Guide Injection Molding EMS–Polyamides

Grilamid (PA12, amorphous PA)

Grivory (semi-aromatic PA)

Grilon (PA 6, PA 66)

Grades of Grilamid, Grivory and Grilon can be processed in an economical way using conventional injection molding equipment and injection molds suitable for thermoplastics, to produce shaped articles.

This technical data sheet provides information about the most important components of an injection molding machine and the design of injection molds for polyamides. Important information about the injection molding process is also given.

EMS-GRIVORY

Table of contents

1. Injection Molding Machine

The following is concerned only with the components of screw injection molding equipment important for the correct processing of Grilamid; Grivory and Grilon injection molding materials.

1.1 Injection Unit

Screw

The common standard 3-zone screws with an L/D ratio of 18:1 to 22:1 and a thread depth ratio of 2:1 to 2.5:1 have proven themselves.

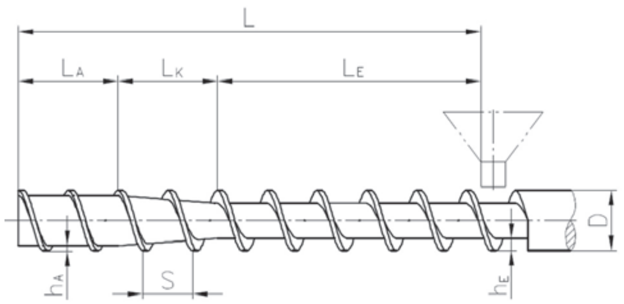


Figure 1: Geometry of a 3-zone screw

L_E	feed zone (50 – 60%)
L_K	compression zone (20 – 25 %)
L_A	discharge zone (20 – 25 %)
S	screw pitch 0,8 – 1,0 D
h_A	thread depth discharge zone
h_E	thread depth feed zone
L	screw length
D	screw diameter

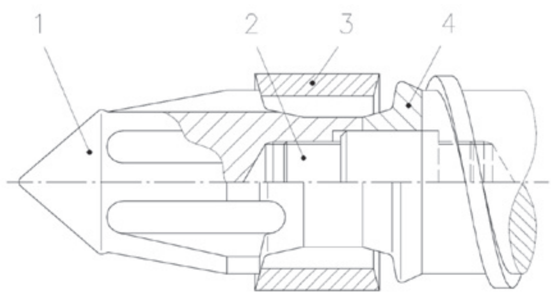
Thread depth and thread depth ratio (Guide values for polyamides)

Screw diameter D	Thread depth feed zone h_E amorphous	Thread depth feed zone h_E semicrystalline	Thread depth discharge zone h_A	Thread depth ratio amorphous	Thread depth ratio semicrystalline
[mm]	[mm]	[mm]	[mm]		
30	4.3	4.3	2.1	2.0 : 1	2.0 : 1
40	5.4	5.4	2.6	2.1 : 1	2.1 : 1
60	7.4	7.4	3.4	2.2 : 1	2.2 : 1
80	9.1	7.6	4.0	2.3 : 1	1.9 : 1
100	10.8	9.1	4.6	2.4 : 1	2.0 : 1
120	12.0	10.4	5.0	2.4 : 1	2.1 : 1
150	14.0	11.0	5.6	2.5 : 1	2.0 : 1

Back Flow Valve

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

Ring back flow valves are standard. However, there are also special back flow valves for certain materials and applications, such as ball & multi-ball and force control non-return valves.



1. Tip
2. Bolt
3. Valve ring
4. Pressure ring

Figure 2: Ring back flow valve

Cylinder
The heat necessary to melt the plastic is supplied via the cylinder although a certain amount of warmth is created during metering by friction between the melt and the screw of cylinder walls. The length of the cylinder should be divided into three heating zones whereby each heating zone should be controlled by its own separate thermocouple. The heating performance of these heating zones should be between 3 and 5 W / cm^2 allowing temperatures up to 400 °C.

Materials for Screw, Barrel and Back Flow Valve

	Wear-resistant	High wear-resistant
Screw	High chromium steel e.g. X155CrMoV12 1 (1.2379) or X230CrVMo13 4 (1.2380)	High-alloy PM (powder metallurgical) steel e.g. Böhler M390 Microclean
Cylinder	Bimetal cylinder	Tungsten carbide (WC) reinforced bimetal cylinder
Back flow valve	High alloy tool steel	High-alloy PM (powder metallurgical) steel e.g. Böhler M390 Microclean
Application area	Unreinforced polyamides or with filler content < 30 % and low corrosion tendency	Polyamides with high filler content (≥ 30 %) and increased tendency to corrosion

For the designs, we recommend contacting the respective machine supplier. Depending on the requirements, an additional PVD coating makes sense.

Nozzle
Generally speaking, both open and shut-off nozzles can be used for processing of Grilamid, Grivory and Grilon injection molding grades. From the material point of view, open nozzles are being preferred to shut-off ones.

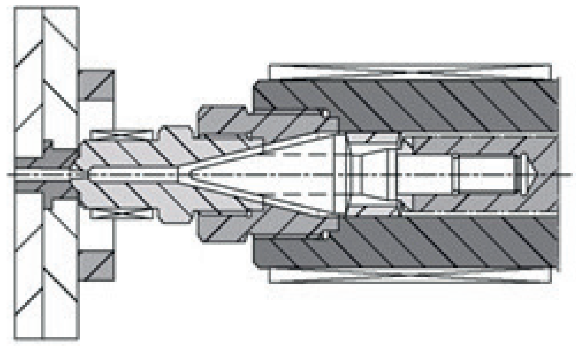


Figure 3: Open nozzle

- \+ easy flow of melt
- \+ easy cleaning
- – filament formation/melt freezing
- – escape of melt
- – no nozzle retraction

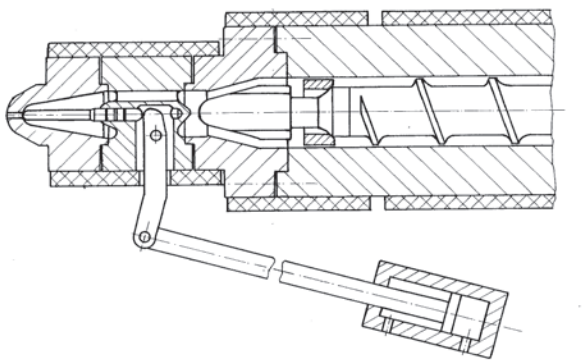


Figure 4: Needle shut-off nozzle

- \+ metering after nozzle retraction
- \+ closed system
- \+ no filament formation/melt freezing
- – reduced flow channel
- – friction, melt flow standstill

Transition from sprue bush/machine nozzle

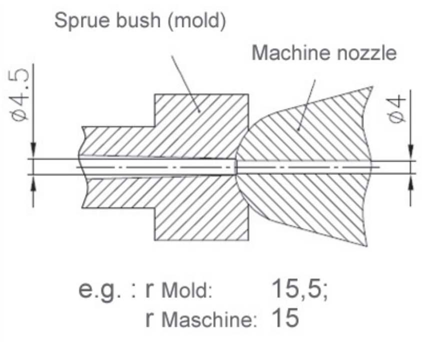


Figure 5: Radius nozzle

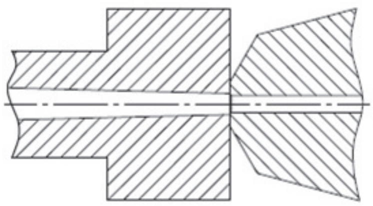


Figure 6: Flat nozzle

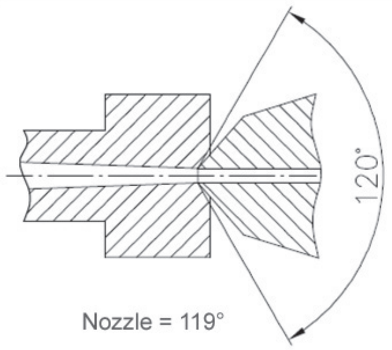


Figure 7: Cone-shaped nozzle

Radius nozzles

With radius nozzles the radius of the mold nozzle must be slightly larger than the radius of the machine nozzle ($R_W > R_M$). This decreases the contact are, increases the intensity of face pressure and prevents undercutting; the nozzle becomes automatically centered.

Flat nozzles

Flat nozzles are simple to manufacture and can easily be copied. However, they do not become centered automatically to the mold nozzle. If the bores are off-set, undercuts are caused and flow resistance increased.

Cone-shaped nozzles

Nozzles with cone-shaped contact surfaces are easy to copy and become centered automatically. Taper angles of 120° for sprue bush and 119° for the nozzle are usual.

Details concerning material selection and design of screw, nozzle, back flow valve, barrel and nozzle must always be coordinated with the injection molding machine supplier.

2. Injection Mold

The injection mold is of importance for the complete injection molding process. Only a correctly designed mold layout can guarantee:

- molded articles of the required quality
- undisturbed production
- short cycle times
- long life-expectancy for the mold
- the predetermined properties of the material
- economical manufacturing

Design or construction mistakes can be compensated to some extent by the adjustment parameters of the injection molding machine, but this limits the processing leeway and may have a negative influence on the points listed above. The usual guidelines for conventional molds for use with thermoplastics materials are valid for the mold design layout. An effective mold internal pressure of maximum 800 bar can be taken as a guide value for mechanical loading (bending, compression). Normal, abrasion-resistant construction steel (hardened to approx. 50 – 65 HRC) is sufficient for the mold areas.

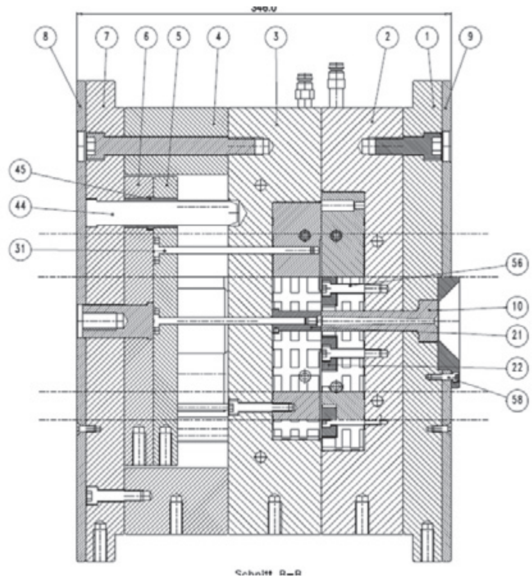


Figure 8: Injection mold

Runner and Gating System

Cold-runner system

Precise dimensioning and design of the runner are therefore very important for both the quality of the molded article and the cost factors of its manufacture. The following review shows a comparison of conventional channel cross-sections.

Circular channel

Advantages:

Lowest surface are in relation to the cross-section, lowest cooling rate, lowest heat and friction loss, the melt material solidifies/freezes last in the center of a round channel, thereby creating good post-pressure influence

Disadvantages:

Must be incorporated into the same area of both mold halves – difficult and expensive

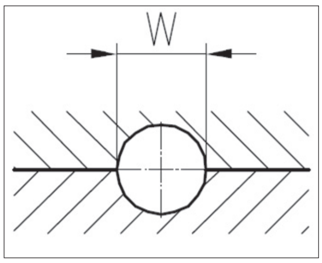


Figure 9: Circular channel

Parabolic-shaped channel

Advantages:

Good approximation of a round channel, simpler manufacture as it must be incorporated in only one half of the mold (ejector side for mold release reasons). Used when the disc must be removed in relation to the mold parting line.

Disadvantages:

Greater loss of heat and more waste production in comparison to a round channel

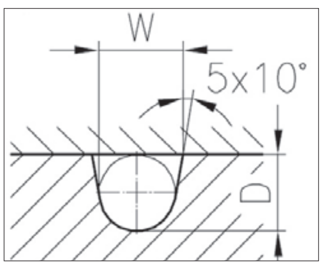


Figure 10: Parabolic-shaped channel

Trapezoidal-shaped cannel
Alternative solution to use of a parabolic-shaped channel

Disadvantages:
Greater loss of heat and more waste production in comparison to a round channel

The following values are valid:

Diameter of runner = 1,4 x greatest wall thickness of part
- minimum diameter 4 mm
- maximum diameter approx. 12 mm

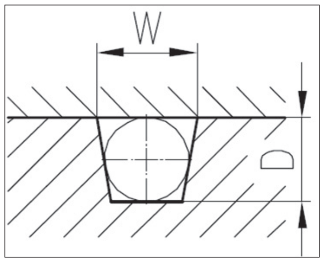


Figure 11: Trapezoidal-shaped cannel

Hot-runner system
A specialty among gating systems is the hot-runner system where the whole channel is heated and, therefore the melt material is kept in a melted state.

Advantages of a hot-runner system are:
- no post-treatment
- saving of sprue material
- simpler automation
- longer flow distances possible

Externally heated hot-runner systems have a particularly great advantage when used with thermally sensitive materials in that they provide an accurate temperature control. In addition they exhibit lower losses of pressure and can be balanced better. Only a material-related correct temperature setting guarantees an optimal functioning of the hot-runner channel system.

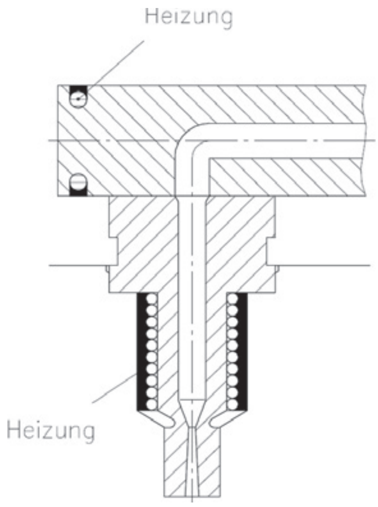


Figure 12: open hot-runner system

Hot-runner channel temperatures for EMS-GRIVORY polyamides	[°C]
Grilamid L / 1S / 2S / 2D unreinforced	240 – 290
Grilamid L reinforced	240 – 280
Grilamid TR / TR reinforced	260 – 300
Grivory G	270 – 310
Grivory HT	320 – 340
Grilon A/B unreinforced	240 – 280
Grilon A/B reinforced	250 – 300
Grilon TS unreinforced	270 – 300
Grilon TS reinforced	270 – 300

To start up the hot runner after shutdowns, the temperature may have to be increased briefly, depending on the system.

Gating

The gating is the transition from the runner into the mold cavity. The following diagrams show different gating systems.

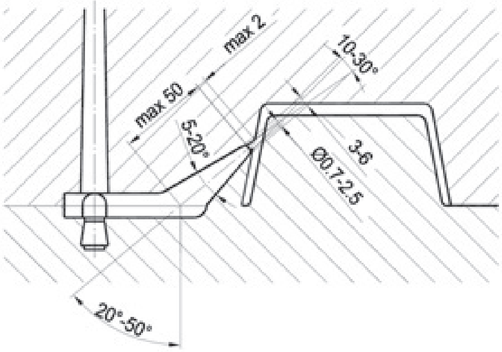


Figure 13: Tunnel gating

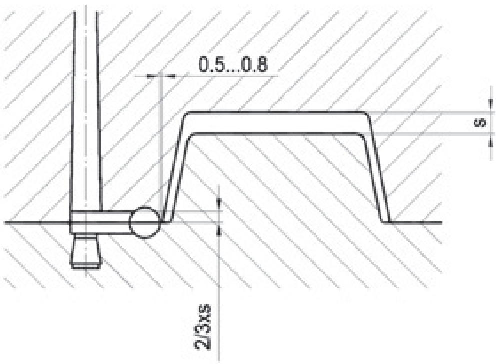


Figure 14: Film gating

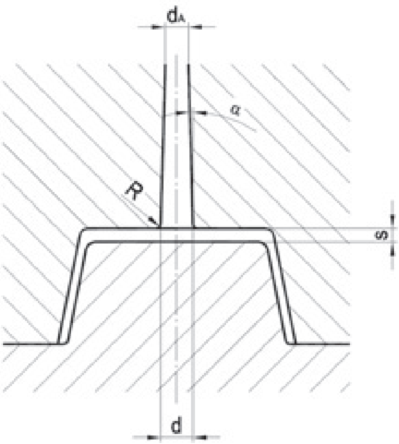


Figure 15: Direct gating

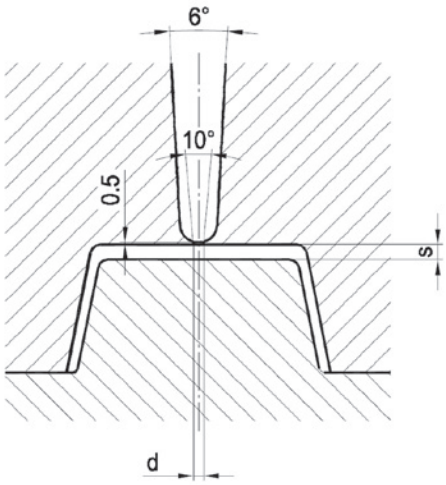


Figure 16: Pin-poinz gating

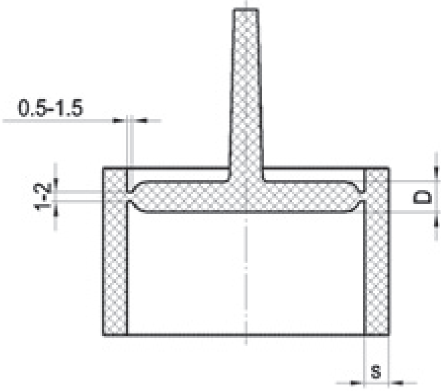


Figure 17: Ring gating

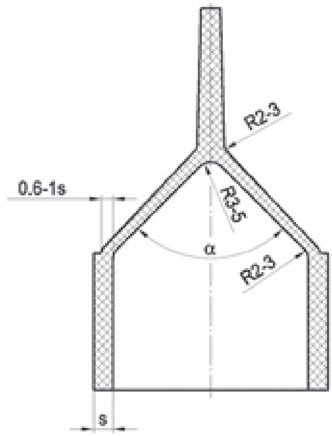


Figure 18: Diaphragm gating

Diameter of gate = 0,8 x greatest wall thickness of part

- minimum diameter 1,5 mm
- maximal approx. 2mm – dependent on the position of the ejector and the strength of the knife edge for tunnel gating

The position of the point gating should also lie in the area of the greatest wall thickness (mass accumulation). Free ejection should be avoided.

Material for Injection Molds

With the objective of high suitability for use, differing requirements are made of construction materials for production of molds.

- High wear resistance
- High resistance to corrosion
- High dimensional stability
- Good heat conduction capabilities

Through-hardened steels

Through-hardened steels such as the materials 1.2343 or 1.2767 have proven suitable for the processing of Grilamid, Grivory and Grilon materials. These steels exhibit a very good resistance to wear and can withstand high pressures, thus enabling very high numbers of shots to be reached.

Shortname	Material-Nr.	Hardness HRC	Comments
X38CrMoV51	1.2343	52 – 54	• Hot work steel, hardened, tough • ESU for high gloss polishing
X40CrMoV51	1.2344	52 – 54	• Hot work steel, hardened, tough
X155CrVMo121	1.2379	61 – 63	• Cold work steel, wear resistant
X45NiCrMo4	1.2767	52 – 54	• Cold-hot work, hardened, good polishability

Corrosion-resistant steels

It is therefore recommended to use corrosion-resistant steels for corrosive materials. Nitriding of corrosion-resistant steels should generally be avoided because of the associated deterioration in corrosion resistance.

Shortname	Material-Nr.	Hardness HRC	Comments
X42Cr13	1.2083	48 – 52	• Cold work steel, corrosion resistant, good polishability
X38CrMo17	1.2316	~ 40	• prehardened tool steel, corrosion resistant, good polishability

The listing of tool steels is freely chosen. We always recommend contacting plastic mold steel specialists, especially for special steels.

Surface Treatment

Different protective surface coatings are used as a solution to problems of wear, abrasion and corrosion. Apart from the well-known thermos-chemical (nitriding, boriding) and galvanization methods (hard chromium plating, nickeling), thin-layer metallurgy methods such as CVD (chemical vapor deposition) and PVD (physical vapor deposition) are used.

PVD coatings have become established for injection molds.

Address for coating:

Oerlikon Balzers Coating AG
Iramali 18
LI-9496 Balzers
www.oerlikon.com/balzers

Technologies of Oerlikon	CrN	CrN-OX	AlCrN	TiAlN
Hardness (HV 0.05)	2.500	2.500	3.200	3.400
Layer thickness [µm]	4 –10	4 –10	2 – 4	8 – 12
Max. Application temp. [°C]	700	700	1100	900
Coating temp. [°C]	250 – 450	250 – 450	470	450
Coating color	silver-gray	rainbow	blue-gray	purple-gray
Coating structure	multilayer	multilayer & top coat	monolayer	nanostructure
Abrasion	++	++	+++	+++
Adhesion	++	+	+	+
Corrosion	++	+	++	++
Demolding	++	+	++	+
Mold filling	+	+	+	++
	+ = conditionally suitable	++ = well suitable	+++ = very well suitable	

Draft Angle for Part Demolding

Demolding forces are created by shrinkage, adhesion, sticking or a vacuum-effect. Draft angles help or allow good demold ability.

The draft angle for unreinforced polyamides must be ≥ 0.5° and for reinforced polyamides ≥ 0.75°.

VDI 3400 [CH]	12	15	18	21	24	27
Roughness Ra [µm]	0.4	0.56	0.8	1.12	1.62	2.2
Draft angle [°]	1	1	1	1	1.5	1.5
Surface (ISO/TC 213)	*N5*		*N6*		*N7*	

VDI 3400 [CH]	30	33	36	39	42	45
Roughness Ra [µm]	3.2	4.5	6.3	9	12.6	18
Draft angle [°]	1.5	2	2.5	3	4	5
Surface (ISO/TC 213)	*N8*		*N9*		*N10*	

Mold Venting

During filling, the melt must be able to displace the air in the mold cavity as quickly as possible. Trapped air prevents complete filling of the mold. Due to the strong compression, enclosed air becomes heated, which can lead to burning of the melt. As polyamids are among the most "diesel-sensitive of plastic materials, good venting of the molds is extremely important.

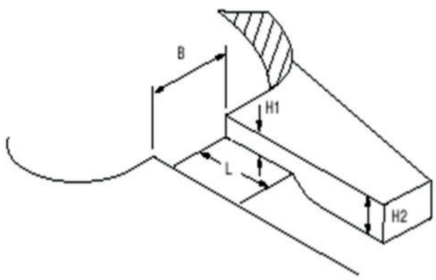


Figure 19: Venting via parting line

The air should always be displaced towards the mold parting line. If this is not possible, additional parting joints must be incorporated.

Vents can also be created by cleverly positioning separate plugs or insert or by using plastic venting pins. A proven method is to place an ejector knock-out in the right position.

The tolerance combination H7/g6 allows an optimal venting. In order for this to work efficiently, a collection channel must be positioned behind the venting gap in the ejectors.

When working with polyamides, the vents (H1) should not be larger than 0,02 (0,03) mm. Their length (L) should be 1,5 to 2,5 mm after which they join the collection channel with a larger cross-section (H2 = min. 0,5 mm).

Venting systems must be given regular maintenance and be kept well cleaned for them to work correctly.

Mold Cooling

Cooling of mold is carried out in order to create the most even temperature distribution possible over the entire surface are of the mold cavity. High quality levels for molded parts can only be reached if the injection mold is well designed with regard to temperature distribution.

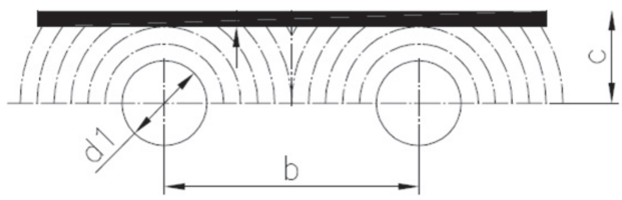


Figure 20: Non-uniform heat removal

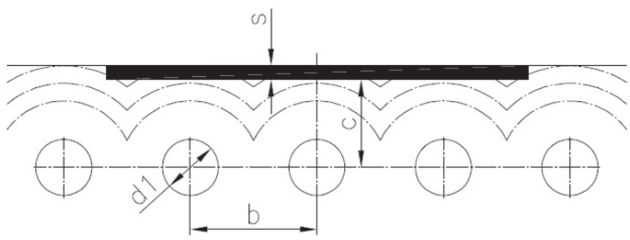


Figure 21: Uniform heat removal

The difference in cooling levels can be seen by the isotherms. Consequently, cooling channels should be placed as close as possible, i.e. as close as stressing of the mold construction material allows, to the structure surface of the mold. They should also be placed close together.

The following guide values are valid:

Wall thickness	Channel diameter d1	Comments
s ≤ 2mm	8 – 10 mm	c = (2 - 3) x d1 b ≤ 3 x d1
s ≤ 4mm	10 – 12 mm	
s ≤ 6mm	12 – 15 mm	

During mold design and construction, cooling should be given priority over ejector systems.

In corners, analogue to melt collection, more warmth must be removed meaning that more cooling is necessary.

Cooling systems with more than one cooling circulation systems allow more freedom of action during processing, particularly when producing molded articles with differing wall thicknesses. The length of a cooling circulation system should be limited so that the temperature increase between entry and exit is maximum 5°; for precision parts, 1°.

In order to achieve a surface temperature of the mold area that is as uniform as possible, the cooling channels should be designed in such a way that the cooling medium is supplied in the area of the gates and discharged at the end of the flow path.

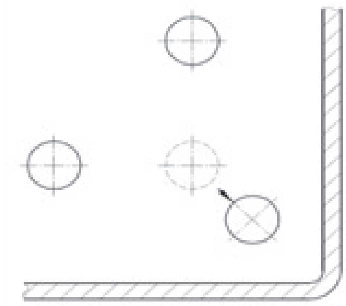


Figure 22: Additional heat-dissipation at corners

Demolding

The following list gives the most widely used methods of mold release systems:

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

Ejector pins

The most commonly used conventional method is the use of ejector pins. Reasons for this are costs and the simple, effective method of installation. What should be taken into consideration with regard to mold release during the design and construction of a mold?

1. Wherever possible, these should not be placed on visible areas as their indentions can nearly always be seen.
2. They should be placed in positions where the largest mold-release resistance is formed e.g. on ribs (rib junctions), corners and side walls.
3. If flat ejectors are used, the danger exists of them bending and/or breaking. For this reason their free lengths should be kept as short as possible.
4. Push-back pins and pull-back springs should be used for a safe return of the ejector before the mold is closed (safety measure).
5. A high number of ejectors provide even and optimum force distribution leading to a lower tendency of the molded part to warp.
6. Profiled ejectors should be secured against twisting.

Ejection sleeves

These provide the additional advantage of good venting for round parts.

Ejection plate

These have the great advantage that they work over a large are. This greatly reduces the specific mold-release pressure on the part. However, this solution is more expensive than using ejector pins. It is used during the production of parts with a simple geometry.

Pneumatic ejectors

Pneumatic ejectors are often used in combination with ejector pins or plates. During their use a small "cushion" of air may be formed e.g. between the mold and the injection part. This reduces friction and, therefore, the necessary ejection force (e.g. filter cups).

Injection Mold Maintenance

Injection molding molds must be serviced after use. Vents, ejector system, sliding plates, cores etc. must be cleaned. The mold must also be sprayed with a protective substance to prevent corrosion. This is also recommended during longer down-times of the machine e.g. over night.

Mold Design

Mold design is actually a completely separate subject. The following gives a list of the most important rules which must be followed in order to obtain a mold design suitable for use with plastic materials.

- The wall thicknesses should be as thin as possible and as thick as necessary.
- Avoid mass accumulation.
- Provide uniform wall thicknesses. As few wall thickness changes as possible, no abrupt changes in wall thickness.
- All corners and edges are to be rounded off ($R \leq 0.6 \times s$; s = wall thickness).
- Ribs stiffen the structure, but bring the risk of warpage and sink marks (draft angles of approx. 0.5 – 2°, height approx. 3 x wall thickness, rib width at the foot approx. 0.4 – 0.6 x wall thickness).
- Ribs can also be avoided by grading (steps, corrugation, spiders etc.).
- Sufficient mold release angle angles for outer and inner surfaces, for ribs, bosses and grooves (approx. 0.5 – 2°). Larger draft angles are necessary for structured surfaces.
- Warping due to shrinkage differences should be minimized by suitable design (e.g. bowing, cambering).
- Avoid undercuts.
- Do not specify tighter tolerances than are necessary for the design to function.
- Highly polish only where necessary (cost).
- Transmission of forces must be taken into consideration.
- Defined supported surfaces.

3. Injection Molding Process

Delivery & Material Preparation

Grilamid, Grivory and Grilon are delivered ready for processing in different packaging forms, i.e. all materials have been pre-dried. Further drying before use in injection molding systems is not necessary as long as the packaging is not damaged or is unopened.

The recommended moisture content for processing of Grilon A/B/TS, Grivory GV & HT and Grilamid TR & L is described in the respective technical data sheet for the product.

Excessive moisture content in the granules can be detected by moisture meters.

Figure 23: Aquatrac Brabender

Figure 24:Hydrotracer Aboni

Conditions for drying of wet granules:

Drier	Drying temperature [°C]	Drying time [h]
Dry air drier 1)	80	4 – 12
Vacuum oven	80 – 100	4 – 10

1) Dewpoint min. -30 °C

The drying time is strongly dependent on the amount of moisture content of the material. In case of doubt, drying should be carried out for at least 12 hours (or overnight). Drying polyamides in circulating-air ovens can lead to problems (actual moistening of the material in high surrounding temperatures or high air humidity). We therefore recommend use of dehumidifying dryers or vacuum ovens. Temperatures higher than 80 °C lead to yellowing of the granules (not applicable for vacuum ovens).

In order to avoid moistening of the granules before and during processing, the following points should be followed:

- Remaining granules should be stored in air-tight containers.
- Residence time in the hopper should not be more than 1 hour.
- Hopper heating should be used.
- No containers with "cold" granules should be opened (containers should be stored in the molding are before processing – equalization of temperature).
- The feed hopper should be emptied at the end of processing or during long standing periods of the machine.

Drying of Polyamide in a circulating air drying oven is not recommended.

Effects of moist granules

Moist material can be identified during processing by:

- silvery streaking on the surface of the parts
- bubbles or foam in the melt cake or crackling during free ejection

In addition to a poor surface quality also losses in component properties are possible (material degradation).

Storage

Sealed, undamaged bags can be stored for years, protected from the weather. An exception applies to the Grilamid TR product family. Here, storage > 6 months should not be exceeded. The recommended storage location is a dry room in which the bags are protected from direct sunlight and damage.

Selection of Injection Molding Machine

The injection molding machine is selected according to the following criteria:

- Tool dimensions
- Shot volume
- Clamping force

Tool dimensions

For a suitable injection molding machine, the following must be taken into account: Tie bar distances (omitted for tie bar-less injection molding machine), maximum and minimum mold installation height, necessary mold opening path and ejection path.

Required shot volume

The shot volume determines the size of the injection unit. As a rule, this should be selected so large that 80 % of the maximum possible metering volume is utilized. The minimum metering stroke should be greater than the length of the non-return valve.

Clamping force

The clamping force must be greater than the buoyancy force in the mold generated during injection or holding pressure. The buoyancy force is calculated from the projected area of the molded part including the gating system multiplied by the effective cavity pressure. For technical parts made of Grilamid, Grivory and Grilon, a cavity pressure of 400 – 800 bar must be expected, depending on the flow path/wall thickness ratio. Since the projected area is often only approximately calculated, we recommend an additional safety margin of 10 %.

Processing Temperatures

Melt temperature

Without taking into consideration the control accuracy, the difference between cylinder temperature and melt temperature can be influenced by the:

a) speed of the screw, dynamic or back pressure during metering
b) residence time of the melt in the cylinder
c) diameter of the cylinder as its design
d) degree of wear on screw and cylinder

Cylinder temperatures

Normally, the temperature settings on the heating cylinder give a profile with an increase in temperature from the feed hopper to the nozzle.
The choice of nozzle temperature is dependent on its design but should be chosen so that thread formation at high temperatures and cold plugging at low temperatures can be avoided.

The temperature of the feed zone is controlled in such a way that

- no premature melting of the granules occurs
- no condensation occurs
- uniform and trouble-free metering is possible.

Mold temperature

The temperature of an injection molding mold is decisive for the quality levels of parts made of Grilamid, Grivory and Grilon. Temperature control is carried out using a mold heating system containing water (up to 95 °C, pressurized water up to 220 °C) or Oil (max. 250 °C) which circulates through bores in the mold. Water should be preferred to oil due to its better and more rapid heat transfer.

The device should be equipped with a controller which compensates heating of the mold during production. The tolerance control should not be more than ±3 °C.

Guide values for the necessary heating performance:

Tool weight [kg]	Heating capacity [kW]
~ 100	3 – 6
~ 1000	6 – 9
~ 2000	9 – 12

For semi-crystalline materials, the mold surface temperature should always be selected above the glass transition temperature (Tg) and above the service temperature. This reduces subsequent distortion due to post-shrinkage to a minimum.

Large molds should be equipped with separate tempering circuits on the nozzle and ejector sides. In all cases, it is important to maintain a uniform, constant temperature over the entire mold surface. Mold cores should also be tempered individually.

Especially if high mold temperatures are necessary (e.g. with Grivory HT), mold insulation significantly reduces the energy consumption for mold temperature control.

Temperature guidelines for the different product families

	Material type	Nozzle [°C]	Zone 1-3 [°C]	Feed [°C]	Mass [°C]	Mold [°C]
GRIVORY GV / HT	Grivory GV-2H – Grivory GV-6H Grivory GVX-5H – Grivory GVX-7H Grivory GVS-5H – Grivory GVN-35H Grivory GC-4H Grivory GM-4H Grivory G4V-5H	270 – 280	260 – 285	70 – 80	270 – 300	80 – 120
	Grivory HT1	330 – 340	330 – 345	80 – 100	330 – 345	≥140
	Grivory HT2	310 – 325	315 – 340	60 – 80	315 – 330	100 – 140
	Grivory HT3	305 – 320	300 – 325	60 – 80	300 – 330	110 – 160
	Grivory HT6	330 – 340	330 – 345	80 – 100	330 – 345	≥160

	Material type	Nozzle [°C]	Zone 1-3 [°C]	Feed [°C]	Mass [°C]	Mold [°C]
GRILAMID TR	Grilamid TR 50	280 – 310	260 – 310	60 – 80	280 – 320	80 – 120
	Grilamid TR 55	280 – 300	270 – 290	40 – 60	280 – 305	80 – 110
	Grilamid TR 55 LX Grilamid TR 55 LY Grilamid TR 55 LZ	240 – 260	240 – 260	40 – 60	250 – 270	40 – 60
	Grilamid TR 30 Grilamid TR 30 LS Grilamid TR 30 UVH	280 – 300	270 – 300	60 – 80	290 – 310	100 – 120
	Grilamid TR 90 Grilamid TR 90 LS Grilamid TR 90 UVH	260 – 280	250 – 280	60 – 80	260 – 280	60 – 80
	Grilamid TR 90 LX Grilamid TR 90 LXS	250 – 270	240 – 270	60 – 80	250 – 270	40 – 80
	Grilamid TR ICR 12	270 – 290	250 – 290	60 – 80	280 – 300	60 – 80

	Material type	Nozzle [°C]	Zone 1-3 [°C]	Feed [°C]	Mass [°C]	Mold [°C]
GRILAMID	Grilamid L	230 – 270	230 – 270	40 – 60	240 – 270	40 – 80
	Grilamid LV	260 – 290	250 – 290	60 – 80	270 – 290	60 – 100
	Grilamid 1S	260 – 290	250 – 290	60 – 80	270 – 290	60 – 100
	Grilamid 2S	260 – 290	250 – 290	60 – 80	270 – 290	60 – 100
	Grilamid 2D	250 – 290	250 – 290	60 – 80	270 – 290	40 – 80

	Material type	Nozzle [°C]	Zone 1-3 [°C]	Feed [°C]	Mass [°C]	Mold [°C]
GRILON	Grilon A	275 – 285	270 – 290		280 – 300	
	Grilon B	255 – 280	250 – 285	60 – 80	240 – 300	80 – 100
	Grilon TS / TSS	280 – 300	270 – 285		270 – 300	

	Material type	Nozzle [°C]	Zone 1-3 [°C]	Feed [°C]	Mass [°C]	Mold [°C]
LFT	Grilamid LVL	260 – 270	260 – 280		260 – 280	80 – 100
	Grilon TSGL	290 – 310	290 – 310	60 – 80	290 – 310	80 – 120
	Grivory GVL					
	Grivory HT1VL	330 – 340	330 – 345	80 – 100	330 – 345	140 – 160

Injection and Holding Pressure

The injection and post pressure is dependent on the material being used and the part to be produced. They must be chosen high enough to fill the cavity, to achieve the necessary surface quality and to prevent the formation of sink marks and voids.

The rate of injection is adapted to the size of part being produced and its design. It must be high when using glassfibre reinforced material. The injection pressure must be set high enough to ensure that the rate of injection does not fall below the chosen set values for the whole injection process.

	Injection	Compression	Holding Pressure
Quality features	Surface Gloss Orientation Distortion (Warpage) Crystallinity	Illustration of surface Flashes Weight Dimensions	Weight Dimensions Shrinkage Distortion (Warpage) Voids/Sink marks Orientations
Processing conditions	Injection speed Cylinder– + Mold temperatures	Change-over point Cylinder– + Mold temperatures	Holding pressure Holding pressure time Cylinder– + Mold temperatures

For optimal processing, the correct change-over point from injection to hold-on must be taken into consideration. Stroke- and pressure dependent change-over have proven very successful.

General guidelines:

- Change-over by stroke: 0.1 – 0.2 x Metering stroke
- Change-over by hydraulic pressure: 2/3 x max. injection pressure
- Change-over by cavity pressure: 0.8 – 0.9 x max. internal pressure

Screw Speed & Dynamic Pressure

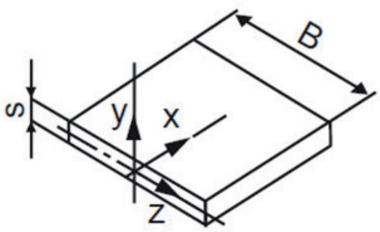
The speed of the screw should be chosen so that the circumference velocity of the screw lies in the range of von 0.05 to 0.3 m/s.
Calculation of the peripheral screw speed:

v = 2 * ¶ * r * n	v	Screw speed	[m/s]
	r	Radius of screw	[m]
	n	Screw rotation	[1/s]

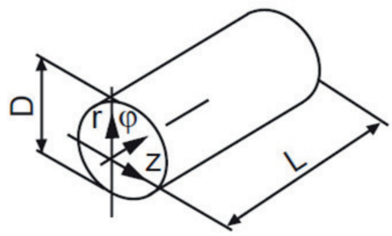
Specific dynamic pressures to support uniform melting and homogenization are between 100 – 150 bar. To compensate for low residual moisture, dynamic pressures up to 300 bar are possible.

Cooling Time

The cycle time is significantly influenced by the cooling time. The cooling time (holding pressure time + residual cooling time) can be quickly estimated with the following formulas.



$$t_K = \frac{s^2}{\pi^2 \cdot a_{eff}} \cdot \ln\left(\frac{8}{\pi^2} \cdot \frac{\vartheta_M - \overline{\vartheta}_W}{\overline{\vartheta}_E - \overline{\vartheta}_W}\right)$$



$$t_K = \frac{D^2}{23.14 \cdot a_{eff}} \cdot \ln\left(0.692 \cdot \frac{\vartheta_M - \overline{\vartheta}_W}{\overline{\vartheta}_E - \overline{\vartheta}_W}\right)$$

t_k	Cooling time	[s]
ϑ_E	Average demolding temperature	[°C]
ϑ_W	Average mold wall temperature	[°C]
ϑ_M	Mass temperature	[°C]

a_{eff}	Effective thermal diffusivity	[mm²/s]
s	Wall thickness	[mm]
D	Diameter	[mm]

The effective thermal diffusivity aeff is calculated as follows:

$$a_{eff} = \frac{\lambda \times 1000}{C_P \times \rho}$$

λ	Thermal conductivity of the melt	[W/(mK)]
C_P	Specific heat capacity	[J/(kgK)]
ρ	Density of the melt	[kg/dm³]

or can be taken from the CAMPUS database.

Metering Stroke

The following options are available for defining the metering volume or the metering stroke:

$$\text{Metering stroke } s_D \text{ [cm]} = 1.2 \times \frac{\text{Volume component + sprue [cm}^3\text{]}}{\text{Cross-sectional area of the screw [cm}^2\text{]}}$$

The factor 1.2 takes into account, on average, the difference between melt and solid density and the volume compression due to the pressure in the screw antechamber during the injection cycle.

The metering stroke should be in the range of 50 – 80 % of the maximum. In any case, the minimum metering stroke must be longer than the length of the non-return valve to ensure proper function.

Melt Cushion

The melt cushion depends on material and component size.
Melt cushion S_M = ~ 0.02 – 0.1 x metering stroke S_D

Calculation of the Dwell Time

$$t_V = \frac{1.2 \times V_H}{V_D} \times t_Z$$

t_z	Cycle time	[s]	
t_v	Dwell time	[s]	
D	Screw-ø	[mm]	
s_D	Metering stroke	[mm]	
V_D	Shot volume	[mm³]	$V_D=D^2*\pi/4*s_D$
s_H	max. possible metering stroke	[mm]	
V_H	max. possible shot volume	[mm³]	$V_H=D^2*\pi/4*s_H$

For more information, please contact your local EMS-GRIVORY sales representative directly.

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EMS-GRIVORY is the leading manufacturer of high-performance polyamides and the supplier with the widest range of polyamide materials. Our products are well-known throughout the world under the trademarks Grilamid, Grivory and Grilon.

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