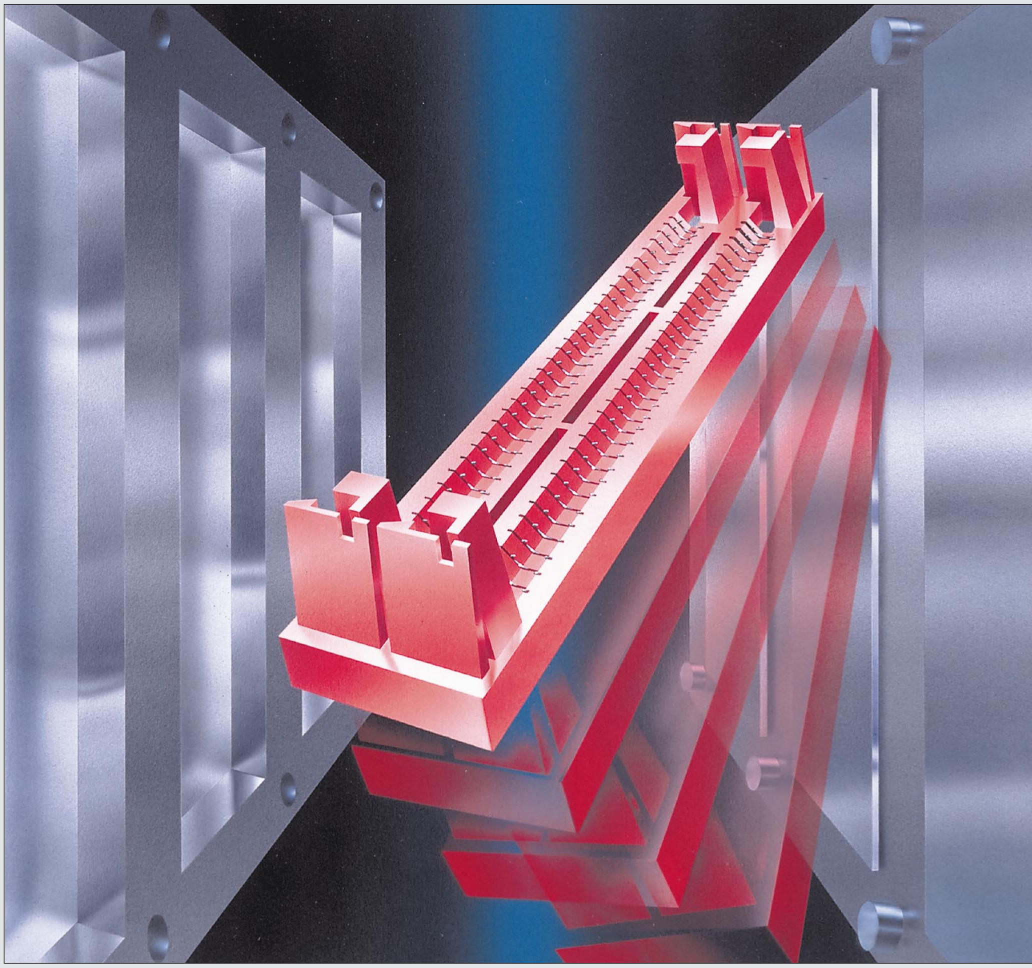
Ticona

Processing Fortron®
Polyphenylene Sulfide (PPS)

Processing And Troubleshooting Guide (FN-6)



Recommended Injection Molding Setup Conditions

	Unreinforced Grades 0205P4, 0214P2	Reinforced Grades 1130 Series, 1140 Series, 4184 Series, 6165 Series
Melt Temperature*, °F (°C)	560-620 (293-327)	590-640 (310-338)
Mold Temperature, °F (°C)	275-325 (135-163)	275-325 (135-163)
Injection Pressure, psi (MPa)	2000-6000 (13.8-41.4)	5000-10000 (34.5-69.0)
Back Pressure, psi (MPa)	0 (0)	0 (0)
Screw Speed, rpm	40-100	40-100
Cushion, in. (mm)	1/8-1/4 (3.18-6.35)	1/8-1/4 (3.18-6.35)
Drying Conditions	3 hours @ 250°F (121°C)	3-4 hours @ 275°F (135°C)

Recommended Extrusion Setup Conditions

	Unreinforced Grades 0214 Series, 0300 Series	Reinforced Grades 1140A0
Feed Zone Temperature, °F (°C)	545-555 (285-290)	555-575 (290-300)
Transition Zone Temperature, °F (°C)	555-565 (290-295)	555-590 (290-310)
Metering Zone Temperature, °F °(C)	555-575 (290-300)	570-610 (300-320)
Adapter Temperature, °F (°C)	570-590 (300-310)	570-610 (300-320)
Die Temperature, °F (°C)	570-590 (300-310)	570-610 (300-320)
Melt Temperature, °F (°C)	560-620 (293-327)	580-640 (304-338)
Typical Draw-down	2:1	2:1
Drying Conditions	3 hours @ 250°F (121°C)	4 hours @ 270°F (132°C)

Fortron® PPS Processing Benefits

- High melt flow, fast cycle grades improve productivity.
- New grades can reduce or eliminate deflashing and exhibit lower flash compared to conventional PPS resins.
- Easily fills long, thin-walled parts.
- Processes very well on wide variety of injection molding equipment including hydraulic and toggle machines.
- Grades have low moisture absorption which improves resin transport in the feed section and reduces “bridging” in the hopper.
- Extrusion grades are available for fiber and monofilament production as well as tubing, rod and slab.

*** Safety Note! Under no circumstances should the melt temperature rise above 698°F (370°C); otherwise polymer decomposition may result with the production of gases which may be irritating to the eyes and respiratory tract. See Fortron® PPS MSDS for further information.**

Foreword

This revised issue of the Fortron® PPS Processing and Troubleshooting Guide (FN-6) is made necessary by both the advances in processing information and the introduction of new Fortron® PPS grades since the first edition was published in 1988. It is primarily intended for the processors (both molders and extruders) of high performance thermoplastic products, who require both general and specific information pertaining to processing Fortron® PPS. It also contains material of interest to the parts designer, specifier and tool builder who wish to obtain a general overview of PPS chemistry and technology.

The manual deals with four fundamental stages of production: dimensional stability of molded parts, equipment selection, tool design including the hot runner systems used in injection molding, and processing parameters. It also includes a troubleshooting guide for solving processing problems which may arise during the molding cycle.

We hope that this manual helps you, the molder/extruder, process engineer, or tool designer to optimize the processing cycle of Fortron® PPS, and in so doing enable your customers to take full advantage of this high performance product. We would welcome your comments and suggestions for improving this manual in future editions.

For more information on the design aspects and material characteristics of Fortron® PPS, the reader is encouraged to consult the following manuals: *Designing with Plastic: The Fundamentals (TDM-1)*, *Designing with Fortron® PPS (FN-10)*, and *Fortron® PPS Short Term Properties Guide (FN-4)*, all of which are available by contacting your local Ticona Sales Office or by calling Technical Information at 1-800-833-4882.

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Chapter 1

Fortron® PPS Overview

Chemistry of Fortron® PPS

Fortron® PPS products are based on an aromatic linear poly(phenylene sulfide) (PPS) polymer produced by a polycondensation reaction. The polymer has the following structure:

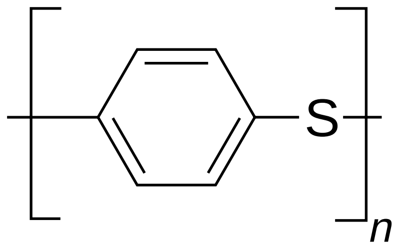

Figure 1.1 Idealized PPS Structure

General Characteristics of Fortron® PPS

The structure of Fortron® PPS polymer contributes to the following desirable properties:

- High thermal stability.
- Excellent chemical resistance.
- Inherent flame resistance without the addition of flame retardants.
- Excellent electrical properties.
- Excellent flow.

Fortron® PPS is further distinguished from highly branched PPS products by the following performance advantages:

- Faster cycle times and possible elimination of the deflashing operation.
- Higher elongation and impact strength.
- Improved viscosity consistency.
- Higher weld line strength.
- A natural light beige color for the Fortron® PPS base resin for easier coloring.

Most designers choose Fortron® PPS because it demonstrates a valuable combination of properties relative to the load-bearing capabilities and dimensional stability when exposed to chemicals and high-temperature environments.

Reinforcements and Fillers

Fortron® PPS resin is available in a range of base polymer, glass-reinforced, and mineral/glass-reinforced systems for injection molding, extrusion blow molding, and extrusion. Selection of the appropriate grade of Fortron® PPS and the use of proper processing conditions will aid in minimizing problems such as incomplete filling, flash, warpage, and part distortion.

When fillers, such as glass fibers, minerals, or mixtures of these are added to the base resin, the heat distortion temperature (HDT), is also raised. The HDT of unreinforced Fortron® PPS is about 221°F (105°C) at 264 psi, while that of a reinforced Fortron® PPS is 500+°F (260+°C). Because of this added value and Fortron® PPS's affinity for fillers, the majority of PPS applications use glass-reinforced or mineral/glass-filled systems.

Product Support

Experienced field engineers and design engineers are available to assist you with product design, material specification, and molding trials. For further information or assistance, please contact your representative from Ticona.

Agency Approvals

Fortron® PPS has been granted ratings by Underwriters Laboratories of UL94 V-0 to 0.031 in. (0.79 mm) thickness and UL94 5VA at 0.0625 in. (1.59 mm) on many filled grades, as well as ratings of A00 and V0 by the CSA (Canadian Standards Agency). UL yellow cards are available upon request. Some Fortron® PPS grades have also been approved under Military Specifications M-24519 and M-46174 (ASTM D4067). Consult your Ticona representative for ratings on specific grades of Fortron® PPS resin.

Chapter 2

Dimensional Stability

It is important for the part designer to understand the exceptional dimensional control obtainable with Fortron® PPS. In the following discussion, the effects of part tolerance as well as the dimensional effects caused by shrinkage, annealing, and moisture absorption will be considered. Dimensional effects caused by exposure to various chemicals are covered in Designing with Fortron® PPS (FN-10).

Coefficient of Linear Thermal Expansion

The coefficient of linear thermal expansion is the slope of the curve divided by the specimen length, i.e., Δ dimension/(Δ temperature X length). Figures 2.1 and 2.2 show the dimensional change for both the flow and transverse directions of 65% mineral/glass-reinforced and 40% glass-reinforced Fortron® PPS, respectively. The curves were measured by the Perkin-Elmer Thermomechanical Analyzer (TMA 7) from -13 to 392°F (-25 to 200°C), ASTM Test Method E831.

At the glass transition temperature, T_g, the rate of expansion changes. Above the glass transition temperature, the rate of thermal expansion may shift due to an increase in molecular chain motion and its attendant effects, stress relaxation and/or crystallization. Thus, samples molded from different sources and under different conditions will probably yield results significantly influenced by the processing and end-use thermal history. This is especially true of data taken in the transverse direction, where the effects of orientation and processing are most pronounced.

Shrinkage from Injection Molding

Typically, the mold shrinkage of Fortron® PPS products is very low, and therefore, quite suitable for precision molding. Typical shrinkage values for Fortron® PPS products are as follows:

40% Glass-Reinforced:

- Flow Direction: 0.002-0.006 in./in.
- Transverse Direction: 0.004-0.006 in./in.

65% Mineral/Glass-Reinforced:

- Flow Direction: 0.002-0.006 in./in.
- Transverse Direction: 0.003-0.007 in./in.

While the shrinkages given above are typical, these values vary, depending on the variables listed on p. 2-3 under Warpage. It is highly recommended that prototyping be employed prior to cutting a tool to determine the proper shrinkage for a given part. If prototyping is not economical, then for safety it is recommended that oversized cores and undersized cavities be cut, since it is always easier and less expensive to cut steel than to add it.

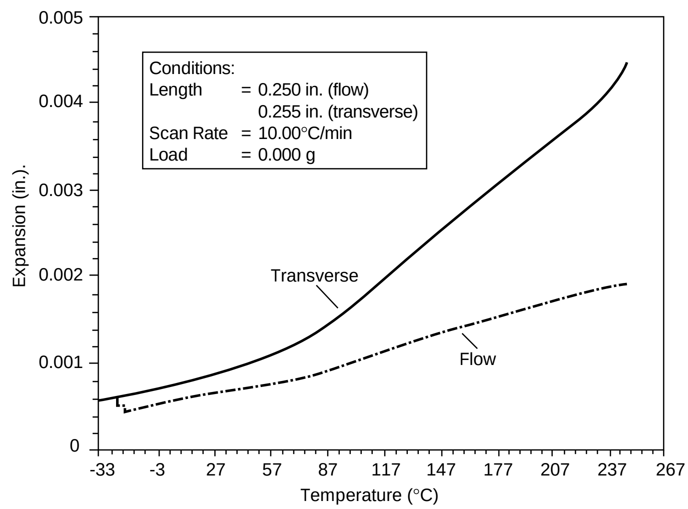

Figure 2.1 Dimensional change of 65% min/glass-reinforced Fortron® PPS

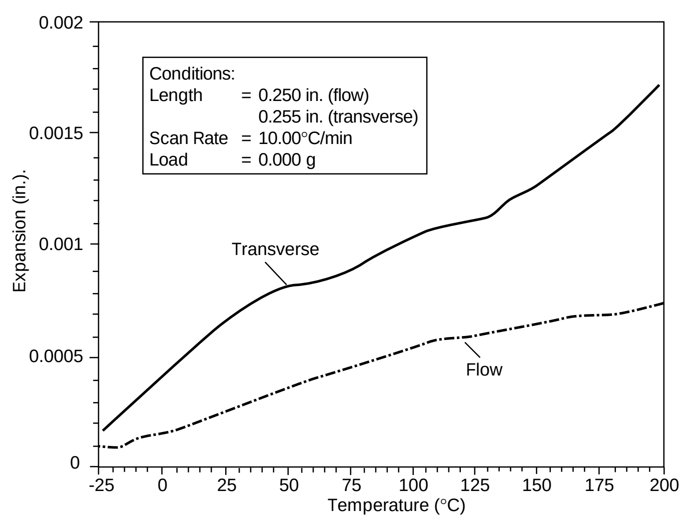

Figure 2.2 Dimensional change of 40% glass-reinforced Fortron® PPS

The effect of part thickness on shrinkage of 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS is shown in Figure 2.3. The reason for greater shrinkage in thicker parts is that thicker parts exhibit slower cooling, which results in a greater degree of crystallization, thus causing more shrinkage. Figure 2.4 illustrates the effect of filler/reinforcement level on shrinkage of Fortron® PPS: as filler level increases, shrinkage decreases and becomes less sensitive to part thickness.

Figures 2.5 and 2.6 show the effect of injection pressure on the shrinkage of 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS, respectively. As injection pressure is increased, the parts are more densely packed, thus slightly decreasing shrinkage. The test piece was 80 X 80 mm, 2 mm thick, with a rectangular (4 X 2 mm) side gate at one point; the cylinder temperature was 608°F (320°C), and the mold temperature was 320°F (150°C).

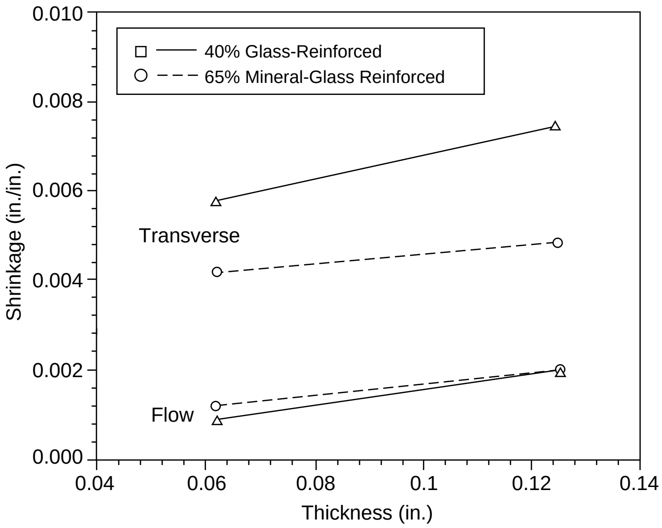

Figure 2.3 Effect of part thickness on shrinkage of Fortron® PPS

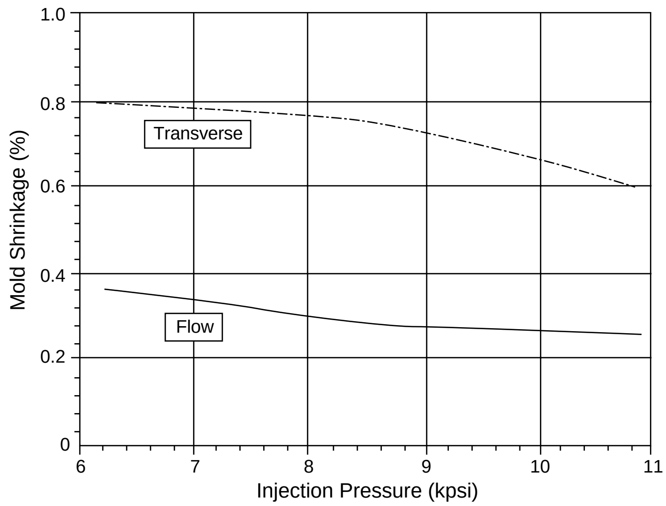

Figure 2.5 Effect of injection pressure on shrinkage of Fortron® PPS (40% glass)

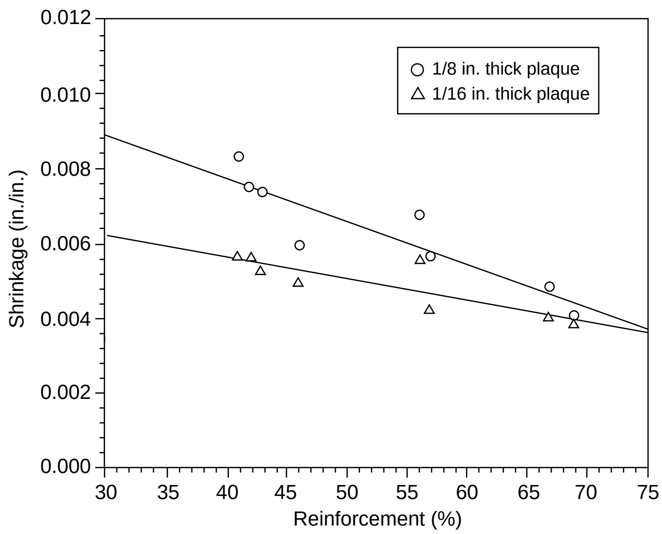

Figure 2.4 Effect of filler level on shrinkage of Fortron® PPS (Please note that not all reinforcement levels are available as commercial products.)

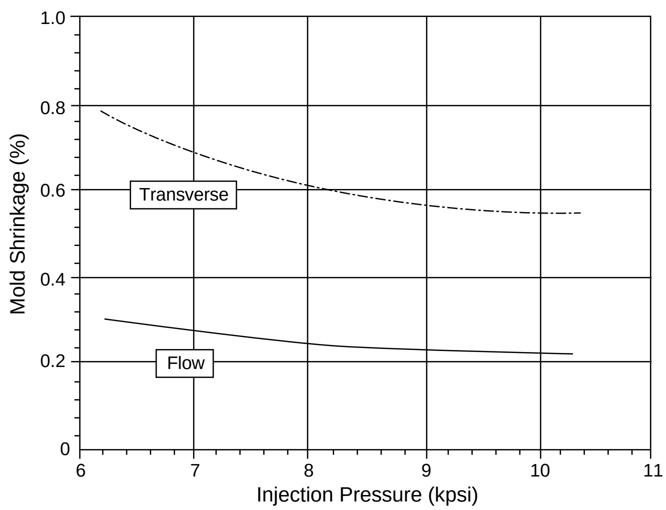

Figure 2.6 Effect of injection pressure on shrinkage of Fortron® PPS (65% mineral/glass)

Warpage

Anisotropic effects on dimensions (warping) can be caused by a number of factors, including the following:

- Mold temperature.
- Nonuniform part thickness.
- Nonuniform cooling.
- Filler type/level.
- Orientation of filler.
- Location of dimensions with respect to the gate.
- Molded-in stresses.
- Gate size.

To describe the effects of anisotropy in geometrically complex parts, a sample part containing a variety of shapes was designed. Figure 2.7 shows the specifications for this warpage sample. Figure 2.8 shows the measured points used to obtain the data shown in Figures 2.9 - 2.12, which compare the largest dimensional differences of 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS products with respect to flatness (Figure 2.9), roundness of a cylinder (Figure 2.10), roundness of a hole (Figure 2.11), and bowing angle (Figure 2.12).

From these figures it can be seen that 65% mineral/glass-reinforced Fortron® PPS has the least warpage, due to the fact that this material uses less glass than the 40% glass-reinforced material, and that mineral filler has a smaller aspect ratio than glass fibers.

Annealing

When processed at a mold temperature of 275°F (130°C) or greater, parts molded of Fortron® PPS are able to fully crystallize, and therefore, show very little continued shrinkage when exposed to temperatures as high as 450°F (232°C) for 24 hr. A study of the effects of annealing Fortron® PPS products showed the following additional shrinkage values for the flow direction, using 1/8-in. thick samples:

40% Glass-Reinforced:
- 0.0009 in./in. after 2 hr. annealing.
- 0.001 in./in. after 24 hr. annealing.

65% Mineral/Glass-Reinforced:
- 0.001 in./in. after 2 hr. annealing.
- 0.0012 in./in. after 24 hr. annealing.

Thus, there is very little advantage in annealing a sample molded at or above 275°F (130°C) for more than 2 hr. to obtain further shrinkage.

Fortron® PPS can be molded at lower mold temperatures at the expense of reduced thermal/load properties, i.e., heat distortion temperature. Annealing parts that have been molded at lower temperatures less than 275°F (130°C) will increase the load-bearing capabilities of those parts, but such practice may cause warpage; thus, strict care (e.g., fixturing the part) should be taken with parts requiring critical tolerances.

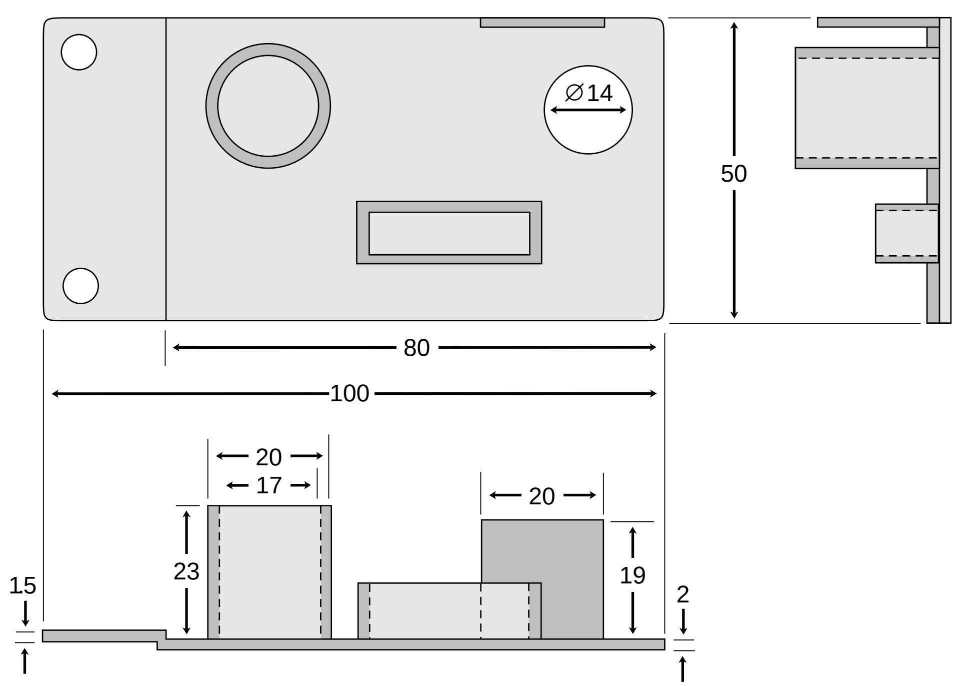

Figure 2.7 Specifications for warpage sample, dimensions in millimeters

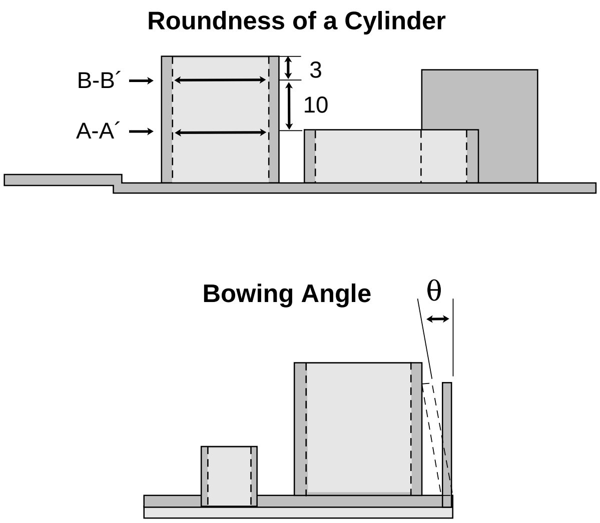

Figure 2.8 Measured points for warpage sample

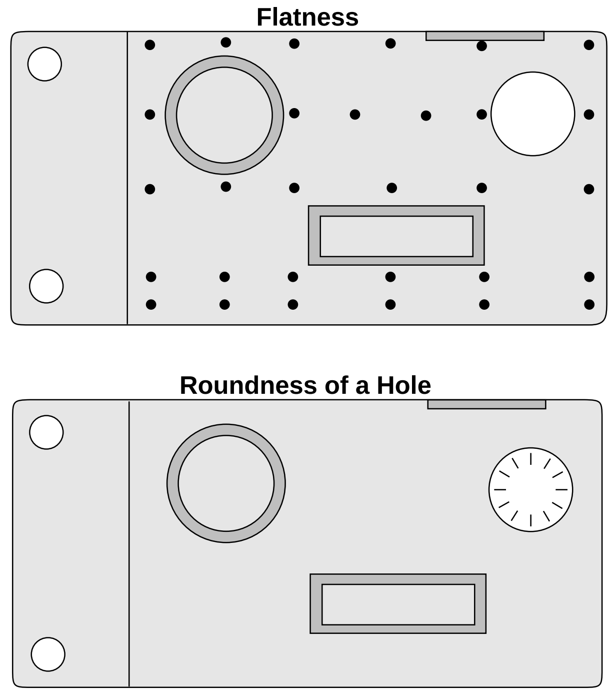

Figure 2.8 Top view

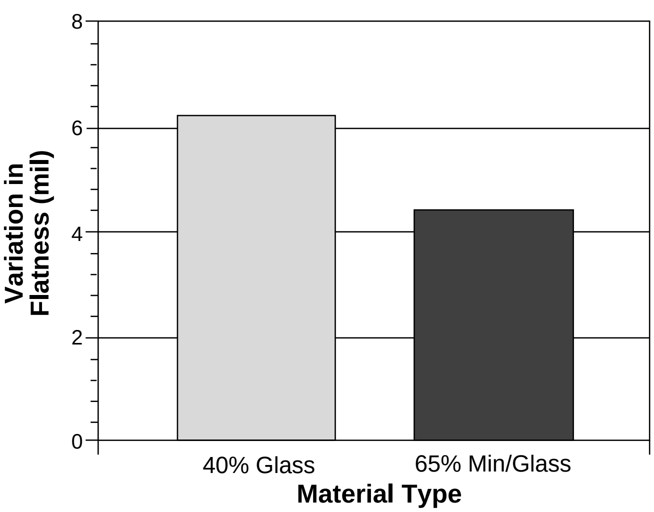

Figure 2.9 Warpage with respect to flatness

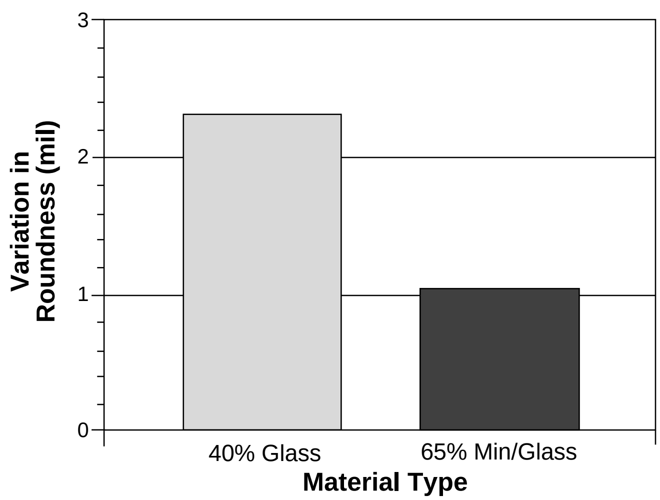

Figure 2.11 Warpage with respect to roundness of a hole

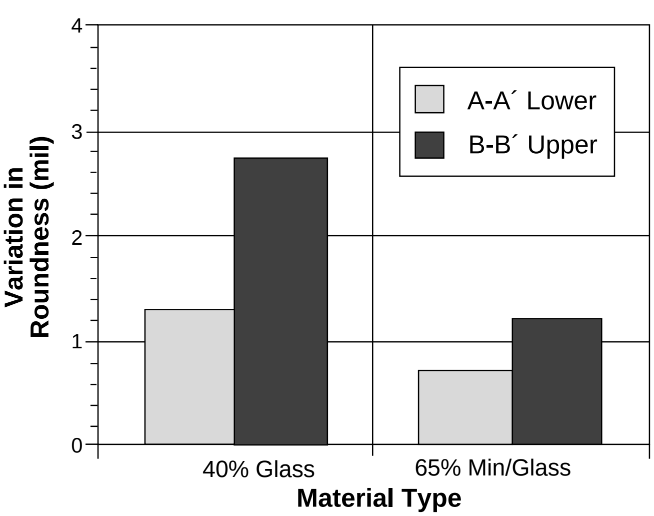

Figure 2.10 Warpage with respect to roundness of a cylinder

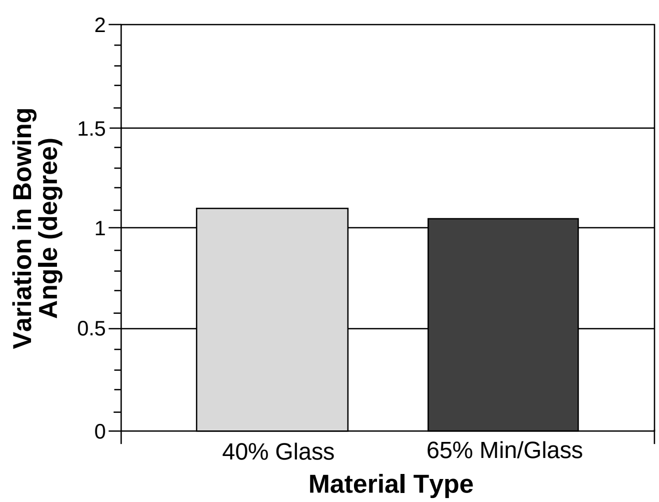

Figure 2.12 Warpage with respect to bowing angle

Tolerances with Injection Molding

When Fortron® PPS is injection molded, it is possible to routinely hold tolerances of 2-3 mil/in. To achieve tolerances such as 1 mil/in., the material should be uniformly oriented in the direction of flow, and precision processing machinery, including at least the following parameters, should be used:

- Uniform tool heating (efficient oil flow and proper placement of cooling lines).
- Closed-loop, feedback controllers for temperatures, pressures, injection speeds, and ram distances.

Table 1 demonstrates the dimensional reproducibility obtained in molding 65% mineral/glass-reinforced Fortron® PPS for 10 months. At the end of 10 months, the variability over a 1.9593 in. dimension was ± 0.0006 in. (0.03%).

Moisture Absorption

Fortron® PPS products are not hygroscopic, and therefore, do not experience dimensional expansion like polyamides. For both 40% glass-reinforced and 65% mineral/glass-reinforced Fortron® PPS products, a typical moisture absorption value is 0.03%, tested according to ASTM Method D-570 by immersion in water at 73°F (23°C) for 24 hr. Figure 2.13 shows how this value compares with those of other engineering plastics under the same conditions.

Table 1. Long-term dimensional reproducibility of injection molded Fortron® PPS

Test Date	$\bar{x}$ (in.)	σ (in.)	$3\bar{\sigma}/\bar{x}$ X 100 (%)	$3\bar{\sigma}/\bar{x}$ X 100 (%) for 3 days	Reproducibility for 10 months
8/10/88	1.9593	0.00016	0.024		
8/11/88	1.9593	0.00012	0.017	0.022	
8/12/88	1.9594	0.00016	0.025		
11/17/88	1.9594	0.00016	0.026		
11/18/88	1.9593	0.00016	0.025	0.025	Dimension = 1.9593 in. ± 0.0006 in. (0.030%)
11/19/88	1.9592	0.00016	0.025		
2/27/89	1.9592	0.00024	0.036		
2/28/89	1.9591	0.00028	0.043	0.035	
2/29/89	1.9592	0.00016	0.026		
5/29/89	1.9593	0.00020	0.029		
5/30/89	1.9593	0.00016	0.022	0.027	
5/31/89	1.9594	0.00020	0.029		

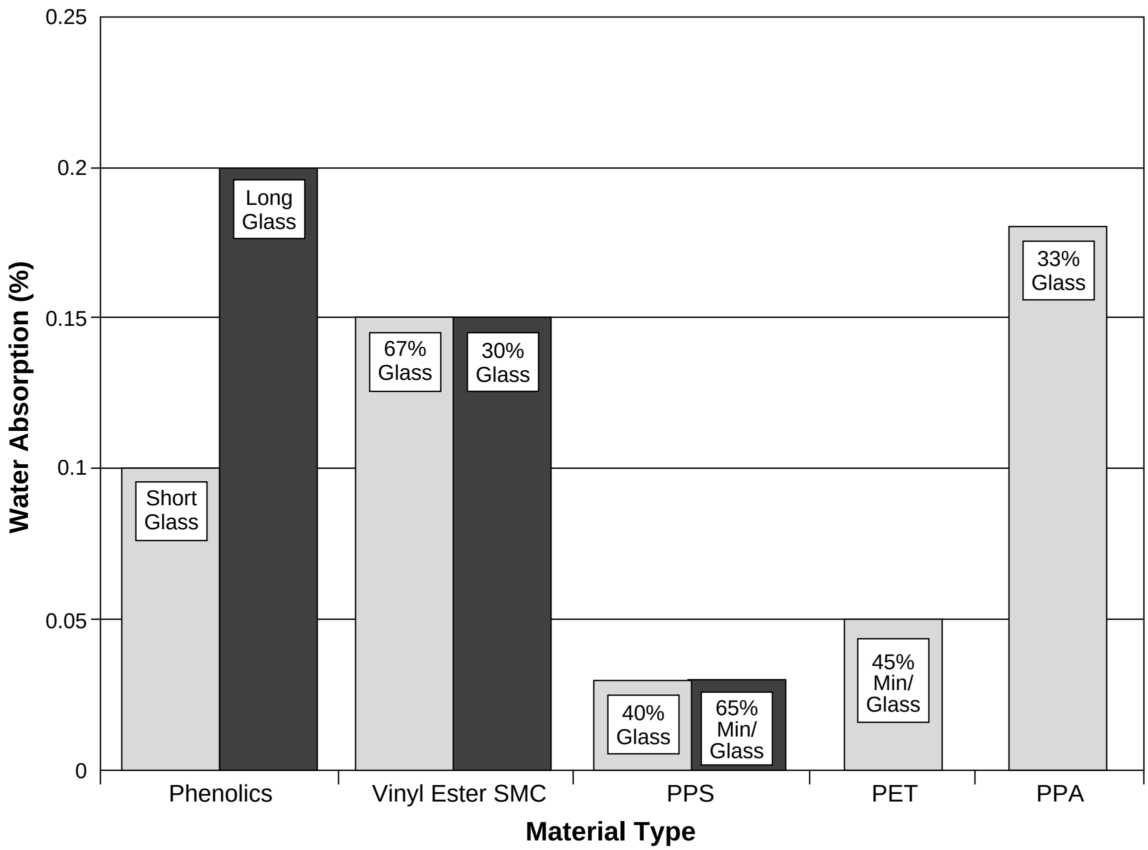

Figure 2.13 Comparison of the moisture absorption of several plastics by immersion in water at 73°F (23°C) for 24 hr

Chapter 3

Equipment Selection and Preprocessing

Selection of the appropriate equipment for an application and the proper drying of the resin can be important factors in producing quality molded parts. This chapter explains how to deal with these considerations when preparing to process Fortron® PPS.

Molding Equipment

Because the molding process is so crucial to the production of high-quality parts, a good understanding of both the molding equipment and the molding process is essential. Figure 3.1 shows a cut-away diagram of a single-stage, reciprocating screw injection molding machine, listing its basic parts.

Clamping Systems

Within the molding machine, the clamp force (to keep the mold closed) is developed either by a toggle mechanism or by a hydraulic cylinder. With Fortron® PPS, the clamp force for a typical molding machine should be between 3 and 5 tons of force per square inch of projected area (including the runner).

The advantages of a toggle clamping system are that it provides a faster mold opening and closing and is less expensive than a hydraulic system. However, there are more parts to wear out in a toggle system than in a hydraulic system.

The advantages of a hydraulic system are that it allows a faster mold setup and the exact clamp pressure can be read to determine its adequacy. However, because a hydraulic system uses oil to drive the clamp, a hydraulic system is more prone to oil leaks than is a toggle system.

A hydromechanical system uses both hydraulic and toggle systems together, thus combining some of the advantages of both the toggle (high-speed close and open) and hydraulic (precise control of clamp tonnage) systems. In such a system, a piston or other similar device provides fast initial closing, while a hydraulic system is used in the final clamp stroke. Thus, the danger of overtoggling is eliminated by the precision of the hydraulic phase.

Plasticizing Capacity

As with other engineering thermoplastics, Fortron® PPS grades should not be exposed to excessive temperatures during processing. The smallest shot size should be selected which allows both adequate part fill and a consistent cushion, A shot weight of 50-70% of the machine's capacity is optimum. Studies have shown that barrel residence times in excess of ten minutes may result in a modest decrease in viscosity and color darkening. Mechanical properties, however, are virtually unchanged.

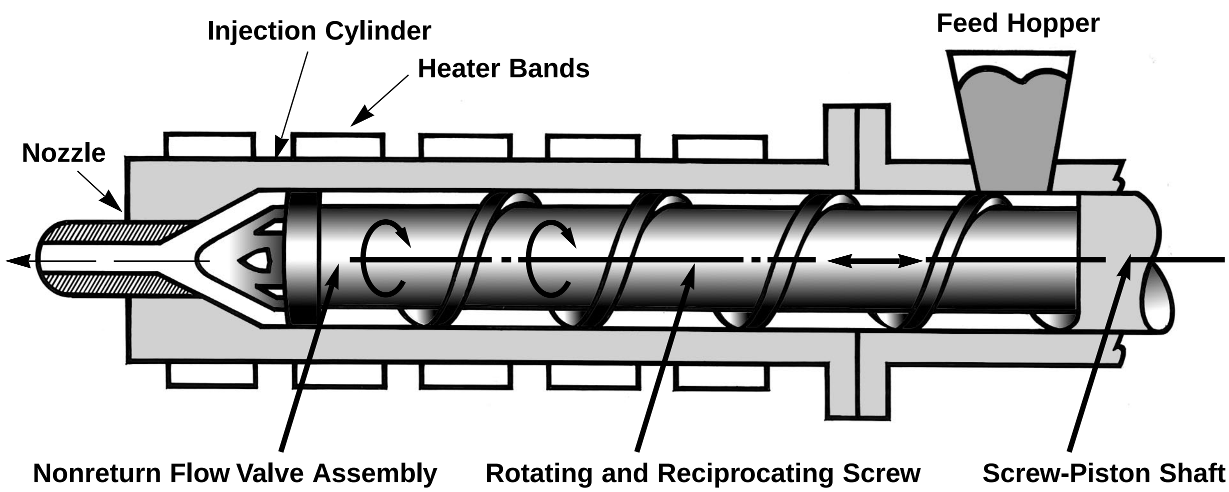

Figure 3.1 Single-stage reciprocating screw injection molding machine

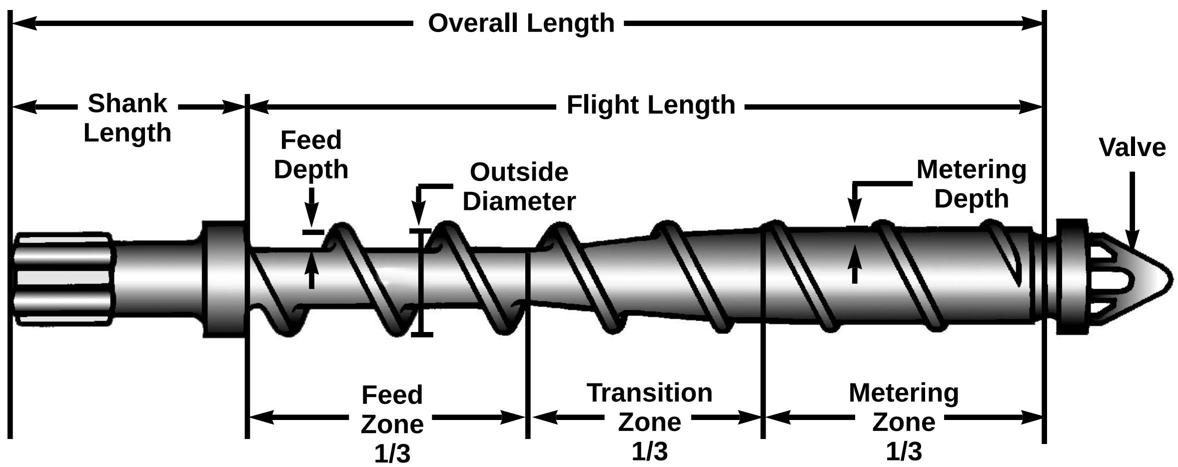

Figure 3.2 Metering type screw recommended for Ticona Fortron® PPS resins (for terminology only)

Screw Design

Figure 3.2 shows a typical metering type screw recommended for Ticona Fortron® PPS resins. The figure shows the three major sections of the screw: the feed section, the transition section, and the metering section. As seen in the diagram, the feed section and metering section both contain a constant root diameter, while the transition section contains an involuted taper. Proper screw design for Fortron® PPS resins follows these general guidelines:

- Zone distribution = 1/3 feed zone, 1/3 transition zone, and 1/3 metering zone.
- L/D ratio = 16:1 to 24:1.
- Compression ratio = 3:1 to 4:1
- Check ring strongly recommended.

Improper combinations of screw and barrel materials can lead to premature wear. It is highly recommended that suppliers of these products be consulted. Construction materials are continuously changing and improving. As a result, new products may be available to improve wear resistance.

Tool Design

Tool, Screw, and Barrel Materials

As with all filled plastic products, proper materials must be used in the construction of molds, screws, and barrel liners because glass and mineral filler materials are abrasive. This is also true of Fortron® PPS products.

The abrasive nature of glass and minerals also affects the screws and barrels. The proper materials for construction are important to ensure long life. Stellite® alloy is recommended for screws, and Xaloy® 800 alloy is recommended for barrel liners for long barrel life. It is important that compatible materials for screw and barrel are utilized. Newer type alloys using vanadium have been extremely successful for processing requiring minimum wear.

For high-volume production parts, the recommended steels for cores and cavities should have good wear resistance properties. The tool steels should have a hardness Rc>50. An SPI/SPE A2 class finish has been successfully used. For tools that are especially difficult to vent adequately, corrosion-resistant steels are recommended.

Drafts and Undercuts

Significant undercuts should be avoided and draft angles of 1/2 to 1° should be incorporated into a well polished mold. In order to obtain strong, stiff dimensionally stable parts, it is necessary to allow Fortron® PPS to fully crystallize in the mold. The above recommendations about drafts and undercuts should be followed to avoid problems in removing parts from the mold.

Gate Location

Gates should be located to provide a flow that is uniform and uninterrupted. Generally, the number of gates should be kept to a minimum. It is common practice to use multiple gates when dealing with a long flow length and/or thin-wall parts to reduce the pressure, and therefore minimize flash. When multiple gates are necessary, they should be placed so that the weld lines in the product are formed in areas with minimal load-bearing requirements. Where possible, adjacent flow fronts should be forced to meet at an acute angle so that a meld line is formed. Venting at the weld line also promotes stronger welds.

Gate Size

The size of the gate is related to the nominal wall thickness. Rectangular gates should always be at least as wide as they are deep.

The high flow of Fortron® PPS materials permits the use of very small gates (as low as 0.04 in. diameter). For example, submarine or pinpoint gates typically have a 0.040-0.070 in. diameter. Highly filled mineral/ glass products may require larger gates. This smaller gate area minimizes gate vestige and provides satisfactory part separation from the runner. For edge gates, a typical starting point is 50% of the nominal wall thickness. Typical land length is 0.020 in.

Gate Geometries

Any kind of gate may be used for molding Fortron® PPS. For a review of the various types of gates, see Figure 2 in Designing with Plastic: The Fundamentals. (Bulletin TDM-1). If a submarine gate is selected, it should conform approximately to the geometry recommended in Figure 3.3.

Runner Design

Full-round runners with a diameter as small as 0.125 in. (6 mm) are used for molding Fortron® PPS. Equivalent trapezoidal runners may also be used. When a multicavity mold is used, the runner system should be balanced to ensure that all cavities finish filling simultaneously. This balance prevents any one cavity from being overpacked.

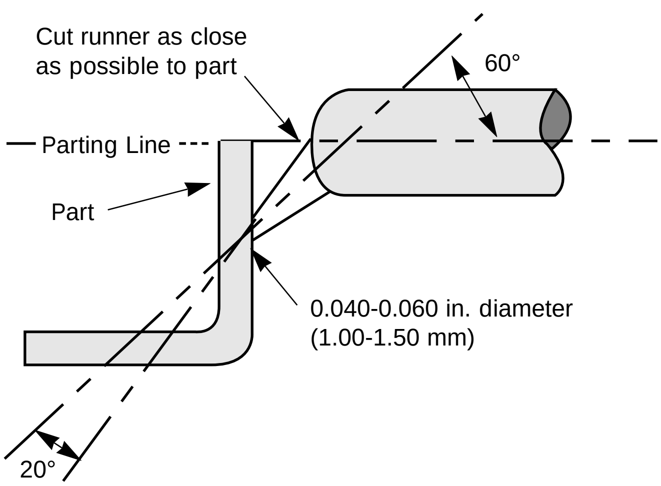

Figure 3.3 Specifications for a submarine gate

Vents

Vents should be located in all sections of the mold cavity where air may become trapped by the molten Fortron® PPS, particularly in the last areas to fill. The tendency of PPS to flash dictates that shallow vents, ca. 0.0005 in. deep by 0.25 in. wide (0.012 mm by 6.350 mm), be used. In areas where flash is not a concern, vents as deep as 0.001 in. (0.025 mm) may be employed. Inadequate venting traps gas, causing incomplete filling of the part, burn marks, mold deposit, corrosion, and/or poor weld line strength. The vent land length should be about 1/16 in. (1.588 mm) and then widened to the edge of the tool.

Mold Heating

When molding Fortron® PPS, oil circulating heaters or electric cartridge heaters should be used to allow the mold temperature to reach the recommended range of 275-325°F (135-165°C). The oil channels, and cartridge heaters should be placed about one channel/heater diameter from the surface of the mold cavity and 3-5 diameters apart. Enough channels/ heaters should be used to ensure that the mold cavity reaches a uniform temperature. Insulation for the mold can also be used to reduced heat loss and energy requirements.

Hot Runner Systems

Because the costs of labor and materials have continued to increase, efforts to lower the costs of processing and to produce higher quality moldings at lower costs have also increased. These efforts have sparked new interest in automation, including the use of runnerless molds. The increased interest in runnerless molds has produced a rapid expansion in this technology and a proliferation of commercially available runnerless molds.

The objective of a hot runner system is to reduce material and labor costs and to increase productivity by accelerating molding cycles and by reducing scrap.

The parts of a hot runner system are shown in Figure 3.4.

Runnerless components/systems are commercially available from suppliers such as D-M-E Co., Ewikon, Husky, Incoe Corp., Kona, Mold Masters Ltd., and Spear Systems.

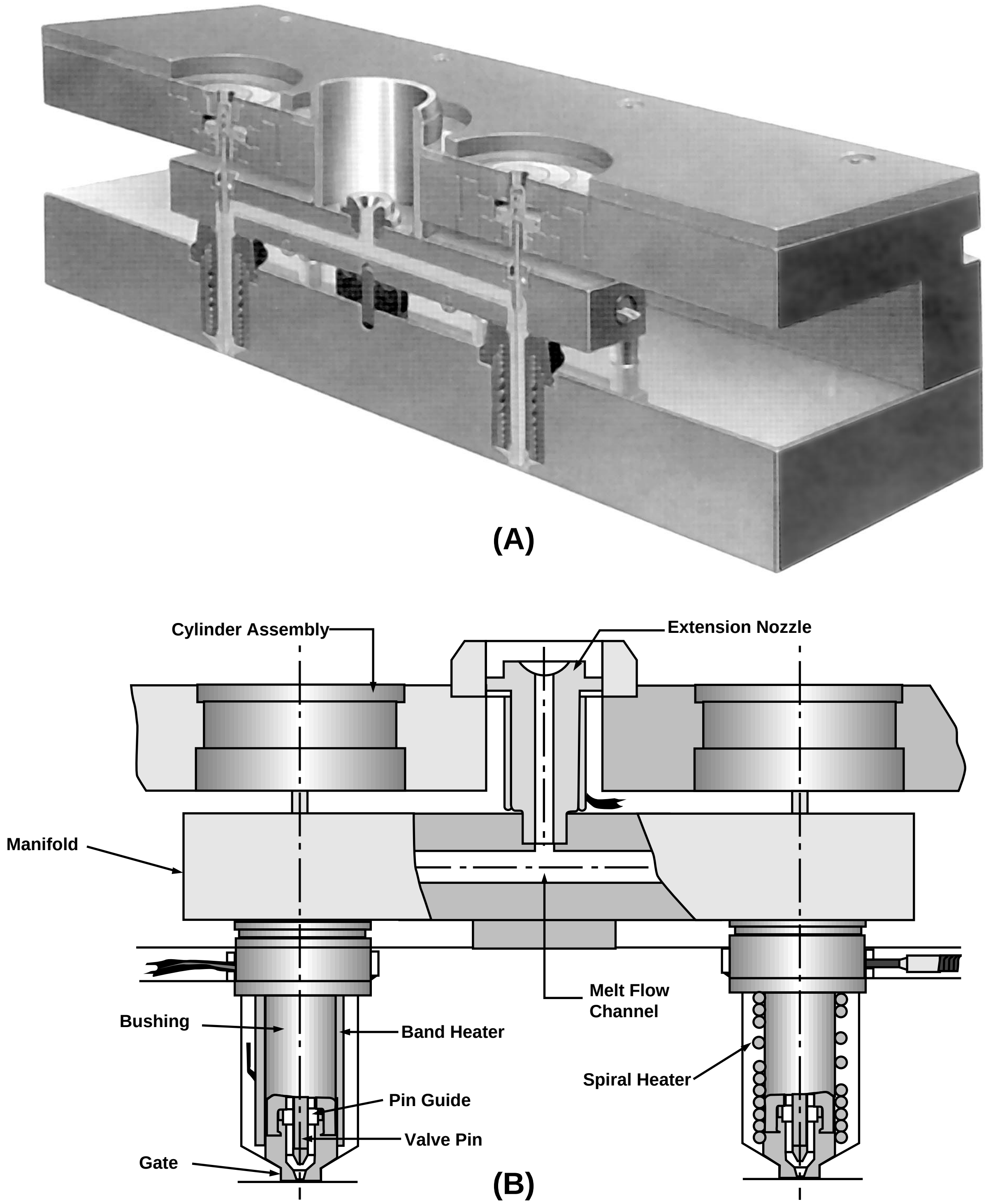

Figure 3.4 Drawing (A) and labeled schematic (B) of a hot runner system

To successfully use Fortron® PPS in a hot runner system, the components making up that system must be properly selected and optimized. These components include the manifolds, bushings or probes, gate types, and controllers. Before a runner system can be designed, the manufacturer/supplier of the runner system must know whether the material is to be neat or filled, the shear rate of the material, the flow length of the material, the wall thickness and weight of the part, and other characteristics of the plastic. This section gives some general guidelines for using Fortron® PPS in a hot runner system. It is imperative that the manufacturer of the system be involved at the concept stage of mold design for success. Most suppliers provide guidelines for such work, while others provide complete design services.

Design Recommendations

Following are recommendations for designing a runnerless mold for use with Fortron® PPS:

- Valve gates are recommended to reduce drool.
- It is important to design a system that can be opened easily for cleaning or maintenance.
- Before designing the mold, inform the mold maker whether the material has a filler. This allows the mold maker to specify the correct tool steel and hardness of steel. For molding Fortron® PPS, A2, or other similar steels are recommended to lessen the effects of wear.
- Because Fortron® PPS has such excellent flowability, it will flow into any dead spots or crevices in the runner system, and eventually degrade there. Take care to design smooth surfaces. Dead spots are also detrimental when processing colors. Smooth surfaces and the absence of dead spots also improve efficient purging.
- Externally heated runner systems are recommended.
- Regarding temperature, the manifold and drops should be viewed as an extension of the barrel. Temperatures should be the same as that of the melt in the barrel—the manifold temperature should neither heat nor cool the plastic.

Temperature control is most important. Typical variations in the melt temperature of Fortron® PPS do not adversely affect the mechanical properties, nor does the material exhibit burning. However, temperature must still be controlled because temperature and fluctuations in temperature may affect the viscosity or filling of Fortron® PPS in the mold. The viscosity of the material slightly decreases with higher temperatures for prolonged periods (up to 15 min).

Variations in temperature can be also caused by variations in the power to the unit. Such variations can be caused by the starting and stopping of motors or other high-current devices, peak loads of communities (particularly on the hot days of summer), etc. A closed-loop temperature control can effectively manage such variations, and is highly recommended.

Finally, the safety aspects of controlling the temperature should not be overlooked. The melt processing temperature for Fortron® PPS should never exceed 698°F (370°C).

Compound Storage

During storage of engineering plastics, it is important to keep all materials as warm and as dry as possible. Cold temperatures bring the danger of moisture condensation on the surface of the compound, while summer poses the problem of surface moisture adsorption due to high humidity. Moisture from all sources must be eliminated by drying.

Use of Regrind

For cost effectiveness, dried regrind resin may be used. However, no more than a 25% concentration is recommended at this time. Too high a percentage of regrind may result in reduced mechanical properties, particularly in glass-reinforced grades because the length of the glass fibers is reduced. Regrind should be as free of dust as possible. It is important that runners, sprues, and rejects be ground and mixed well with virgin pellets. After mixing, the mixture of regrind and virgin pellets should be treated with the same care as virgin pellets, including keeping the mixture free of contamination and moisture just as meticulously as with virgin resin. Table 2 below shows the excellent mechanical property retention for two Fortron® grades after multiple (5) molding cycles using 100 % regrind.

Table 2. Property Retention after Five Molding Cycles

Property	ASTM Method	Initial Value	40% Glass-Reinforced after 5th Molding	65% Mineral/ Glass-Reinforced after 5th Molding
Tensile Strength	D638	100%	81%	79%
Elongation	D638	100%	82%	83%
Flexural Strength	D790	100%	88%	82%
Flexural Modulus	D790	100%	84%	95%

Drying Considerations

Fortron® PPS is not hygroscopic, yet it is important to use dry resin in molding parts. High moisture levels can create voids, which could adversely impact part performance or affect aesthetics.

Drying Equipment

Fortron® PPS should be dried in dehumidifying hopper dryers, such as the one shown in Figure 3.5. It should be noted that hot-air ovens are not recommended, although they may be used if extreme care is taken. The reasons such ovens are not recommended are: a) if the trays are filled too high (more than 1-1.5 in.), the material on the bottom of the tray is not properly dried; b) if several different kinds of materials are being dried in the oven (on different trays) at the same time, pellets can easily fall onto a lower tray, causing contamination of the material on the lower tray.

Drying Process

In Figure 3.5, a vacuum loader (1) drops resin into the insulated drying hopper on demand. Heated, dehumidified air enters the drying hopper (2), penetrating the resin and carrying moisture vapor up to the return line outlet. The moisture-laden air passes through a filter (3) to remove very small particles before the air reenters the desiccant cartridge. This filter must be kept clean! Dirty, plugged filters restrict air flow and reduce drying efficiency. The process air blower (4) forces moisture-laden air through onstream desiccant cartridges (5), where moisture is trapped. The dehumidified air is then reheated (6) and delivered back to the drying hopper. While the desiccant cartridge is on stream, removing moisture, another cartridge is being regenerated. Separate regeneration blowers (7) and heaters (8) are used for that purpose.

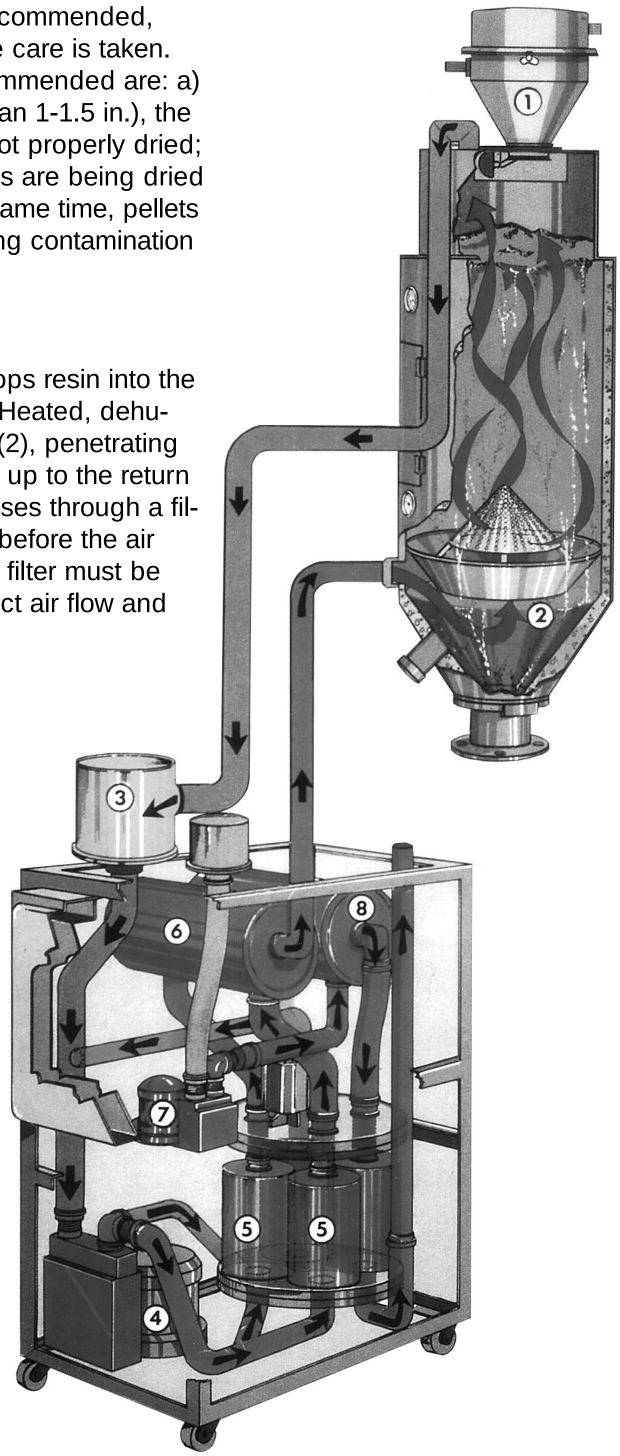

Figure 3.5 Hopper dryer unit (Reprinted with permission of Novatec™, Inc., Baltimore, MD)

Chapter 4

Processing Parameters

Careful control of processing plays a crucial role in producing high-quality plastic parts. It is advantageous for all concerned to be fully aware of the optimum processing parameters, since only in this way can one achieve the full capabilities of Fortron® PPS resin.

Injection Molding

Fortron® PPS injection-molded parts exhibit a desirable combination of high-temperature mechanical properties, low creep, superior chemical resistance, and excellent electrical properties. All grades can be processed easily.

Recommended Drying Conditions

Although Fortron® PPS resins do not absorb a high percentage of atmospheric moisture, exposure to ambient air should be kept to a minimum. Both virgin and regrind Fortron® PPS resin of all grades should be dried for 3-4 hours at 275°F (135°C) for filled grades and 3 hours at 250°F (121°C) for unfilled grades with the dryer dew point setting of about -20°C.

Injection Molding Conditions

Startup Conditions

Table 3 shows the recommended molding conditions for Fortron® PPS resin. The operator should allow the machine to stabilize for half an hour at the recommended zone temperatures before rotating the screw. Upon startup, the molding machine should be purged with high-density polyethylene or polypropylene at the temperatures recommended for molding Fortron® PPS. Once the machine has been purged, Fortron® PPS may be fed into the machine and purged until only Fortron® PPS is present in the barrel. The melt temperature should then be checked with a pyrometer to ensure that the melt is within the recommended temperature range.

The most critical practice in molding Fortron® PPS resin is the use of a hot mold, i.e., a minimum mold temperature of 275°F (135°C). This temperature is required to allow full crystallization of the resin and to achieve the necessary resistance to heat distortion of the part being molded (see Figure 4.1).

Shutdown Conditions

When a machine is being shut down from molding Fortron® PPS resin, the nozzle and barrel heaters should be maintained at the molding temperature. The machine should be first purged with high-density polyethylene or polypropylene. When the barrel is completely purged of Fortron® PPS resin and is filled with polypropylene or high-density polyethylene, the machine may be shut down. Leave the ram in the forward position when the machine is shut down.

Table 3. Injection Molding Conditions for Fortron® PPS

Molding Parameters	Molding Values
Cylinder Temperatures	°F (°C)
Feed Zone	585-635 (307-335)
Intermediate Zone	590-640 (310-338)
Front Zone	600-640 (315-338)
Nozzle Temperature	600-640 (315-338)
Melt Temperature*	590-640 (310-338)
Mold Temperature	275-325 (135-163)
Injection Pressure, psi (MPa)	5,000-15,000 (34-104)
Injection Speed	Medium to Fast
Back Pressure, psi	None
Screw Speed, rpm	40-100
Cushion, in. (mm)	1/8-1/4 (3-6)

***Safety Note! Under no circumstances should the melt temperature rise above 698°F (370°C); otherwise polymer decomposition may result with the production of gases which may be irritating to the eyes and respiratory tract. See Fortron® PPS MSDS for further information.**

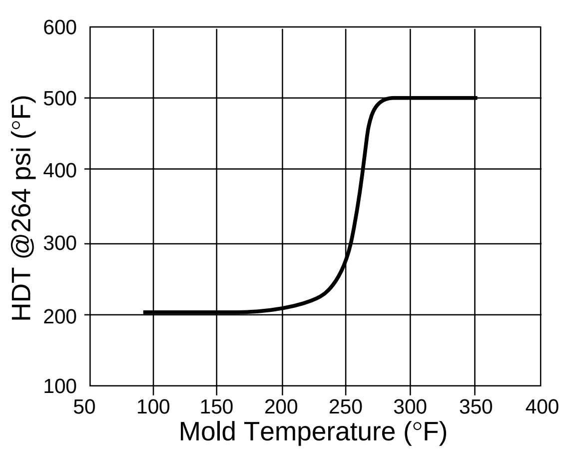

Figure 4.1 Effect of mold temperature on heat deflection temperature.

Extrusion Parameters

Fortron® PPS has been successfully extruded into various shapes and sizes including:

- Monofilament
- Rods
- Slabs
- Tubing

Extrusion Guidelines

The following guidelines are for establishing conditions for extruding Fortron® PPS. Careful control of temperatures and proper screw design is necessary for optimum productivity.

Table 4. Extrusion Conditions for Fortron® PPS

Extrusion Parameters	Unfilled	Filled
Feed Zone	545-555°F (285-290°C)	555-575°F 290-300°C)
Transition Zone	555-565°F (290-295°C)	555-590°F (290-310°C)
Metering Zone	555-575°F (290-300°C)	570-610°F (300-320°C)
Adapter	570-590°F (300-310°C)	570-610°F (300-320°C)
Die	570-590°F (300-310°C)	570-610°F (300-320°C)
Melt Temperature *	560-620°F (293-327°C)	570-610°F (304-338°C)
Typical Draw-down	2:1	2:1

***Safety Note! Do not exceed 698°F (370°C) melt temperature; otherwise polymer decomposition may result with the production of gases which may be irritating to the eyes and respiratory tract. See Fortron® PPS MSDS.**

Screw Design

For the best results a metering-type screw with a uniform “square” pitch should be used. The compression ratio (depth of feed zone/depth of metering zone) should be from 3:1 to 4:1. Screws in this range of ratios will provide the best combination of high output and low melt temperature and pressure variations. The screw L/D ratio may range from 16:1 to 24:1. As with injection molding, the zone distribution should be equal: 1/3 metering zone, 1/3 transition zone, and 1/3 feed zone. Table 5 shows the proper flight depths for several typical sizes of extruders.

Table 5. Typical extruder screw dimensions

Extruder Size inches (mm)	Metering Depth inches (mm)	Feed Depth inches (mm)
1.5 (35)	0.08 (2.03)	0.24 (6.1)
2.5 (60)	0.09 (2.29)	0.27 (6.9)
3.5 (90)	0.10 (2.54)	0.30 (7.6)

Drying Resin for Extrusion

A dehumidifying air circulating hopper dryer is recommended for extrusion of Fortron® PPS. Although Fortron® PPS is not a hygroscopic material, drying is recommended to remove moisture that may adsorb on the surface of the pellets. Such moisture adsorption may cause fill consistency problems or microscopic gas voids in the finished product.

Drying Conditions:

Filled Materials: 270°F (132°C) for 4 hours.
Unfilled Materials: 250°F (121°C) for 3 hours.
Dew Point Setting: -4°F (-20°C)

Safety and Health Information

The usual precautions employed in working with high-temperature plastic resins should be observed in working with Fortron® PPS resins.

Use process controls, work practices, and protective measures described in the MSDS to control workplace exposure.

Material Safety Data Sheets and product literature have been developed by Ticona, to provide customers with valuable safety, health, and environmental information. A copy of the MSDS for each specific Fortron® PPS resin grade is available on request. Please contact your local sales office or the Technical Information phone numbers given at the end of this publication.

Chapter 5

Troubleshooting Guide

Overview of Troubleshooting

Many processing problems are caused by easily corrected conditions, such as inadequate drying, incorrect temperatures and/or pressures, etc. Often solutions can be found by following the recommendations given below. Try them in the order in which they are listed under each problem category.

Burn Marks

Recommendations:

- Check for adequate ventilation.
- Decrease the injection speed
- Decrease the booster time.
- Alter the position of the gate.
- Increase the gate size.

Discoloration

Discoloration in Fortron® PPS may be caused by excessive temperatures. It is more of a surface phenomenon and is not necessarily indicative of degradation.

Recommendations:

- Purge the heating cylinder.
- Reduce the material temperature by:
  - Lowering the cylinder temperature settings.
  - Decreasing the screw rotational speed.
  - Lowering the back pressure.
- Lower the nozzle temperature.
- Shorten the overall cycle time.
- Check the hopper and feed zone for contamination.
- Check the ram and feed zone for proper cooling.
- Move the mold to a press with a smaller shot size.
- Provide additional vents in the mold.

Dull Surface Appearance

This is generally caused by too cold a mold (less than 275°F).

Recommendations:

- Increase the mold temperature.
- Increase the injection speed.
- Increase the packing/hold pressure.

Flash Reduction

Recommendations:

- Check to see that the mold is closing properly.
- Check for material caught on the parting surface.
- Reduce the material temperature by:
  - Lowering cylinder temperature settings.
  - Decreasing screw rotational speed.
  - Lowering back pressure.
- Decrease injection pressure/speed.
- Decrease injection hold time/booster time.
- Check parting line of mold for wear.
- Move the mold to a larger (clamp) press if injection pressure is too high.
- Reduce pressure by using lower viscosity grade of resin.
- Refinish mold surfaces.

Nozzle Problems

Nozzle Drool

Recommendations:

- Lower the nozzle temperature.
- Increase the decompression time.
- Lower the material temperature by:
  - Lowering the cylinder temperature settings.
  - Decreasing the screw rotational speed.
  - Lowering the back pressure.
- Reduce the back pressure.
- Decrease the mold open time.
- Dry the material.
- Use a nozzle with a smaller orifice.
- Use a nozzle with a reverse taper.
- Use a nozzle with a positive shutoff.

Nozzle Freeze-off

Recommendations:

- Increase the nozzle temperature.
- Decrease the cycle time.
- Increase the mold temperature.
- Use a nozzle with a larger orifice.
- Insulate nozzle from mold if using a cold mold (ca. 180 °F).

Poor Dimensional Control

Recommendations:
- Maintain a uniform feed/cushion from cycle to cycle.
- Fill the mold as rapidly as possible.
- Increase the gate size.
- Balance the layout of the runners, gates, and cavity.
- Use closed-loop controllers.
- Add vents.
- Check the machine's hydraulic and electrical systems for erratic performance.
- Reduce the number of cavities in the mold.

Short Shots, Pit Marks, and Surface Ripples

These problems indicate that the part is not being packed out or that there is leaking through the check ring.

Recommendations:
- Check the hopper to see that the resin supply is adequate. If not, add resin.
- Check to ensure that a proper cushion exists and increase/decrease feed if necessary.
- Increase the injection pressure.
- Increase the injection speed.
- Increase the booster time.
- Increase the melt temperature by:
  - Raising the cylinder temperature(s).
  - Increasing the screw speed (with unfilled grades only).
- Raise the mold temperature.
- Check the cavity vents for blockage (trapped gas prevents the part from being filled).
- Increase the size of the sprue/runners/gates.

Sinks and Voids

Recommendations:
- Increase the injection pressure.
- Increase the hold time.
- Use a booster and maximum injection speed.
- Raise the mold temperature (do this only with voids).
- Lower the mold temperature (do this only with sinks).
- Decrease the cushion/pad (should be 1/8-1/4 in.).
- Increase the size of the sprue/runners/gates.
- Relocate the gate(s) into a heavier cross section(s).
- Use a higher flow grade of resin.

Sticking Problems

Sticking in the Cavity

Recommendations:
- Check the mold temperature for overheating.
- Decrease the injection/hold temperature.
- Decrease the injection speed.
- Decrease the booster time.
- Decrease the injection hold time.
- Increase the mold close time.
- Lower the mold temperature.
- Decrease the cylinder and nozzle temperature.
- Check the mold for undercuts and/or insufficient draft.

Sticking Problems (Continued)

Sticking on the Core

Recommendations:
- Increase the injection pressure.
- Increase the booster time.
- Increase the injection speed.
- Decrease the mold close time.
- Decrease the core temperature.
- Check the mold for undercuts and/or insufficient draft.

Sticking in the Sprue Bushing

Recommendations:
- Check the sizes and alignment of the holes in the nozzle/sprue bushing.
- Decrease the injection pressure.
- Decrease the injection hold time.
- Increase the mold close time.
- Increase the nozzle temperature.
- Provide a more effective sprue puller.

Unmelted Pellets

Recommendations:
- Increase the melt temperature.
- Increase the back pressure.
- Dry/preheat the resin.
- Use the proper screw design (see Chapter 3, Screw Design subsection, for guidelines).
- Ensure that check valve is working properly to prevent back flow. (Does machine hold cushion?)
- Move the mold to a press with a larger shot capacity.

Warpage and Part Distortion

Recommendations:
- Equalize the temperature in both halves of the mold (eliminate hot spots).
- Observe the mold for uniformity (or lack thereof) of part ejection.
- Check for proper handling of parts after ejection.
- Increase the injection hold time.
- Increase or decrease the pressure as appropriate.
- Check for contamination.
- Reduce the mold temperature.
- Increase the mold close time.
- Lower the material temperature by:
  - Lowering the cylinder temperature settings.
  - Decreasing screw rotational speed.
  - Lowering the back pressure.
- Try differential mold temperatures to counter act warp.
- Fixture the part and cool uniformly.

Weld Line Integrity

Recommendations:
- Increase the injection pressure.
- Increase the injection hold time.
- Increase the injection speed.
- Increase the mold temperature.
- Increase the material temperature by:
  - Raising the cylinder temperature settings.
  - Increasing the screw rotational speed.
  - Increasing the back pressure.
- Vent the cavity in the weld area.
- Provide an overflow well adjacent to the weld area.
- Change the gate location to improve the flow pattern.

Troubleshooting Guide for Runnerless Molds

If you are using a runnerless mold system, then the following guidelines are suggested to solve problems that can typically occur with such systems. Consult the manufacturer of the hot runner system for further information.

Gate Freezes Off

Recommendations:

- Raise temperature of gate bushing.
- Raise temperature of hot runner manifold.
- Raise temperature of hot runner drop.
- Check all heater circuits to ensure that all heaters are functioning.
- Put heater band on machine if none is present.
- Decrease cycle time.
- Raise temperature of mold cavity detail.
- Check clearance of gate to mold to ensure no heat loss.
- Disassemble mold and check for obstruction in gate or a restriction in the runner.
- Change gate type to an edge gate.
- Inject into a short secondary cold runner.

Some Gates Freeze Off While Others Remain Open (in Multicavity Mold)

Recommendations:

- Raise temperature of gate bushings at frozen gate only.
- Try above solutions for “Gate Freezes Off”.

Drooling at Gate

Recommendations:

- Ensure that suck back control is operating.
- Reduce temperature of gate bushing.
- Reduce temperature of hot runner manifold.
- Reduce temperature of hot runner drop.
- Increase cycle time.
- Decrease mold open time.
- Reduce temperature of mold cavity detail containing the gate.
- Alter the mold to reduce the gate size or to increase the gate land length.

Bubbles in Molded Part

Recommendations:

- Ensure that the material is dry.
- Increase injection pressure.
- Increase temperature of hot runner manifold.
- Increase the probe temperature.
- Disassemble the mold and check for jammed spring mechanism (for spring-loaded probe type) or jammed piston (air cylinder operated probe).

Positive Shutoff Gate Does Not Close

Recommendations:

- Decrease second stage injection pressure.
- Increase temperature of hot runner manifold.
- Increase probe temperature.
- Disassemble the mold and check for obstruction at gate or jammed spring or piston.

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