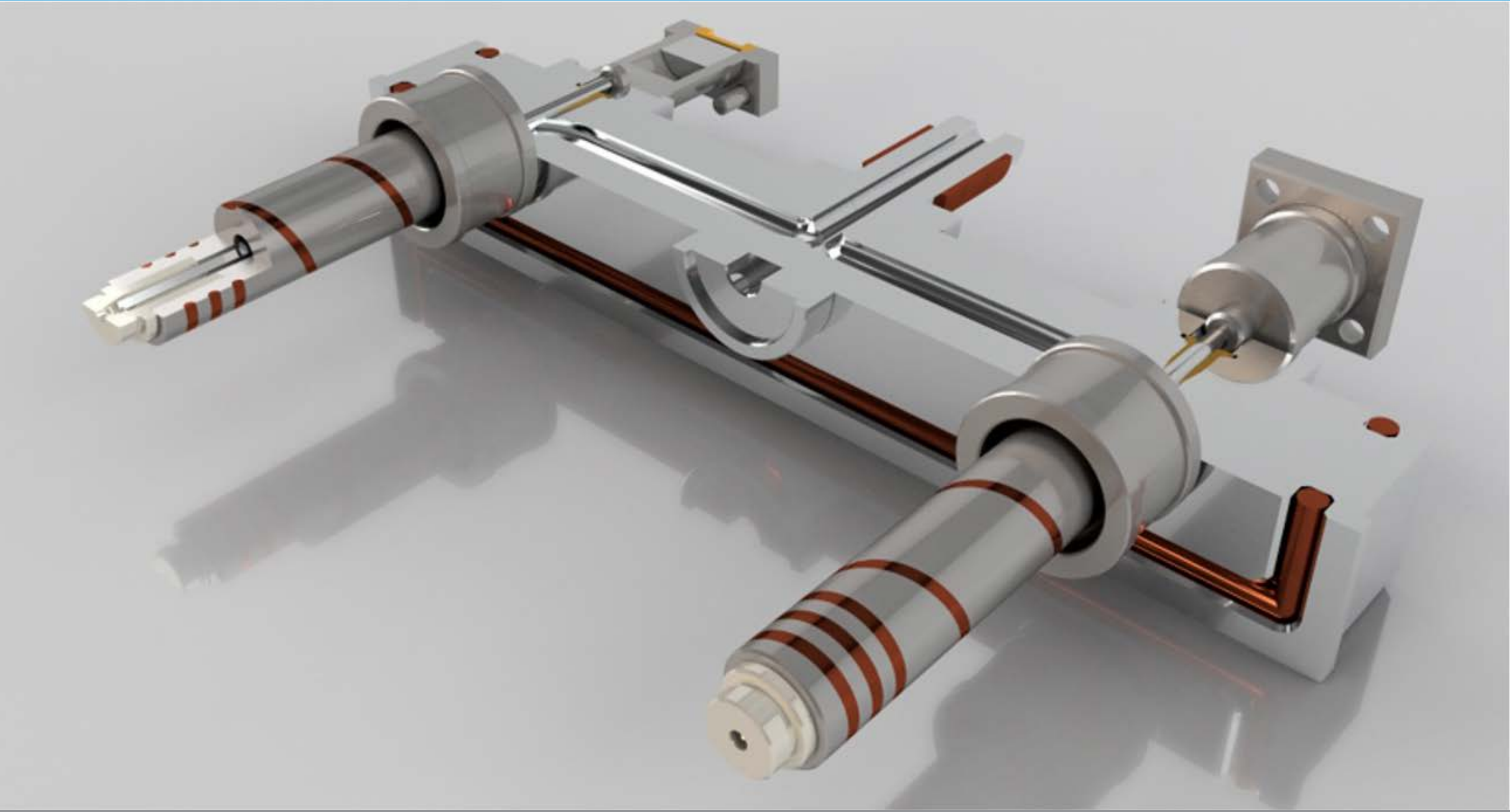
Delrin® Acetal Homopolymer Hot Runner Manual



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Introduction

Maximizing productivity with injection molding is an important factor in determining part cost. One way to improve productivity is using a hot runner system. The decision when to use a hot runner system is mainly influenced by "yield" as hot runners can add complexity and cost to molds and will require additional maintenance. Due to continuous improvement in hot runner designs, a robust molding process is possible even with traditionally more thermally sensitive thermoplastic resins.

Delrin® acetal homopolymer is a high performance semi-crystalline polymer. Versus alternative plastic types, Delrin offers superior mechanical performance, such as higher tensile strength, stiffness, creep and fatigue resistance, and significantly higher impact resistance, without need of glass or other reinforcements. The combination of these properties in a single material allows for thinner, lighter-weight parts to be developed and, subsequently, for shorter molding cycles to be achieved, delivering potential cost reductions. Typical applications of Delrin include, but are not limited to, actuator gears, push buttons, clips, valves, springs, handles and conveyor belts across a range of industries, including industrial products, consumer goods and medical device components. Given the wide range of uses, Delrin is often selected for components that are manufactured by use of hot runner systems.

The hot runner design requirements for semi-crystalline polymers, such as Delrin® (POM), differs from amorphous polymers given the difference in their softening, melting and freezing behaviors. Amorphous materials gradually soften with slowly decreasing viscosity from the solid state (Tg) to the processing temperature. This behavior provides a wide temperature range to control viscosity when melting or freezing the resin. Whereas a semi-crystalline polymer becomes fluid with a relatively low viscosity at a defined melting temperature (Tm). In the same way, a semi-crystalline resin freezes again at a defined freezing temperature, where no flow is possible. As a result, the processing window for the melting and freezing of semi-crystalline resins is relatively narrow, which needs to be considered when designing a hot runner system.

This brochure provides guidance on basic gate design and hot runner selection for the robust molding of semi-crystalline resins like Delrin® acetal homopolymer. You will learn that the best suited systems for Delrin typically:

- Use a small sub-runner where possible and implement a semi-crystalline gate design
- Employ hot runner systems with valve nozzles if direct gating is needed
- Utilize a titanium or DuPont™ Vespel® cap at the nozzle tip versus a self-insulation design
- Ensure there is good thermal balance through the entire system to allow optimal temperature settings to be applied
- Minimize risk of material stagnation in all areas of the hot runner

Other design options are also described in this guide, with the understanding that certain constraints may not allow the implementation of all these optimum design recommendations.

1. Gate designs

When using a hot runner system in a mold, there are essentially two different gating scenarios possible:

- Indirect hot runner gating of the part using cold sub runners
- Direct hot runner gating of the part

The advantages and disadvantages of the different hot runner gate designs, as well as the preferred solution based on the part design and material choice, are described in the following chapter.

1.1 Indirect hot runner gating using cold sub runner

Whenever possible, it is recommended to use a hot runner combined with a cold sub runner for molding Delrin® and other semi crystalline resins. This combination requires less precise thermal control around the nozzle tip and therefore contributes to a more robust process. With indirect gating, it is recommended to move the nozzle tip back from the parting line to avoid heat loss at the nozzle tip area once the tool is closed. Especially with parts requiring a long hold pressure time and a good packing, indirect gating is highly recommended as the freezing time of a cold runner is easier to control versus a hot tip. For the cold sub-runner, a cold slug trap in front of the hot tip should be provided to catch any frozen or degraded material, preventing it from entering the cavity.

Cold runner and gate designs for Delrin should follow the guidelines for semi-crystalline resins (left side of Figure 1). It is recommended that the gate diameter (d) should be at least half of the wall thickness (T) of the part. The diameter (D) of the tunnel next to the gate should be at least 1.2 times the part thickness. The amorphous gate design shown on the right side in Figure 1 is not recommended for semi-crystalline resins due to the risk of an early freezing and therefore an insufficient hold pressure time. This can result in uncontrolled shrinkage that causes voids and/or sink marks, low mechanical performance, and dimensional problems.

Using a well-designed hot runner system and optimum process settings for Delrin® can greatly enhance productivity and reduce overall manufacturing costs.

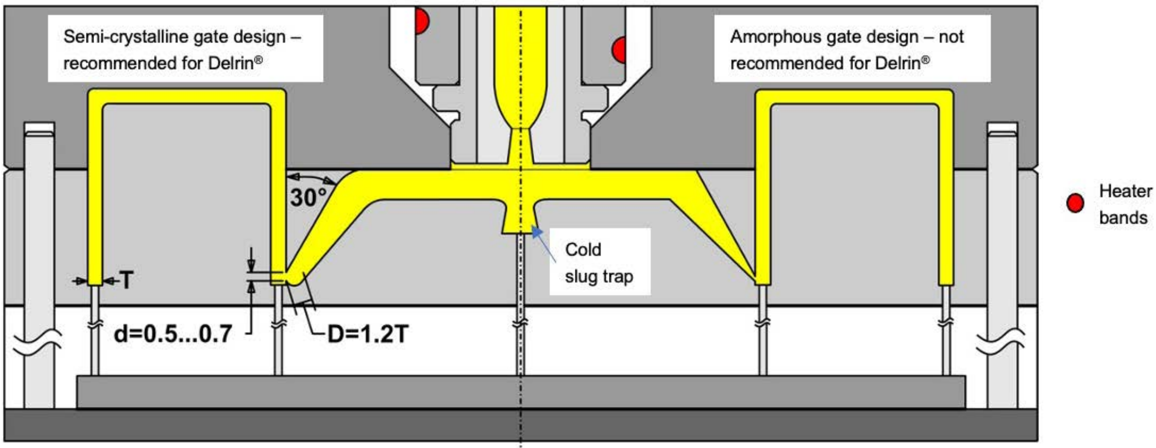

Figure 1: Indirect hot runner gating using a cold sub runner. Tunnel gate for semi-crystalline resins (left), tunnel gate for amorphous resins (right)

1.2 Direct hot runner gating of the part

If it is required to gate directly onto the part, it is important to consider the choice of gate location carefully. Try to avoid cosmetic surfaces where possible, since the material will be more stressed around the gate location and more prone to markings. A similar approach should be taken if the area will be subject to mechanical stresses or is needed to act as a sliding or bearing surface since mechanical properties and surface smoothness will not be optimal around the gate location. Beyond this, the choice of nozzle design is key in determining the success of a direct-gated system. We will cover this in the next section.

2. Hot runner selection

2.1 Nozzle design

There are two basic types of designs for hot runner nozzles that are widely used in injection molding:

- Open nozzle (includes also open nozzle with torpedo and internally heated nozzles)
- Valve gate nozzle (shut-off nozzle)

When molding semi-crystalline resins like Delrin®, the nozzle design should allow a precise freezing and therefore a controlled separation between molten material in the nozzle tip and frozen material in the cavity. Poor nozzle design often leads to freezing of the material in the nozzle or, conversely, to stringing and drooling. Both result in production and quality issues.

To avoid this, attention needs to be given to the thermal insulation between the hot nozzle tip and the mold. Insufficient thermal insulation between the nozzle tip and mold generally leads to unacceptably high temperature settings of the hot runner and therefore to material degradation. Regardless of the nozzle type used, careful attention should always be paid to ensure optimal thermal insulation is achieved. This topic will be revisited several times throughout this guide.

2.1.1 Hot runners with open nozzle or torpedo

An open nozzle design, as shown in Figure 2, offers good flow properties and is often used when molding highly filled and abrasive materials. This design is not recommended for unreinforced materials as the freezing behavior of those materials limits precise separation of the bushing/runner and the molten material at the nozzle tip. Thus, stringing in the gate area can occur during mold opening. For an open nozzle design, it is recommended to always use indirect gating, with a cold sub runner equipped with a cold slug trap (as covered in Chapter 1.1). For highly filled resins, it is recommended to use an exchangeable nozzle tip for ease of maintenance.

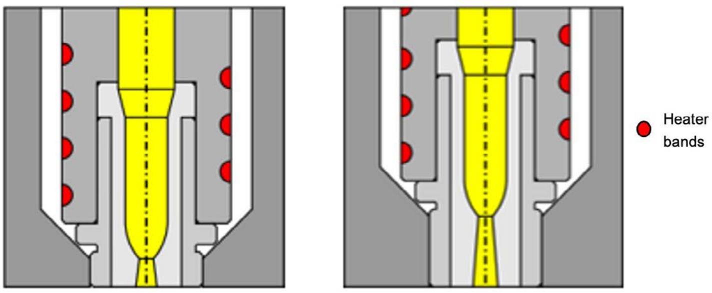

Figure 2: Open nozzle design with short bushing (left) and long bushing (right)

If direct gating with an open nozzle design is needed, a system equipped with a flow restrictor will help to minimize problems with stringing. A torpedo is one such example of a flow restrictor. This is an internal element that helps to break the flow of the melt and create a more homogeneous filling of the part. However, for direct gating of parts with high surface aspect requirements, there is a risk of uncontrollable flow marks around the gate depending on the design of the flow restrictor being used. Various open nozzle types are shown below in Figure 3.

Internally heated torpedo nozzles, as in Figure 3 (a), are not recommended for molding semi-crystalline resins, like Delrin®, because of the risk of stagnation of the material on hot steel surfaces. To counter this, it is good practice to add a separate cooling circuit around the nozzle to be more independent from the mold temperature in controlling the temperature around the nozzle and the nozzle tip.

Figure 3 (b) shows a nozzle design with a flow restriction at the tip. Again, this is not ideal due to concerns with material hold-up in the tip area. A better solution is a non-heated torpedo nozzle designed, as in Figure 3 (c), to avoid such flow restrictions.

Another key point to highlight, is that when the nozzle tip is self-insulated by the molding resin, there is a higher risk of stagnation and subsequent purging of degraded resin into the part. This can cause surface defects around the gate and black specks in the finished parts. To avoid the stagnation and hold-up spots, customers have good experience using titanium or DuPont™ Vespel® caps at the nozzle tip, as shown in Figure 3 (d). Another advantage of non-self-insulating nozzle tips is improved maintenance in the case of abrasion and corrosion. If the part is gated on a surface which does not allow an exchangeable nozzle tip, a self-insulating nozzle can still be used provided the above recommendations are followed.

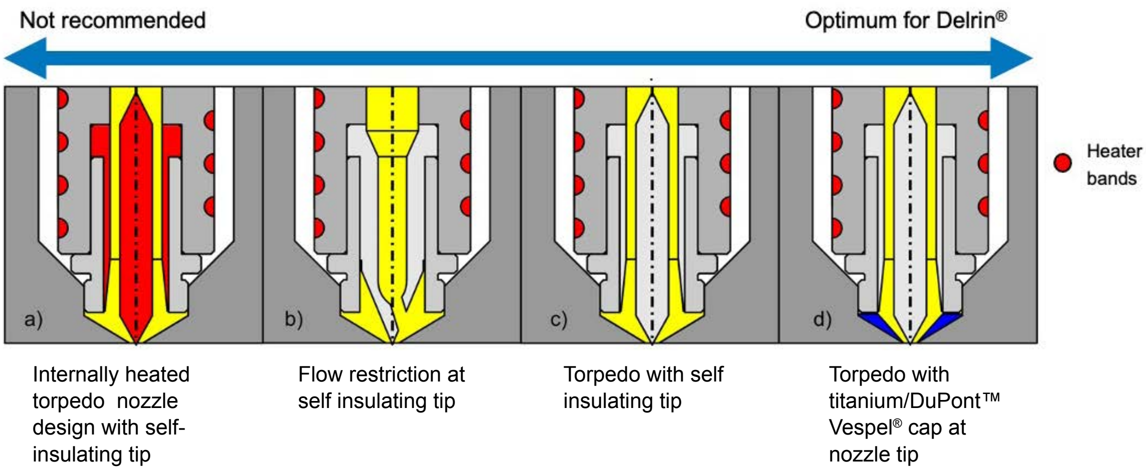

Figure 3: Open nozzle designs

2.1.2 Hot runners with valve gates (shut-off nozzles)

Hot runner systems with valve gates are more commonly used for the molding of precision parts made from Delrin®. Especially for multi-cavity tools, with more than one nozzle, it is strongly recommended to use a valve gate system to ensure balanced filling of all cavities. Furthermore, when molding bigger parts where the pressure drop for filling is too high, a valve-gated hot runner system with a selected number of nozzles allows a segmented filling and stable packing by opening the valves in cascade.

Depending on the nozzle design and the thermal insulation between nozzle and tool, a valve-gated hot runner nozzle may lead to a limited hold pressure time. This is due to an early freezing at the valve pin guide before achieving the sealing time of the part. In these instances, often a cold deformation occurs when the needle is closing, or a remaining pin is visible on the molded part. If this happens, the thermal insulation of the hot runner nozzle needs to be improved to avoid part breakage in the gating area as well as dimensional instability and an increased number of voids of the molded parts.

Cylindrical guidance of the valve pin is always recommended when molding Delrin and semi-crystalline resins. With a conical shape, there is a high risk of deforming the sealing surface especially with reinforced resins. For thermally sensitive resins, which are critical to hold up time, an adapted manifold design with an improved purging behavior is preferred (see Figure 4). This is covered in the next chapter.

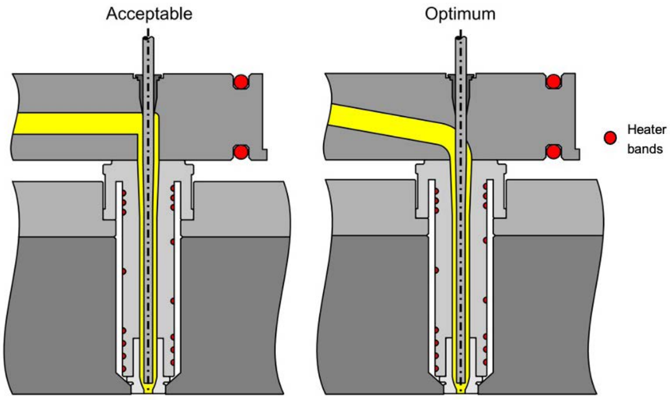

Figure 4: Valve gate design, standard manifold design (left), improved design minimizes stagnation (right)

3. Hot runner manifold

If there is more than one nozzle used in the tool, the melt is transported to the hot runner nozzles by the manifold system. In general, the channels of the manifold should be as smooth as possible to minimize melt sticking to the tool steel. To avoid corrosion inside the hot runner, a steel with a higher chrome content is preferred.

To achieve uniform filling of all cavities, it is recommended to use naturally balanced systems. All channel corners should be flow optimized to avoid hold-up spots and minimize pressure drop in the manifold. Sharp corners in manifolds result in high shear stress, potential degradation of the material and increased abrasion for reinforced resins. Hot runner suppliers offer a wide range of flow optimized geometries. Figure 5 shows channel corner designs which are available from hot runner suppliers.

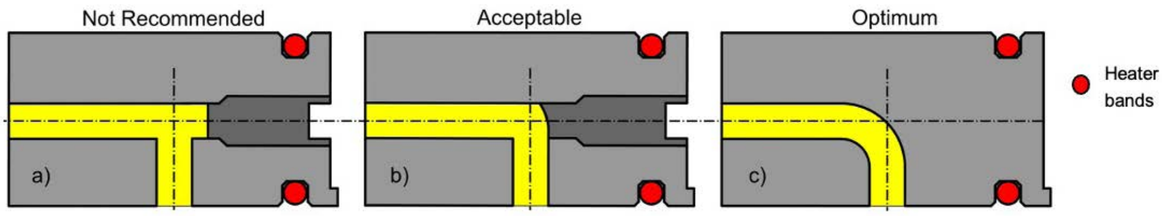

Figure 5: Manifold channel corner design

The design shown in Figure 5 (a) is not suitable for molding semi-crystalline resins. In addition, the purging behavior is very limited when changing the color or the material. An optimum flow design which minimizes shear, pressure drop and the risk of hold-up spots is shown in Figure 5 (c). This solution is the most expensive but offers the best flow properties and purging behavior. In Figure 5 (b) a compromise between design and cost of the hot runner is shown. However, this is not recommended for molding optical parts and resins which are highly reinforced and/or less thermally stable.

4. Temperature distribution inside the hot runner

To achieve a stable and robust molding condition, it is important that the temperature distribution inside the nozzle and the manifold is as uniform as possible. Therefore, when assembling a hot runner system into a mold, the gap between nozzle, manifold and the tool needs to be well defined. A too narrow gap leads to a heat loss of the hot runner system to the tool by heat radiation. However, a too big gap leads to a chimney effect and therefore also to an unacceptable heat loss of the hot runner system. At the supporting pins, there is always a higher heat transfer to the tool. To minimize the heat transfer, it is recommended to use a material with low thermal conductivity.

To achieve a temperature distribution as uniform as possible at the manifold, it is strongly recommended that the manifold is heated from both sides, as shown in Figure 5.

When assembling a hot runner nozzle into the tool, as shown in Figure 6, the contact area between tool and hot runner should be minimized to avoid a freezing of the nozzle due to an unacceptable heat transfer from the nozzle tip to the mold. To assess the performance, it is recommended to stop the process for five minutes. If a startup after five minutes is possible using recommended melt temperature settings of the hot runner nozzle, the thermal insulation is sufficient.

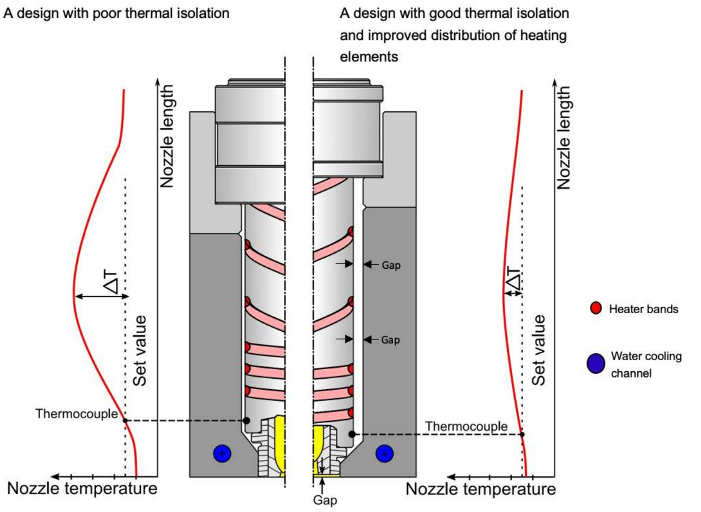

Figure 6: Nozzle temperature gradient, large contact area = wide temperature difference (left), good thermal isolation= flat temperature profile (right)

5. Temperature control of the cavity

Cavity wall temperature uniformity can be a challenge close to the hot runner nozzle. To control the temperature around the nozzle, it is recommended to add separate cooling circuits around the nozzle as shown in Figure 7. For parts with high mechanical and optical requirements, it is always recommended to use a cold sub runner to avoid defects close to the gate due to non-uniform cavity surface temperatures.

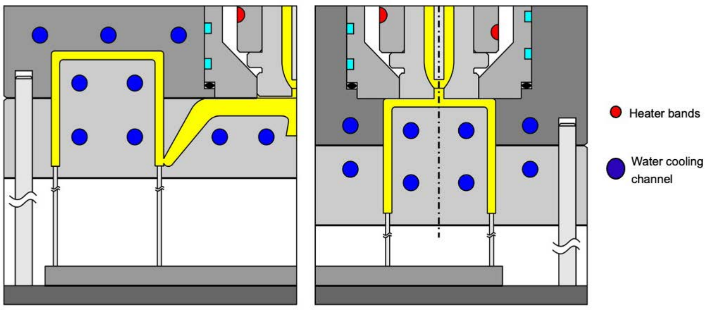

Figure 7: Separated temperature control to achieve uniform mold surface temperature, indirect gating with cold sub-runner (left), hot runner direct gating (right)

6. Temperature settings for Delrin®

It is worth noting that a hot runner system does not contribute to the homogeneity of the melt; this is the job of the screw and the barrel temperature settings. The task of a hot runner itself is to transfer the melt to the cavity without significant heat-loss. Therefore, it is not recommended to run a hot runner at a higher temperature than recommended to improve melt quality and/or reduce viscosity.

Running a hot runner system above the recommended temperature settings may cause degradation of the resin. As a result, problems with surface defects and black specks as well as mold deposit increase dramatically. Table 1 shows an overview of the recommended temperature settings for Delrin®.

Delrin® material	Melting point (°C)	Recommended temperature setting screw/ barrel (°C)	Recommended temperature setting for nozzle and hot runner (°C)
Standard grades	178	215	190
Toughened grades	178	205	190
Low emission grades	178	205	190

Table 1. Recommended temperature settings

For complete data, visit Delrin® Material Data Center at https://delrin.materialdatacenter.com

As shown in the table, the optimum barrel temperature for Delrin® is higher than the recommended hot runner temperature. Melted Delrin sticks to hot metal surfaces in the laminar flow areas like hot runners and nozzles. Therefore, high temperatures on those sections may degrade the material and generate splays or black specks. The lower temperature minimizes the heat exposure of the resin and is generally high enough to avoid freezing of the Delrin resin in the hot runner channel.

Temperature settings shown in Table 1 are intended as an initial guideline. As hot runner systems can vary from case to case, adjustments may be necessary. The manifold temperature should be set according to Table 1. However, the temperature of the hot runner nozzle should not exceed those temperatures by more than 5 to 10°C.

7. Safety considerations

When processing thermoplastic resins, all potential hazards must be anticipated and either eliminated or guarded against by following established industry procedures. Hazards may include:

- Thermal burns resulting from exposure to hot molten polymer
- Fumes generated during drying, processing and regrind operations
- Formation of gaseous and liquid degradation products

Safety data sheets include such information as hazardous components, health hazards, emergency and first aid procedures, disposal procedures, and storage information. Refer to the specific product Molding Guide for more information on safe handling.

Note: Adequate ventilation and proper protective equipment should be used during all aspects of the molding process. Refer to the Delrin® Ventilation Guide for more detailed information.

Conclusion

Given the productivity benefits on offer, the use of hot runner systems is growing across the plastics industry, spanning many application areas and involving various material types. Whilst providing clear advantages in manufacturing, these remain complex and costly systems, so it is important to consider all design aspects before investing in such equipment. In this guide, a series of recommendations have been provided in order to achieve the optimal hot runner setup for Delrin, while taking account that each case is unique. With this in mind, in addition to reviewing the guide, we encourage you to engage directly with your Delrin representative to ensure the best decisions are taken. Our team of experts will be happy to assist you.

To learn more, contact your Delrin representative or visit Delrin.com.

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