

I N J E C T I O N M O U L D I N G

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**Rhodia**

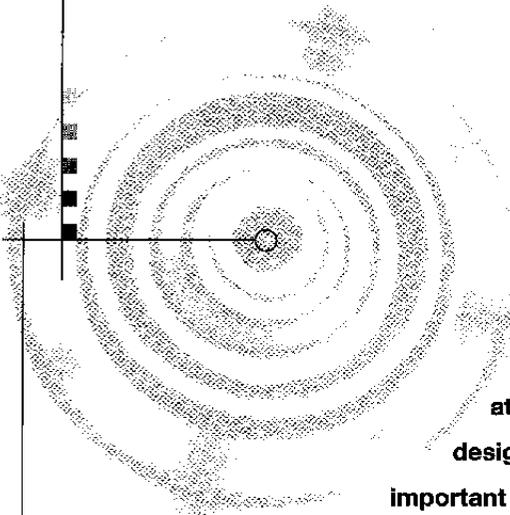
*Engineering Plastics*

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## RECOMMENDATIONS



However carefully polyamides are processed, the importance of the design of the part and the mould in the final result must not be forgotten. Particular attention should be given to the design of the mould, as it is the most important element in the production line.

Detailed information on the correct design of parts and moulds can be found in the "Part Design" brochure.

# PREPARING THE POLYAMIDE PRODUCTS

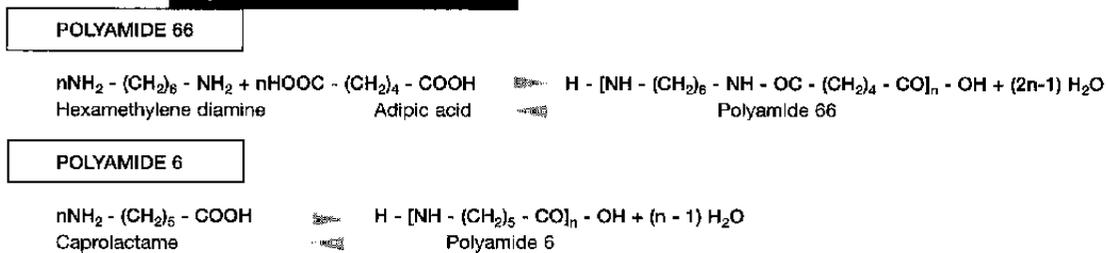
## 1.1. Action of water on polyamides

Polyamides are polycondensate and therefore need bifunctional monomers for their production, such as caprolactam for polyamide 6 - TECHNYL C - and copolyamide 66/6 - TECHNYL B, and hexamethylene diamine and adipic acid for polyamide 66 and copolyamide 66/6 - TECHNYL A and B. In these cases water molecules are eliminated through polycondensation (Figure 1.1). These reactions occur at high temperatures and under pressure.

As seen on Figure 1.1, polycondensations are equilibrated reactions.

Figure 1.1

Polycondensation of PA 66 and PA 6



Conditions for the polycondensation to occur are also met during the injection moulding process. With an excess of water in the polyamide granules, hydrolysis «degradation» of the polymer will take place, because the equilibrium reaction is displaced to the left (referring to Figure 1.1).

It is thus very important for TECHNYL® polyamides to be processed with a water content lower than 0.2%, as delivered in Nyltech sealed bags. If not, melt viscosity will drop, and several problems may arise during the process : production parameters may not suit a change in melt viscosity, thus affecting material pressure. The filling of the part can be changed due to the material pressure being modified, which will alter the quality of the parts. Moreover, a damp material tends to drool at the nozzle, parts can be brittle and their surface finish can be poor (bubbles, streaks, flash, etc.). Finally, damp granules cause gas emissions during the process, which can increase the wear of the screw and block the vents of the mould.



TRANSFORMER  
LEGRAND  
TECHNYL A 31 III V25  
PA66, 25% glass fibres  
Flame retardant UL94 V1

## 1.2. Risks and precautions

In a solid state, polyamide polymers tend to capture water molecules, due to their chemical structure (amide groups): polyamides absorb water contained in the ambient air. Moisture absorption by the granules depends essentially on the relative humidity (RH) in the air (Figure 1.2). The higher the temperature, the faster the rate of water absorption and the higher the air humidity, the higher the absorbed rate.

This is why Nyltech delivers TECHNYL® polyamides in sealed bags, to avoid humid air to be put in contact with the granules. Granules should be handled carefully before being processed:

- keep the granules in their airtight bags or containers until required,
- be sure to use the polyamide within one hour after opening its sealed packaging (Figure 1.3)

- any partly finished bag should be sealed again to reduce any moisture absorption,
- in winter, keep containers and bags in the workshop to prevent condensation on the cold granules,
- use a feed hopper equipped with a dehumidifying system.

Figure 1.2

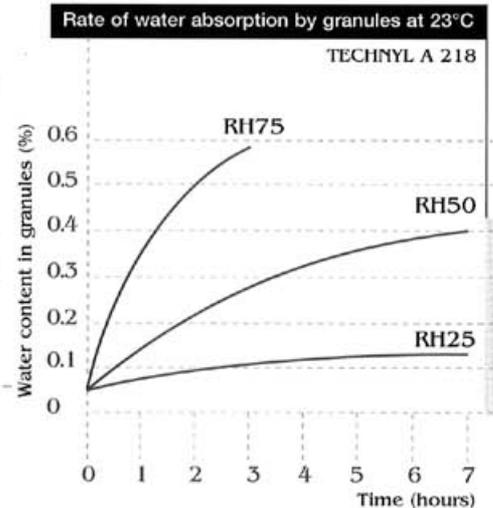
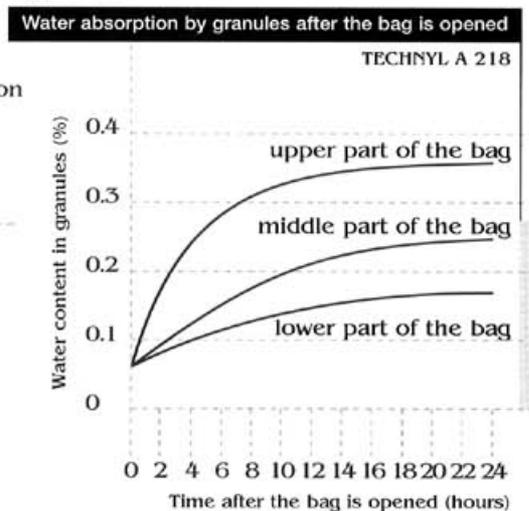


Figure 1.3



## 1.3. Drying

If the above precautions cannot be taken for any reason, the granules must be dried in order to maintain good quality in the moulded parts.

Water can be removed from the granules by using a hot air dryer, a vacuum dryer or a desiccant dryer.

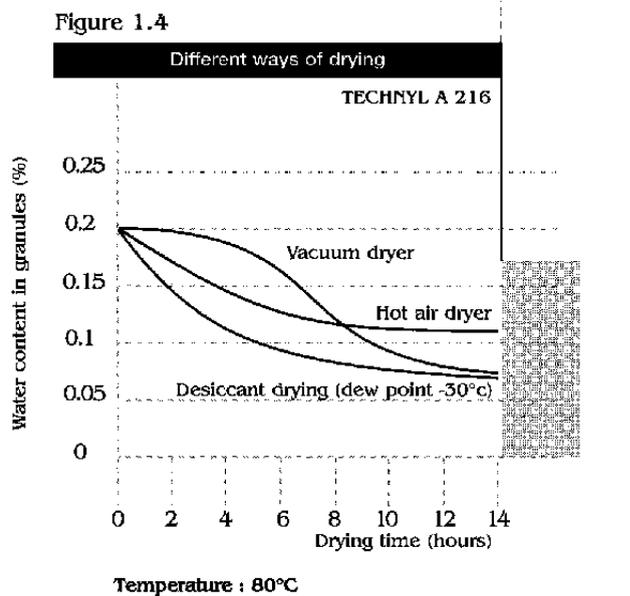
### 1.3.1. Hot air dryer

When air is warmed, its relative humidity content decreases and its drying capacity therefore increases (Table 1.1).

In the use of light colours, the use of this kind of dryer is limited by the fact that at temperatures higher than 80°C the polyamide can oxidise (light colours tend to yellow).

### 1.3.2. Vacuum dryer

By using a vacuum dryer, problems of oxidation can be limited and temperatures can be much higher: 110°C to 150°C. It is absolutely essential to decrease the temperature of the granules to 80°C before any contact with ambient air in the case of light colours. Compared to drying processes using hot-air dryers, when drying with a vacuum dryer the heat does not circulate as quickly through the granules, and drying therefore takes longer (Figure 1.4).



**1.3.3. Desiccant dryer**

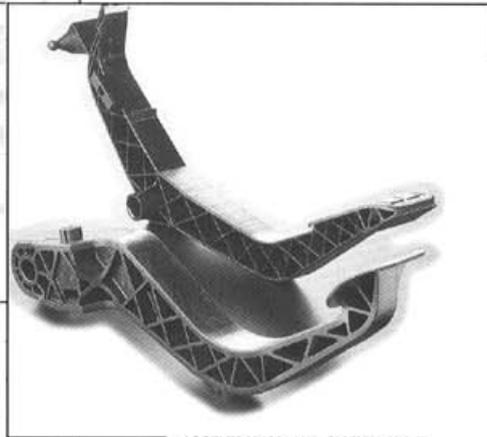
The principle is to lower the moisture content of the air by regulating the dew point (condensation temperature) and so the relative rate of moisture absorption decreases (Table 1.1).

Fast and effective drying can be carried out with a desiccant dryer at a temperature of 80°C and a dew point below -30°C.

Table 1.1

Water content of the air in...

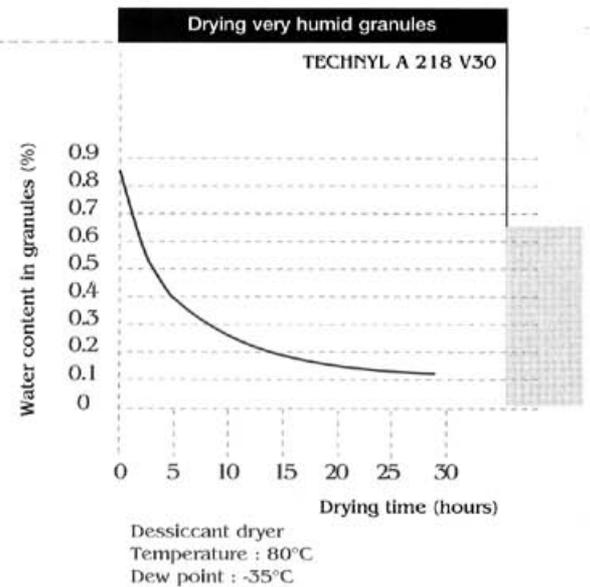
	Temperature (°C)	Relative humidity (%)	Water content in the air (g/m <sup>3</sup> )	Dew point (°C)
... a hot air dryer	20	90	17	18
	50	17	17	18
	60	11	17	18
	75	5	17	18
	100	2	17	18
... a desiccant dryer	80	100	300	80
	80	50	150	60
	80	17	50	40
	80	1.5	5	0
	80	0.3	1	-20
	80	0.1	0.4	-30



ACCELERATION AND CLUTCH PEDAL  
VOLKSWAGEN GOLF  
Moulded by VW  
TECHNYL C 216 V40  
FAG, 40 % glass fibres

Figure 1.5 gives an idea of necessary time for drying very humid granules with a desiccant dryer

Figure 1.5



## CHOICE OF EQUIPMENT

# 2

Choice of equipment

TECHNYL® products can be processed with standard injection moulding machines. Some features must, however, be taken into account when choosing the equipment.

### 2.1. Moulds

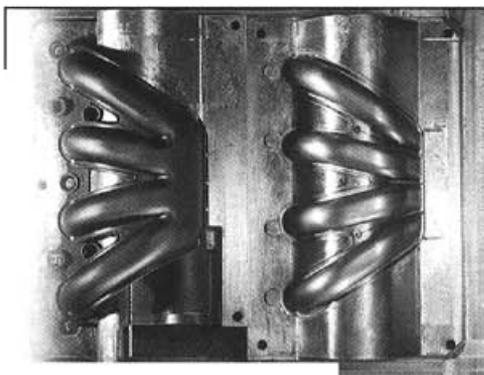
#### 2.1.1. Different geometry types

There are many alternatives for the design and layout of the moulds used when processing TECHNYL® polyamides.

Filling simulations may help to define the geometry of the moulds, such as size and position of gates and runners, location of ventings and ejector pins, and design of cooling channels.

#### 2.1.2. Steel for moulds

When choosing a steel, the following compromises should be taken into account: wear resistance / toolability, corrosion resistance / thermal resistance, corrosion resistance / wear resistance, and polishing / tooling properties.

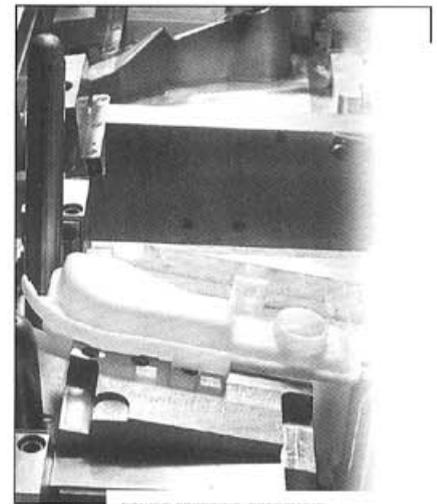


AIR INTAKE MANIFOLD  
FORD  
Moulded by MARK IV - Orbecy  
TECHNYL A 21B V50  
PA66, 30% glass fibres

**Polishing** : the steel must have a fine micro-structure and a high degree of hardness for a good polished surface. When using a high alloyed steel, the carbides in the metal will make it difficult to obtain a good polished finish. The sulphur content must be low to avoid manganese sulphur inclusion. This, however, can cause difficulties when machining the metal.

**Wear resistance** : ideally, a steel with a high carbon content and a high degree of hardness is preferred, due to the ability of the carbides to limit the wear. The presence of carbides will, however, make it difficult to polish the mould.

**Corrosion resistance** : steels with a very high chrome content ( $Cr > 13\%$ ) and very low carbon content ( $C < 1\%$ ) should be used. As the carbon content is low, the wear resistance is poor.



POWER STEERING RESERVOIR  
Moulded by MABX IV - Orbey  
TECHNYL A 218 V30  
PA66, 30 % glass fibres

### 2.1.3. Mould heating elements

Mould temperature control is very important for proper filling of the cavity, especially in the case of complex or thin-walled parts. It is advisable to keep the mould at a constant, ideal temperature. Due to the very nature of the injection moulding process, the heat input to the mould is variable and it is thus necessary to regulate the mould temperature by external or internal sources.

This regulation can be done for most polyamides with heated water circulating around the mould, controlled separately by a heating unit. This in effect will cool and control the mould temperature to the optimum temperature required for the part. Cartridge heaters can also be used, although a circulation system is recommended.

Heating elements are characterised by their power. A low power element is sufficient if the mould is preheated, depending on the size of the mould. If not, a more powerful element must be used to speed up the warming.

## 2.2. Injection moulding machine

### 2.2.1. Closing unit

There are different types of closing units on the market: hydraulic, toggle, a mixture of both, or electric ones (Figure 2.1).

The required clamp force is between 5 and 8 kN per square centimetres of projected surface (perpendicular to the clamping axis, runners included).

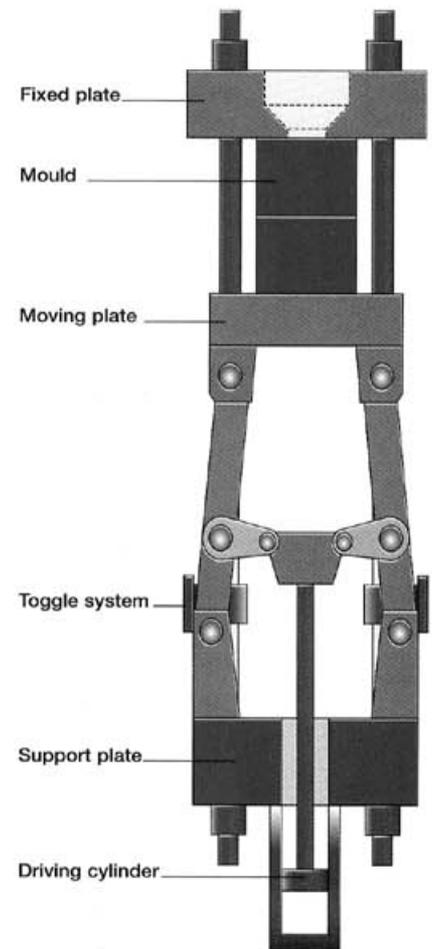


Figure 2.1

Four Point Double Toggle Lever System

### 2.2.2. Injection unit

Because of the residence time of the material in the barrel, the injected volume should be set between 30% and 60% of the maximum injectable volume of the injection unit.

The machine's minimum capacity of injection pressure should not be lower than 1500 bars.

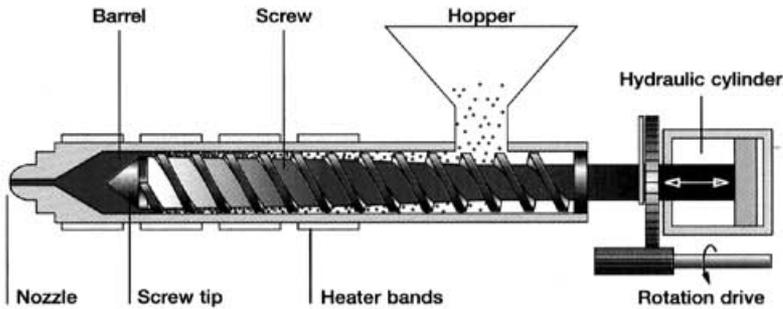


Figure 2.2  
Injection unit

#### 2.2.2.1 Screw profile

The design and efficiency of the screw affect the quality of the polymer melt and the homogeneity of the melt temperature (Figure 2.2).

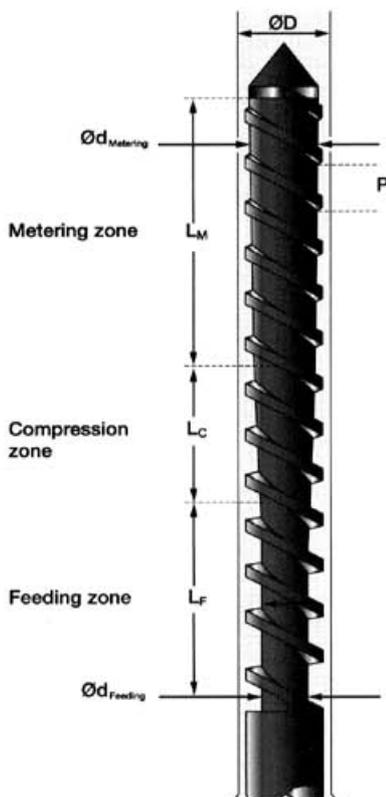
Most of standard 3-zone profile screws are suitable for the processing of TECHNYL® polyamides. This type of a screw is described as follows (Figure 2.3):

Figure 2.3

Three zone screw

- a cylindrical FEEDING zone, length  $L_F \geq 12 D$
- a tapered COMPRESSION zone, length  $L_C = 4 D$
- a cylindrical METERING zone, length  $L_M \geq 4 D$
- total length  $\geq 20 D$
- pitch (P) = diameter (D)
- compression ratio between 2 and 3

$$\left[ \text{compression ratio} = \frac{D^2 - d_{\text{Feeding}}^2}{D^2 - d_{\text{Metering}}^2} \right]$$



A good finish to the screw and barrel is essential, and clearance between the flight of the screw and the barrel must be kept to a strict minimum to ensure a good seal.

#### 2.2.2.2 Non-return valve

The non-return valve not only allows the polymer melt to be fed to the head of the screw, but also stops the melt flowing back during the injection and packing phase (Figure 2.4).

Due to the low viscosity of molten polyamides, the seal of the non-return valve and screw must be sufficiently tight to maintain the pressure during the process cycle phases.

The valve is subjected to heavy wear, particularly when reinforced plastics are being processed. Problems of premature wear can be avoided with a surface treatment such as gas-phase chemical coating (titanium carbide or iron boride) or stellite coating (grade 6).

The profile of the valve must be very carefully designed to allow the plastic to flow easily, as any stagnation will lead to degradation of the material.

**2.2.2.3**

**Nozzle**

One side of the nozzle touches the mould (about 80°C), and the other the barrel (about 280°C). The nozzle also has its own heating system. Complex temperature exchanges take place in the nozzle.

The nozzle should be of a suitable size with well-positioned heat elements to avoid too big a thermal loss or local overheating, which would tend to freeze the material or degrade it (characterised as streaks on the parts).

The nozzle diameter plays an important role as far as the freezing off of the sprue and drop pressure are concerned. Generally, it should be between 3 mm and 6 mm depending on the volume of the part. The nozzle channel should be slightly tapered so as to remove the cold slug when ejecting the part.

Two main types of nozzle are currently used: open nozzle and shut-off nozzle (or plug-valve nozzle). The use of a shut-off nozzle helps prevent drooling at the nozzle by driving the injection unit backwards and working with back-pressure when feeding (Figure 2.5). Conversely, there is more risk of material stagnation and degradation than with an open nozzle.

Figure 2.5

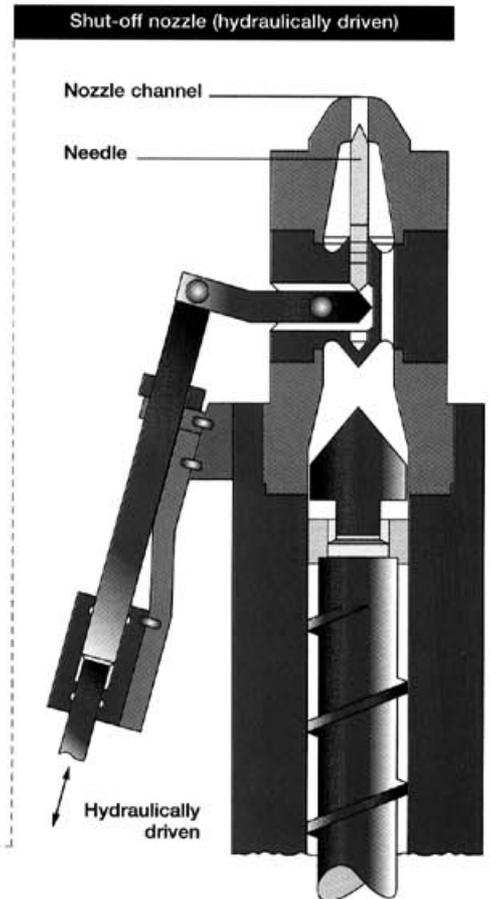
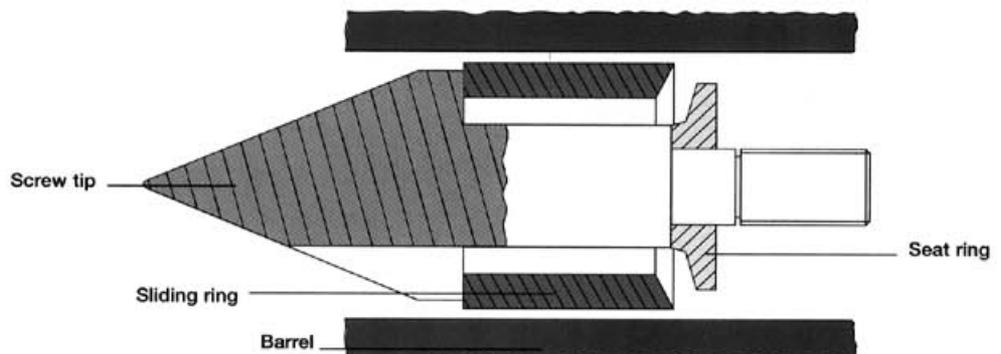


Figure 2.4

**No-return valve with a movable retainer ring**



#### **2.2.2.4** | Barrel

An important aspect of barrel design is thermal inertia which depends on the barrel's thickness and its electric band heaters. The material, power and regulating systems affect the rate of temperature increase.

Polyamides have a narrow temperature range between the moulding temperature and the temperature at which material degradation occurs. An efficient temperature control system is therefore necessary.

#### **2.2.2.5** | Feed hopper channel

The cooling system for the feed hopper channel must be correctly located and controlled. Otherwise, the temperature in the feed zone may increase and the granules may begin to melt and become sticky and risk blocking the feed hopper channel. If the temperature is too low, water condensation will occur on the granules.

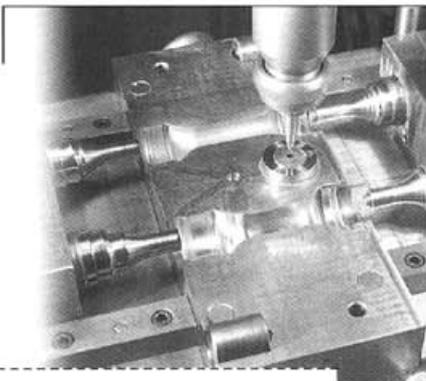
To avoid these problems, a temperature of 60°C in the hopper channel is recommended.

#### **2.2.2.6** | Wear problems

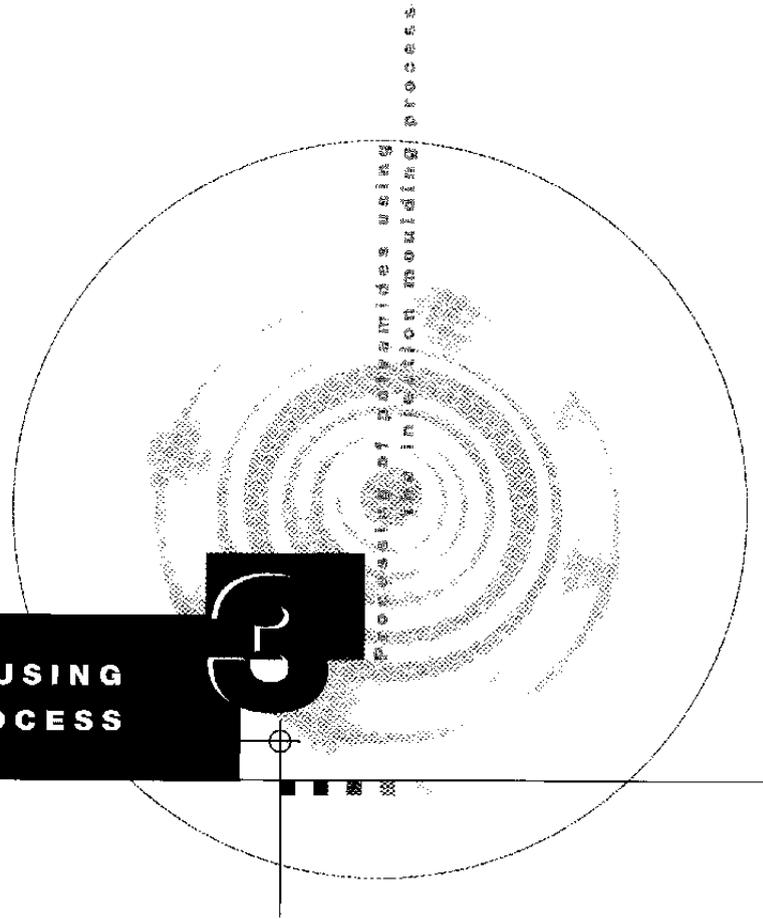
Screws and barrels are subjected to heavy wear : abrasion wear due to the fillers, and corrosion wear due to the emission of gases.

The nitride screws available are not resistant to the abrasion of fillers currently in use. To overcome this, it is normal to perform further treatment on the screw: this treatment involves extra cost but can be a worthwhile investment. A stellite coated screw (grade 6 stellite) or a bi-metallic barrel (obtained by the internal centrifugation of a Ni-Cr-Co alloy) can help in this area.

It is possible to recondition screws by arc resurfacing and stellite coating. Barrels can also be repaired, but the procedure can be expensive. Each time the screw or the non-return valve are changed or repaired, the barrel should be checked to detect any possible damage.

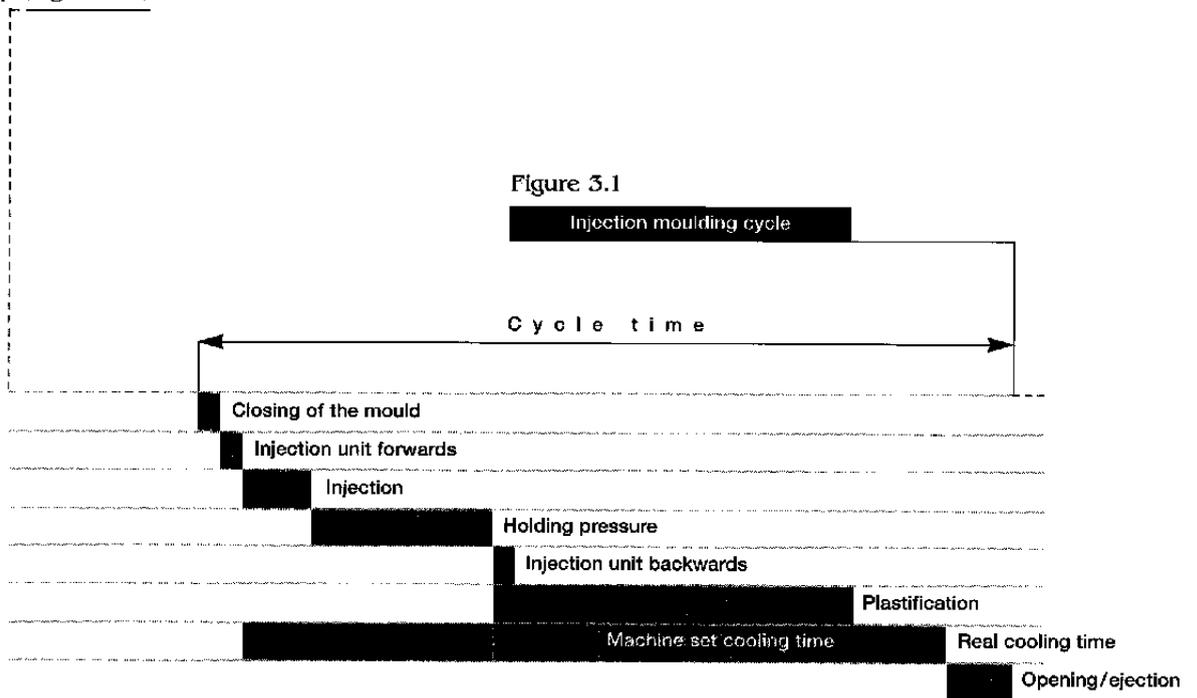


# PROCESSING OF POLYAMIDES USING THE INJECTION MOULDING PROCESS



The injection moulding process is the most widely-used way of transforming the granules into a viscous fluid, and then into a final part, for Nyltech's different TECHNYL® polyamides. In principle, all types of injection moulding machines can be used for processing.

The injection moulding cycle can be divided into several phases, which partly overlap (Figure 3.1).



Under appropriate temperature conditions, there are no particular risks involved in processing polyamides. Products containing flame retardants give off no toxic fumes. The workshop must, however, be well ventilated, and ideally have extractor systems at the nozzle. In all cases, whatever the polyamide references, cleaning by pyrolysis (high temperature oven or torch) results in toxic gases occurring above 500°C. In this case, efficient ventilation is required.

The following pages will present the main injection moulding issues that directly influence material behaviour and subsequent part quality.



## 3.1. Plasticising

Plasticising the polyamide granules to obtain a homogeneous melt depends on the temperature set, the velocity of the screw, back pressure, and screw design.

### 3.1.1. Temperatures

In order to set the different temperatures of the barrel correctly, major attention should be paid to shot weight and dwell time. The optimum shot weight amounts to approximately 60% of the barrel's maximum capacity. Temperatures should be set at 60°C at the feed hopper. Temperature should then be set to increase along the barrel.

Please refer to paragraph 3.2 for further details on recommended melt temperatures.

When shot weights are higher or when dwell time is shorter, unmolten granules remain in the polymer melt, resulting in poor surface aspect (dull surface) on the part. Such defects can be avoided by setting an inverse temperature profile for the barrel. Temperature in the first barrel zone should be increased slightly.

### 3.1.2. Screw rotation velocity and back pressure

The rotation velocity of the screw and the back pressure applied to the screw during the plasticising phase have great impact on melt homogeneity, plasticising time, and possible material degradation.

By increasing both parameters, plasticising time can be shortened, and melt homogeneity improved. Material degradation may, however, occur : breakage of glass fibres, loss of molecular weight, colour browning, and degradation of flame retardant.

Table 3.1 gives recommendations on velocity and back pressure values.

Table 3.1

Moulding parameters

PA 66 TECHNYL A

	Melt Temperature(°C)	Mould Temperature(°C)	Injection speed (cm <sup>3</sup> /s)	Back pressure (bar)	Peripheral speed of screw (mm/s)
Standard viscosity	270-290	60-80	50-150	50-100	300-600
Medium viscosity	270-290	60-80	50-150	50-100	300-600
GF Reinforced	270-300	80-120	120-170	20-50	200-300
Mineral filled	270-300	80-120	120-170	50-100	300-400
Flame retardant	270-280	60-90	80-120	20-50	200-300
Impact modified	270-290	60-90	80-150	50-100	300-600

PA 6 TECHNYL C

Standard viscosity	230-250	40-80	50-150	50-100	300-600
Medium viscosity	230-250	40-80	50-150	50-100	300-600
GF Reinforced	230-260	80-100	120-170	20-50	200-300
Mineral filled	230-260	80-100	120-170	50-100	300-400
Flame retardant	230-240	40-80	80-120	20-50	200-300
Impact modified	230-250	40-80	80-150	50-100	300-600

## 3.2. Melt and mould temperatures

### 3.2.1. Melt temperature

Too low a melt temperature can cause unmolten granules in the polymer melt and incomplete parts. It can also generate an uneven part surface, poor surface gloss, and weld lines and glass fibres visible on the part surface.

Conversely, too high a melt temperature especially in the case of damp granules, results in significantly lower mechanical properties, due to polymer degradation.

The final choice of melt temperature depends on polymer grade, part geometry, mould design, and dwell time. For example, a thin-walled part will need a more fluid material to avoid incomplete shot, and thus a higher melt temperature.

A mould with small gates (pin-point) would also need higher melt temperatures to ensure good packing of the material. In both examples, there is a risk of thermal and mechanical degradation of the polymer. In the case of a long dwell time, the melt temperature should be lowered in order to avoid thermal degradation in the barrel.

Melt temperatures can be measured by purging the material in a PTFE-pot equipped with a thermocouple. The purge should not produce excessive smoke or make bubbles.

Table 3.2 shows the influence of melt temperature on processing and part quality.

Table 3.2

Melt temperature ↗

Weld line strength ↗

Surface aspect ↗

Cycle time ↗

Packing phase ↗

### 3.2.2. Mould temperature

Depending on the grade of TECHNYL® polyamides, and on the required quality of part surface, the mould temperature should be set between 60°C and 100°C (Table 3.1). Higher mould temperatures normally result in better surface quality and higher mechanical properties. Higher mould temperatures also allow a better filling of the mould cavity, especially in the case of thin-walled designs and/or long flow distances.

Lower mould temperatures help reduce part shrinkage. However, they also imply higher post shrinkage, identified by warpage due to the release of residual stress.

Table 3.3 shows the main influence of mould temperatures on part quality

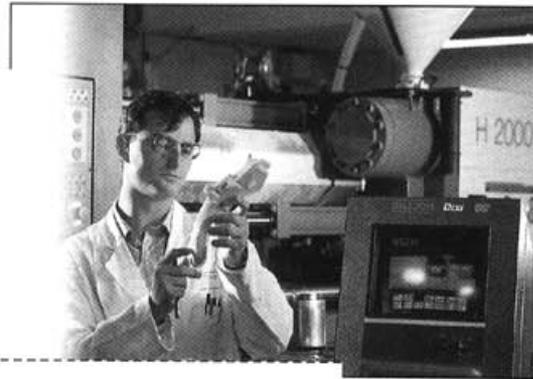


Table 3.3

Mould temperature ↗

Shrinkage ↗

Surface aspect ↗

Weld line strength ↗

Part stabilisation ↗

### 3.2.3 Hot runners

It is generally advisable to use a hot-runner system, equipped with an external heat regulation system, to process semi-crystalline polymers such as polyamides. Built inside the mould, the hot-runner system is made up of a distribution network and a group of hot sprues, which drive the molten polymer from the barrel through the mould into the different cavities. The system should be insulated in order to avoid any heat exchange between the hot runners and the mould's body, although differences in temperature are very great (for example, a mould temperature of 80°C, and a melt temperature inside the hot-runner channels of 280°C). Using a hot-runner system in the injection moulding process of PAs, however, may create problems at the injection points, such as threading when the part is ejected or solidification of the polymer (cold slug), or an increase in the diameter of the injection gate due to heavy wear.

Besides the composition of the material itself (including glass fibres or fire retardants in the case of reinforced PAs), melt temperature and moulding pressure have a great impact on the injection moulding process. The general properties of a suitable hot-runner system should include the following:

- thermal homogeneity and stability,
- rheological balance,
- tight seal,
- efficient and independent control of the temperature of the mould near the injection points.



## 3.3. Injection speed

The injection speed at which the melt is injected into the cavity has significant influence on the final quality of the part. Fast injection secures good copying of the mould surface, high weld line strength, and homogeneous solidification of the melt in the cavity. Additionally, shrinkage and warpage are minimised, if the switch to holding pressure is optimised. To achieve a fast filling of the cavity, the mould must have properly located vent channels. Proper venting minimises air enclosure, as well as burn marks at the end-of-filling area or at weld lines. When using moulds equipped with small gates, the injection speed should be moderate, in order to avoid too much shear heating which could cause material degradation.

Recommended injection speeds are given in Table 3.1.

Table 3.4 shows the main influence of injection speed on part quality.

Table 3.4

Injection Speed
Weld line strength
Surface aspect
Filling facility

### 3.4. Holding phase

The holding pressure phase starts immediately after the injection phase. Holding pressure is necessary as it compensates for the shrinkage of the melt during solidification by continuously pushing melt into the cavity. It is therefore necessary to have enough polymer melt in the barrel at the front of the screw tip, known as the "melt cushion". The melt cushion should not be too big, so as to avoid thermal degradation.

The level of holding pressure and the holding pressure time depend on the maximum wall thickness of the part and the gate geometry. As the maximum wall thickness increases, so do the recommended holding pressure and the holding time. If the gate size and runner system are small, the material will tend to solidify quickly in the gate and the sprue, which will not allow any increase in holding pressure time. Cavity pressure is a useful tool for measuring and controlling the action of the holding pressure.

There are three alternatives for switching from the dynamic injection phase to the holding phase:

- switch after a given injection time,
- switch at a given position of the screw,
- switch at a given pressure.

The pressure mentioned in the last option generally refers to hydraulic pressure, but it can also refer to the pressure of the material in the barrel head or in the mould.

As a general rule, the switch should occur when the cavity is filled completely. If the switch takes place too late, the pressure of polymer melt in the mould will be too high, which may cause defects known as flashes.

To set up the pressure, one should start with low pressure and increase it to its highest value before flashing. The holding pressure time can be determined by weighing the parts, until the weight no longer varies.

Table 3.5 shows the main influence of holding pressure time on part quality.

### 3.5. Cooling

The cooling phase should be set up so as to minimise waste in production time. Still, the part should be stiff enough to be ejected correctly, without any deformations or ejector marks. Increasing the diameter of the ejectors or the number of ejectors can help decrease the cooling time. The design of the parts and moulds has significant influence on cooling time. Thickness concentrations must be avoided, and, overall, wall thickness should be minimised. By increasing wall thickness, cooling time is squared.

Table 3.6

Variation of mechanical properties with percentage of added reground material

	Unreinforced	Glass fibre reinforced TECHNYL A 218 V50		
	< 30% of reground material	15% of reground material	30% of reground material	100% of reground material
Stress at break	-3%	-3%	-12%	-35%
Elongation	< 25%	+10%	+15%	+35%
Charpy impact	-20%	-10%	-15%	-60%

All values are given at 23°C/RH0

### 3.6. Regrinding

Regrinding is only for processing polyamide waste that has not been submitted to any ageing treatment. Typically, material to be reground is waste that comes directly from sprues and feeding channels. This waste is reground and mixed with fresh granules; the mix can then be processed in an injection moulding machine.

Material properties depend on the material grade, and on the percentage of reground material used. Table 3.6 gives the loss mechanical properties using first generation reground material. In the case of on-line regrinding, where polymer wastes are directly mixed at the feed hopper, actual values of mechanical properties might be lower.

The mix of reground material and fresh granules should be absolutely free of any impurities, which may greatly degrade the mechanical properties of polyamide parts. Reground material should also be dried when it is not reprocessed immediately after first processing.

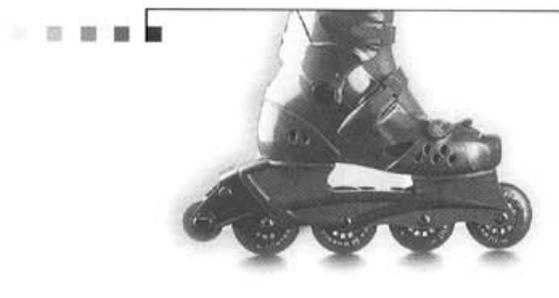
Table 3.5

Holding pressure time

Shrinkage	↘
Sink marks	↘
Residual stress	↘
Part quality	↘

To ensure production of consistent quality, all the moulding factors must be controlled, particularly:

- temperature of plastic: quality of control device, location of monitoring point, adequate heating power,
- pressures and speeds: choice of transition point, speed control,
- moulding cycle: consistency - any influence by the operator must be minimised,
- plastification: consistency of plastification time, importance of the choice of screw speed. A high speed increases plasticising capacity but results in uneven temperatures. A slow speed, compatible with an acceptable production cycle, is preferable,



CHASSIS FOR IN-LINE SKATES  
ULTRAWHEELS  
Moulded by MINSON  
TECHNYL PSB 189  
Impact modified PA6,  
25 % glass fibres

- quality of shut-off valve,
- melt cushion,
- oil temperature in the hydraulic circuit,
- cooling temperature (machine and mould),
- cooling circulation rate (mould),
- condition of cooling circuits (scale),
- temperature of granules when they enter the hopper.

The quality of the finished parts depends directly on the state of the material when the cavity has been filled completely (pressure, volume, and temperature) and the control of these three factors during the packing and cooling stages.

## DIMENSIONAL STABILITY OF THE MOULDED PARTS

# 4

Dimensional stability of the moulded parts

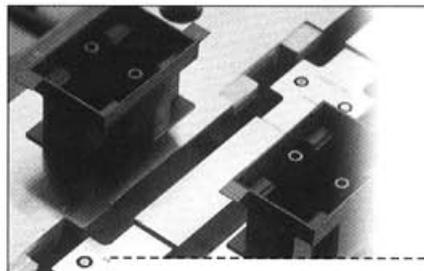
### 4.1. Shrinkage, post shrinkage, annealing

#### 4.1.1. Shrinkage

Polyamides always shrink during moulding.

Moulding shrinkage is the difference between the size of the dry moulded part, cooled at 23°C, and the size of the mould at the same temperature. Calculations are usually made 24 hours after moulding.

This phenomenon is due to the volumetric contraction which polyamides undergo during the cooling phase, when the melt polymer is transformed into a solid state.



Considering it is not easy to foresee this phenomenon, in general shrinkage depends on :

- the PA grade used (unreinforced, reinforced, mineral charged, viscosity etc.) :
- In the case of glass-fibre-reinforced material, the shrinkage in the direction in which the fibres are oriented is less than that in the transversal direction. Some values of both parallel and transverse shrinkage are given in Table 4.1

Table 4.1

Shrinkage after moulding according to ISO 294-4

		Shrinkage Longitudinal %	Shrinkage transverse %
<b>PA 66 TECHNYL® A</b>			
Unreinforced grade	A 216	1.9	1.9
GF reinforced	A 216 V30	0.8	0.85
Mineral filled	A 228 MT40	0.9	1
Flame retardant	A 30H1 V30	0.8	0.8
<b>PA 6 TECHNYL® C</b>			
Standard viscosity	C 216	1.3	1.3
GF reinforced	C 216 V25	0.4	0.7
Mineral filled	C 228 MT30	0.8	1.1
Flame retardant	C 30H1 V30	0.25	0.65

- moulding parameters:

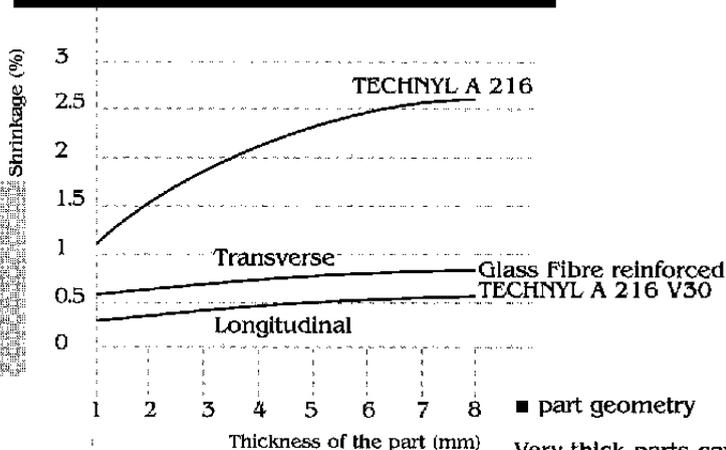
The holding pressure and its application time have a significant influence on shrinkage, as the additional supply of polymer counterbalances volumetric contraction during the cooling phase.

A high mould temperature allows a low cooling rate, which in turn means high moulding shrinkage.

Table 4.2 gives the general influences of moulding parameters on shrinkage.

Figure 4.1

Influence of the thickness of the part on the shrinkage



- part geometry

Very thick parts cause a decrease in the cooling rate, resulting in high moulding shrinkage (see Figure 4.1).

A very large thickness variation in a part causes differential shrinkage and thus a risk of warpage and distortion.

Table 4.2

Parameters affecting mould shrinkage

By increasing ...	The shrinkage
Holding pressure	↓
Injection speed	↓
Gate size	↓
Mould temperature	↑
Part thickness	↑

#### 4.1.2 Post shrinkage and annealing

Post shrinkage is the further contraction of the part as full crystallisation takes place under thermal treatment: for instance, painting in a hot environment. It may also be caused by the service temperature of the parts when in use.

Post shrinkage thus depends mostly on moulding conditions such as mould temperature (see Figure 4.2), which determine the degree of crystallisation of the polymer. The less the crystallisation during the moulding process, the greater the post shrinkage.

In some cases, it is necessary to stabilise the part's dimensions before post shrinkage occurs. The method called annealing accelerates the post shrinkage process, and consequently prevents dimensional variations during use. More specifically, annealing helps to stabilise parts with tight tolerances used in high temperature conditions.

##### ■ Procedure

The method consists in heating the parts to bring about dimensional variations.

The treatment is carried out in an environment which does not affect the polyamide, and in which there is no contact with air, so as to prevent oxidation.

Mineral or soluble oils, which can be washed off with water, are generally used.

##### ■ Treatment temperature and time

10 to 20°C above the maximum service temperature

TECHNYL<sup>®</sup> A : 175°C

TECHNYL<sup>®</sup> C : 160°C

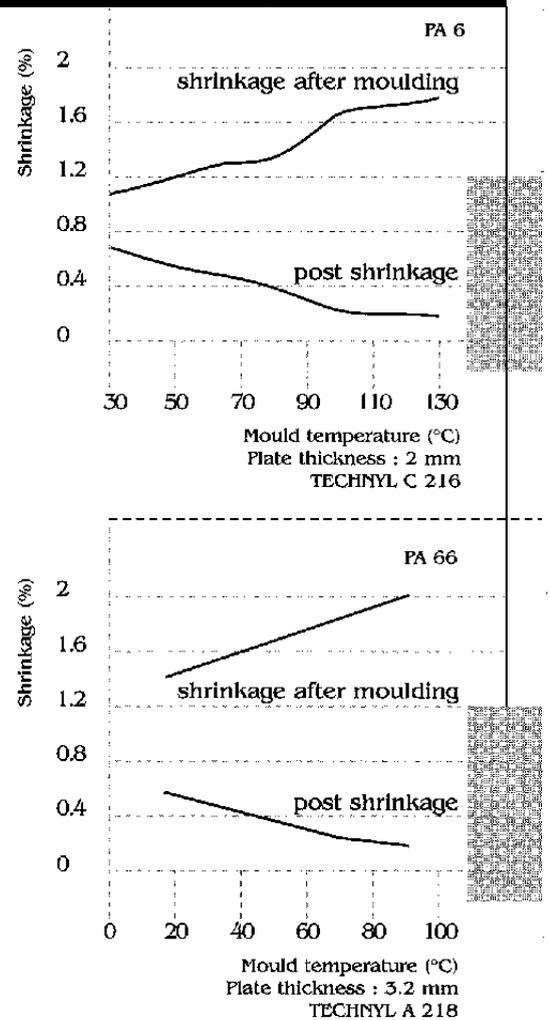
Thick parts: about 45 minutes

Parts less than 5 mm thick: 20 minutes

Heating and cooling must be gradual in order to prevent thermal shocks.

Figure 4.2

Influence of mould temperature on shrinkage and post shrinkage



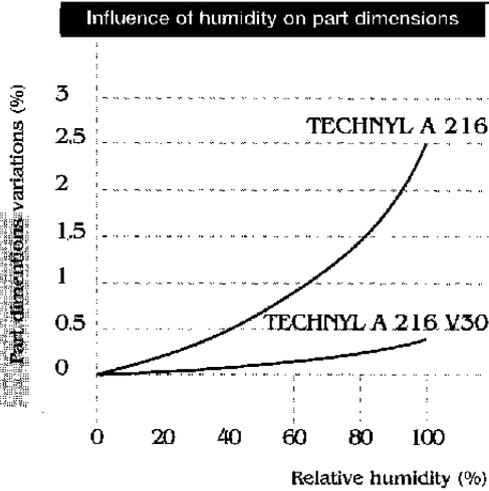
## 4.2 Moisture regain, accelerated treatment in water, air

#### 4.2.1 Water absorption

Polyamide parts that are exposed to a humid environment, especially when they come into direct contact with water, undergo changes in their weight, dimensions, and properties.

Polyamide parts placed in a humid environment reach water absorption equilibrium. The equilibrium value depends on the relative humidity (RH) of the environment. Maximum equilibrium values are reached through total immersion of the part in water, with a weight increase of around 9.5% for PA 6 and 8.5% for PA 66. In air with a relative humidity of 50%, equilibrium values are lower, with a weight increase of around 2.8% for PA 6 and around 2.5% for PA 66.

Figure 4.3 illustrates the impact of relative humidity on part dimensions.



Water absorption phenomena in polyamides are reversible: the polymer always seeks equilibrium with surrounding humidity, losing or absorbing water, until a new equilibrium value is reached.

The kinetics of absorption varies with temperature conditions : the higher the temperature, the faster the absorption.

Water molecules, which penetrate between amidic groups of macromolecules, modify the physical and mechanical properties of PA. In other words, water molecules raise the flexibility of the structure.

The most relevant changes occur in elastic modulus, tensile strength, impact resistance, stiffness and electrical resistivity Table 4.3.

**Table 4.3**  
Effects of water absorption

		Conditions	Stress at break (Mpa) ISO 527-2	Charpy notched impact strength (KJ/m <sup>2</sup> ) ISO 179/1eA
<b>PA 66 TECHNLYL<sup>®</sup> A</b>				
Standard viscosity	A 216	RH0/RH50	85*/60*	4,5/14
GF Reinforced	A 216 V25	RH0/RH50	160/120	10/13
Mineral filled	A 228 MT40	RH0/RH50	90/56	4/8
Flame retardant	A 30 H1 V30	RH0/RH50	100/80	6,5/12
<b>PA 6 TECHNLYL<sup>®</sup> C</b>				
Standard viscosity	C 216	RH0/RH50	85*/45*	5,5/13
GF Reinforced	C 216 V25	RH0/RH50	162/100	11/26
Mineral filled	C 216 MT30	RH0/RH50	85/50	9/20
Flame retardant	C 30 H1 V30	RH0/RH50	105/75	11/17,5

\* stress at yield

#### 4.2.2. Treatment

After moulding, polyamide parts do not contain any water. In some cases, parts need to be moistened up to a certain equilibrium level. By being more flexible, for instance, they may make it easier to assemble systems. Parts might also need to reach moisture equilibrium before being used in a humid environment, in order to stabilise dimensional variations and mechanical properties.

Figures 4.4, 4.5 and 4.6 can be used to calculate the treatment times needed to raise water content up to the required level, depending on the type of polymer and the thickness of the part.

The distribution of water in a part that has just been removed from the conditioning bath will not be uniform. There will be a greater concentration on the surface areas, while the middle part may still be dry. In general, the larger the surface of the part, and the less thick it is, the less time required to reach moisture equilibrium.

After treatment in water a certain amount of time is necessary to allow the water absorbed by the surface to reach the core and thus obtain a part in a uniform state.

Figure 4.4

Conditioning TECHNYL® polyamides -RH 65- temperature 20°C

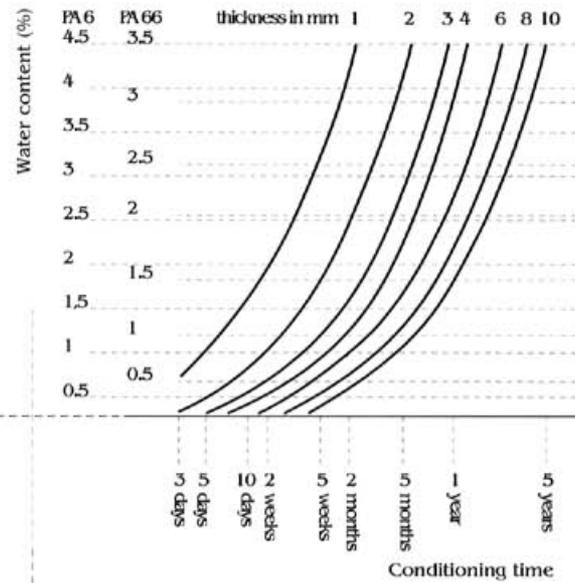


Figure 4.5

Conditioning TECHNYL® polyamides in water at 20°C

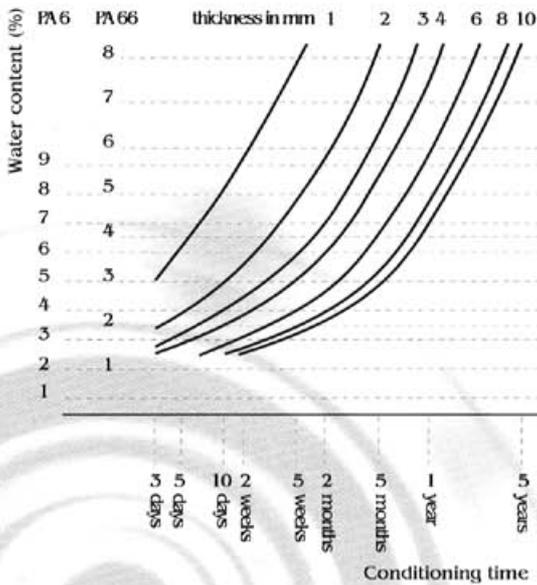
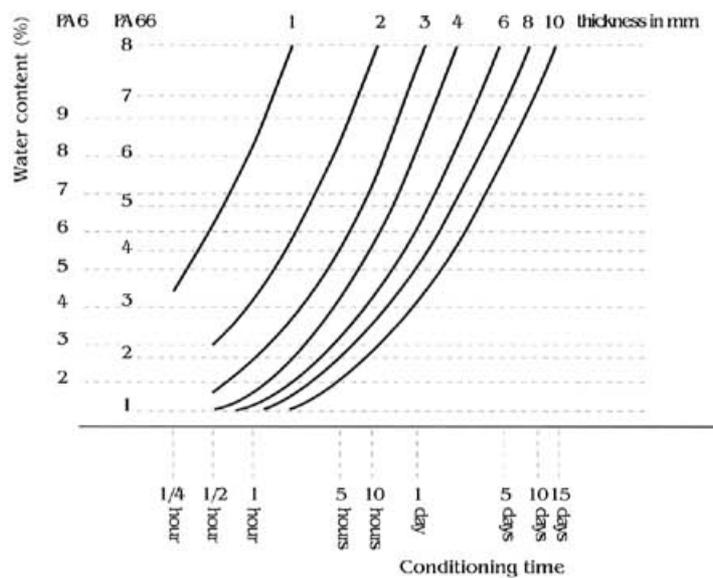


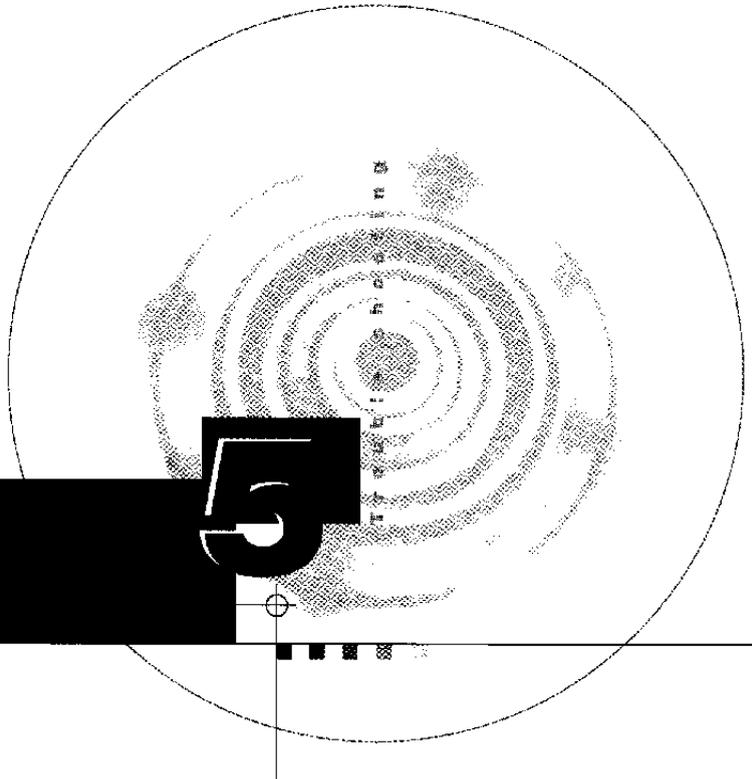
Figure 4.6

Conditioning TECHNYL® polyamides in water at 98°C



# TROUBLE SHOOTING

# 5



Defect	Cause	Remedy
Brittle part	Moisture content in polymer too high Thermal degradation  Poor plastification  Material contamination	Check moisture content and possibly dry the material again Reduce the residence time and barrel temperature  Adjust back pressure  Purge the barrel - check the hopper
Incomplete part	Material with too high a viscosity  Too high a pressure drop in the mould or in the nozzle  Entrapped air  Improper balance of plastic flow in multiple cavity moulds  Unsuitable moulding conditions	Use a more fluid material Increase melt and mould temperature, and injection speed  Check the length / thickness ratio of the plastic flow  Vent the mould  Check sizes of gates, runners and cavity  Increase dose and cushion Raise injection pressure Raise holding time and pressure Raise injection unit capacity

Defect	Cause	Remedy
Flashing	Parting lines of the mould not entirely locked	Adjust clamping force Check the clamping force in relation to the part geometry
	Material too fluid	Reduce melt and mould temperature
	Excess of material	Reduce dose and anticipate switching injection speed to holding pressure Reduce injection speed and holding pressure
Sink marks	Insufficient amount of plastic melt in the mould to compensate for polymer shrinkage (it usually occurs when the part is very thick)	Increase gate size Reduce barrel and mould temperature Increase dose, holding time and holding pressure Increase cooling time Adjust cushion
Cold slug	Tip of the nozzle too cold Nozzle too long	Catch the cold slug Check nozzle design Check nozzle temperature regulation system Increase nozzle temperature Move injection unit backwards
Glass fibre on surface	Material not sufficiently packed	Increase packing Raise mould temperature and injection speed Delay switching injection speed to holding pressure
Warpage	Different shrinkage in the various dimensions of the part	Balance the mould temperature Increase injection speed Check holding pressure Revise gate (size and location)
	Ejected part temperature too high	Reduce mould temperature Increase cooling time
	Defective ejection	Check ejection system
	Poor temperature control of mould	Revise and modify cooling channels
Very marked welding lines	Too high a melt viscosity	Use a more fluid material Increase melt and mould temperatures Improve injection speed and holding time or pressure Check design of injection system
Burn marks	Poor venting	Enlarge venting section or relocate Reduce injection speed Anticipate switching to holding pressure
Streaks on surface	Too high a percentage of moisture in the granules	Dry material
	Thermal degradation	Reduce melt temperature or shorten overall cycle
	Poor melt homogeneity	Increase back pressure or melt temperature
Black spots	Stagnation of material in machine or hot runners	Optimise the melt flow, avoid dead zones in barrel, nozzle, hot runners

Defect	Cause	Remedy
Colour variation	Thermal - oxidative degradation Poor plastification High moisture content	Shorten melt residence time and melt temperature Check components of the master batch used Increase back pressure and lower screw rotation speed Dry material
Shrinkage	Improve injection parameters	Reduce melt and mould temperature Raise value and time of holding pressure Delay switching to holding pressure
Dull surface	Problems in melt plastification Material contaminated	Raise melt and mould temperatures Increase injection speed and mould temperature Check the presence of extraneous granules and possibly the size of reground material
Jetting	Poor gate design	Relocate and/or modify gate size (width/thickness ratio) Modify the gate so that the melt flow goes towards the wall of the cavity to achieve a regular melt flow
Too long a cycle	Material with low crystallisation rate Poor thermal exchange between mould cavity and part during cooling time	Replace with a more suitable material Reduce sprue diameter Check or improve cooling channel Lower mould temperature
Bubbles	Moisture in granules Poor plastification	Dry granules before moulding, Increase back pressure and lower screw rotation speed
Void	Insufficient material in the mould to prevent excessive shrinkage due to heavy sections, ribs, bosses	Increase dose and decrease screw rotation speed Adjust injection pressure and injection time Adjust cushion Adjust temperature setting - may be too hot
Delamination	Material contaminated	Purge the barrel
Problems ejecting the part	The article remains in the mould	Reduce part packing Improve knockout system Raise cooling time Eliminate undercut and roughness in the mould Increase draught in the cavity walls Increase diameter or number of ejector pins
Flow lines	Melt temperature and/or mould too cold	Increase melt flow speed
Drooling	Material too fluid	Reduce nozzle and melt temperature Use a proper nozzle Increase suckback slightly at the end of plastification phase Dry material



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- the extent of our knowledge of the products as listed,
- the tests and experiments carried out in our laboratories.

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