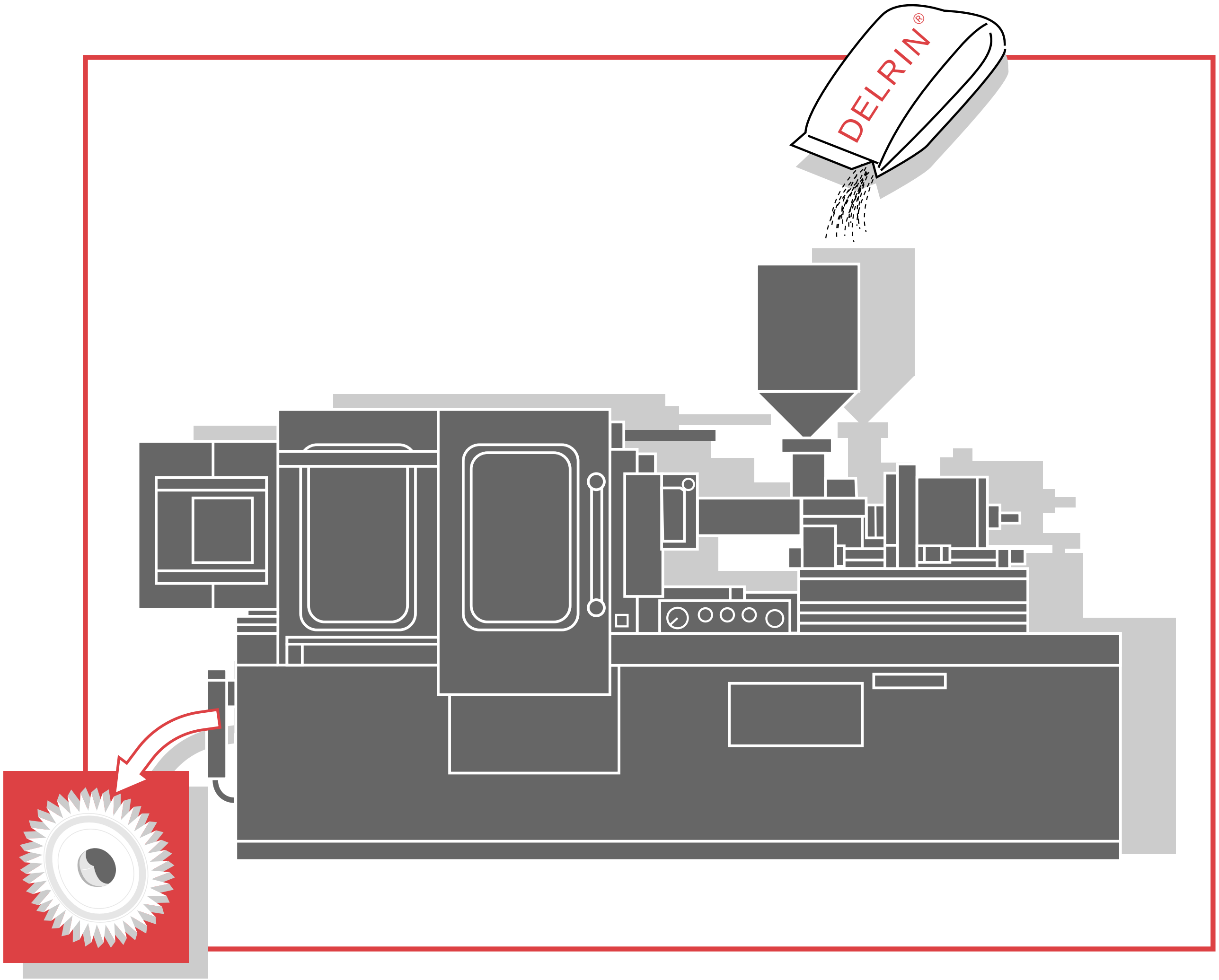
Delrin®

acetal resin



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General Information

Description

Delrin® acetal resins are semi-crystalline, thermoplastic polymers made by the polymerization of formaldehyde, and are also commonly referred to as polyoxymethylene (POM). They have gained widespread recognition for reliability in many thousands of engineering components all over the world. Since commercial introduction in 1960, Delrin® has been used in the automotive, appliance, construction, hardware, electronics, and consumer goods industries, among others.

Delrin® is noted for:

- High mechanical strength and rigidity
- Excellent dimensional stability
- Natural lubricity
- Fatigue endurance
- High resistance to repeated impacts
- Excellent resistance to moisture, gasolines, solvents and many other neutral chemicals
- Toughness at low temperature (down to –50°C [–58°F])
- Wide useful temperature range (in air: –50 to 90°C [–58 to 194°F], with intermittent use up to 120°C [248°F]).
- Good electrical insulating characteristics
- Ease of fabrication

Delrin® acetal resins are available in a variety of compositions to meet different end-use and processing requirements.

Compositions

The main available Delrin® compositions can be classified as follows:

a. Standard
b. Toughened
c. Low wear/Low friction
d. Glass filled
e. UV-stabilized

The standard compositions cover a broad range of melt viscosities. The highest viscosity composition, Delrin® 100, is often molded when maximum toughness properties are needed. The intermediate melt viscosity Delrin® 500 is used for general-purpose injection applications. The resins having lower melt viscosity, Delrin® 900 and 1700, are usually chosen for injection molding applications with hard-to-fill molds.

A summary of the main compositions is shown in **Table 1**.

Table 1
Main Compositions of Delrin® Acetal Resins

High viscosity grades	
Delrin® 100	POM homopolymer. High viscosity molding material. Excellent tensile strength and resistance to creep over a wide temperature range, even under humid ambient conditions. High fatigue endurance and impact resistance. Applications: molded parts such as highly loaded gears, plain bearings and snap-fits.
Delrin® 100 P	Same characteristics and applications as Delrin® 100, plus best molding stability for deposit free molding in demanding processing conditions, e.g., hot runner tools.
Delrin® 111 P	Characteristics: Delrin® 100 P with enhanced crystallinity. Resistance to creep and fatigue endurance improved over Delrin® 100 P. Typical applications: Highly loaded gears, bearings, snap-fits.
Medium viscosity grades	
Delrin® 500	POM homopolymer. General-purpose molding resin with medium viscosity. Applications: general mechanical parts.
Delrin® 500 P	Same characteristics and applications as Delrin® 500, plus best processing stability for deposit-free molding in demanding processing conditions, e.g., hot runner tools.
Delrin® 511 P	Characteristics: Delrin® 500 P with enhanced crystallinity. Applications: fuel system components, gears, fasteners.
Low viscosity grades	
Delrin® 900	POM homopolymer. General purpose molding resin with low viscosity. Applications: Multicavity molds and parts with thin sections, e.g., consumer electronics parts, zippers.
Delrin® 900 P	Characteristics: Low viscosity, fast molding resin plus best processing stability for deposit-free molding in demanding processing conditions, e.g., hot runner tools. Applications: Multicavity molds and parts with thin sections, e.g., consumer electronics parts, zippers.
Delrin® 911 P	Characteristics: Delrin® 900 P with enhanced crystallinity. Resistance to creep and fatigue endurance improved over Delrin® 900 P. Excellent resistance to gasoline, lubricants, solvents and many neutral chemicals. Applications: Multicavity molds and parts with thin sections, e.g., consumer electronic parts, zippers.
Delrin® 1700 P	POM homopolymer. Characteristics: Very low viscosity, best flow, easy mold ejection. Applications: Multicavity molds and parts with thin sections which require best flow properties.

(continued on page 2)

Table 1 (continued)
Main Compositions of Delrin® Acetal Resins

Toughened grades

Delrin® 100 ST
POM homopolymer, Super Tough. High viscosity, super tough material for injection molding and extrusion. Excellent combination of super-toughness, impact fatigue resistance, solvent and stress crack resistance, as well as high tensile elongation at low temperature. Applications: Mainly used for parts requiring resistance to repeated impacts and loads, such as automotive fasteners, helmets, hoses and tubing.

Delrin® 500 MT
Characteristics: Medium toughness, medium viscosity resin. Applications: Fasteners, seats belt restraint systems, gears.

Delrin® 500 T
Medium viscosity, toughened resin for injection molding and extrusion. Excellent notched Izod and tensile impact strength. Applications: Mainly used for parts subjected to repeated impacts and alternating loads, such as automotive fasteners, helmets, hoses and tubing.

Low-wear/low-friction grades

Delrin® 100 AF
High viscosity grade with 20% Teflon® PTFE fibers, outstanding friction and wear properties.

Delrin® 100 KM
Delrin® 100 P modified with Kevlar® aramid resin for abrasive wear reduction. Applications: Specialty friction and wear.

Delrin® 500 AF
Medium viscosity grade with 20% Teflon® PTFE fibers, outstanding friction and wear properties. Applications: Specialty friction and wear, conveyor systems.

Delrin® 520 MP
Delrin® 500 P with 20% Teflon® PTFE micropowder, with low-wear and low-friction properties. Applications: Specialty friction and wear.

Delrin® 510 MP
Delrin® 500 P with 10% Teflon® PTFE micropowder, with low-wear and low-friction properties. Applications: Specialty friction and wear.

Delrin® 500 TL
Delrin® 500 with 1.5% Teflon® powder, with low-wear and low-friction properties. Applications: Specialty friction and wear, conveyor systems.

Delrin® 500 AL
Medium viscosity resin with advanced lubricant system, very good low-friction and low-wear properties. Applications: Gears, drive trains, sliding devices.

Delrin® 900 SP
Delrin® 900 P with special polymer additive for low-wear/low-friction against itself and other plastics. Applications: Gears, drive trains, sliding devices.

Delrin® 500 CL
Chemically lubricated Delrin® 500, very good low-friction and low-wear properties. Applications: Gears, drive trains, sliding devices.

Glass-filled/glass-reinforced grades

Delrin® 570
Medium viscosity resin, with 20% glass filler. Applications: Where high stiffness and creep resistance are required.

Delrin® 577 BK
Delrin® 570 with carbon black for improved weathering. Applications: General engineering parts for high stiffness and strength.

Delrin® 510 GR
10% glass-reinforced resin. Applications: Parts requiring high stiffness and strength, and creep resistance.

Delrin® 525 GR
25% glass-reinforced resin. Applications: Parts requiring very high stiffness and strength, and creep resistance.

UV-stabilized grades

Delrin® 127 UV
Delrin® 100 P with UV stabilizer. Applications: Automotive interior parts with maximum UV performance requirements, ski bindings, seatbelt restraint parts.

Delrin® 527 UV
Delrin® 500 P with UV stabilizer. Applications: Automotive interior parts with maximum UV performance requirements, interior trim, seatbelt restraint parts.

Delrin® 927 UV
Delrin® 900 P with UV stabilizer. Applications: Automotive interior parts, loudspeaker grills.

Delrin® 1727 UV
Delrin® 1700 P with UV stabilizer. Applications: Automotive interior parts, loudspeaker grills.

Safety Precautions to Observe When Molding Delrin® Acetal Resins

Delrin® as well as many other thermoplastic polymers decomposes to gaseous products when heated for a prolonged time. These gases can generate high pressures if confined. If material is not free to exit from an injection cylinder through the nozzle, it may blow back through the hopper.

In the case of Delrin® acetal resin, decomposition is almost entirely to gaseous products, so pressure build-up can be rapid. The product of decomposition is formaldehyde.

When molding Delrin®, it is important that the operator be familiar with the factors that can cause decomposition, with the danger signals that warn of this problem, and with the action that should be taken. This information is summarized on a card for display at the molding machine.

The information given here is based on our experience to date. It may not cover all possible situations and it is not intended as a substitute for skill and alertness of the operator.

Follow correct start-up, operating and shut-down procedures as described later in this guide.

Be aware of troublemakers—causes of decomposition:

- High temperature—sticking temperature controller, faulty thermocouple connections, incorrect reading, burned-out heater or heater with a hot spot, heat surges on start-up
- Cycle delay
- Hold-up areas—in cylinder, adapter, nozzle, screw tip, hot runner and check valve assembly
- Plugged nozzle—from scrap metal or higher melting point resin, or from closed nozzle valve
- Foreign materials
    - Additives, fillers or colorants other than those specifically recommended for use in Delrin®
    - Contaminants (especially those containing chlorine or generating acid materials) such as polyvinylchloride resin or flame retardants
    - Copper, brass, bronze or other copper alloys in contact with molten Delrin® (not in molds where the resin solidifies after each cycle)
    - Copper-based lubricants or grease for threads
    - Contaminated rework—especially rework or reprocessed resin from outside or unknown sources

Watch for Danger Signals

- Frothy nozzle drool
- Spitting nozzle
- Pronounced odor
- Discolored resin—brown or black streaking
- Badly splayed parts—whitish deposit on molding or mold
- Screw push back from gas pressure

Action Required When Any of the Danger Signals Occur

- AVOID PERSONAL EXPOSURE—When DANGER SIGNALS are present, DO NOT look into hopper or work around nozzle as violent ejection of melt is possible.
- MINIMIZE PERSONAL EXPOSURE TO DECOMPOSITION GASES by using general and local ventilation. If necessary, leave area of machine until ventilation has reduced concentration of formaldehyde to acceptable levels. Persons sensitized to formaldehyde or having existing pulmonary disabilities should not be involved in processing Delrin®.
- FREE NOZZLE PLUG by heating with torch. If this fails, cool down cylinder, make sure PRESSURE IS RELIEVED, and CAREFULLY REMOVE NOZZLE and clean.
- TAKE AIR SHOTS to cool the resin—PURGE WITH CRYSTAL POLYSTYRENE. DROP ALL MOLTEN Delrin® INTO WATER to reduce odor level.
- Turn off cylinder heaters.
- Check temperature control instruments.
- Discontinue automatic molding and run manually until job is running smoothly.
- Provide adequate means of venting feed mechanism in case of blowback.
- Use exhaust ventilation to reduce formaldehyde odor.

Packaging

Delrin® acetal resin is supplied as spherical or cylindrical pellets approximately 3 mm (0.12 in) in dimensions. They are packaged in 1,000 kg (2,200 lb) net weight bulk corrugated boxes or 25 kg (55.16 lb) moisture protected, tear resistant polyethylene bags. The bulk density of the unfilled resin granules is about 0.8 g/cm^3.

Polymer Structure and Processing Behavior

The behavior of a polymer during the molding process and the behavior of a molded part during its whole end-use life are highly dependent on the type of structure that the polymer tends to form during solidification.

Some polymers exhibit in the solid state roughly the same molecular arrangement as in the melt, i.e., a random mass of entangled molecules with no order. This class is named “amorphous polymers” and includes for example ABS, polycarbonate and polystyrene.

Other polymers tend to solidify in an ordered manner: the molecules arranging into crystalline forms (lamellae, spherulites). Because of the length of the macromolecules, parts of them cannot belong to crystals (due to lack of space and mobility) and create an amorphous inter-crystalline zone. These polymers are therefore partially crystalline or semi-crystalline; for simplicity, in this text we will refer to them as “crystalline” (opposed to “amorphous”).

Typical crystalline materials are Delrin® (acetal resins), Zytel® (polyamide resins), Rynite® PET and Crastin® PBT (thermoplastic polyester resins), polyethylene and polypropylene.

Table 2 summarizes some fundamental differences between amorphous and crystalline polymers. These points are described in more detail in the following paragraphs. This information is essential to understand why the optimization of the molding process is substantially different for the two categories of polymers.

Table 2
Comparison of Amorphous and Crystalline Polymers

Resin type	Amorphous	Crystalline
Properties		
Thermal parameters	T_g	T_g, T_m
Maximum T in use*	Below T_g	Below T_m
Specific volume vs. T	Continuous	Discontinuity at T_m
Melt viscosity vs. T	High dependence	Low dependence
Processing		
Solidification	Cooling below T_g	Crystallization below T_m
Hold pressure	Decreased during cooling	Constant during crystallization
Flow through gate	Stops after dynamic filling	Continues until end of crystallization
Defects if bad process	Over-packing, stress-cracking, sink marks	Voids, deformations, sink marks

* For typical engineering applications

Glass Transition and Melting

Amorphous Polymers

The overall behavior of amorphous polymers is largely determined in relation to their glass transition temperature T_g.

Below this temperature, the molecules are essentially blocked in the solid phase. The material is rigid and has a high creep resistance, but it also tends to be brittle and sensitive to fatigue.

When the temperature is increased above the glass transition temperature T_g, the molecules have some freedom to move by rotation around chemical bonds. The rigidity decreases gradually and the material shows elastomeric properties, lending itself to processes like thermoforming, blow molding and (at temperatures 120–150°C [248–302°F] above T_g) injection molding.

Amorphous polymers used in engineering applications have T_g above the ambient temperature, and the maximum temperature for end-use should be below T_g; for example polystyrene has T_g = 90–100°C (194–212°F), and is injection molded between 210 and 250°C (410 and 482°F).

Crystalline Polymers

In crystalline polymers, the onset of molecular movement in the material also defines the glass transition temperature T_g.

When the temperature is increased above T_g, the crystalline polymers maintain rigidity appropriate for engineering applications (for example with Delrin® a part can easily withstand temperatures well above the T_g).

Upon further heating the material reaches its melting temperature T_m, where the cohesion of the crystalline domains is destroyed. Within a few degrees, there is a considerable change of mechanical properties from solid to liquid behavior. Above T_m, the crystalline polymers behave as high viscosity liquids, and can generally be processed by injection molding, typically at temperatures 30–60°C (86–140°F) above their melting temperature. As a consequence, the temperature domain for the use of crystalline polymers is not limited by the glass transition temperature T_g, but by the melting temperature T_m. For Delrin®, the effect of the T_g is negligible and very difficult to measure, due to its very low amorphous content. There are two transitions for Delrin®, a weak one around 0–15°C (32–59°F) and a stronger one at –80°C (–112°F). The transition just below room temperature is so weak there is minimal effect on properties. For Delrin® acetal homopolymer, T_m = 178°C (352°F) and the typical processing range is 210–230°C (410–446°F).

PVT Diagrams

The PVT diagram is a condensed presentation of the interrelations of three variables that affect the processing of a polymer: Pressure, Volume and Temperature.

The effect of the temperature (T) or volume (V) is illustrated in **Figure 1** for an amorphous and a crystalline polymer. When the temperature of the material is increased, its specific volume (the inverse of density) also increases due to thermal expansion. The rate of increase becomes higher at the glass transition temperature, because the molecules have more freedom to move and they occupy more space. This change of slope is observed with both amorphous and crystalline polymers. At higher temperature, the melting of crystalline polymers is marked by a sudden increase of the specific volume, when the well-ordered and rigid crystalline domains become randomly oriented and free to move. The specific volume is therefore a signature of the changes of structure of the polymer as a function of temperature.

A PVT diagram is simply the presentation of the series of curves obtained when the measurement of specific volume versus temperature is repeated at different pressures. The PVT diagram of a typical amorphous polymer (polystyrene) is shown in **Figure 2**, and the PVT diagram of Delrin® is shown in **Figure 3**.

The molding process can be illustrated by a cycle of transitions on the PVT diagram. For simplification, it will be assumed in the following description that heating takes place at constant pressure (“along isobar lines”) and that application of pressure is isothermal (vertical lines).

For an amorphous material the molding cycle is as follows (see **Figure 2**):

- Starting from room temperature and 1 MPa pressure (point A) the material is heated in the barrel. The specific volume increases according to the isobar at 1 MPa to reach the molding temperature (point B).
- The material is injected into the cavity and the pressure is applied. This process is roughly isothermal (to point C), and the specific volume is decreased to a value close to that at 1 MPa and T_g.
- The resin is cooled in the mold, and at the same time the hold pressure is decreased, to follow a horizontal line in the PVT diagram and reach point D where the part can be ejected when it is at 1 MPa pressure and a temperature below T_g. Ideally, there should be no flow of material through the gate during this cooling phase to produce a stress-free part.

For a crystalline material, the picture is different (see **Figure 3**):

- the material is heated at 1 MPa pressure from room temperature (point A) up to the processing temperature (point B). This results in a large change of volume (almost 25% for Delrin®);
- the resin is injected and compressed in the cavity. The specific volume is decreased to point C, where its value is still much higher than at 1 MPa/23°C (73°F);
- crystallization takes place in the mold under constant hold pressure. When the crystals build up from the liquid phase, a large difference of volume occurs, which must be compensated by injection of additional liquid resin through the gate (otherwise voids are created within the part);
- at the end of crystallization (point D), the part is solid and it can be ejected immediately; the molding shrinkage is the difference between the specific volumes at the crystallization temperature (point D) and at room temperature (point A).

This difference in behavior has important implications for injection molding. During the solidification process (after dynamic filling):

- the hold pressure is decreased with time for amorphous polymers, whereas it is maintained constant for crystalline polymers;
- the flow through the gate is stopped for amorphous polymers, while it continues until the end of the crystallization for crystalline polymers. This implies that for crystalline materials the design of parts, gates, runners and sprue should follow special rules that will be described in the Molds section.

Figure 1. Specific Volume as Function of Temperature for Amorphous And Crystalline Polymers

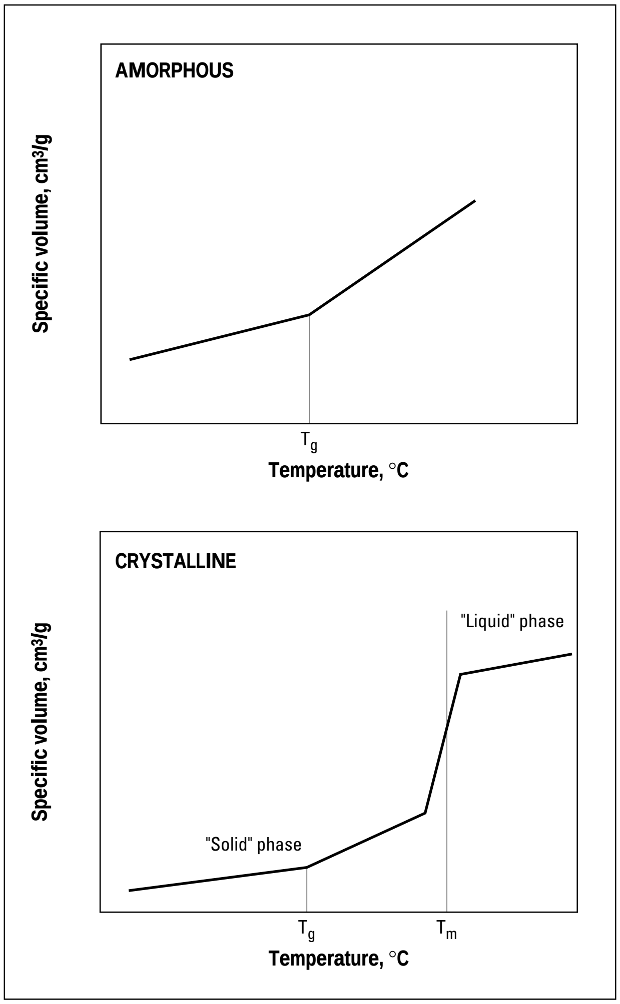


Figure 2. Pressure-Volume-Temperature (PVT) Diagram For Polystyrene. Points A, B, C, and D Refer to Different Steps of the Molding Process (See Text).

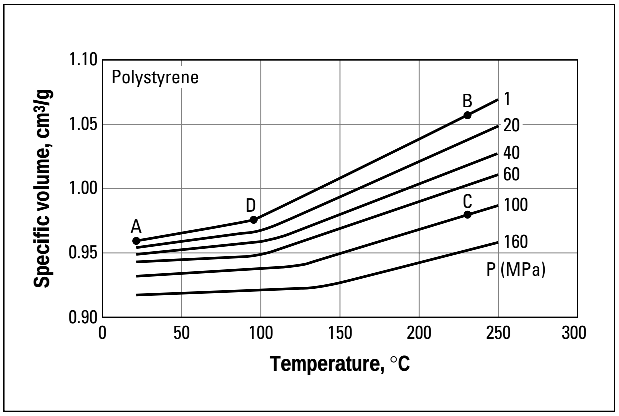
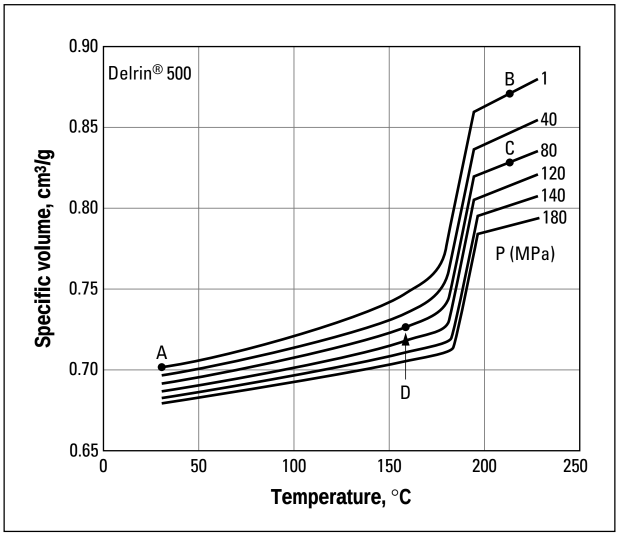


Figure 3. Pressure-Volume-Temperature (PVT) Diagram For Delrin® 500. Points A, B, C, and D Refer to Different Steps of the Molding Process (see text).



Heating-Cooling Behavior

For any substance, the energy needed to increase the temperature of 1 g material by 1°C (1.8°F) is defined as its specific heat. This quantity is generally determined by Differential Scanning Calorimetry, and the results for Delrin®, polyamide 6-6 and polystyrene are shown in **Figure 4**. The two crystalline polymers, Delrin® and polyamide 6-6, show a large peak that is due to the additional heat required to melt the crystalline phase (latent heat of fusion). The amorphous polymer does not show such a peak, but exhibits a change of slope at T_g.

The total energy to bring each material up to its molding temperature is given by the area under the curve. From **Figure 4** it is clear that the crystalline polymers need more energy than the amorphous ones. This explains why the design of a screw for a crystalline polymer like Delrin® should be different (and usually more critical) than for an amorphous polymer.

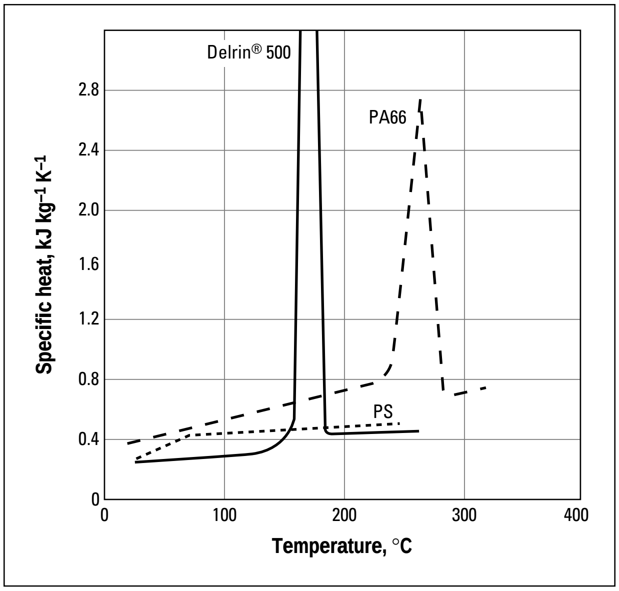
Viscosity and Rheological Behavior

Melt viscosity determines to a large extent the ability to fill the mold cavity. High viscosity means difficult flow through thin sections and higher injection fill pressure.

Temperature and shear rate are crucial parameters when considering the viscosity of molten polymers, and they should always be specified together with a value for melt viscosity.

For polymers consisting of linear molecules like Delrin®, the viscosity is also in direct relation to the average molecular weight.

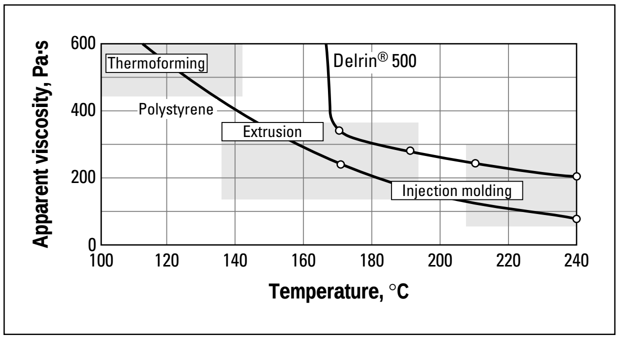
Figure 4. Specific Heat versus Temperature for Delrin® 500, PA66 and Polystyrene



Influence of Temperature

The general rule that liquids become less viscous when increasing temperature is also true for molten thermoplastics. However crystalline and amorphous polymers behave differently, as shown in **Figure 5**. The curves for Delrin® and polystyrene were both obtained by reducing gradually the temperature of the materials from 230 to 100°C (446 to 212°F). Two differences are worth mentioning. First, at temperatures above 180°C (356°F), the dependence of viscosity on temperature is more pronounced for the amorphous polystyrene than for Delrin®; therefore, increasing the melt temperature of Delrin® does not greatly improve its ability to flow through a thin section. Second, below 170°C (338°F) the viscosity of Delrin® rises sharply because the material crystallizes within a few degrees of that temperature.

Figure 5. Viscosity/Temperature Curves for Delrin® 500 and for Polystyrene at a Constant Shear Rate of 1000 s^{-1} (Temperature Reduced from 230 to 100°C [446 to 212°F])



Influence of Shear Rate

The shear rate characterizes the rate of deformation of the material and is defined as the derivative of the velocity over the direction perpendicular to flow (see **Figure 6**); in other words, the shear rate is proportional to the variation of speed within the part thickness. So it depends on the velocity of the flow and on the geometry of the flow channels.

For Delrin®, the melt viscosity decreases considerably when the shear rate increases, as shown in **Figure 7**. This effect is more important than the differences resulting from variations of the melt temperature within the processing window for injection molding.

Figure 6. Approximate Shape of the Velocity Distribution Between Two Parallel Plates. The Shear Rate is the Derivative dv(y)/dy.

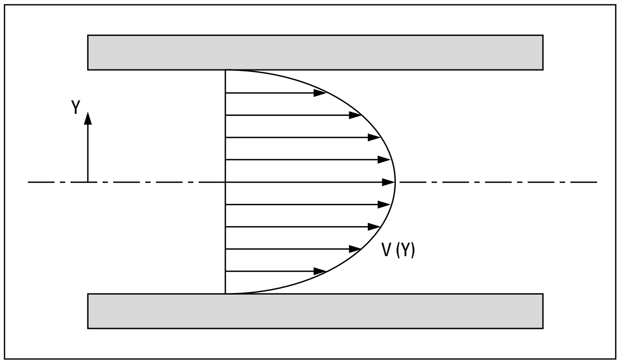
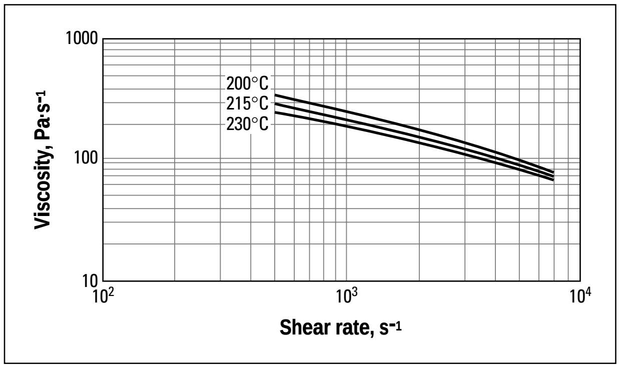


Figure 7. Viscosity versus Shear Rate of Delrin® 500 at Three Temperatures



Influence of Molecular Weight

Delrin® is available in four grades of molecular weight. They are coded according to their ability to flow, as measured by MFR or melt flow rate (see **Table 3**). High values mean easy flow and ability to fill thin parts, whereas low values mean high viscosity, high molecular weight and high toughness (impact resistance, elongation at break).

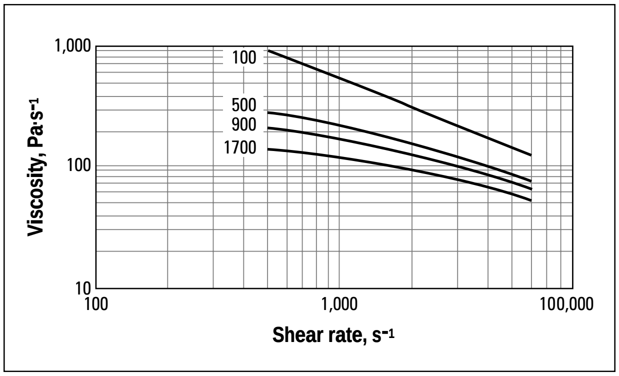
MFR is a measurement performed at low shear rate, but the relative differences between the grades are maintained at high shear rates, as shown in **Figure 8**.

A more direct comparison of the ability to fill can be obtained using an open-ended snake-flow mold. Results for the different grades of Delrin® are presented in the Molds section.

Table 3
Viscosity, Flow and Molecular Weight (Mw) of the Delrin® Grades

Grade	MFR (190°C/ 1.06 kg)	MFR (190°C/ 2.16 kg)	Ease of flow	Mw, toughness	Spiral flow length (215°C/100 MPa/2 mm) 90°C mold temperature
100	1	2.3	lowest	highest	170 mm
500	7	14			295 mm
900	11	24			350 mm
1700	17	37	highest	lowest	400 mm

Figure 8. Viscosity versus Shear Rate for Various Grades of Delrin® at a Constant Temperature of 215°C (419°F) ***(source: Campus)***



Injection Molding Unit

Delrin® acetal resins are molded throughout the world in a wide variety of types and designs of injection and extrusion equipment.

The first purpose of the injection unit for molding a crystalline material is to deliver to the mold the necessary amount of a homogeneous melt (with no unmelt and no degraded material). The rules of construction of the injection unit are then dependent on the molding material requirements in term of thermal behavior and heat needed. The first point to take into account for a crystalline material is the thermal stability at melt temperature, to avoid degradation. Then, screw, nozzle, back flow valve, adaptor, should be designed to provide efficient melting of crystalline material and delivery of molten polymer to the mold.

Two rough methods to evaluate the presence of unmelt and of degraded material will be presented in “Evaluation of Melt Quality” (see page 12).

Thermal Stability During Processing

As presented in the previous chapter, one difference between amorphous and crystalline material is the "melting" behavior. The amorphous polymer starts softening just after T_g and presents a continuous change in viscosity. This gives a very large temperature range to operate (but a large variation of viscosity with temperature). In contrast, the crystalline polymer stays solid up to the melting point and suddenly melts to the liquid phase at high temperature. This limits the processing range of temperature between unmelt and thermal degradation (specifically for Delrin® 190–250°C [374–482°F]).

The second factor is the time the material stays at that temperature. For all polymers, the molecules can withstand a certain time at a certain temperature before degradation can start. Obviously this acceptable time limit becomes shorter when the temperature is higher. The typical behavior of Delrin® is presented in **Figure 9**. Degradation of Delrin® will result in generation of gases which cause bubbles in the melt, splays on parts, mold deposit, yellow and brown marks on the parts.

The average residence time (or Hold-Up Time, HUT) in the injection unit is linked to the amount of polymer in the cylinder, the shot weight and the cycle time and can be calculated with the following equation:

$$\text{Average HUT} = \frac{\text{weight of resin in cylinder}}{\text{shot weight}} \times \text{cycle time}$$

A quick approximation can be done by :

$$\text{Average HUT} = \frac{\text{maximum screw stroke} \times 2}{\text{current screw stroke*}} \times \text{cycle time}$$

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* Effective screw stroke = distance the screw travels during rotation only

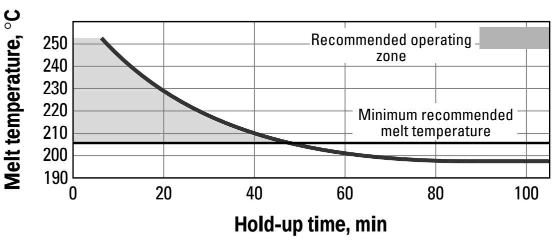
With a screw stroke of 1 diameter (a small shot) and a cycle time of 1 min (a very long one), the average HUT is equal to 8 min. According to the degradation curve shown in **Figure 9**, Delrin® should be stable enough for injection-molding with this HUT at a melt temperature of 240°C (464°F). Some customers have experienced molding Delrin® successfully at that temperature.

At the recommended melt temperature of 215°C (419°F), the maximum HUT is over 30 min and Delrin® (standard grades) is thermally stable even under these extreme conditions.

There are 3 main potential causes of degradation:

- *Material trapped in Hold-up spots.* In the injection unit, trapped molten material will stay for very long times in any dead spots and will start to degrade. So all the injection unit (screw, back flow valve, adaptor, nozzle and hot runners) should be designed to avoid Hold-up spots (see following recommended design).
- *Material sticking to "hot" steel.* Due to the high viscosity of polymers, the speed next to the steel of the injection unit (screw, back flow valve, adaptor, nozzle and hot runner) is almost zero and the residence time is almost infinite (as evidenced by how long it takes to change colors in an injection unit). Whereas inside the barrel the molten polymer is cleaned by the screw and the valve, inside all other areas the material will stick to the walls. To withstand a very long residence time, the steel in contact should be controlled at a temperature lower than 190°C (374°F) (see **Figure 9**).
- *Chemical degradation.* Contamination (e.g., PVC, flame retardant resins, acid generating resins), incompatible coloring systems (acid or basic pigments), contact with copper (pure, alloys, grease) will accelerate the thermal degradation of molten Delrin® in the injection unit. Note that mold components in copper or copper alloys (such as copper-beryllium) do not cause any degradation and have been used for years without problems.

Figure 9. Effect of Temperature on Hold-up Time of Delrin® 500



Screw Design

Screw design is a key parameter for productivity, because for crystalline materials the screw rotation time is an inherent part of the cycle time.

As mentioned above, it should take in consideration the specific melting behavior of the crystalline material, i.e., solid up to the melting point, high demand of heat during melting and low viscosity of the molten material.

Although general-purpose screws are widely used for molding Delrin®, optimum productivity will require a specific design. Exceeding the output capability of an inadequately designed screw will cause wide temperature variations and unmelted particles (sometimes unmelt and degraded material have been observed at the same time). The result is loss of toughness, variability in shrinkage and dimensions, warping, surface defects, plugged gates (leading to short shots) or other molding problems.

Due to the specifics of the melting process of a crystalline polymer, a screw designed for Delrin® will have shallow flight depths in the metering section and a slightly higher compression than a general-purpose screw. Specific suggestions are given for various screw diameters and composition of Delrin® acetal resin in **Table 4**. Compression ratio is the ratio of volume of one turn in the feed section to that in the metering section (can be approximated to the ratio of the depth of the two zones).

The length of the screw will also affect the melt quality (an insulating material needs some time to get the thermal energy transferred even if the shear contributes to the heating process). The preferred length is about 20 times the screw diameter or 20 turns when the pitch and diameter are equal. The screw should be divided as follows: 30–40% (6–8 turns) feed section, 35–45% (7–9 turns) transition and 25% (5 turns) metering section. Screws with 20 turns are commonly divided into 7 turns feed, 8 turns transition and 5 turns metering. In screws less than 16 diameters long, it may be necessary to reduce the pitch to get up to 20 turns. Definitively, the feed section should never be less than 6 turns.

The relatively high compression ratio screws suggested for Delrin® are designed to increase the heat input by mechanical working of the resin. Because the energy for this increase comes from the screw motor, additional horsepower must be available if an increase in melting capability is to be realized.

Screw Size

The ideal screw size is determined by the volume of the current shot. Optimum productivity will be achieved when the shot size requires a screw travel during plasticization equal to or lower than 50% of the capacity of the injection unit. Otherwise, screw rotation speed will have to be decreased at the end of the travel to guarantee an homogeneous melt, leading to a loss in productivity. Practically, optimum productivity is achieved with a screw travel of between 1 and 2 diameters of the screw.

Thermal settings of the injection unit will be dependent on the residence time (HUT) and hence dependent on the cycle time. Rules will be presented under “Molding Process.”

Screw Design for the Use of Color Concentrate

A flow analysis shows that the major part of the flow in the screw is laminar, then divided in the back flow valve (due to the changes in flow direction), and still laminar in the adaptor, nozzle, sprue, etc. To get optimum melt quality, to disperse pigments and color concentrates, it is strongly recommended to add a mixing head. The purpose of a properly designed mixing head is not to mix material by turbulence (turbulent flow is impossible with highly viscous molten polymer), but by forced changes in flow direction.

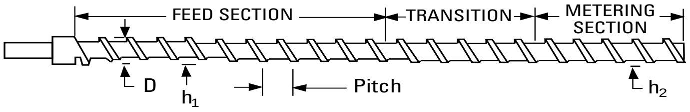
Cylinder Temperature Control

This is determined by the machine manufacturer, but two comments should be made.

- The temperature control should provide at least three independent zones, with thermocouples placed near the center of each zone. Burn-out of one or more heater bands within a zone may not be readily apparent from the temperature controllers, so some molders have used ammeters in each zone to detect heater band malfunctions.

Table 4
Screw Design for Delrin® Acetal Resins

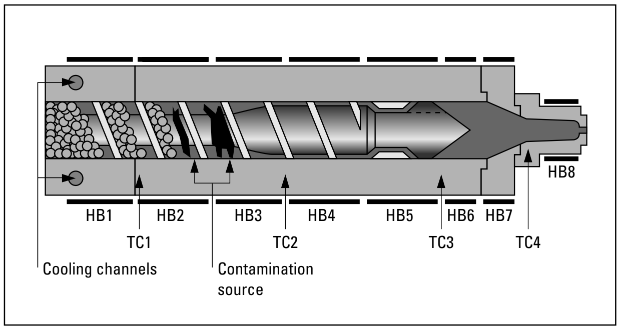
(20/1 Length/Diameter Ratio)



Nominal diameter (D)	Delrin® 500, 900, 500 T, 1700		Delrin® 100, 100ST	
	Depth of feed section (h_1)	Depth of metering section (h_2)	Depth of feed section (h_1)	Depth of metering section (h_2)
mm	mm	mm	mm	mm
30	5.4	2.0	5.2	2.6
45	6.8	2.4	6.5	2.8
60	8.1	2.8	7.5	3.0
90	10.8	3.5	8.7	3.6
120	13.5	4.2		
(in)	(in)	(in)	(in)	(in)
(1½)	(0.240)	(0.087)	(0.230)	(0.105)
(2)	(0.290)	(0.100)	(0.270)	(0.115)
(2½)	(0.330)	(0.110)	(0.300)	(0.120)
(3½)	(0.420)	(0.140)	(0.340)	(0.140)
(4½)	(0.510)	(0.160)		

- Usually for Delrin® there is no need to cool the feed throat, but in case such a need exists, the water flow should be kept to a minimum. Overcooling the feed throat has been observed as a major reason for contamination by black specks. These are generated in the barrel, between the first and second heating zones, with the following mechanism (see **Figure 10**). The thermocouple TC1 is influenced by the low temperature due to excessive cooling, and the system will respond by switching ON the heating bands HB1 and HB2. This causes no problem with HB1, but results in overheating and degradation in the area under HB2. To reduce the risk of formation of black specks, the following recommendations should be observed:
  a) the feed throat cooling should be limited to a minimum temperature of 80–90°C (176–194°F);
  b) the heater band HB2 should be controlled by TC2, or TC1 should be placed in the middle of HB2, or HB2 should have half the power density of HB1.

Figure 10. The Risk of Black Specks Contamination That Could Arise From the Presence of a Cooling System of the Feed Throat



Cylinder Adaptor

The adaptor shown in **Figure 11** is designed to avoid holdup areas and flow restrictions, the two main causes of degradation and problems linked to this area. Note that the concept is the same for screwed adaptors as represented in **Figure 11** (used for small screws ≤ ∅ 40 mm) and for bolted adaptors (used for larger screws). The adaptors has short cylindrical sections (A and B) where it joins both the nozzle and the cylinder to maintain accurate matching of these diameters, even if it becomes necessary to reface the mating surfaces. The mating surfaces (C) should be narrow enough to develop a good seal when the nozzle or adaptor is tightened and yet wide enough to avoid deformation. In addition to its mechanical function of reducing the diameter, the adaptor acts to isolate the nozzle thermally from the front of the cylinder for better control of nozzle temperature. A separate adaptor, made of softer steel than the one used for the cylinder, is easier and less expensive to repair and change than a cylinder. It also protects the cylinder from damage due to frequent changing of the nozzle. With the bolted adaptor, special care should be taken during assembly to ensure parallelism (don't overtighten screws from one side only).

Non-Return Valve (Back Flow Valve—BFV)

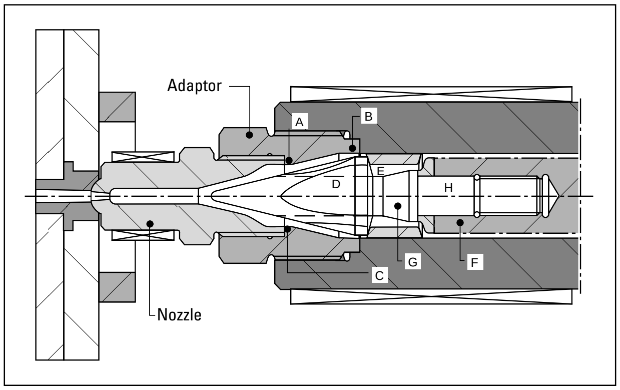
The non-return valve or check ring shown in **Figure 11** prevents melt from flowing backward during injection. This unit is frequently not properly designed to eliminate holdup of resin and flow restrictions. Malfunctioning that allows resin backflow is also a common experience and is caused by poor design or maintenance. A leaking non-return valve will add to screw retraction time, which can increase cycle, and it will also cause poor control of packing and dimensional tolerances.

The non-return valve must meet the following requirements:

- No holdup spots
- No flow restrictions
- Good seal
- Control of wear

These requirements are provided for in the non-return valve shown in **Figure 11**.

Figure 11. Design of Adaptor and Non-Return Valve



The slots or flutes (D) in the screw tip are generously proportioned, and the space (E) between the check ring and tip is sufficient for resin flow.

The seating of the fixed ring is cylindrical where it joins both the end of the screw (F) and the screw tip (G) to permit accurate matching of these diameters and avoid holdup.

The screw tip thread has a cylindrical section (H) ahead of the threads that fits closely in a matching counterbore for support and alignment of the screw tip and seat ring.

The screw tip and check ring seat should be harder (about Rc 52) than the floating ring (Rc 44), because it is less expensive to replace the floating ring when wear occurs.

Corrosion resistant steel is suggested for the tip. Good matching of cylindrical diameters is essential to avoid holdup spots.

Nozzle

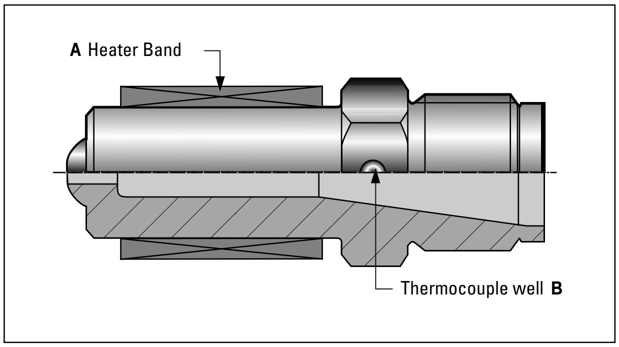
As with other semi-crystalline polymers, Delrin® may drool from the nozzle between shots if the nozzle is too hot, or it may freeze if too much heat is lost to the sprue bushing.

The nozzle design shown in **Figure 12** can solve these problems. The following should be considered:

1. The heater band (A) should extend as close to the nozzle tip as possible and cover as much of the exposed surface as practical. This counteracts any heat loss, especially heat loss to the sprue bushing.
2. The thermocouple location is important. An appropriate location (B) is shown in the same picture.
3. Adequate temperature uniformity is required so that local overheating or premature freezing is avoided.
4. To prevent polymer degradation the steel temperature should not exceed 190°C (374°F).
5. The nozzle heater should have its own independent temperature controller.

Screw decompression or "suck back" is frequently used to make control of drool easier with these open nozzles. This feature is available in most machines.

Figure 12. Reverse Taper Nozzle

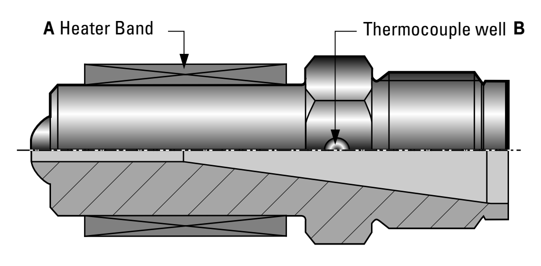


When not available, a design such as the one illustrated in **Figure 13** should be used.

Although shutoff nozzles have occasionally been used successfully with Delrin®, they tend to cause holdup of resin that results in brown streaks or gassing, especially after some wear has occurred in the moving parts of the nozzle. These nozzles are not generally recommended for Delrin® on safety grounds alone.

Note: With a long nozzle, the thermocouple well B should be positioned in the middle of the nozzle and not at the back of the nozzle.

Figure 13. Straight Bore Nozzle, Only for Machines Without Screw Decompression



Evaluation of Melt Quality

Below are presented two quick and easy tests to evaluate the melt quality delivered by the injection unit. Although the result is linked with the temperature setting of the injection unit, it is also highly dependent on the design of the injection unit.

Foaming Test

The foaming test is recommended to determine the quality of the resin after melting in the injection unit, i.e., the quality of the resin AND the quality of the injection unit.

Procedure:

1. When the machine is running in cycle, stop the machine after screw retraction for 3 min for pigmented Delrin® (10 min for natural material).
2. Purge at low speed (to avoid hot splashes) into a cup and observe the molten material for 1 or 2 min. Then put the molten material in a bucket of water.
3. Then recharge the screw and wait 2 more minutes (10 more minutes for natural material).
4. Repeat operation 2.

An unstable melt will grow (foam) during the observation and float in the bucket. A stable melt will stay shiny with a tendency to shrink during the observation, and will sink in the bucket.

Foaming resin will quickly cause mold deposit and will accelerate screw deposit, which may lead to black speck contamination.

This technique is useful to evaluate non-DuPont color systems (color masterbatches, liquid coloring).

The foaming test can also be used to detect inadequate quality of the injection unit (e.g., problems of throat cooling and consequent overheating, excessive nozzle temperature, hold-up spots, etc).

Unmelt Test

The unmelt test is recommended to evaluate melt homogeneity:

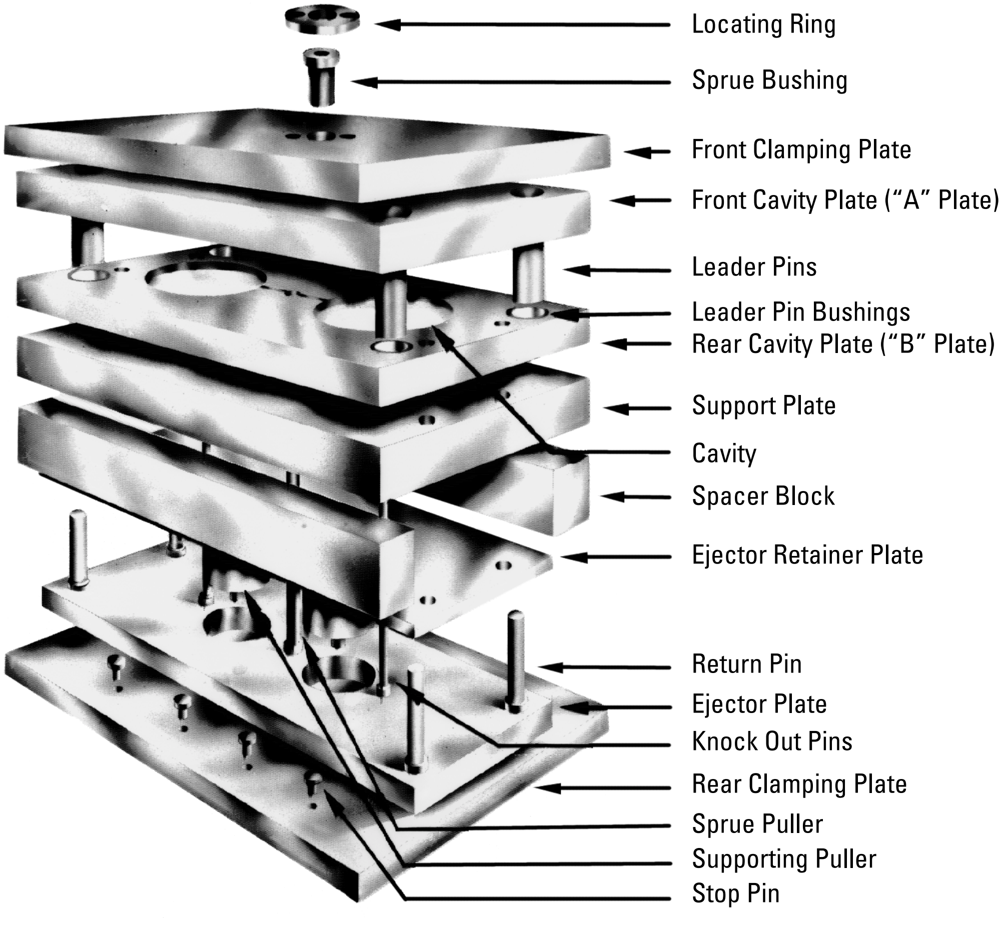
- When the press is running on cycle, stop at the end of a cycle and purge one shot;
- charge the screw immediately with the shot volume used and purge again;
- repeat the operation until detection of lumps/irregularities in the purge coming out of the nozzle.

If such lumps/irregularities appear after less than 3 purges, the risk of unmelt is very high and should be dealt with by increasing cylinder temperature, by lowering screw RPM and by increasing back pressure. If such changes lengthen the cycle time too much, a more appropriate screw design should be used (see **Table 4**). If lumps/irregularities appear after 3 purges but before 6, the situation is acceptable, but there is not much safety margin. If they appear after 6 purges, there is a very low risk of unmelt.

Molds

Delrin® acetal resins have been used in many types of molds, and molders have a wealth of knowledge concerning mold design for Delrin®. Molds for Delrin® are basically the same as molds for other thermoplastics. The parts of a typical mold are identified in **Figure 14**.

Figure 14. Exploded View of Mold



This section will focus on the elements of mold design that deserve special consideration for processing Delrin® and can lead to higher productivity and lower cost for the molder. These topics are:

- Ability to fill
- Gates
- Runners
- Vents
- Undercuts
- Runnerless molds
- Mold maintenance

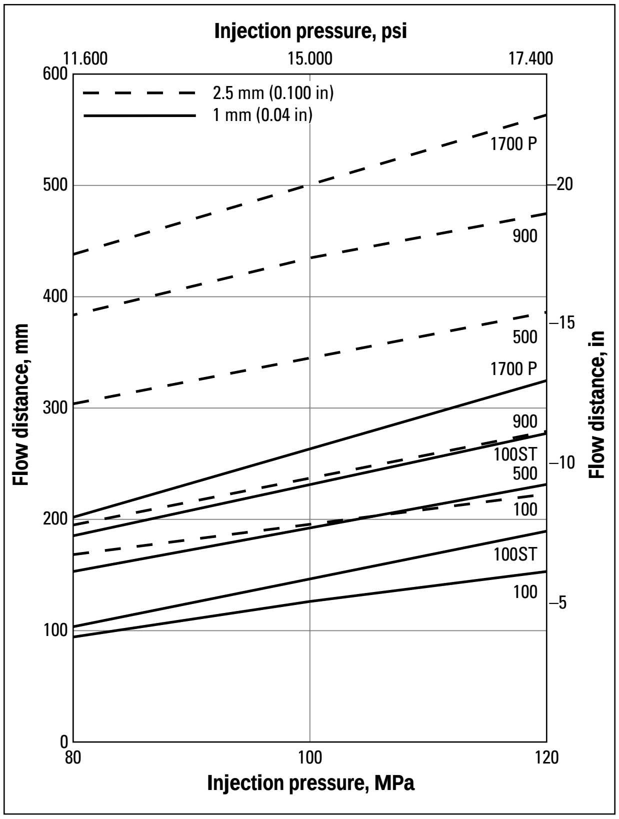
Mold shrinkage and other aspects of mold sizing are discussed in “Dimensional Considerations” (see page 30).

Ability to Fill

Melt viscosity largely governs the ability of a resin to fill a mold. Delrin® acetal resins range in melt viscosity from Delrin® 1700, the lowest in viscosity or most fluid, to Delrin® 100, the highest. The viscosity of Delrin® does not decrease rapidly as melt temperature increases, in contrast to amorphous thermoplastic resins. Increasing melt temperature will not greatly improve the ability of Delrin® to fill a thin section.

In addition to the properties of the resin, the molding conditions and cavity thickness determine the distance of flow. **Figure 15** shows the maximum flow distances that can be expected at two cavity thicknesses for Delrin® acetal resins as a function of injection fill pressure. These comparisons were made in an open-ended snake flow mold with no gate restriction. Obstructions in the flow path, such as sudden changes in flow direction or core pins, can significantly reduce the flow distance.

Figure 15. Maximum Flow Distance of Delrin® Acetal Resins



Gates

The gates of a mold play a major role in the success or failure of a molding job. The location, design, and size of a gate are key factors to allow optimum packing. Obviously, the design will be different than the one used for molding amorphous material. In that case the flow should stop as soon as possible after filling the cavity to avoid overpacking (flow in) and sink marks at gate (flow back). With crystalline material, the location, design and size of the gate should be such that it will allow a continuous flow during ALL the packing phase (Hold pressure time—see page 26).

Gate Location

As a key rule, when a part is not uniform in wall thickness, the gate must be located in the thickest section. The respect of this basic principle plays an essential role in obtaining optimum packing and consequently the best mechanical properties, dimensional stability and surface aspect. Of course every bottleneck (reduced section along the flow of the melt) should be avoided between the gate and all areas of the part.

An area where impact or bending will occur should not be chosen as the gate location, because the gate area may have residual stress and be weakened since it works as a notch. Similarly, the gate should not cause a weld line to occur in a critical area.

The gate should be positioned so that the air will be swept toward a parting line or ejector pin—where conventional vents can be located. For example, a closed-end tube such as a pen cap should be gated at the center of the closed end, so air will be vented at the parting line. An edge gate will cause air trapping at the opposite side near the closed end. When weld lines are unavoidable, for example around cores, an escape for gases must be provided to avoid serious weakness and visual flaws. Specific recommendations for venting are given later in this section.

Another consideration in choosing a gate location for Delrin® is surface appearance. Gate smear or blush, as well as jetting, are minimized by locating the gate so that the melt entering the cavity impinges against a wall or core pin.

A central gate location is often necessary to control roundness of gears and other critical circular parts.

Multiple gates, usually two to four, are commonly used when there is a central hole to avoid a difficult-to-remove diaphragm gate.

Gate Design

As mentioned above, for crystalline materials like Delrin® the thickness of the gate or its diameter (for a pin-point gate or tunnel gate) determines the freeze-off time, and therefore also determines whether it is possible to pack the part (to compensate the volume reduction due to crystallization) and maintain the pressure during solidification. The gate should remain open until the part density is maximum for a specific material. The thickness (or diameter) of the gate should amount to 50–60% of the wall thickness at the gate. The width of the gate should always be equal or greater than the gate thickness. The length of the gate should be as short as possible and never exceed 0.8 mm (0.03 in). The gate area of the part should not be subjected to bending stresses during actual service. Impact stresses are particularly liable to cause failure in the gate area.

The most common types of gates are summarized in **Figure 16**.

- DIAPHRAGM GATE: Circular gate used to fill a single symmetrical cavity. The advantages are a reduction of weld line formation and improvement of filling rates. However the part has to be machined to remove the gate.
- DIRECT GATE: The sprue feeds directly into the mold cavity without runners. This design may often lead to surface defects coming from the nozzle (e.g., cold slug, cold skin, entrapped air.)
- EDGE GATE: Usual type of gate with two plate molds. It is not self degating.
- FAN GATE: This gate is used to enlarge the flow front. Usually it leads to a reduction of stress concentrations in the gate area. Less warpage of parts can usually be expected by the use of this gate type.
- PIN POINT GATE: This gate is used with three plate molds. It is self degating.
- RING GATE: See DIAPHRAGM GATE.
- SPRUE GATE: See DIRECT GATE.
- SUBMARINE GATE: A type of edge gate where the opening from the runner into the mold is not located on the mold parting line. It is used to separate the gate from the part with a two plate mold (self-degating).
- TUNNEL GATE: See SUBMARINE GATE.

Details of a typical edge gate suitable for Delrin® are shown in **Figure 17**.

Figure 16. Schematic View of the Most Common Types of Gates

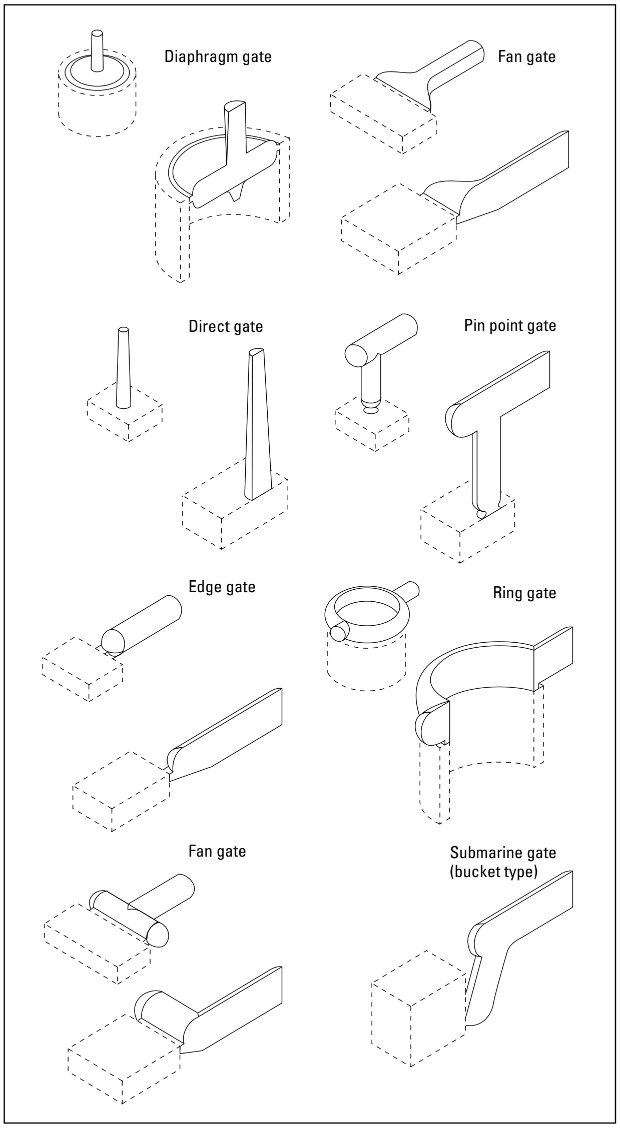


Figure 17. Details of a Typical Edge Gate Suitable for Delrin®

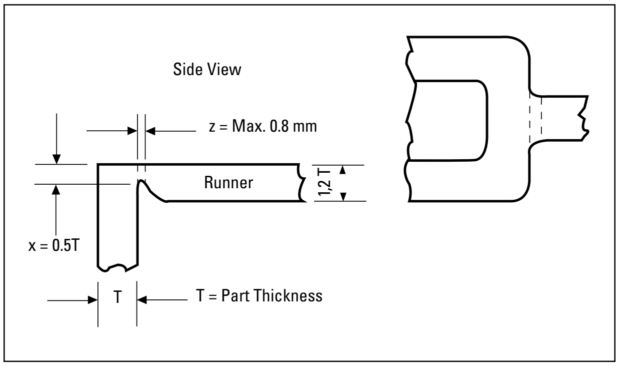


Figure 18 shows details of a submarine gate adequate for Delrin® (left), compared to a similar type of gate not recommended for crystalline materials (right).

Design criteria:

- always gate in thickest area of the part;
- diameter of the gate "d" must be at least half the part thickness. The length must be shorter than 0.8 mm (0.03 in) to prevent premature gate freezing during packing;
- the inscribed diameter "D" of the tunnel next to the gate must be at least 1.2 × the part thickness "T."

The gate shown on the right side of **Figure 18** is not recommended for crystalline materials like Delrin®, because such conical gate sections crystallize before the end of complete part pack out. This results in low mechanical performance and uncontrolled shrinkage.

Figure 19 shows details of a three plate gate design adequate for Delrin® (left), compared to a similar type of gate not recommended for crystalline materials. The design criteria illustrated above are also applicable to this kind of gate.

Note: Restrictions around the sprue puller will lead to incomplete part pack out. So, the diameter D1 in **Figure 19** should be at least equal to diameter D.

Runner System

Guidelines

Key guidelines to follow when designing a runner system include:

a. runners should stay open until all cavities are properly filled and packed;

b. runners should be large enough for adequate flow, minimum pressure loss and no overheating;

c. runner size and length should be kept to the minimum consistent with previous guidelines.

Each of these factors can affect quality and cost of molded parts. Factor (a) should be regarded as the most critical.

The cross section of the runners is most often trapezoidal, which represents an optimum practical compromise with respect to the full round section. The effective cross section of the runner is in this case the diameter of the full circle that can be inscribed in it.

For parts of Delrin® to have the best physical properties, the runners next to the gate must have at least an inscribed diameter of 1.2 times the part thickness "T."

Figure 18. Details of a Submarine Gate (Tunnel Gate) Adequate for Delrin® (left side). The One on the Right is Not Adequate for Crystalline Polymers and Would Give Problems with Delrin®.

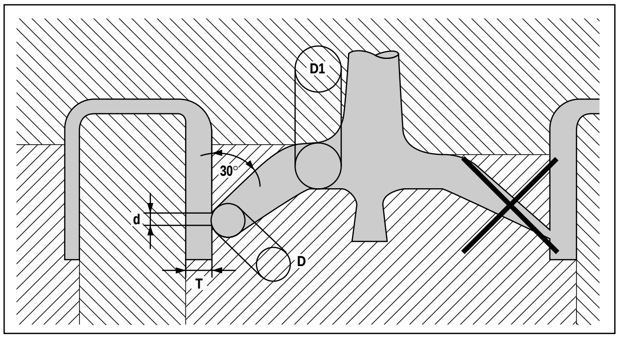
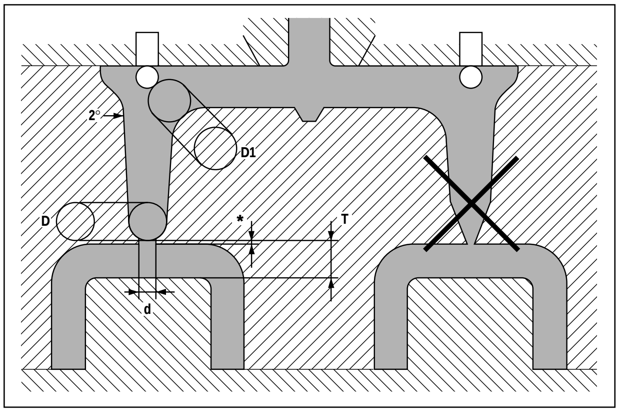
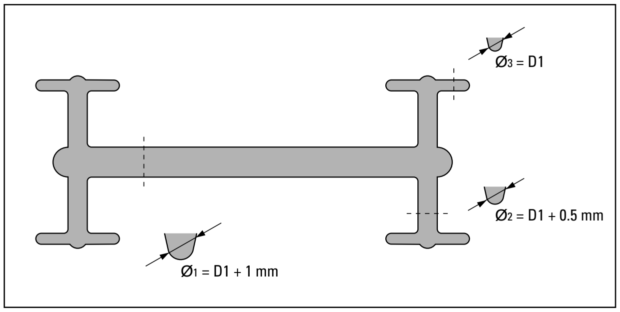


Figure 19. Details of a Three Plate Gate Design Adequate for Delrin® (Left Side). The One on the Right is Not Adequate for Crystalline Polymers and Would Give Problems with Delrin®. *Gate Length Should be <0.8 mm (0.03 in).



When the moldings are very thin, however, this runner cannot be less than about 1.5 mm (0.06 in) in thickness. The runner thickness is usually increased at each of the first one or two turns from the cavity, as shown in the example of **Figure 20**.

Figure 20. Correct Runner Thickness for an Eight Cavity Mold



Single Cavity Mold

The simplest runner configuration for a single cavity mold could be direct gating (see **Figure 21**). In this case, however, it would be necessary to have a “cold slug catcher” directly on the part, with associated surface problems and lower mechanical properties in that area. The preferred solution is then to “break the flow” as indicated in **Figure 21**.

Runner Layout

A perfectly balanced layout (with equal flow distance from the sprue to each cavity) is best achieved if the number of cavities is equal to a power of 2 (2, 4, 8, 16, 32, 64, 128, etc.). See an example of a 16-cavity mold in **Figure 22** with balanced (left) and unbalanced runner systems. A perfectly balanced layout may be impractical and expensive.

When an unbalanced runner system is selected, the layout shown in **Figure 23** (left) could present more risks of quality problems. The flow tends to stop at each of the early gates due to the restriction and the material starts to crystallize. Then, as the runner continues to be filled, the pressure rises and the the cold slugs which started to be built up, are pushed into the cavity.

To reduce such risk, the solution shown in **Figure 23** (right) is recommended. In such configuration, the cold slugs tend to be trapped into each overflow well.

In case of multi-cavity molds (≥16 cavities), the so-called “spiral effect” could take place in the “internal” cavities of the layout (see for instance **Figure 24**), due to over-heating of the melt in runners, caused by localized shear. To minimize negative effect like splays or mold deposit, shear should be reduced by using appropriate runner dimensions.

Figure 21. Direct Gating (Left) and Indirect Gating to Break the Flow (Right), in a One-Cavity Mold

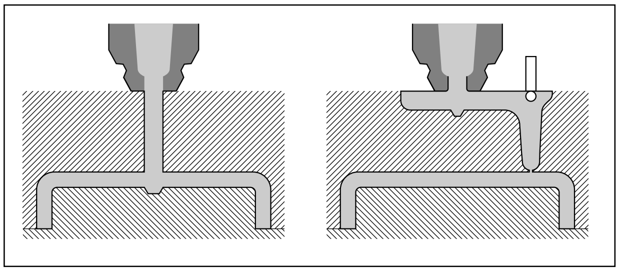
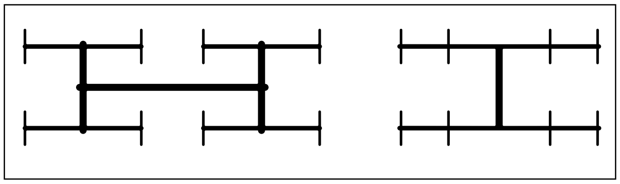


Figure 22. Balanced (Left) and Unbalanced (Right) Runner Systems in a 16-Cavity Mold



For multi-cavity molds for small thickness parts (≤1 mm [0.04 in]), the design of runners should be checked by running a detailed flow analysis study.

Nozzle and Sprue

Nozzle and sprue diameters are directly linked with the dimensions of the part and of the runners. The designer should first decide if the sprue is needed or not. If yes, a design like the one shown in **Figure 25** could be selected, one that in many cases has proved to be the most effective with crystalline materials like Delrin®. Due to its parallel cylindrical shape it is easy to machine and polish, allows large nozz1e diameters, and it is easy to eject due to high shrinkage. Guidelines for the dimension are:

- a sprue diameter $\varnothing_1$ at least equal to the inscribed diameter of the main runner;
- a nozzle diameter “DN1” equal to $\varnothing_1$ minus 1 mm.

Figure 23. Examples of Unbalanced 16-Cavity Mold. The Solution on the Right is Provided with Overflow Wells to Trap Cold Slugs.

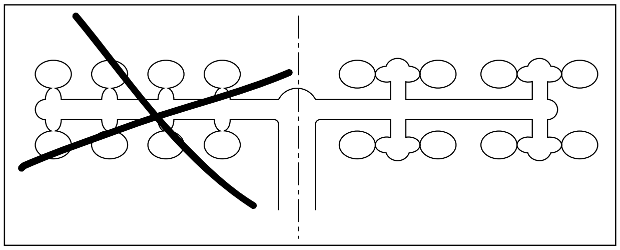
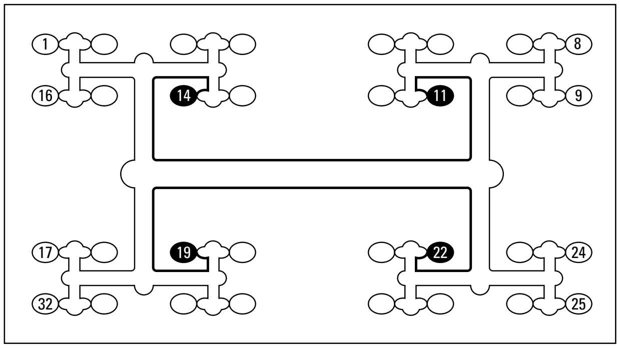


Figure 24. Example of “Spiral Effect” in a 32-Cavity Mold. Cavities 11, 14, 19, 22 Will Be Filled First and May Show Splays and Mold Deposits.



In case the designer selects a design without a sprue, a long nozzle may be required as shown in **Figure 26** for a 2 plate tool, and in **Figure 27** for a 3 plate tool. Again, the dimensions are linked to the dimensions of the part and of the runners (guideline: nozzle diameter “DN1” equals to the main runner inscribed diameter minus 1 mm).

Figure 25. Sprue and Nozzle Design Often Used with Delrin®. The Dimensions are Linked with the Dimensions of the Part and of the Runners.

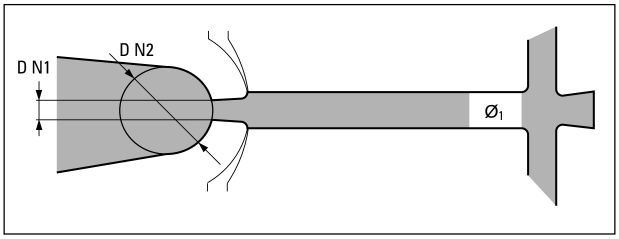


Figure 26. Example of a Design of a Nozzle Without Sprue Used with 2 Plate Molds. Remember that for Delrin® the Nozzle Temperature Should Not Exceed 190°C (374°F).

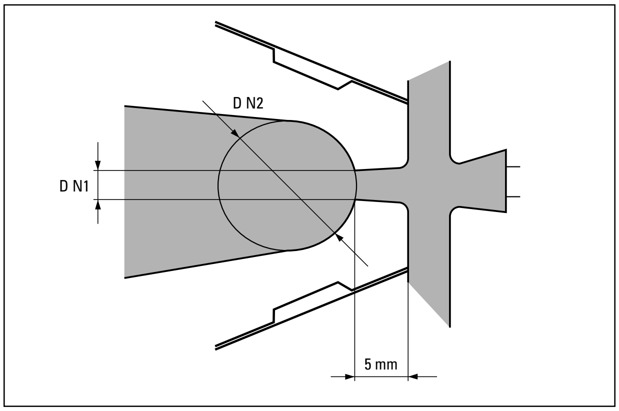
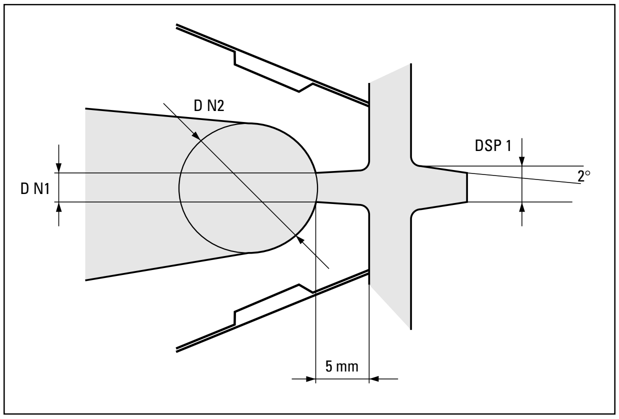


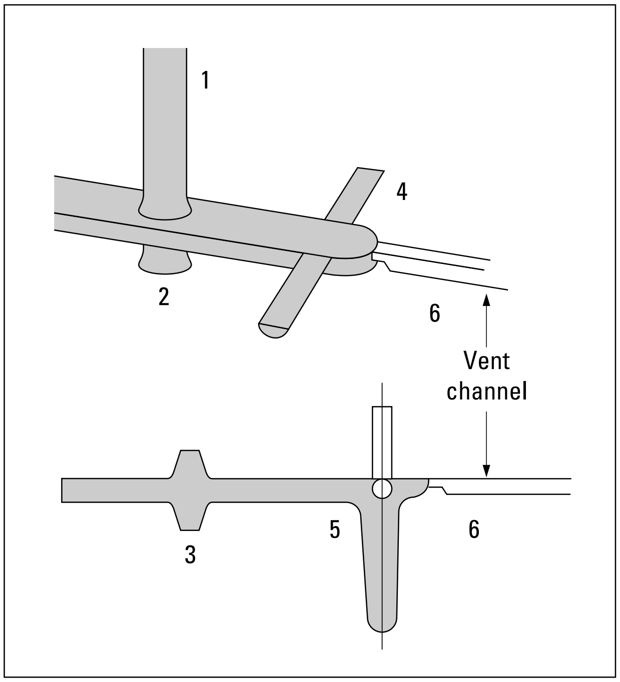
Figure 27. Example of a Design of a Nozzle without Sprue Used with 3 Plate Molds. Remember that for Delrin® the Nozzle Temperature Should Not Exceed 190°C (374°F).



A review of the key recommendations related to the sprue and runner system follows. It can be used as a quick reference list to check their design.

1. Cylindrical parallel sprue preferred: see **Figure 25** and **Figure 28-1**.
2. Sprue puller for 2 plate mold: see **Figure 28-2.**
3. Cold slug well for 3 plate mold: see **Figure 28-3.**
4. Perpendicular flow splits with cold slug wells at each split, see **Figure 28-4**.
5. No flow restriction caused by sprue puller in 3 plate mold, see **Figure 28-5**.
6. Runner dimensions:
   - for parts having thickness >1.5 mm (0.06 in), follow general rules for crystalline polymers (**Figure 20**);
   - for thinner parts and multi-cavity molds, a flow analysis may be required to select dimensions that will avoid over-shearing.
7. Runners should be properly vented, see **Figures 28**, **29** and **30**.
8. Balanced runners recommended (see **Figure 24**).
9. For thin parts and large number of cavities, unbalanced runners may be acceptable. However, parts should never be gated directly onto the main runner (see **Figure 23**).

Figure 28. Key Rules for the Design of the Sprue and Runners of a 2 Plate Mold (Top) and of a 3 Plate Mold (Bottom)



Hot Runner Mold for Crystalline Polymers

Preliminary Comments

This section includes all hot runner, hot sprue bush, and runnerless molds. The following is not intended to recommend any trademark or system but to present the behavior and the needs of crystalline polymers in such tools.

The question that frequently arises is when to use hot runner molds with crystalline polymers like Delrin®. This is a highly controversial subject. The choice depends on many factors, and particularly on the quality needed, i.e., mechanical performance, surface aspect, percentage of rejects.

Status

All such molds give the obvious advantages of less material to plastify, no (or minimum) regrind and shorter cycles. On the other hand, hot runner molds are more expensive and heavier; they need more maintenance and better-trained operators than conventional molds. In addition, if they are not properly designed, the heat needed to run them could spread to all parts of the mold and can in fact cause the cycle time to increase.

One approach is to evaluate the expected increase of theoretical productivity versus conventional molds. If such an increase is lower than 25%, it would be wise to stay with a 3 plate mold that will be cheaper to build, start and run.

The break-even of about 25% applies to full hot-runner systems; for other molds (with hot sprue bushes, cold sub-runners) the break-even point is much lower.

Direct Gating Versus Cold Sub-Runners for Crystalline Polymers

When designing a hot runner mold for crystalline polymers, it should be kept in mind that direct gating via hot runner is more difficult with crystalline polymers than with amorphous ones. The difference comes from the softening or melting behavior of these two types of polymers.

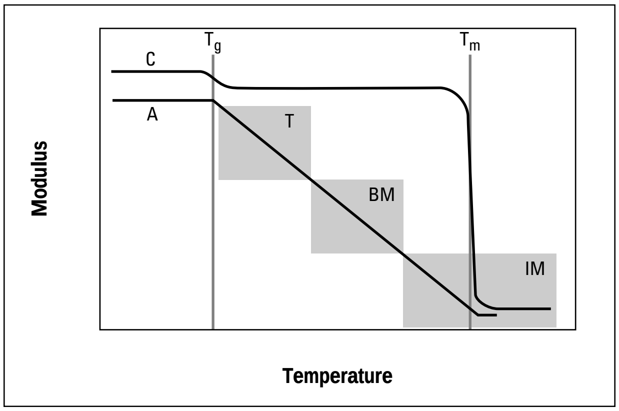
An amorphous material exhibits a gradual softening behavior above T_g from the solid state to the liquid state, allowing a wide processing window in terms of temperature and viscosity. In fact, as its temperature increases above T_g (see **Figure 29**) an amorphous polymer (curve "A") lends itself first to thermoforming ("T"), then to blow molding ("BM") and finally to injection molding ("IM").

On the contrary, the T_g has usually a limited or negligible effect on the structure of crystalline polymers, which are solid above T_g. At the temperature T_m, crystalline polymers melt sharply and become liquid (curve "C").

Such behavior of a crystalline material may involve the risk of:

- Drooling around the gate with consequent problems of bad surface aspect and deformation.
- Plugging of the gates by solidified material, plugs which will be pushed into the cavities, with consequent problems of surface defects and lower mechanical performances. The best way to prevent such problems is to use COLD SUB-RUNNERS.

Figure 29. Softening/Melting Behavior of Amorphous and Crystalline Polymers



Thermal Control of Hot Runner Molds

Thermal management and streamlining of the flow are very important for hot runner tools. It should be checked that a relatively low temperature setting (≤190°C [≤374°F]) gives an easy flow of the material with no hold-up spots.

The reason is that, due to the viscosity of the polymer, its flow is always laminar. This means that the material will remain against the steel wall of the hot runner, and residence time will be very long. For Delrin®, to avoid thermal degradation with prolonged times, the steel temperature should never exceed 190°C (374°F). If the hot runner system solidifies at that temperature, then it must be modified to improve thermal insulation and heat distribution to remove cold spots. Degradation can result in splays, odor, black specks and mold deposit.

Conclusions

With crystalline polymers such as Delrin®, we recommend the following:

- A minimum of 25% theoretical cost decrease should be expected before a hot runner is considered.
- Highly trained machine operators and mold maintenance toolmakers should be available.

- Use of cold sub-runners, never direct gating straight onto the part.
- Use of Delrin® P grades.
- All temperatures in the hot runner system must not exceed 190°C (374°F).
- Avoid the use of hot runner molds if surface defects are not acceptable and high part mechanical performance is required.
- Avoid the use of hot runners for toughened grades.

Vents

Venting a mold for Delrin® is particularly important, and special attention should be given to this factor during both the design of the mold and its initial trial. This attention is required because burning of parts caused by inadequate venting is not easily observed with Delrin®. With other resins, poor venting results in a blackened and burned spot on the part. With Delrin®, however, there may be either no visible flaw or an inconspicuous whitish mark on the molding.

Venting problems with Delrin® acetal resins may be made more obvious by spraying the mold with a hydrocarbon or kerosene-based spray just before injection. If venting is poor, the hydrocarbon will cause a black spot where the air is trapped. This technique is particularly useful for detecting poor vents in multi-cavity molds. A convenient source of hydrocarbon spray is a rust preventative spray.

Vents should be located at:

1. the end of any runner;
2. any flow junction where air is entrapped and a weld line results. The position of weld lines can be defined by short shots.

Only NO venting together with excessive fast injection speed will cause corrosion of the tool at the weld lines with Delrin® (diesel effect). Inadequate venting of molds for Delrin® may cause a gradual buildup of mold deposit where vents should be located and in mold crevices through which limited venting has taken place. These deposits consist of a white solid material formed from the traces of gas evolved during normal molding. Good vents allow this gas to escape with the air from the cavities.

Poor venting may also reduce physical properties at weld lines.

Venting problems may be aggravated by high melt temperature, long holdup time, or holdup areas in the injection cylinder, which will generate more than normal amounts of gas. Fast injection fill speed will also aggravate these problems. Remedies for mold deposit problems are listed in the Troubleshooting Guide (see page 38).

Venting usually occurs through the parting line of a mold and is provided by machining channels in the cavity plate and inserts.

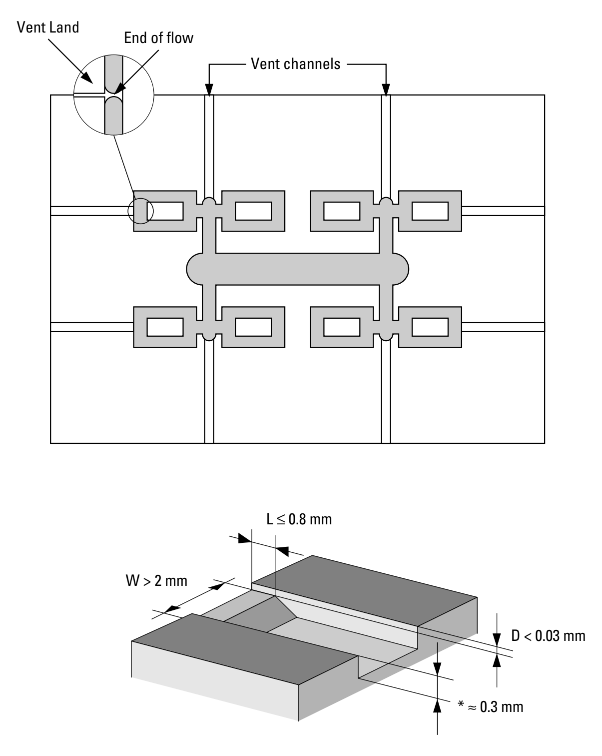
In some cases, venting may be accomplished around an ejector pin. This vent will also be improved by grinding flats on the pin and relieving the vent after a short land. Pins that do not move with the ejection system tend to clog and no longer provide venting after a short time.

Venting the runner system is helpful in reducing the amount of air that must be vented through the cavities. Because flash is unimportant on the runner, these vents can be slightly deeper than cavity vents, for example, 0.06 mm (0.0024 in).

The drawings in **Figure 30** show the recommended dimensions for vents in cavities for Delrin®.

Note: During mold maintenance, vent depth and/or hobbing should be carefully checked. Vents should be modified if the vent depth is less than 0.01–0.015 mm (0.0004–0.0006 in).

Figure 30. Recommended Venting of a Part and of its Runner System

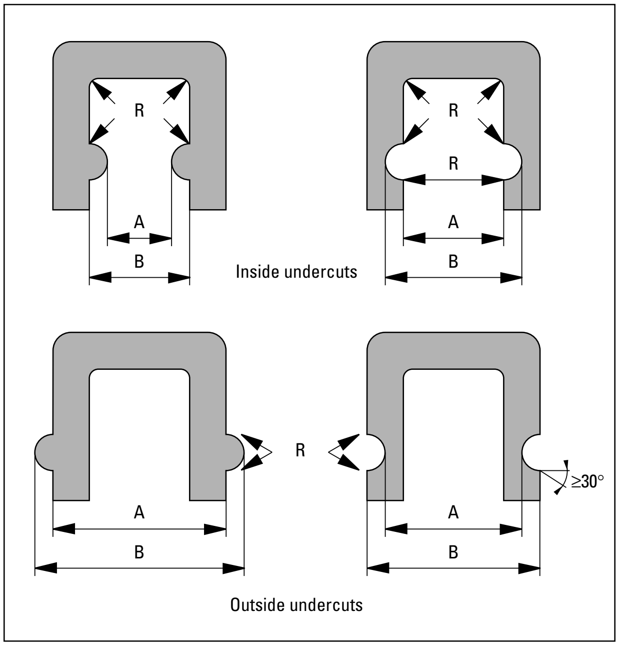


Undercuts

General suggestions for stripping undercuts with Delrin® acetal resins are:

- The undercut part must be free to stretch or compress, that is, the wall of the part opposite the undercut must clear the mold or core before ejection is attempted.
- The undercut should be rounded and well-filleted to permit easy slippage of the plastic part over the metal and to minimize stress concentration during the stripping action.
- Adequate contact area should be provided between the knockout and plastic part to prevent penetration of the molded part or collapse of thin wall sections during the stripping action.
- The length of the molding cycle and specifically the Hold (Pressure) Time (HPT) should be optimum to avoid excessive shrinkage with inside undercuts. Sufficient part rigidity must be developed without causing binding due to excessive shrinkage around pins forming an internal undercut. Ejection of parts with undercuts on the outside diameter will be aided by mold shrinkage.
- Higher mold temperature, which keeps the part hotter and more flexible when the mold opens, may aid ejection from an undercut.
- Generally, parts of Delrin® acetal can be molded with a maximum 5% undercut. Calculation of allowable undercut is illustrated in **Figure 31**. The allowable undercut varies somewhat with both wall thickness and diameter.

Figure 31. Calculations for % Undercut (B–A)/B ≤ 5%



Sharp Corners

One of major causes of failure of plastic parts are internal sharp corners. A sharp corner in a part acts as a notch and initiates break at a very low energy. The diagram in **Figure 32** shows the effect of notch radius on impact resistance of test bars molded in two grades of Delrin®. Note that the notches have been molded (simulation of real life and not machined as required by the standard Izod test).

From this diagram it can be seen that an increase of an internal radius of curvature from 0.01 (almost a sharp corner) to 0.2 mm doubles the impact resistance.

Note also that sharp corners are not desirable in plastic parts because they are an important contributing factor to warpage.

Ribs Design

Very often, ribbed parts will perform much better in term of cycle time, mechanical performances and warpage than very thick unproperly packed parts. It is economically impossible to pack sections above 6–8 mm (0.24–0.32 in) thickness during all the crystallization time (solidification: see **Figure 30** for Hold [pressure] Time vs part thickness). However an improper rib design could also cause defects such as sink marks. Recommended rib dimensions are shown in **Figure 33**. Note that the radius at the base of the rib should not be too small to preserve part toughness (see **Figure 32**).

Weld Lines

Weld lines occur where two melt flows join together. Weld line position can be defined by short shots, or by flow simulations (if the mold does not exist yet). If the mold is provided with proper venting (see page 19), the weld line strength should be at least 80–90% of the nominal strength value of the resin.

To optimize weld-line strength, two parameters are important:

1. optimum Hold (Pressure) Time, to ensure the welding of the flow fronts under pressure (for the correct HPT see page 26);
2. optimum filling rate, which will depend on part thickness (approximately 1 second per mm (0.04 in) of part thickness).

Figure 34 shows the weld line strength of a 4 mm (0.16 in) thick test bar in Delrin® 100 gated at both ends. Both tensile strength and toughness are seriously affected if filling time is not optimized.

Figure 32. Impact Strength as a Function of Molded Notch Radius

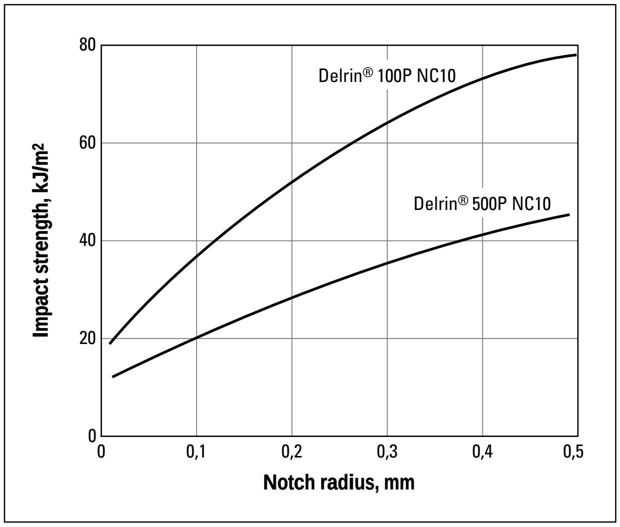


Figure 33. Suggested Rib Dimensions Versus Wall Thickness

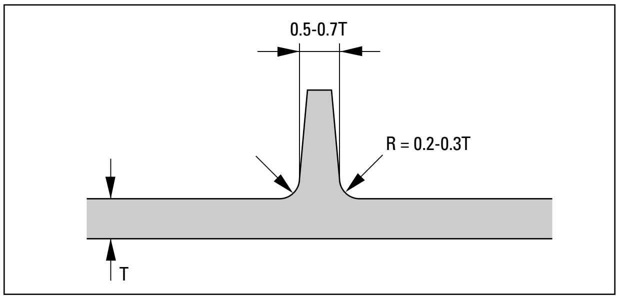
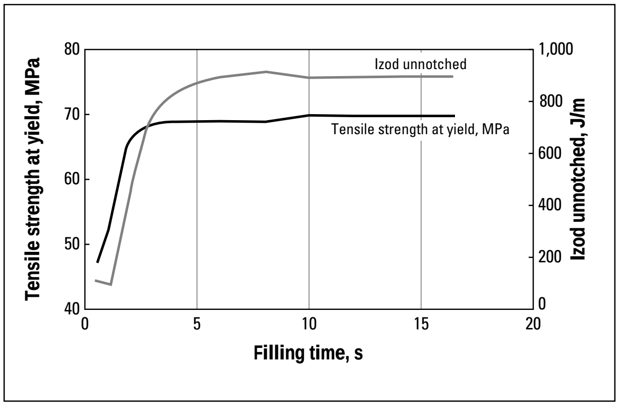


Figure 34. Tensile Strength (Left Scale) and Unnotched Izod Impact (Right Scale) of a Delrin® 100 Test Bar, 4 mm thick, Molded at Both Ends with Different Filling Times



Mold Maintenance

As a general rule, molds for processing Delrin® require the same care as those for processing other thermoplastic materials. Wiping the mold and applying a rust-preventing solution is usually adequate after a production run.

Vent Maintenance

Due to the critical nature of the vents, the vent dimensions should be checked during routine maintenance. Vent depth and /or hobbing (deformation of the parting line opposite the vent) should be carefully checked. Vents should be modified if the vent depth is less than 0.01 mm to 0.015 mm. Any hobbing that blocks the vents should be ground off.

Mold Cleaning

Depending on the type of deposit the cleaning procedure is as follows:

- **White deposit**
  White deposit is due to the accumulation of paraformaldehyde. This deposit can be removed with benzyl alcohol or isopropanol. Frequent cleaning of the tool with these solvents during molding will prevent the accumulation of this deposit.
- **Translucent or colored deposit**
  This deposit is normally observed near the gate (in case of overshear of the material), on pins or near hot spots. The use of a less shearing gate (see gate design recommendations) or a more even mold temperature will stop or tremendously decrease the build up of this deposit. It can be removed with commercial alkaline chemical cleaners. Efficiency of the cleaning agent can be improved with an ultrasonic bath.

Molding Process

Injection molding of Delrin® acetal resin is similar to that of other thermoplastic resins. The engineering applications for which Delrin® is used, however, frequently require tight specifications on strength, dimensions and surface condition, so that control of the molding operation becomes more critical.

The information discussed in this section includes suggestions for:

- Start-up and shutdown procedures, handling precautions
- Operating conditions for Delrin®
- Techniques for optimum productivity molding

Start-up and Shutdown Procedures

Start-up with Resin Change

The suggested start-up procedure with Delrin® is designed to prevent overheating of the resin and contamination in the injection unit with material from previous runs.

To start up a machine which contains another resin, the injection unit must be purged with crystal polystyrene until the cylinder and other high temperature zones have been cleared. This can normally be done with cylinder temperatures in the range 210–250°C (410–482°F), if appropriate for the previous material. The nozzle is quite difficult to clean by purging, because the laminar flow in this area leads to a layer of polymer sticking to the metal (this is also true for hot runners). It is therefore recommended to switch off the nozzle heater, remove the nozzle, clean it to get rid all traces of previous polymer, and reassemble it. The cylinder temperatures should then be adjusted to about 215°C (419°F), and the nozzle temperature to 190°C (374°F). When both cylinder and nozzle have reached the expected temperatures, Delrin® can be added to the hopper.

In unusual circumstances, an intermediate purge with a harsher compound may be required to remove adherent deposits from the screw and cylinder. Special purge compounds are used for this purpose.

These purge compounds must also be removed from the cylinder by purging with polyethylene or polystyrene before Delrin® is introduced. In the worst cases, e.g., after use of glass-reinforced resins or severe degradation of previous material, it may be necessary to pull the screw and clean the equipment manually to prevent contamination of moldings.

Safety point: Polystyrene is chemically compatible with Delrin®, whereas even a trace of polyvinyl chloride (PVC) is not. Contamination of Delrin® with such material can cause objectionable odor or even a violent blowback.

Start-Up From a Cylinder Containing Delrin®

After a safe shut-down procedure, the screw and the cylinder should be essentially empty. To restart, the nozzle and cylinder temperatures should be set at 190°C (374°F) to preheat the cylinder and the resin it contains. When the cylinder has reached the set temperature, ensure that the nozzle is open and increase the cylinder settings to normal operating temperatures. When all temperatures are in the operating range, the hopper can be filled and molding can begin after a brief purge with Delrin®.

Shutdown When a Restart with Delrin® is Planned

Shut off the hopper feed and continue molding until the cylinder is empty. For large machines (with a screw diameter above 40 mm [1.57 in]) it is recommended to purge the cylinder with crystal polystyrene, move the screw fully forward, then switch off the heater bands. For small machines move the screw fully forward and switch off the heater bands.

Shutdown When a Restart with Another Resin is Planned

Shut off the hopper feed and continue molding until the cylinder is empty. Purge with crystal polystyrene, leave the screw fully forward, then switch off the heater bands.

Temporary Interruption

A molding machine with Delrin® in the cylinder at molding temperatures should not be allowed to stay idle. The maximum recommended cylinder residence time, under normal molding conditions, is 10 min for pigmented material and 20 min for natural standard material. In excess of these times, resin decomposition may occur.

If, during the temporary interruption, the cylinder residence time reaches the above limits, close the hopper feed, empty the cylinder and leave the screw forward. The cylinder temperatures should be reduced to about 150°C (302°F) (at these temperatures Delrin® will be stable even for a weekend shutdown).

Action to Follow When the Nozzle Heater Band Breaks Down

Retract the injection unit, close the hopper and slide it out of the way. If the nozzle is still open, follow the normal shutdown procedures. If the nozzle is frozen, heat the nozzle with a gas torch to melt the frozen material inside the nozzle and then purge.

Start-up after Emergency Shutdown

A different procedure should be used after an emergency shutdown due to loss of power or other causes. In this case, the screw may be full of Delrin® that cooled slowly and was exposed to melt temperatures for a prolonged period. The screw may even be in the retracted position with a large quantity of Delrin® in front of the screw. In order to vent gases from resin that may be degraded, it is essential that the nozzle be open and heated to operating temperature and Delrin® in this area be completely melted before the cylinder reaches melt temperature. The cylinder zones should be heated to an intermediate temperature below the melting point of Delrin® and the machine allowed to equilibrate at that temperature. Cylinder temperatures of

150–175°C (300–350°F) are suggested. After all zones have been at this temperature for 30 min, cylinder temperatures should be raised to 195°C (380°F). As soon as the Delrin® has melted, it should be purged from the cylinder with fresh Delrin®. The partly degraded, hot purge resin should be placed in a pail of water if it emits an odor. When the old resin is purged from the cylinder, the cylinder temperatures may be raised to normal production settings.

Operating Conditions for Delrin® —Temperature Settings

Introduction

The basic purpose of the injection unit is to deliver to the mold the necessary amount of a homogeneous melt (no unmelt and no degraded material). The rules of construction of the injection unit for molding a crystalline material have been presented in "Injection Molding Unit," (see page 8); the rules for the settings are presented below.

Note: Two rough but practical methods to evaluate the presence of unmelt and of degraded material were described on page 12 and can be used here as well.

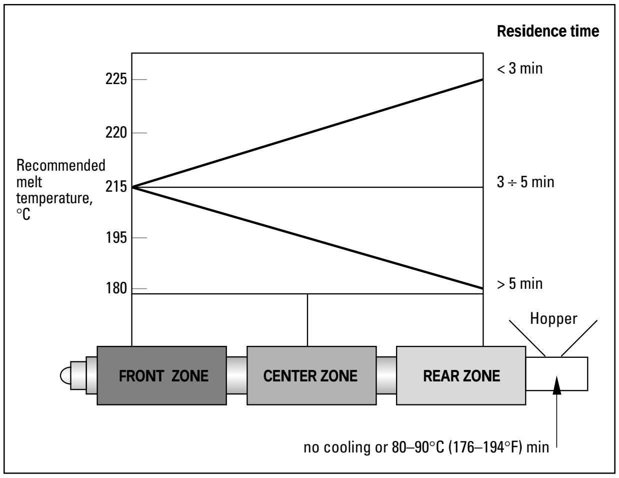
Delrin® acetal resin is a crystalline polymer with a melting point of 178°C (352°F). For most grades of Delrin® the preferred melt temperature range is 215°C (419°F) ± 5°C*, as measured with a needle pyrometer in the melt. The calories needed to heat and melt Delrin® will be provided by shear (from scew rotation) and the balance by conduction in the heated cylinder (slow heat transfer due to the insulating character of polymers).

Cylinder temperature

The main parameter influencing the temperature profile of the cylinder is the residence time (or Hold-Up Time—HUT) of the polymer in the plastification unit (see page 8 to calculate HUT).

With a short HUT (<3 minutes, short cycle time, high melt output), higher than normal cylinder settings may be required. With a long HUT (>5 minutes, long cycle time, low melt output), lower settings, especially in the rear zone, may be used. Since generalization of cylinder temperature settings is difficult, it is often wise to begin with a level profile and adjust as needed. The diagram shown in **Figure 35** can be used as a guideline for initial temperature settings.

Figure 35. Cylinder Temperatures Profile Versus Residence Time for a Given Recommended Melt Temperature. Recommended Nozzle Temperature is 190°C (374°F) for All Delrin® Grades.



Notes:

1. As the preferred melt temperature for Delrin® 100 ST and Delrin® 500 T is about 10°C (18°F) lower, the zone settings should be 10°C (18°F) lower than shown in **Figure 35**.
2. Hopper cooling is not needed and should not be used for Delrin®. As described in Chapter 3, excessive hopper cooling may create problems of screw deposit and black specks.
3. With very small injection units and/or short residence time (HUT), pre-heating the granules (e.g., with a heated hopper) may help to achieve an homogeneous melt.

Nozzle Temperature

The nozzle temperature is adjusted to control drool and freezing (see "Nozzle" page 11), but it should never be set above 190°C (374°F) in order to prevent polymer degradation (the laminar flow and high viscosity of the molten polymer result in very long contact time with the metal wall). If the nozzle freezes with a setting of 190°C (374°F), its insulation from the sprue bushing should be improved, or its inside diameter should be increased if feasible.

Notes:

1. Practically, it is always easier to set the nozzle temperature correctly by using sprue break. The injection unit is pulled back after screw rotation and then the nozzle is insulated from the cold mold. This allows the calories to flow to the tip of the nozzle without having to set too high a temperature, and reduces the risk of stringing from the nozzle.

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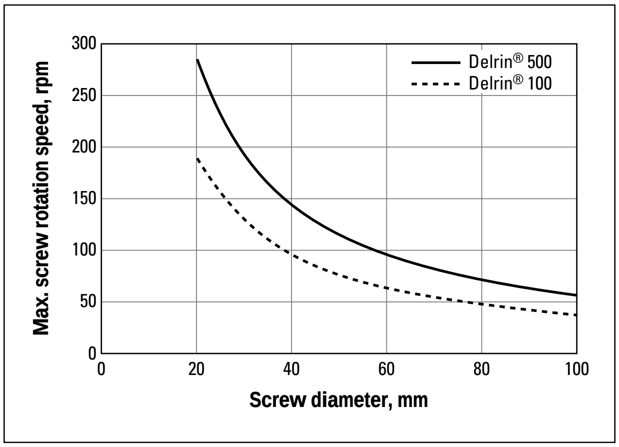
* The preferred melt temperature for Delrin® 100ST and Delrin® 500T is about 205°C (401°F).

2. Hot runner. By analogy, a hot runner system is a nozzle transferring the molten resin from the injection unit to the part. Hence the principles and recommendations for nozzles are also valid for hot runners. In particular, the laminar flow and high viscosity of the molten polymer again result in very long contact times with the metal wall; so the temperature of the metal in the hot runner should never exceed 190°C (374°F), in order to prevent degradation of the polymer.

Screw Rotation Speed

Screw rotation speed behaves as a "thermal setting," because the rotation of the screw will "shear" the material and supply around half of the calories needed to melt and heat Delrin® to the recommended melt temperature range of 215°C (419°F) ± 5°C (205°C [401°F] ± 5°C for Delrin® T and ST). As with all polymers, Delrin® is sensitive to shear and a maximum of 0.2 to 0.3 m/s of screw peripheral speed is recommended. **Figure 36** shows the optimum screw rotation speed for high viscosity Delrin® (type 100) and low viscosity Delrin® (types 500 to 1700) as a function of screw diameter.

Figure 36. Maximum Screw Rotation Speed as Function of Screw Diameter. The Curve for Delrin® 500 is Also Valid for the Low Viscosity Grades Delrin® 900 and 1700.



Back Pressure

Back pressure also behaves like a thermal setting. Increasing back pressure increases the work done by the screw on the melt.

The use of the optimum screw design for crystalline materials, such as Delrin®, should provide the necessary work to melt and bring Delrin® to the recommended melt temperature with the minimum back pressure. Only melting of highly viscous Delrin® such as Delrin® 100 may require some back pressure to avoid the screw worming back (leading to inconsistent shot volume and pad).

The use of an inappropriate screw may require some back pressure to increase the work done by the screw on the melt, to increase the melt temperature and its uniformity. Higher back pressure may be used to eliminate unmelted particles and to improve color mixing when color concentrates are used. Increasing back pressure, however, tends to reduce glass fibre length and change properties of filled resins such as Delrin® 570. More importantly, increasing back pressure always decreases the output of the screw, leading to longer cycle times and lower productivity. This increases the buildup of screw deposit leading to contamination and low part performance.

Therefore, back pressure should be used only when increasing cylinder temperature or other changes are not effective or possible.

For all materials, the back pressure used (specific or inherent to the injection unit) will create some pressure on the melt in front of the screw. To control drool at the end of the screw rotation, some suck back is required. This should be kept to a minimum.

Mold Temperature

The best mold temperature for long term part performance would be just below the crystallization temperature of Delrin®, e.g., 155°C (311°F). This temperature would allow the polymer to crystallize in an optimum state and eliminate any risk of re-crystallization (post molding shrinkage). Obviously it is economically impossible to set the mold at that temperature as the crystallization time becomes almost infinite along with the cycle time.

Practically, a lower mold temperature is used, leading to shorter crystallization time (HPT), hence shorter cycle time, lower mold shrinkage but higher post mold shrinkage (especially if parts are then exposed to elevated temperatures). A compromise should be found depending on the temperature in use and the required dimensional precision of the molded part short and long term.

For standard Delrin®, a mold temperature of 80–100°C (176–212°F) is a good compromise for normal use, giving relatively short crystallization time, high shrinkage but low post mold shrinkage (see "Dimensional Considerations," page 30). A higher mold temperature will lead to higher mold shrinkage, longer cycle time but lower post mold shrinkage. It is specially recommended for high precision parts used at high temperature. A lower mold temperature leads to shorter cycle time, lower mold shrinkage but much higher post mold shrinkage leading to stresses and distortion.

For toughened resins such as Delrin® 100 ST and 500 T, the use of a lower mold temperature (50°C [122°F] ± 10°C [50°F]) is acceptable without endangering long term part performances.

Note 1: "Mold temperature" is always the term used but the important parameter is the surface cavity temperature. With fast cycling operations, it may be necessary to use a lower mold coolant temperature to maintain the mold surface temperature in the recommended range. Chilled water is often used for very short cycles or to cool core pins and other mold sections that tend to run very hot.

Note 2: Coolant: Closed cooling circuits are the most common types used today. Coolants for closed circuits need to resist heat, freezing, pressure and vacuum. They should neither leave deposits in the circuit, nor corrode the cooling channels and tubes (tubes can be in steel, copper, plastic, rubber etc.). By analogy, the situation is similar to automotive engine cooling systems, and hence it is recommended to use the same fluid (anti-freeze + corrosion inhibitor) but in lower concentration. Initially the thermal exchange is less efficient than with water, as the fluid is more viscous due to the glycol (more power is needed for turbulent flow). However, for long term use, a coolant (such as those used in cars) is the most effective solution (no corrosion or deposit, low erosion from cavitation).

In the case of coolants for open tower circuits, there is a need for chemical treatment to prevent build-up of micro-biological organisms that could cause disease and respiratory problems.

Operating Conditions for Delrin® —Molding Cycle

Introduction

As previously mentioned, the fact that Delrin® is a crystalline material leads to a molding cycle different from that of amorphous polymers. For Delrin®, a molding cycle generally consists of the following phases (see **Figure 37**):

A = *Mold Open Time.* This includes the Opening Time, the Ejection Time and the Closing Time.

B = *Filling Time or Injection Time.* Molten resin is introduced into the mold in a "dynamic filling phase."

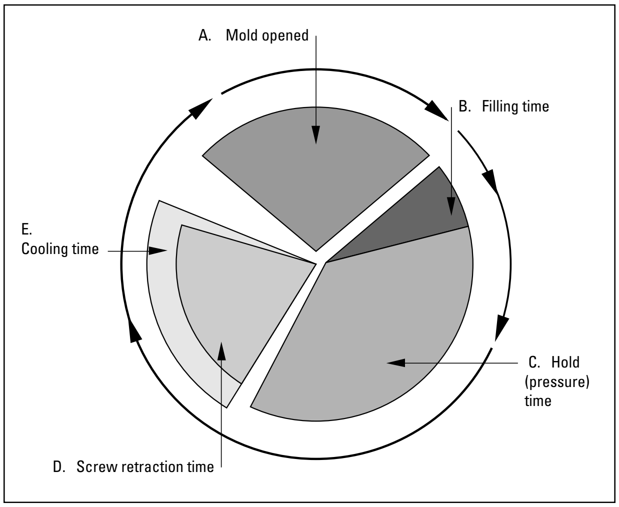
C = *Hold (Pressure) Time.* During this "packing phase," the resin is solidified under pressure, while additional resin is introduced into the mold to compensate for volume shrinkage occurring within the mold.

D = *Screw Retraction Time.* The screw rotates and prepares new molten material for the next shot.

E = *Cooling Time.* Since the part is crystallized (solid) and ready to be ejected at the end of the HPT, there is no need for a cooling time; hence the cooling time is only the Screw Retraction Time plus a short safety time.

The Overall Cycle Time (OAC) for Delrin® is the addition of the various times set for each of the molding operations.

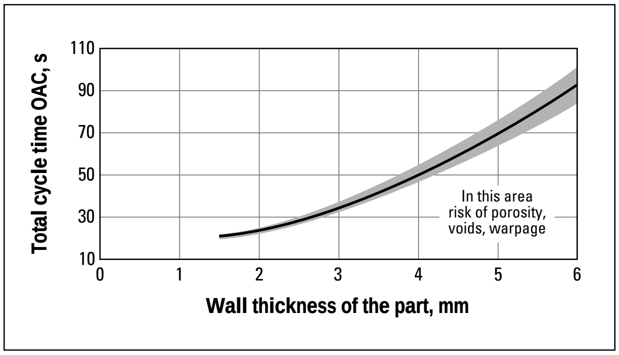
Figure 37. The Molding Cycle for Delrin®



Note: Frequently the sum of the Filling (Injection) Time and the Hold (Pressure) Time is defined as Screw Forward Time (SFT), as often stated in previous Delrin® literature.

The cycle estimation graph in **Figure 38** shows a range of total cycle times that have been used for good quality molding of Delrin® in parts of various thickness. The actual cycle will be close to the lower limit when a high productivity resin such as Delrin® 1700 P is used and when end-use requirements are less stringent.

Figure 38. Estimation of Overall Molding Cycle Times for High Quality Molding of Delrin® Parts



Filling Phase

Injection Time

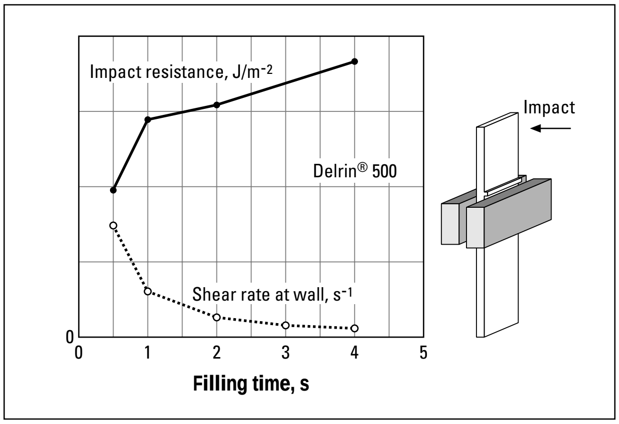
The optimum fill rate for a mold depends on the part geometry and thickness, the runner size, the size and location of the gate.

As rule of thumb, a filling time of 1 sec per mm (0.04 in) of part thickness is a good starting point for fill speed setting. The surface aspect will govern this adjustment. Higher and more uniform surface gloss can be obtained if the injection rate is fast enough to allow the cavity to be filled before the resin begins to solidify, although localized surface flaws, such as jetting and gate smear, are often reduced by decreasing the initial injection rate.

If maximum part toughness is required for the application, the shear applied to the material in the runner(s) and part should be checked to ensure optimum molding performance and part properties. **Figure 39** shows the impact performance of a 2 mm (0.08 in) part versus the shear during filling. If needed, please contact your DuPont representative to analyze your specific case.

Note: Minimizing the shear in the gate can also be an important factor towards optimum part performance.

Figure 39. Shear Strain Rate at the Wall (s^{-1}) and Impact Resistance (J/m^2) as Function of the Filling Time. This Data was Obtained with the Sample Shown (180 by 27 mm with 2 mm thickness). For Impact Resistance, the Part is Clamped Under the Rib and Hit by a Pendulum.



With non-optimum gate designs (conical, excessive gate length), shear in the gate may become an important limiting factor for part toughness.

With the optimum gate design presented in the mold design section (dimensions that allow optimum packing during crystallization, gate length <0.8 mm), in most cases the shear at the gate has no effect on part performance. Flow analysis should be performed to check the shear at the gate for molding very large parts only.

Injection Pressure

This terminology often leads to misunderstanding.

The so-called “injection pressure” serves to move the screw and push the material in the mold. During this dynamic filling phase, the pressure built up in front of the screw is only equal to the pressure drop in the mold, from the nozzle to the position of the flow front. There is no pressure at the flow front itself during this dynamic filling phase.

Before the front of the flow reaches the end of the mold (when around 95% of the part volume is full), the machine should switch from dynamic filling (under velocity control) to quasi-static feeding (controlled by the HOLD pressure). This is the V-P switching point. The hold pressure will then be applied everywhere in the mold during the whole packing phase. For a crystalline material, more material (≈14% for Delrin®) should be added to the part to compensate the crystallization, leading to a slow screw forward movement during Hold (Pressure) Time.

With that definition, the injection fill pressure can be set to whatever value needed by the geometry of mold (including runners), as long as the filling rate is adequate for the part performance.

In case the V-P switch is incorrectly set (no switch or too late of a switch), the inertia of the system will create a pressure peak at the end of filling, leading to molded-in stresses and flash. For that reason, in most practical cases it is safer to set the V-P switch point with distance rather than with pressure (as would typically be done for an amorphous material).

Packing Phase

Hold (Pressure) Time (HPT)

The recommended Hold (Pressure) Time (HPT) for Delrin® is the time for the molten polymer to fully crystallize in the mold cavity.

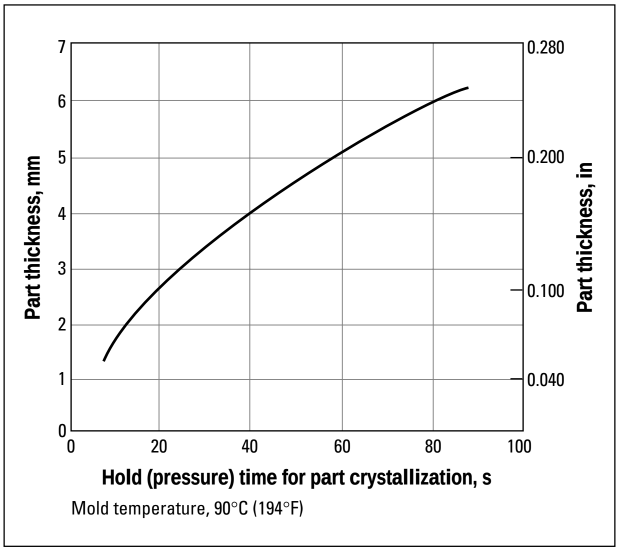
As the crystallization (solidification) leads to a large volume drop (≈14%, see page 4), more melted material has to be pushed into the cavity during all the HPT. This leads to special design rules for the gate and runners, as discussed in the Molds section, so that the gate will not freeze before the cavity is properly packed.

The HPT is obviously a function of the part thickness. **Figure 40** shows the optimum HPT for Delrin® 500 as a function of the part thickness (with the recommended HPT of 85 MPa (12.3 kpsi or 12,300 psi) and the recommended mold temperature of 90°C [194°F]).

Note: For the Delrin® Eleven Series resins, the enhanced crystallization leads to a shorter HPT of up 10%.

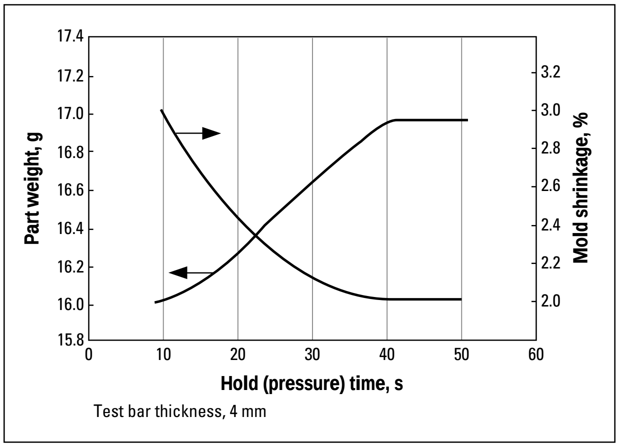
To check the efficiency of the HPT for a given part geometry, the traditional method is to plot the part weight as a function of the HPT. The maximum part weight should correspond to the optimum HPT that can be read in **Figure 40** for the part thickness at the gate. At this time, the part is solidified and no more material can be added to the part. As an example, **Figure 41** shows the effect of HPT on part weight for a 4 mm thick ISO test bar. **Figure 41** also shows the evolution of part shrinkage with the HPT, which will be discussed in more detail in "Dimensional Considerations" (see page 30).

Figure 40. Hold (Pressure) Time Versus Part Thickness of Delrin® 500



Mold temperature, 90°C (194°F)

Figure 41. Hold (Pressure) Time Versus Part Weight and Mold Shrinkage of Delrin® 500



Test bar thickness, 4 mm

Another technique to define optimum HPT, using instrumented molds, has been developed and is presented as an appendix later in this guide.

All the above considerations on HPT and its effects assume that the non return valve functions properly and maintains a cushion of melt in front of the screw as discussed earlier in the "Injection Molding Unit" section.

Too short or inefficient HPT leads to higher than normal and uncontrolled shrinkage. Additional side-effects such as voids, porosity, warpage, sink marks should be expected (see "Dimensional Considerations").

Hold Pressure

Optimum hold pressures for Delrin® acetal resins lie in a range of 60–110 MPa (8.7–16 kpsi) to achieve an homogeneous crystallization. If higher or lower pressures are used in special conditions, they tend to lead to lower part performance. The following table shows the hold pressure range recommended for the various Delrin® types.

Resin type	Grades of Delrin®	Hold pressure, MPa (kpsi)
High viscosity	100, 100 P, 111 P	90–110 (13–16)
Medium- and low-viscosity	500, 500 P, 511 P, 900 P, 911 P, 1700 P	75–100 (11–14.5)
Toughened	100 ST, 500 MT, 500 T	60–80 (8.7–11.6)

To obtain a homogeneous crystallization, the hold pressure should remain constant until the part is fully packed (solidified).

Clamping Force

This does not really belong to the description of the molding cycle, but it is directly correlated to the hold pressure and for that reason it is discussed here.

The clamping force is the force required to keep the mold closed during filling and hold (pressure) time. This force is calculated by multiplying the projected area of the cavity (cavities), including runner system, by the maximum internal pressure (the hold pressure).

Commonly, molds are set using the maximum clamping force of the molding machine. However in many cases, the machine used has a much higher clamping force than actually needed. In these conditions, it is recommended to lower the clamping to the force actually needed by the mold (see calculation following). This will prevent excessive pressure at the parting line (compression of the vents, hobbing of the parting line, deformation of the mold components), leading to longer lifetime of the mold and less costly mold maintenance.

Estimating the maximum internal pressure can be done by carrying out a flow analysis. However, for parts with a flow length to thickness ratio less than 100 to 1, normally the internal pressure is equal to the hold pressure. The following guidelines can be used:

1. For parts needing optimum mechanical properties, the specific clamping pressure must be 1 ton/cm^2 for Delrin® 100, and 0.85 ton/cm^2 for other Delrin® grades.

   Example calculation:
   - projected area of part (or parts), including runner system = 115 cm^2
   - material = Delrin® 500
   - machine clamping force required = 115 × 0.85 = 98 tons
2. For parts not requiring optimum mechanical properties, it may be possible to mold acceptable parts with lower specific hold pressures (and lower clamping forces).

Plastification Phase

Screw Retraction Time

Given a fixed amount of resin to plasticize for the next shot, the screw retraction time is directly dependent on the screw rotation speed.

It is crucial to check that the applied screw rotation speed is low enough to avoid over-shearing the resin in the barrel (which may lead to degradation), but high enough to provide a homogeneous melt (with no unmelted particles). This can be done with the two practical tests for the presence of unmelt and degraded material, as described on page 12.

Note: since Delrin® is a highly crystalline polymer, its thermal requirements are different from those of amorphous materials. Screws specifically designed for Delrin® and an appropriate ratio of shot weight to machine capacity provide an efficient plastification. For more details about screw dimensions, see pages 9–10.

Cooling Time

The cooling time is an important parameter for the injection molding of amorphous polymers. The situation is completely different with Delrin® (see also pages 6–7). At the end of a correctly set and efficient hold pressure time (HPT), the Delrin® part is crystallized and solid. There is no need for further cooling time, and the part could in principle be ejected immediately from the mold. This can be demonstrated by stopping the cycle at the end of the HPT and ejecting the part immediately.

In most practical cases the part is ejected after the screw retraction time, so the cooling time (as defined in **Figure 37**) is simply the screw retraction time plus a small safety margin. An exception is the case of machines with shut-off nozzles, where part ejection can take place during the screw rotation. This theoretically gives shorter cycles, although practical problems may arise and limit productivity (see page 11 for more details on shut-off nozzles).

Optimum Productivity Molding

Economic constraints are pushing for lower part cost, which can be reached by increasing the yield of quality parts and/or shortening the Over All Cycle time. This guide recommends the parameters to achieve optimum part properties in the short and in the long term, leading to an optimum Over All Cycle time (OAC).

Any modification to the cycle should be done only after realistic evaluation of part performance short and long term. Decreasing the cycle too much may lead to a) lower part properties and other quality problems (especially shrinkage, warpage and post shrinkage), and b) process not running in a robust area, which could lead to lower yield of quality parts and higher part cost.

Before trying to shorten the current OAC, the following items should be considered:

- The design of the part may not be optimum, i.e., the part may be too thick. Changes to the design (adding ribs, use of pins) are costly but may allow significant reduction of the cycle time.
- The design of injection unit may not be optimum. With Delrin® the cooling time can be minimized to the time required for proper screw retraction. Optimum screw size and design will facilitate this.
- The sorting of parts from runners may not be optimized.

Having decided to decrease the OAC, the following actions may be carried out (in order of increasing risk):

- Investigate obvious bottlenecks in the cycle.
- Minimize the Mold Open stroke.
- Minimize the Mold Open time by increasing the opening/closing speeds. Rubber bumpers or springs can be used to prevent banging of the floating plate in 3 plate molds, giving no effect on part quality.
- Minimize time between the screw stopping and the mold opening. No effect on part quality.
- Minimize Filling Time (faster injection fill). It may result in overshearing and decreased weld line strength. Larger nozzle and runners, as well as improved venting may be required.

- Decrease Screw Retraction Time:
  1. Use a larger screw and limit the stroke to between 1 and 2 screw diameters, no effect on part quality.
  2. Use an optimized screw design for Delrin® (screw for crystalline polymers with correct depth of metering zone, mixing head). This ensures a homogeneous melt even at high screw rotation speeds, hence there are no effects on part quality. Using higher screw rotation speeds with a general purpose screw would reduce SRT, but with the risk of poor melt quality and part failure.

     Note: as there is no need for cooling time, shutoff nozzles (where the screw can be rotated during mold opening) have been tried. Unfortunately, problems such as wear, contamination, hold up spots etc. have been observed, and no long-term satisfactory solution was found.

- Decrease Hold (Pressure) Time. With a lower than optimum HPT, higher mold shrinkage and deformation leading to warpage will be seen. Voids will also be formed in the center of the part, leading to lower mechanical properties (lower elongation at break), and quality control should be carried out on larger lots of molded parts. If the mold temperature is decreased as an attempt to compensate for the shorter HPT, this action will lead to a lower mold shrinkage but will result in very high post molding shrinkage, deformation and warpage.

Standard Molding Conditions for ISO Tensile Bars

Standard processing parameters to injection mold Delrin® into tensile bars ISO 294-1 are shown in **Table 5**. They can help molders in establishing molding parameters when processing Delrin® acetal resins. However, it must be emphasized that for parts of different shapes and dimensions such parameters should be modified using the information presented on pages 30–35.

Table 5
Processing conditions for ISO 294 tool (insert type A)

Resin grade	**Delrin® 100, 100 P, 111 P**	**Delrin® 500, 500 P, 511 P, 900, 900 P, 911 P**	**Delrin® 100 ST**	**Delrin® 500 T**
Characteristics	**High viscosity polyacetal homopolymer**	**Medium and low viscosity polyacetal homopolymer**	**Super tough high viscosity polyacetal homopolymer**	**Toughened medium viscosity polyacetal homopolymer**
Pretreatment				
Moisture level for processing	<0.2%	<0.2%	<0.05%	<0.05%
Drying temperature, °C (°F)	80 (176)	80 (176)	80 (176)	80 (176)
Drying time, hr	2 hr	2 hr	4 hr	4 hr
General parameter				
Type of screw	HC screw	HC screw	HC screw	HC screw
Max. screw tangential speed, m/s	0.2	0.3	0.15	0.3
Melt temperature, °C (°F)	215 (419) ± 5	215 (419) ± 5	205 (401) ± 5	205 (401) ± 5
Mold temperature, °C (°F)	90 (194) ± 10	90 (194) ± 10	50 (122) ± 10	50 (122) ± 10
Hold pressure, MPa	90–110	75–100	60–80	60–80
Back pressure, MPa	<1.0	<0.25	<1.0	<0.25
Specific parameters, insert A				
Injection fill time, s	1–5	0.5–2	0–5	0.5–2
Flow front velocity, mm/s	40–200	100–400	40–200	100–400
Hold (Pressure) Time, s	35–45	35–45	25–35	25–35
Cycle time, s	40–60	40–60	35–50	35–50

Hold Pressure Time via In-cavity Pressure Measurement

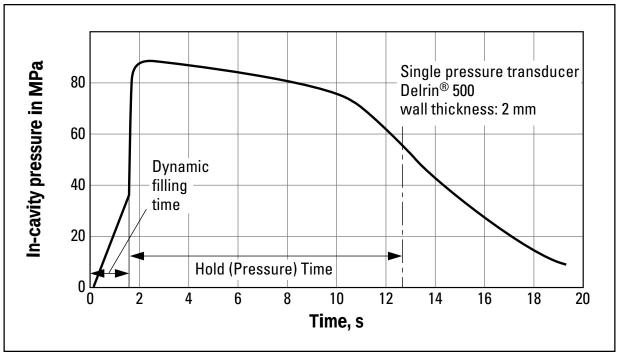
This technique has been developed during recent years, particularly for amorphous resins. The main objective was to optimize and control the hold pressure profile in order to reduce internal stresses, which have been a frequent cause of failure of molded articles in amorphous polymers.

Even if such problems of internal stresses do not apply to a crystalline polymer like Delrin®, this technique is proving to be an effective method to determine the crystallization time (HPT) of a part molded with a specific polymer grade at given processing parameters.

A flexible data acquisition system has been set up by DuPont. It consists of a computer with a data acquisition card and proprietary software CAVAN (CAVity ANalysis), and allows all available analog signals (e.g., injection fill speed, hydraulic pressure, etc.) to be acquired, displayed and analyzed. The system measures the crystallization time of each cycle with a precision, depending on the sensor location, down to 0.1 sec.

A single pressure sensor close to the gate is usually sufficient to determine the crystallization time of a Delrin® part. This is done within a single molding cycle, by analysing the pressure changes during the packing phase. **Figure 42** shows a typical CAVAN curve from which the Hold (Pressure) Time of a 2 mm (0.08 in) thick Delrin® part can be determined.

Figure 42. Cavity Pressure Measured During the Filling and Packing (1 sensor)



Dimensional Considerations

Delrin® acetal resins have good dimensional stability, compared to other polymers, over a wide range of temperatures and in the presence of moisture, lubricants or solvents. They find extensive use in industry for the fabrication of precision gears, bearings, housings and similar devices, because of their unique combination of dimensional stability with other properties, such as fatigue resistance and tensile strength. However, as with all materials of construction, there are factors affecting the dimensional stability of Delrin® which must be considered when close tolerances are essential.

Fundamentals of Dimensional Control

The dimensions of a molded part are determined primarily by the dimensions of the cavity, and secondly by all those variables that affect resin packing and crystallinity (for example hold pressure, HPT, mold temperature). It may seem obvious to mention cavity dimensions as the main factor for part dimensions; however experience has demonstrated that dimensional problems are often addressed by changes in molding conditions, generally with a limited success. Isotropic dimensional problems can in principle be corrected by changes to hold pressure. In the more frequent cases where a few dimensions are out of specification, attempts to correct with the molding parameters generally greatly reduce the acceptable processing window, leading to a higher risk of rejects.

Mold shrinkage and post-mold shrinkage occur as natural consequences of the molding process. They influence the tolerances that can be obtained for molded parts. Data on these effects are presented in this section.

Further dimensional variations in molded parts of Delrin® can arise from changes in the temperature or nature of the surroundings. Reversible changes result from thermal expansion or contraction and from absorption of water or other solvents. These are discussed later in this section, under “Environmental Changes.”

Irreversible changes in dimension occur when polymer chains frozen in an unstable condition move towards a more stable state. An example is when parts molded in a tool at low mold temperature are exposed to elevated temperatures. These changes are discussed under “Post-Mold Shrinkage” and “Annealing.”

Mold Shrinkage

Mold shrinkage is the shrinkage that occurs within 24 hr of molding. It is defined as the difference between cavity and actual part dimension, both measured at room temperature. It is due to the difference in specific volume of Delrin® at the crystallization temperature and its specific volume at room temperature (see “PVT Diagrams,” page 4).

The typical mold shrinkage of Delrin® resins is between 1.8 and 2.2%, except for the supertough and fiber-containing grades (Delrin® 100 ST, 500 AF, 570 and 577) which have a lower shrinkage. **Table 6** summarizes the average mold shrinkage of a 4 mm (0.16 in) thick part molded in the specific recommended conditions. These values should be considered as an approximate guide only, because the shrinkage for an actual part depends on its design and on the molding conditions, as described in more detail below.

Table 6
Average Mold Shrinkage for Various Grades of Delrin®

	Average mold shrinkage	
Delrin® grade	**in flow (% ± 0.2%)**	**transverse (% ± 0.2%)**
100, 100 P, 127 UV	2.1	1.9
500, 500 P, 527 UV	2.1	2.0
511 P, 911 P	1.9	1.8
900, 900 P, 927 UV	2.1	2.0
1700 P	1.9	1.8
1727 UV	1.7	1.7
colors*	1.8–2.1	1.7–2.0
500 T	1.8	1.7
500 MT	1.4	1.5
100 ST	1.3	1.4
500 TL	1.9	1.9
500 AF	2.1	1.5
500 CL, 500 AL	1.9	1.9
570, 577	1.2	2.1
510 GR	1.0	1.4
525 GR	0.5	1.2

* depends on the pigments

Factors Affecting Mold Shrinkage

Mold shrinkage is dependent on the factors that affect the crystallinity of Delrin®. These include:

- hold pressure
- hold (pressure) time
- mold temperature
- part thickness
- gate dimensions

Table 7 summarizes the effect of these parameters on mold shrinkage. They are discussed in more detail below.

Furthermore, mold shrinkage is also highly dependent on the geometry of the part and on the flow pattern of the resin. Experiments have been done in our laboratory with 180 × 27 mm plaques with thicknesses from 1.5 to 6 mm. Four values of shrinkage were measured, close to and far from the gate, parallel and perpendicular to the flow. For most Delrin® grades it is observed that the shrinkage is higher far from the gate than close to the gate (typically by 0.1 to 0.3%), and that the shrinkage in the flow direction is about 0.1% higher than transverse to the flow.

Hold Pressure

Injection pressure has two functions in the molding process:

1. Transfer the molten polymer from the injection unit into the mold. This “injection fill pressure” is needed only to overcome the resistance to flow of the polymer from the injection unit to the cavity. Usually this is a high speed process (dynamic phase of the screw).
2. Control the packing and crystallization process. The hold pressure pushes more material into the cavity to compensate for the volume reduction that occurs in the polymer during crystallization. This is a low speed process (slow motion of the screw). This phase is more important for the dimensional stability since it

Table 7

Parameter	Effect on Shrinkage	Remarks
Hold (Pressure) Time (HPT)	↘	up to optimum HPT, then no effect
Hold Pressure	↘	
Mold Temperature (cavity)	↗	but post-mold shrinkage ↘
Part Thickness	→ or ↘	if all settings optimized
Gate Thickness	↘	up to optimum thickness, then no effect
Melt Temperature	→	if mold temperature is kept constant and HPT is optimized

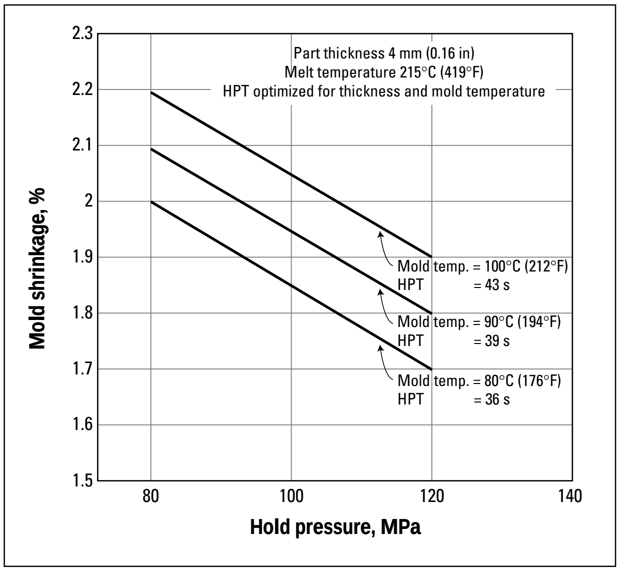
Key parameters affecting mold shrinkage: Symbol ↗ means that the shrinkage increases when the value of the parameter increases, and the opposite for the symbol ↘. Symbol → means that there is no effect on shrinkage provided that the conditions listed under “Remarks” are met.

helps maintain a uniform and gradual crystallization. When a lower hold pressure is used, it will pack less material into the cavity and the shrinkage will be higher. This is shown in **Figure 43** for three mold temperatures.

Small changes of hold pressure may be used to help fine tune the dimensions of a part, because this parameter is essentially independent and has relatively small adverse effects.

Note that hold pressure should be constant during the whole packing time.

Figure 43. Effect of Hold Pressure on Mold Shrinkage at Three Mold Temperatures, for Delrin® 500. Hold Pressure Can be Used for Small Adjustments of Part Dimensions, as it has Negligible Effect on Post-Molding Shrinkage.



Hold (Pressure) Time (HPT)

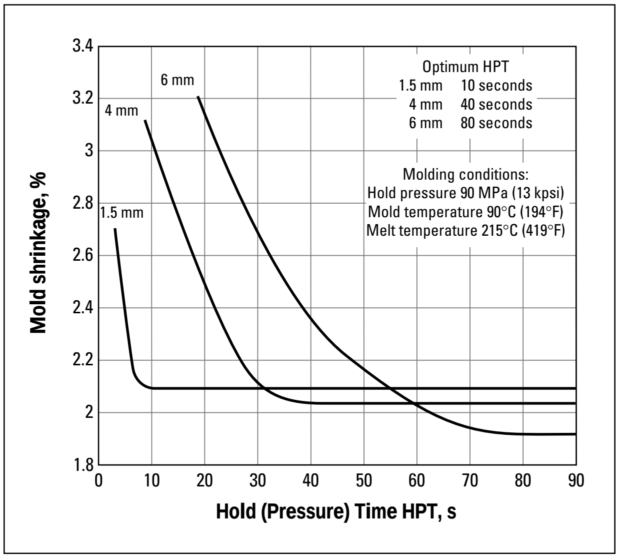
Hold (Pressure) Time is the time during which the hold pressure is applied. The HPT is important for the value of shrinkage and its uniformity over the part.

Figure 44 shows the effect of HPT on mold shrinkage for Delrin®.

When the HPT is below the optimum value required for the specific part (see pages 26–27), the packing process is interrupted before completion and mold shrinkage is higher than its optimum value. Additional side-effects of a short HPT are porosity, voids, warpage, sink marks, lower mechanical properties.

On the contrary, any increase of HPT above its optimum value would have no effect on mold shrinkage, because the part (and the gate) are already solidified.

Figure 44. Effect of Hold (Pressure) Time on Mold Shrinkage of Delrin® 500 P



Mold Temperature

Mold temperature influences mold shrinkage through its effect on cooling rate and crystallization temperature of the molten polymer. The effect of mold temperature on shrinkage is also shown in **Figure 43**.

At high mold temperatures, the polymer crystallizes slowly. In such conditions the mold shrinkage is high, but since the crystallization is more complete, a better long-term dimensional stability is to be expected for the molded parts (less post-mold shrinkage).

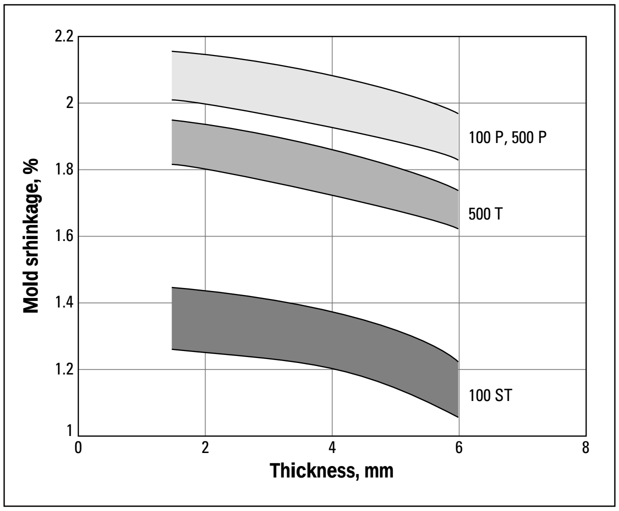
Low mold temperatures, on the other hand, tend to cool the polymer at a very high rate. This results in a lower mold shrinkage and better toughness. However, in the long term, higher dimensional variations leading to build up of internal stresses will occur, particularly if the part is exposed during its end-use life to temperatures exceeding the mold temperature at which the part was molded.

Part Thickness

As shown in **Figure 44** for Delrin® 500, the thickness has a minor influence on mold shrinkage, provided that the gate dimensions and the Hold (Pressure) Time are correct for each thickness. **Figure 45** shows the shrinkage of various Delrin® compositions vs. part thickness, as measured with correct HPT. Note that, to optimize toughness, the mold temperature is reduced from 90°C (194°F) for the standard grades to 50°C (122°F) for the toughened grades (without leading to a high post-molding shrinkage).

For parts of uniform wall thickness, the mold shrinkage tends to be uniform. In the case of variable thickness, shrinkage will tend to be nearly uniform if the part is gated into the thickest section, if the gate is properly sized and if the Hold (Pressure) Time equals or exceeds the gate freeze time. When these criteria are not met, the mold shrinkage tends to be greater for larger sections, with possible problems of voids, warpage, sink marks and lower mechanical properties.

Figure 45. Average Mold Shrinkage Versus Thickness, for Various Delrin® Compositions



Gate Dimensions

Adequate gate dimensions are required to ensure proper packing of the part (see “Gates,” pages 13–15).

When the thickness of the gate is smaller than its optimum value, mold shrinkage will increase due to the premature solidification of the resin at the gate. This situation is then equivalent to a shorter Hold (Pressure) Time, and the approximate effect on shrinkage can be observed in **Figure 44**. In this range the mold shrinkage is not stable, and it is very difficult to control. The resulting warpage could even make difficult the measurement of certain dimensions of the part.

Melt Temperature

Melt temperature has an effect on mold shrinkage. It is however limited by the narrow range of melt temperatures needed to maintain a consistent quality of the molded part. Consequently, the melt temperature should not be considered as a variable to adjust mold shrinkage.

Mold Shrinkage of Filled Resins

The mold shrinkage of compositions containing fibrous fillers, such as Delrin® 570 (glass) and Delrin® 500 AF (Teflon®), is less predictable, because of the fiber orientation effects. The shrinkage in the direction of flow tends to be significantly different from that in the transverse direction (see **Figure 45**).

In general, the mold shrinkage of Delrin® 500 AF in the flow direction is similar to that of Delrin® 500. The mold shrinkage in the transverse direction, however, ranges up to 50% of the shrinkage of Delrin® 500.

In contrast, the mold shrinkage of Delrin® 570 in the flow direction is about half of that for Delrin® 500. In the transverse direction, the mold shrinkage of Delrin® 570 approaches that of Delrin® 500.

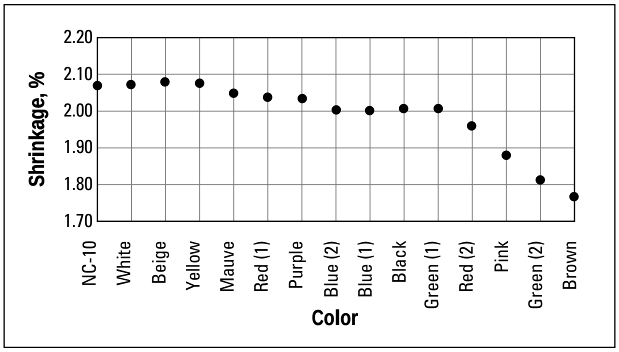
Effect of Pigments

The presence in the melt of crystallization nuclei such as pigments and regrind can have an influence on crystallization and consequently on mold shrinkage.

An accurate study has been carried out to evaluate the effect of various types of pigments on the mold shrinkage of Delrin®. It appears, as depicted in **Figure 46**, that pigment systems giving the same resin color may have a different effect on mold shrinkage and part dimensions.

Note: This study has been carried out on standard bars and in typical molding conditions. The shrinkage values shown here should not be considered valid for all parts of different geometry and/or molded in different molding conditions.

Figure 46. Effect of Selected Pigments on Mold Shrinkage of Delrin® 500. Part Thickness 2 mm



Post-Molding Shrinkage

Post-molding shrinkage is defined as the shrinkage which takes place more than 24 hr after molding. It is a consequence of continued crystallization and relaxation of molded-in stresses, where the resin moves towards a more stable state.

The post-mold shrinkage of parts molded in Delrin® can be estimated from **Figure 47**.

Parts molded with the recommended mold temperature (90°C [194°F]) or higher will have a low post-mold shrinkage, which ensures good dimensional stability over the lifetime of the part.

However, parts molded with a cold mold (<80°C [<176°F]) will have a higher post-mold shrinkage, because fast cooling leaves the Delrin® in an unstable crystalline state and results in more significant recrystallization. If such Delrin® parts are then exposed to high temperatures, the recrystallization causes a high and rapid post-mold shrinkage.

Remarks:

1. For parts requiring tight tolerances and exposure to elevated temperatures for prolonged periods of time, it is strongly recommended to use high mold temperatures (up to 120°C [248°C]). This provides a more effective solution than annealing a part molded at low mold temperature.
2. For exposure at moderate temperatures, good dimensional stability and part performance can be achieved using a 90°C (194°C) mold temperature.

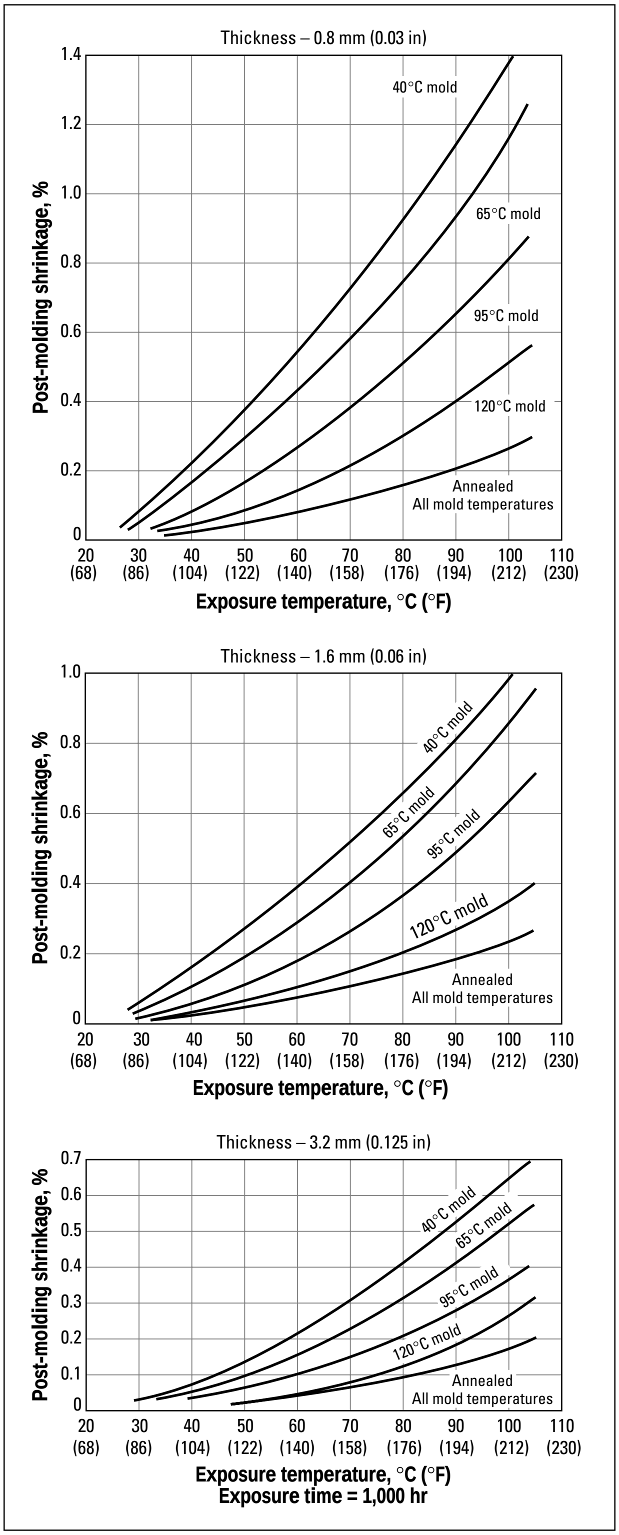
Insert Molding

Almost all the problems of insert molding are linked with shrinkage around the insert, mold shrinkage and post-molding shrinkage. To minimize total shrinkage, the following should be taken into consideration:

- High mold temperatures should be used (90°C [194°F] or above) in order to minimize the total shrinkage (sum of mold shrinkage and post-mold shrinkage). At lower temperatures the mold shrinkage is indeed smaller, but the post-mold shrinkage is much higher.
- Optimum Hold (Pressure) Time for the part thickness, to minimize part shrinkage. The shrinkage increases dramatically with shorter HPT (see **Figure 44**).
- Inserts should be preheated to the same temperature as the mold. This is very important for large inserts.
- Inserts should be free of sharp corners and contamination.
- To minimize cracking, high-viscosity Delrin® is recommended due to its higher elongation.

Note: If a cracking problem cannot be overcome by using the above measures, other inserting techniques should be evaluated, such as insertion after molding by press-fitting, insertion by sonic energy, or a self-tapping insert.

Figure 47. Post-Molding Shrinkage of Delrin® Acetal Resins



Annealing

Annealing is occasionally used to accelerate stress relaxation and dimensional stabilization of parts.
It is a complex process and should only be used when molded parts require very tight tolerances and exposure to high temperatures for prolonged periods.

Annealing is also suggested as a test procedure in setting up molding conditions on a new mold, to evaluate post-molding shrinkage and molded-in stresses. The changes in dimensions during annealing will closely represent the ultimate change in part size in use.

When dimensional precision is a prime requirement, the use of a high mold temperature (90–120°C [194–248°F]) is strongly recommended. Attempts to reach good dimensional stability by annealing parts molded in a cold mold (<80°C [<176°F]) will lead to high post-molding shrinkage and may introduce stresses during the re-crystallization process, resulting in uncontrolled deformation.

Annealing Procedure

Annealing should be performed in air or in inert mineral oils at 160 ± 3°C (320°F), for 30 minutes + 5 minutes per mm of wall thickness. Overheating and hot spots should be avoided, and parts should neither contact each other nor the walls of the oven/bath. Parts should be left in the oven to cool slowly until 80°C (176°F) is reached. Stacking or piling, which may deform the parts while they are hot, should be delayed until the parts are cool to the touch. This procedure was used to obtain the results shown in **Figure 47**, and permits evaluation of the ultimate dimensional changes that a part is likely to experience in normal use.

To simply stabilize parts for continuous high temperature use (<90°C [<194°F]), parts may be heated to 90°C (194°F) for up to 24 hr. Post-molding shrinkage of around 0.1 to 0.2% will then be seen if the parts were molded in a mold at 90°C (194°F) ± 10°C.

Environmental Changes

Part dimensions of Delrin® acetal resin change with the environmental temperature and with the absorption of small amounts of water. Data concerning dimensions for various Delrin® acetal resins are plotted in **Figure 48**, which combines the effects of moisture content and temperature. The graph shows several lines representing different exposure conditions with respect to moisture (50% RH, 80% RH, 100% RH, and immersion).

Dimensional Tolerances

General

Taking into account mold dimensions and processing variability, experience suggests that the following dimensional tolerances are achievable with good molding practice:

- dimensions up to 150 mm (5.9 in):
  ±0.15% for precision molding
  ±0.3% for technical molding
- dimensions above 150 mm (5.9 in):
  ±0.25% for precision molding
  ±0.4% for technical molding

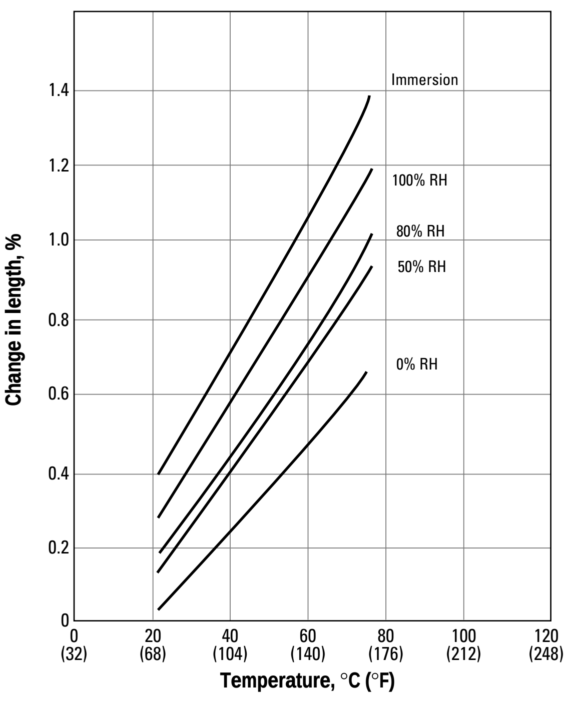
Molds

For multi-cavity molds, the tool making tolerances are important. They have a direct effect on the dimensional tolerance of the part. As an example, for a mold dimension of 30 mm (1.2 in) manufactured to within ± 0.01 mm, experience has shown that dimensional consistency better than ± 0.03–0.04 mm cannot be expected for parts from different cavities in a single shot.

Molding Conditions

Parts molded under recommended conditions (gate, runner, nozzle, screw, machine parameters) as defined in the molding guide are subject to small shot-to-shot variations in dimensions. Any change in machine parameters or conditions will effect dimensional tolerance. For example, a colder mold leads to higher post-molding shrinkage, too short Hold (Pressure) Time leads to inconsistent shrinkage, deformation and larger variability in part dimensions.

Figure 48. Environmental Dimensional Change of Delrin® 100 and 500



Auxiliary Operations

Several auxiliary operations associated with the molding of Delrin® acetal resins are discussed in this section. They include the following subjects:

- Material handling
- Drying
- Reground resin
- Coloring
- Disposal

Material Handling

Delrin® acetal resin is shipped dry and need not be dried before molding. Resin that has been stored in a cold warehouse area should be brought to room temperature prior to molding. This will prevent moisture condensation and variations in heat required to melt and thus in melt temperature.

Particular care is required for the toughened compositions of Delrin®. Bags of Delrin® 500 T, 500 MT and 100 ST should not be opened until they are ready to be used. If a bag is opened for any significant period of time and the resin has picked up moisture, the material should be dried before it is molded.

Pellets of Delrin® are surface lubricated with ethylene di-stearamide. Further lubrication of these compositions is not necessary.

Reground Resin

Recommendations to Regrind Delrin®

The use of contamination free and uniformly reground Delrin® has minimal influence on mechanical properties and molding performance of standard grades (see details below). To regrind the material properly, the following should be considered:

- Do not regrind molded parts, sprues or runners that are discolored or splayed—these conditions may indicate that the resin was degraded during processing.
- Avoid accumulation of reground resin whenever possible by continuous reuse of sprues and runners. Ideally regrind at the molding machine and feed back immediately using a close loop system to avoid any contamination. If grinding is done in a batch process away from the molding machine, care should be taken to avoid contamination of sprues and runners. Protect reground resin from contamination and dirt by storing in clean, dry, clearly labelled, covered containers.
- Maintain a constant ratio of virgin to reground resin, and mix adequately prior to molding. A suitable ratio depends upon the quality of the reground resin and the requirements of the part. A 3 to 1 ratio of virgin to reground resin is common, although larger quantities of reground resin can be used successfully.
- Ideally use a low speed grinder, but higher speed grinders are acceptable if knives are well sharpened and if holes in the screen are large enough (4 mm) to avoid fines. The grinder should be thoroughly cleaned before grinding a different material.
- Excessive fines should be removed.
- Avoid reprocessed resin from outside sources.
- For optimum properties of toughened grades, sprues and runners should be reground and used as soon as possible, as moisture pick-up is fast for these resins (see previous paragraph). The fraction of regrind for these compositions should not exceed 25% in the feed, and it should be fed immediately back into the hopper.

Effect on Mechanical Properties

Figure 49 shows the results of a 10 pass regrind study which has been run using either 100% or 50% regrind with Delrin® 500. A 10 pass 50% addition regrind study is equivalent to a molder continuously regrinding 50% of the shot weight. Excellent retention of mechanical properties is observed in these conditions.

Drying

As a general rule, Delrin® does not require drying. However drying is recommended in some cases.

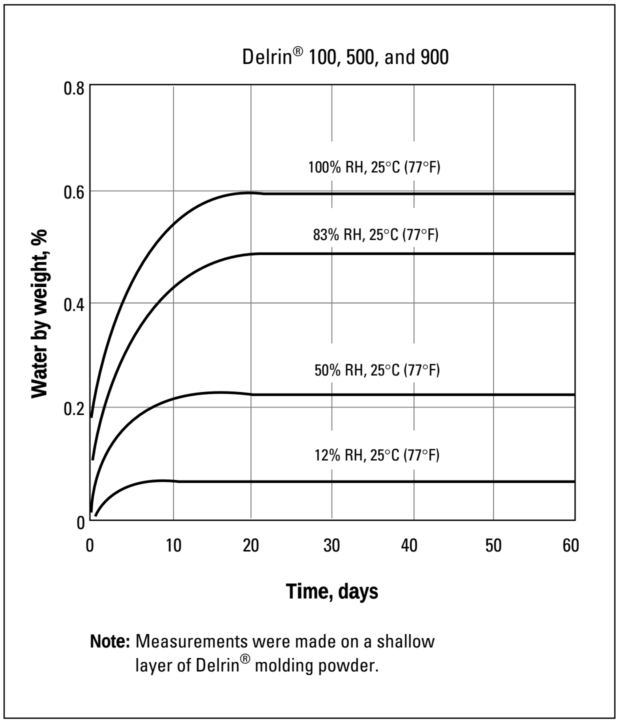
Standard Grades

- When a resin container stays open for a significant time, drying at 80°C (176°F) for two hours may improve the melt quality. The water absorption rate of Delrin® acetal resins at various humidity levels is shown in **Figure 49**.
- When using more than 50% of the capacity of the machine, preheating the resin at 80°C (176°F) for two hours may improve the homogeneity of the melt and decrease the torque on the screw.
- When thermal stability is a concern (e.g., with some difficult colors), blowing air at 80°C (176°F) through Delrin® may help. This will result in less mold deposit and better surface finish.

Toughened Grades

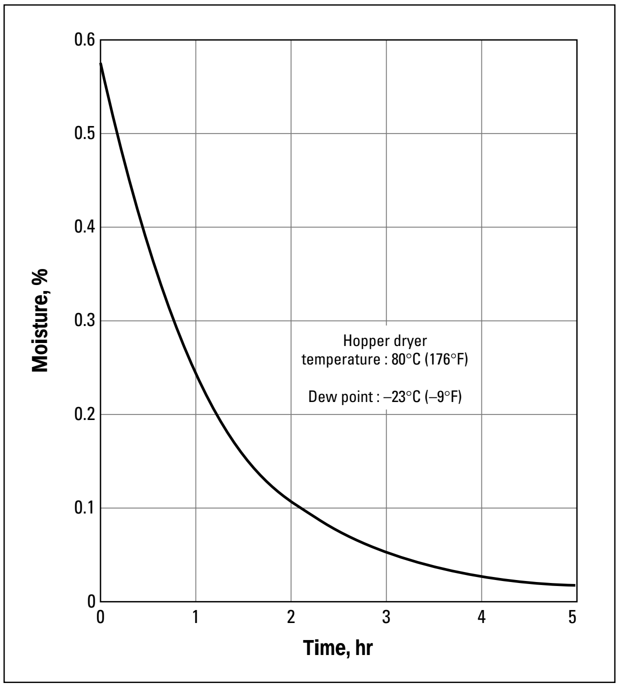
Molding of toughened Delrin® compositions with excessive moisture (>0.05%) has a negative effect on toughness. Therefore, it is recommended that the resin is dried for 4 hr at 80°C (176°F) in a dehumidified dryer (see the drying behavior of Delrin® 100 ST in **Figure 50**).

Figure 49. Rate of Water Absorption at Various Conditions



Note: Measurements were made on a shallow layer of Delrin® molding powder.

Figure 50. Drying Behavior of Delrin® 100 ST



At 23°C (73°F) and 50% RH, Delrin® 100 ST picks up 0.1% moisture in 4 hr; at 30°C (86°F) and 85% RH it will pick up 0.3% moisture in 2 hr. For this reason runners and sprues should be reground and reused as soon as possible.

Coloring

Delrin® is available in a range of standard and custom colors.

When molding natural Delrin® with a coloring system from a manufacturer other than DuPont, the following should be noted:

- The pigment or masterbatch manufacturer's safe handling procedures must be applied.
- Small scale tests should be run initially to check melt stability (see page 12, foaming test), as some acidic, basic or metallic pigments will decompose Delrin®.
- Different coloring systems (even those giving the same color) could cause different shrinkages, as can be seen from **Figure 46**. Part dimensions should be checked in the small scale tests.
- Flow along injection unit screws is laminar and color dispersion could be unsatisfactory. A proper mixing head should be used (see page 10).
- Total pigment loading should be as low as possible to maintain resin properties.

Disposal

Waste disposal must be in accordance with all applicable regulations. Preferred options for disposal are:

1. recycling,
2. incineration with energy recovery, and
3. landfill.

Recycling of sprue and runners is best done directly at the molding machine (see Reground Resin, page 36). Mechanical recycling of post-consumer parts is rarely attractive. Since resin stability and mechanical properties can be severely affected by contamination, the separation and cleaning logistics become complicated and expensive. Chemical recycling is technically possible, but again it is presently limited by waste collection and separation.

The high fuel value of acetal resins makes option (2) very desirable for material that cannot be recycled. However, parts or regrind of resins containing Teflon® (such as Delrin® 500 AF and 520 MP) should not be incinerated.

Troubleshooting Guide

Problem	**Suggested remedies** (listed in order of convenience)
Melt quality problems	
Mold deposit	• Decrease injection fill rate • Decrease melt temperature • Avoid resin contamination • Correct hold-up spots in cylinder, screw, nozzle assembly • Increase gate size, flare gate • Enlarge vents • Change vent location • Use hopper drier to improve the resin's thermal stability in extreme cases
Odor	• Observe melt appearance (gassing) and measure melt temperature • Reduce cylinder temperatures if melt temperature is high • Avoid resin contamination • Reduce overall cyle to decrease holdup time • Correct holdup spots in cylinder, adaptor, nozzle, screw tip, and check valve assembly • Use smaller injection unit
Unmelted particles	• Increase cylinder temperatures • Increase back pressure • Reduce screw rpm • Use hopper drier to preheat resin • Increase overall cycle • Use screw designed for Delrin® • Use larger machine or injection unit
Screw deposit	• Lessen severity of screw (esp. for Delrin® 100 flow grades)—within recommendations • Avoid overcooling the feed throat • Check % of feed/transition/metering—within recommendations
Black spots or brown streaks	• Decrease residence time in injection unit (smaller screw) • Avoid resin contamination • Correct holdup spots in cylinder, screw, nozzle assembly • Check hopper cooling (80–90°C [176–194°F])
Pigment streaks	• Increase back pressure to improve dispersion • Use a mixing head screw • Evaluate other coloring systems • Evaluate fully precompounded color
Filling problems	
Short shots	• Maintain uniform pad • Repair leaking back flow valve if pad cannot be maintained • Increase injection fill pressure • Increase injection fill rate • Increase melt temperature • Increase mold temperature • Enlarge vents • Change vent location • Increase overall cycle • Use screw designed for Delrin® • Use larger machine or injection unit
Note: Minimize nozzle length when molding at or near limit of injection pressure capacity of molding equipment. This will be particularly true for Delrin® 100 type resins having high melt viscosity.	
Voids in parts	• Increase hold pressure • Increase hold (pressure) time • Locate gate in thickest area • Decrease injection fill rate • Decrease melt temperature; improve melt uniformity • Repair leaking back flow valve if pad cannot be maintained • Enlarge vents • Improve gate thickness or location • Eliminate any restrictions in runner or nozzle
Weak weld lines	• Increase hold pressure • Adjust injection fill rate (around 1 s per mm of part thickness) • Increase melt temperature, but avoid excessive temperature • Enlarge vents • Increase mold temperature • Avoid mold release spray • Change vent or gate location • Use larger machine or injection unit

Problem	**Suggested remedies** (listed in order of convenience)
Ejection problems	
Parts sticking in mold	• Increase hold (pressure) time • Correct mold defects (undercuts) • Change or add ejector pin locations • Decrease hold pressure • Decrease injection fill rate • Increase cycle (possibly only temporarily) • Use mold release temporarily
Sprue sticking	• Remove burrs on sprue • Correct alignment between sprue and nozzle • Radius sharp corners where the sprue meets the runner (or the part) • Increase hold (pressure) time • Increase nozzle temperature • Increase mold cooling time • Use nozzle orifice smaller than sprue bushing • Improve sprue puller • Increase taper of sprue • Use mold release temporarily
Dimensional problems	
Shot-to-shot dimensional variations	• Increase injection hold pressure • Maintain uniform pad (cushion) • Repair leaking back flow valve if pad cannot be maintained • Increase hold (pressure) time • Increase gate thickness and/or location • Maintain uniform cycle • Eliminate unmelted particles (see below) • Use larger machine or screw designed for Delrin®
Warpage	• Balance mold temperature • Locate gate in thickest area • Increase hold (pressure) time • Increase gate thickness and/or location • Round sharp corner • Clean water channels in mold; improve mold cooling system • Improve part design (e.g., avoid bottlenecks in melt flow) • Change or add ejector pin locations
Surface problems	
Blush, frost, and folds	• Decrease injection fill rate • Increase mold temperature • Change gate location
Gate smear	• Decrease injection fill rate • Flare gate • Increase gate size • Change gate location
Jetting	• Increase or decrease injection fill rate • Increase gate size, flare gate • Increase mold temperature • Change gate location
Pits, orange peel, wrinkles	• Increase hold pressure • Increase injection fill rate • Increase hold (pressure) time • Increase mold temperature • Increase melt temperature • Enlarge vents • Increase gate size
Sink marks	• Repair leaking back flow valve if pad cannot be maintained • Increase hold pressure • Increase hold (pressure) time • Increase gate size • Change gate location • Decrease melt temperature if it is too high
Splay	• Decrease melt temperature if it is too high • Avoid resin contamination • Decrease injection fill rate • Correct holdup spots in cylinder screw, nozzle assembly • Increase size of small gate

DuPont Engineering Polymers
Molding Data Record

JOB	MOLD DESCRIPTION	MACHINE SETUP INSTRUCTIONS	SPECIAL INSTRUCTIONS
OPERATORS	SCREW USED		SAFETY CHECK
ENGINEERS	PRESS NO.	NOZZLE #	

				TEMPERATURES, °C (°F)								PRESSURES, MPa (PSI)				CYCLE TIMES, sec									WEIGHTS, g		REMARKS
DATE TIME	Run Number	Resin	Lot Number	Rear	Center		Front	Nozzle	Fixed	Movable	Melt	Injection 1st Stage	Injection 2nd Stage	Clamp (Tons)	Back	Injection	Hold	Open	Overall	Booster	Ram in Motion	Screw Retraction	Pad (Inches)	RPM	Full Shot	Part Only	

COMMENTS ON MOLDING OPERATION, START-UP, ETC.

PAGE NO.

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Only joint ventures and resellers who have signed special agreements with DuPont to resell DuPont products in their original form and/or packaging are authorized to use the Oval trademark, subject to the approval of an External Affairs representative.

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All other customer usage is limited to a product signature arrangement, using Times Roman typography, that allows mention of DuPont products that serve as ingredients in the customer's products. In this signature, the phrase, "Only by DuPont" follows the product name.

Delrin® Only by DuPont   or   Delrin®
Only by DuPont

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*Delrin® is a DuPont registered trademark.

Delrin®
acetal resin

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