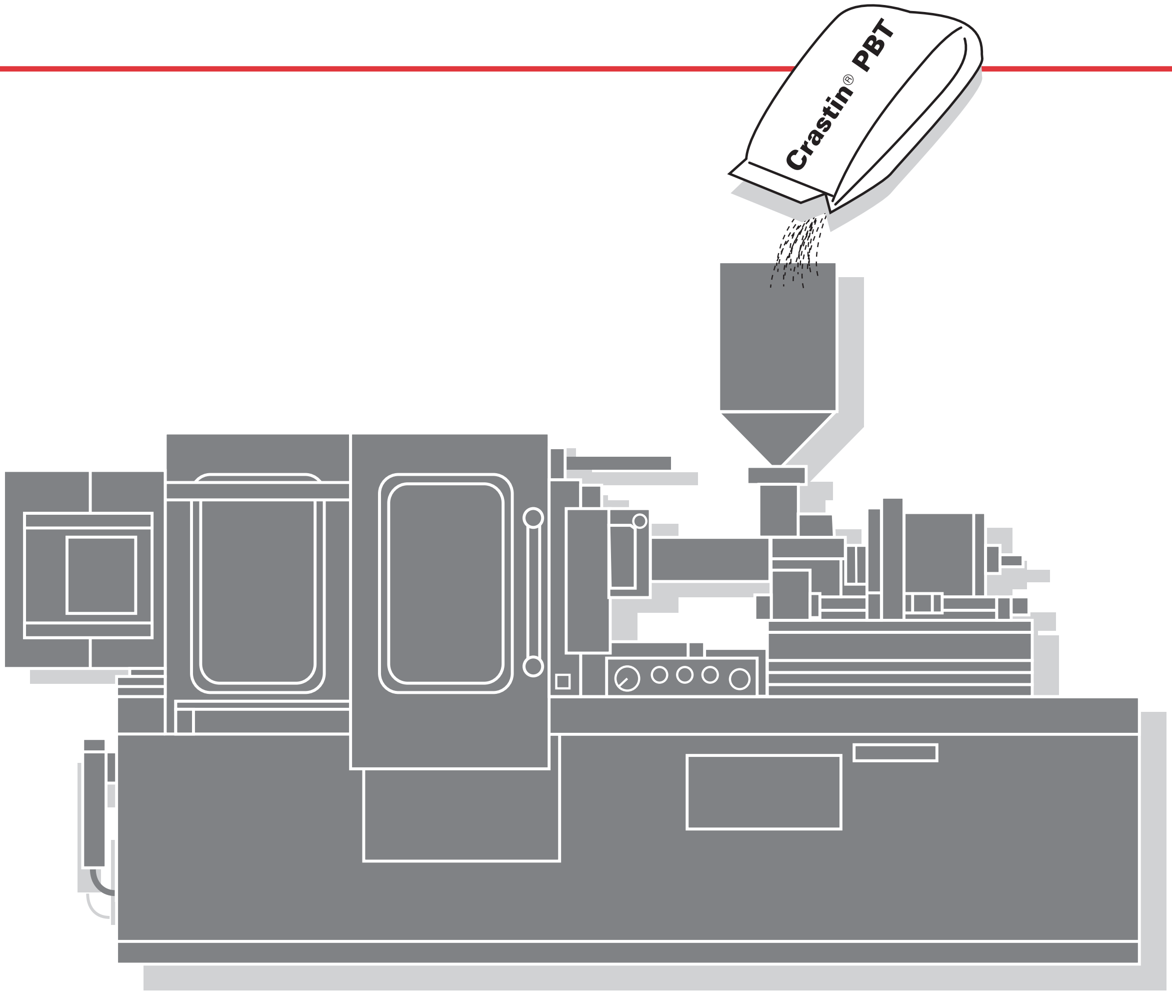
Crastin® PBT

thermoplastic polyester resin



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Introduction

Crastin® PBT Thermoplastic Polyester Resin

Crastin® PBT thermoplastic polyester resins are polybutylene terephthalate (PBT) resins modified to offer exceptional performance in a variety of demanding applications. Crastin® PBT resins are readily processed on conventional molding machines using standard industry practices. They are crystalline materials with sharp melting and freezing points, which have good flow characteristics and mold in fast cycles. The processing details in this manual will enhance part quality and productivity.

While all types of Crastin® PBT are based on PBT, the product line can be divided into groups with common performance advantages. By adding reinforcing agents and tougheners, the inherent characteristics of PBT polymers like low creep, dimensional stability, and good electrical properties are augmented to provide a family of molding resins with exceptional strength, stiffness, and toughness. Alloying with other polymers and selecting the proper reinforcement technology can improve dimensional stability and surface appearance. Most types of Crastin® PBT are also available in flame-retarded versions that are recognized by Underwriters Laboratories as UL 94 V-0. Key features of the Crastin® PBT product line are described below, along with some illustrative examples. For more detailed information on specific types, see the Crastin® PBT Product and Properties Guide.

General-Purpose Resins

Crastin® PBT formulations and compounding technologies are carefully selected to produce high-quality injection molding resins that generally outperform other PBT resins in strength, stiffness, and toughness. These resins are used in mechanical and electrical goods that require low creep, good stiffness at elevated temperatures, dimensional stability in humid environments, or good electrical properties. Typical examples include the following:

Crastin® S610	Unreinforced. General-purpose molding resin, lubricated for mold release and good feeding characteristics in molding screws. Available in colors. UL 94 HB.
Crastin® SK602 **Crastin® SK605**	Glass-reinforced for additional stiffness and strength. UL 94 HB. Lubricated and available in colors.
Crastin® S660FR	Unreinforced. Flame-retarded version of Crastin® S610. UL 94 V-0 at 0.032 in. Lubricated and available in colors.
Crastin® SK652FR1 **Crastin® SK655FR1**	Glass-reinforced. Flame-retarded versions of Crastin® SK602 and SK605. UL 94 V-0 at 0.032 in. Lubricated and available in colors.

Toughened Resins

The resilience and impact resistance of Crastin® PBT can be increased by employing proprietary toughening technologies. Products range from Tough grades, with improved elongation and impact strength, to Super Tough products designed for severe mechanical abuse. Tough resins are especially well suited to part designs that require additional extensibility, e.g., snap fits. Super Tough resins are designed for high abuse applications, especially those where ductile failure modes are required. Typical examples include the following:

Crastin® ST820 **Crastin® ST830FR**	Super Tough. Unreinforced. “No Break” in Notched Izod Impact tests. Use in applications where mechanical abuse is anticipated. Good flexibility and recovery allow large deflection snap fit designs.
Crastin® HR5015F **Crastin® HR5030F**	Glass-reinforced. Tough resins with high ultimate elongation. Can be used to solve cracking problems with glass-reinforced resins. Also flow well.

Low Warp Resins

The high shrinkage and glass fiber orientation effects that cause PBT parts to warp or distort are alleviated in these resins. Polymer alloys are designed to afford low shrinkage while preserving the mechanical properties expected of PBT. Glass/mineral compositions rely on glass reinforcement for strength and mineral reinforcement for stiffness.

Crastin® LW9320 **Crastin® LW9330**	Glass-reinforced alloys. Combine improved flatness with good surface aesthetics. Especially useful in parts where the strength and stiffness of PBT are required, but dimensional control is a problem. Also low specific gravity.
Crastin® LW685FR	30% glass/mineral-reinforced. Flame-retarded resin. UL 94 V-0 at 0.032 in and UL 94 5VA at 0.084 in. An excellent choice for box shapes or parts with large flat sections.

High Flow Resins

Proprietary technology allows dramatic increases in flow and reduced pressure drops in cavities while maintaining the strength, stiffness and toughness expected of glass-reinforced PBT resins. These resins will flow up to 50% further than standard PBT resins at comparable injection pressures. Especially useful in parts with delicate cores where reduced injection pressures and lower pressures in cavities can extend tool life.

Crastin® HF672FR **Crastin® HF675FR**	Glass-reinforced and flame-retarded. Enhanced flow without losses in mechanical properties. UL 94 V-0 at 0.032 in with a 50% regrind rating.
Crastin® HR5015F **Crastin® HR5030F**	Combine high flow with improved toughness and hydrolytical stability. Solve breakage problems with standard PBT resins. Especially well suited for snap fit designs.

Safety and Handling

While processing Crastin® PBT is ordinarily a safe operation, all of the potential hazards associated with injection molding of thermoplastic resins must be anticipated and either eliminated or guarded against by following established industry procedures. Consideration should be given to the following.

Thermal Effects

Because Crastin® PBT resins are molded at high temperatures, the molten resin can inflict severe burns. Furthermore, above the melting point, moisture and other gases may generate pressure in the cylinder, which, if suddenly released, can cause the molten polymer to be violently ejected through the nozzle.

Be particularly alert during purging and whenever the resin is held in the machine at higher than usual temperatures or for longer than usual periods of time—as in a cycle interruption. Pay particular attention to the section “Molding Conditions.”

In purging, be sure that the high volume (booster) pump is off and that a purge shield is in place. Reduce the injection pressure, and “jog” the injection forward button a few times to minimize the possibility that trapped gas in the cylinder will cause “spattering” of the resin. Immerse the purged material immediately in cold water in a metal container to decrease the evolution of gaseous fumes.

If polymer decomposition is suspected at any time, a purge shield should be positioned, the carriage (nozzle) retracted from the mold, and the screw rotated to empty the barrel. After the screw starts to rotate, the feed throat should be closed, and then a suitable purge compound should be introduced. The temperature can then be gradually lowered, and the machine shut down. If jogging the injection or screw rotation buttons does not produce melt flow, the nozzle may be plugged. In this case, shut off the cylinder heats, and follow your established safe practices.

Always assume that gas at high pressure could be trapped behind the nozzle and that it could be released unexpectedly. A face shield and protective long-sleeved gloves should be worn at such times.

In the event molten polymer does contact the skin, cool the affected area immediately with cold water or an ice pack, and get medical attention for thermal burn. Do not attempt to peel the polymer from the skin.

Off-Gases and Particulates

Small amounts of gases and particulate matter (i.e., low molecular weight modifiers) may be released during the molding, purging, or drying of Crastin® PBT. As a general principle, local exhaust ventilation is recommended during processing of all thermoplastic resins. For Crastin® PBT, a ventilation rate of 75 ft^3 of air per minute per pound of resin processed per hour will keep the concentration of particulates below the OSHA limit (15 mg/m^3) for nuisance dusts and will also be sufficient to remove any gaseous products if the resin is being processed at or below the recommended maximum melt temperatures and residence times.

Crastin® PBT resins, like all thermoplastic polymers, can form gaseous decomposition products during long hold-up times at high melt temperatures. This is especially true of flame-retarded resins. Purged material should be immersed in cold water to reduce evolution of volatiles.

Adequate exhaust ventilation should also be provided during regrind operations and equipment burn-out procedures.

Resin Handling

Granules of Crastin® PBT present a slipping hazard if spilled on the floor. They are cylindrical and have a low coefficient of friction. Spills should be swept up immediately.

Care should be taken to prevent static discharge when resin is conveyed in pneumatic materials handling systems.

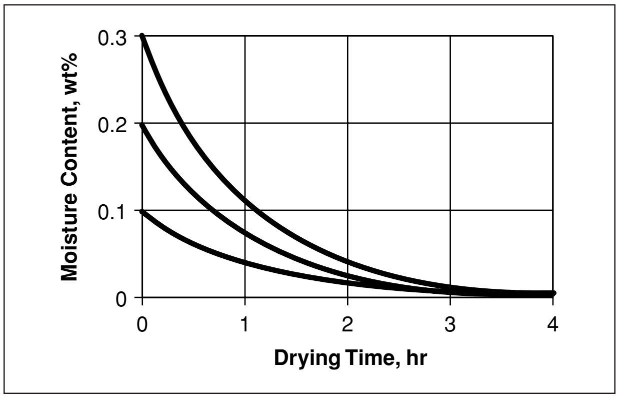
Drying

Crastin® PBT should be dried prior to processing to remove moisture that can reduce the strength and toughness of finished parts. In order to ensure good performance of molded parts, the moisture content of resin must be less than 0.04 wt% during processing.

Conditions

Drying to moisture level less than 0.04 wt% can best be accomplished by using desiccant type dryers. Dryers should be sized to afford a residence time of 2–4 hr at 250°F (120°C). Dryers should be capable of maintaining a dew point below –4°F (–20°C) with an air flow of at least 1 cfm per pound per hour. Typical drying curves are presented in **Figure 1**. Alternatively, resin can be dried at lower temperatures using longer residence times (220°F [105°C]) for 4–8 hr.

Figure 1. Drying Times in Dehumidifying Dryers. Air Temperature 250°F (120°C) with Dew Point Under –4°F (–20°C)



Equipment

Desiccant type dryers are required to achieve optimum molding performance and part quality when processing Crastin® PBT. These dryers physically remove the moisture from the resin and transfer it to a desiccant bed. Circulating air ovens rely on temperature to drive the moisture out of the resin and are only effective when the humidity of ambient air is very low.

Because the temperatures required to dry Crastin® PBT are relatively high, dryers and air transfer lines should be well insulated to ensure drier effectiveness and to conserve energy. Designs that incorporate an after cooler (which lowers the temperature of return air before it enters the desiccant bed) are preferred because desiccants can remove and hold more moisture at lower temperatures. After coolers are required at drying temperatures over 250°F (120°C). Dryers should be capable of maintaining a dew point below –4°F (–20°C) with an air flow of at least 1 cfm per pound per hour.

Drier maintenance is very important to production of high quality parts in a robust process. Connections should be air tight and filters should be checked regularly to maintain proper air flow. Air flow, temperature, and dew point should be monitored continuously (downstream of the desiccant beds) to ensure the drier is functioning properly.

Vented Barrels

While injection cylinders fitted with vented barrels can be used with Crastin® PBT, they are not a suitable substitute for dehumidifying drier systems. Moisture reacts very quickly with PBT resins at melt processing temperatures, and venting of moisture in these systems occurs after the resin is molten.

Molding Equipment

Crastin® PBT can be processed in all standard screw injection molding machines. Both toggle and hydraulic clamp machines fitted with either electrical or hydraulic drives can be used. Clamp pressure of 3 to 5 ton/in^2 (40 to 70 MPa) of projected shot area is desirable.

Screw Injection Molding Machines

In order to obtain good melt homogeneity and to ensure good quality parts, the length to diameter ratio of the screw should be at least 18 to 1. Three-zone heating control of the barrel should be provided for close temperature control and high output rates. In all cases, the temperature of the nozzle should be independently and precisely controlled.

Plunger injection molding machines are not recommended for Crastin® PBT.

Screw Design

The general-purpose, gradual transition screws that are installed in molding machines as original equipment are usually suitable for molding Crastin® PBT resins. Length to diameter (l/d) ratio should be at least 18 to 1.

At high output rates, specific screw designs will provide better melt temperature uniformity and eliminate unmelt. Screw l/d should be 20 to 1 with 10 diameters in feed length, 5 in transition and 5 in metering length.

Table 1
Suggested Screw Design for Improved Melt Quality*

Screw Diameter (in/mm)	Feed Section Depth (in/mm)	Meter Section Depth (in/mm)
1.5 (38.1)	0.300 (7.62)	0.085 (2.17)
2.0 (50.8)	0.320 (8.13)	0.105 (2.67)
2.5 (63.5)	0.380 (9.65)	0.120 (3.05)
3.5 (88.9)	0.440 (11.18)	0.140 (3.56)
4.5 (114.3)	0.500 (12.7)	0.150 (3.81)

*Square pitch screw with 20:1 l/d.

Screw Check Ring Assembly

Check valves (non-return valves) are necessary during injection to ensure constant cavity pressure and part weight uniformity from shot to shot. Ring check valves are preferred over ball check valves. If used, ball check valves must have carefully streamlined flow passages to avoid holdup.

Wear

Glass-reinforced resins are abrasive and tend to wear the lands and edges of screw flights. Eventually, the root of the screw in the transition and metering sections will wear. Use of heat treated and stress relieved alloy steel with a hard surface (e.g., Colmonoy® 56, UCAR WT-1) is necessary. Nitriding is not recommended.

Sliding type ring check valves will undergo rapid wear when used with glass-reinforced resins. Even when properly hardened, these valves should be considered expendable and replaced after three to four months of operation. Nitriding has been found useful in extending the life of check rings. A typical material of construction is Nitralloy 135M. The valve seat is generally hardened more than the sleeve; seat Rc55 and sleeve Rc45 are typical.

Screw tips should be made of a stress-relieved AISI 4140 steel, hardened to Rc55 with an abrasion resistant surface coat (e.g., “Borafuse”). This treatment will lead to an appreciably harder surface than that of the check ring.

Nozzles

Straight through reverse taper nozzles should be used when molding Crastin® PBT. Melt decompression (suck-back) at the end of plastification (screw retraction) can be used to minimize drool. Positive shut-off nozzles are not recommended.

The nozzle must be equipped with an independent temperature controller. Crastin® PBT is a very crystalline resin with a sharp melting point. Unheated nozzles will not draw sufficient heat from the barrel to prevent freeze-off. Trying to maintain nozzle temperature by increasing the settings of the third (metering section) barrel controller will result in excessive melt temperature and resin degradation.

Pressure Control

Because Crastin® PBT thermoplastic polyester resins are very crystalline, they solidify very rapidly. Glass-reinforced grades must be processed with high injection speeds to allow complete filling of the mold cavity. Therefore, it is essential that the machine have a sufficiently high injection capacity. To achieve short injection times, high injection pressures are usually necessary to overcome flow resistance in areas of small cross section.

Precise switching from injection pressure to holding pressure will avoid over-injection and overpacking of molded parts or damage to the tool. A switch from injection pressure to holding pressure initiated by screw position has proved to be advantageous in conventional molding machines. A prerequisite for this technique is that metering is carried out with back pressure applied, to ensure that variations in the metered quantity are small.

If time-controlled switching is used, adjustable steps of 0.1 s are too large for the short injection times needed with Crastin® PBT, because the screw travel rate is too great. Good results can be obtained with adjustment steps of 0.01 s.

Using cavity pressure to control switching can further improve shot-to-shot uniformity in the production of precision parts. Recording the cavity pressure/injection time curve simplifies optimization of the process.

Molding Conditions

Crastin® PBT has good thermal stability at processing temperatures; however, like most thermoplastic resins, excessive residence times and/or temperatures can cause degradation. Processing temperatures should be matched to shot size. Fast injection rates provide the best flow in thin sections, and mold temperature must be regulated to control shrinkage.

Cylinder Temperatures

Typical melt temperatures are 480°F (250°C) in parts using 30–70% of machine rated capacity operating on cycles under 60 s. Cylinder temperatures usually increase from 455°F (235°C) in the rear zone to 475°F (245°C) in the center and front zones. Melt temperature should be measured with a needle pyrometer after the machine has been cycling for at least 15 min. The front and center barrel zones can be adjusted to achieve the desired melt temperature. The nozzle, which should be controlled independently, is generally set at the desired melt temperature. For parts demanding very high melting capacity, e.g., running over 80% of rated capacity, it is usually advisable to raise the temperature of the first (feed section) zone.

Table 2
Suggested Temperatures for Parts Using 30–70% of Machine-Rated Capacity

	Temperature, °F (°C)
Cylinder Zone	
Rear (Feed)	455 (235)
Center	475 (245)
Front (Meter)	475 (245)
Nozzle	480 (250)
Melt Temperatures	
Typical	480–500 (250–260)
Maximum	520 (270)
Minimum	455 (235)

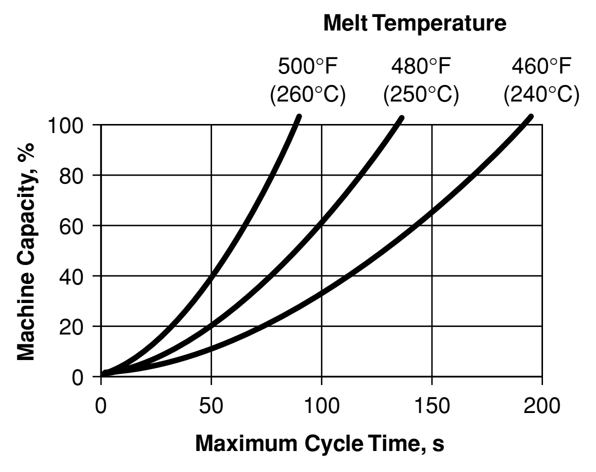
Higher melt temperatures are sometimes used to reduce resin melt viscosity and improve flow in the mold. Melt temperatures can be raised to 500°F (260°C) for parts that use at least 60% of rated capacity and run in cycles of less than 45 s. This assumes the resin, including any regrind, is dried to below 0.04 wt% water. Higher moisture content will result in hydrolytic degradation, even at lower melt temperatures. See "Drying." Melt temperatures over 520°F (270°C) should be avoided, especially for flame-retarded compositions.

Because all types of Crastin® PBT are semicrystalline materials with very sharp freezing points, melt temperatures below 455°F (235°C) should be avoided to guard against premature freeze-off that can lead to dangerous over-pressure situations.

Hold-Up Time

Figure 2 illustrates the relationship between maximum recommended cycle time and machine capacity for several melt temperatures. For example, for parts using 40% of machine capacity melt temperatures up to 500°F (260°C) can be used if overall cycle time is less than 50 seconds. This chart is based on the assumption that moisture content of the resin is below 0.04 wt%.

Figure 2. Permissible Cycle Times for Different Shot Weights at Several Melt Temperatures



Mold Temperature

In order to achieve optimum mechanical properties and post-molded dimensional stability in parts molded out of Crastin® PBT, mold temperature must be controlled to produce a uniform degree of crystallinity in the resin as it solidifies. Although dimensional stability is determined to a large degree by part design, differences in cavity surface temperature will result in differential shrinkage and produce parts with a tendency to warp. In addition, overall shrinkage depends on absolute mold temperature. See "Resin Characteristics and Part Design" for more information on these subjects.

Because Crastin® PBT is a very crystalline polyester resin, it freezes rapidly and can be successfully molded over a broad range of mold temperatures

(85 to 265°F [30 to 130°C]). Mold temperatures under 150°F (65°C) will produce short cycles with unreinforced resins, while mold temperatures over 150°F (65°C) will produce better surface aesthetics, flow, and dimensional stability with reinforced resins. Higher mold temperatures should be used for parts with critical dimensional stability requirements to reduce the risk of dimensional changes caused by post-shrinkage. Generally, a mold temperature of 175°F (80°C) is sufficient to obtain parts with good dimensional stability. For precision parts that will be subject to high temperatures in service, a mold temperature over 200°F (93°C) may be required.

Fill Rate

Crastin® PBT resins exhibit fast set-up in the mold. To prevent premature surface freezing (which results in poor surface appearance and weak weld lines), fast fill rates (1 to 4 s) are recommended. To accommodate these fast injection rates, the mold must be adequately vented. See "Mold Design."

Screw Speed and Back Pressure

In general, screw speed should be adjusted to achieve a screw retraction time that is 75% of the available mold closed time, because slower screw speeds produce more uniform melt. Back pressure will also improve melt uniformity and is particularly useful in obtaining good mixing uniformity when adding concentrated colorants. With glass-reinforced resins, high screw speeds and/or high back pressure can cause glass fiber breakage and reduce mechanical properties of parts.

Purging

If the cycle must be interrupted for a time equal to several times the normal cycle, the cylinder should be purged with fresh resin. Failure to purge after such interruptions can result in defective parts due to thermal degradation of the resin. This is especially important in hot runner molds.

The cylinder (and hot runner manifolds) should be purged when switching to or from materials that process at temperatures over 550°F (288°C). In general, it is good molding practice to purge the machine when changing to a different resin family.

The best purging materials are high-density polyethylene and polystyrene. Cast acrylic purge compounds are very effective, but the nozzle must be removed during purging. See "Safety and Handling" for important suggestions on purging procedures.

Resin Characteristics and Part Design

Crastin® PBT thermoplastic polyester resins are injection molding resins based on polybutylene terephthalate (PBT). PBT is a semi-crystalline thermoplastic resin.

Amorphous versus Crystalline Materials

Thermoplastic materials can be broken up into two general categories: amorphous resins and crystalline resins. Amorphous materials have no real structure, but rather gain their mechanical and physical properties from loose associations of polymer molecules. Because the strength of these associations decreases at high temperatures, the polymer will flow and can be formed into a new shape. Crystalline materials, on the other hand, owe their mechanical and physical properties to a regular structural framework as well as to amorphous-like molecular associations. To mold a crystalline resin, sufficient heat must be added to both overcome this regular structure and to reduce melt viscosity to a point where the resin will flow into a mold.

The regular structural framework of crystalline resins is responsible for their advantages in creep, chemical resistance, toughness, and fatigue properties, and retention of strength and stiffness at elevated temperatures. It also influences processing characteristics such as flow, shrinkage, and dimensional stability.

Flow Properties

Crastin® PBT has very good flow properties. It will readily fill molds with long or complicated flow paths with good replication of mold surface details. However, because it is crystalline, it solidifies rapidly and fast injection rates are necessary.

Because the melt viscosity of Crastin® PBT decreases with increasing temperature, higher melt temperatures are suggested for hard to fill parts. The effect of injection pressure and melt temperature on flow length of glass-reinforced resins is illustrated in **Figure 3**. High flow grades of Crastin® PBT typically flow 50% further than standard grades at the same injection pressure. They are well suited for parts with thin sections. Flow of standard and high flow resins is compared in **Figure 4**.

Figure 3. Effect of Melt Temperature and Injection Pressure on Flow of 30% Glass-Reinforced Resins. Endless Flow Channel 0.5 in Wide, 0.100 in Thick

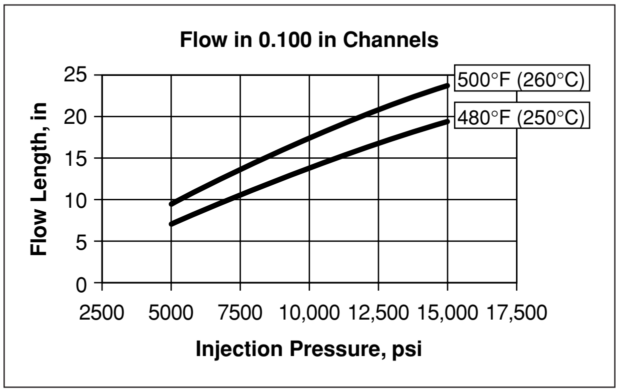
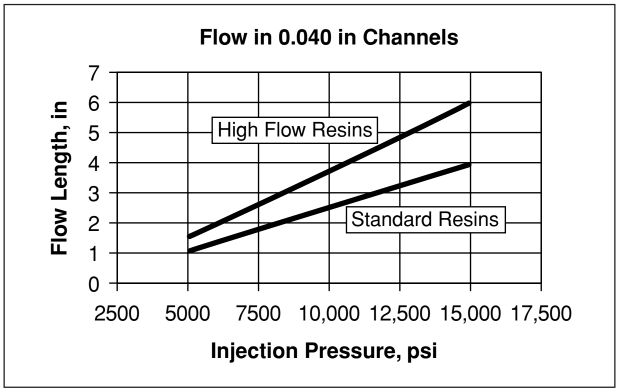


Figure 4. Effect of Injection Pressure on Flow of 30% Glass-Reinforced Standard and High Flow Resins. Endless Flow Channel 0.5 in Wide, 0.040 in Thick. Melt Temperature 480°F (250°C).



Shrinkage

In amorphous thermoplastics, shrinkage is caused primarily by contraction of the molded part as it cools to room temperature. With semicrystalline thermoplastics, like Crastin® PBT, shrinkage is also influenced greatly by the crystallization of the polymer. The degree of crystallization depends on the transient and local temperature changes in the mold. High mold temperatures and heavy wall thicknesses (high heat content of the melt) promote crystallization and increase shrinkage. These effects are illustrated in **Tables 3** and **4**.

Table 3
Effect of Mold Temperature on Shrinkage (3″ × 5″ × 0.125″ Plaques)

	Mold Shrinkage, %		
Mold Temperature	100°F (38°C)	150°F (66°C)	200°F (93°C)
Unfilled Resins	1.4	1.6	1.8
30% Glass-reinforced Resins			
Flow (length)	0.17	0.19	0.21
Transverse (width)	0.65	0.75	0.85
Super Tough Resins	2.0	2.2	2.4

Table 4
Effect of Part Thickness on Shrinkage (Mold Temperature 150°F [66°C])

	Mold Shrinkage, %	
Part Thickness	0.125 in	0.250 in
Unfilled Resins	1.6	2.0
30% Glass-reinforced Resins		
Flow (length)	0.19	0.35
Transverse (width)	0.75	0.85
Super Tough Resins	2.0	—

In addition to mold temperature effects, both holding pressure and holding time affect the shrinkage of Crastin® PBT. These effects are illustrated in **Figures 5** and **6** for unreinforced and glass-reinforced grades, respectively.

Figure 5. Shrinkage versus Holding Pressure for Unfilled (Top Line) and Glass-Reinforced (Bottom Line) Resins. Measured on a Flat Quadrant with 100-mm Radius and 4-mm Thickness

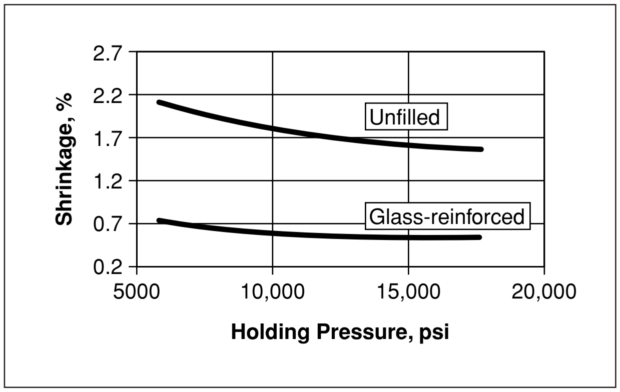
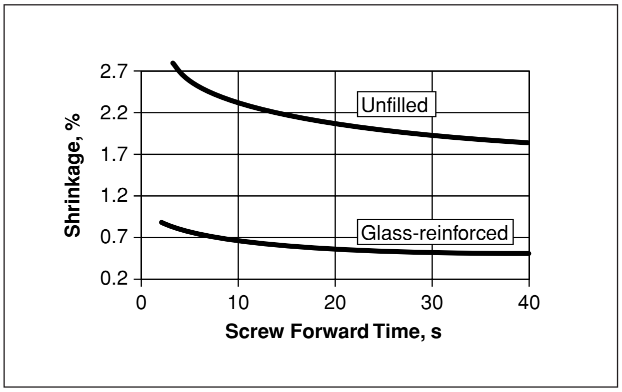


Figure 6. Shrinkage Versus Screw Forward Time for Unfilled (Top Line) and Glass-Reinforced (Bottom Line) Resins. Measured on a Flat Quadrant with 100-mm Radius and 4-mm Thickness



Part and mold design features can also influence shrinkage. For example, if undersized gates are used, much higher shrinkage will be observed than is shown in the illustrations due to premature gate freeze-off that reduces effective holding (pack out) pressure. Mold features such as cores, slides, and inserts can restrict shrinkage, leading to values lower than expected. In glass-reinforced resins, shrinkage depends on the direction in which the glass fibers are oriented. As a result, there is a difference in shrinkage parallel to (longitudinal) and perpendicular to (transverse) the direction of flow (see tables), and this makes accurate prediction of shrinkage difficult. Depending on the fiber orientation, which is determined by the flow pattern in the mold, shrinkage values that lie between the longitudinal and transverse values reported in the tables may be observed.

Dimensional Stability

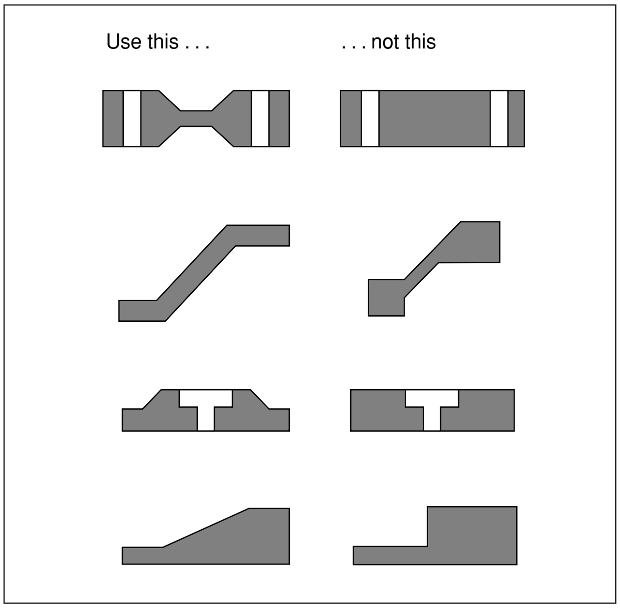
Dimensions and shape of plastic parts may change after they are ejected from the mold. These changes are usually due to differences in shrinkage caused by differential cooling rates or, with reinforced resins, to glass fiber orientation effects. In addition to dimensional changes, these effects can lead to internal stresses in parts that may lead to breakage problems.

Differential Cooling

Because the shrinkage of a crystalline plastic depends on the rate at which it is cooled, part or mold designs that lead to differential cooling rates may warp.

Parts should be designed with uniform wall thickness where possible. **Figure 7** illustrates routes to achieving uniform wall thickness in part design. Where non-uniform sections cannot be avoided, wall intersections should be blended gradually.

Figure 7. Uniform Wall Thickness in Part Design



Molds should be capable of delivering uniform cooling across the entire cavity surface. It is advisable to provide independent temperature control of the fixed and movable halves of the mold, and to check and adjust surface temperatures after the machine is on cycle. Provision for cooling large or deep cores must be included in the mold design. See “Mold Design.”

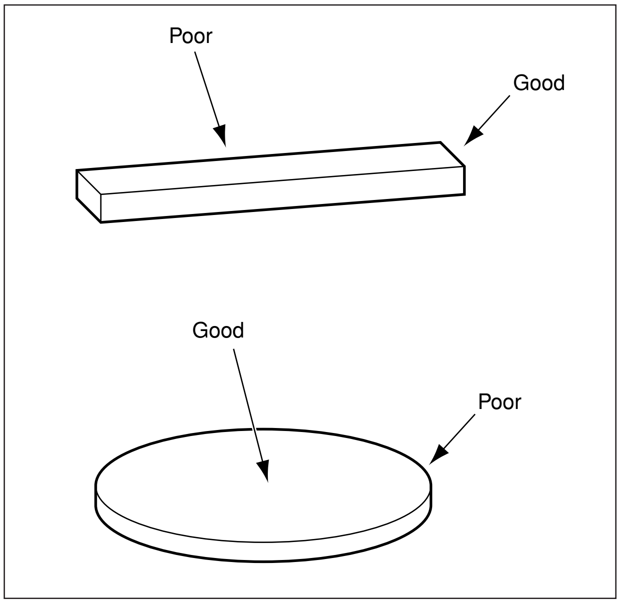
Uniform cooling is especially important with unreinforced resins or resins filled or reinforced with low aspect ratio (i.e., round) materials, such as glass beads or most minerals. The effects are so pronounced that differential cooling of mold halves is sometimes used to control overall flatness in part designs that are prone to distortion.

Fiber Orientation

In glass fiber reinforced resins, shrinkage is influenced by the direction in which the glass fibers are oriented. This anisotropic shrinkage of reinforced resins probably contributes more to part distortion than any other factor.

Parts molded out of glass-reinforced resins should be designed and gated with this shrinkage difference in mind. Any condition that will create a random distribution of glass fibers will reduce the tendency of the part to warp. An alternative strategy is to encourage fiber orientation. For example, long, thin parts are best gated at the end to encourage fibers to orient along the length of the part (see **Figure 8**). The mold can then be cut to accommodate different shrinkage values along the length and across the width of the cavity. Round parts are often center-gated to achieve radial orientation of the fibers. See “Mold Design.”

Figure 8. Gate Positions for Glass-Reinforced Crastin® PBT Resins



Material Selection

Often the realities of part function conflict with the theories of part design. In these cases, using a Crastin® PBT resin especially designed to be less susceptible to differential cooling or fiber orientation effects can produce parts with little or no distortion.

By alloying with polymers with inherently low shrinkage, the overall shrinkage of a Crastin® PBT resin can be reduced. Thus, while glass fiber orientation effects are still present, part distortion is reduced, because the differences in shrinkage along and across the fiber orientation direction are reduced. An example is Crastin® LW9330, a 30% glass-reinforced polymer alloy, which molds flatter than 30% glass-reinforced PBT resins while retaining strength and stiffness.

Glass fibers are added to Crastin® PBT resins to increase both strength and stiffness. Low-aspect ratio minerals, which raise stiffness but do little to improve strength, are used in place of some of the glass in some Crastin® PBT resins. This combination reduces fiber orientation and leads to less differential shrinkage. An example is Crastin® LW685FR, a flame-retarded, 30% glass/mineral-reinforced resin, which is especially well suited to box shapes or parts with large flat areas. Crastin® LW685FR is listed by Underwriters Laboratories as UL 94 V-0 at 0.032 in and UL 94 5VA at 0.084 in.

See the Crastin® PBT Product and Properties Guide for other low warp resin choices.

Post-Shrinkage

Post-shrinkage is shrinkage associated with the reorganization of crystalline structure to alleviate stresses in molded parts. It is accelerated by conditioning parts at high temperatures (annealing). In general, parts molded at higher mold temperatures achieve a more stable crystalline structure and exhibit less post shrinkage. This is illustrated in **Figures 9** and **10**.

Figure 9. Effects of Conditioning Temperature, Mold Temperature, and Part Thickness on Post-Shrinkage of Unreinforced Resins

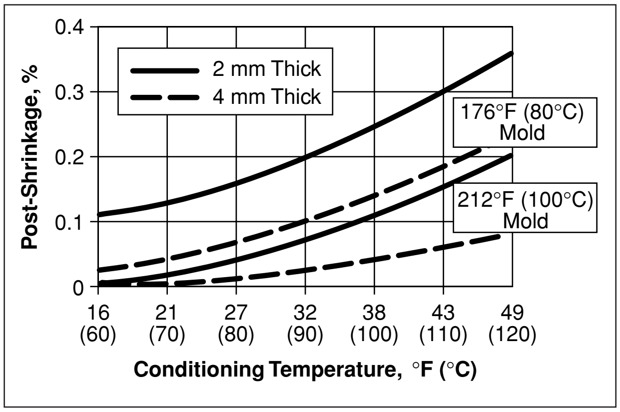
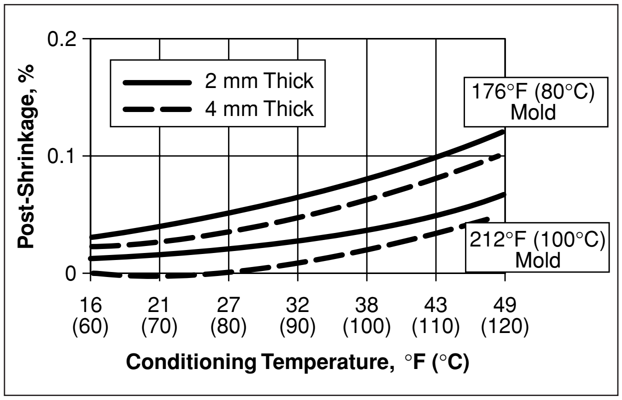


Figure 10. Effects of Conditioning Temperature, Mold Temperature, and Part Thickness on Post-Shrinkage of 30% Glass-Reinforced Resins



Mold Design

Sprues and Runners

Sprues and runners for Crastin® PBT are similar in design to those used for any other semicrystalline material, such as nylon or acetal. The entrance diameter of the sprue should be in the range of 0.15 to 0.28 in (3.8 to 7.1 mm). The smallest diameter sprue should be used where possible. Hot sprue bushings can be used.

Runners should have a full round or trapezoidal cross section. Normally, a runner diameter about 0.060 in (1.5 mm) larger than the thickness of the gated wall is sufficient. Runners should be as short as possible to minimize rework and to reduce pressure drop to the cavity. In multicavity tools, flow paths to individual cavities should be of equal length.

Gate Position

If possible, the gate should be located in the thickest wall section of the part to ensure that holding pressure remains effective throughout the time that solidification is taking place.

With glass-reinforced resins, the number and position of the gates have a significant effect on the orientation of the glass fibers and, therefore, on the strength and warpage of the part. Where possible, the mold should be filled "in a straight line." For example, flat plates should use a fan or flash gate, and long thin parts should be gated at an end rather than from the side. In parts subject to mechanical loads, gate positions that avoid orientation of the glass fibers parallel to the applied load should be selected.

Gates

Round or Rectangular Gates

Typically, round gates should have a diameter of about 50% of wall thickness and rectangular gates should have a thickness greater than 50% of part thickness with a gate width of 1.5 to 2 times gate thickness. For both round and rectangular gates, the land should be short (0.030 to 0.060 in [0.76 to 1.52 mm]).

In three-plate molds, the gate diameter should be less than 0.090 in (2.29 mm) to ensure automatic degating.

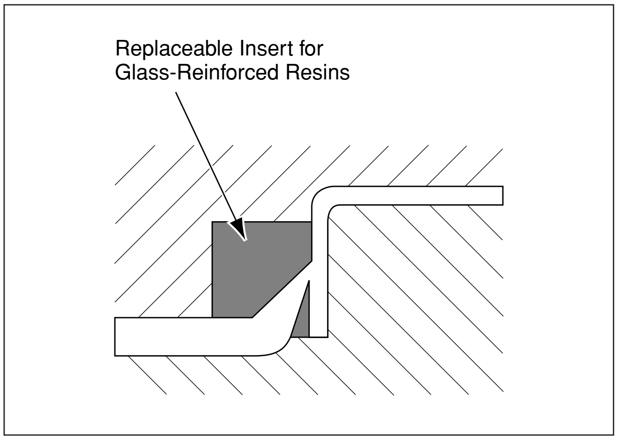
Center or Sprue Gates

Direct injection with a sprue gate is effective for axially symmetrical parts and thick-walled parts. It is particularly useful for precision engineering components with narrow tolerances. If the gate is correctly dimensioned and located, holding pressure will remain effective during the entire solidification time, producing parts free of voids or sinks. The sprue should be kept as short as possible, and the diameter of the gate should be only as large as needed to allow sufficient pack time. A 1° taper angle on the sprue is sufficient for ejection.

Tunnel Gates

For small parts with wall thicknesses up to 0.080 in (2 mm), tunnel gates may be used, provided the gate diameter is greater than 0.020 in (0.5 mm). Land lengths should be kept short. Clean separation of the runner is generally achieved with both unreinforced and glass-reinforced types of Crastin® PBT. With glass-reinforced types, increased wear must be expected in the gate area. It is good practice to design the gate area as an insert (block) that can be easily replaced (**Figure 11**).

Figure 11. Tunnel Gate



Fan and Flash Gates

In parts with a large surface area (e.g., flat plates) molded out of glass-reinforced resins, it is often advantageous to use flash gates (**Figure 12**) or fan gates (**Figure 13**). These gates provide a uniform flow front and even glass fiber orientation. This ensures that distortion of parts is reduced to a minimum.

Diaphragm Gates

Diaphragm gates (**Figure 14**) are useful in axially symmetrical parts that must have close dimensional tolerances and high strength. They provide uniform and symmetrical filling of the mold without weld lines and are particularly useful in processing glass-reinforced resins.

Figure 12. Flash Gate

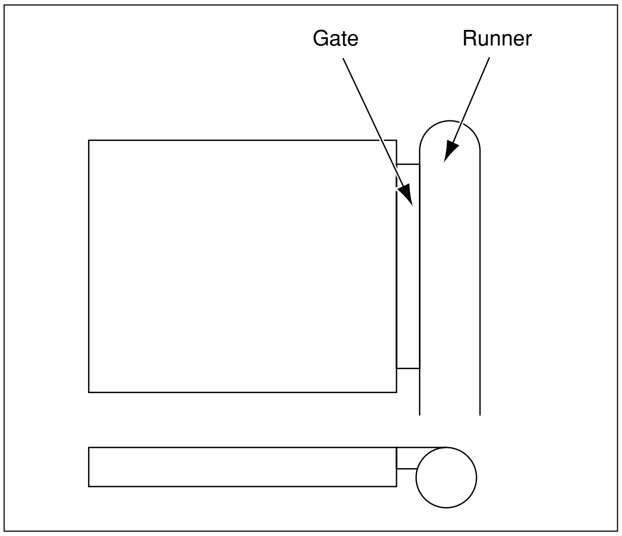


Figure 13. Fan Gate

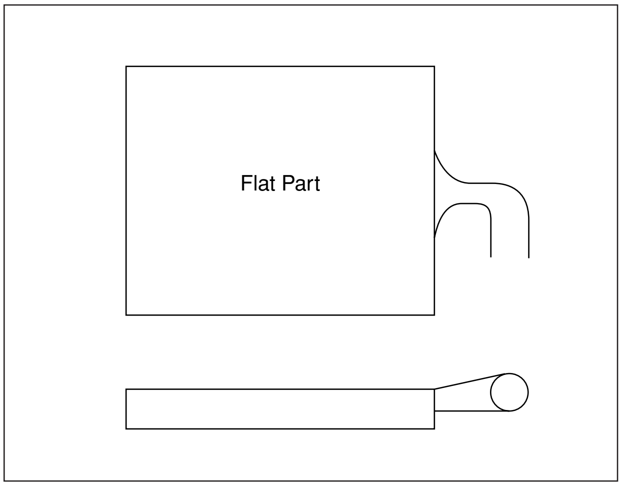
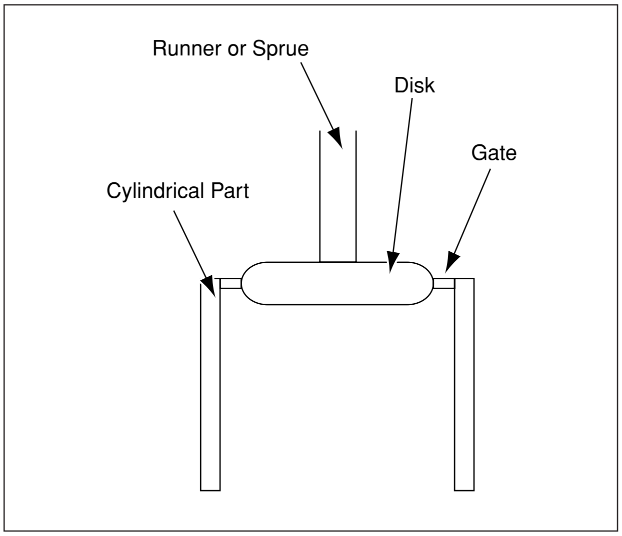


Figure 14. Diaphragm Gate



Venting

Injection molds must be vented in order to allow easier filling of the cavity. Poor venting can cause localized burning of the part, poor weld line strength, incomplete filling, and sinks. Because trapped air insulates the plastic part from the mold, shrinkage may vary and parts may warp. Insufficient venting can also result in damage to the mold and excessively high injection pressures.

Vents for unreinforced grades of Crastin® PBT should be less than 0.001 in (0.025 mm) deep, while those for reinforced grades should be 0.0010 to 0.0015 in (0.025 to 0.019 mm) deep. In both cases, after a distance of about 0.030 in (0.76 mm) from the cavity, the vents should be deepened to at least 0.020 in (0.5 mm) and extended to the edge of the mold. Vent width is not critical, but should be at least 0.25 in (6.4 mm). Vents should be located liberally around the entire parting line.

Areas of the mold that are filled after they are sealed off from the parting line must be vented through clearances between moving cores, sleeves, or ejector pins.

Draft

Mold surfaces that are perpendicular to the parting line should be tapered to allow easy part ejection. These include ribs, bosses, and sides. A taper (draft angle) of 0.5 to 1° is usually satisfactory with Crastin® PBT.

Undercuts

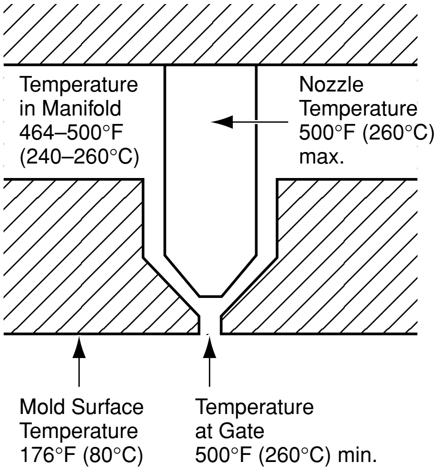
Undercuts should be avoided with unreinforced resins and are not recommended with glass-reinforced resins.

If undercuts are used with unreinforced resins, they should be designed to minimize distortion of the part as it is stripped from the mold. The part must be free to deflect sufficiently in the area of the undercut to clear the mold. A radius or bevel on the undercut will reduce the force required to strip it. Mold temperature should be selected to ensure the part is warm enough to deflect, yet cool enough to prevent permanent distortion. The amount of undercut depends on wall thickness and part diameter.

Runners Molds

When processing Crastin® PBT on hot runner molds, careful attention must be paid to the melt temperature and melt residence time. As a general rule of thumb, at melt temperatures below 500°F (260°C), residence times should be less than 10 min (less than 5 min for flame-retarded resins). A minimum melt temperature of 455°F (235°C) is needed to prevent material from freezing in the hot runner nozzle. These suggestions are illustrated schematically in **Figure 15**.

Figure 15. Temperature Suggestions in Hot Runner Molds



Temperature Control

As for most semicrystalline resins, the need to maintain melt temperature in a fairly narrow range must be addressed in the design of the system. The hot runner nozzle must be well insulated from the mold steel; this is accomplished by designing for minimum contact and incorporating large air gaps. Separate and accurate (power proportionating) temperature controllers for each nozzle in the manifold are recommended to accomplish accurate temperature control and to avoid localized overheating of the melt. Fitting the nozzle area with heating/cooling channels that are independent from the main mold cooling circuits makes it easier to control nozzle temperature without affecting the overall mold temperature.

Nozzle Manifolds

In order to maintain uniform pressure drop and melt residence time to each cavity, nozzle manifolds must be designed so that flow paths to the various injection paths have equal length. In conventional molding, differences in flow length to each cavity will produce poor part-to-part uniformity, because of differences in effective injection pressure at the gates. In hot runner manifolds, there is the added complication of different melt residence times leading to part-to-part differences in resin quality. Of course, manifold systems must be carefully streamlined to avoid hold-up spots.

Nozzles

Externally heated nozzles with a free flow orifice are preferred over those heated internally with a cartridge. With internal heaters, additional heat energy must be passed through the melt to compensate for heat losses to the surrounding tool steel. External heaters can lose heat directly to tool steel, while maintaining the melt at the appropriate temperature. If internally heated nozzles are used, they should not be mounted directly, but should use an antechamber bushing. A large gate cross section should be used. See **Figures 16** and **17**.

Direct injection of parts is possible if a short tip or a large gate diameter (0.060 to 0.080 in [1.5 to 2.0 mm]) can be used. With direct injection, it is often difficult to obtain parts with clean separation that require no finishing operations. With indirect injection, where the hot runner nozzle injects into a short runner system, the gate diameter should be large (0.080 to 0.120 in [2 to 3 mm]). Because the parts in indirect injection are fed by a conventional runner system, part separation is not usually a problem.

Figure 16. Good design of internally heated hot runner nozzles. Bushing with air gap insulates melt from tool steel.

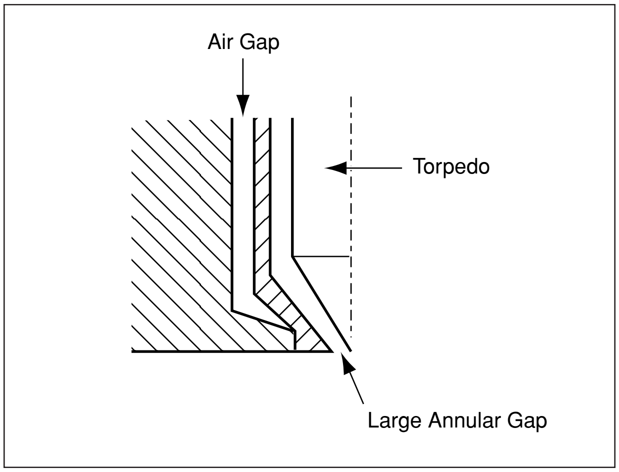
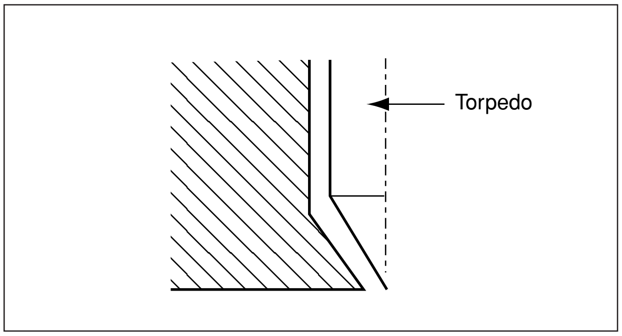


Figure 17. Poor design of internally heated hot runner nozzles. Direct mount leads to high heat loss to surrounding tool steel.



Needle-type, self-closing nozzles can experience functional problems in the sealing system when running glass-reinforced resins.

Mold Temperature Control

The location and efficiency of the cooling system in a mold affects both the properties of the finished part and the cycle time. As with all semicrystalline thermoplastics, the dimensional accuracy and distortion of parts molded out of Crastin® PBT are also influenced by mold temperature. Temperature control must be part of the overall design concept for molds.

Cooling circuits should be designed and located to ensure a rapid removal of heat from the mold, while maintaining a uniform temperature across the entire mold. Inserts, ejector pins, splits, and cores must also be considered in the design if uniform cavity surface temperature is to be achieved.

Flat Parts

Good temperature distribution can usually be achieved in flat parts with either spiral or drilled cooling channels. For large parts, it may be necessary to use several separate cooling channels.

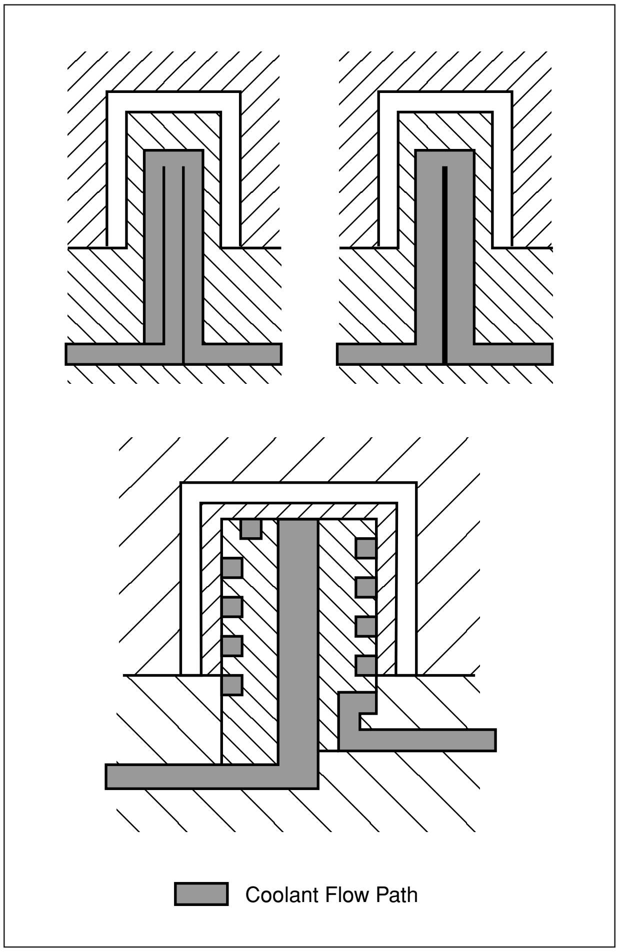
Multicavity Molds

Multicavity molds can be designed with annular cooling channels. In order to avoid variation in cavity surface temperatures, several circuits must be used in large molds.

Cores

When molding sleeves or long cylindrical sections, most of the heat must be removed through the tool core. The ratio of cooling surface to the amount of heat to be removed becomes less favorable as the core diameter is reduced. **Figure 18** shows some possibilities for cooling cores.

Figure 18. Some Methods for Cooling Cores



Regrind

Crastin® PBT is a thermoplastic resin that can be reground and molded repeatedly, as long as care is taken to minimize degradation during processing. Both virgin resin and regrind must be dry (less than 0.04 wt% water), and excessive melt temperatures and residence times should be avoided. If the recommendations in “Drying and Molding Conditions” are followed, up to 25% of regrind can be used without significant losses in strength and toughness.

The actual amount of regrind that can be added must be determined for each part by a suitable end-use test, because parts have differing functional requirements. Parts subject to high mechanical loads may require 100% virgin resin, while parts requiring only stiffness or electrical properties may tolerate regrind levels greater than 25%.

Grinder screens should have a hole size of about 5⁄16 in and yield particles with a diameter of about 1⁄8 in. Cutting blades should be kept sharp to reduce fines. With glass-reinforced resins, strength and toughness depend on glass fiber length that can be reduced in grinding operations. Scrap parts, sprues, and runners should be ground while warm to reduce fiber breakage.

It is common industry practice to use a melt viscosity or melt flow rate test to monitor regrind quality. The value determined for regrind is compared to the value for a virgin resin control, and this ratio, or percentage, is correlated with a target value based on part performance testing or previous experience. In the case of melt viscosity tests, regrind will have lower melt viscosity than virgin resin; in melt flow rate tests, regrind will have higher melt flow rates than virgin resin. In either case, the change of regrind relative to virgin resin control must be correlated to end-use performance before a decision regarding regrind quality can be made. However, as general rules of thumb, it is typical to see changes up to 25% when virgin resin is processed under good conditions (low moisture, reasonable combinations of melt temperature/residence time); regrind that differs from virgin resin by greater than 50% is likely to be severely degraded and should be discarded.

Melt viscosity tests run on piston rheometers are recommended over melt flow rate tests run on melt indexers. Piston rheometers operate at constant shear rate that can be set to a value typical of the injection molding process. Melt indexers operate at very low shear rates (typically well under 100 reciprocal seconds) and are better suited to monitoring resins in extrusion processes. In addition, the shear rates in melt flow tests depend on the flow characteristics of the material being tested (shear rate is the volume of material passing through a given orifice per unit time; melt flow rate is the weight of material passing through a given orifice per unit time, i.e., 10 min (under a given load) and are inherently less accurate, because the flow characteristics of polymer melts depend on shear rate. Thus, melt viscosity by piston rheometer gives more accurate values measured at shear rates more representative of those actually observed in the mold.

Melt viscosity or melt flow rate changes can be used with Crastin® PBT to monitor regrind quality; however, the test must be performed in a manner that ensures consistent results. Because moisture will degrade molten Crastin® PBT very quickly, the moisture content of regrind must be controlled during testing. Typically, regrind and a virgin resin control are dried (usually overnight) in a vacuum oven at 248°F (120°C) until moisture content is below a target level (e.g., 0.003 wt%). A dry nitrogen blanket may be required to attain this level of dryness. Typical test conditions are 482°F (250°C) at a shear rate of 1000 reciprocal seconds for melt viscosity and 482°F (250°C) with a weight of 2160 g for melt flow rate (ASTM D 1238 Condition T).

Troubleshooting

Although Crastin® PBT thermoplastic polyester resins are generally easy to mold in trouble-free, robust processes, occasional problems will arise. The following Troubleshooting Guide offers some suggested remedies for common problems. Most problems can be related to three characteristics of the resin.

Moisture Content

Crastin® PBT resins must be processed with a maximum moisture content of less than 0.04 wt% to avoid hydrolytic degradation. Processing wet material may contribute to excessive flow (flash) and will produce brittle parts. Most moisture problems can be traced to dryer maintenance problems—clogged filters, inaccurate instrumentation, air leaks. If regrind is being used, it must be dry and of good quality. Parts, sprues, and runners from resin that was processed wet will be degraded and may produce brittle parts if mixed with virgin resin and properly dried before molding. For more information, see "Drying and Regrind."

Freezing Rate

Crastin® PBT resins are very crystalline and freeze very rapidly. Fast injection times are required to give the resin a chance to fill the mold before it freezes. Short shots, sink, and excessive (or variable) shrinkage can often be traced to premature freezing as can weak or very visible weld lines. Fast injection rates mean the mold must be well vented and call for careful control of the transition from injection to holding pressure. Gates must be large enough to allow complete packing of the part. For more information, see "Molding Conditions" and "Mold Design."

Shrinkage

Because Crastin® PBT is crystalline, it shrinks on freezing. Apart from the obvious impact on control of dimensional tolerances, shrinkage also plays a major role in dimensional stability. Parts that are undersize or are variable in dimension (or contain sink) may benefit from longer screw forward times or larger gates to allow more resin to flow into the cavity to compensate for the volume change that occurs during shrinkage. Parts may warp, especially in unreinforced resins, if mold temperature varies in the cavity area, because shrinkage depends on mold temperature. Because thick sections cool more slowly than thin sections, part design may also lead to differential shrinkage that causes parts to distort. For more information, see the sections "Molding Conditions" and "Resin Characteristics and Part Design."

Troubleshooting Guide

	Problem									
Suggested Remedies*	**Brittle Parts**	**Short Shots**	**Voids in Part**	**Sinks**	**Parts Burned**	**Parts Warp**	**Weak Weld Lines**	**Sprue Sticks**	**Part Sticks**	**Poor Surface**
Ensure Resin Is Dry	1						1			
Change Injection Pressure		2	2	2		2	3	2	2	2
Increase Injection Speed		3	4				2			5
Decrease Injection Speed				4	3	3				4
More Screw Forward Time			3	3						
Less Screw Forward Time									3	
Check Melt Temperature	2	4	5	5	1	6	6			3
Increase Mold Temperature		5					5	3	1	1
Increase Nozzle Temperature								1		
Increase Gate Size		7	6	6	5					8
Increase Vent Size		6	7		2		4			7
Use Reverse Taper Nozzle								4		
Decrease Hold-up Time	3									
Change Cycle					4	4			4	6
Check Pad Size (Cushion)		1	1	1						
Repair Mold								5	5	
Increase Taper								6	6	
Change Gate Location					6	5	7			9
Reduce Regrind Level	4									
Balance Mold Temperature						1				
Check Puller Design								7		
Check for Contamination	5									
Check for Voids	6									
Decrease Mold Temperature						7				

*Try in order listed.

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