The processing of Ultramid®

Processing characteristics

Ultramid® can be processed by all methods known for thermoplastics. The main methods which come into consideration 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 usually further processed by cutting tools to form finished molded parts.

The following text examines various topics relating to the injection molding of Ultramid®. Further general and specific information can be found on the internet at www.plasticsportal.eu or the Ultra-Infopoint (ultraplaste.infopoint@basf.com). More details on the injection molding of individual products are given in the respective processing data sheets.

Melting and setting behavior

The softening behavior of Ultramid® on heating is shown by the shear modulus and damping values measured in accordance with ISO 6721-2 as a function of temperature (Figs. 5 and 6). Pronounced softening only occurs just below the melting point. Glass fibers raise the softening point. A measure commonly used to determine the softening temperature is the heat deflection temperature HDT in accordance with ISO 75.

The melt also solidifies within a narrow temperature range which is about 20°C to 40°C below the melting point depending on the rate of cooling and the Ultramid® grade in question. At the same time there is a contraction in volume of 3% to about 15%. The total volumetric shrinkage can be seen by the PVT diagrams in Fig. 25.

The cristallization and PVT behavior can also be found in the material data of programs for injection molding simulation.

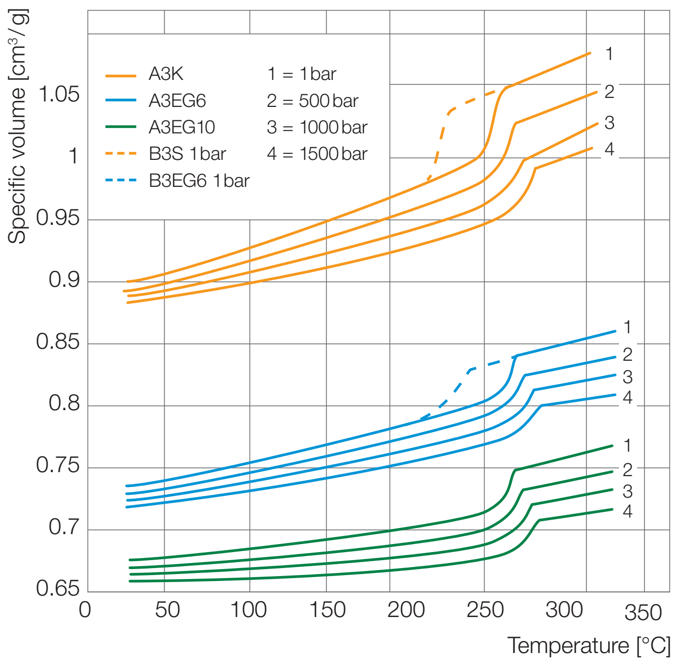


Fig. 25: PVT diagrams for Ultramid® A and B

Thermal properties

The relatively high specific enthalpy of Ultramid® requires powerful heating elements. The setting and cooling times increase by the square of the wall thickness, which is why wall thickness clusters should be avoided to ensure cost-efficient production.

Melt viscosity

The rheological properties of Ultramid® melts are evaluated on the basis of viscosity diagrams obtained 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 (Figs. 26 and 27), 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 nomenclature), the higher is the melt viscosity and the greater the resistance to flow (Fig. 26). 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 (Fig. 27).

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 the polymer chains only occurs when the residence time is relatively long. The recommended melt temperatures for processing may be found in Table 7 and in the Ultramid® product range.

If the melt does not come into contact with oxygen, no noteworthy color changes occur. Upon exposure to air, for example, when open injection nozzles are used or in case of interruptions in production, the surface can already become discolored after a brief time.

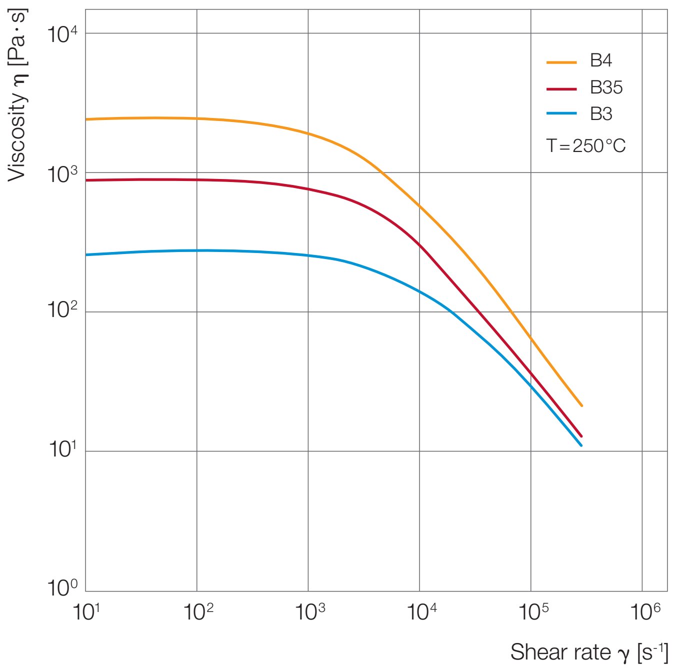


Fig. 26: Apparent viscosity of Ultramid® B (unreinforced) as a function of shear rate

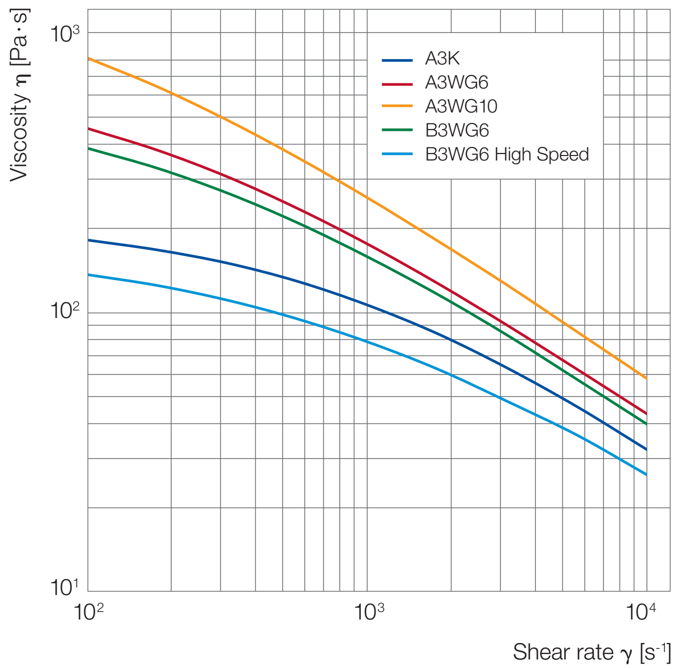


Fig. 27: Apparent viscosity of Ultramid® A and B with different glass fiber contents, T = 280°C

General notes on processing

Preliminary treatment, drying
Ultramid® must be processed dry. If the moisture content is too high, this can result in losses of quality. They may affect the quality of the molded part surface. A loss in mechanical properties, e. g. resulting from polymer degradation, is also possible. With the flame-retardant grades, plate-out can increasingly form.

The maximum permissible moisture content for processing by injection molding is 0.15 %; for extrusion it is 0.1 %. Detailed recommendations can be found in the processing data sheets. In the case of Ultramid® T, the moisture content should be at a much lower level of ≤ 0.03 %. The granules supplied in moisture-proof packaging can be processed without any special preliminary treatment. However, if the containers have been stored open or damaged, drying is advisable or may be required.

In order to prevent the formation of condensation, containers which are stored in non-heated rooms may only be opened once they have reached the temperature in the processing room.

The drying time – usually from 4 to 8 hours – is dependent on the moisture content and product. Among the different dryer systems, dehumidifying dryers are the most efficient and reliable. The optimum drying temperatures for Ultramid® are approx. 80 °C to 120 °C. As a general rule, the specifications of the equipment manufacturer should be followed. The use of vented screws for releasing the moisture as part of the injection molding process is not advisable.

Pale granules and thermally sensitive colors should be dried under mild conditions at granule temperatures not exceeding 80 °C in order to avoid a change in color hues. By contrast, temperatures of up to 120 °C do not influence the mechanical properties of the moldings.

Self-coloring
Self-coloring of Ultramid® by the converter is generally possible. In the case of Ultramid® T, which is usually processed at temperatures above 310 °C, the thermostability of the color additive is to be considered.

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.

Ultramid® grades that are UL94-rated must adhere to the stipulations of UL 746D if the UL rating is to be retained. Only PA-based color batches that are HB-rated or higher may be used for the self-coloring of UL 94 HB-rated Ultramid® grades. Ultramid® grades that are UL 94 V-2, V-1 or V-0 rated may only be dyed with UL-approved color batches (special approval required).

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

Reprocessing, recycling of ground material
Ground sprue material, reject parts and the like from the processing of Ultramid® can be reused to a limited extent, provided they are not contaminated. It should be noted that the ground material is particularly hygroscopic, and so it should generally be dried before being processed. Repeated processing can cause damage.

In specific cases, it may be helpful to check the solution viscosity or the melt viscosity. It must be checked in advance whether the addition of regenerated material is permitted in the respective application. With flame-retardant products, restrictions on the permitted amount of regenerated material (e. g. UL specifications) must also be noted.

As Ultramid® is not homogeneously mixable with most other thermoplastics, including PS, ABS, and PP, only single-variety mixtures of new product and regenerated material may be processed. Even small amounts of such “extraneous material” usually have a negative effect which becomes apparent, for example, as laminar structures – especially close to the gate – or in a reduced impact strength.

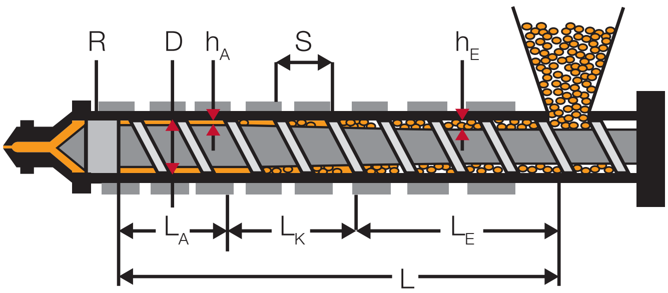
Machine and mold technique for injection molding

Ultramid® can be processed on all commercial injection molding machines.

Plasticizing unit

The single-flighted three-section screws usual for other engineering thermoplastics are also suitable for the injection molding of Ultramid®. In modern machines the effective screw length is 20-23 · D and the pitch 1.0 · D. The geometry of the three-section screw which has long proved effective is shown in Fig. 28.

Recommended flight depths are shown in Fig. 29. These flight depths apply to standard and more shallow-flighted screws and afford a compression ratio of about 1 to 2. 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 granules and greater homogeneity of the melt can be an advantage for the quality of injection-molded parts.



D	outer diameter of the screw	
L	effective screw length	20-23 D
L_E	length of the feed section	0.5 - 0.55 L
L_K	length of the compression section	0.25 - 0.3 L
L_A	length of the metering section	0.2 L
h_A	flight depth in the metering section	
h_E	flight depth in the feed section	
S	pitch	1.0 D
R	non-return valve	

Fig. 28: Screw geometry – terms and dimensions for three-section screws for injection-molding machines

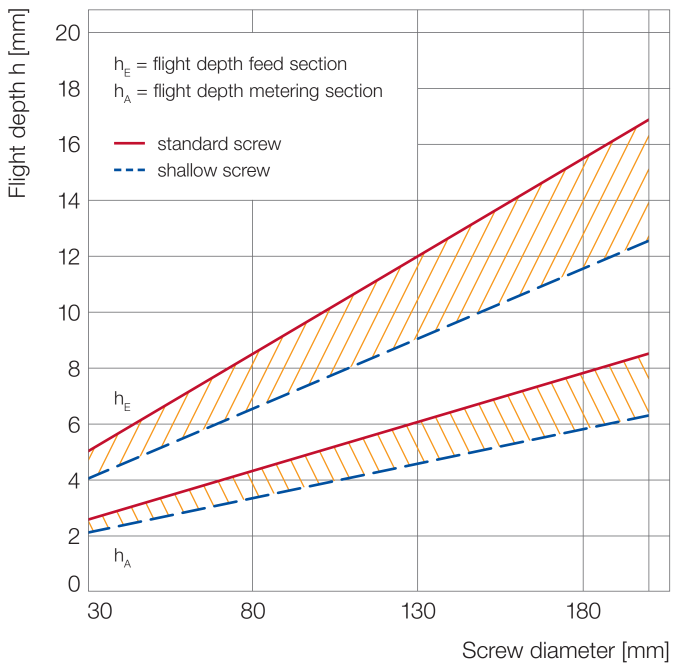


Fig. 29: Screw flight depths for three-section screws in injection-molding machines

In order to ensure that moldings can be manufactured in a reproducible way, it is important to have a non-return valve which is designed to favor a good flow and closes well. This allows a constant melt cushion and a sufficient holding pressure time to be achieved. The clearance between the cylinder and the valve ring should be no more than 0.02 mm.

Due to the low shear stress of the melt, open nozzles are generally used for the injection molding of Ultramid®. They are also advantageous when materials have to be changed comparatively quickly. 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 these cases, shut-off nozzles are recommended to ensure uninterrupted production.

The machine nozzle should be easy to heat and have an additional heater band for this purpose if necessary. So it is possible to prevent undesired freezing of the melt. When processing most glass-fiber reinforced thermoplastics, it is also advisable with glass-fiber reinforced Ultramid® to use hard-wearing plasticizing units. With flame-retardant grades, the use of corrosion-resistant steels may be necessary.

Injection mold

The design rules for injection molds and gating systems which are specified in the relevant literature also apply to moldings made from Ultramid®.

Filling simulations at an early stage can make an important contribution to the design, especially where molded parts have complex geometries.

Molded parts made of Ultramid® are easy to demold. The draft on injection molds for Ultramid® is generally 1 to 2 degrees. With drafts of a lower angle, the demolding forces increase greatly, which means that more attention has to be paid to the ejector system.

In principle, Ultramid® is suitable for all usual types of gate. When hot runner nozzles are used, it should be possible to regulate them individually. Heated components must have a homogeneous temperature level.

Exterior mirror base

Gates must be sufficiently large in size. Gate cross sections which are too small can cause a wide range of problems. These include material damage resulting from excessively high shear stress or insufficiently filled molded parts as a result of pressure losses. Premature freezing of the melt before the end of the holding pressure time can cause voids and sink marks.

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 using interchangeable mold inserts. Corrosion-resistant, high-alloy steels (for example X42Cr13, DIN 1.2083) have proven suitable for processing flame-retardant products.

When the melt is injected, the air in the mold cavity must be able to escape easily – especially at the end of the flow path or at places where flow fronts meet – so that scorch marks from compressed air are not produced (diesel effect). This applies particularly to the processing of flame-retardant grades. Figure 30 illustrates how mold vents can be realized.

The quality of moldings is very highly dependent on the temperature conditions in the mold. A precise and effective mold temperature control is possible only with a well-designed system of temperature control channels in the mold together with temperature control devices of appro-priate power. The mold temperatures required for Ultramid® can be achieved with temperature control devices using water, with system pressure being superimposed in a controlled way if necessary.

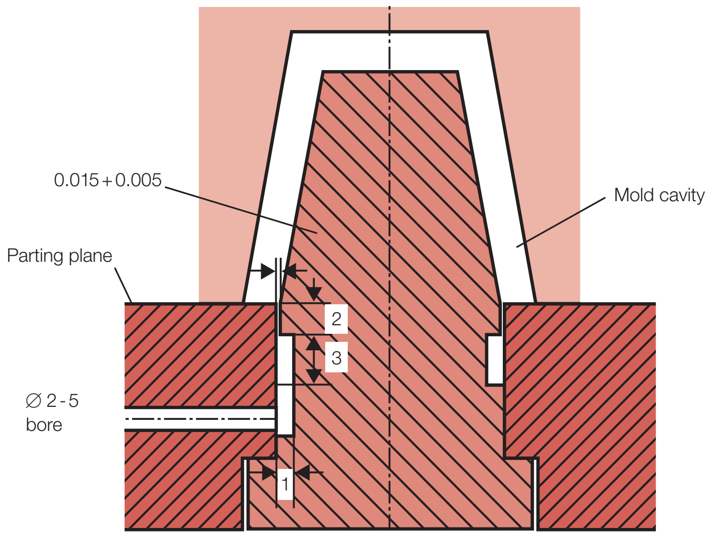


Fig. 30: Design diagram for mold venting (all size in mm)

Thermal dowel

Injection molding

The processing machine is started up in the usual manner for thermoplastics: cylinder and nozzle heaters are set to achieve the melt temperature required in each case (Table 7 gives guideline 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 processing flame-retardant 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 during processing”).

The residence time of the plastic in the plasticizing cylinder is a major factor determining the quality of the molding. Residence times which are too short can result in thermal inhomogeneities in the melt whereas, if they are too long (> 10 min), they often result in heat damage.

Melt temperature

The correct melt temperature within the specified ranges (Table 7) 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.

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 toward the nozzle. In the case of short residence times, flat temperature control on the cylinder is sensible (Fig. 31).

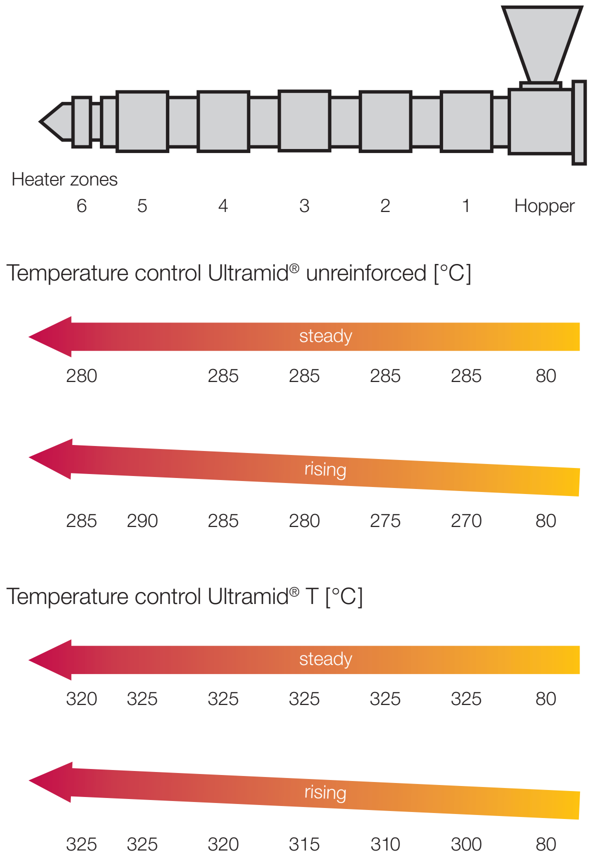


Fig. 31: Examples of cylinder temperature control

Mold temperatures

Unreinforced Ultramid® is processed as a rule at mold temperatures of 40 °C to 80 °C. Reinforced Ultramid® grades require higher temperatures. In order to achieve good surface qualities and moldings meeting high requirements for hardness and strength, the surface temperatures of the mold cavities should be 80 °C to 90 °C, and in special cases 120 °C to 140 °C (Table 7).

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 75 to 115 min^{-1} (corresponding to a peripheral screw speed of 0.2 to 0.3 m/s) is often adequate for a 50 mm diameter screw. Too high screw speeds lead to temperature rises due to frictional heating.

Ultramid®	Melt temperature range [°C]	Mold temp. range [°C]	Melt temp. [°C]	Mold temp. [°C]	Molding shrinkage [%] Testbox[1]	Sheet[2] crosswise	Sheet[2] lengthwise
A3K, A3W	280-300	60-80	290	60	0.85	1.40	1.70
A3HG5, A3EG5, A3WG5	280-300	80-90	290	80	0.55	0.50	1.10
A3X2G5	280-300	60-90	290	80	0.50	0.50	1.25
A3EG6, A3WG6	280-300	80-90	290	80	0.55	0.40	1.05
A3X2G7	280-300	80-90	290	80	0.45	0.35	1.15
A3EG10, A3WG10	290-310	80-90	300	80	0.45	0.35	0.80
A3U40G5	280-300	80-90	290	80	0.50	0.40	1.10
B3S	250-270	40-60	260	60	0.55	0.90	1.00
B3ZG3	270-290	80-90	280	80	0.50	0.60	0.70
B3ZG6	270-290	80-90	280	80	0.40	0.30	0.70
B3EG6, B3WG6	270-290	80-90	280	80	0.40	0.25	0.75
B3WG6 High Speed	260-290	80-90	280	80	0.50	0.25	0.75
B3WG7	270-290	80-90	280	80	0.35	0.25	0.75
B3WG10	280-300	80-90	300	80	0.30	0.20	0.70
Structure B3WG10 LF	280-305	80-100	305	80		0.30	0.50
B3WGM24 HP	270-290	80-90	280	80	0.40	0.40	0.60
B3U30G6	250-275	80-90	270	80	0.50	0.40	0.90
C3U	250-270	60-80	270	60	0.80	1.25	1.30
S3WG6 Balance	270-290	80-90	270	80	0.40	0.40	0.90
T KR 4350	310-330	70-100	315	90	0.60	0.90	1.10
T KR 4355 G5	310-330	80-120	320	100	0.40	0.50	0.90
T KR 4355 G7	310-330	80-120	320	100	0.35	0.30	0.90
T KR 4355G 10	310-330	80-120	320	100	0.30	0.20	0.70
T KR 4357 G6	310-330	80-120	320	100	0.35	0.40	1.00
T KR 4365 G5	310-330	80-120	320	100	0.40	0.30	0.80

Table 7: Typical values for the process temperature and molding shrinkage

[1] Impeded shrinkage, lengthwise, see Fig. 33: distance A, test box: P_N = 800 bar, wall thickness 1.5 mm
[2] Free shrinkage acc. to ISO 294-4, sheet: P_N = 500 bar, wall thickness 2 mm
P_N = holding pressure

Injection rate

The rate at which the mold is filled affects the quality of the moldings. Rapid injection leads to uniform setting and the quality of the surface, especially in the case of parts made from glass-fiber reinforced Ultramid®. However, in the case of moldings with very thick walls, a reduced injection rate may be appropriate in order to avoid a free jet.

Holding pressure

In order to prevent sink marks and voids, the holding pressure and the holding pressure time must be chosen to be sufficiently high so that the contraction in volume which occurs when the melt cools is largely compensated for.

Flow behavior

The flow behavior of plastic melts can be assessed in practical terms through what is known as the spiral test using spiral molds on commercial injection molding machines. The flow path covered by the melt – the length of the spiral – is a measure of the flowability of the processed material.

The spiral flow lengths for some Ultramid® grades are presented in Table 8. Via the ratio of flow path to wall thickness the flow behavior of thermoplasts can be compared. These ratios (i) are given in Table 8 for spirals 1.0, 1.5 and 2.0 mm thick. The advantage of flow-optimized Ultramid® High Speed can easily be seen. With the processing conditions, essentially the melt temperature, the flow paths can be influenced, partly between 100 and 150 mm.

	Temperature		Flow characteristics					
			Spiral length (mm)	Spiral length/spiral thickness (i)				
	T_M	T_W	1.0 mm		1.5 mm		2.0 mm	
Ultramid®	°C	°C	mm	(i)	mm	(i)	mm	(i)
A3K	290	60	200	200	385	257	640	320
A3X2G5	300	80	145	145	300	200	430	215
A3EG7	290	80	130	130	245	163	400	200
A3X2G7	290	80	105	105	180	120	295	148
A3U40G5	300	80	160	160	270	180	365	183
B3S	260	80	170	170	305	203	520	260
B3U30G6	270	80	230	230	380	253	645	323
B3WG3	280	80	170	170	290	193	490	245
B3WG6	280	80	140	140	245	163	405	203
B3WG6 High Speed	280	80	200	200	375	250	605	303
B3WG10	300	100	150	150	265	177	410	205
Structure B3WG10 LF	300	100	165	165	350	233	455	228
S3WG6 Balance	290	80	150	150	280	185	335	168
T KR 4350	330	90	170	170	295	197	400	200
T KR 4355G5	330	100	145	145	215	143	350	175
T KR 4355G7	330	100	125	125	200	133	325	163
T KR 4357G6	330	100	130	130	210	140	330	165
T KR 4365G5	330	100	100	100	165	110	265	133

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

T_M = Melt temperature, T_W = Surface temperature of mold cavity

Shrinkage and aftershrinkage

ISO 294-4 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 influenced by the geometry (free or impeded shrinkage), and the wall thickness of the molding (Fig. 32). 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 difficult.

A useful resource for the designer are the shrinkage values determined on a test box measuring 60 mm · 60 mm, which is molded via a film gate, for it shows the minimum and maximum shrinkage due to the high orientation of the fibers and thus the shrinkage differences in flow diection. The value measured on the test box (Fig. 33) can serve as a guideline for an average shrinkage that occurs in a real component as the flow fronts tend to run concentrically from the gate pin here (Table 7).

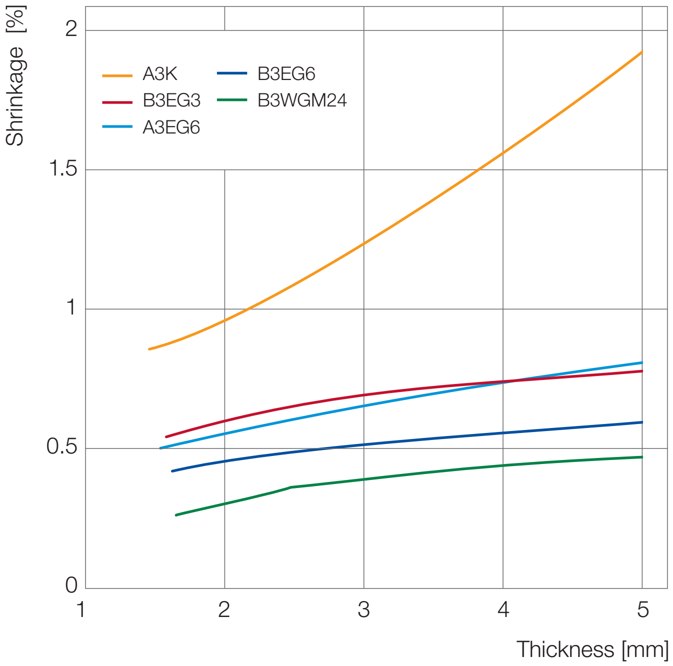


Fig. 32: Impeded shrinkage of Ultramid® as a function of the wall thickness of a test box ($P_{holding\ pressure}$ = 600 bar)

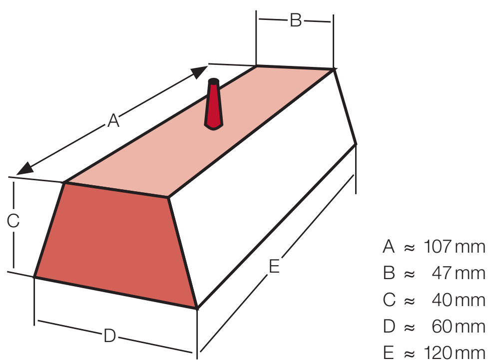


Fig. 33: Test box

As a basic rule, unreinforced polyamides shrink to a greater extent than reinforced grades. Tailored modification of the process parameters can influence dimensional tolerances for unreinforced products. The melt and mold temperatures as well as the holding pressure level and holding pressure time must be mentioned here. By contrast, with reinforced Ultramid® the influences of injection molding are only limited. Figures 34, 35 and 36 show shrinkage values for reinforced and unreinforced Ultramid® with different processing parameters.

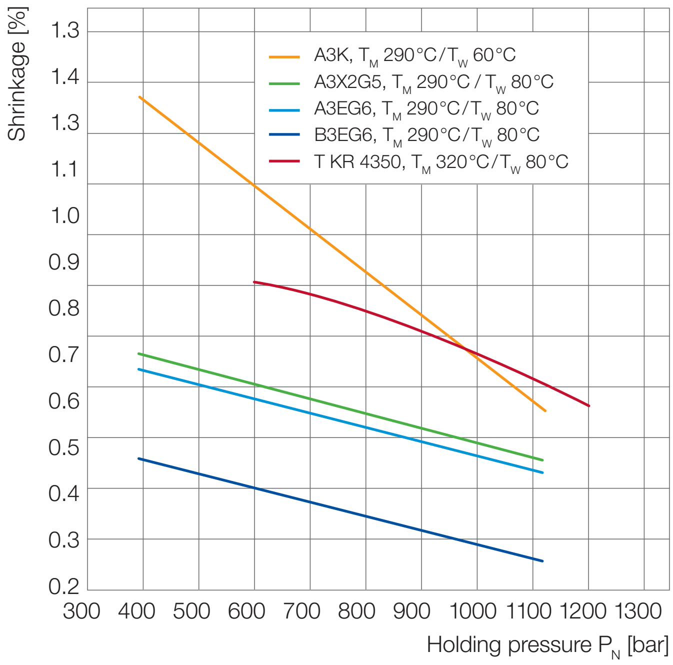


Fig. 34: Shrinkage of Ultramid® A, B and T as a function of holding pressure (test box, 1.5 mm thick)

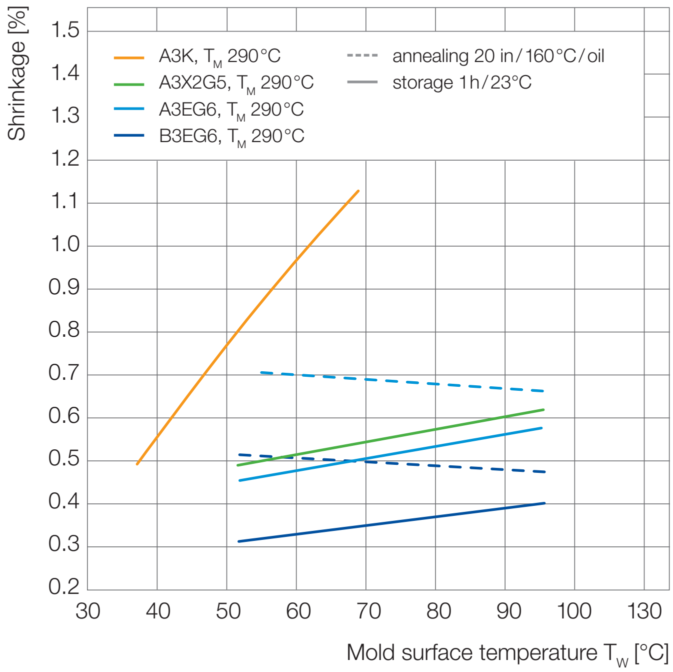


Fig. 35: Shrinkage of Ultramid® A and B as a function of mold surface temperature and annealing (test box, 1.5 mm thick)

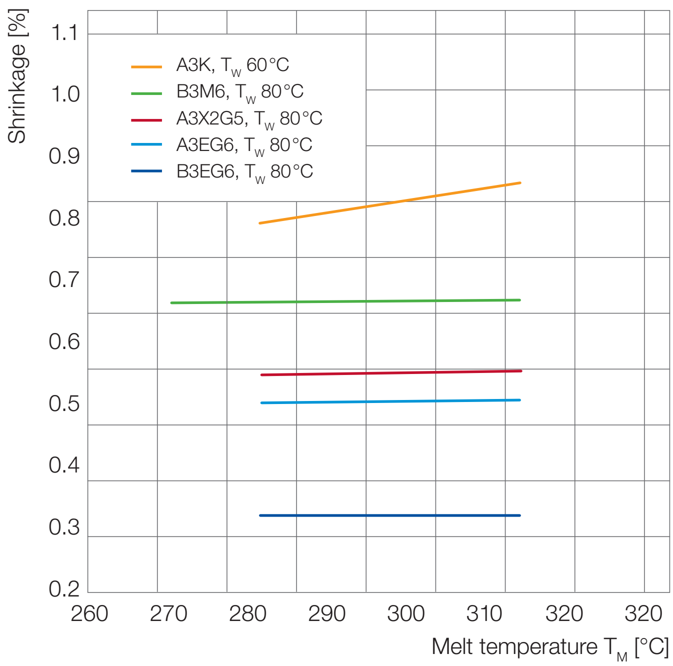


Fig. 36: Shrinkage of Ultramid® A and B as a function of melt temperature (test box, 1.5 mm thick)

Moldings of glass-fiber reinforced products show a marked difference in the shrinkage perpendicular and parallel to the direction of flow (shrinkage anisotropy). This is the result of the typical orientation of the glass fibers longitudinally to the direction of flow (Fig. 37).

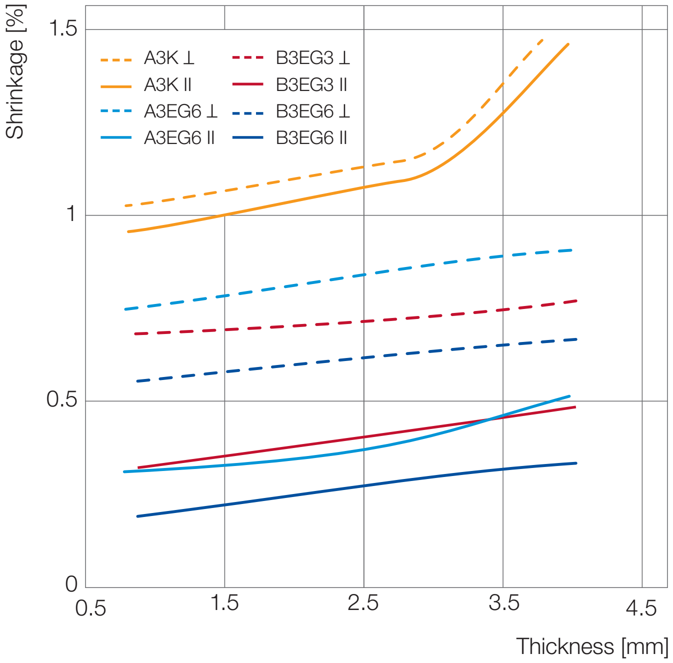


Fig. 37: Impeded shrinkage of different Ultramid® grades as a function of wall thickness (sheet measuring 110 x 110 mm made using a film gate; $P_N = 500$ bar; ⊥ means perpendicular and II means parallel to the melt flow direction)

Post-shrinkage means that the dimensions of the moldings may change slightly over time because internal stresses and orientations are broken down and post-crystallization can take place depending on time and temperature. Whereas the post-crystallization is comparatively low at room temperature, at higher temperatures it can result in a possibly significant dimensional change. The process of post-shrinkage can be accelerated by annealing. High mold temperatures reduce the level of post-shrinkage and can therefore replace a subsequent annealing process (Fig. 35).

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. That is why molds made of glass-fiber reinforced materials tend more to warpage than those made of unreinforced products. In addition it depends on the shape of the moldings, the distribution of wall thicknesses and on the processing conditions.

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.

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

Transmission cross beam

Special methods

Multi-component technology
The combination of several materials in one molding has become firmly established in injection molding technology. Various Ultramid® grades are used here, depending on what component properties are required. The components must be matched to one another in respect of their processing and material properties. A lot of experience exists in relation to the way that different materials adhere to Ultramid®. Information can be obtained from the technical information "Hard/soft compounds in injection molding technology".

Injection molding with fluid injection technology (FIT)
Fluid injection technology offers opportunities that are interesting from a technological and economic point of view for producing complex, (partially) thick-walled molded parts with cavities and functions that can be integrated. Typical FIT components made of Ultramid® are media lines in automobiles, handles, brackets and chairs.

After the plastic has been injected, the parts which are still molten are displaced with the aid of a fluid. Depending on the application, the fluid used can be gas or water. With projectile injection technology, a fluid-driven projectile is used.

With the fluid pressure applied internally, the warpage of the component can be reduced. Shorter cycle times resulting from the greater dissipation of heat and the avoidance of any accumulation of melt are also possible. Other advantages are greater freedom of design and the opportunity to create components with high specific rigidity.

At present, the products used are primarily reinforced Ultramid® grades. Some Ultramid® grades are optimized for FIT; for example the hydrolysis-resistant Ultramid® A3HG6 WIT is particularly suitable for cooling-water lines, while other grades, e.g. Ultramid® B3WG6 GIT, allow particularly good surface qualities.

Overmolding of inserts
Particularly for applications in the automotive sector, it is very important to be able to produce lightweight, high-strength plastic components. The combination of thermoplastic laminates and tapes with Ultramid® offers opportunities for innovative solutions here. Laminates can be inserted heated into the injection mold, reshaped and then overmolded with Ultramid®. Suitable Ultramid® grades fitted to each other are available for this purpose. The draping of the laminates in the cavity as well as the overmolding process and the resulting mechanical component properties can be analyzed using Ultrasim®.

Metal parts can also be overmolded with Ultramid®. However, if they are of a fairly large size, they should be preheated to 100°C to 150°C, but at least to the mold temperature, so that no excessive internal stresses occur in the molding. The metal parts must be clean of any grease and if necessary have knurlings, circumferential grooves or similar features for better anchoring.

Thermoplastic foam injection molding (TFIM)
The addition of chemical or physical blowing agents causes the melt to expand during the filling of the mold. So sink marks can be avoided even with large wall thicknesses. If necessary, it also allows the weight of the component to be reduced. In addition, the fill pressure is considerably reduced so that a machine with a lower closing force can be used. However, it should be noted that the mechanical and the surface properties can be influenced in a negative way depending on the level of expansion. Ultramid® B3WG6 SF is particularly suited to the TFIM process.

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.

Coolant water pipe

Joining methods

Parts made from Ultramid® can be joined at low cost by a variety of methods. They can be easily joined using special screws suitable for plastics 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.

Metal inserts have proved to be effective for screw connections subjected to high stresses. These are overmolded 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:

- Vibration welding (linear, biaxial)
- Spin welding
- Ultrasonic welding
- Laser beam welding
- Infrared welding
- Hot gas welding

All these methods have their own specific advantages and disadvantages (Table 9). 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.

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), on polymerizable, pressure-sensitive and contact adhesives.

Parts made from Ultramid® grades can be bonded securely to rubber, e.g. after surface treatment.

Method	Advantages	Disadvantages	Applications
Vibration	relatively short cycle times; high strength	high welding pressure; stress caused by vibration; grainy weld flash; wide seam	air intake manifolds, containers, air ducts
Rotation	relatively short cycle times; high strength	rotation-symmetrical seam necessary	containers, connection pieces, covers, linear sections, filter housings
Ultrasound	short cycle times; possibility of integration into production lines	high mechanical stress due to vibrations; possible damage due to covibration	housings, devices, bearing cages, filters
Laser	flash-free, clean welding seam; stress-free welding; design freedom	material adaptation conceivably necessary	housings, covers, filters, medical devices
Heating element Heat contact	high strength; smooth, contiguous flash	long cycle time; adhesion of the melt to the heating element; process possible, if the heating element is cleaned	containers
Heating element radiation	high strength; smooth, contiguous flash	long cycle time; only minor warpage permissible or else compensation by mold necessary	housings

Table 9: Advantages and disadvantages of welding methods

Printing, embossing, laser marking, surface coating, metallizing

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.

The following information is intended only to provide initial guidance. The Ultra-Infopoint 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. The Ultra-Infopoint will be happy to send you an overview on request.

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 Nd-YAG laser (1064 nm). 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. Waterborne paints and primers can also be applied to Ultramid®. A mixture of isopropanol and water or other specific cleaning agents can be used for preliminary treatment. Industrial processes, such as preliminary treatment in automotive paint shops, are also suitable for cleaning. Coating based on electrostatics is only possible with what is known as a conductive primer as Ultramid® is not sufficiently conductive in its own right.

Metallizing

After proper pre-treatment, parts made of Ultramid® can be metallized galvanically or in a high vacuum. With unreinforced as well as reinforced materials a flawless surface is achievable. Metallized parts made of Ultramid® are increasingly used in the sanitary, the electronics and automotive industries.

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 (Fig. 16 and individual values in the Ultramid® product range).

Practical conditioning method

Immersion in warm water at 40°C 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.

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 10 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.

The technical information "Conditioning Ultramid® moldings" provides further details.

Annealing

Annealing, e.g. by heat treatment for 12 to 24 hours (in air or in an annealing liquid at 140°C 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.

Ultramid®	Equilibrium moisture content atmosphere HSC 23/50 [%][1]	Conditions		Thickness [mm] 1	2	4	6	8	10
A grades		Water bath	40°C	6	31	110	240	480	670
unreinforced	2.8		60°C	1.5	6	24	60	120	190
			80°C	0.5	2	8	20	36	60
glass-fiber reinforced	1.2…2.2	Atmosphere	40°C/90%	24	96	430	960	1700	2900
mineral-filled	1.4…1.5		70°C/62%[2]	15	60	240	550		
B grades		Water bath	40°C	3.5	14	60	120	240	380
unreinforced	3.0		60°C	1	4	16	36	72	110
			80°C	0.5	1	4	10	18	24
glass-fiber reinforced	1.5…2.6	Atmosphere	40°C/90%	15	60	260	600	1100	1700
mineral-filled	2.0…2.4		70°C/62%[2]	10	48	120	240		

Table 10: Time in hours required for Ultramid® sheet to attain a moisture content corresponding to the equilibrium moisture content obtained in a standard atmosphere (23°C/50%)[1] at storage of Ultramid® sheet in hot waterbath or in moist climate

[1] Values for individual grades in SC 23/50 are given in the Ultramid® product range
[2] Used in ISO 1110-Polyamides-Accelerated conditioning of test specimens in SC 23/50

General information

Safety notes

Safety precautions during processing
As far as the processing is done under recommended conditions (see the product-specific processing data sheets), Ultramid® melts are thermally stable 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. Further information can be found in the product-specific data sheets.

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.

Food regulations for Ultramid®
The grades in the Ultramid® range marked FC comply with the current legislation on plastics in contact with food in Europe and the USA. In addition, the conformity of these products is guaranteed by manufacturing in accordance with the GMP (Good Manufacturing Practice) standard. If detailed information about the food approval status of a particular Ultramid® grade is required, please contact BASF directly (plastics.safety@basf.com). BASF will be happy to provide an up-to-date declaration of conformity based on the current legal regulations.

Available under the name FC Aqua® are Ultramid® grades which, in addition to being used in components in contact with food, also have different country-specific approvals for applications involving contact with drinking water. All plastics in the Aqua® range have the approvals in line with KTW[1)], DVGW[2)], and WRAS[3)] in cold-water applications, and a large proportion of them for warm and hot water, too. In order to make it easier for the finished components to be approved, BASF provides all the certifiates required for Germany and Great Britain. If approvals from the ACS[4)], the 5NSF[5)] or other institutes are required, BASF assists by disclosing the formulation to the institutes. For questions regarding compliance with further regulations and certificates, please contact your local BASF representative or Plastics Safety (e-mail: plastics.safety@basf.com, fax: +49 621-60-93253).

[1)] KTW: Kontakt mit Trinkwasser (Germany)
[2)] DVGW: Deutscher Verein des Gas- und Wasserfachs (Germany)
[3)] WRAS: Water Regulation Advisory Scheme (UK)
[4)] ACS: Attestation de Conformite Sanitaire (France)
[5)] NSF: National Sanitation Foundation (USA)

Quality and environmental management

Quality and environmental management are an integral part of BASF's corporate policy. One key objective is to ensure customer satisfaction. A priority is to continuously improve our products and services with regard to quality, environmental friendliness, safety, and health. The business unit Engineering Plastics Europe has a quality and environmental management system, which was approved by the German Society for Certification of Management Systems (DQS):

- Quality management system in accordance with ISO 9001 and ISO/TS 16949
- Environmental management system in accordance with ISO 14001

The certification covers all services by the business unit in terms of the development, production, marketing, and distribution of engineering plastics. In-house and external audits and training programs for employees are conducted on a regular basis to ensure the reliable functionality and continuous development of the management systems.

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 11. Many other test methods suitable for Ultramid® are presented in ISO 1874-2 "Polyamide molding compounds for injection molding and extrusion – Part 2".

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

Test method[1]	Typical value given in Ultramid® range chart	Test standards	Remarks
Identification		DIN 53746	Simple methods of indentification by means of melting point, density, solubility
Melting point	•	ISO 11357	Plastics – Differential scanning calorimetry (DSC)
Density	•	ISO 1183	BASF simplified density titration method
Ash	•[2]	ISO 3451-4	To determine the content of reinforcing material
Viscosity number VZ	•	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	•	ISO 1133	Preferred test conditons: 275 °C/5 kg load (Ultramid® T 325 °C/5 kg); material must contain less than 0.05 % water
Moisture content	•[3]	ISO 15512	Coulometric Karl-Fischer-Titration

Table 11: Test methods for goods inward inspection of Ultramid®

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 product range.
3) Ultramid® is supplied ready for processing with moisture content of less than 0.15 % (injection molding) or 0.1 % (extrusion).

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 proce ssing 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
- Mold surface temperature

Modern injection molding machines are fitted with process regulation instruments with which the defined variables can be kept constant within a narrow tolerance range. Narrower process tolerances during processing generally give rise to injection-molded parts having a uniform quality. Quality assurance can be facilitated through documentation of the actual values.

Important quality criteria for Ultramid® moldings are:

- Dimensional stability (freedom from warpage)
- 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.

A light-microscopic image showing the structure of thin layers of injection-molded parts is an important quality criterion, especially in the case of the non-reinforced grades. It serves to depict defective crystalline structures and other irregularities inside the parts. Consequently, the quality of Ultramid® molded parts can be assessed so that conceivable causes for flaws can be ascertained.

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 of the tests.

Design cutlery

Delivery and storage

Ultramid® is supplied in the form of cylindrical or lenticular granules. The bulk density is approximately 0.7 g/cm³. The products are dried so as to be ready for processing and they are delivered in moisture-tight packaging. The standard types of packaging are 25-kg special bags and 1000-kg bulk-product containers (octagon IBC = intermediate bulk container made of corrugated cardboard with a liner bag). Upon consultation, other kinds of packaging and shipment in silo trucks or railway cars are likewise possible. All packaging is tightly sealed and should only be opened immediately prior to the processing. The material, which is delivered completely dry, should not be permitted to absorb any moisture from the air, so that all packaging has to be stored in dry rooms and must always be carefully sealed again after any portions have been removed.

When Ultramid® is kept in undamaged packaging bags, it can be stored indefinitely. Experience has shown that the product delivered in an IBC can be stored for approximately three months without the processing properties being impaired by moisture absorption. Packaging stored in cold areas should be allowed to warm up to room temperature before being opened so that no condensation can precipitate onto the granules. Individual products differ in details of drying conditions and the optimum moisture at processing. These details can be found in the processing data sheets.

Colors

Ultramid® is supplied in both uncolored and colored forms. Uncolored Ultramid® has a natural opaque white color. Many products are available in black. Individual grades are available in several standard colors on request.

The H and W stabilized Ultramid® grades as well as Ultramid® A3X 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.

Door handle

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 "Delivery and storage" and "Behavior on exposure to weather").

Ultramid® is not a hazardous material as defined by the CLP ordinance (EG) No.1272/2008 and hence is not a hazardous material for transportation (cf. Ultramid® safety data sheet).

Ultramid® is assigned as not posing any risk to water.

Waste disposal
Subject to local authority regulations Ultramid® can be incinerated. The calorific value of unreinforced grades amounts to 29000 to 32000 kJ/kg (Hu according to DIN 51900).

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. In order to produce defect-free injection-molded parts containing regenerated material the ground material must be clean and dry (drying is usually necessary). 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.

Adapter for gardening tools

Services

Ultrasim®

Ultrasim® is BASF's comprehensive and flexible CAE expertise with innovative BASF plastics. The modern calculation of thermoplastic components is very demanding for the developer. When it comes to the interaction between manufacturing process, component geometry and material, only an integrated approach can lead to an ideal component. Plastics reinforced with short glass fibers in particular have anisotropic properties depending on how the fibers perform in injection molding. Modern optimization methods support the component design and can improve it in every phase of its development.

BASF's Integrative Simulation incorporates the manufacturing process of the plastic component into the calculation of its mechanical performance. This is provided by a completely new numerical description of the material which takes the properties typical of the plastic into account in the mechanical analysis. These properties include

- anisotropy
- non-linearity
- dependence on strain rate
- tension-compression asymmetry
- failure performance
- dependence on temperature.

So, BASF is more than a raw material manufacturer supplying innovative plastics that meet delivery time and quality requirements. Ultrasim® adapts flexibly to meet individual customer requirements – for highly loadable efficient, lightweight parts and thus longterm market success.

Torque rod support

Materials testing, parts testing and processing service

The accredited laboratory for molding compound or materials testing can advise and support customers on all aspects of materials science and plastics-specific tests (accreditation certificate D-PL-14121-04-00 in accordance with DIN EN ISO/IEC 17025: 2005). The range of testing services available covers the full spectrum of mechanical, thermal and electrical properties, but also topics such as weathering or fire performance.

Another vital service is offered by the laboratory for parts testing and joining technology which supports customers' project work. The extensive test capabilities include:

- heat aging, temperature and climate storage tests
- temperature shock tests
- tensile, compression, bending, pull-out tests
- impact tests (crash, drop, head impact, stone impact)
- cyclic internal pressure tests with superimposed temperature and climate profiles
- flow tests, leak tests
- acoustic analyses
- deformation and strain measurements by means of stereo photogrammetry
- optical 3D digitizing of components
- documentation of all transient processes with high-speed cameras
- testing, evaluation and optimization of all relevant joining technologies
- laser transparency and laser markability analyses

An experienced team of processing experts is available to answer questions about processing, processing technology as well as special processing techniques. A well-equipped technical processing center can be used for project work. There the processing of high temperature thermoplasts, multicomponent injection molding, GIT and WIT as well as the overmolding of thermoplastic composites is possible.

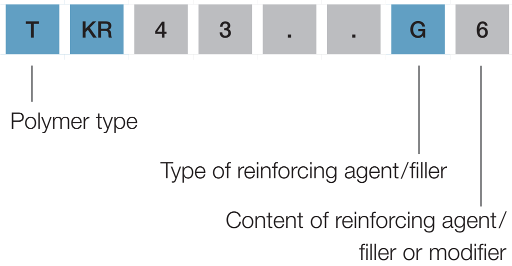
Nomenclature

Structure

The name of Ultramid® commercial products generally follows the scheme below:

Ultramid®	Subname	Technical ID	Suffixes	Color

Ultramid® T generally has the following classification scheme:



Subnames

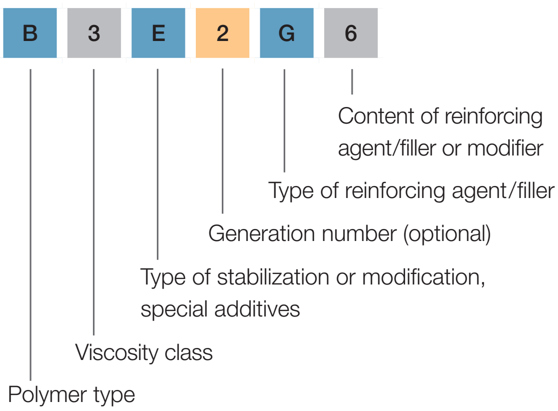
Subnames are optionally used in order to particularly emphasize a product feature that is characteristic of part of a range.

Examples of subnames:

Endure	Particularly good long-term stabilization against hot air
Structure	Particularly good notched impact strength at low temperatures, and without any disadvantages for the stiffness and strength

Technical ID

The technical ID is made up of a series of letters and numbers which give hints about the polymer type, the melt viscosity, the stabilization, modification or special additives and the content of reinforcing agents, fillers or modifiers. The following classification scheme is found with most products:



Letters for identifying polymer types

A	Polyamide 66
B	Polyamide 6
C	Copolyamide 66/6
D	Special polymer
S	Polyamide 610
T	Polyamide 6T/6

Numbers for identifying viscosity classes

3	Free-flowing, low melt viscosity, mainly for injection molding
35	Low to medium viscosity
4	Medium viscosity

Letters for identifying stabilization

E, K	Stabilized, light natural color, enhanced resistance to heat aging, weather and hot water, electrical properties remain unaffected
H	Stabilized, enhanced resistance to heat aging, hot water and weather, only for engineering parts, electrical properties remain unaffected, depending on the grade light-beige to brown natural color
W	Stabilized, high resistance to heat aging, can only be supplied uncolored and in black, less suitable if high demands are made on the electrical properties of the parts

Letters for identifying special additives

F	Functional additive
L	Impact-modified and stabilized, impact resistant when dry, easy flowing, for rapid processing
S	For rapid processing, very fine crystalline structure, for injection molding
U	With flame-retardant finish without red phosphorus
X	With red phosphorus as the flame-retardant finish
Z	Impact-modified and stabilized with very high low-temperature impact strength (unreinforced grades) or enhanced impact strength (reinforced grades)

Letters for identifying reinforcing agents/fillers

C	Carbon fibers
G	Glass fibers
K	Glass beads
M	Minerals
GM	Glass fibers in combination with minerals
GK	Glass fibers in combination with glass beads

Key numbers for describing the content of reinforcing agents/fillers or modifiers

2	approx. 10 % by mass
3	approx. 15 % by mass
4	approx. 20 % by mass
5	approx. 25 % by mass
6	approx. 30 % by mass
7	approx. 35 % by mass
8	approx. 40 % by mass
10	approx. 50 % by mass

In the case of combinations of glass fibers with minerals or glass beads, the respective contents are indicated by two numbers, e. g.

GM53	approx. 25 % by mass of glass fibers and approx. 15 % by mass of minerals
GK24	approx. 10 % by mass of glass fibers and approx. 20 % by mass of glass beads

M602 represents approx. 30 % by mass of a special silicate (increased stiffness).

Suffixes

Suffixes are optionally used in order to indicate specific processing or application-related properties. They are frequently acronyms whose letters are derived from the English term.

Examples of suffixes:

Aqua®	Meets specific regulatory requirements for drinking water applications
Balance	Based at least partly on renewable raw materials
CR	Crash Resistant
EQ	Electronic Quality
FC	Food Contact; meets specific regulatory requirements for applications in contact with food
GIT	Gas Injection Technology
GP	General Purpose
High Speed	High flowability of the melt
HP	High Productivity
HR	Hydrolysis Resistant, increased hydrolysis resistance
HRX	New generation of HR products
LDS	Laser Direct Structuring, for preparing the electroplating of electrical conductor tracks
LF	Long Fiber Reinforced
LS	Laser Sensitive, can be marked with Nd:YAG laser
LT	Laser Transparent, can be penetrated well with Nd:YAG lasers and lasers of a similar wavelength
SF	Structural Foaming
SI	Surface Improved, for parts with improved surface quality
ST	Super Tough
WIT	Water Injection Technology

Color

The color is generally made up of a color name and a color number.

Examples of color names:

Uncolored
Black 00464
Black 00564
Black 20560

Subject index

Selected Product Literature for Ultramid®:

- Ultramid® – Product Range
- Ultramid® Structure – Recommended by Leading Testers
- Ultramid® Endure – Polyamide Speciality for Injection Molding and Blow Molding
- Ultramid® B High Speed – Polyamide 6 with Improved Flow Properties
- Ultramid® 1C – A Clear Case for Coatings
- Conditioning Ultramid® Moldings – Technical Information
- Ultramid®, Ultradur® and Ultraform® – Resistance to Chemicals
- Ultramid® and Ultradur® – Engineering Plastics for Photovoltaic Mounting Systems
- From the Idea to Production – The Aqua® Plastics Portfolio for the Sanitary and Water Industries
- Engineering Plastics for the E/E Industry – Standards and Ratings
- Engineering Plastics for the E/E Industry – Products, Applications, Typical Values
- Engineering Plastics for Automotive Electrics – Products, Applications, Typical Values

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If you have technical questions on the products, please contact the Ultra-Infopoint:

Ultra Infopoint
+49 621 60-78780
ultraplaste.infopoint@basf.com

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