

Injection moulding LFT Long Fibre Thermoplastics

**Grilamid LVL (PA 12)
Grivory HTVL (aromatic PA)
Grivory GVL (partially aromatic PA)
Grilon TSGL (PA 66+6)**

Long glass fibre or long carbon fibre reinforced Grilamid, Grivory and Grilon grades can be processed economically to manufacture moulded parts using conventional injection moulding equipment.

All LFT pellets are about 10 mm long, diameters are between 2 and 2,7 mm. The fibres are as long as the pellet itself.

This technical data sheet is intended to serve as a guide for correct processing and, in particular, to provide guidelines for the selection of optimal processing and mould temperatures.

Please request our specialised literature for data concerning mechanical, thermal and electrical properties as well as for long-term test values. We will be pleased to advise you.



EMS
EMS-GRIVORY

Injection Moulding Machine

The following sections will provide information about those components of an injection moulding machine which are important for an optimized processing of Grilamid-, Grivory- and Grilon- injection moulding grades.

Dosing Unit

The dosing unit consists out of the following machine elements:

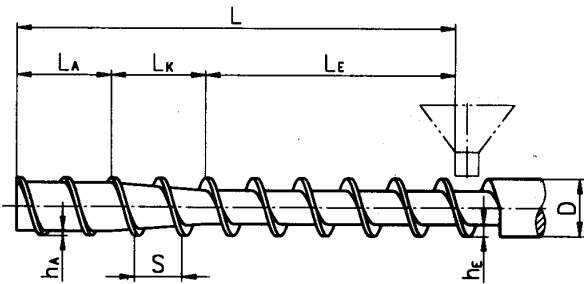
- Screw
- Back Flow Valve
- Barrel / cylinder
- Cylinder-Head
- Nozzle

Screws

Conventional 3-zone screws with a L/D-ratio between 18:1 and 22:1 have shown good performance in moulding LFT-products. The flight depth in the feed zone should have a depth of preferably 3 mm, a compression ratio of 2:1 to 2,5:1 are recommended. Screws with diameters of 35 mm are preferred, but in special cases 22 to 25 mm screws will also work.

Geometry of a universal screw:

We recommend the use of a feed zone with approx. 60% of the screw length (compression 20%, metering 20%). However, a standard 3-zone screw will also work by slightly adjusting the temperature profile.



- L_E = feed zone (60%)
- L_K = compression zone (20%)
- L_A = discharge zone (20%)
- s = screw pitch 0.8–1.0 D
- h = thread depth
- L = screw length
- D = screw diameter

The target is that the pellets are sufficiently heated up so that they will enter the compression zone at a temperature above melting temperature.

If a standard screw (feed zone 1/3 of L) is used or should the stroke be larger than the screw diameter, we recommend using a "flat" temperature profile instead of increasing temperatures. Should the screw stroke be larger than 2 to 3 times the screw diameter, it is recommended to even use a decreasing temperature profile.

If the cylinder temperatures allow the pellets to enter the compression zone in a pre-soften state, wear will be equal or even lower than conventional compounds as the number of scratching fibre ends will be much lower due to the length of the fibres.

Screws with integrated mixing elements, venting screws with double compression zones or screws with other shear elements are not recommended for the processing of long fibre reinforced polyamides.

Steel selection for processing long fibre polyamides:

Heavy duty Cr alloys through hardened such as X155CrVMo121 (1.2379); X165CrMoV12 (1.2601); X210Cr12 (1.2080); X20CrMo122 (1.2378) X20CrW12 (1.2436)

Screw crosspiece armouring made of satellite with iron-nitrided Cr steel such as X35CrMo17 (1.4122); heat-treated X22CrNi17 (1.4057); heat treated for bigger diameters X5CrNi134 (1.4313)

Hopper selection

The hopper should have, preferably, a discharge angle of at least 45°, better 60°, flat bottoms and long transition tubes to the feed throat must be avoided. Small feed throat diameters and safety bars, magnets or other inserts can lead to flow stagnations. Allow at least 15 mm free space for the pellets to move.

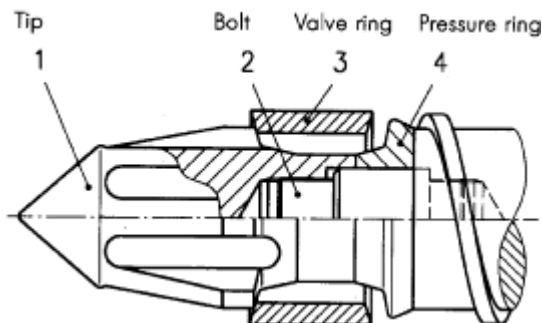
All inside seams must be flush, circular sections are preferred over rectangular flow channels.

Pellet conveying

The LFT pellets are 3 times heavier than conventional granules. Adjust vacuum feeder systems to slow conveying speed to reduce the impact on tubes and hoppers. Use rounded tubes and tangential entries rather than flat impact plates. Keep conveying distances as short as necessary. Bends and bows should be equipped with wear resistant hardened steel or use ceramic / glass bows. Conveying tube diameter should be at least 50 mm in diameter.

Back flow valve

When processing Grilamid, Grivory or Grilon LFT, a screw equipped with a back flow valve (check valve) must be used in order to create the necessary injection and post pressure.



Screw tip with back flow valve

Description of operation

The pressure of the conveyed melt during the metering pushes the valve ring forward against the screw tip. A circular gap between the valve ring and the pressure ring is opened that allows the molten material to flow in front of the screw. Please ensure this gap is sufficiently large to avoid high shear especially for LFT products. When the injection phase starts, the valve ring is pushed backwards closing the gap and sealing off the screw tip against the pressure ring. The melt cannot flow back along the screw tip and the necessary injection pressure can build up.

Back flow valves for long fibre-reinforced polyamides should provide a large melt passage under the valve ring with sufficient valve ring stroke. In general, ball back flow valves are not recommended for LFT products.

Steel selection for back flow valves:

A Tip and pressure ring

Screw crosspieces of the blade tips should be armoured with CrNiB-alloys containing carbide additives.

Highly alloyed Cr steel through-hardened (see section b under screws)

B Valve ring

Highly alloyed Cr steel with good toughness through-hardened or heat-treated, ion-nitrided, e.g. X155CrVMo121 (1.2379)
X35CrMo17 (1.4122)

Cylinder

The necessary temperature to melt the plastic material is supplied by the cylinder. The friction of the pellets with the screw and the barrel creates a certain amount of heat; the majority of the energy should be generated by the heater belts of the cylinder itself. The heater zones must be individually controlled and monitored and should allow a barrel temperature of up to 350°C. The installed power should be at least 3 to 5 Watts/cm². The thermocouples should be located as close as possible to the inner surface of the cylinder to allow a precise and fast regulation of the temperatures. Ensure a clean and good contact of the thermocouple tips with the barrel steel. The feed throat of the cylinder (lower hopper area) should be equipped with a cooling system to prevent from overheating.

For long fibre reinforced materials, please check:

- material is sufficiently heated when entering into the compression zone
- amount of heat brought in by friction should be as small as possible (low screw speed, low back pressure, first heating zones relatively high settings)
- keep the feed throat at 80 to 100°C (drying temperature) to ease heating up to melt temperature

Steel selection for cylinders

- a) Coating with a suitable protection layer, usually Ni-Co-Cr-W-B based, minimal iron content non-alloyed or alloyed C-steels
- b) Use of coated bushings, nitrided steels e.g. 34CrA1N17 (1.8550)
31CrMoV9 (1.8519)
- c) Boronised nitrided steels, small diameters

Cylinder head

The cylinder head acts as a reducing adapter between cylinder and nozzle

Steel selection for cylinder heads

- a) Highly alloyed Cr-steels, ion-nitrided (see point b under screws)
- b) Standard nitrided steels, hard-chromium plated, e.g. 31CrMoV9 (1.8519)

Nozzle

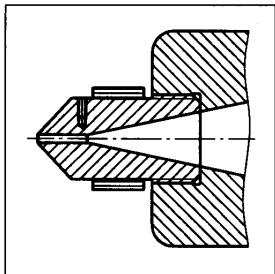
For the processing of LFT polyamides of EMS, open as well as shut-off nozzles can be used. Nozzles with complicated flow paths, dead corners are less suitable. In general, open nozzles will suit very well and are preferred over shut-off systems.

Make sure, the diameter of the sprue is sufficiently large (approx. 1,4 times the maximum wall-thickness of the moulded part) to avoid heating and fibre damage due to high shear.

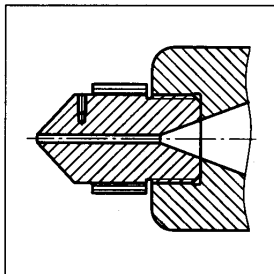
Open nozzles

Open nozzles can be used when the dosing time is within the cooling time with the nozzles shutting off the cylinder against the mould and no molten material can exit the barrel.

The contact surface as well as the contact time of the hot nozzle to the colder mould should be kept as small as possible to avoid frozen material in the tip (cold plugging).



Open nozzle allowing a free flow



Open nozzle with long bore to slow the exit of the melt.
Disadvantage: higher shear and pressure

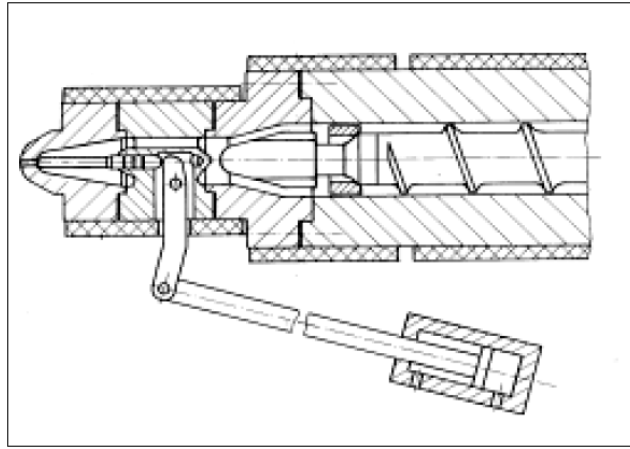
A screw retraction is recommended after the dosing stroke completion in order to release the pressure along the screw. This release stroke should be kept as small as possible to avoid an excessive air entry into the cylinder.

Shut-off nozzles

Shut-off nozzles are used to prevent molten material from dripping out of the nozzle tip. If such nozzles are used, please assure that the nozzle has smooth flow channels without any stagnation zones and sharp corners or edges. For the processing of Grilamid, Grivory and Grilon long fibre materials, shut-off nozzles with axial needles externally controlled (hydraulically) have shown good results.

With such systems, an internal needle pushed forward by a lever with external movement control closes the nozzle.

Spring loaded systems are less recommended as the spring will try to close the tip at any time and may create a very small material passage



with high shear and poor control in the holding phase.

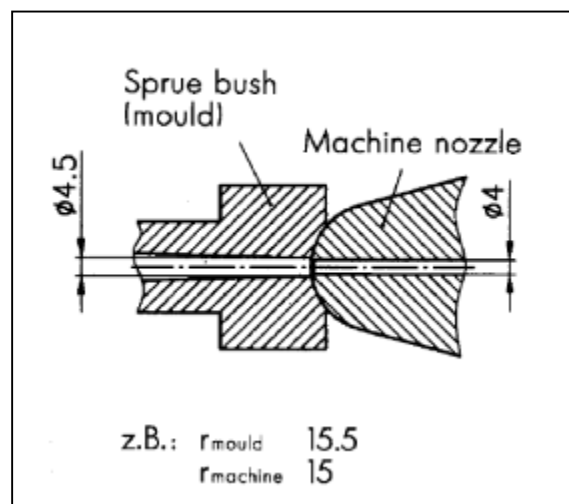
All nozzles used for the processing of Grilamid, Grivory or Grilon LFT materials, whether they are open or shut-off types, must be equipped with a sufficient heating system to prevent "freezing" of the nozzle at any time.

The diameter of the nozzle bore must be slightly smaller than the outer sprue bush diameter to allow demoulding of the sprue and runner.

Transition from machine nozzle to sprue bush

Radius nozzles

With radius nozzles the radius of the mould must be slightly bigger than the radius of the machine nozzle ($R_{\text{mould}} > R_{\text{machine}}$). This decreases the contact area to a fine line and hence the temperature loss to the colder mould decreases, and increases the surface pressure to seal the nozzle with the sprue bush and avoids undercutting. The nozzle is automatically aligned if these conditions are ensured.



Example of a correct nozzle/gating system

Nozzles with cone-shaped contact surfaces

Nozzles with cone-shaped (tapered) contact surfaces are easy to copy and become centred automatically. Taper angles of 120 degree are usual.

Choice of injection moulding machine

The choice of the injection-moulding machine depends on the following criteria:

- mould dimensions
- required shot volume
- clamping / locking pressure

Mould dimensions

The mould dimensions will define the necessary platen size and tie bar distances. The available minimum and maximum mould height limits need to be considered as well as a full surface mould support. Please consider centre holes rather small to provide the mould with sufficient mechanical support even in the centre of the mould.

Necessary shot volume

The injection volume determines the required barrel and screw size. As a general rule, 30 to 70% of the maximum shot volume should be used when producing parts with long fibre reinforced polyamides. Materials with higher melt temperatures should be processed using rather high percentages of the maximum shot volume to reduce the dwell time.

The minimum dosing stroke must be longer than the travel of the back flow valve ring.

With increasing metering stroke, turn to a flat temperature profile or even a decreasing temperature setting of the barrel.

Clamping / locking force

The clamping force must be bigger than the opening forces of the mould to avoid flashing in the parting line of the mould. The opening force can be calculated by the projected surface of the injected article multiplied by the average cavity pressure.

For technical parts produced in Grilamid, Grivory or Grilon long fibre materials, the average pressure inside the cavity will vary from 500 to 800 bar, depending on the flow length to wall-thickness ratio.

As a rule of thumb for a first clamping force estimation, the following formula can be used

Clamping Force

$$7.5 \text{ kN}^{1)} \times \text{projected area [cm}^2\text{]}$$

1) average cavity pressure of 750 bar

Injection mould

The injection mould is the most important element in the moulding process. Only a good mould and part design will lead to good moulded parts and will ensure:

- moulded articles of the required quality
- reliable production
- short cycle times
- long-life of the mould
- predetermined properties of the material
- economical manufacturing

Design or manufacturing mistakes can be compensated only to a certain extent by adjusting the parameters of the moulding process, but this will limit the processing window and may have a negative influence on the points listed above.

Guidelines given for the design of standard moulds are also applicable for the moulds for long fibre-reinforced polyamides. When sufficient sections of the runner system and gates are provided, no special design requirements need to be considered. Wear of long fibre materials for the mould will not be greater than moulding conventional materials.

For mould calculations, an effective internal mould pressure (cavity pressure) of 800 bar can be taken as guide value (bending, compression).

Tool steels alloyed with Cr and hardened to 55 to 65 HRC are recommended for conventional polyamide processing.

Manufacturers of semi-finished mould elements offer steels such as:

- X40Cr14
- X210 CrW12
- X19NiCrMo4
- 45NiCrMo16.....

Sprue and gating systems for Long Fibre Reinforced polyamides

A centrally positioned direct gating close to the maximum wall-thickness is the safest way to obtain easy filling of the cavity and to avoid sink marks. However, pinpoint or tunnel gating systems are more economical and are also used for the production of technical parts. The following rules should be considered in order to avoid early freezing of the part, voids, lack of control in the holding phase as well as to avoid too much shear (melt temperature and fibre damage):

Diameter sprue = > 1,4 x biggest wall-thickness part

Diameter gate = > 0,8 x biggest wall-thickness part

Minimum gate diameter for LFT: 1,5 mm

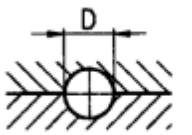
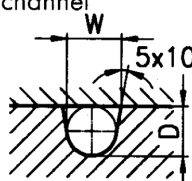
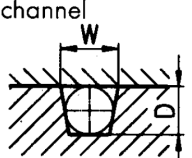
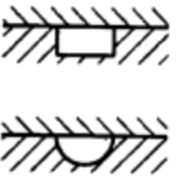
Sprue and runner

The sprue channel is the connecting piece from the machine nozzle to the runner and the gating of the part.

- The sprue needs to convey the melt as easy (fast, little pressure and temperature loss) as possible to the cavity
- The ratio of the surface to the volume of the sprue should be as small as possible
- The runner needs to provide each gating of the part with the same pressure, temperature and volume flow at the same time

- The runner must not freeze in the filling phase (injection and holding) to allow good control in the holding phase

Precise dimensioning and design of the sprue and runner are very important for the quality of the parts as well as for the cost of production. The following table shows a comparison of conventionally used runner channels:

| | |
|--|--|
| <p>Circular channel</p>  <p>$D = s_{max} + 1,5 \text{ mm}$</p> | <p>Advantages: Lowest surface area in relation to the cross-section. Lowest cooling rate, lowest heat and friction loss, molten material solidifies / freezes last in the centre of a round channel, good post pressure control</p> <p>Disadvantages: Must be manufactured in both mould halves, high effort and expensive</p> |
| <p>Parabolic-shaped channel</p>  <p>$W = 1,25 \cdot D$ $D = s_{max} + 1,5 \text{ mm}$</p> | <p>Advantages: Good approximation of a round channel, easier to manufacture only one mould half (ejector side) to be machined</p> <p>Disadvantages: Greater loss of heat, more waste in production in comparison to a round channel</p> |
| <p>Trapezoidal-shaped channel</p>  <p>$W = 1,25 \cdot D$</p> | <p>Alternative solution to a parabolic-shaped channel</p> <p>Disadvantages: Greater loss of heat, more waste in production in comparison to a round channel</p> |
|  | <p>Unsuitable cross-sections for runners, should be avoided</p> |

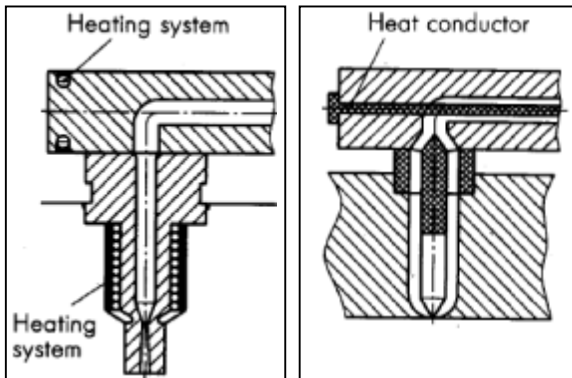
The use of pin-point 3-platen moulds with long fibre reinforced materials is not recommended as the runner and the gate will show very high strength and will be hard to break to degate the parts. As a sufficient gate size is strongly recommended, hot runners should be used instead of a 3-platen tool design.

Hot runner systems

Hot runner systems have been established in the last years and are very well suited for the processing of the long fibre reinforced polyamides like Grilamid, Grivory and Grilon. The advantages of hot runner systems are:

- no post treatment (degating)
- saving of sprue material
- easy automation
- lower shear stresses for the melt
- better post pressure control
- longer flow lengths can be achieved

For the processing of LFT polyamides, we recommend the use of externally heated systems. Thermocouples should be positioned as close as possible to the melt and to the nozzle tip to ensure accurate temperature control.



Externally heated, suited for use with LFT polyamides

Internally heated, not recommended for use with LFT polyamides

LFT polyamides do not tend to drip off the hot runner tips; needles or torpedoes should not be used as they will form a ring gap with small open sections and high shear. For shut-off hot runners (cascade injection, no screw retraction possible), plunger systems are recommended over needle systems.

Short cold runners linking the exit of the hot runner to the part can be used in case of difficult geometries. Please follow the design guidelines for runners above.

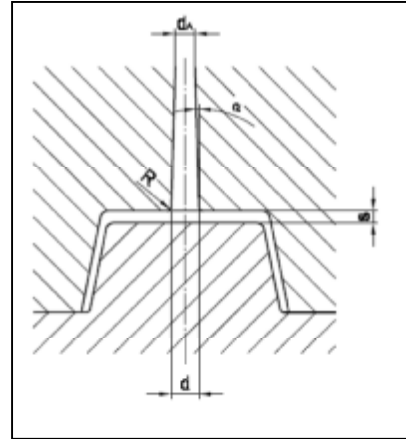
Hot runners should maintain the melt temperature at a constant level as provided by the barrel of the machine. Please do not try to heat or cool down the molten material by the hot runner system.

| | |
|---|-------------|
| Hot runner channel temperatures for LFT PA: | |
| Grilamid LFT | 270 - 290°C |
| Grivory GV LFT | 290 - 305°C |
| Grivory HT LFT | 330 - 350°C |
| Grilon TS LFT | 285 - 305°C |

Gating

The gate is the transition of the sprue channel into the cavity of the mould. The following pictures describe some variants of gating systems.

Direct gating



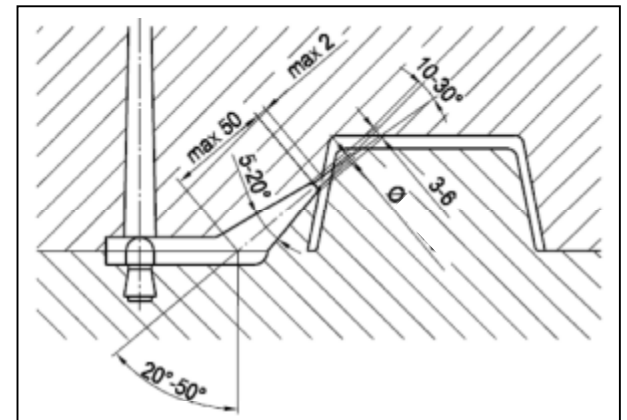
$$d_a = 1 - 1,2 s$$

$$d = s + 1 \text{ mm}$$

$$R > 1 \text{ mm}$$

$$\alpha > 1^\circ$$

Tunnel gate



The gate diameter (\varnothing) should be $\geq 0,8$ x the maximum wall-thickness of the part to ensure good control in the holding phase of the cycle without early freeze-off of the runner as well as to limit shear to the molten material. High shear will lead to fibre damage as well as to uncontrolled melt temperatures in the gate area.

For processing LFT polyamides, the use of film or diaphragm gating is not recommended. Rectangular (thick film) gates however are recommended to lower shear speeds especially for heavy parts with high shot weights. Use the available width at the part together with a thickness as recommended for tunnel gates ($0,8$ x maximum wall-thickness).

Avoid jetting into the cavity to improve filling behavior and fiber orientation, try to use a mould side wall to spread the melt smoothly into the entire cavity.

Do not position the gate in the areas of maximum or high stresses to allow the fibers to align and to avoid non stress aligned orientations of the fibers in the holding phase.

Golden rules for design of sprue and gating system for LFT polyamides

1. Use direct gating in the centre of the injected parts if possible
2. Position the gate close to the area of the highest wall-thickness
3. Position the gate away from zones of high stresses to allow fibres to orient in the desired direction
4. Always incorporate a plug connector (to remove potential cold slugs of the nozzle)
5. The thickness of the runner must be bigger than the maximum wall-thickness of the part
6. Avoid jetting of the melt into the cavity

Steel selection for long fibre polyamide processing moulds

Mould steels should exhibit some special characteristics to improve life-time as well as processing stability and productivity.

High wear resistance

Similar to all reinforced (fibres, minerals) or filled (colour pigments, additives) materials, mould steels for processing long fibre reinforced polyamides should show an improved resistance to abrasion, although the amount of fibre tips with LFT materials is much lower than for conventional grades.

Following internal studies as well as experiences of several machine manufacturers, LFT materials will not show more tool or machine wear than conventional grades.

High resistance to corrosion

Some polymer melts such as PC and PA as well as some additives (flame retardants) can chemically attack unprotected steel compositions. For this reason it is recommended to use corrosion protected steels or to use surface coatings to improve mould life-time. Many through-hardening steels contain alloy components to protect the carbon from extraction off the steel composition.

High dimensional stability

Processing high temperature resistant polymers requires mould wall-temperatures of up to 200°C. Heat resistant steel must hence be used to design and manufacture moulds for such polymers. When designing moulds that will be operated at temperatures well above 100°C, the thermal expansion must be compensated in order to ensure flawless processing and correct cavity dimensions.

Good thermal conductivity / insulation

Mould steels will show thermal conductivities almost independently of their composition. If special alloy inserts shall be used locally to improve heat flow off the mould (copper alloys), the lower mechanical strength and hardness must be taken into consideration. Such inserts can be surface treated by coatings in order to increase wear resistance.

Please consider a good thermal insulation of the mould from the machine platens to reduce the mass of material to be heated. Heating times and mould temperature adjustments will be significantly shorter to help better control the process, and to allow less energy consumption, especially for moulds operated at 120°C or higher.

Mechanical requirements

The stiffness of mould steel alloys will basically all stay at the same level. Steel variants and surface treatments will however change some properties such as surface hardness, fatigue behaviour, corrosion and ease of polishing. Please use small location rings to provide the mould with the maximum stiffness support by the platens of the machine.

Through-hardening steels

Through-hardening steels such as 1.2343 or 1.2767 have proven to be suitable for processing long fibre reinforced Grivory-, Grilamid- and Grilon-grades.

Corrosion-resistant steel

Besides corrosion treatments such as galvanising, plasma treating (TiN, TiCN, CrN) or nitriding (which is not recommended for moulds), mould steels with an integrated corrosion protection are available. The position of the carbon atoms in the steel are protected by alloy components such as Cr, V, Mo and Mn.

Surface treatments

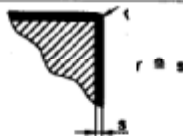

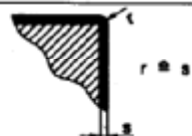
Protective surface coatings are used to keep the mould surface in good shape and to enhance tool life-time. Besides the established technologies of thermo-chemical treatments (nitriding, boriding) and galvanisation methods (chromium, nickeling), thin-layer metallurgical processes such as CVD (Chemical Vapour Deposition) and PVD (Physical Vapour Deposition) are used.

Most commonly, TiN-coatings are used to protect moulds with layer thicknesses below 5 micrometers. The risk of a tool warpage is small compared to other treatments; temperatures stay below the tempering limits of the steel.

Mould steel table

| Steel-Abbrev | Matl' No | C | Si | Mn | Cr | Mo | V | Other | HRC | Comments |
|----------------|----------|------|--------|--------|------|-------|--------|--------|---------|-----------------------------------|
| X 38 CrMoV 5-1 | 1.2343 | 0,38 | 1,05 | 0,4 | 5,15 | 1,25 | 0,38 | | 48 - 52 | standard steel, easy cutting |
| 45 NiCrMo 16 | 1.2767 | 0,45 | 0,25 | 0,3 | 1,35 | 0,25 | | 4,05 | 50 - 54 | through hardening, good polishing |
| 90 MnCrV 8 | 1.2842 | 0,9 | 0,25 | 2 | 0,35 | | 0,1 | | 56 - 62 | normal wear resistance |
| X 135 CrMoV 12 | 1.2379 | 1,5 | 0,25 | 0,3 | 12 | 0,7 | 1 | | 58 - 62 | good wear resistance |
| X 40 Cr 14 | 1.2083 | 0,42 | 0,4 | 0,3 | 13 | | | | 54 - 56 | corrosion resistant (polished) |
| X 33 CrS 16 | 1.2085 | 0,33 | < 1,00 | < 1,00 | 16 | 0,075 | < 1,00 | < 0,03 | 56 - 60 | corrosion resistant, low wear |

Comparison of surface treatments

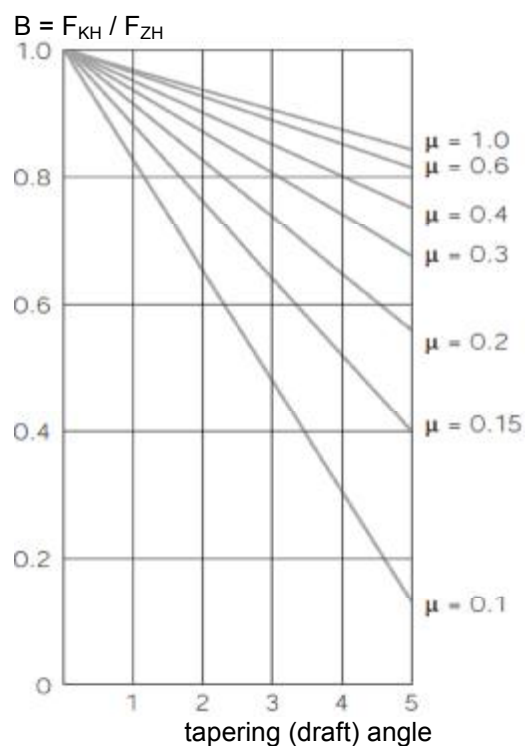
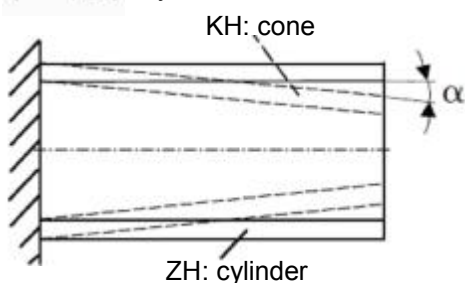
| | Chemical nickelling | Hard chromium-plating | TiN | TiCN | CrN |
|---|---|--|---|------|------|
| Hardness (HV) | 400 - 600 900 - 1000 tempered | 800 - 1000 | 2300 | 3000 | 1750 |
| Layer thickness [μm] | 5 - 150 (> 20) | 5 - 1000 | 1 - 4 | | |
| Resistance to abrasion | low - medium | medium | high | | |
| Resistance to corrosion | good | limited | limited | | |
| Mould release improvement | limited " | limited " | good " | | |
| Reduction in mould deposits | limited | limited | good | | |
| Degree of gloss of the moulded articles | ↑ | ↓ | no difference | | |
| Structured surface of the coating | limited possibilities | limited possibilities | microrays | | |
| Cutting edge |  |  |  | | |
| Coated cores | yes (rinsing system) | $\varnothing > 3 \text{ mm}$ crevice $> 2 \text{ mm}$ | limited | | |
| Coating removal | yes | yes | yes | | |

Mould draft angles

Ejection forces of the parts are created by the shrinking onto the core pin, friction between the part and the mould surfaces and vacuum-effects.

Sufficient draft angles help easy mould release and low stress onto the parts. The diagram besides shows the reduction of the demoulding forces relative to a non tapered cylinder

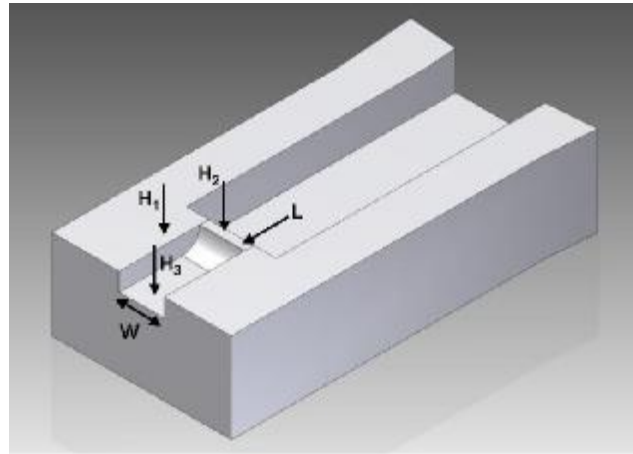
$(B = \frac{F_{KH}}{F_{ZH}})$ Ratio ejection forces cone vs. cylinder



The surface roughness influences the coefficient of static friction and determines the required draft angles. With decreasing surface roughness, a decreasing mould release angle will be required.

| Area of mould | Erosion testing standard VDI 3400 class | Depth of μm roughness | | Mould release angle |
|-----------------|---|----------------------------------|-------|---------------------|
| | | R_{max} | R_a | |
| Blasted | 18 | 5.0 | 0.85 | 1° |
| | 21 | 8.3 | 1.12 | |
| Finely eroded | 24 | 12.0 | 1.60 | 2° |
| | 27 | 19.0 | 2.50 | |
| Medium eroded | 30 | 26.5 | 3.20 | 3° |
| | 33 | 39.0 | 4.50 | |
| Coarsely eroded | 36 | 53.0 | 6.30 | 5° |
| | 39 | 70.0 | 9.00 | |

R_{max} = maximum depth of roughness R_a = average depth of roughness



$H_1 - H_2 = 0.01 - 0.02 \text{ mm}$, $H_1 - H_3 = 1 - 3 \text{ mm}$
 $L = 0.8 - 1.5 \text{ mm}$, $W = 2 - 5 \text{ mm}$
 The venting channels must go to the edge of the mould. The increase from H_2 to H_3 should be rather steep.

Venting

During the dynamic filling phase, the melt needs to displace the air entrapped in the cavity as quickly and as easily as possible. Trapped air prevents complete filling and can cause burn marks due to the temperature increase of the compressed air. In addition the mould will be damaged if burn marks are happening during each cycle for a long period of time due to high thermal stress to the mould steel.

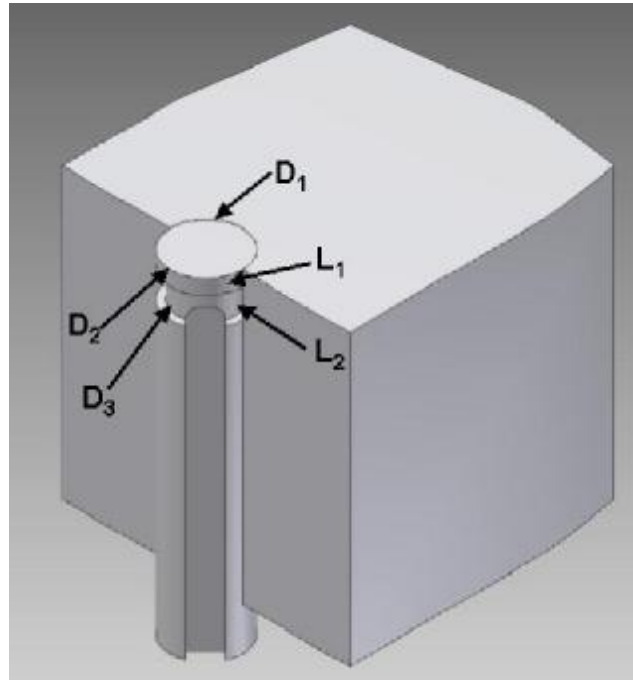
For long fibre-reinforced polyamides, venting is very important as the melt will show a "foamy" structure. The long fibres will straighten and increase the volume of the melt in areas of low pressure. The trapped air at the melt front requires good venting with little counter pressure.

With the right choice of the gate position, venting can be optimised already in the mould design phase. The air needs to be vented into the mould parting surface. If this is not possible, additional venting surfaces or gaps need to be provided.

Vents can be created by additionally positioning of plugs, inserts or ejector pins at areas of air traps. For pins, tolerance combinations of H7/g6 show sufficient venting without risk of flashes. The sealing length should be kept relatively short (1 to 2.5 mm) followed by a large collection channel.

In the parting line, a vent gap of 0,015 to 0,02 mm is suggested with a length of 1.5 to 2.5 mm. Similar to venting pins, the following collector channel should be provided with cross-sections of at least 0.5 mm.

Venting systems must be given regular maintenance and cleaning to ensure cleanliness and function. If burn marks appear in production, cleaning of the vent channels frequently solves the problems.

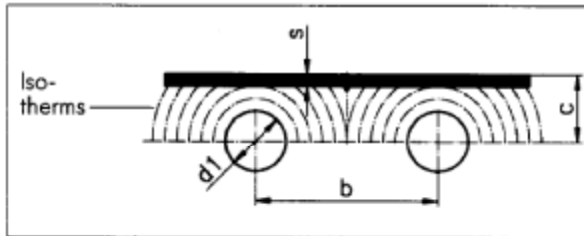


$D_1 - D_2 = 0.01 - 0.02 \text{ mm}$, $D_2 - D_3 = 1 - 2 \text{ mm}$
 $L_1 = 2 - 4 \text{ mm}$, $L_2 = 3 - 5 \text{ mm}$
 Relief channel should be as large as possible, should run up to the edge of the mould.

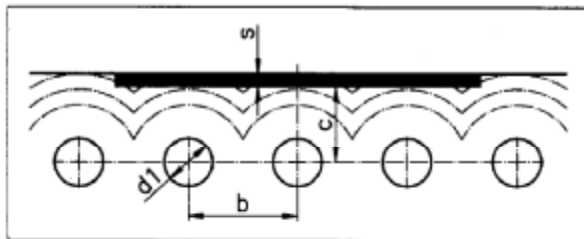
Venting is most important for the area of weld lines. Vents must help to exit the air volume compressed between the 2 melt fronts. In such areas, using vent gaps of 0.02 mm is recommended to help to improve the weld line strength.

Mould cooling

Cooling of the moulds is necessary to transport the heat energy brought into the tool by the molten polymer material. The target of the cooling is to provide the entire cavity and core parts of the mould with one uniform temperature. Any deviation in temperature uniformity will result in a risk of unbalanced part properties such as shrinkage, crystallinity and orientations of surface gloss marks.



Non-uniform heat removal



Largely uniform heat removal

In order to achieve a uniform mould surface temperature, the position and dimension of the cooling channels is a main driver for the temperature variations on the surface (number of isotherms).

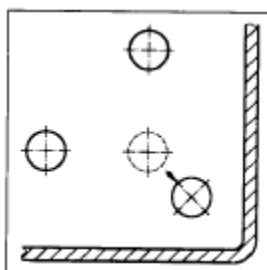
Cooling channels should be positioned close to the tool surface and close to each other.

Cooling systems can be calculated in the mould design phase and should be given priority over the design of the ejector system (first cooling, then ejectors).

With reference to the above pictures, the following guidelines for cooling channels can be applied:

| | Channel diameter |
|--------------------------------------|------------------|
| $s \leq 2 \text{ mm}$ | 8 - 10 mm |
| $s \leq 4 \text{ mm}$ | 10 - 12 mm |
| $s \leq 6 \text{ mm}$ | 12 - 15 mm |
| $C = (2 - 3) d_1 \quad b \leq 3 d_1$ | |

In mould corners, more heat will be collected and needs to be removed by the cooling system.



Cooling bores must be at least 8 mm in diameter, but larger channels are preferred, as the pressure drop will stay on lower levels. Cooling systems with more than one circuit offer a locally adaptable cooling power. This is needed if there is a unbalanced heat dissipation in the mould (locally higher wall-thickness, corners). The length of the cooling channels should be kept as short as possible so that the temperature increase between entrance and exit is kept below 5°C (precision parts 1°C).

Ejection / mould release

The following table shows the most frequently used ejection systems in moulding:

- ejector (knock-out) pins (round, flat, etc.)
- ejector sleeve
- ejector plate or stripper plate
- pneumatic ejector

LFT parts do not require special equipment regarding demoulding of the parts. The shrinkage is slightly more isotropic and will cause less warpage. As the mechanical performance at elevated temperatures is higher than conventional moulding compounds, parts can be ejected slightly earlier at higher temperatures of the parts.

General guidelines for ejector pins (most commonly used):

1. If possible, do not position ejector pins in visible areas of the part
2. Position ejectors in areas of the highest mould release forces, e.g. on ribs, corners and side walls
3. The free length of ejectors should be kept as short as necessary to limit the risk of break
4. Use pin retraction systems rather than pushing ejectors back by the mould closing stroke
5. Use a sufficient number of ejectors to spread the ejection forces to a wide area of the part
6. Profiled ejectors must be secured against twisting

Ejection plates

The great advantage of ejection plates is the full support of the moulded part reducing the stress to the part and the mould release forces.

Ejector plates are more expensive than pins and are most commonly used for parts with even parting lines and thin wall geometry.

Pneumatic ejectors

Pneumatic ejectors are commonly used as additional support to mechanical systems and to create a slight air cushion between mould and part.

Maintenance of injection moulding equipment

Injection moulding tools must be serviced after use. Vents, ejector systems, moving mould parts, cores and runner systems must be cleaned. Corrosion protection of the tool parts by applying appropriate sprays is recommended.

Mould design

Mould design is the most important factor for a flawless and reliable production. EMS will provide recommendations and technical support in the mould design phase. Please contact our specialists.

Some general guidelines for a good mould design are listed below:

- Wall thickness should be as thin as possible (but at least 1,6mm) and must be as big as necessary
- No melt volume accumulation (thick sections)
- Wall thickness should remain constant, however, if changes are appropriate for the part design, design smooth thickness transitions into the part
- Ribs will stiffen the part but will increase the risk of warpage and of visible sink marks. Mould draft angle for ribs should have 0,5 - 2°, rib height 3 times the wall thickness, ribs as thin as possible, maximum 0,4 - 0,6 times the wall-thickness
- Bosses can be used instead of ribs to stiffen parts, less stress concentration and no risk of sink marks
- Sufficient draft angles should be applied wherever possible for the outer as well as for the inner surfaces and for slider parts.
- No undercuts should be designed
- Do not position the gate in area of the highest stresses to the part, use sufficient cross sections for gates (> 0.8 times maximum wall-thickness, for LFT as well as for conventional materials)
- Gate should be located at the area of the maximum wall-thickness
- High gloss surface finishing only in required areas
- Provide the mould with sufficient support area of the machine platens

Injection moulding process

Form of delivery

LFT materials are delivered as pellets with a length of 10 mm. Each pellet is reinforced by individually impregnated fibres that have the same length as the pellet itself.

Grilamid, Grivory and Grilon products are packed dry, ready for moulding as bagged material or in octabins. Drying will become necessary in case of opened or damaged packaging units.

Drying of moist granules

Material that was able to pick up moisture can be re-dried. Recommended conditions:

| Drier | Drying temperature | Drying time |
|---------------|--------------------|--------------|
| Dry-Air dryer | 80°C | 4 - 12 hours |
| Vacuum dryer | 80°C - 100°C | 3 - 6 hours |

The use of circulating hot air ovens is not recommended.

- The drying time is strongly dependent on the amount of moisture content of the material. In case of doubts, dry up to 12 hours.
- Temperatures higher than 80°C will lead to a yellowing of the material (except vacuum dryer).

In order to avoid moisture pick-up during processing, the following points should be followed:

- Remaining granules should be stored in air-tight containers
- Residence time inside the hopper should stay below 1 hour
- Dry-air filters should be used in hot-humid climate conditions
- Do not open cold material containers inside normal temperature environment as the granules will act as condensation points (bring containers into production some hours before use)
- Empty machine hopper and store material air-tight in case of production stops

Effect of moist granules

Processing humid material will develop a risk of polymer degradation followed by a decrease of mechanical properties and surface quality of the parts.

Humid material shows warning signs in production by:

- silvery streaks on the surface of the parts
- bubbles or foam in the purged material

Processing temperatures for long fibre reinforced polyamides

Melt temperature

The true melt temperature may vary from the temperature settings of the barrel. Influences can be caused by:

- screw speed during metering stroke
- back pressure settings
- residence time of the melt in the barrel
- viscosity of the melt
- tolerances between screw and barrel, inside return valve dimensions

The melt temperature can also increase by shear inside the runner, especially the gate and even in the cavity itself. Small runner and gate cross-sections can lead to a thermal degradation of the material.

Grivory, Grilamid and Grilon LFT materials exhibit excellent thermal stability. Depending on the production process (residence time) and the part (wall-thickness, flow length), these materials can well be processed at the upper temperature limits.

The LFT polyamides show significantly enhanced thermo-mechanical properties and will keep their strength at very high temperatures. It is hence very important to heat the pellets already in the feed zone to their melting temperature. The compression and the metering zone should only serve as second step heating to further increase the melt temperature to the processing level.

The true melt temperature is not indicated by the barrel temperature reading. Make sure, that the temperature indicated in the compression zone stays below or at the set temperature.

Temperature indications above the set level are a hint for excessive shear in the compression zone by insufficient temperature of the pellets entering the metering zone.

Cylinder temperature

The standard temperature settings will show an increasing profile from the hopper to the barrel tip and nozzle.

With increasing shot volume it is advised for long fibre reinforced polyamides to change to a rather flat temperature profile and even inversed settings to ensure sufficient heat (without shear) is transferred into the granules before they enter the compression zone.

Please set the hopper cooling to temperatures of 80°C to 100°C to avoid cooling down of the pellets off the dryer systems. This will save energy and ease the heat flow into the pellets within the feed zone.

Nozzle temperatures should be set to a level to avoid cold slugs formed in the nozzle tip as well as to overheat and to let material flow off the tip by low viscosity (open nozzle).

Recommended temperature settings as a function of the dosing stroke (relative to the screw diameter):

| Grivory GVL | Dosing stroke (of screw diameter) | | |
|------------------|-----------------------------------|---------------|---------------|
| | <=1 d | 1 - 2 d | >= 2 d |
| Hopper base | 80°C - 100°C | 80°C - 100°C | 80°C - 100°C |
| Feed zone | 290°C | 300°C | 310°C |
| Compression zone | 300°C | 300°C | 305°C |
| Metering zone | 310°C | 300°C | 300°C |
| Nozzle | 300°C | 300°C | 300°C |
| Mould | 80°C - 120°C | 80°C - 120°C | 80°C - 120°C |
| Melt | 290°C - 310°C | 290°C - 310°C | 290°C - 310°C |

| Grivory HT1VL | Dosing stroke (of screw diameter) | | |
|------------------|-----------------------------------|---------------|---------------|
| | <=1 d | 1 - 2 d | >= 2 d |
| Hopper base | 80°C - 120°C | 80°C - 120°C | 80°C - 120°C |
| Feed zone | 340°C | 345°C | 350°C |
| Compression zone | 345°C | 345°C | 350°C |
| Metering zone | 350°C | 345°C | 345°C |
| Nozzle | 340°C | 340°C | 340°C |
| Mould | 140°C - 170°C | 140°C - 170°C | 140°C - 170°C |
| Melt | 340°C - 350°C | 340°C - 350°C | 340°C - 350°C |

| Grilamid LVL | Dosing stroke (of screw diameter) | | |
|------------------|-----------------------------------|---------------|---------------|
| | <=1 d | 1 - 2 d | >= 2 d |
| Hopper base | 80°C - 100°C | 80°C - 100°C | 80°C - 100°C |
| Feed zone | 270°C | 280°C | 290°C |
| Compression zone | 280°C | 280°C | 285°C |
| Metering zone | 285°C | 280°C | 280°C |
| Nozzle | 280°C | 280°C | 280°C |
| Mould | 80°C - 120°C | 80°C - 120°C | 80°C - 120°C |
| Melt | 280°C - 290°C | 280°C - 290°C | 280°C - 290°C |

| Grilon TSGL | Dosing stroke (of screw diameter) | | |
|------------------|-----------------------------------|---------------|---------------|
| | <=1 d | 1 - 2 d | >= 2 d |
| Hopper base | 80°C - 100°C | 80°C - 100°C | 80°C - 100°C |
| Feed zone | 290°C | 300°C | 310°C |
| Compression zone | 300°C | 300°C | 305°C |
| Metering zone | 310°C | 300°C | 300°C |
| Nozzle | 300°C | 300°C | 300°C |
| Mould | 80°C - 120°C | 80°C - 120°C | 80°C - 120°C |
| Melt | 290°C - 310°C | 290°C - 310°C | 290°C - 310°C |

The above temperature recommendations can be used for products with 50% long glass fibre reinforcement. With increasing or decreasing fibre loadings, these temperatures can also be increased respectively decreased.

Detailed recommendations per product can be found in the individual data sheets

Mould temperature

The mould temperature is decisive for the quality of the moulded article.

Higher mould temperatures will lead to easier cavity filling, less shear in the part and less post-shrinkage. Higher mould temperatures can significantly improve the surface quality. A correct level of crystallinity requires sufficient mould temperatures well above the glass transition temperatures of the polymers. For parts that will be submitted further thermal processes (sterilisation, printing, painting,...), mould temperatures at the high end of the above ranges are mandatory to avoid post crystallisation and warpage.

Mould heating can be obtained by using heating systems operated by water (without pressure up to 95°C, pressurised up to 160°C) or oil (up to 265°C).

Guide values for the necessary heating performance of mould heaters (water for mould temperatures of 80°C - 120°C):

| Mould weight | Heating performance |
|----------------|---------------------|
| ≈ 100 - 250 kg | 3 - 6 kW |
| ≈ 1000 kg | 6 - 9 kW |
| ≈ 2000 kg | 9 - 12 kW |

Cleaning of the injection unit

During longer machine stop times (>15 minutes), it is recommended to purge the injection unit with a glass fibre reinforced PA6 or PA66 and to lower the temperatures to a stand by level. This avoids material decomposition in the barrel and the risk of a contamination for the following production.

Purging the barrel

Before the start of a production run, the barrel should be sufficiently purged to remove material with long residual time inside the barrel. LFT polyamides will show a dull, rope-like appearance when purged. The surface will be very rough showing fibres that are already self-supporting.

Do not try to achieve a shiny and smooth surface, as this will be an indicator of damaged fibre length.

Injection and holding pressure, injection speed

In the dynamic filling phase for long fibre reinforced polyamides, try to use speeds as slow as the filling process and the required surface quality will allow.

Ensure, that without any holding pressure, that part is filled by at least 95% before changing to the holding phase.

The holding pressure and -time must be set to a level of constant part weight. This can be checked by increasing the holding pressure step by step until the part weight does not change any more. The holding time can be verified by decreasing the holding time up to a beginning loss of part weight and slightly increasing this time again.

As a rule of thumb for many parts, the holding pressure should read about 60% of the pressure necessary to fill the cavity.

The changeover from filling to holding can be controlled by:

- screw position (most commonly used)
- pressure switches (hydraulic or cavity pressure)
- thermocouples at the end of filling (best accuracy)
- time (not recommended)

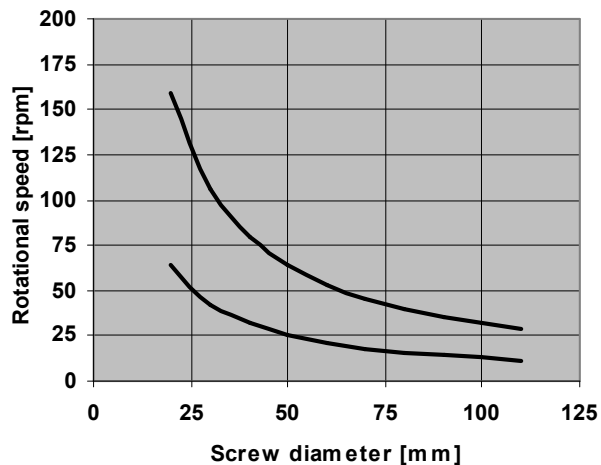
Screw speed / back pressure

The screw speed should, as for all polyamides, be set in a way to fully utilise the available cooling time for the dosing stroke.

Low screw speeds will help to avoid excessive shear with uncontrolled temperatures as well as fibre damage. Machine wear will also remain low if the screw is allowed to rotate at moderate speeds.

The backpressure should also be set to low levels, just enough to ensure sufficient degassing of the pellets and the melt and to ensure a constant amount of molten material before the start of the injection.

Recommended screw speeds for processing long fibre reinforced polyamides:



Cooling time

The cycle time is significantly influenced by the holding and the cooling time. Holding time must be set to ensure a constant part weight (see above). The cooling time can be estimated by the following guideline:

$$t_k = (2 \text{ to } 3) s^2 \quad (s = \text{wall thickness})$$

For further information, please contact our specialists.

Use of regrind

The use of LFT regrind is not recommended for molding other LFT parts as the average fiber length will decrease due to the grinding. However, the use of LFT regrind in standard material processing up to 10% should not be critical.

Golden rules for processing LFT polyamides

1. Ensure pellets are in melt stage when entering the compression zone
2. Use flat or even decreasing temperature profiles with short feed zone screws or shot volumes starting 1 to 1,5 d dosing stroke
3. Tend to work with the higher end of the temperature range to ease injection, to reduce shear in the melt and to lower internal stresses due to high pressure
4. Wear will be at comparable or even slightly lower level than equivalent short fibre compounds due to less fibre ends in the melt. Use through hardening steels to prevent corrosion and wear for long mould life-time
5. Ensure mould temperature is at the recommended level, prefer hot moulds to ease filling with low shear and pressure and to improve surface finish
6. Position gate in the area of highest wall-thickness, but always away from the areas of maximum stresses in the part to allow the fibres to orient in the desired direction
7. Use sufficient runner and gate sizes, gate 80% of the maximum wall-thickness or even larger (wider) to reduce shear and fibre breakage as well as to ensure good control in the holding phase. LFT polyamides will process very well in good hot-runner systems (prefer externally heated open systems, no needle valve shut-off)
8. Tend to a rather slow cavity filling to limit the shear inside the cavity and to avoid temperature peaks due to high shear in the runner and gate
9. Ensure sufficient venting of the tool especially at the filling end and in areas of potential weld lines
10. Optimise and control the holding phase to ensure constant part weight

The recommendations and data given are based on our experience to date. No liability can be assumed in connection with their usage and processing.

Domat/Ems, July 2011





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