the hood	KTUM 9706 d, e
Ultramid products in injection moulding	KTUM 9701 e

Other literature

ISO 1874, Parts 1 and 2

VDI/VDE 2479, Sheets 1 and 2, Polyamid-Formstoffe, 1978. Polyamide molding compounds for injection molding and extrusion (Classification and names: Determination of properties).

Spritzgießen, Verfahrensablauf, Verfahrensparameter, Prozeßführung [Injection molding, process sequence, process parameters and process control]. Published by the "Institut für Kunststoffverarbeitung", RWTH, Aachen, C. Hanser-Verlag, Munich, 1979.

G. Erhard, E. Strickle: Maschinenelemente aus thermoplastischen Kunststoffen [Machine components made from thermoplastics], VDI-Verlag, Düsseldorf, Volume 1, 1974, Volume 2, 1977.

G. W. Ehrenstein: Polymer-Werkstoffe [Polymer materials], C. Hanser-Verlag, Munich, 1978.

G. Schreyer (editor): Konstruieren mit Kunststoffen [Construction with plastics], Parts 1 and 2, C. Hanser-Verlag, Munich, 1972.

Qualitätssicherung im Spritzgußbetrieb [Quality assurance in injection-molding plants], VDI-Verlag, Düsseldorf, 1987.

Plastics from BASF

The product range at a glance

Products from BASF Aktiengesellschaft

Terluran®	Acrylonitrile/butadiene/styrene polymer	ABS
Ronfalin®	Acrylonitrile/butadiene/styrene polymer	ABS
Luran® S	Acrylonitrile/styrene/acrylate polymer	ASA, (ASA + PC)
Luran®	Styrene/acrylonitrile copolymer	SAN
Terlux®	Methyl methacrylate/acrylonitrile/butadiene/ styrene polymer	MABS
Terblend® N	Acrylonitrile/butadiene/styrene polymer and polyamide	ABS + PA
Luranyl®	Blend of polyphenylene ether and PS-I	(PPE + PS-I)
Polystyrol, impact-modified	Styrene/butadiene polymer	PS-I
Polystyrol, impact modified	Polystyrene	PS
Styrolux®	Styrene/butadiene block copolymer	SBS
Styroblend®	Blend based on styrene/butadiene polymer	PS-I blend
Styroflex®	Styrene/butadiene block copolymer	SBS
Ecoflex®	Biodegradable plastic/polyester	
Ultradur®	Polybutylene terephthalate	PBT, (PBT + ASA)
Ultraform®	Polyoxymethylene	POM
Ultramid®	Polyamides	PA 6, 66, 6/66, 6/6T
Ultrason® E	Polyethersulfone	PES
Ultrason® S	Polysulfone	PSU
Styropor®	Expandable polystyrene	EPS
Neopor®	Expandable polystyrene	EPS
Styrodur® C	Extruded rigid polystyrene foam	XPS
Neopolen® P	Polypropylene foam	EPP
Neopolen® E	Polyethylene foam	EPE
Basotect®	Foam from melamine resin	MF
Palusol®	Silicate foam	

® = reg. trademark of BASF Aktiengesellschaft

Polyurethanes

Lupranat®	Diisocyanates	PU
Lupraphen®	Polyester polyols	PU
Lupranol®	Polyether polyols	PU
Pluracol®*	Polyether polyols	PU
Elastan®	Systems for sportsfield coverings	PU
Elastocoat®	C systems as coating and casting compounds	PU
Elastoflex®	Soft polyurethane foam systems	PU
Elastofoam®	Soft integral polyurethane foam systems	PU
Elastolit®	Rigid integral polyurethane foam systems and RIM systems	PU
Elastonat®	Flexible integral polyurethane systems	PU
Elastopan®	Polyurethane shoe foam systems	PU
Elastopor®	Rigid polyurethane foam systems	PU
Elasturan®	Systems as cold curing cast elastomers	PU
SPS®	Steel-polyurethane systems	PU
Elastospray	PU system	PU
Autofroth®	PU system	PU
Elastoskin™*	Flexible integral polyurethane systems	PU
Cellasto®	Components made from microcellular PUR elastomers	PU
Elastocell®	Components made from microcellular PUR elastomers	PU
CeoDS®	Multifunctional composits made from Cellasto® components	PU
Emdicell®	Components made from microcellular PUR elastomers	PU
Elastollan®	Thermoplastic polyurethane elastomers	TPU

® = reg. trademark of Elastogran GmbH
®* resp. TM* = reg. trademark of BASF Corporation

Further Information:
www.basf.com
www.basf.de

Additional information

on polyurethanes can be found at:
www.elastogran.de

on polyolefines can be found at:
www.basell.com

on PVC and PVDC can be found at:
www.solvay.com and
www.solvay.de

Note

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Do you have technical questions about Ultramid?

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