

DuPont Engineering Polymers

Moulding Manual for MINLON® and ZYTEL® Resins

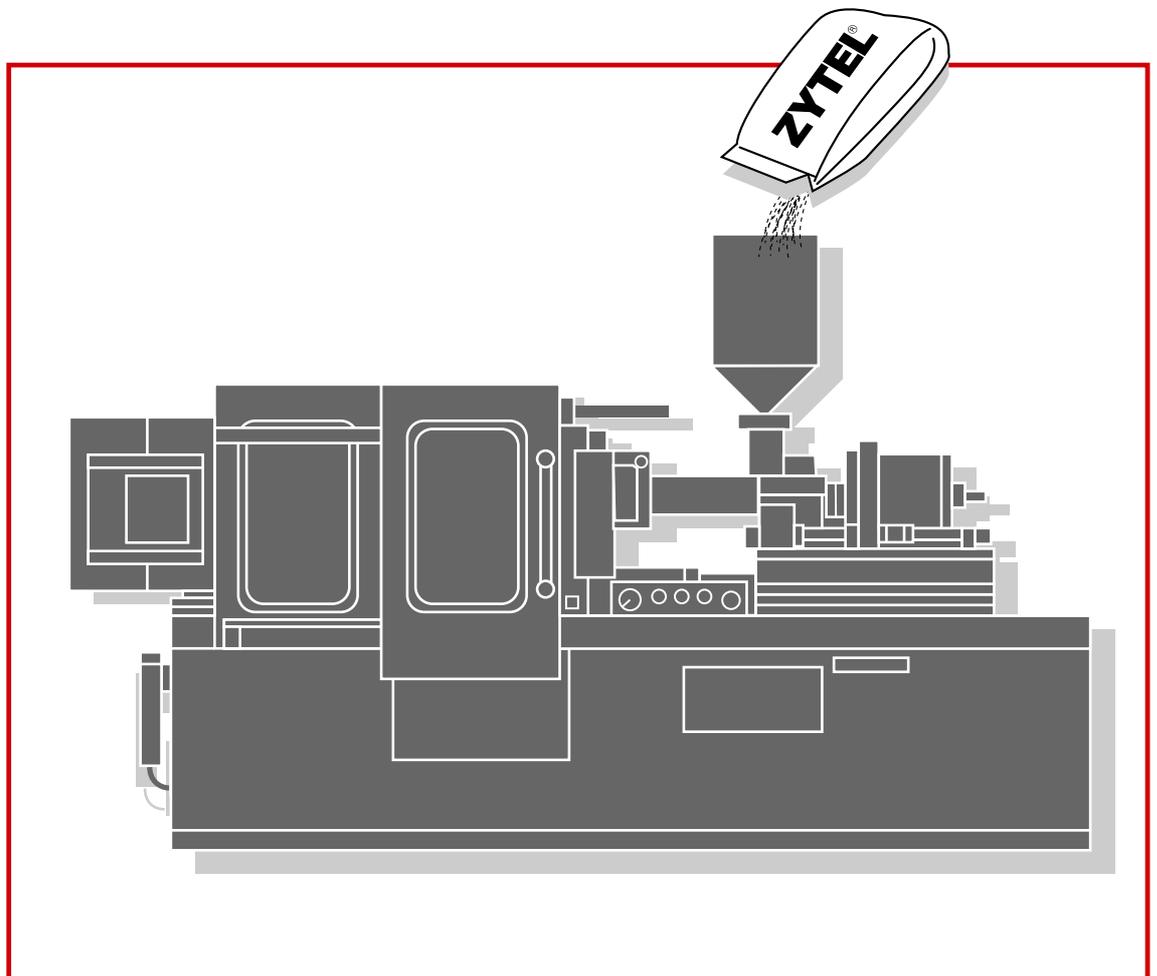


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Part II

Material processing data list and brief resin description.

1. Foreword

This brochure consists of two parts. The first part presents a comprehensive overview of the injection moulding process for nylons. The objective is to better understand what occurs during this moulding process. The polymer phenomena and processing guidelines are designed to provide a comparison of the various attributes of different nylon families rather than in-depth characteristics of specific grades.

A subdivision of the nylon family is explained in the section "Injection moulding of nylons".

The second part provides tables illustrating the most important setting parameters that are recommended during the injection moulding process. The complete range of nylon resins from DuPont is listed.

Injection moulding of nylons

Despite the fact that MINLON® and ZYTEL® nylon resins have been injection moulded for over 50 years, it is still as important as ever to optimise conditions in order to be able to benefit from the material properties available when using these resins. In basic terms, the process involves heating the solid moulding granules to melt them, then transferring this molten material to a mould and holding it under pressure until it crystallises.

Each type of nylon has its own specific processing characteristics which must be considered and understood before it can be successfully moulded to produce parts that achieve the expected quality level. The moulding conditions considerably affect the part quality of characteristics such as weld line strength, surface appearance, and dimensional stability. The optimum processing conditions for any given grade are determined by combination of the nature of the polymers used as well as modifiers and additives which have their own melt properties.

The basic understanding of these melt properties helps one to understand the influence of changes in a moulding parameter on the quality of the moulded parts. Section 2 covers this aspect.

Many of the recommendations in this brochure are applicable for the majority of DuPont nylons. In an attempt to simplify the moulding guidelines and make them easy to read, the grades have been classified under generic types.

The DuPont nylon family

MINLON® and ZYTEL® nylon resins are classified by chemical composition into the following groups:

- Nylon 66.
- Nylon 6.
- Nylon 66/6 copolymers.
- Nylon 66 + 6 blends.
- Nylon 612.
- Transparent amorphous nylon.

The key features of ZYTEL® nylons are:

- High mechanical strength.
- Excellent balance of stiffness/toughness.
- Good high temperature performance.
- Good electrical and flammability properties.
- Good abrasion and chemical resistance.

Properties such as melting point, moisture absorption and modulus of elasticity are primarily determined by the type of nylon. The molecular weight of the nylon determines the melt viscosity and impact resistance.

In addition, nylons can be readily modified and reinforced, to create a wide range of products with tailored properties for specific processes and end-uses.

Major "families" of ZYTEL® nylons described in this brochure include:

- Unreinforced.
- Tough/Supertough.
- Glass reinforced.
- Mineral reinforced.
- Mineral/glass reinforced.
- Flame retardant.
- High viscosity/Extrusion.
- Speciality.

1.1 Operating precautions

As with most thermoplastic resins, the moulding of glass-reinforced MINLON® and ZYTEL® resins is ordinarily a safe operation. Good practice dictates that consideration should be given to the following potential hazards:

- Thermal effects.
- Off-gases and particulates.
- Slipping hazards.

1.1.1 Thermal effects

Skin contact with molten glass-reinforced MINLON® and ZYTEL® resins can inflict severe burns. This could happen when gases generate pressure in the machine cylinder and violently eject molten polymer through the nozzle or hopper.

To minimise the chance of an accident, the instructions given in this guide should be followed carefully. Potential hazards must be anticipated and either eliminated or guarded against by following established procedures, including the use of proper protective equipment and clothing.

Do not allow the resin to remain in the moulding machine for more than 15 minutes at melt temperature. If this situation occurs, e.g., during a prolonged cycle interruption, be particularly alert during purging. Pay particular attention to Section 7: Moulding Machine Operations.

When purging, be sure that the high volume (booster) pump is off and that a purge shield is in place. Reduce the injection pressure and “jog” the injection forward button a few times to minimise the possibility of trapped gas in the cylinder which will cause “splattering” of the polymer melt. Put the purge into a container with water in order to suppress gassing and smell.

If resin decomposition¹⁾ is suspected at any time, a purge shield should be positioned, the carriage (nozzle) retracted from the mould, and the screw rotated to empty the barrel. After the screw starts to rotate, the feed throat should be closed and then a suitable purge compound (high-density polyethylene) introduced. The temperature can then be gradually lowered and the machine shut down. See “Purging” under Section 7: Moulding Machine Operations for further details.

If jogging the injection or screw rotation buttons does not produce melt flow, the nozzle may be plugged. In that case, shut off cylinder heats and follow your established safe practices. Always assume that gas at high pressure could be trapped behind the nozzle and that it could be released unexpectedly. A face shield and protective long-sleeve gloves should be worn at such times. Before restarting, both the machine and material should be evaluated to determine the cause of the decomposition.

In the event that molten polymer does contact the skin, cool the affected area immediately with cold water or an ice pack and get medical attention for thermal burn. Do not attempt to peel the polymer from the skin. Consult the Material Safety Data Sheet (MSDS) for advice. For further questions contact the phone number which is listed on the Material Safety Data Sheet (MSDS).

Because glass-reinforced ZYTEL® and MINLON® resins are dried at high temperatures, contact with hot hoppers, ovens, or air hose lines could result in severe burns-insulation of these components will reduce this possibility.

1.1.2 Off-gases and particulates

During drying, purging, moulding, and grinding operations, small amounts of gases and particulate matter are released. As a general principle, local exhaust ventilation is recommended during the processing of glass-reinforced MINLON® and ZYTEL® resins as it is for all plastic resins. A ventilation rate of about 5 m³ air/min per kg/h of resin processed will keep the concentration of particulates (and gases) well below the limit of 5 mg/m³ (Europe) for nuisance dusts while being processed at the maximum recommended times and temperatures (moulding, purging, and drying). For more details, refer to the DuPont publication, “Proper Use of Local Exhaust Ventilation During Hot Processing of Plastics.” A copy of this brochure is available from your DuPont representative.

1.1.3 Safety information

DuPont supplies Material Safety Data Sheet (MSDS) information to its customers with the initial order of glass-reinforced MINLON® and ZYTEL® resin and on the next order after an MSDS is revised. MSDSs include such information as hazardous components, health hazards, emergency and first aid procedures, disposal procedures, and storage information.

1.1.4 Slipping hazards

Granules of glass-reinforced MINLON® and ZYTEL® resins are a slipping hazard if spilled on the floor. Any spills should be swept up immediately.

1.1.5 Regrinding operation

When performing any regrinding operation, besides using equipment with state of the art safety performance, the installation should provide appropriate protection against noise and dust. Screens, filters and ventilation in good operating condition should be used. Operating personnel should wear adequate personal protective equipment including gloves and a face shield.

1) Excessive gas escaping from the nozzle, severely discoloured molten polymer, screw backing up beyond the rear limit switch, etc.

2. Melt properties

The melt physical properties of a polymer dictate the way in which it must be moulded. Among these are:

- The overall molecular structure which is basically semi-crystalline and the various changes which occur with changes in temperature and pressure.
- The energy content (specific heat and latent heat).
- The flow behaviour of the melt, and particularly the viscosity as the most important rheological parameter.
- The crystallisation rate of the resin.
- The thermal stability of the resin particularly at high temperatures and in the presence of water.

2.1 Material structure

2.1.1 Crystallinity

Most polyamides have a partially crystalline structure. This means that a proportion of the polymer solidifies in a certain ordered and regular crystalline structure. The rest solidifies in an amorphous state having no regularity.

During the crystallisation process, the molecules fold into lamellae that normally lock together and form spherulites up to 0,2 mm in diameter. If the orientation of the lamellae is in one direction, as is often the case on the part surface, the zone of material is transparent.

Fundamental differences in structure between properties of semi-crystalline and amorphous polymers results in differences as much in properties (“cohesive energy” reinforces the properties) as in moulding conditions.

Among the most important properties of crystalline materials, in contrast to amorphous materials, are the following:

- Big volume changes with temperature when changing from liquid to solid and vice-versa
- Large amount of heating is required to melt the polymer.

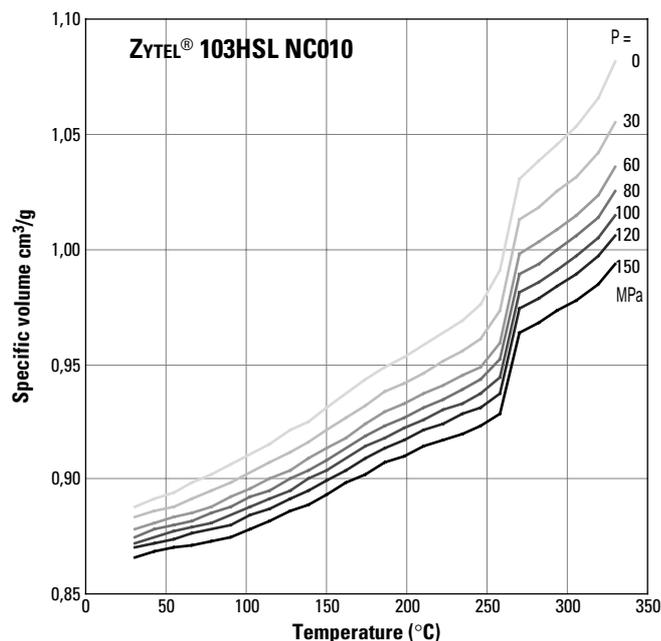
These two phenomena, along with the others imply, in contrast to amorphous materials, that there is no danger of overpacking even with very high injection fill and hold pressures.

2.1.2 Volume changes

Volume changes are normally described in terms of the specific volume which is the inverse of the density. For semi-crystalline materials, the specific volume is a function of temperature, pressure and, in the solid phase, the degree of crystallinity.

Some experimental curves of the specific volume of un-reinforced ZYTEL® are shown in Fig. 1. In the liquid or melt phase, the specific volume is much greater than in the solid phase. During moulding the melt is held under pressure, typically 70 MPa, which means there is a smaller change in volume as the melt crystallises than at zero pressure. Shrinkage is the direct result of the melt crystallising. Since it is best to keep shrinkage as low as possible, the melt should always be kept under pressure until it fully crystallises.

Fig. 1 Pressure-Volume-Temperature diagram (specific volume as a function of temperature and pressure)



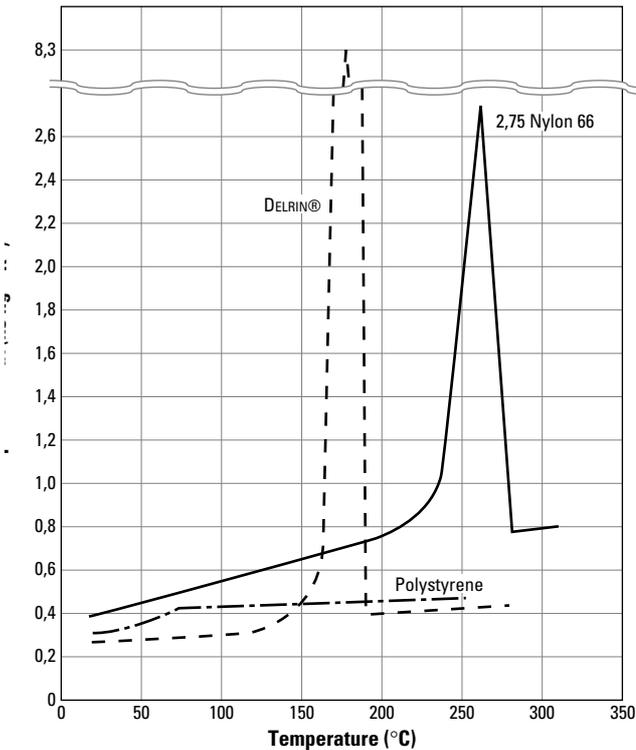
In the solid phase, nylon resins have a crystallinity between 40% and 60%. The corresponding curve in Fig. 1 should be seen as a band to reflect this variation and the other factors which influence the crystalline structure.

Nylon 66 resins have the highest degree of crystallinity within the nylon family. This has a significant influence on many end-use characteristics including the mechanical properties, moisture absorption and chemical resistance.

2.2. Heating requirements

The energy needed to increase the temperature of a polymer is determined, in general, by its specific heat, defined as the amount of heat needed to raise the temperature of unit mass of material by 1 K. In case of materials with a crystalline structure, additional heat is necessary to bring the material from the solid state to the liquid state. This energy is represented by a peak on the specific heat curve (Fig. 2).

Fig. 2 Temperature dependence of specific heat



Thus, the total amount of heat needed to bring each polymer to the processing temperature is the area under each curve. It turns out that crystalline resins need higher heat energy than amorphous resins and the unreinforced nylon resins need twice as much total heat compared to polystyrene, for example, as seen from Table 1.

This difference in behaviour influences the screw and barrel design which is much more critical for semi-crystalline materials than for amorphous polymers.

Table 1 Heat energy required for processing

Resin	Heat of fusion (kJ/kg)	Total heat required (kJ/kg)
Polystyrene	0	372
DELRIN®	163	419
High density polyethylene	242	721
ZYTEL® 101L	130	791

2.3 Melt viscosity

Melt viscosity determines to a large extent the filling pressure of a mould – high viscosity implies less flow and higher pressure drops. The melt viscosity is also primarily a function of the molecular weight (for example, ZYTEL® 42 has a higher molecular weight and, therefore, a higher melt viscosity than the ZYTEL® 101L).

The melt viscosity of nylons is influenced by a large number of factors, in particular by the temperature of the melt, shear rate and moisture content of the resin.

2.3.1 Dependence of Melt Viscosity upon Temperature

The general rule that liquids become less viscous with increasing temperature is certainly true for plastic melts. For this reason, it is necessary to specify a temperature when giving a value for melt viscosity. Fig. 3 shows that viscosity of un-reinforced ZYTEL® is less sensitive to changes in temperature than toughened and reinforced grades are.

2.3.2 Dependence of Melt Viscosity upon Shear rate

Shear rate is a parameter characterising deformation velocity of the material flow. It is dependent on velocity of the flow and geometry of the flow channels.

Viscosity decreases considerably with increasing shear rate, see Fig. 4.

Therefore, by increasing the injection speed the viscosity can be reduced, thereby improving the filling of difficult parts. Viscosities among particular grades of nylon resins differ significantly, as shown in Fig. 3 and 4.

Fig. 3 Dependence of melt viscosity upon temperature

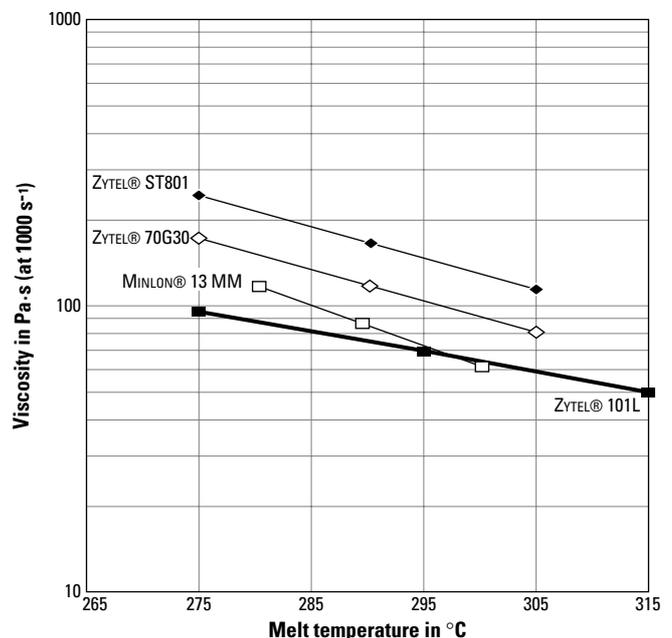
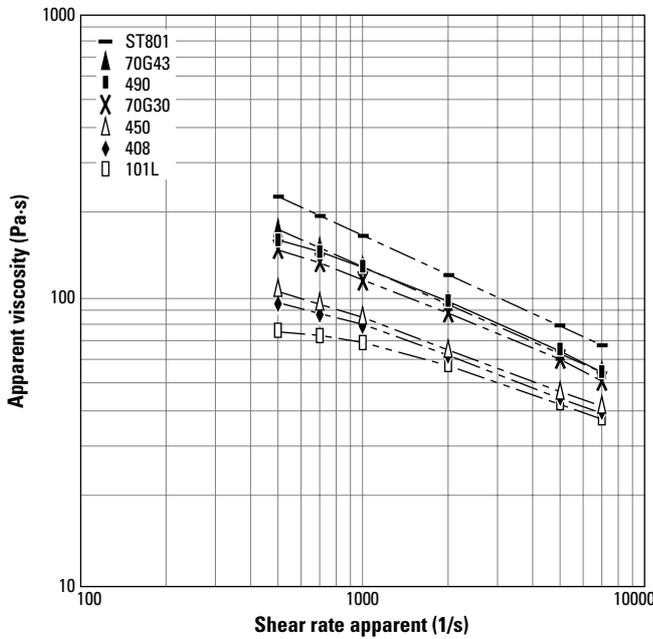


Fig. 4 Dependence of melt viscosity upon shear rate at 290 °C

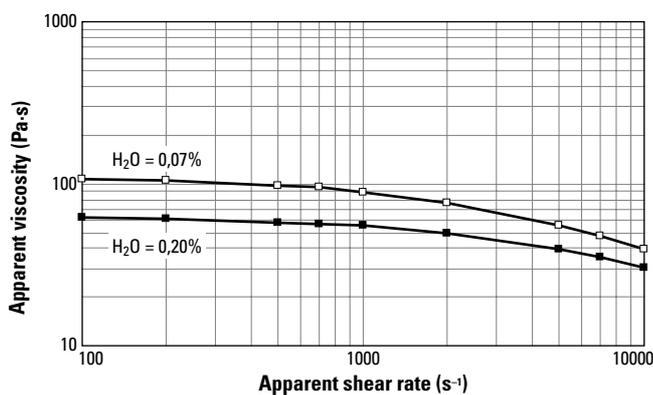


2.3.3 Dependence of Melt Viscosity upon Moisture

Since the viscosity of the melt coming out of the injection unit is a concern, the chemical reactions that may occur in the barrel as a result of water moisture cannot be ignored. The moisture level of the resin granules affects melt viscosity, as a result of hydrolysis occurring during the injection moulding process (see Section 2.5).

As a general rule, for all nylons the higher moisture content, the lower the melt viscosity (Fig. 5).

Fig. 5 Influence of granule moisture content on viscosity of ZYTEL® 101 at 295 °C



2.3.4 Relative viscosity (RV)

The relative viscosity is a (dimensionless) measurement of the average molecular weight of the resin. The higher the relative viscosity the higher the molecular weight of the polymer.

2.3.5. Melt temperature and melting point

Most MINLON® and ZYTEL® nylon resins are crystalline materials and therefore have true melting points instead of softening temperatures as found with amorphous resins. Optimal melt temperature may change slightly not only grade by grade, but from application to application as well. This is another reason why the temperatures listed in Part II are only recommended melt temperatures indicating a range of melt temperatures for each grade.

Generally, in order to achieve easy flow of the melt, temperature is set as high as possible, but below the point where material may start degrading for the given processing conditions (see Section 2.5).

Low melt temperature can lead to undesirable effects such as melt heterogeneity or self-nucleation.

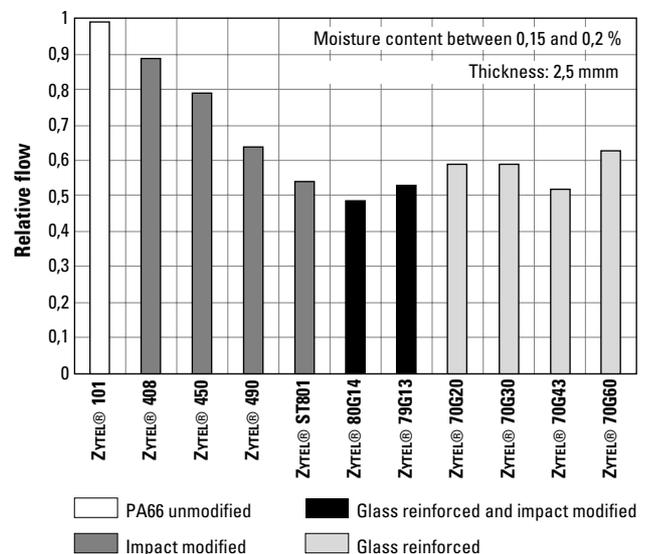
2.4 Melt flow

Melt flow is a crucial parameter for moulding performance. In order to compare the melt flow of various materials, one standard method of measurement called snake-flow or spiral-flow is generally accepted.

It measures flow-length versus pressure for a given material, section of the flow channel (round or rectangular) and mould temperature. Moisture of the resin must be taken into consideration (see Section 2.2) in order to arrive at the correct conclusion.

For the DuPont nylon resins, the more modified the resin, the shorter the flow length. Fig. 6 shows the relative flow characteristics of ZYTEL® 66 resins. The resins were moulded using standard conditions following the recommended setting for each resin.

Fig. 6 Relative flow characteristics of ZYTEL® resins



2.5 Melt stability

Every moulder is concerned about the stability of the resin with respect to degradation during moulding. Degradation decreases the molecular weight and therefore end-use properties. Degradation may occur through one of the following:

- Hydrolysis resulting from resin with high moisture content.
- Thermal degradation because of too long a hold-up time (or the presence of hold-up spots) or excessively high cylinder temperatures.

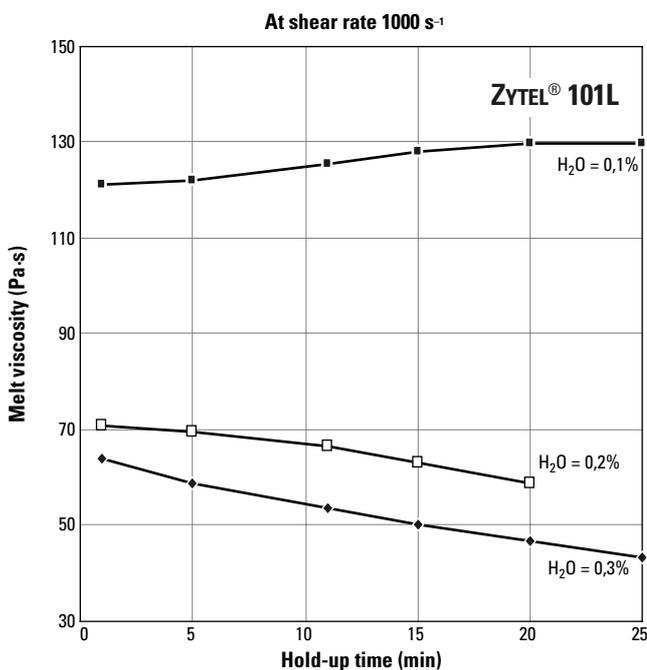
2.5.1 Hydrolysis

Nylons are polycondensation products and therefore either condensation or hydrolysis may occur depending on pressure, moisture level, temperature and time of exposure.

During the moulding process the molecular weight and consequently relative viscosity (RV) change, depending on the above mentioned parameters. Fig. 7 shows that during the moulding process the very dry resin undergoes polycondensation and increases in RV, whereas high moisture leads to hydrolysis and a decrease in RV. The equilibrium moisture content is around 0,12% with a melt temperature of 295°C for that particular resin.

Provided the water content of the granules is not above about 0,20% by weight, the reaction speed of the hydrolysis process and polycondensation are so low at normal processing conditions, that the properties of the moulded parts remain practically unaffected.

Fig. 7 Melt viscosity versus time and moisture for ZYTEL® 101



Once the moisture content exceeds 0,25%, there will be a loss of properties in the moulded parts, particularly with a decrease in toughness and elongation, poor surface aspect and easy flashing.

2.5.2 Thermal degradation

As with all plastics, DuPont nylon resins can be thermally degraded. The thermal degradation will not be significant unless the hold-up time of the material in the barrel is too long, or the melt temperature too high. Under normal conditions, the rate of thermal degradation is so low that it does not need to be considered.

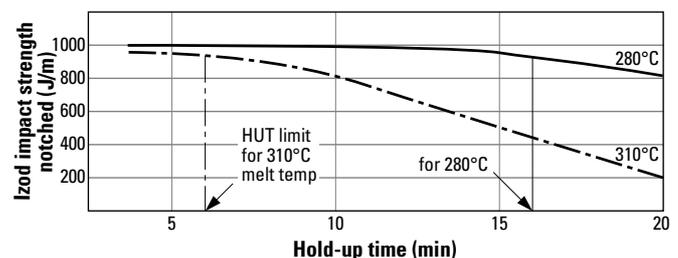
If however, a very high melt temperature of 310°C were to be used, then the molecular weight of ZYTEL® 101 would be reduced by 6% after a 10 minute and 17% after a 30 minute hold-up time.

The hold-up time (or barrel residence time) is the average time taken for a granule to pass from the hopper throat to the moment when it is injected into the mould. Nylons, like any plastic, can be degraded during the moulding process. The degradation of the polymer will affect the molecular weight and reduce the properties, as explained above.

Degradation depends both on the melt temperature and hold-up time (i.e. residential time of resin in the injection machine). The higher the melt temperature the shorter the hold-up time that will lead to damaged material (see Fig. 8).

Special attention should be provided to flame retardant-ed, heat stabilised and other especially tailored grades with regards to optimum HUT.

Fig. 8 Effect of hold-up time on impact properties of toughened nylons



2.6 Melt characterisation with instrumented moulds

A new diagnostic system using measurement of pressures in the mould cavity during moulding allows rapid evaluation of very small differences in resin characteristics (flow and crystallisation behaviour) and gives a better understanding of how various moulding parameters influence the quality of moulding.

For this method of analysing signals during the moulding cycle, the electronic controller takes the readings from one or two pressure transducers in the cavity and a computer measures the in-cavity pressure during each cycle, displays it graphically and analyses it.

A single pressure sensor close to the gate is usually sufficient to determine the crystallisation time (CT) of the part (Fig. 9). If information about consistency of resin viscosity is needed, a second sensor is placed at the furthest point of melt flow, to allow calculation of the pressure drop between the two during the filling and the packing phase (Fig. 10).

Fig. 9 Cavity pressure measured during the filling and packing (1 sensor)

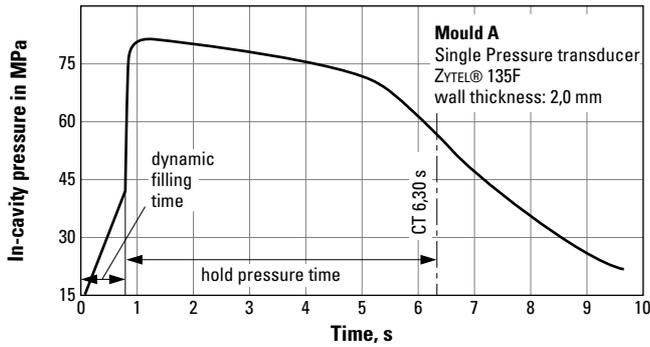
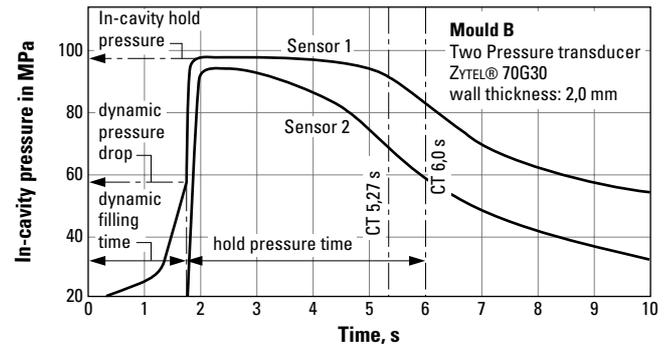


Fig. 10 Cavity pressure measured during the filling and packing (2 sensors)



3. Material handling

3.1 Material shipping

3.1.1 Physical form of resins

ZYTEL® nylon resins are solid granular materials, typically cylinder cut with nominal dimensions of 3 × 2,5 mm. Most compositions are available in colours, either cube blended or fully compounded.

Some of the bulk properties, needed for proper sizing of equipment such as hoppers, rotary valves and the feed zones of barrels are shown in Table 2.

The families based on Nylon 6, 6/66, 612 have a slightly lower bulk density (up to 5%).

Table 2 Bulk properties

Material		Bulk density (kg/m ³)	Angle of Repose (deg.)
Unmodified	Nylon 66	720-800	45
Impact modified	Nylon 66	640-720	< 60
Glass reinforced	Nylon 66	800-870	< 60
Super toughened	Nylon 66	640-720	< 60

The bulk density is the density of the material particles including the voids between them.

The angle of repose characterises the ability of the pellets to flow in feeders and in hoppers. Angles of repose between about 0° and 45° indicate free flowing materials. When angles get over about 50° the materials are non-free flowing or cohesive.

3.1.2 Packaging

ZYTEL® nylon resins are available in 4 standard packaging types:

- 40 × 25 kg bags.
- 1000 kg octabin.
- 1000 kg octabin (with bottom unloading).
- Bulk shipments.

Full details of these packaging types are given in the brochures: “Introduction to Engineering Polymers Packaging Materials” and “Silo Shipments”.

3.2 Handling nylon resins

When using nylon resins, the important requirement is to ensure that the resin is fed “dry” and “clean” into the injection unit.

3.2.1 Storage

- Nylon resin should be stored in dry area at a temperature close to that of the operating area. When the material is stored in a cold location, the container must be allowed to come to the moulding area temperature before opening it.
- Storage should allow a “first in/first out” inventory policy. Even though the bags are protected against moisture by a special lamination, some pickup could occur over time.

3.2.2 Procedure for handling virgin resin

Following the guidelines below will greatly eliminate moulding difficulties that could result from excessive moisture or contamination:

- To avoid condensation of ambient moisture on the resin, make sure that the container of resin is kept for a certain time at, or above the moulding area temperature, before the container is opened. Therefore, it is suggested that at least one day’s supply of containers is stocked in the moulding area.
- No more than 1 hour’s supply of resin should be placed in the hopper. Keep the hopper covered with a tight fitting lid.
- To avoid absorption of moisture by the granules, do not expose unused moulding resin to the atmosphere. Opened bags may be resealed with an ordinary household iron or heated sealing pliers.

All DuPont nylon resins are supplied dry and are ready to be moulded directly from the shipping containers.

3.2.3 Handling rework

As long as the procedures summarised below are followed closely, it is possible to grind up and re-use previously moulded resin of the same grade. Depending on the proportion of regrind in the feed the drop in mechanical properties could become significant with reinforced ZYTEL® (see Fig. 11 and 12). Recommended practice is to use only rework as it is generated and to restrict the levels to a maximum of 50% or preferably to 25% blended with virgin material. The final properties of parts moulded using reground resin are more likely affected by the quality of the regrind rather than by the percentage of regrind.

Fig. 11 Retention of mechanical properties vs number of passes (100% regrind)

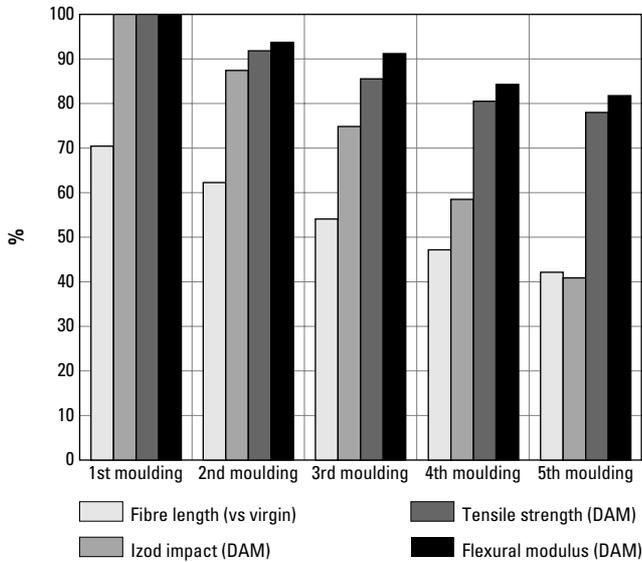
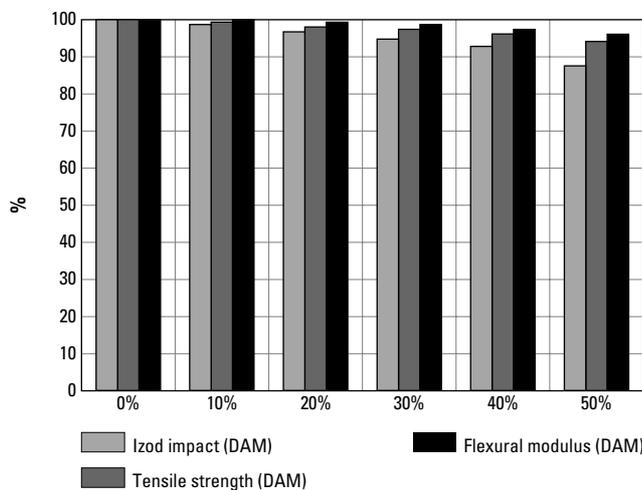


Fig. 12 Retention of mechanical properties vs regrind portion of feed



To use regrind successfully, the following principles should be kept in mind:

1. Regrind absorbs more moisture, and faster, than virgin resin. Therefore:
 - Protect the regrind material from moisture. Keep it in sealed moisture proof containers.
 - Sprues and runners should be regrind, mixed and used as soon as they are removed from the machine, thus avoiding an extra drying operation.
2. Regrind may contain significantly more contaminants than virgin material, and therefore
 - Do not use moulded parts and runners that are discoloured or splayed. These may be indications that the resin has been degraded.
 - Make sure regrind material is free of contamination.
 - Minimise the handling of sprues and runners. Use lint-free gloves.

- Keep the particle size of the regrind material uniform. Fine particles rapidly absorb moisture (because of the large surface-to-volume ratio) and stick to the cylinder walls. Fine particles also develop an electrostatic charge that attracts contamination that can plug the filters on vacuum loaders. Keep grinder blades sharpened and properly set to minimise fines. Fines can be separated from the regrind material by vibrating screening units equipped with 12 or 16 mesh screens.
 - Clean grinders and regrind containers frequently.
3. Some material properties can vary depending on the number of passes through the injection machine. In order to maintain a constant level of properties for the moulded parts, it is necessary therefore
 - To maintain a constant proportion of virgin resin to regrind material in the feed. Virgin resin and regrind material should be mixed prior to feeding.
 - To avoid accumulation of rework, use it as it is generated. The closed circuit separating, grinding and converging system is ideal.
 - Rework from glass reinforced nylons should ideally be ground hot in order to minimise glass fibre breakage.

Glass-fibre reinforced nylon resins show the highest sensitivity to recycling. This is mostly due to the breakage of fibres during the regrinding process. To document the impact of multiple material re-use on moulded part mechanical properties, 33% glass-reinforced ZYTEL® is shown in Fig. 11. This figure shows the relationship between the number of passes of ZYTEL® through the injection machine and the drop in mechanical properties. Loss of mechanical properties with 100% regrind is expressed as a percentage of virgin material properties.

If the rework is handled in a closed circuit and mixed with virgin material according to the guidelines mentioned above, the effect of regrind upon mechanical properties of moulded parts is small.

This is illustrated in Fig. 12 as property retention of parts moulded from 30% glass-reinforced ZYTEL® for several regrind ratios.

3.2.4 Disposal of material waste

In following the guidelines of this manual, the amount of processing waste and reject parts generated will be minimised. However, during the production of moulded parts, a certain amount of non reusable waste will still be generated. This waste should be disposed of properly.

DuPont recommends as the preferred option incineration with energy recovery. The incinerator has to be equipped with a state of the art scrubber in order to clean the flue gases before release.

MINLON® and ZYTEL® are not soluble in water and have practically no additives which can be extracted by water. Therefore MINLON® and ZYTEL® represent no known risk to human health or the environment when land filled.

For any disposal local regulations have to be observed which significantly can vary from locality to locality.

Polyamide is mentioned on the “green list” of the European Regulation EEC 259/93, Annex II. Thus, MINLON® and ZYTEL® are not restricted for inter-European transport of waste destined for recovery.

3.3 Effect of moisture

The moisture content of nylon moulding resins is a particularly important parameter, and has a direct effect on moulding, on mechanical properties, on the viscosity of the melt and on the appearance of the moulded parts.

All nylons are hygroscopic and absorb moisture from the atmosphere as illustrated earlier (Section 3.2.2).

- Water reacts chemically with polyamides at temperatures above the melting point. This reaction (hydrolysis) results in lower molecular weight and thus decreased the performance properties of the mouldings (Section 2.5).

The rheological behaviour of the melt is then modified and may cause processing troubles in the form of easy flashing. Control of part dimensions can become difficult.

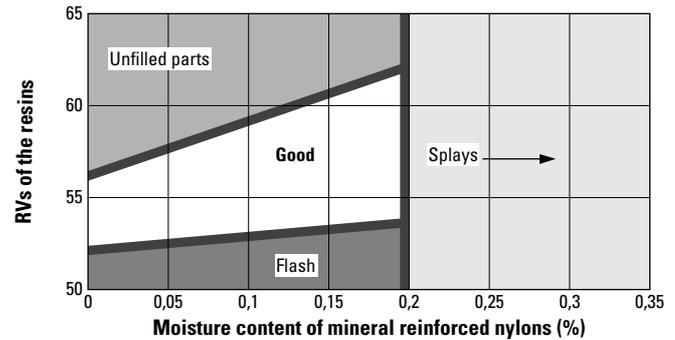
- At the same time, absorbed water can form steam that results in splay marks and internal bubbles in the moulded parts.
- The moisture effect on molten nylons is aggravated by prolonged exposure (long HUT) and/or high melt temperatures exceeding 315°C. This is due to a decrease of molecular weight which is reflected in the relative viscosity. In such cases it is advisable to reduce the water content accordingly.

As an example, Fig. 13 shows the effect of moisture content and relative viscosity on the surface appearance of parts moulded from mineral reinforced nylons.

In general, the moisture content of the resin fed into the injection machine should be no greater than 0,2% (by weight), as specified for each grade.

DuPont nylon resins are supplied dry and are ready to be moulded directly from the shipping containers. Under normal conditions the virgin resin can be used directly from the original sealed containers.

Fig. 13 Effect of RV and moisture content on the surface appearance of parts



3.4 Drying

The required final water content is determined by the moulding requirements and should be less than 0,2% and in certain cases less than 0,1%.

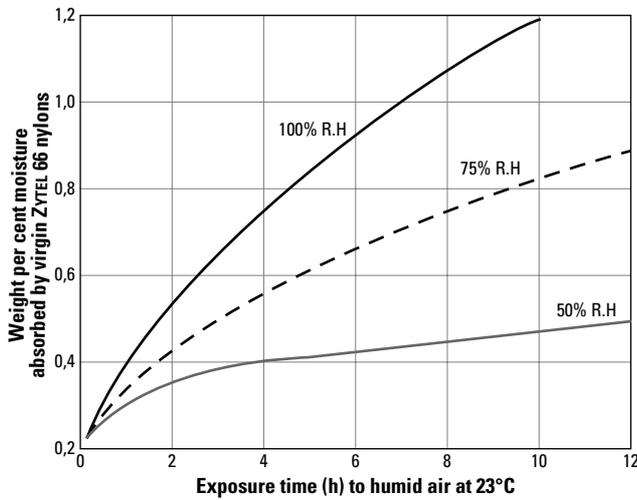
All nylons are hygroscopic and will absorb moisture from the atmosphere. So, if virgin nylon is kept in an open container for any appreciable length of time, or regrind material is used, additional drying is required.

The rate at which nylon can be dried depends on:

- **The relative humidity of the drying atmosphere.**
The drying rate increases as the water content of the drying air decreases.
- **The drying temperature.** Increasing the drying temperature increases the drying rate.
Air temperatures in excess of 93°C for periods of time greater than three hours will result in unacceptable discolouration of the nylon. Compromises are required between drying rate and temperature.
The recommended maximum temperature for drying DuPont nylon is 80°C.
- **The surface-to-volume-ratio of the nylon.**
The particle size is pre-set by the manufacturing specifications and by the size of the regrinder screens.

The water content of the nylon exposed to the atmosphere can be estimated from Fig. 14. The moisture content of ZYTEL® 66 nylon resins at various relative humidities as a function of exposure time is represented.

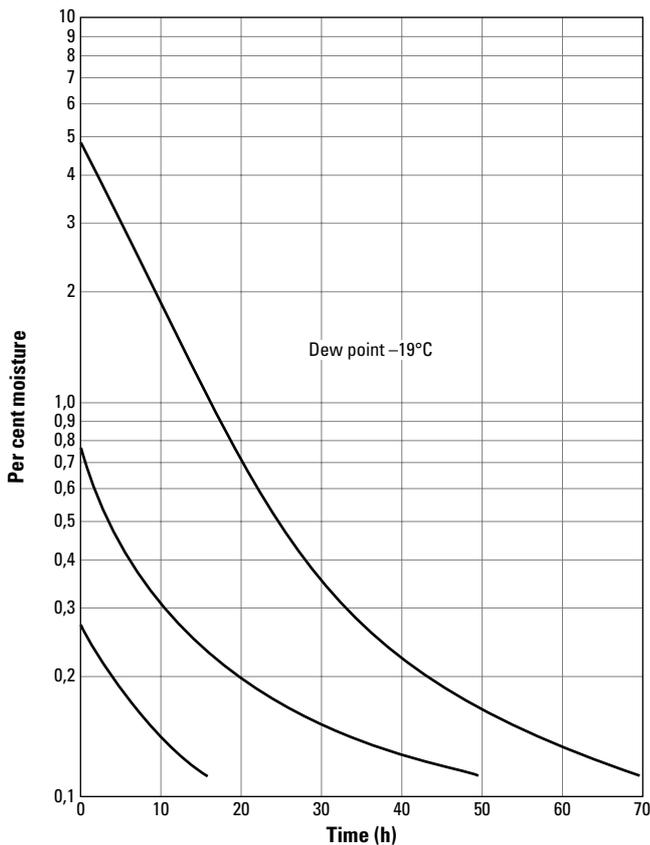
Fig. 14 Moisture absorption of virgin ZYTEL® nylon (granules)



DuPont recommends that a dryer for nylon resins must work with dehumidified air (dehumidifying hopper/oven) or an oxygen-free environment (vacuum oven). The latter is difficult to use in an automatic continuous process. Resin can only be dried in batches which fit the capacity of the oven.

The rough estimate of the time necessary to dry the resin is indicated in Fig. 15. The values for glass reinforced, mineral filled or impact modified nylon may be longer.

Fig. 15 Drying data for virgin MINLON® and ZYTEL® nylon (granules) (dehumidified oven at 80°C)



3.5 Colouring

A range of cube-blended standard colours is available for certain nylons. The freedom of design is even greater in that almost any colouring system can be used: dry pigment, paste, liquid colour or dyes. But such systems can also lead to variations in properties and/or performance.

When ordering liquid masterbatch or dry pigments, special attention should be given to these aspects;

- The dry pigments or liquid masterbatch used have to be chemically compatible with nylon resins and must have good thermal stability above the processing temperature of the resin.
- Pigments usually affect the crystallisation rate and consequently the shrinkage. Additionally the carrier of liquid colours has an effect on moulding.
- The carrier can be considered as a surface lubricant, which may, theoretically, cause screw slippage leading to filling problems.
- The key issue when moulding with colouring techniques is to ensure a homogeneous dispersion and mixing of the pigment in the polymer matrix.

When using a colouring technique, the following points should be carefully observed:

- Use of reasonable ratio between polymer and masterbatch
- Use of mixing head or high-compression screws.
- Use of screw retraction stroke less than 30% of the maximum screw retraction of the machine.

Important note

DuPont cannot give any guarantee for the performance and properties of moulded parts when DuPont manufactured nylon resins are mixed with other products like liquid pigments or colourants.

3.6 Quality control

The quality of a moulded part of nylon is a reflection of the quality of the resin used and the moulding procedures employed. If acceptable moulding conditions, mould design and quality resin are used, part quality will be satisfactory. If either resin or moulding procedures are deficient, part quality could be unacceptable. Usually, part quality problems can be classified into three general areas: toughness, appearance and dimensions. See section 8 for a discussion of dimensions.

3.6.1 Resin specifications

All ZYTEL® resins are monitored and carefully controlled for uniform quality. This quality will be preserved if the shipping containers remain intact during transit or storage. If the container or seal is broken, the resin will absorb moisture which will affect its quality.

All additives such as colour stabilizers and UV stabilizers, lubricants and colourants are controlled to give consistency of performance both in moulding and in end-use.

Moisture content

ZYTEL® nylon resins are supplied in moisture proof packaging, so that drying should not normally be necessary. However, nylon resins are hygroscopic and absorb moisture on exposure to the atmosphere. If excessive moisture absorption has occurred, then the resin must be dried at 80° C to less than 0,2% moisture content before processing.

Excessive moisture not only affects the flow of the resin but also reduces toughness as well as producing other common flaws (See Section 3.3).

Solution viscosity

The solution viscosity (relative viscosity [RV], viscosity number [VN] or inherent viscosity [IV]) of a resin is a measure of the molecular weight, which in turn controls toughness and mouldability. ZYTEL® nylons are manufactured with a good molecular weight balance between flow in the machine and part toughness.

Since excessive moisture and heat can cause a loss of molecular weight and hence a loss of toughness, care must be exercised to protect this property. For resins that are soluble in common nylon solvents, the solution viscosity can be measured. For resins that have been modified with insoluble additives (glass, minerals, tougheners, etc.) other means such as melt viscosity must be employed to evaluate molecular weight.

Toughness

Since ZYTEL® nylons are often specified because of their toughness, Izod impact strength is closely controlled on the “as shipped” resin. Excessive moisture during moulding degrades the molecular weight and reduces toughness.

3.6.2 Specifications on moulded parts

In injection moulding certain visual observations and laboratory results can be used to determine the quality of a part. These are discussed below.

Appearance

The moulding operator can detect flash, burn marks, etc., by visually inspecting the moulded parts. Usually these problems can be corrected by changing moulding conditions or revising the mould. For many resins, contamination, voids and sinks can best be detected by illumination from a standard lamp such as “Illuminant” C or by transmitted light. In some cases, microscopic examination (10 to 100× magnification) can be used to inspect small but important details of the moulding (voids, crystallinity and contamination). Some of the more common problems that affect the appearance and toughness of moulded nylon parts are:

- *Colour* – Rating may be done with respect to both the actual shade and the uniformity of colour throughout the part. Discoloured parts should be discarded and not reground.
- *Splay* – Although major amounts of splay are usually observed at the machine, small amounts may go undetected until subjected to closer visual examination.
The observation of small amounts of splay may also give clues to moulding machine trends that will lead to large amounts of splay. Usually splay is caused by excessive moisture or heat.
- *Flash* – Visual examination is the simplest way to check for flash
- *Burn Marks* – These marks may be detected at the machine. They result from poor venting.
- *Short Shots* – Gross short shots are easily detected at the machine. However, small depressions can be caused by incomplete fill.
- *Weld Lines* – The presence of visual weld lines constitutes a cosmetic defect and may also result in reduced part strength.
- *Contamination* – Surface contamination can often be detected at the machine.

Internal contamination within thin section parts can often be found by viewing with a strong light.

For small amounts of contamination, microscopic examination can be used.

- *Finish* – The accuracy of reproduction of the mould surface as well as the existence of unwanted scratches can be detected by visual examination.
- *Unmelted Particles* – These can often be seen by careful visual inspection of the part. They appear as discrete particles of different shade.
- *Voids* – In thin sections, voids can be detected by viewing the moulded part through a powerful light beam. Microscopic examination of sliced sections of the parts also can be used to detect small voids.

Toughness

The toughness of parts moulded in ZYTEL® nylon can be estimated by relative viscosity, pass-or-fail tests, destructive testing techniques and end-use tests.

In any of these tests water content must be specified since the toughness of moulded nylon parts is influenced by moisture.

Relative Viscosity (RV) and Viscosity Number (VN)

The potential level of toughness of nylon is roughly proportional to its molecular weight. The relative viscosity, which is a measure of the molecular weight, can be determined as described in ASTM Procedure D789. The viscosity number, which is also a measure of molecular weight, can be determined according to ISO 307. Since these tests depend upon the samples dissolving in formic- or sulphuric acid their usefulness is limited to unmodified nylons such as ZYTEL® E101L and E103HSL. An acceptable RV or VN is necessary but not sufficient to ensure toughness of a given part. Uneven molecular degradation throughout the part, contamination and stress risers reduce toughness but will not necessarily be detected by measurement of relative viscosity.

Pass-or-fail impact tests

The results from these tests are difficult to quantify. In most cases, a large number of individual tests must be conducted before a trend can be discerned. Frequently a criterion is chosen where 50% of all samples pass a given height (or weight) and the other 50% fail. The corresponding height or weight is a measure of the toughness.

Izod impact, dart impact or instrumented impact tests all fall into this category. In some cases the actual test parameters are specified (see ISO 180/1U and 1A for Izod impact) and in others the conditions are chosen arbitrarily.

In establishing a test programme, several factors must be specified and controlled.

- *Sample Orientation and Geometry* – The impact dart must apply the same load to the same location every time.
- *Sample Temperature* – Must be constant and controlled. This is particularly important at test temperatures other than room temperature. Any unusual temperature variation will influence the result. Cold temperature impact tests are especially difficult to control.
- *Sample Moisture Content* – The moisture content in each part influences its behaviour in an impact test. Moisture content must be kept constant for each sample and preferably should be measured.

End-use tests

These tests should be representative of the end-use application of the part. Care must be taken to make sure that meaningful conditions are employed. These conditions should simulate and not exceed the design stress level; otherwise, good parts may be rejected.

4. The injection moulding machine

DuPont nylon resins have been successfully moulded in many types of moulding machines. Since most nylon is moulded on screw machines, this section is devoted only to that type.

4.1 Machine requirements

Today, single reciprocating screw machines are recognised as being the most efficient equipment for injection moulding.

Almost all current models of reciprocating screw machines can be used to process DuPont nylon if the recommendations below are followed.

Moulding machines are usually characterised by the three basic factors; clamping force, shot capacity and plastifying or melting rate.

- **Clamping Force.** In accordance with the suggestions for injection pressure in this report, we recommend that machines for processing DuPont nylon have roughly 0,7 tons of clamping force per cm² of projected shot area.
- **Shot Capacity.** Shot size is equal to the volume (weight) of molten resin injected by the screw during the cycle. The melt densities of ZYTEL[®] un-reinforced nylons are approximately equal to the melt density of polystyrene (the standard used for specifying moulding machines) at normal processing temperatures and pressures. Therefore, the maximum shot weight for ZYTEL[®] unreinforced nylons will be approximately equal to the nameplate or specified polystyrene shot weight.

For short cycle time and good melt homogeneity, the actual retraction stroke should be between 1 and 2 D when using a L/D screw ratio of 20 D. Although it is possible to mould parts outside of the specified range, moulding outside those limits should be done cautiously because it may cause a too long hold-up time or inadequate melt capacity.

When purchasing a machine, the supplier usually gives the purchaser the choice of equipping the machine with one of three different cylinder capacities. This selection will, of course, determine the screw diameter and the maximum effective injection pressure on the resin.

- **Plastifying or Melting Rate.** The plastifying or melting rate is the maximum rate at which an injection machine will steadily melt polymer under a given set of conditions: screw speed, overall cycle and barrel temperature (profile).

Quite often this value can be misleading since the plastifying rate is usually based on the moulding machine operating almost as an extruder.

In a moulding machine, as opposed to an extruder, the polymer is melted in an intermittent manner and thus its effective plastifying or melting rate is considerably lower than that which is usually defined.

The effective melting rate is determined by the following factors:

1. Overall cycle.
2. Shot weight.
3. Cylinder capacity.
4. Screw design.
5. No hold-up spots.
6. Screw speed.
7. Heater band power.
8. Type of resin – structure (amorphous, crystalline), density, melting point, softening point, etc.
9. Form of granules.
10. Percentage of regrind.

Since nylon undergoes a physical change of state and volume (PVT diagram, Fig. 1) during the process of plastification, additional consideration must be given to the selection of equipment and conditions for processing.

The benefit of all these precautions and careful machine selection could be lost if the problem of hold-up spots is not carefully considered.

The injection system should be capable of injecting the nylon at melt pressures up to 140 MPa.

Accurate and reproducible control of the injection pressure is essential to maintaining tolerance of moulded dimensions and other quality characteristics.

4.2 Machine design

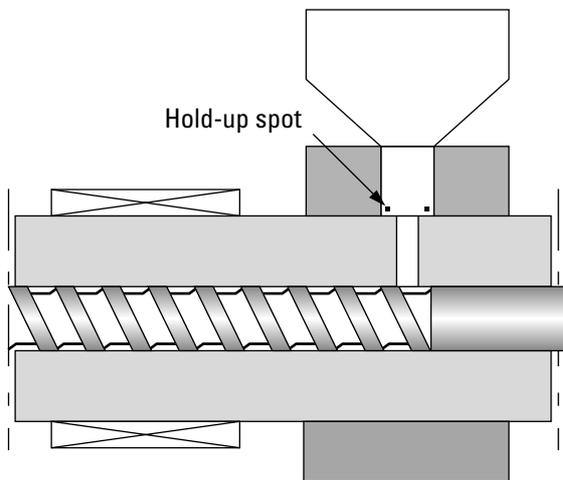
In this section several basic guidelines leading to the correct choice of the injection machine are summarised. It is advisable to follow the instructions pointed out under “Wear” when considering long-term moulding of nylon that contains glass fibres or mineral reinforcement.

4.2.1 The hopper throat

Too often the hopper throat temperature and cooling system of the hopper are neglected or considered unimportant or only as a means of avoiding “bridging” on the screw. Actually, this is the first area where the resin comes into contact with the moulding machine and it is here the awareness of quality becomes important.

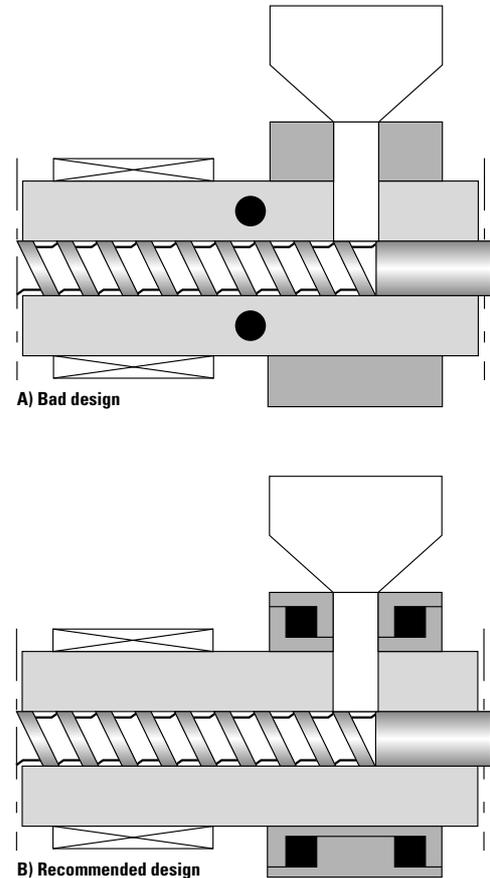
The hopper throat should be well designed so as to avoid any possible hold-up spots (see Fig. 16) where the resin, fines, pigments, lubricants or other additives may be retained. Even if the hopper temperatures are low, the quality of the material can be effected by stagnating in those areas. For example, material or aggregates may fall in batches, thus causing inconsistency in the shot size or screw retraction time. This will affect the MELT QUALITY.

Fig. 16 Bad hopper throat design



Hopper throat cooling is very often badly located in an area where cooling efficiency is poor (see Fig. 17). The result is that hopper throat temperatures can reach high values (above 100° C). For this reason granules in the lower hopper throat area may begin to soften and become sticky when reaching the screw. They will aggregate, or stick to the screw, and so give shot-to-shot consistency problems, screw retraction-time variations, and will directly affect MELT QUALITY. Also, a too low hopper throat temperature may cause the humidity contained in the atmosphere to condense, resulting in moulding problems, such as hydrolysis, melt foaming or splay.

Fig. 17 Hopper throat cooling



4.2.2 Barrel

Several zone heating controls of the barrel (corresponding to the screw's functional zones) are necessary for close temperature control. In all cases, the temperature of the nozzle tip should be independently and precisely controlled by a thermocouple. Barrel length of 20 diameters is required for uniform melt temperature at high outputs.

Wear. Bi-metallic barrel liners have shown outstanding resistance to wear from glass fibres. Nitrided barrel surfaces on the other hand, do not withstand abrasion by glass fibre reinforced nylons and often exhibit spalling (surface flaking) and excessive diametral wear after short term use.

4.2.3 Screw design

Melt quality is achieved only through good homogeneous plastification of the resin. The rate at which a screw can deliver a quality melt depends on its design, on the thermal and rheological behaviour of the polymer and on processing parameters.

In an injection unit, the energy necessary to reach the processing temperature of a resin is provided by conduction of heat from the cylinder and by the heat generated by the screw shearing the polymer.

The conduction heat is limited by the thermal conductivity of the polymer which is poor. The shearing heat is mainly dependant on the viscosity of the resin and on the shearing rate (back pressure and screw speed). Amorphous resins which have a gradual change in viscosity with temperature and usually have a higher viscosity at processing temperature requiring less shearing and deeper screws (Fig. 19 – top).

Crystalline polymers have a sharp drop of viscosity at the melting point. To generate the required shearing heat, it will be necessary to have more friction and therefore shallower and longer metering sections (Fig. 19 below).

For these reasons, and to achieve the best melt quality at the highest output, screw design should be appropriate. Nevertheless, the general-purpose screws that are supplied with most injection moulding machines are usually suitable for moulding DuPont nylon resins at low (recovery) output rates*. At high output rates, however, a screw specifically designed for moulding ZYTEL® nylons will provide greater uniformity of melt temperature and freedom from unmelted particles.

The recommended screw design for high output rates is given in Fig. 18.

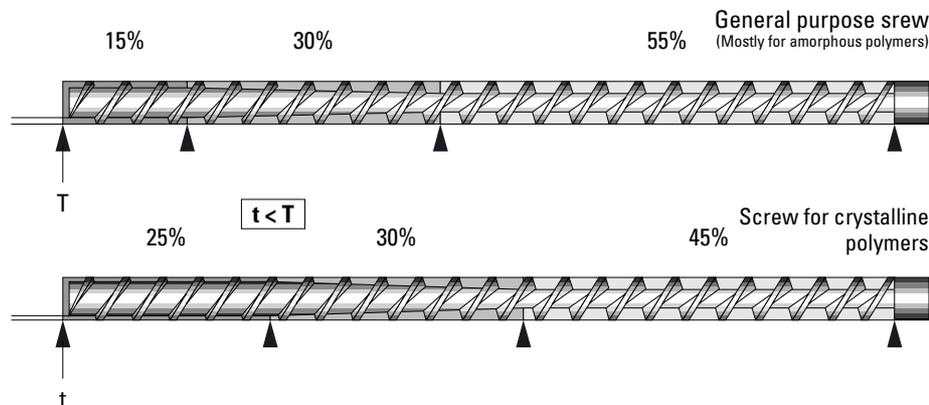
* N.B. "Low Output Rates" means no more than 2-3 D for the screw retraction stroke.

Fig. 18 Suggested screw design for unreinforced ZYTEL®

		Injection unit guidelines for 20L/D screw		
Screw diameter	mm	30	50	70
Compression ratio		2,8 – 3	3 – 3,2	3 – 3,2
Metering depth	mm	1,95	2,10	
Screw rotation speed	rpm	250	150	110
Screw tangential speed	m/s		0,4	
Back pressure	MPa		*	
Optimum stroke vs screw diameter		1 to 2 screw diameters		
Hold Up Time (rough estimation)	min	$\frac{\text{maximum capacity stroke}}{\text{Screw retraction rate}} * 2 * \text{cycle time (s)}$		
Screw retraction rate	g/s		20 – 25	
Cycle time	s	HPT + SRT + opening + ejection + clamping		

HPT: Hold Pressure Time SRT: Screw Retraction Time * Minimum for consistent feeding. Typically 5 to 10 MPa in front of the backflow valve

Fig. 19 Comparison of screw design



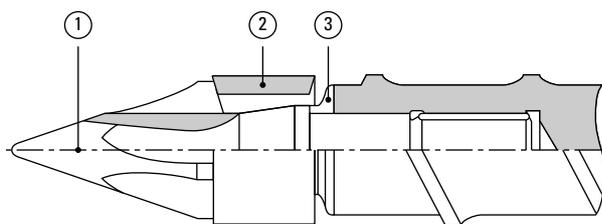
Wear. Abrasive wear of injection screws occurs primarily on the lands and edges of the screw flights. In time, the root diameter will wear somewhat in the transition and metering zones. (Wear in the feed zone is usually the result of too low rear zone temperature for the output involved.)

Flight lands may be hard surfaced with an alloy such as “Stellite” to give better wear resistance than flame hardened or ordinary nitrided screws. Thus, “Stellite” surfaced flights are recommended for screws used in continuous moulding of glass-reinforced resins. Hard chrome plating of the screw is also recommended. (It is even possible to apply abrasion resistant coatings to the entire surface of the screw for ultimate wear protection.)

4.2.4 Back-flow valve

Valves with a check-ring (non-return valve) are necessary for moulding DuPont nylon resins, to ensure constant cavity pressure and weight uniformity from shot to shot. The back-flow valve (Fig. 20) must be carefully designed to close tolerances in order to prevent flow restrictions and should be perfectly streamlined to avoid any possible hold-up spots. The appropriate wear resistant steels must be specified.

Fig. 20 Back flow valve



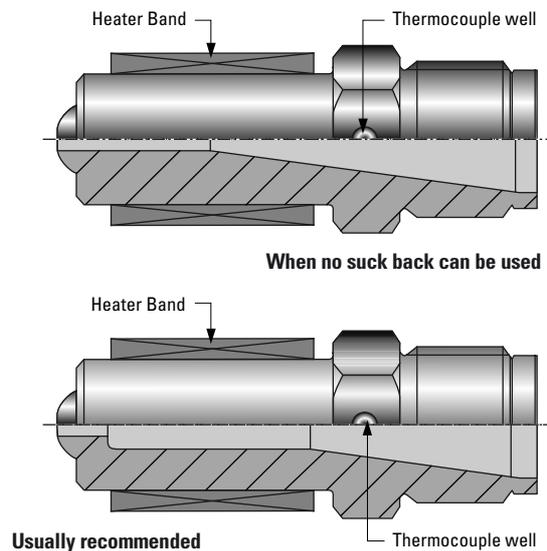
Wear. The back flow valve is the assembly most affected by wear in the injection unit. Sliding type back-flow valves undergo rapid and appreciable wear when used with glass-reinforced resins especially when not properly hardened. Even when hard surfaced, these valves wear and need close checking. Prior to that, worn seats and ring sleeves need replacing since it is important to maintain a pad (cushion) during injection of melt. Good results have been obtained with high chrome loaded tough steels.

4.2.5 Nozzle

Heated, open nozzles (see Fig. 21) are recommended for use in moulding all DuPont nylon resins. Because of the higher melt viscosity of glass-reinforced nylons, the nozzle bore diameter should be about 25% larger than used for un-reinforced nylons.

The temperature control and heating location are very important in order to avoid either undue material degradation or cold slugs.

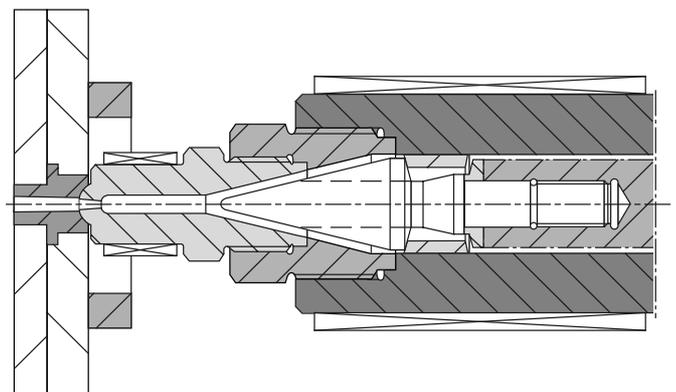
Fig. 21 Recommended open nozzles



4.2.6 Nozzle shut-off valve

Use of a shut-off nozzle invariably leads to a build-up of contamination. As the plunger abrades against the wall of the nozzle, it leaves areas for hold-up spots. If decomposition occurs at these hold-up spots, pressure can only be released through the rear of the screw, leading to blow-backs.

Fig. 22 Open nozzle adapter



4.2.7 Eliminating hold-up spots

The basis of the design of the injection machine, which includes the heating cylinder and the sections through which the melt flows (back-flow valve, head of the screw, adapter and nozzle), should be to obtain a stream-lined flow. Of special importance is the elimination of all possible or potential hold-up spots such as:

- a. The mating surfaces between the adapter and the cylinder and between the adapter and the nozzle.
- b. The check-valve, or shut-off valve on the screw head, where the mating surfaces do not meet at a point where cylindrical machining can ensure the absence of crevices and/or hold-up spots. Experience has shown that whenever such defects are present there are contamination and black spots problems.

- c. Shut-off nozzle which leads to a build-up of contamination especially with glass reinforced nylons and to a high risk of injuries.

An optimum design is illustrated in Fig. 22 (recommended open nozzle, adapter, back-flow valve assembly). Here, the mating surfaces are located at cylindrical joints and an open nozzle is used.

4.3 Maintenance and safety precautions

Once the correct equipment is used in the right way, nylon materials do not require the operator to make any extra checks of the injection machine. Attention should, however, be given to checking the ring assembly wear when moulding nylons containing glass-fibre.

The injection cylinder should have a guard to prevent burns to personnel.

5. Mould design

5.1 Mould material

In general, wear in the cavity, sprue and runners is not as critical as for gates. As the melt flows through the runners and the cavities, a thin frozen skin of resin is formed that reduces wear. In areas where high flow and shear rates occur, local wear will be created since the protective frozen skin may fracture (particularly with reinforced resins).

Premature flashing of the cavity will lead to high wear. It is important for reinforced resins to have a well supported mould (to avoid any possible bending) and sufficient clamping force on the machine to avoid flashing. Cavities must be well vented to avoid corrosion from entrapped gases at weld points (Diesel effect).

The gate area is subject to wear especially when thin gates are used, i.e. pin-point or submarine, and should be checked periodically for erosion which can lead to undesirable projections and faulty sub-sprue ejection.

5.2 The runner systems

Key guidelines to follow when designing a runner system include the following:

- Plan a layout to transmit pressure uniformly to all cavities.
- Make large enough for adequate flow, minimum pressure drop, minimum shear (especially gates for reinforced nylons) and sufficient to allow holding pressure during the whole crystallisation process (Fig. 23).
- Keep size and length to the minimum consistent with minimum cycle time.

5.2.1 Sprues

Sprues should be as short as possible and well polished, with their outlets blended into the runners via smoothly radiused surfaces. The entry into the sprue bush should be 1 to 3 mm larger in diameter than the exit from the machine nozzle. The sprue bush should be tapered with an included angle of 1° to 7°.

Sprues should be large enough to prevent premature melt freezing or poor flow. It is important to design the sprue puller carefully to avoid sprue sticking.

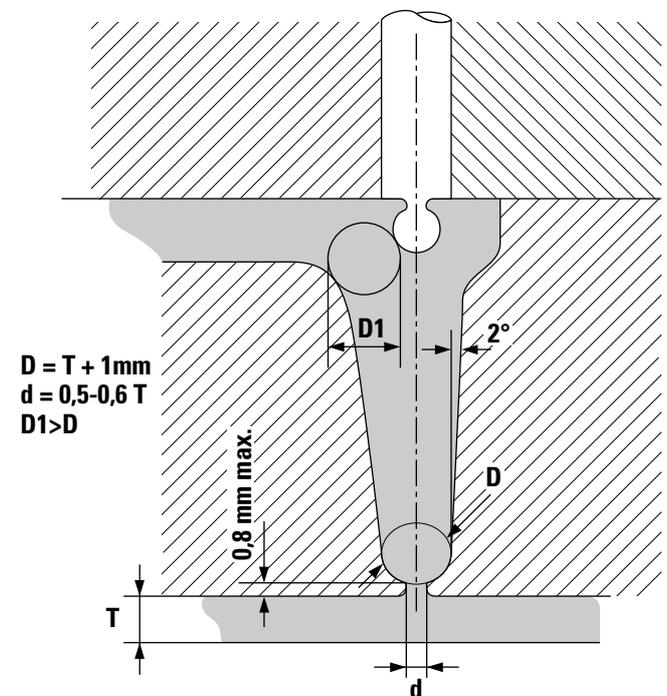
For this reason the sprue bush must be carefully cleaned out with no sharp undercuts. The puller has to be long but thin enough to be frozen when the cycle is finished.

5.2.2 Runners

Balanced vs. Unbalanced Runner Systems.

In balanced runner systems, flow distances from the sprue to the various cavities are equal. Balanced runner systems give the greatest uniformity of flow from the sprue to each cavity, which promotes tight part tolerances if runners and gates are properly sized. Runners and connections between them should be generously radiused for smooth and uniform melt flow, and should have no restrictions (Fig. 23).

Fig. 23 Pin point gate design



When possible, round runners are recommended. A round runner has the minimum surface area per unit volume, thereby giving the lowest pressure and heat loss. The minimum diameter of a round runner is usually about 3 mm, or roughly 1.5 times the thickness of the component. Thicker ones should be used for thick parts and thinner ones might be used for thin parts. The most accurate way to determine runner size is to calculate the anticipated pressure drop and size the runner accordingly.

When trapezoidal runners are used, the slope of the sides should be 5° per side, while the depth should be determined by the diameter of an inscribed circle.

Fig. 24a Tunnel or submarine gate for reinforced nylon

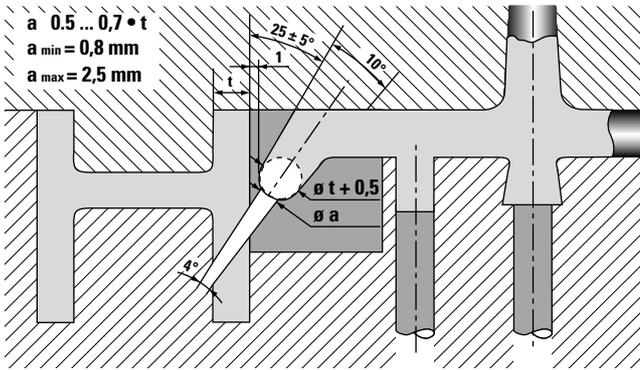


Fig. 24b Tunnel or submarine gate for unreinforced nylon

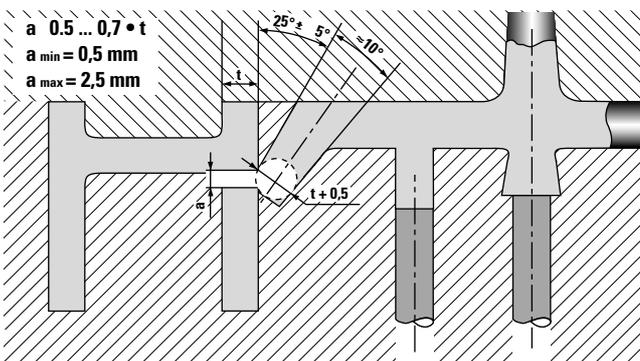
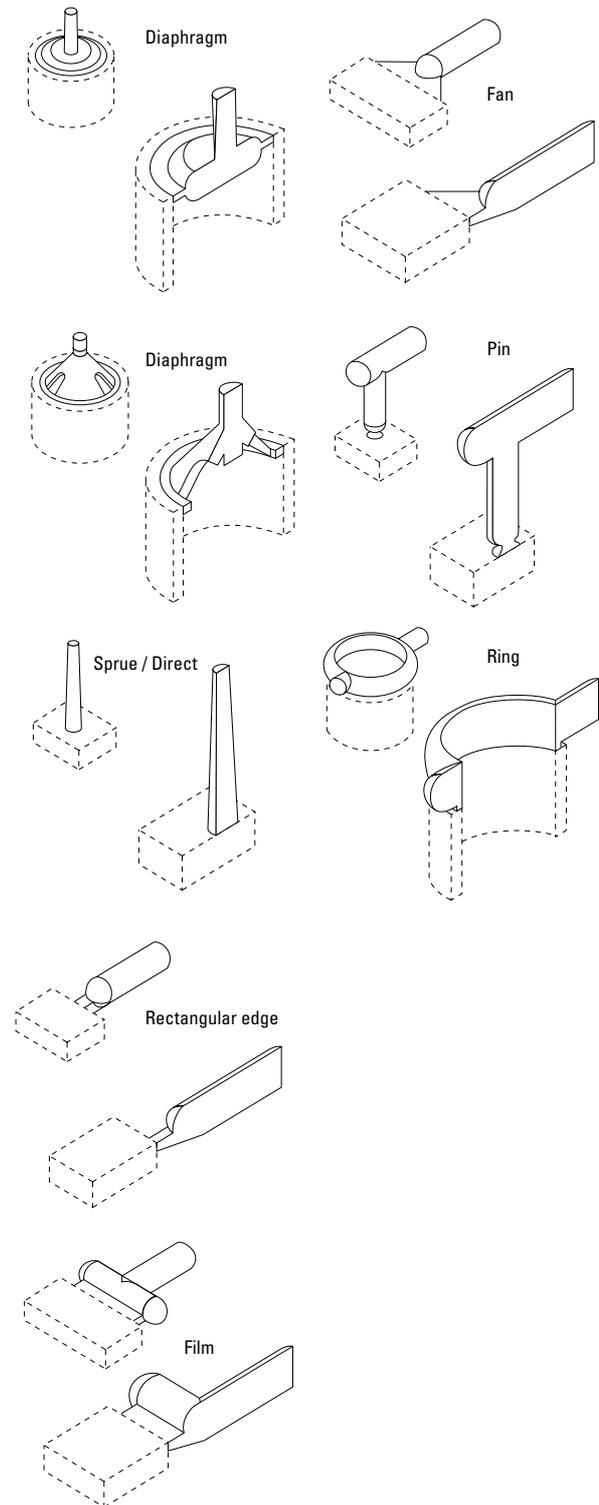


Fig. 25 Different types of gate



5.2.3 Gates

All types of gates have been used successfully with DuPont nylon resins. The location, size and number of gates are important considerations. In Fig. 24a and Fig. 24b tunnel- or submarine gate designs are given. Other types of gate are illustrated in Fig. 25.

Estimating gate dimensions

Generally, gate thickness should be 45% to 75% of the part thickness. For rectangular gates, the gate thickness should be 65% of the part thickness, the gate width should be one to two times the gate thickness and the gate land should be no more than 1 mm.

For tunnel or submarine gates the minimum recommended diameter is 0,7 mm, however it should never exceed 2,5 mm. The design of a long tunnel gate is critical and the typical “amorphous design” must be avoided.

For glass reinforced nylons, tunnel and pin gates can be used provided the gate diameter is greater than 0,7 mm.

Gates that are too small will usually increase shrinkage and warpage, and increase the risk of fibre breakage (see Fig. 11: *Retention of mechanical properties vs. fibre length*). Pin gate diameters larger than 2,0 mm should be avoided because of their too high resistance to breakage during the ejection phase.

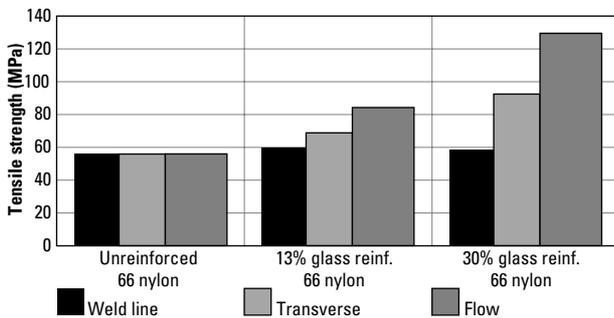
Gate position. When there are large differences in the thickness of the part, it is best to make the entry point at the thicker section in order to simplify filling and to minimise sinks and voids.

To minimise surface defects and jetting, the flow from the gate should impinge against the wall of the cavity or a core pin. However, gates should not be positioned so that the incoming melt stream is directed against the core that is not registered in both mould halves.

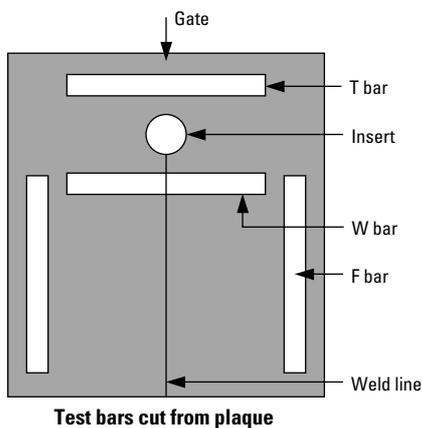
Location of the gate will determine the position of the weld lines and consequently of the vents (see Section 5.3 *Venting*).

For glass-reinforced nylons, gate location is extremely critical to minimise part distortion after moulding and control end-use properties, as the fibres tend to orient in the direction of melt flow (see Fig. 26).

Fig. 26 Effect of gate location and flow orientation on mechanical properties



Relationship between polymer orientation, weld line and tensile strength



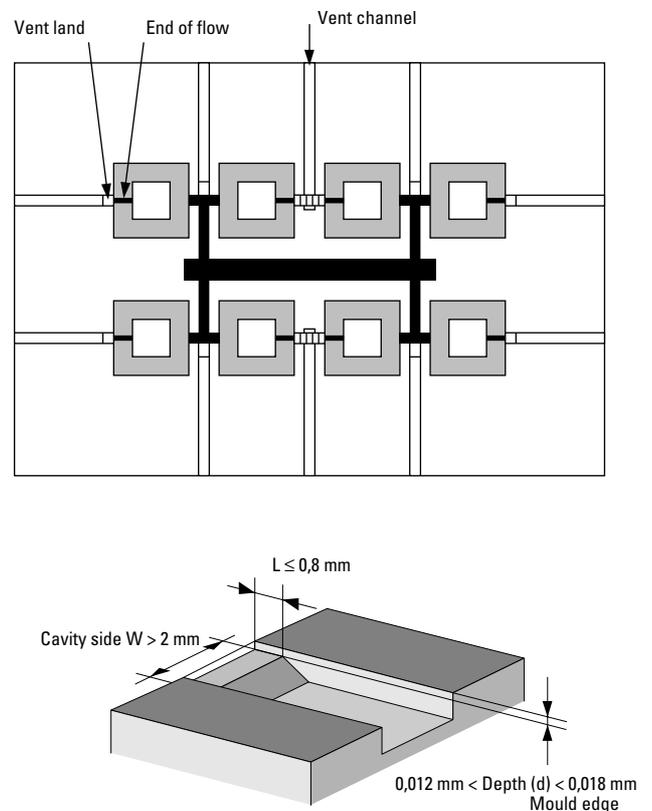
5.3 Venting

Inadequate mould venting can cause the following problems:

- Poor weld line strength.
- Discolouration (burning) of the nylon.
- Erosion or corrosion of the mould.
- Dimensional variation on the moulded part.
- Short shots.

Both cavities and runners should be vented at the parting line as recommended on Fig. 27.

Fig. 27 Vent geometries for nylon resins



The area of the vent must be large enough ($W \times d$) to prevent a rise of gas pressure in the mould cavity. The vent length should not exceed 1 mm. The area of the escape passage leading from the vent should increase in proportion to its distance from the cavity edge. It helps to reduce the “Venturi effect”, and therefore mould deposit.

5.4 Undercuts and tapers

The following are general suggestions for ejecting undercuts with nylon resins:

- The undercut should be rounded and well filleted to enable easy slippage of the plastic part over the metal.
- If deformation of the undercut is evident, the moulding parameters should be adjusted to minimise the effect. Frequently, higher mould temperatures or shorter cycles can be useful in stripping internal undercuts while longer cycles and higher shrinkage could aid the stripping of external undercuts.

Because of the low elongation of glass-reinforced nylons, undercuts greater than 3% should be avoided. A taper (draft) of $\frac{1}{4}$ to 1° on ribs, bosses, sides and sprues should be sufficient.

5.5 Thermal regulation circuit of the mould

As a result of the high influence of mould temperature on crystallisation quality – and mechanical properties – with crystalline resins, the regulation circuit should be designed carefully to provide the best homogeneous wall temperature.

Moulds operated without any cooling ultimately reach an equilibrium temperature, as the heat added to the mould by the molten polymer equals the heat lost by radiation, conduction and convection. The mould temperature at the optimum moulding cycle will be a compromise between a hot mould for ease of filling and surface quality and a cold mould for rapid solidification and ejection of the part. Ideally, the mould-cooling channels should be located in those areas that require the most heat transfer. These channels should not be closer to the cavity wall than 1 channel diameter.

For uniform mould temperature, the temperature difference between the entering and exiting coolant (water, oil, etc.) should be as small as possible (5°C maximum). The flow rate of coolant through the channels should be high enough that small fluctuations in flow rate will not alter the mould temperature. For high tolerance moulding, the cavities should be cooled in a parallel arrangement which makes each cavity temperature more uniform than in a series configuration.

When dimensioning the channel, the mould designer needs to meet two opposing goals:

- The channel must be large enough to ensure the coolant throughput rate is sufficient for the heat removal required.
- The channel must be small enough to ensure turbulent flow, as the heat transfer coefficient is far better in turbulent flow conditions.

5.6 Hot runner moulds

There are a lot of commercially available hot runner systems on the market. Suppliers offer a wide range of designs. This allows the choice of the right system for the application and the raw material.

The processing window and behaviour in terms of solidification are very different between amorphous and semi-crystalline materials. Special attention has to be given to this point. A careful selection of the hot runner system is always required, in particular for flame retardant grades.

The main guidelines for hot runner selection and design requirements for MINLON[®]/ZYTEL[®] are given in this chapter.

Thermal insulation

Due to the narrow processing window in terms of melt temperature for nylon, a very well designed thermal insulation between hot runner and mould is needed. This is to avoid big temperature differences within the system.

See examples in Fig. 28 and 29 shown for nylon 66 types.

Manifold

For a careful treatment of the melt, uniform temperature distribution is essential. The following principles must be considered for the manifold:

- Low pressure drop.
Only manifolds with full diameter for the flow are recommended (Fig. 30). Internally heated systems with a ring flow are not recommended.
- A flow path without dead ends is recommended (Fig. 31).
- Naturally balanced nozzle arrangements are recommended (Fig. 32). This ensures a uniform pressure drop and the same dwell time to each injection point.

Fig. 28 Temperature in the hot runner area for PA66

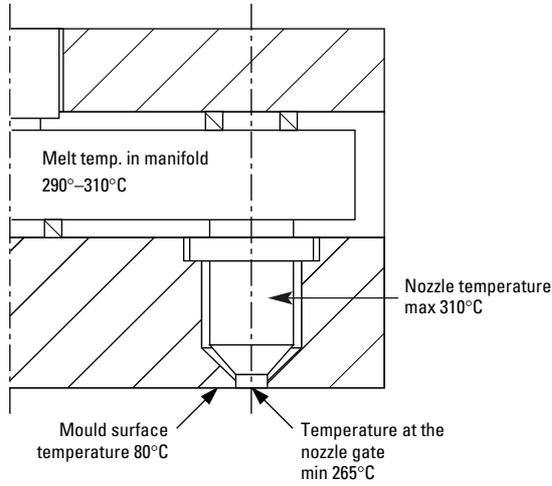


Fig. 29 Effects of thermal insulation on the temperature profile in the nozzle

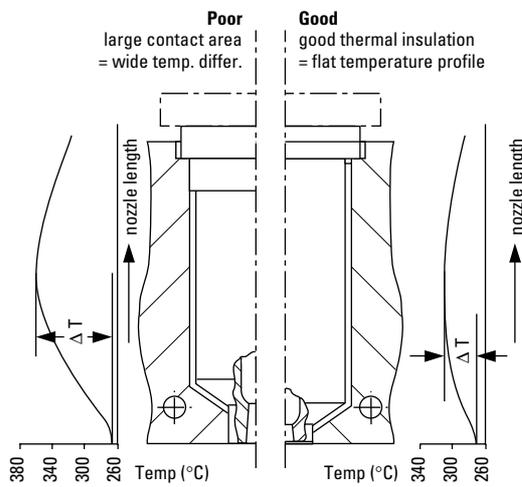


Fig. 30 Cross section for flow and heating of manifold

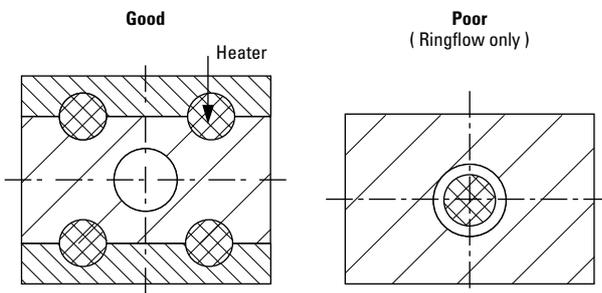


Fig. 31 Flow path design

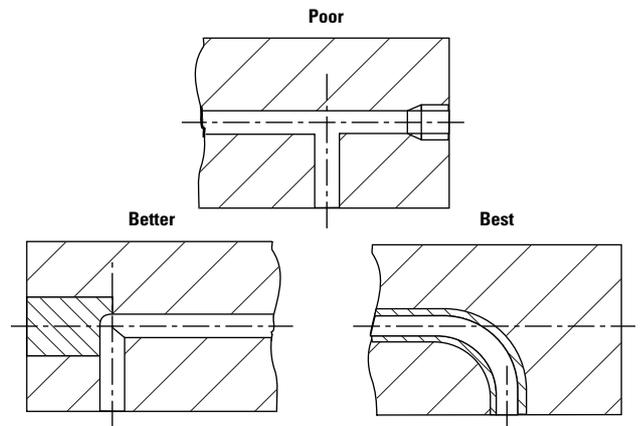
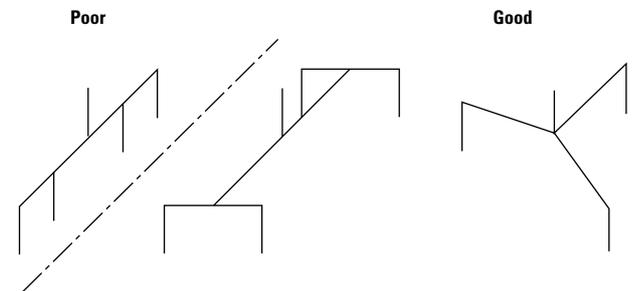


Fig. 32 Nozzle arrangement for multiple cavity mould



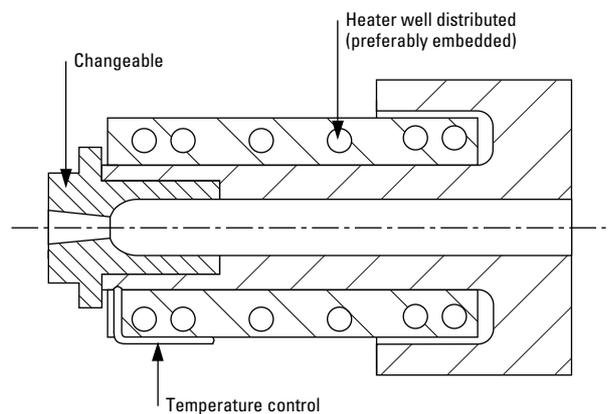
Nozzles

The main points for good results are low pressure drop and very well designed temperature distribution with a thermocouple control in the gate area.

Best solution:

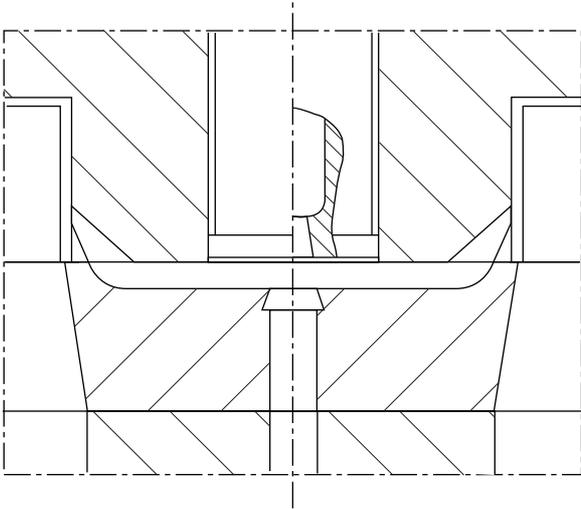
Externally heated open nozzles with a full free flow channel must be used whenever possible (Fig. 33).

Fig. 33 System for recommended nozzles



These can be used for applications with cold sub-runners (Fig. 34).

Fig. 34 Cold sub-runner with externally heated nozzle



In particular, materials with fibre or mineral reinforcement should preferably be processed in this way. A hole opposite the gate will catch any cold plug from the nozzle.

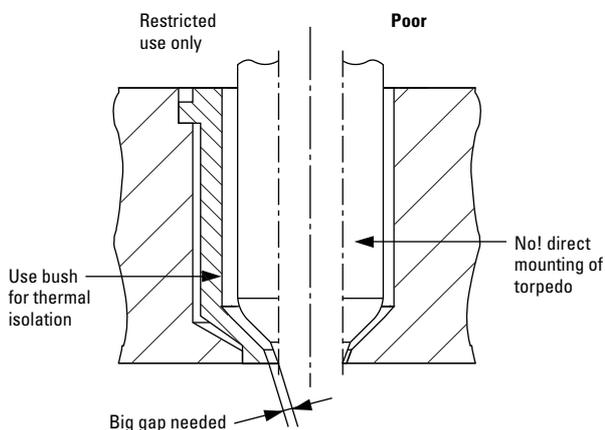
For direct injection, these nozzles can be used with a modification in the gate area (small torpedo) to avoid the formation of “threads”.

Less preferable:

- Nozzles which divide the flow in two or more small flows.
- Nozzles with hold-up spots in the front zone.
- Internally heated systems with only a ring flow.

If these types have to be used for direct injection to get a very small injection point, a bushing as thermal insulation is very important (Fig. 35).

Fig. 35 Internally heated hot runner nozzle



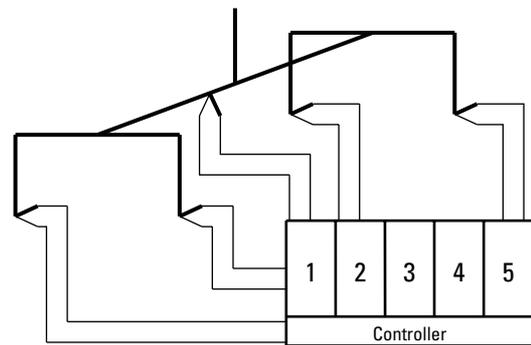
Usage of needle type nozzles is always a compromise. When they are used to get a very good surface quality in the gate area the following has to be kept in mind:

- Apart from the very high cost, they cause a big pressure drop due to the ring flow. The flow path cannot be well designed. With reinforced products functional problems can occur in the sealing systems.
- A nozzle / needle combination with large cross sectional area for flow should be used. Hydraulically operated units are recommended, a system with a spring is not recommended.

Temperature control

A separate temperature control circuit for the manifold and each nozzle with fully closed loop control is recommended (Fig. 36). The best results are obtained with automatic temperature controllers with PID response. They permit a minimum variation round the setpoint temperature.

Fig. 36 Temperature control for each nozzle and the manifold

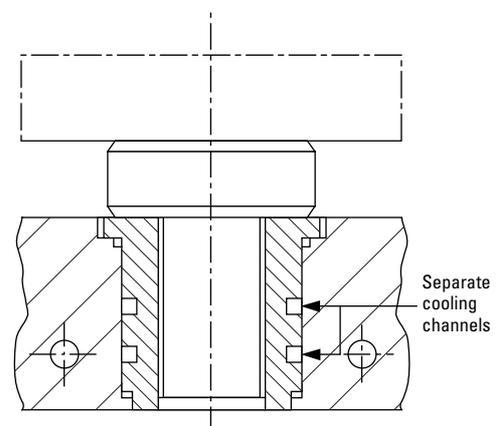


Cooling channels in hot runner moulds

The use of separate heating/cooling channels in the hot runner nozzle area is advantageous (Fig. 37).

The temperature conditions in the hot runner area are then more easily achieved without affecting the overall mould temperature.

Fig. 37 Separate heating/cooling channels in hot runner area



6. Moulding conditions

6.1 Melt temperature

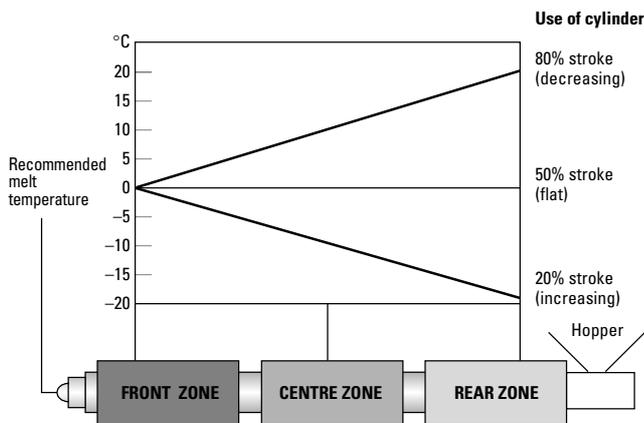
The melt temperature is taken directly from the molten polymer (using a needle pyrometer) and should be checked periodically during a moulding run to ensure that it does not exceed the recommended limits. Typical melt temperatures for DuPont nylons are shown in PART II.

6.2 Cylinder temperature profile

The temperature of the melt and its homogeneity in an injection screw machine is determined by the cylinder temperature settings, the screw design and the hold-up time. Independent temperature control of the three zones of the cylinder should be provided. The temperature of the nozzle must be independently controlled too.

In figure 38 the cylinder temperature profile to reach the recommended melt temperature as function of the stroke is given. The design of screw, machine and cylinders varies and therefore it is not possible to specify a temperature profile that will be applicable in all cases.

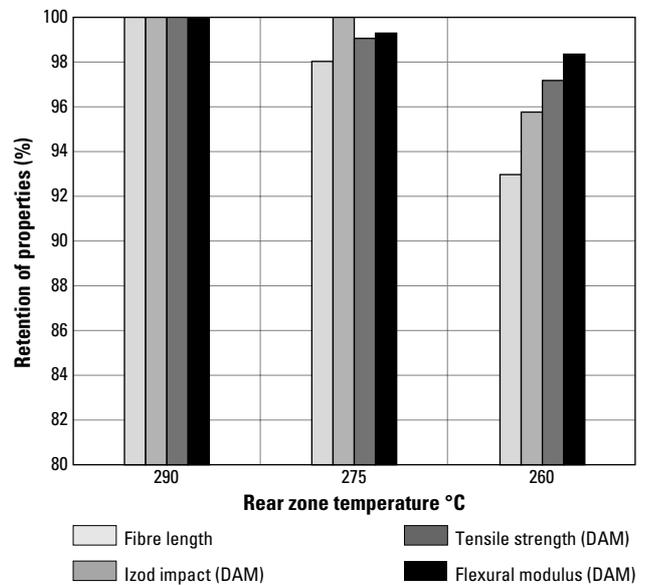
Fig. 38 Cylinder temperature profile for a constant melt temperature



The hopper zone temperature is important and must be kept, with a well located cooling system, between 70 and 90°C in order to avoid bridging or overheated resin. (see Fig. 16 and 17).

With glass-reinforced nylons, the cylinder temperature profile can reduce fibre length in the moulded part, especially when the control setting of the rear zone is too low. In addition, the screw retraction time increases while high torque loads are observed. As illustrated in Fig. 39, decreasing the critical rear zone temperature lowers the average glass fibre length, and thus tensile strength Izod and flexural modulus also decrease, although the most significant drop is seen in impact properties.

Fig. 39 Effect of rear zone temperature on average fibre length and properties (for reinforced 66 nylon)



A rear temperature setting of 290°C is suggested as a minimum for glass-reinforced 66 nylons. Excessive rear zone temperature may result in premature melting of the polymer and bridging problems, thus leading to erratic feed.

When moulding glass-reinforced nylons, high rear cylinder temperatures should be used to:

- Improve screw recovery rates.
- Reduce damage to glass fibres.
- Reduce potential wear problems resulting from abrasion between un-melted particles, the screw and/or barrel.
- Reduce torque loads on the screw, thus reducing screw stalling or damage at fast cycles.

6.3 Nozzle temperature

The nozzle should act merely as a melt conveying pipe and must not affect the temperature of the melt. The nozzle temperature should be adjusted to prevent freeze-off or drool. For optimum performance, the nozzle should be controlled independently at a point near the orifice.

To prevent drooling, the use of a few millimetres of decompression only is recommended when using a standard open nozzle as in Fig. 21. A second heater for a longer nozzle, also independently controlled and kept at the lowest temperature possible, may be necessary. When using a long nozzle it is advisable to use one heater at the front to control the freezing/drooling, and a second heating system independently controlled that must be kept at the lowest temperature possible.

6.4 Injection speed (rate) and injection pressure

All modern injection moulding machines give the injection pressure required to achieve the fill rate or injection speed setting.

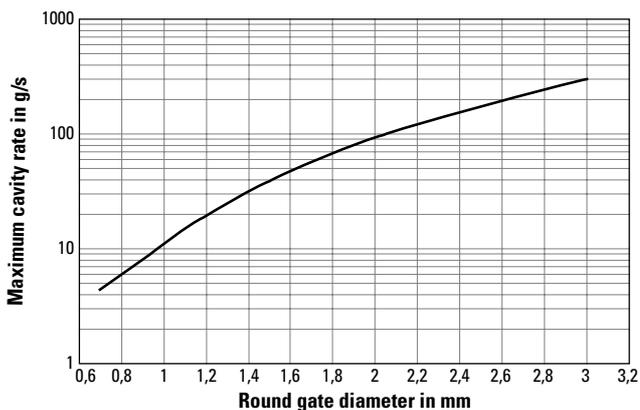
The optimum fill rate for a part depends on the geometry of the part, the size of the gate and the melt temperature. When moulding thin section parts, high injection rates are usually required to fill the part before the resin freezes. When moulding thick section parts or parts with relatively small gates, it is sometimes desirable to use a slow injection rate to delay freezing of the gate and thereby allow packing of the part for the longest possible time.

Surface gloss will be more uniform if the injection rate is fast enough to allow the cavity to be filled before the nylon begins to solidify.

Because glass-reinforced or otherwise nucleated nylon resins freeze more rapidly than un-reinforced nylons, fast fill rates (injection speed) are necessary.

Nevertheless, too high a shear rate at the gate may affect properties. Fig. 40 gives guidelines for un-reinforced nylon grades. Note that a poor surface finish (frosting) usually results from premature solidification due to a too slow fill rate, and can frequently be mistaken for either poor glass fibre dispersion or wet resin (splay).

Fig. 40 Maximum fill rate vs round gate diameter for unreinforced nylon 66



Melt viscosity increases with the glass content. For this reason the injection pressure necessary for glass-reinforced nylon resins will be higher than those for un-reinforced nylons. Pressures in the range of 75 to 100 MPa are usually required.

The effect of injection pressure on the flow of several nylon grades in the 1,0 and 2,5 mm snake flow configurations is shown in Figs. 41 and 42.

Fig. 41 Flow characteristics vs pressure for ZYTEL® 101 at 65°C mould temperature

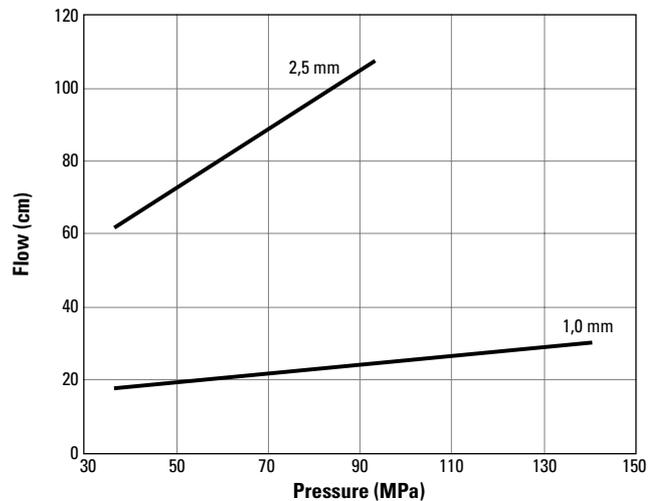
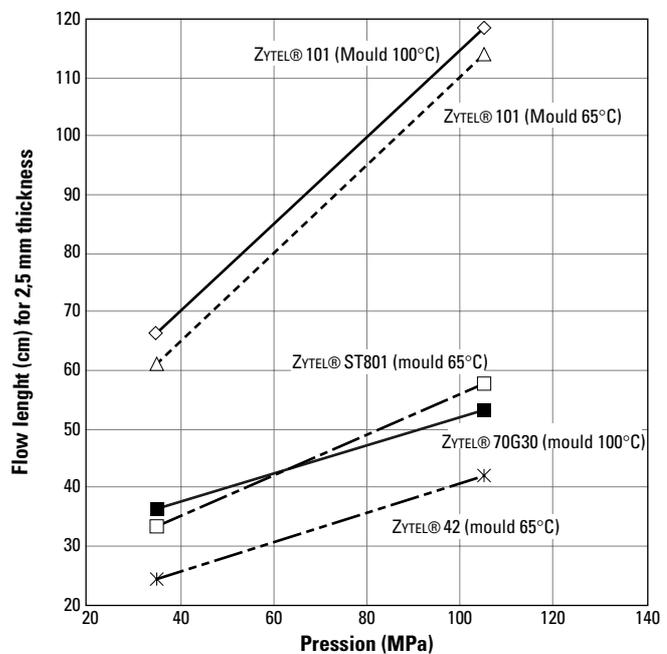


Fig. 42 Flow characteristics vs pressure for several ZYTEL® grades



Excessive pressure just before the part is full can result in a highly stressed area near the gate and lead to reduced performance of the part in use.

It is often desirable to use a two-stage filling cycle:

- Initially injecting at high speed to fill the part at the desired rate, and then
- Filling with a **reduced** speed to avoid burning at the end of the flow.
- Set the change-over point from the dynamic injection phase to the static holding pressure phase (V/P or switch point) as late as possible, but not after the mould is completely full.

6.4.1 Dynamic Pressure Drop (DPD)

When the mould is equipped with pressure transducers, a change in melt viscosity resulting in a change of the pressure needed to fill the cavity can be detected.

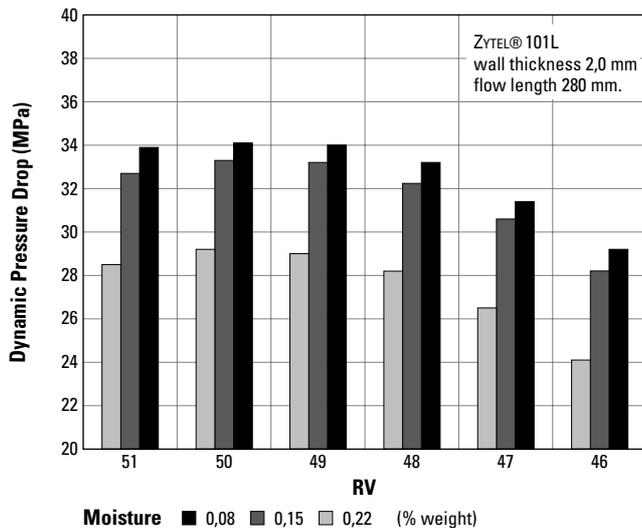
Two pressure transducers are needed for this purpose, as calculation is based on the dynamic pressure drop – the pressure at the first sensor when the melt reaches the second as Fig. 10 shows.

For example, a change in relative viscosity of the resin or in the moisture content can indirectly be measured through the DPD measurement.

Relative viscosity is a reliable measure of average molecular weight, and is determined routinely in the laboratory. It is a useful guide to impact strength and correlates with melt viscosity.

Hydrolysis and polycondensation reactions occur during processing and bring about changes in the molecular weight and melt viscosity, and thus in DPD. The cross effects are difficult to control, since moisture, melt temperature and hold-up time all affect the reactions. Fig. 43 shows the relationship between DPD, RV and moisture content for nylon 66.

Fig. 43 Dynamic Pressure Drop vs moisture content and RV of granules



6.5 Hold Pressure and Hold Pressure Time (HPT)

6.5.1 The Hold Pressure

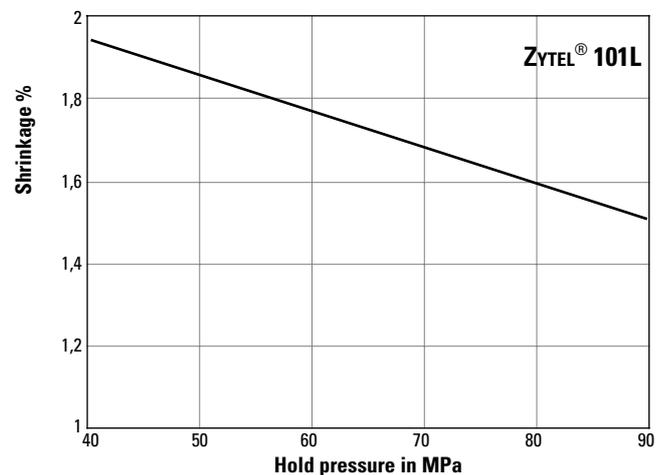
As with all thermoplastic materials, the mould shrinkage of nylons depends mostly on the holding pressure and on the time the pressure is maintained on the molten resin in the cavity. The holding pressure is applied to the resin during the crystallisation process in order to compensate the volume change and then limit the shrinkage of the part (see Section 2.1 *Material structure*).

Due to the crystalline character of nylons, the highest possible holding pressure is applied in order to diminish the mould shrinkage, usually around 90 MPa. A variation of 10 MPa will result in about 0,1 % variation in shrinkage.

It is essential that only one pressure setting is used on the machine for the whole of the HPT. If not, then the moulded part could show non-uniform crystallinity, resulting in lower mechanical properties.

Fig. 44 illustrates the influence of the Hold Pressure on the shrinkage of ZYTEL® 101L.

Fig. 44 Shrinkage as a function of hold pressure for a part 3 mm thick and a mould temperature of 70° C

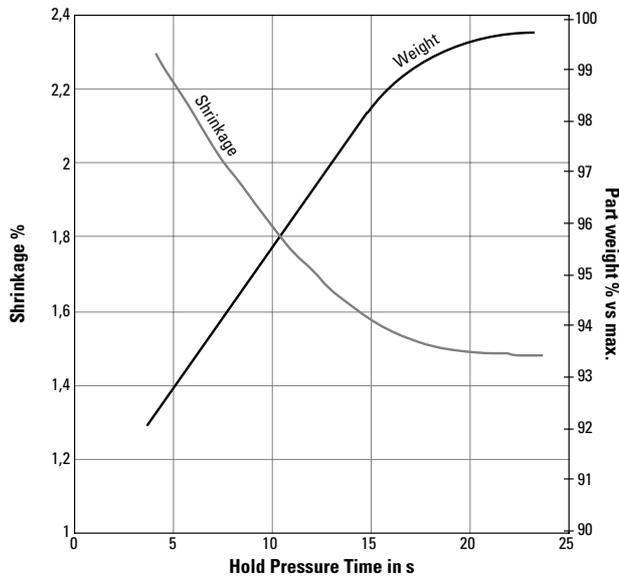


6.5.2 The Hold Pressure Time (HPT)

The mould shrinkage of nylons depends on the holding pressure (HP) but also on the time the pressure is maintained on the molten resin in the cavity. This is called the Hold Pressure Time (HPT). To obtain parts with a good appearance, good mechanical properties, dimensional stability and no distortion, it is essential to have a sufficient Hold Pressure (HP) and a sufficient HPT to allow a high rate of crystallisation at constant pressure. It must be emphasised, however, that the HPT is only effective with parts that have adequate gate dimensions. The gate should freeze off at the same time the part has completely crystallised and not before. The HPT depends on the part thickness and to a lesser extent on the mould temperature.

An excellent method for establishing the correct HPT with standard moulding conditions for any part is to weigh the part at different values of HPT. A typical graph of such measurements is shown in Fig. 45.

Fig. 45 Shrinkage and part weight as a function of HPT for ZYTEL® 101L (for a part of 3 mm thickness)



During the trial the total cycle time should be kept constant to maintain a constant melt temperature. The correct HPT is achieved when the part weight first reaches the maximum. Also shown in Fig. 45, is the fact that the shrinkage reaches a minimum at the correct HPT.

Typical HPT are listed for resins moulded at standard conditions in Part II.

With a single sensor, the crystallisation time is determined by analysing in-cavity pressure in the area close to the gate. This is done within a single moulding cycle, by analysing the pressure curve changes during the holding pressure phase.

The system determines the rate of crystallisation of the resin under fixed moulding conditions – the crystallisation can vary with the melt temperature or with the mould temperature. The presence in the melt of crystallisation nuclei such as pigments or regrind influences the rate of crystallisation, which can be measured.

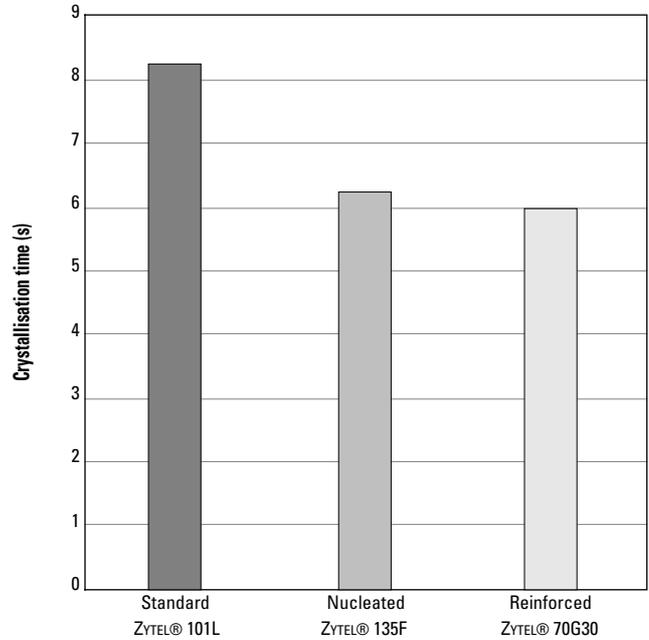
Crystallisation time of several nylon resins measured using this method are shown in Fig. 46.

6.6 Screw rotation speed and back pressure

Energy input from the screw should constitute about 80% of the energy to raise the temperature to a uniform value (heater bands contribute a minor amount). Therefore the design and operational characteristics of the screw should also be considered.

For un-reinforced nylons, the suggested maximum peripheral speed is 0,4 m/s.

Fig. 46 Crystallisation time for several nylon grades

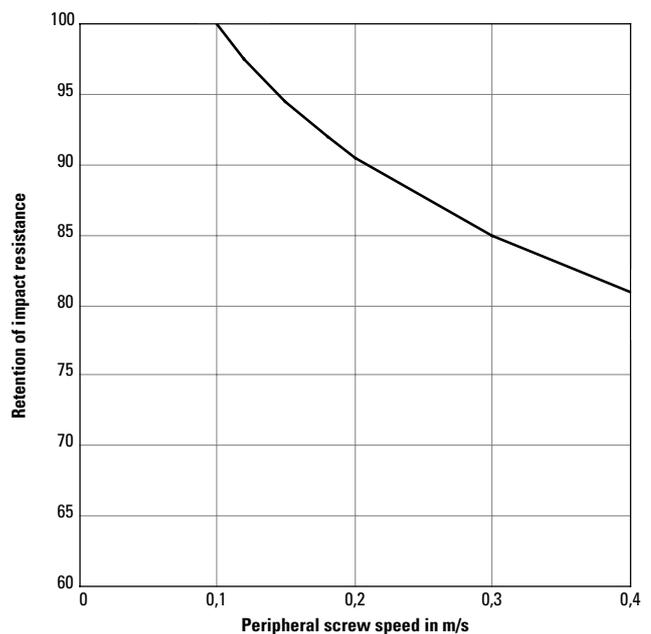


Part 2 mm thickness, moulded at typical mould temperature with a hold pressure of 85 MPa. The melt temperature is 290 °C

For glass-reinforced nylons the Screw Rotation Speed (RPM) should be low. A maximum of 0,15 m/s peripheral screw speed is suggested in order to minimise glass fibre breakage, and to avoid excessive wear of the screw or the barrel.

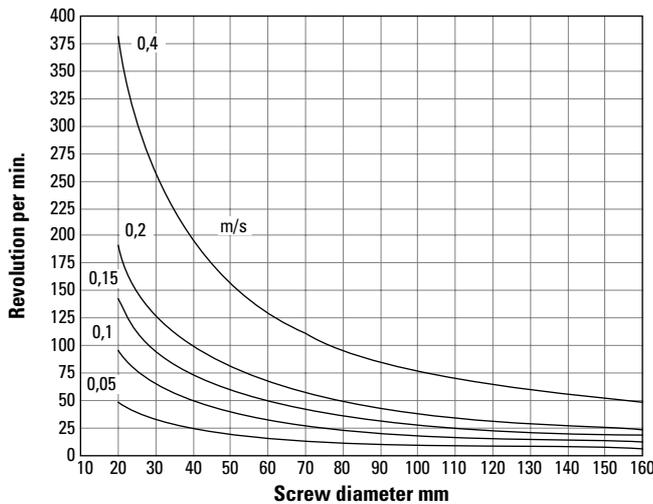
The effect of excessive peripheral speed for glass reinforced resins is illustrated in Fig. 47.

Fig. 47 Effect of screw speed on impact properties



The graph of Fig. 48 can be used to find the maximum screw rotation speed (RPM) as a function of the screw diameter and of the peripheral speed.

Fig. 48 Screw speed vs. screw diameter



Increasing the screw speed when using a low compression general-purpose screw often results in a decrease in melt temperature. Screws with deep and short metering sections may pump un-melted particles at high screw speeds.

Little back pressure should be used. The effect of back pressure is to produce additional screw working which can cause fibre breakage with reduction in physical properties of the moulded part. Increasing back pressure increases the work done by the screw on the molten polymer. This could incrementally increase melt temperature and uniformity. Where melt quality is marginal, higher back pressure may reduce un-melted particles, but it will not substantially increase melt quality.

Increasing back pressure also increases recovery time. The lowest possible back pressure consistent with good melt quality is recommended during the moulding of DuPont nylon resins.

6.7 Decompression

Normally only melt decompression, is required in order to avoid leakage of material from the nozzle. The use of decompression helps to prevent nozzle drool from hot-runner tools and to stop vent discharge in vented cylinders.

Use of excessive decompression can cause air to be sucked in through the nozzle. This can result in oxidation of material which will be seen as areas of discoloration in the moulding. Another consequence could also be the injection of a cold slug in the next shot leading to surface defect, to part weakness and inconsistent weight.

6.8 Mould temperature

It has been seen that since nylon is a semi-crystalline material, it has a relatively high mould shrinkage when compared with amorphous materials. In general, the cooling rate influences the degree of crystallisation, and therefore the shrinkage.

The cooling rate in injection moulding is mainly determined by the part thickness and the mould temperature.

At low temperature, the cooling rate is high, resulting in a lower degree of crystallinity than for high mould temperatures. Therefore, mould shrinkage increases with mould temperature, as shown in Fig. 49.

Fig. 49 Shrinkage as a function of mould temperature for a part 3 mm thick and a pressure of 90 MPa

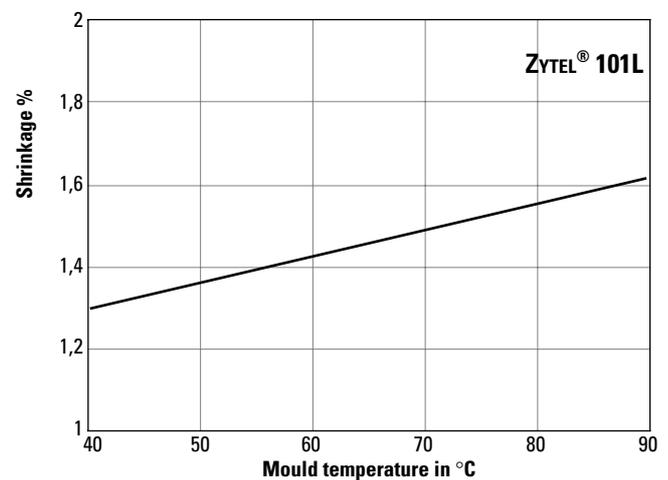
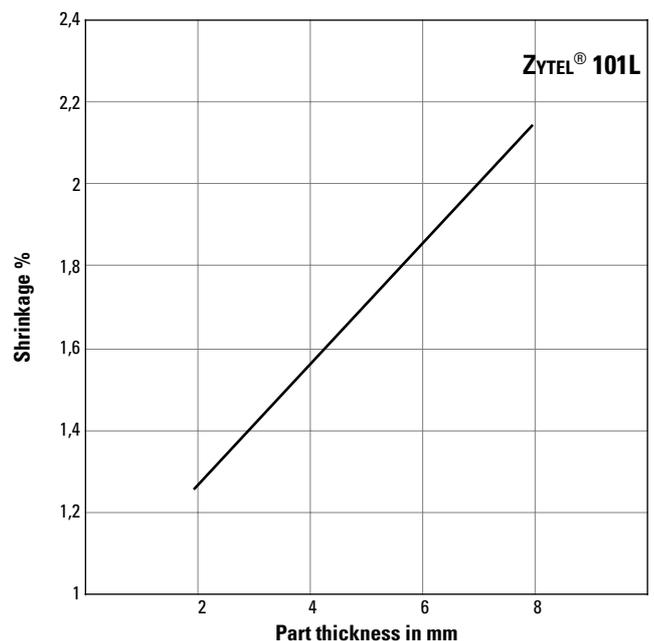


Fig. 50 Shrinkage as function of part thickness, for a mould temperature of 70°C and a hold pressure of 90 MPa



For thick parts, the cooling rate is much slower than for thin ones because of the low thermal conductivity of thermoplastics. Thus, thin parts have a lower degree of crystallinity. Therefore, mould shrinkage increases with part thickness, as shown in Fig. 50.

At the optimum mould temperature, as listed for every grade in Part II the optimum degree of crystallisation can be reached.

Also, parts moulded at high temperatures have a low post-moulding shrinkage and good dimensional stability. Parts moulded at low temperatures, however, have a high post-moulding shrinkage which sometimes gives rise to severe internal stresses. These can often cause premature failure of moulded parts.

Sometimes a cold mould is used to improve toughness. However, the benefits gained from this are marginal since moisture absorption in itself improves the toughness of moulded parts. If the cold mould causes internal stresses, then nothing has been gained. Also a cold mould leads to considerable post-moulding crystallisation and shrinkage, so it is best to avoid its use.

Glass-reinforced nylon resins can be moulded over a wide range of mould temperatures. However, for best part surface appearance, the mould should be hot (usually 100°C to 120°C). High mould temperatures require oil heaters or pressurised water temperature controllers, but will significantly improve surface finish, mould filling, and reduce surface blemishes (frosting).

6.9 Cooling time

Because of the crystalline characteristics of nylon resins, there is no need to cool the part once the crystallisation process is over (after HPT). The part is stiff enough to be ejected.

6.10 Mould release

The lubricant present in MINLON® and ZYTEL® nylon resins is normally adequate for part ejectability even in difficult cavities such as for helical gears.

7. Moulding machine operation

7.1 Start-up

Machines, containing thermally sensitive resins like acetal, PVC or resins with higher processing temperatures than nylons, should be purged with high density polyethylene (HDPE) or polystyrene (PS).

Large machines previously moulding ABS or polycarbonate may require a special purging procedure, for example:

- Purge with HDPE (preferably extrusion grades).
- Purge with glass reinforced ZYTEL®.
- Purge with acrylic.
- Purge with HDPE.

During the final HDPE purge, the cylinder temperature should be set as for the particular type of nylon.

This is common start-up procedure:

1. Check that the hopper feed slide is closed.
2. Set the cylinder temperature to 10°C below the minimum moulding temperature and set the nozzle to operating temperature. Allow heat to “soak in” for at least 20 min. Raise cylinder temperatures to their operating temperatures.
3. Check to see if the nozzle is at the correct temperature.
4. Jog the screw, if it will not rotate, allow a longer soak time for the cylinder temperature.
5. When the screw begins to rotate, open the feed slide briefly and then close it. Check the load on the screw drive. If it is excessive, increase the rear zone temperature. The nozzle must be “open” at this time.
6. Open the feed slide and keep the screw in the forward position. Extrude melt and increase the front zone temperature if un-melted particles are seen.
7. Adjust the stroke to approximate shot weight; take several air shots at the approximate overall cycle. Purge on cycle for 10 minutes and then check the melt temperature with a needle pyrometer. Make any adjustments in the cylinder temperatures necessary to obtain the recommended melt temperature. (This procedure should be repeated when a significant cycle change occurs.)
8. Bring the injection cylinder forward. Start at low injection fill pressure and speed (except where short shots will interfere with part ejection) and adjust the moulding variables for best part appearance (maximum shot weight). A fast fill will usually be required.

7.2 Cycle interruption

In case of a short moulding interruption the following procedure is recommended in order to avoid degradation of the polymer.

1. Retract the injection unit.
2. Reduce the cylinder temperature settings and adjust the melt temperature to 30°C below the recommended melt temperature.
3. During the interruption take frequent air shots from the barrel to purge the degrading resin.

If the interruption is likely to be extended, purging with HDPE or polystyrene is recommended.

7.3 Shut down

The machine should be shut down with polystyrene, or polyethylene, which cuts the time required for subsequent start-up and reduces problems of contamination. The following shut down procedure is suggested.

1. Shut the hopper feed slide while continuing to mould on cycle. Don't shut down the cylinder and nozzle heaters.
2. Empty the hopper; add a quantity of polystyrene or polyethylene; extrude until the screw pumps itself dry.
3. Leave the screw in its forward position.
4. Shut down the power supply to the cylinder heater bands.

7.4 Purging

Common purging materials that effectively remove nylons are polystyrene, cast acrylic (the nozzle must be removed during purging), and high density polyethylene (or glass-reinforced PE, followed by HDPE).

Glass-reinforced nylons can be purged effectively at temperature using the following procedure:

1. Retract screw injection unit from sprue bushing and keep the screw in the forward position.
2. Run the screw at high RPM and pump out as much of the material as possible. Add and extrude purge compound until it comes out clean. Cylinder temperatures may have to be adjusted depending on purge material used.
3. It is good practice to “shoot” several air shots at a fast injection rate to scrub walls of cylinder before switching to another resin. Care should be employed to avoid possible splatter of molten resin when this is done.

8. Moulding and post-moulding dimensional considerations

Changes in the dimensions of moulded parts occur during the moulding and can occur after moulding and during their service life. Sometimes these changes are induced or accelerated. In any case, the dimensional stability of the parts is affected by the following:

- Shrinkage.
- Water absorption.
- Post mould shrinkage.
- Annealing.

In order to better control the process of water absorption and post-mould shrinkage, the technological step of water conditioning and annealing is often recommended.

8.1 Mould shrinkage

Once the part drops out of the injection machine and has cooled to room temperature, its dimensions are generally smaller than cavity dimensions and the difference stated in per cent is commonly understood as mould shrinkage.

The shrinkage however differs considerably with variety of the moulded part shapes. Therefore, in order to be able to compare the resins, the mould shrinkage has been defined. It is the shrinkage of a frontally gated rectangular rod ($127 \times 12,7 \times 3,2$ mm), dry as moulded at 23°C. Mould shrinkage is mentioned for particular grades in PART II.

Mould shrinkage depends on the type of nylon being processed, moulding conditions and mould design. The most critical parameters in each category are:

1. Type of resin:

- Percentage of glass fibre in the composition.
- Presence of a nucleant.
- Pigments.

2. Moulding conditions:

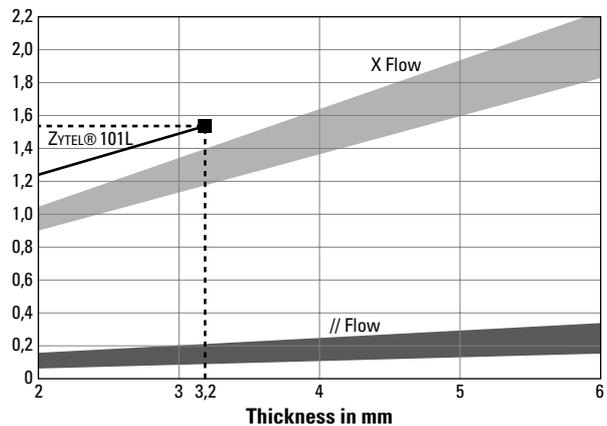
- Mould temperature (Fig. 49).
- Melt temperature.
- Injection and holding pressure (Fig. 44).
- Hold Pressure Time (Fig. 45).

3. Mould design:

- Part thickness (Fig. 50, 51 and 52)
- Gate design and its location.

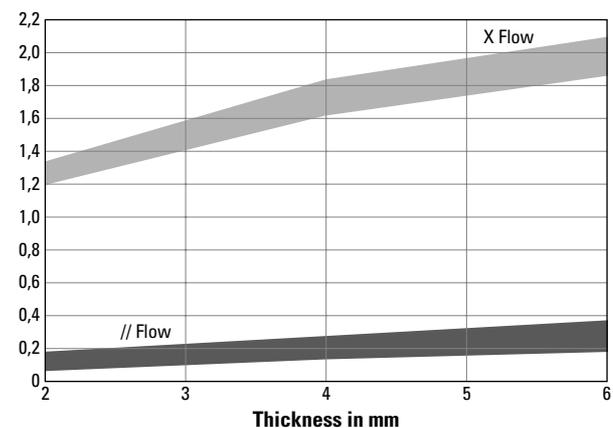
For glass-reinforced nylons, the fibre orientation produces less shrinkage in the flow direction than in the transverse direction as shown in Fig. 51 and 52.

Fig. 51 Restrained shrinkage* vs. thickness of ZYTEL® 70G35



* Hold pressure 75 MPa, optimum HPT, mould temperature 90°C and melt temperature 295°C

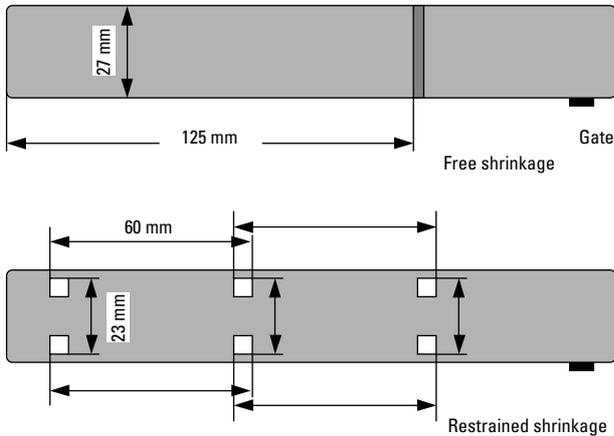
Fig. 52 Free shrinkage* vs. thickness of ZYTEL® 70G35



* Hold pressure 75 MPa, optimum HPT, mould temperature 90°C and melt temperature 295°C

For this reason, it is more practical to use a plate mould to differentiate the shrinkage in the flow direction from the shrinkage across the flow. Because parts are composed of both free and blocked shrinkage configurations, a comparison of restrained shrinkage and free shrinkage is shown in the figure 53.

Fig. 53 Free vs. restrained shrinkage

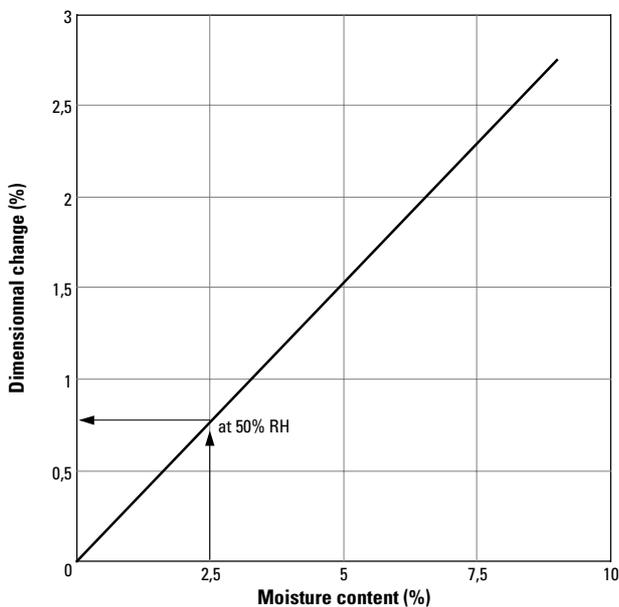


Shrinkage values given in Fig. 51 and 52 are intended as approximate guides for estimating mould shrinkage in the specified directions. Because of the isotropy of the shrinkage and the influence of the above mentioned factors, it is recommended to use prototype moulds to obtain more accurate dimensional data for complicated precision parts.

8.2 Effect of Water absorption on dimensions

Freshly moulded parts in nylon resins usually have a relatively low water content. As soon as they are ejected, they begin to slowly absorb moisture from the environment until an equilibrium condition is reached. This condition depends both on the relative humidity and the nylon type. The absorption of water results in an increase of part dimensions as shown in Fig. 54.

Fig. 54 Dimensional change as a function of moisture content for ZYTEL® 101



The equilibrium of water absorption of DuPont nylon depends on the type used, as seen from Table 3. The toughened grades have an equilibrium level slightly lower due to the insensitivity of the toughener to water.

Table 3 Water absorption of nylons in air and water

	Polyamides in water at 20° C	Absorption in air at 50%RH/23° C
6	8,5%	2,8%
66	7,5%	2,5%
6/66	7,5%	2,5%
6/12	3,0%	1,3%
6/10	3,0%	1,2%
Amorph.	5,8%	2,8%

The time needed to reach the equilibrium state depends on the wall thickness, moisture content and temperature.

Fig. 55 Shows the water absorption of un-reinforced ZYTEL® based on nylon 66 versus time under different environmental conditions for different part thicknesses. The moisture absorption time of a 1 mm disk for un-reinforced ZYTEL® 101 and 135F are shown in Fig. 56. The dimensional changes due to the water absorption can be accelerated by moisture conditioning.

Fig. 55 Moisture contents as a function of time for moulded parts

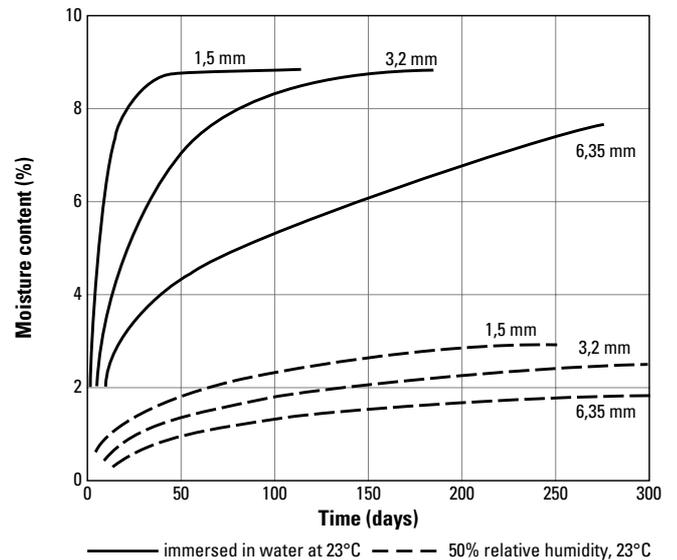
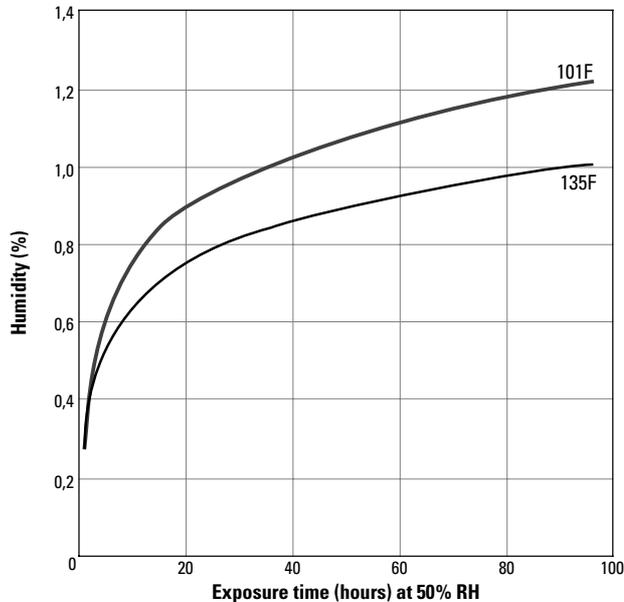


Fig. 56 Moisture absorption of 1 mm disk vs time



For the moisture conditioning of parts which are to be used in normal atmospheric conditions (50% R.H., 23°C), it is advisable to condition them to approximately 3% water content (by weight). The excess surface moisture will evaporate rapidly. The remaining moisture will eventually become evenly distributed and approximately 2,5% of the water content will be retained.

Moisture-conditioning procedures are discussed in detail in the “Design handbook for nylon resins”.

8.3 Post-moulding shrinkage and annealing

Like other semi-crystalline polymers, parts moulded in DuPont nylon undergo post-moulding shrinkage. This is basically because of an increase in the degree of crystallinity which occurs over a long period of time. Thin sections show more post-moulding shrinkage than thick sections. Parallel to shrinkage, water absorption causes expansion. Thus the final part dimensions are determined by a combination of both factors.

In a well-moulded part of moderate wall thickness, expansion by water absorption dominates the shrinkage from increasing crystallinity. On the other hand, in a part moulded at too a low mould temperature, or with thin sections, the shrinkage from post-crystallisation will be higher than the swell due to water absorption.

8.4 Warpage

Warpage of parts using glass-reinforced nylon resins is caused by non-uniform shrinkage (anisotropic shrinkage) that may be due to:

Flow/fibre orientation: Due to fibre orientation, the difference of shrinkage between the flow direction in which fibre restricts normal resin shrinkage and the transverse direction (where shrinkage values are similar to un-reinforced nylon), will result in an anisotropic shrinkage which can induce warpage of the part on cooling. Mould shrinkages as shown in Fig. 51 and 52 are always lower in the flow direction and nearly the same as for un-reinforced nylons in the transverse direction. Therefore, any condition that can create a random distribution of the glass fibres will reduce the warpage, i.e. abrupt change in flow directions, impinge melt on cores, multiple gating, etc.

Part wall thickness: Whenever possible, parts should be designed with a uniform wall thickness. Thick parts should always be cored out in order to minimise shrinkage. Complicated shapes must be able to shrink without restraint; ribs on projections as well as coring of thick sections should always be considered to minimise local deformation.

Mould design: Centre gating of round parts and full edge gating of thin rectangular or square shapes (less than 1,5 mm thick) is recommended. For long flow parts, the gate should be located to impinge melt flow on to a core of a wall. Use larger gates (approximately 50% larger, but not thicker) than for un-reinforced nylons. In many situations, cube blending to lower glass loading (if possible from an end-use/design standpoint) will reduce warpage tendencies.

In extremely difficult warpage cases, consult your local DuPont representative.

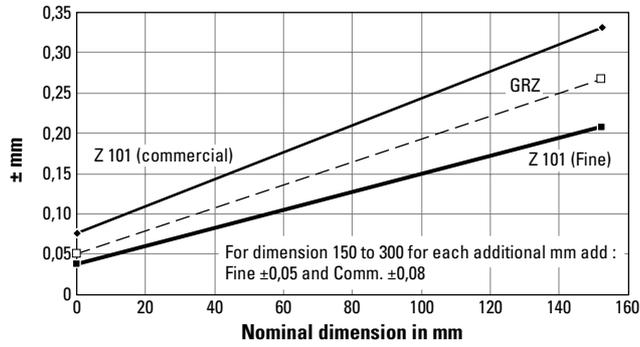
Non-uniformity of mould temperature, local overheating of cores, or absence of water channel in an area of the cavity can lead to differences in crystallisation rates and consequently to non uniform shrinkage.

8.5 Tolerance field of mouldings

The tolerances achievable are determined by the material, part design and the constant processing parameters.

Experience has proven that given favourable part design, correct gate location and a stable and optimum processing conditions, the following tolerances can be achieved with un-reinforced nylons (Fig. 57).

Fig. 57 A guide to tolerances of nylon resins as moulded



These tolerances do not include allowance for ageing characteristics of the material. Tolerances based on 3,0 mm wall thickness.

Tolerance for parts moulded in glass-reinforced nylons vary according to the complexity and wall thickness of the design. Although mould shrinkage of glass-reinforced nylons is significantly lower than for unreinforced nylons, predicting dimensional uniformity (see Section 8.1) can be more difficult. This will depend to a large degree on the glass fibre orientation in the part and to the moulding conditions.

Moulded tolerances in glass-reinforced nylon tend to be a compromise between commercial tolerances and fine tolerances specified by the Society of the Plastics Industry for unreinforced nylon.

DuPont Engineering Polymers

Processing data for MINLON® and ZYTEL® resins



Processing data

Grade	Material	Remarks	Solid density g/cm ³	Melt density at 0 MPa g/cm ³	Processing temperature Rec. °C	Cavity Surface temp. Rec. °C	Screw tang. speed Max. m/s	Flow front speed mm/s	Hold pressure			Back pressure LMH	Hold pressure time <3 mm s/mm	Max. hold-up time min.	Shrinkage measured on test bars		Max. process moisture %	Drying		Campus Dec. 94 Y/N
									Min. MPa	Rec. MPa	Max. MPa				paral. %	trans. %		at °C	Time h	
PA66 UNREINFORCED																				
101L	PA66	L	1,14	0,95	290	70	0,4	300	50	85	100	L	4	15	1,2	1,2	0,2	80	2-4	Y
101F	PA66	L	1,14	0,95	290	70	0,4	300	50	85	100	L	4	15	1,4	1,4	0,2	80	2-4	Y
EFE1068	PA66	L	1,14		290	70	0,4	300	50	85	100	L	4	15			0,2	80	2-4	
103HSL	PA66	HS L	1,14	0,95	290	70	0,4	300	50	85	100	L	4	15	1,2	1,3	0,2	80	2-4	Y
105F BK010	PA66	L	1,15		290	70	0,4	300	50	85	100	L	4	15	1,5		0,2	80	2-4	Y
122L	PA66	L	1,14		290	70	0,4	300	50	85	100	L	4	15	1,4		0,2	80	2-4	Y
EFE1166	PA66	L medium nucleat.	1,14		290	70	0,4	300	50	85	100	L	4	15			0,2	80	2-4	
135F	PA66	L nucleated	1,15	1,02	290	70	0,4	300	50	85	100	L	3,5	15	0,7	1,5	0,2	80	2-4	Y
EFE1152	PA66	L	1,14		290	70	0,4	300	50	85	100	L	4	15	0,8	1,5	0,2	80	2-4	N
E40	PA66	HV	1,14		290	70	0,3	150	50	85	100	L	4	15	1,8	2,2	0,15	80	2-4	N
E42A	PA66	HV	1,14		290	70	0,3	150	50	85	100	L	4	15			0,15	80	2-4	N
E50	PA66	HV	1,14		290	70	0,3	150	50	85	100	L	4	15	1,9	2,2	0,15	80	2-4	Y
E51HS	PA66	HV	1,14		290	70	0,3	150	50	85	100	L	4	15	1,9	2,2	0,15	80	2-4	N
E53	PA66	HV extr.	1,14		290	70	0,3	150	50	85	100	L	4	15	1,9	2,2	0,15	80	2-4	N
PA66 TOUGHENED, PA66 TOUGHENED/GLASS REINFORCED																				
114L BK097	PA66	T	1,12	0,94	290	50	0,3	300	50	85	100	L	4,5	15	1,5		0,2	80	2-4	Y
408	PA66	T	1,09	0,95	290	50	0,3	150	50	85	100	L	4,5	10	1,5	1,6	0,2	80	2-4	Y
450	PA66	T	1,08	0,92	290	70	0,3	300	50	85	100	L	4,5	10	1,7		0,2	80	2-4	Y
490	PA66	T	1,09	0,92	290	70	0,3	300	50	85	100	L	4,5	10	1,5	1,5	0,2	80	2-4	Y
ST801	PA66	ST, ST A	1,08	0,92	290	70	0,3	150	50	85	100	L	3	10	1,5	1,5	0,2	80	2-4	Y
79G13	PA66	G13 T L	1,21		295	60	0,3	150	50	85	100	L	2,5	15	0,5	1,2	0,2	80	2-4	Y
FE270020 BK039	PA66	G13 medium T			295	80	0,15	150	50	85	100	L	2,5	10			0,2	80	2-4	
80G14	PA66	G14 T	1,25		295	80	0,15	150	50	85	100	L	2,5	10	0,6	1,2	0,2	80	2-4	Y
80G25	PA66	G25 T	1,26		295	80	0,15	150	50	85	100	L	2,5	10	0,35		0,2	80	2-4	N
80G33HS1L	PA66	G33 ST HS L	1,34		295	80	0,15	150	50	85	100	M	2,5	12	0,3	1,1	0,2	80	2-4	Y
PA66, 66/6 GLASS REINFORCED																				
70G20	PA66	G20*	1,29	1,12	295	100	0,15	150	50	85	100	L	2,5	15	0,5	1,2	0,2	80	2-4	Y
70G25	PA6	G25*	1,33		295	100	0,15	150	50	85	100	L	2,5	15	0,35	1,07	0,2	80	2-4	Y
70G30	PA66	G30*	1,37	1,2	295	100	0,15	150	50	85	100	L	2,5	15	0,3	1,1	0,2	80	2-4	Y
70G33	PA66	G33*	1,45		295	100	0,15	150	50	85	100	L	2,5	15			0,2	80	2-4	N
70G35	PA66	G35*	1,47	1,27	295	100	0,15	150	50	85	100	L	2,5	15	0,4	1,1	0,2	80	2-4	Y
70G43	PA66	G43*	1,49	1,28	295	100	0,15	150	50	85	100	L	2,5	15	0,3	0,8	0,2	80	2-4	Y
70G50	PA66	G50*	1,57		295	100	0,15	150	50	85	100	L	2,5	15	0,3	0,7	0,2	80	2-4	Y

* Various comb. L, HS, R, A

Processing data (continued)

Grade	Material	Remarks	Solid density g/cm ³	Melt density at 0 MPa g/cm ³	Processing temperature Rec. °C	Cavity Surface temp. Rec. °C	Screw tang. speed Max. m/s	Flow front speed mm/s	Hold pressure			Back pressure LMH	Hold pressure time <3 mm s/mm	Max. hold-up time min.	Shrinkage measured on test bars		Max. process moisture %	Drying		Campus Dec. 94 Y/N
									Min. MPa	Rec. MPa	Max. MPa				paral. %	trans. %		at °C	Time h	
PA66, 66/6 GLASS REINFORCED (continued)																				
EFE7392 BK039B	PA66	G&MG 30	1,37		295	100	0,15	150	50	85	100	L	2,5	15			0,2	80	2-4	
70GB40HSL	PA66	GB40 HS L	1,46		295	100	0,15	Fast	50	85	100	L	2,5	15	1,2	1,2	0,2	80	2-4	Y
CDV95 BK409	PA66	conductive	1,32		295	100	0,15	150	50	85	100	L	2,5	15			0,2	80	2-4	
74G20HSL	PA66/6 ¹⁾	G20 HS L	1,3		290	100	0,3	300	50	85	100	L	2,5	10	0,3		0,2	80	2-4	N
74G30EHSL	PA66/6 ¹⁾	G30 HS L	1,4		290	100	0,3	300	50	85	100	L	2,5	10	0,18		0,2	80	2-4	N
PA66 MINERAL , PA66 MINERAL/GLASS REINFORCED																				
10B140	PA66	M40	1,5	1,28	295	100	0,15	100	40	70	100	L	3	12	1	1	0,2	80	2-4	Y
11C140	PA66	M40 T	1,46	1,27	295	100	0,15	100	40	70	100	L	3	12	1,4	1,4	0,2	80	2-4	Y
EFE6096	PA66	M15 T	1,23		295	100	0,15	100	40	70	100	L	3	8			0,2	80	2-4	
13MM	PA66	M16 T	1,24		295	100	0,15	100	40	70	100	L	3	8	1,5		0,2	80	2-4	N
14D1	PA66	M26 T	1,35		295	100	0,15	100	40	70	100	L	3	12	1,4		0,2	80	2-4	Y
23B1	PA66	M28G9	1,46		295	100	0,15	100	40	70	100	L	3	12	0,6	1,4	0,2	80	2-4	Y
EFE6053	PA66	M16G24	1,47	1,25	295	100	0,15	100	40	70	100	L	3	12	0,4		0,2	80	2-4	Y
PA66 and PA66/6 FLAME RETARDANT																				
FR7026VOF	PA66	FR VO	1,15		280	70	0,15	150	50	85	100	L	2,5	10			0,2	80	2-4	
FR70G25VO	PA66	FR G25 VO	1,49		280	70	0,15	150	50	85	100	L	2,5	10	0,4	0,8	0,2	80	2-4	N
FR70G25GW NC	PA66	FR G25 GW			280	70	0,15	150	50	85	100	L	2,5	10			0,2	80	2-4	
FR70M30VO	PA66	FR M30 VO	1,62		280	70	0,15	150	50	85	100	L	2,5	10	0,9		0,2	80	2-4	Y
FR70M40GW	PA66	FR M40 GW			280	70	0,15	150	50	85	100	L	2,5	10			0,2	80	2-4	
FR7200VOF	PA66/6 ²⁾	FR VO	1,18		280	70	0,15	150	50	85	100	L	2,5	10			0,2	80	2-4	N
FR72G25V1	PA66/6 ²⁾	FR G25 V1	1,44		280	70	0,15	150	50	85	100	L	2,5	10			0,2	80	2-4	Y
FR72G25V0LM	PA66/6 ²⁾	FR G25VO LM	1,52		280	70	0,15	150	50	85	100	L	2,5	10			0,2	80	2-4	
EFE7298 NC010	PA66/6 ²⁾	FR G30	1,51		280	70	0,15	150	50	85	100	L	2,5	10			0,2	80	2-4	
PA6 UNREINFORCED																				
7300	PA6	L	1,13		270	70	0,4	150	50	85	100	L	3	15	0,8		0,2	80	2-4	Y
7335F	PA6	L nucleated	1,13		270	70	0,4	150	50	85	100	L	3	15	0,6		0,2	80	2-4	Y

1) Blend 2) Copolymer

Processing data (continued)

Grade	Material	Remarks	Solid density g/cm ³	Melt density at 0 MPa g/cm ³	Processing temperature Rec. °C	Cavity Surface temp. Rec. °C	Screw tang. speed Max. m/s	Flow front speed mm/s	Hold pressure			Back pressure LMH	Hold pressure time <3 mm s/mm	Max. hold-up time min.	Shrinkage measured on test bars		Max. process moisture %	Drying		Campus Dec. 94 Y/N
									Min. MPa	Rec. MPa	Max. MPa				paral. %	trans. %		at °C	Time h	
PA6 TOUGHENED, PA6 TOUGHENED/GLASS REINFORCED																				
7300T	PA6	T	1,1	270	70	0,3	150	50	85	100	L	3	15	1	1	0,2	80	2-4	N	
ST7301	PA6	ST	1,07	270	70	0,3	150	50	85	100	L	3	15	2,1	2,2	0,2	80	2-4	N	
ST811HS	PA6	ST HS	1,04	270	70	0,3	150	50	85	100	L	3	15			0,2	80	2-4		
73G15T	PA6	G15 T	1,19	270	80	0,3	300	50	85	100	L	3	15	0,3	0,9	0,2	80	2-4	N	
73G30T	PA6	G30 T	1,34	270	80	0,3	300	50	85	100	L	3	15	0,2	1	0,2	80	2-4	Y	
EFE7374	PA6	G40 T	1,41	270	80	0,3	300	50	85	100	L	3	15			0,2	80	2-4		
PA6 GLASS REINFORCED																				
73G15	PA6	G15	1,23	270	100	0,3	300	50	85	100	L	3	15	0,3	1,1	0,2	80	2-4	Y	
73G20	PA6	G20	1,27	270	100	0,3	300	50	85	100	L	3	15	0,25	1,1	0,2	80	2-4	Y	
73G30	PA6	G30	1,36	270	100	0,3	300	50	85	100	L	3	15	0,2	1	0,2	80	2-4	Y	
73G35	PA6	G35	1,42	270	100	0,3	300	50	85	100	L	3	15	0,18	1	0,2	80	2-4	Y	
73G45	PA6	G45	1,51	270	100	0,3	300	50	85	100	L	3	15	0,15	0,9	0,2	80	2-4	Y	
PA6 MINERAL, PA6 MINERAL/GLASS REINFORCED																				
73M30	PA6	M30	1,35	270	85	0,2	100	40	70	100	L	3	12	0,9	0,9	0,2	80	2-4	Y	
73M40	PA6	M40	1,46	270	85	0,2	100	40	70	100	L	3	12	0,8	0,8	0,2	80	2-4	N	
73GM30HSL	PA6	M20 G10 HS L	1,38	270	85	0,2	100	40	70	100	L	3	12	0,5	0,8	0,2	80	2-4	Y	
73GM40	PA6	M25 G15	1,46	270	85	0,2	100	40	70	100	L	3	12	0,6	1	0,2	80	2-4	N	
PA6/12																				
151L	PA6/12	L	1,06	250	70	0,3	300	50	85	100	L	4	15	1,3		0,2	80	2-4	Y	
153HSL	PA6/12	HS L	1,06	250	70	0,3	300	50	85	100	L	4	15	1,3		0,2	80	2-4	Y	
158	PA6/12	HV	1,06	250	70	0,3	300	50	85	100	L	4	15			0,2	80	2-4	Y	
EFE4168	PA6/12	T	1	250	70	0,3	300	50	85	100	L	4	15			0,2	80	2-4		
77G33L	PA6/12	G33 L	1,32	290	100	0,15	150	50	85	100	L	3	15	0,2	0,9	0,2	80	2-4	Y	
FE5382 BK276	PA6/12	G33, encapsul.	1,32	290	100	0,15	150	50	85	100	L	3	15			0,2	80	2-4		
77G43L	PA6/12	G43 L	1,46	290	100	0,15	150	50	85	100	L	3	15	0,1	0,8	0,2	80	2-4	N	
Transparent/Translucent																				
330	PA6I/6T	Transparent	1,18	300	85	0,2	150				L		10	0,5	0,5	0,1	80	6-10	N	
TRA500	PA6I/6T	G8, translucent		300	85	0,2	150				L		10			0,1	80	6-10		

Processing data (continued)

Grade	Material	Remarks	Solid density g/cm ³	Melt density at 0 MPa g/cm ³	Processing temperature Rec. °C	Cavity Surface temp. Rec. °C	Screw tang. speed Max. m/s	Flow front speed mm/s	Hold pressure			Back pressure LMH	Hold pressure time <3 mm s/mm	Max. hold-up time min.	Shrinkage measured on test bars		Max. process moisture %	Drying		Campus Dec. 94 Y/N
									Min. MPa	Rec. MPa	Max. MPa				paral. %	trans. %		at °C	Time h	
Flexible nylon alloy																				
FN714	PA66	fl. alloy	1,02		285	60	0,3	300	50	85	100	L	4	10			0,15	80	4	N
FN718	PA66	fl. alloy	1,03		285	60	0,3	300	50	85	100	L	4	10			0,15	80	4	N
FN727	PA6	fl. alloy	1,01		270	65	0,3	300	50	85	100	L	4	10			0,15	80	4	N
ZYTEL-KEVLAR® SFC																				
70K20HSL	PA66	K20 HS L	1,19		290	110	0,15	150	50	85	100	L	2,5	15	0,8	1,3	0,2	80	2-4	N
Semi-aromatic polyamide																				
HTN51G15HSL	PA6T/XT	G15 HS L	1,31		325	150	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN51G25HSL		G25 HS L	1,38		325	150	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN51G35HSL		G35 HS L	1,47		325	150	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN51G35HSLR		G35 HS L R	1,47		325	150	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN51G45HSL		G45 HS L	1,58		325	150	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN51G45HSLR		G45 HS L R	1,58		325	150	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN51GM65HSL		M40 G25 HS L			325	150	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTNFE350006		M30 T			325	150	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTNFR51G35L		FR G35 L	1,65		325	150	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTNFE8200		T HS L	1,13		325	150	0,3	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN52G15HSL	PA6T/66	G15 HS L	1,31		325	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN52G35HSL		G35 HS L	1,47		325	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN52G45HSL		G45 HS L	1,58		325	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTNFR52G15BL		FR G15 L	1,53		325	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTNFR52G35BL		FR G35 L	1,67		325	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTNFR52G45BL		FR G45 L	1,76		325	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN53G50HSLR	PA66+PA6I/6T	G50 HS L R	1,6		295	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN53GM40HSL		M25 G15 HS L			295	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN54G15HSLR	PA6T/XT+ PA6T/66	G15 HS L R			325	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN54G35HSLR		G35 HS L R	1,42		325	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTN54G50HSLR		G50 HS L R	1,6		325	95	0,15	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTNFE18502		T HS L	1,1		325	95	0,3	300	50	85	100	L	3,5	10			0,1	100	6-8	
HTNHPA-LG2D		T			325	95	0,3	300	50	85	100	L	3,5	10			0,1	100	6-8	

9 **Processing data** (continued)

Grade	Material	Remarks	Solid density g/cm ³	Melt density at 0 MPa g/cm ³	Processing temperature Rec. °C	Cavity Surface temp. Rec. °C	Screw tang. speed Max. m/s	Flow front speed mm/s	Hold pressure			Back pressure LMH	Hold pressure time < 3 mm s/mm	Max. hold-up time min.	Shrinkage measured on test bars		Max. process moisture %	Drying		Campus Dec. 94 Y/N
									Min. MPa	Rec. MPa	Max. MPa				paral. %	trans. %		at °C	Time h	
PA66 low moisture absorption																				
DMXST601AH		ST A	1,08		285	70	0,3	300	50	85	100	L	3	10			0,2	80	2-4	
DMX61G15AH		G15 A	1,17		285	100	0,15	300	50	85	100	L	3	10			0,2	80	2-4	
DMX61G30AH		G30 A	1,3		285	100	0,15	300	50	85	100	L	3	10			0,2	80	2-4	

A = Advantage, higher flow
 FR = Flame retardant
 G = Glass reinforced
 GW = Glow wire
 GB = Glass bead reinforced
 HS = Heat stabilised
 HV = High viscosity
 K = KEVLAR® reinforced
 L = Lubricated

LM = Laser markable
 M = Mineral reinforced
 MG = Milled glass
 R = Hydrolysis resistant
 ST = Super tough
 T = Toughened
 UHV = Ultra high viscosity
 UV = UV stabilised

For further information on Engineering Polymers contact:

Internet location: <http://plastics.dupont.com>

Belgique / België

Du Pont de Nemours (Belgium)
Antoon Spinostraat 6
B-2800 Mechelen
Tel. (15) 44 14 11
Telex 22 554
Telefax (15) 44 14 09

Bulgaria

Serviced by Biesterfeld Interrowa GmbH & Co. KG.
See under Österreich.

Česká Republika a Slovenská Republika

Du Pont CZ, s.r.o.
Pekarska 14/268
CZ-155 00 Praha 5 – Jinonice
Tel. (2) 57 41 41 11
Telefax (2) 57 41 41 50-51

Danmark

Du Pont Danmark ApS
Skjøtevej 26
P.O. Box 3000
DK-2770 Kastrup
Tel. 32 47 98 00
Telefax 32 47 98 05

Deutschland

Du Pont de Nemours (Deutschland) GmbH
DuPont Straße 1
D-61343 Bad Homburg
Tel. (06172) 87 0
Telex 410 676 DPD D
Telefax (06172) 87 27 01

Egypt

Du Pont Products S.A.
Bldg no. 6, Land #7, Block 1
New Maadi
ET-Cairo
Tel. (00202) 754 65 80
Telefax (00202) 516 87 81

España

Du Pont Ibérica S.A.
Edificio L'Illa
Avda. Diagonal 561
E-08029 Barcelona
Tel. (3) 227 60 00
Telefax (3) 227 62 00

France

Du Pont de Nemours (France) S.A.
137, rue de l'Université
F-75334 Paris Cedex 07
Tel. 01 45 50 65 50
Telex 206 772 dupon
Telefax 01 47 53 09 67

Hellas

Ravago Plastics Hellas ABEE
8, Zakythou Str.
GR-15232 Halandri
Tel. (01) 681 93 60
Telefax (01) 681 06 36

Israël

Gadot
Chemical Terminals (1985) Ltd.
22, Shalom Aleichem Street
IL-633 43 Tel Aviv
Tel. (3) 528 62 62
Telex 33 744 GADOT IL
Telefax (3) 528 21 17

Italia

Du Pont de Nemours Italiana S.r.L.
Via Volta, 16
I-20093 Cologno Monzese
Tel. (02) 25 30 21
Telefax (02) 25 30 23 06

Magyarország

Serviced by Biesterfeld Interrowa GmbH & Co. KG.
See under Österreich.

Maroc

Deborel Maroc S.A.
40, boulevard d'Anfa – 10°
MA-Casablanca
Tel. (2) 27 48 75
Telefax (2) 26 54 34

Norge

Distrupol Nordic
Niels Leuchsvei 99
N-1343 Eiksmarka
Tel. 67 16 69 10
Telefax 67 14 02 20

Österreich

Biesterfeld Interrowa GmbH & Co. KG
Bräuhäusgasse 3-5
P.O. Box 19
AT-1051 Wien
Tel. (01) 512 35 71-0
Fax (01) 512 35 71-31
e-mail: info@interrowa.at
internet: www.interrowa.at

Polska

Du Pont Poland Sp. z o.o.
ul. Powazkowska 44C
PL-01-797 Warsaw
Tel. +48 22 320 0900
Telefax +48 22 320 0910

Portugal

ACENYL
Rua do Campo Alegre, 672 – 1°
P-4100 Porto
Tel. (2) 69 24 25/69 26 64
Telex 23 136 MACOL
Telefax (2) 600 02 07

Romania

Serviced by Biesterfeld Interrowa GmbH & Co. KG.
See under Österreich.

Russia

E. I. du Pont de Nemours & Co. Inc.
Representative Office
B. Palashevsky Pereulok 13/2
SU-103 104 Moskva
Tel. (095) 797 22 00
Telex 413 778 DUMOS SU
Telefax (095) 797 22 01

Schweiz / Suisse / Svizzera

Dolder AG
Immengasse 9
Postfach 14695
CH-4004 Basel
Tel. (061) 326 66 00
Telefax (061) 322 47 81
Internet: www.dolder.com

Slovenija

Serviced by Biesterfeld Interrowa GmbH & Co. KG.
See under Österreich.

Suomi / Finland

Du Pont Suomi Oy
Box 62
FIN-02131 Espoo
Tel. (9) 72 56 61 00
Telefax (9) 72 56 61 66

Sverige

Serviced by Du Pont Danmark ApS.
See under Danmark.

Türkiye

Du Pont Products S.A.
Turkish Branch Office
Sakir Kesebir cad. Plaza 4
No 36/7, Balmumcu
TR-80700 Istanbul
Tel. (212) 275 33 82
Telex 26541 DPIS TR
Telefax (212) 211 66 38

Ukraine

Du Pont de Nemours International S.A.
Representative Office
3, Glazunova Street
Kyiv 252042
Tel. (044) 294 96 33/269 13 02
Telefax (044) 269 11 81

United Kingdom

Du Pont (U.K.) Limited
Maylands Avenue
GB-Hemel Hempstead
Herts. HP2 7DP
Tel. (01442) 34 65 00
Telefax (01442) 24 94 63

Argentina

Du Pont Argentina S.A.
Avda. Mitre y Calle 5
(1884) Berazategui-Bs.As.
Tel. +54-11-4229-3468
Telefax +54-11-4229-3117

Brasil

Du Pont do Brasil S.A.
Al. Itapecuru, 506 Alphaville
06454-080 Barueri-São Paulo
Tel. (5511) 7266 8229

Asia Pacific

Du Pont Kabushiki Kaisha
Arco Tower
8-1, Shimomoguro 1-chome
Meguro-ku, Tokyo 153-0064
Tel. (03) 5434-6935
Telefax (03) 5434-6965

South Africa

Plastamid (Pty) Ltd.
43 Coleman Street
P.O. Box 59
Elsies River 7480
Cape Town
Tel. (21) 592 12 00
Telefax (21) 592 14 09

USA

DuPont Engineering Polymers
Barley Mill Plaza, Building #22
P.O. Box 80022
Wilmington, Delaware 19880
Tel. (302) 999 45 92
Telefax (302) 892 07 37

Requests for further information from countries not listed above should be sent to:

Du Pont de Nemours International S.A.

2, chemin du Pavillon
CH-1218 Le Grand-Saconnex/Geneva
Tel. (022) 717 51 11
Telex 415 777 DUP CH
Telefax (022) 717 52 00

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