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# Ryton® PPS

## Processing Guide

SPECIALTY
POLYMERS

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# Introduction

## Ryton® Polyphenylene Sulfide (PPS)

The information presented in this processing manual is intended to assist designers and customers in the use of Ryton® PPS engineering thermoplastics. The processing requirements discussed are topically organized to enable the reader to apply Ryton® PPS to his specific needs and equipment.

It is impossible to review all of the processing difficulties that might arise, or the procedures to correct these problems, in one manual. Instead, a practical and expedient approach to the processing requirements for successful use of Ryton® PPS compounds is offered here.

# Processing Requirements

Unlike many other high-performance plastics, Ryton® PPS compounds are remarkably easy to process. Marketing surveys indicate that the processibility of Ryton® PPS is one of its principal benefits to users. The molder has a wide “window” of molding parameters that yields dimensionally accurate and reproducible parts. Furthermore, Ryton® PPS performance is much less sensitive to molding parameters than competitive engineering thermoplastics. In general, Ryton® PPS compounds are easily processed on conventional reciprocating screw injection molding machines using molding practices standard for filled engineering thermoplastics. The following guidelines have proven successful for optimal processing.

## Drying

All Ryton® PPS compounds are more readily processed if dried thoroughly before molding. The resin itself is essentially not hygroscopic, but some mineral fillers may be, so drying is particularly important for mineral filled compounds. The following procedures have proven effective.

### Forced Draft Oven

The Ryton® PPS molding compound should be placed in trays no deeper than 50 mm (2 inches) and dried at 135–163 °C (275–325 °F) for 2 to 3 hours. Longer drying times are not harmful, but temperatures above 260 °C (500 °F) can reduce melt flow values over a period of time.

### Dehumidifying Dryer

The size of the dryer should allow for drying times of 2 hours with 149 °C (300 °F) inlet air temperature having a –40 °C (–40°F) dew point.

NOTE: Simple convection ovens are not recommended, because no escape for moisture-laden air from the oven cavity is normally provided.

## Stock Temperature & Barrel Profile

Due to their inherent thermal stability, Ryton® PPS compounds can be processed at stock temperatures ranging from 304–343 °C (580–650 °F). Over that range, spiral flow increases more than 30 %. This ability to control flow can help packing and therefore improve physical properties.

For most parts, the optimal stock temperature is between 315–343 °C (600–620 °F). This range ensures good flow and fluxing of glass and mineral fillers which will minimize screw, check ring, and barrel wear. In some cases, however, temperatures outside this range can be beneficial. For example, stock temperature from 304–327 °C (580–620 °F) can help minimize drool or prevent solder wash while encapsulating certain electronic devices. On the other hand, temperatures up to 343 °C (650 °F) can help fill complex or thin-walled parts. Typical temperature ranges are shown below.

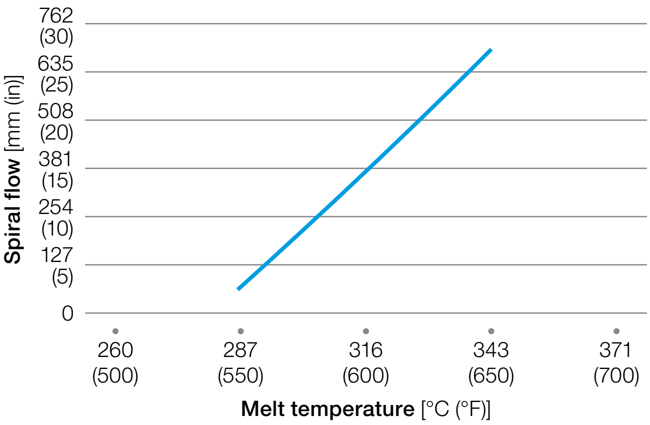
### Stock temperatures

| <304 °C (<580 °F) | **304–343 °C (580–650 °F)** | >343 °C (>650 °F) |
|---|---|---|
| **Don’t use** | **Preferred** | **Use caution** |

As melt temperature is varied within the specified range, some minor changes occur in the physical properties. These properties vary due to changes in crystallinity, glass fiber orientation, and melt viscosity. Tensile strength increases slightly with increasing stock temperature. Izod impact strength, flexural strength, flexural modulus and heat distortion temperature exhibit insignificant changes with varied melt temperatures.

Figure 1 shows the effect of melt temperature on spiral flow of Ryton® R-4-200NA. Appendix A lists typical temperature ranges for all zones of the barrel and nozzle for different Ryton® PPS compounds.

**Figure 1:** Effect of melt temperature on spiral flow of Ryton® R-4-200NA



## Injection Pressure

First stage or injection fill pressure should be set 200 to 400 psig higher than the peak pressure obtained at the end of part fill and transfer to pack pressure. This will allow the injection rate to be the controlling parameter during part fill and should help minimize any part variation because of material lot-to-lot differences. To ensure proper packing, the second stage pressure (Pack or Hold Pressure) should be the maximum possible. This is especially true since the amount of molten plastic packed into the cavity can affect the physical characteristics of the material. Substantially under-packed parts may exhibit poor mechanical strength.

The pack pressure used when molding Ryton® PPS compounds will determine the degree of molecular packing obtained, and therefore the uniformity of polymer distribution. Well-packed parts molded with higher pack pressures have consistent part weight and surface finish, with fewer voids, less warp and lower shrinkage. For these reasons, the maximum pack pressure should be used.

## Injection Rate

Part size, wall thickness and gate size all play a large role in determining the proper injection rate. Typically the injection rate should be medium to fast or the maximum possible without trapping gas and/or causing molded-in stresses. Varying the injection rate will affect appearance properties such as surface gloss. Typically, the best overall part appearance is obtained with fast injection rates. A faster injection rate results in a more polymer rich surface layer. Also, faster rates help avoid premature cooling of the melt front, which will cause irregular surface replication and poor weld line strength.

For thick-walled parts, slow injection rates result in more uniform polymer distribution. This will produce parts with a low level of molded-in stress, and thus reduced part warp. Slower rates can also reduce burning in poorly vented areas. However, a poor surface finish may occur.

In any case, it is essential that the combination of pressure and rate yield a fully packed part. Proper part packing may be evaluated by monitoring part weight and obtaining densities close to the data sheet values.

## Mold Temperature Effects

The following paragraphs discuss the effects of different mold temperatures on physical properties directly related to crystallinity. This will aid in determining the mold temperature for specific end use parts.

### Crystallinity

Ryton® PPS can be molded in either an amorphous or a semi-crystalline state. Ryton® PPS will crystallize at temperatures above its glass transition temperature of 88 °C (190 °F). Mold temperature largely determines the crystallinity of Ryton® PPS parts, and thus affects the part's final physical properties and appearance.

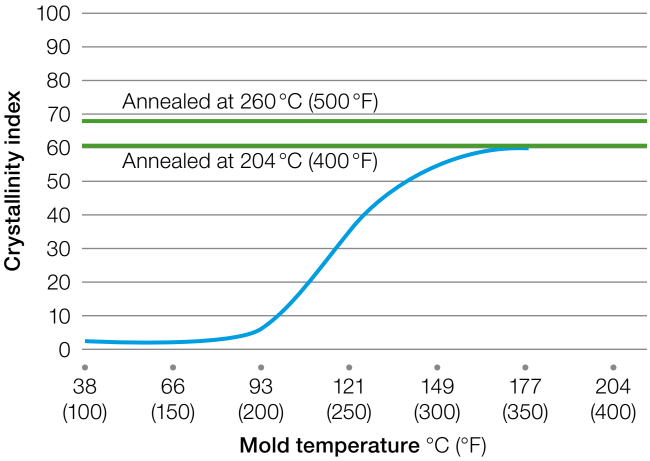
When Ryton® PPS compounds are molded in a cold mold below 88 °C (190 °F), the polymer is quenched below its glass transition temperature so quickly that the polymer matrix is frozen in the orientation of the injected plastic. These "cold molded" parts have very low crystallinity and are generally considered amorphous.

Mold temperatures from 135–149 °C (275–300 °F) will produce parts that are highly crystalline and, as illustrated in Figure 3, do not increase cycle time substantially. Ryton® PPS crystallizes so rapidly that a hot mold will produce dimensionally stable parts able to resist dimensional changes even at elevated temperatures.

NOTE: The crystallinity increases very rapidly between the cold and hot molding conditions. Therefore, the 88–127 °C (190–260 °F) range yields unpredictable crystallinity and should be avoided.

As illustrated in Figure 2, parts shot in molds below 88 °C (190 °F) develop little crystallinity  while parts from molds at 149 °C (300 °F) develop a crystallinity index of over 50. However, the interior of thick sections may retain sufficient heat to develop most of the crystallinity when shot in a 88 °C (190 °F) mold. Thin sections cool more rapidly, so mold temperatures of 135–149 °C (275–300 °F) may be required for substantial crystallization. Continued crystallization becomes progressively slower as it approaches the ultimate degree of crystallinity.

**Figure 2:** Effect of mold temperature on crystallinity



In some situations, the shortest possible cycle time may be desirable, or the use of a hot mold may prove impractical. Cold molded parts can be made crystalline by post mold annealing at temperatures above the glass transition temperature. Since the rate of crystallization depends on temperature, the time required to reach maximum crystallinity depends on the temperature to which the parts are exposed. Crystallization will begin to occur as the annealing temperature reaches the glass transition temperature of 88 °C (190 °F). The rate of crystallization will increase as the temperature increases from that point.

When annealing typical injection molded parts, experience shows ultimate crystallinity is reached in 1–2 hours at 204–232 °C (400–450 °F). It will typically require 4–6 hours at an annealing temperature of 121 °C (250 °F).

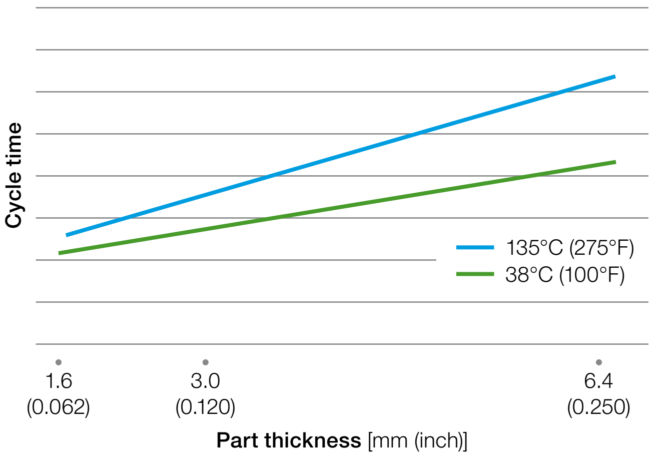
NOTE: Annealing may cause some dimensional changes (shrinkage and potential warping) as well as some differences in surface appearance due to the smaller crystalline structure.

To summarize, the most convenient way to obtain parts with high crystallinity is to mold them in a hot mold. These parts will be dimensionally stable at elevated temperatures, and require a cycle time only marginally longer than those obtained with a cold mold. Cold molded parts are considered amorphous and have somewhat better mechanical properties, but are not as dimensionally stable at temperatures above the glass transition temperature.

## Cycle Time

Figure 3 illustrates the effect of mold temperature and part thickness on cycle time for a typical glass filled Ryton® PPS compound. Cycle times will be at least 10–30 % less with glass and mineral filled compounds.

**Figure 3:** Effect of mold temperature on cycle time of Ryton® PPS



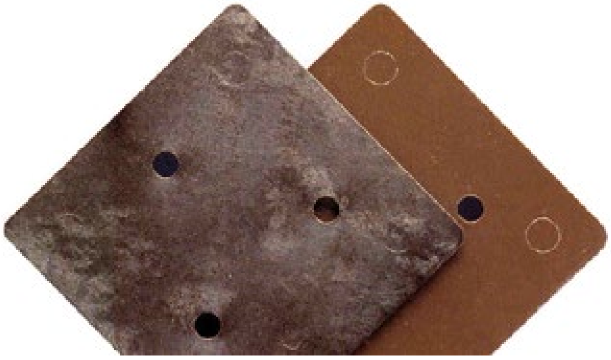
## Polymer Flow

In addition to its effect on polymer crystallinity, the mold temperature can affect the flow of Ryton® PPS in the mold. With all other conditions equal, the spiral flow of Ryton® PPS increases about 10 % as mold temperature increases from 79–135 °C (175–275 °F).

## Surface Appearance

Mold temperature has a dramatic effect on the surface appearance of a part. As shown in Figure 4, the sample molded in a hot mold duplicates the mold surface accurately and has a polymer rich surface. However, the cold molded surface is rough and mottled with variations in color. This is due to rapid freezing of the glass and polymer at the surface of the mold.

**Figure 4:** Cold mold vs. hot mold part appearance



| **Cold mold**<br>**38–88 °C (100–190 °F)** | **Hot mold**<br>**135–149 °C (275–300 °F)** |
|---|---|
| • Rough and mottled surface | • Duplicate mold surface |
| • Low level of crystallinity | • High level of crystallinity |
| • Less dimensional stability | • Increased dimensional stability |
| • Shorter cycle | • Longer cycle |
| • Less external heat on mold | • Molds must be heated and insulated |

## Mechanical Properties

Since Ryton® PPS's crystalline lattice structure restricts movement in the polymer matrix, molded parts can resist certain external forces and remain dimensionally stable. As the mold temperature is increased, more crystalline, stable, and rigid parts are produced, as indicated by an increase in flexural modulus and heat distortion temperature.

Parts molded in either hot molds or cold molds with subsequent annealing generally develop adequate crystallinity to resist distortion at temperatures up to 260 °C (500 °F). If the part is heat treated at 271 °C (520 °F) for 4 hours, heat distortion temperatures above 260 °C (500 °F) are possible. At these conditions, slight curing of the resin may occur in addition to crystallization. Parts may require annealing at a lower temperature prior to heat treatment to avoid blistering.

Amorphous parts are not as restricted by the crystalline lattice, so the matrix may align or orient itself somewhat to bear certain types of stresses. Though the crystalline matrix is very strong, it is not as strong as the polymer chain itself, so amorphous polymers exhibit slightly higher flexural and tensile strengths. This effect is most dramatic in response to sudden, concentrated stress, like impact. Impact strength is substantially higher in amorphous Ryton® PPS.

## Summary of Mold Temperature Effect

This is a basic summary of the effects of mold temperature on the properties of Ryton® PPS parts:

| **Cold mold**<br>below 88 °C (190 °F) | **Hot mold**<br>above 135 °C (275 °F) |
|---|---|
| Amorphous part | Crystalline part |
| Best physical properties | Best overall appearance |
| Less shrinkage (directly out of mold) | Best thermal and dimensional stability |
| Mottled/grainy surface appearance | |

## Start Up and Shut Down Procedures

After the mold and barrel are heated to the molding temperature, any previous polymer should be purged from the barrel with low melt index high density polyethylene (HDPE). The following conditions should be checked prior to injecting Ryton® PPS into the mold.

| | **Start Up/ Shut Down** | **Typical on Cycle** |
|---|---|---|
| Clamp tonnage | Maximum possible with mold | Maximum possible with mold |
| Melt temperature | 304 – 343 °C (580 – 650 °F) | 316 – 329 °C (600 – 625 °F) |
| Injection rate | Slow to medium | Medium to fast |
| Injection pressure, 1st stage | Medium | 200 – 400 psig > peak |
| Injection pressure, 2nd stage | Low or zero | High as possible |
| Injection time, 1st stage | 3 to 7 seconds | 0.5 to 2 seconds |
| Injection time, 2nd stage | 10 to 15 seconds | 5 to 12 seconds |
| Screw speed | Medium | Medium (typ. 100 rpm) |
| Back pressure | Less than 50 psig | 50 to 100 psig |
| Mold temperature | 135 – 149 °C (275 – 300 °F) | 135 – 149 °C (275 – 300 °F) |

Mold release is only needed until the machine is on cycle. Mold cavities should be coated with a high temperature mold release, particularly in ribs and bosses. High temperature fluorocarbons have proven to be effective.

Once these guidelines have been followed, short shots should be made to observe fill patterns and prevent potential flashing. After the first few short shots, injection pressure should be raised to ensure velocity control during injection. Adjust injection speed to obtain satisfactory fill time. Adjust shot size and cut-off transfer position to obtain a part that is 95 to 99 % full at transfer with the desired injection speed. Gradually add pack and hold pressure until the part is fully packed, leaving a cushion of 2.54 – 6.35 mm (0.1 – 0.25 inches).

Final adjustments to the stock temperature, injection rate, times, and pressures can then be made to minimize cycle time. Each variable should be adjusted independently, however, to allow for determination of that parameter's effect.

After molding with Ryton® PPS, the barrel should be purged with the same fractional melt index HDPE. Finally, the mold should be sprayed with a good rust-inhibitor type lubricant.

**CAUTION: Off-gas products produced during molding can be irritants to mucous membranes. Adequate ventilation of the molding shop area is strongly recommended when injection molding Ryton® PPS compounds.**

## Other Processing Considerations

### Regrind

With Ryton® PPS compounds, all runners, sprues, and reject parts can be reused with insignificant effect on properties. Flow rate change is minimal if regrind levels are kept below 30 – 35 %. Since Ryton® PPS compounds are inherently flame retardant, regrind is as flame resistant as virgin material.

Regrind levels up to 35 % can be utilized, with 25 % maximum for UL applications. However, tests have been run using 100 % regrind. After 7 passes through an injection molding machine, specimens retained 85 % of mechanical properties and nearly 100 % of their electrical properties. Table 1 shows the results of one such experiment with different Ryton® PPS compounds.

Like other glass reinforced and mineral filled materials, Ryton® PPS compounds should be granulated using carbide blades or blades made from wear resistant steel that is hardened. A low speed, screenless type granulator typically produces regrind with the best yield. If regrind is stored at ambient temperatures for extended periods, it should be dried before molding. (Processing Requirements – Drying).

**Table 1:** Effects of regrind on flow, mechanical and electrical properties

| | | Ryton® R-4-200NA | | Ryton® R-7-120NA | |
|---|---|---|---|---|---|
| **Property** | **Unit** | Virgin Compound | 100% Regrind | Virgin Compound | 100% Regrind |
| Tensile strength | ksi | 28 | 23 | 19 | 13 |
| Flexural strength | ksi | 39 | 36 | 32 | 20 |
| Insulation resistance | ohms | $6 \cdot 10^{10}$ | $1.6 \cdot 10^{11}$ | $5 \cdot 10^{10}$ | $1.6 \cdot 10^{11}$ |
| Spiral flow * | mm (inch) | 472 (18.6) | 508 (20.0) | 324 (12.75) | 333 (13.1) |

**Spiral flow thickness – 1.5 mm (0.06 inch), 335 °C (635 °F)*

## Purging

Before and after molding Ryton® PPS, the barrel should be purged thoroughly. To ensure effective cleaning, the barrel temperature should be the same as when processing Ryton® PPS. A fractional melt flow HDPE (e.g., a melt index of 0.5) is ideal for removing any previous polymer as well as for purging after molding with Ryton® PPS. Low melt flow HDPE is preferred because it can withstand typical Ryton® PPS barrel temperatures for a short period of time.

## Check Ring Function and Cushion

It is essential that the injection molding machine have a fully functional check ring, which is preferred to a ball check due to its long-term reliability. This ensures the machine's ability to maintain a cushion and fully pack the parts and not to allow any plastic to back up around the screw.

## Drool

Ryton® PPS is a highly crystalline polymer with a sharply defined melting point which results in a rapid transformation from a solid to a low viscosity melt. With certain compounds, the viscosity of the melt is low enough to discharge from the nozzle without injection pressure. This phenomenon is known as drool.

There are a number of ways to minimize or eliminate drool. The most common methods include drying the compounds, applying specialized processing techniques, and using special equipment such as positive shut-off and reverse taper nozzles.

### Drying

For Ryton® PPS compounds, surface moisture is typically an issue. If stored in a humid environment, the resins may pick up some surface moisture and require drying techniques. When heated in the barrel, the moisture vaporizes and the resulting steam pressure can force molten compound out of the nozzle. Many mineral fillers are hygroscopic and can absorb moisture from the atmosphere. Therefore, the mineral filled compounds are more susceptible to moisture driven drool. Ryton® PPS glass and mineral filled compounds should always be dried for 2–3 hours at 135–163 °C (275–325 °F). In some cases the glass-fiber-only reinforced compounds can be molded without drying, but the best practice is to dry all compounds.

### Processing

In many situations, thorough drying will eliminate drool completely. However, if drool persists after drying, certain processing conditions can be manipulated to control it effectively. First, the barrel temperatures should be kept as low as possible, but not below the 304 °C (580 °F) limit. Operating below this limit has the effect of reducing barrel and screw life as well as not allowing good fluxing of the mineral and/or glass prior to injection into the mold.

Second, melt decompression or "suck-back" can often help prevent drool. Most injection machines are equipped with this feature to pull the screw back in the barrel, thus decompressing the melt forward of the screw. The necessary amount of decompression must be determined by trial and error, as it will vary depending on the compound, shot size, barrel temperature, etc.

Nozzle temperature is often the key to controlling drool. Since abrasive wear is not a serious concern in the nozzle, its temperature can be reduced below the 204 °C (580 °F) limit. The nozzle tip contacts the mold and thus is the coolest point because it transfers heat to the mold itself. In most cases, the nozzle temperature can be cooled enough to prevent drool without freezing off the nozzle tip. This temperature also varies depending on the barrel temperature, nozzle size and type, mold temperature, etc., and must be determined by trial and error. A temperature between 293–310 °C (560–590 °F) usually proves successful.

Reverse taper nozzles like those used for processing nylon compounds work well for Ryton® PPS. In these nozzles the flow path narrows down to a small diameter for a distance of 6.35–25.4 mm (0.25–1.0 inches). In many cases, the narrowed flow path restricts flow enough to prevent drooling, especially when the nozzle temperature is reduced. These nozzles can be obtained from most suppliers of plastic processing equipment for about the same price as ordinary general purpose nozzles.

### Special equipment

See Equipment Requirements – Equipment to Manage Drool for a complete description of the most effective methods of preventing drool.

## Machines

Ryton® PPS compounds can be easily processed on conventional reciprocating screw injection molding equipment. Both sprue and parting line injection machines are widely used. Most parts require 2.5–4.0 tons of clamp force per square inch of the projected surface area of the part. A temperature controller on the nozzle is helpful when making adjustments to control drool.

Mold temperature is crucial in controlling crystallinity and thus the high temperature performance of Ryton® PPS. Mold heating equipment should be capable of maintaining mold temperatures at 135–149 °C (275–300 °F) by the use of electric cartridges, hot oil or high-pressure water. Each type is capable of achieving desired mold temperatures; however, the hot oil and high pressure water systems provide the added benefit of being able to add to, as well as remove heat from the mold. Appendix B lists manufacturers of all three types of temperature control equipment.

## Screw, Barrel and Mold

All highly-filled engineering plastics can cause wear on conventional injection molding screws, barrels and molds constructed of steel with insufficient hardness. Of the factors contributing to wear, fiberglass and mineral filler content are the most important. For example, fiberglass has a Mohs hardness of 5–7 compared to common tool steels with a hardness of 4. Certain processing parameters can be adjusted to minimize abrasion. Stock temperatures above 327 °C (620 °F) will help the molten polymer lubricate the fillers through the injection unit. Even so, special consideration should be given to the wear-resistance of screw, barrel, check ring and nozzle materials. A general recommendation is Xaloy® 802 or CPM 10V for the barrel liner and Stellite®, Colmonoy® 56 or CPM 9V flighted screws.

The mold itself is also affected by the abrasive nature of glass and particulate mineral fillers. The mold cavity and core finish play an important role in the tool longevity, and machining marks in these areas have been shown to accelerate wear. Therefore, a 0.0001 mm (4 microinch) or better finish is recommended for high-production cores and cavities. Gates should be hardened and replaceable, if possible, to obtain greatest mold longevity.

Many mold steels are able to resist the erosion caused by fillers. The choice of mold steel is dictated by economics, location within the mold and life expectancy required. Since new coatings and protective treatments are continually introduced, a single "best" choice has not been listed. More complete information on mold steels, coatings, and wear are included in the Ryton® PPS Design Guide.

After an extended time of processing, mold surfaces, especially vent areas can accumulate polymer residue on the surface of the mold. Commercially available spray-on mold cleaners typically work well enough to remove this residue. It has been found that Slide Products Inc., Slide Mold Cleaner Plus Degreaser III and Slide Resin Remover "Stripper" are good products for mold cleaning. Along with the cleaning products a plastic scouring pad may be useful to scrub the mold. In addition, a semi-chrome polish on the end of a cotton swab can get into difficult to reach areas.

A more modern and less labor intensive approach for mold cleaning is the utilization of ultrasonic cleaning baths. A mild detergent in the ultrasonic bath will typically provide a clean mold surface and can clean residue from difficult to reach areas. More details of ultrasonic cleaning of molds are available from commercial suppliers. After any mold cleaning and before mold storage, mold surfaces should be sprayed down with a good rust inhibiting lubricant or shield.

# Equipment Requirements

## Mold Plating

Mold plating is an excellent way to improve the service life of a mold made of insufficient quality steel. To ensure good plating, the most important variable is the condition of the substrate surface. The importance of a clean, highly-polished surface cannot be over-emphasized. A more complete description of mold plating is included in the Ryton® PPS Design Guide. The following are coatings proven to be effective for use with Ryton® PPS compounds.

- Electroless nickel plating
- Slow deposition chrome (dense chrome)
- Nye-carb plating

## Equipment for Managing Drool

If large quantities of Ryton® PPS compounds are to be processed, an investment in specific equipment can be worthwhile in preventing drool.

### Reverse Taper Nozzles

Many molders already have special nozzles for processing nylon compounds. In these reverse taper nozzles, the flow path narrows down to a small diameter for a distance of 6.35–25.4 mm. (0.25–1.0 inch). These have proven advantageous in processing Ryton® PPS compounds. In many cases, the narrowed flow path restricts flow enough to prevent drooling, especially when the nozzle temperature is reduced as previously described. These nozzles can be obtained from most suppliers of plastic processing equipment for about the same price as ordinary general purpose nozzles.

### Positive Action Shut-off Nozzles

To date, an externally actuated, positive action shut-off nozzle is the only “fail-safe” cure found for drool. There are many different types of shut-off nozzles available. These can be categorized into two basic types: spring loaded and externally actuated shut-off nozzles. Different types of spring loaded nozzles have been tested with moderate success. With this type of nozzle, spring pressure is maintained on the shut-off components at all times. When material is injected, the injection pressure forces the shut-off components open only far enough for material to pass through. High pressure is maintained on the components as the compound is forced through a very small opening at very high velocity. As a result, the abrasive action of the glass fiber and mineral fillers can wear the components very quickly if hardened materials are not used.

**Note: Shut-off nozzles incorporating an internal spring have limited utility. The springs lose their stiffness at the high stock temperatures used in processing Ryton® PPS (up to 343 °C (650 °F)).**

Externally actuated shut-off nozzles operate on an entirely different principle. An actuating mechanism, triggered by the machine cycle sequence, opens the nozzle upon injection. This allows material to flow freely through the nozzle into the mold. After the injection sequence, the mechanism reverses, positively shutting off the nozzle. The actuating mechanism can be a hydraulic cylinder properly tied to the machine’s hydraulic system, an electrical solenoid keyed off the electrical control system, or a pneumatic cylinder triggered electrically or mechanically.

Externally actuated shut-off nozzles are available from:

**Xaloy Inc.**
102 Xaloy Way
Pulaski, VA 24301
+1 540-994-2269
+1 800-773-1356 (toll free)
www.xaloy.com

**Northern Supply Co.**
1901 Oakcrest Ave.
St. Paul, MN 55113
+1 651-638-0888
+1 800-365-6565 (toll free)
www.northernsupply.com

### Vented Barrels

Some injection molding machine manufacturers offer vented barrels for their equipment. These are reported to provide advantages in processing Ryton® PPS compounds by preventing drool and eliminating the need to dry the compounds. The barrels have a vent port cut in the barrel, which permits gasses to escape from the barrel while the compound is first melted and plasticized. Vented barrels also require a special screw.

## Resin Drying Equipment

The Ryton® PPS resin itself absorbs very little atmospheric moisture. Some Ryton® PPS compounds, however, include mineral fillers which are hygroscopic and therefore should be dried. The compounds can be dried effectively using either forced draft ovens or dehumidifying dryers with plenum hoppers (see Processing Requirements – Drying). Appendix B lists a few of many auxiliary equipment manufacturers of drying equipment.

## Hot Runner Systems

Hot runner systems work on the principle of keeping the plastic material fluid up to the point of injection. The material flows from the nozzle through a hot manifold and bushings that keeps the material plasticized by typically using electric heating cartridges or heating bands. The manifold and bushings that extend from the manifold are thermostatically controlled. The two most popular types of systems that exist are:

- One with no moving parts which relies on the insulating properties of the plastic at the gate area to keep it from drooling, and
- A mechanical shut off type called "valve gate"

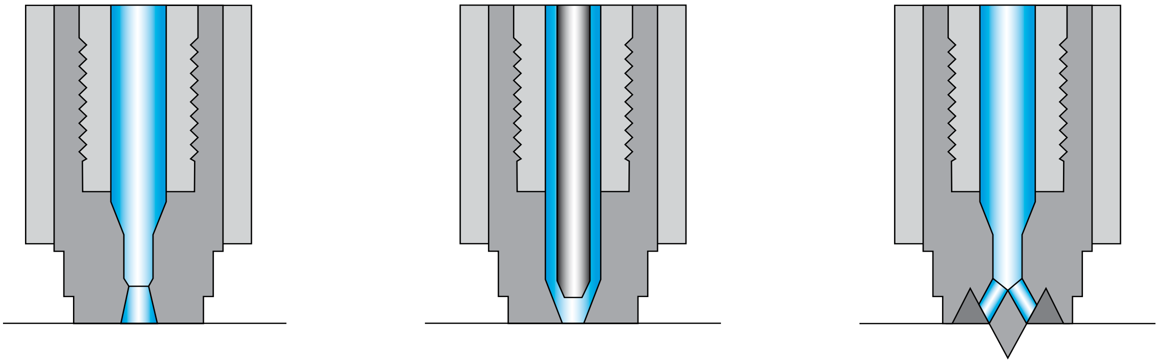
Figure 5 illustrates three generic types of hot runner gates.

A hot runner system is typically more difficult to start up and control than a conventional 2-plate or 3-plate mold when running Ryton® PPS. Extra time and effort is typically required due to balancing the temperature between several cavities to prevent freezing off or drooling.

Temperature control at the gate is very important when selecting a hot runner system for processing Ryton® PPS successfully. Utilizing a mechanical type hot runner system with a valve gate shut-off will reduce problems with drool and shorten start-up time.

Hot runner systems help lower costs by reducing material requirements and eliminating regrind. However, hot runner systems typically are more expensive to purchase and may require additional set-up and start-up time. For specific details about hot runner systems and processing we recommend calling the supplier directly.

**Figure 5:** Generic hot runner gating types



Through flow type

Valve gate type

Hot tip type

**NOT SUGGESTED FOR FILLED PPS**

# Appendix

## Appendix A – Ryton® PPS Compound Typical Processing Data

| | Unit | R-4-200NA, R-4-220NA | R-7-120NA, BR111 |
|---|---|---|---|
| **Machine Data** | | | |
| Shot size | % of capacity | 50 | 50 |
| Clamp | tonnage/in$^2$ | 2.5–4 | 2.5–4 |
| Screw type – L/D, comp. ratio | | 16–20:1, 2.5:1 | 16–20:1, 2.5:1 |
| Check valve type | | Ring, abrasion resistant | Ring, abrasion resistant |
| Nozzle type | | Shut-off or reverse taper | Shut-off or reverse taper |
| Special materials, screw | | Stellite® or Colmonoy® 56 Flights | Stellite® or Colmonoy® 56 Flights |
| Barrel | | Xaloy® 802 | Xaloy® 802 |
| **Temperature ranges** | | | |
| Nozzle | °C (°F) | 302–327 (580–620) | 302–332 (580–630) |
| Front | °C (°F) | 316–343 (600–650) | 316–343 (600–650) |
| Middle | °C (°F) | 302–327 (580–620) | 302–327 (580–620) |
| Rear | °C (°F) | 293–316 (560–600) | 293–316 (560–600) |
| Melt (typical/max) | °C (°F) | 327/343 (620/650) | 332/343 (630/650) |
| Mold (optimum) | °C (°F) | 135–149 (275–300) | 135–149 (275–300) |
| **Pressures setting** | | | |
| Injection, 1st stage | psi | 200–400 > peak pressure | 200–400 > peak pressure |
| Injection, 2nd stage | psi | Max. to achieve density | Max. to achieve density |
| Back | psi | 50–100 | 50–100 |
| Injection fill time (typical) | sec | 0.5–2.0 | 1.0–2.0 |
| Injection hold time (typical) | sec | 7–10 | 5–8 |
| **Screw settings** | | | |
| Cushion | mm (inch) | 2.54–6.35 (0.10–0.25) | 2.54–6.35 (0.10–0.25) |
| RPM | | 100 | 100 |
| **Mold Data** | | | |
| Special materials | | A-2, D-2 Steel, Rc 60+ | A-2, D-2 Steel, Rc 60+ |
| **Gates** | | | |
| Tunnel, diameter | mm (inch) | 1.0–2.5 (0.040–0.100) | 1.0–2.5 (0.045–0.120) |
| Pin, point diameter | mm (inch) | 1.0–2.5 (0.040–0.100) | 1.0–2.5 (0.045–0.120) |
| Edge, thickness | mm (inch) | 1.0–2.5 (0.040–0.100) | 1.0–2.5 (0.045–0.120) |
| Width | mm (inch) | 1.5–5.0 (0.060–0.200) | 1.5–5.0 (0.080–0.200) |
| Land | mm (inch) | 0.5–0.76 (0.020–0.030) | 0.5–0.76 (0.020–0.030) |
| **Vent** | | | |
| Thickness | mm (inch) | 0.008–0.013 (0.0003–0.0005) | 0.008–0.013 (0.0003–0.0005) |
| Land | mm (inch) | 1.52–2.29 (0.060–0.090) | 1.52–2.29 (0.060–0.090) |
| **Minimum runner diameter** | | | |
| L = 127 (5) | mm (inch) | 3.175 (0.125) | 4.775 (0.188) |
| L = 254 (10) | mm (inch) | 4.775 (0.188) | 6.350 (0.250) |
| L = 381 (15) | mm (inch) | 6.350 (0.250) | 7.950 (0.313) |
| Draft angle | Degree | 0.5–2 | 0.5–2 |
| Undercut maximum | % | 0 | 0 |

|  | Unit | R-4-200NA, R-4-220NA | R-7-120NA, BR111 |
|---|---|---|---|
| **Maximum flow** |  |  |  |
| Part thickness, mm (inch) |  |  |  |
| 1.02 (0.040) | mm (inch) | 12.7 (5) | 12.7 (5) |
| 1.52 (0.060) | mm (inch) | 33 (13) | 30.5 (12) |
| 2.03 (0.080) | mm (inch) | 16 (40.6) | 14 (35.6) |
| 2.54 (0.100) | mm (inch) | 19 (48.3) | 16 (40.6) |
| Thinnest allowable wall | mm (inch) | 0.010 (0.254) | 0.015 (0.381) |
| Material drying time | hrs | 2–4 | 2–4 |
| Temperature | °C (°F) | 135–149 (275–300) | 135–149 (275–300) |

## Appendix B – Auxiliary Equipment

Application Engineering Corp./AEC Inc.
1100 Woodfield Rd., Suite 588
Schaumburg, IL 60173
+1 847-273-7700
www.aecinternet.com

Conair
One Conair Drive
Pittsburg, PA. 15202
+1 412-312-6000
www.conairnet.com

Sterling
2900 S. 160th Street
New Berlin, WI 53151
+1 262-641-8610
www.sterlco.com

Wittmann Inc.
One Technology Park
Torrington, CT 06790
+1 860-496-9603
www.wittmann-ct.com

## Appendix C – Injection Molding Ryton® PPS Trouble-Shooting Guide

In using this trouble-shooting guide, it should be kept in mind that only one change should be made at a time, and the result determined unless it is very apparent that more than one factor is in error. In addition, the “Possible Cause” and “Solution” should each be taken in the order listed – again, unless it is obvious which factor should be corrected.

In some cases, a composite of several causes may complicate the situation to a point where no single solution would be satisfactory. Under these conditions, a systematic review of the molding conditions and operation would be necessary to determine the major problem.

| Problem | Possible Cause | Solution |
|---|---|---|
| Mold does not fill | Shot size too small | Increase shot size, maintain a 3.2 mm (0.25 inch) cushion minimum. |
|  | Cut-off transfer position too short | Decrease cut-off transfer position. |
|  | Inadequate pressure | Increase boost, pack or hold pressure. |
|  | Injection rate too low | Increase injection rate and/or increase boost pressure if pressure limited. |
|  | Material too cold | Increase melt temperature. |
|  | Injection time too short | Increase boost, pack or hold time. |
|  | Trapped air or gas | Vent mold in unfilled area 0.0127 mm (0.0005 inch) deep. |
|  | Mold temperature too low | Increase mold temperature. |
|  | Gate/runner too small | Increase gate/runner/sprue size and/or decrease gate land length. |
|  | Insufficient material in hopper | Add resin to hopper. |
|  | Excessive clearance between non-return valve and barrel | Replace worn parts. |

| | | |
|---|---|---|
| Part contains voids | Part not packed out | Increase shot size. |
| | | Decrease cut-off transfer position. |
| | | Increase injection boost pressure. |
| | | Increase injection pack or hold pressure. |
| | | Increase injection time forward. |
| | | Increase pack or hold time. |
| | Mold temperature too low | Increase mold temperature to 135–149 °C (275–300 °F). |
| | Injection rate too high | Decrease injection rate. |
| | Excessive wall thickness | Reduce wall thickness or core out thick sections. |
| | Material is wet | Dry compound, 135–163 °C (275–325°F) for 2 to 3 hours. |
| | | Reduce melt temperature. |
| | Trapped air or gas | Change gate location. |
| Dull or mottled surface | Mold too cold | Increase mold temperature to 135–149 °C (275–300° F). |
| | Part not packed out | Increase injection boost pressure. |
| | | Increase injection pack pressure. |
| | | Increase injection time forward. |
| | | Increase shot size. |
| | | Decrease cut-off position. |
| | | Increase pack or hold time. |
| | Injection rate too slow | Increase injection rate. |
| | Material too cold | Increase melt temperature. |
| Parts develop internal cracks | Molded-in stress | Reduce fill rate. |
| | | Increase mold temperature. |
| | Wall thickness too heavy for compound | Reduce wall thickness or core out thick sections. |
| | | Use compound with higher molecular weight base. |
| | Corner radius too sharp | Increase corner radius. |
| | Parts cool too quickly | Increase mold temperature. |
| | | Put parts in insulated container to cool. |
| Parts warp | Parts cool unevenly | Correct mold temperature variation. |
| | | Reduce variation in wall thickness. |
| | | Reduce mold temperature. |
| | | Increase mold closed time. |
| | | Apply a differential mold temperature to counteract warpage. |
| | | Use a post mold cooling fixture. |
| | | Reduce melt temperature. |
| | Parts under packed | Increase injection pack or hold pressure. |
| | | Increase injection pack or hold time. |
| | | Increase shot size. |
| | Injection speed too high | Reduce injection speed. |
| | Parts eject unevenly or stick | Check for proper part ejection. |

| | | |
|---|---|---|
| Weld lines are weak (crack) | Inadequate melt temperature | Increase melt temperature. |
| | Parts under packed | Increase injection pack or hold pressure. |
| | | Increase injection pack or hold time. |
| | | Increase shot size. |
| | Injection rate too low | Increase injection rate. |
| | | Increase injection boost pressure. |
| | Air entrapment in cavity | Improve venting in weld line area, 0.0127 mm (0.0005 inch) deep. Provide material overflow. |
| | Gate location | Move gate to place weld line in area of reduced stress or thicker section. |
| | Restricted flow path | Increase nozzle, sprue, runner or gate size. |
| Light tan or black<br>Burned area on parts | Air entrapment | Reduce injection rate. |
| | | Vent cavity in problem areas by flattening ejector pin sides, parting line vents, 0.0127 mm (0.0005 inch) deep, or vacuum vent. |
| | | Move gate to allow better venting. |
| Parts do not have adequate dimensional stability or stiffness after exposure to elevated temperature | Parts do not have adequate crystallinity | Increase mold temperature to 135–149 °C (275–300 °F). Anneal or heat treat parts before use, 2 to 6 hours at 204 to 232 °C (400 to 450 °F). |
| Parts do not eject from mold cores | Parts shrink onto core | Check mold for undercuts. Draw polish cores and cavities. |
| | | Reduce core temperature. |
| | | Increase injection pressure. |
| | | Increase injection time forward. |
| | | Increase injection rate. |
| | | Reduce mold closed time. |
| | | Use mold release spray<br>(Zinc stearate, tge silicones, etc.). |
| | | Dry blend 0.05 to 0.10 % zinc stearate into resin. |
| | Insufficient draft on core | Increase draft on core. |
| Parts do not eject from mold cavity | Part sticks in cavity | Polish out undercuts in cavity or add undercuts to core to keep part on core. |
| | | Reduce mold temperature. |
| | | Reduce injection time forward. |
| | | Reduce injection rate. |
| | | Increase mold closed time. |
| | | Reduce stock temperature. |
| | Insufficient draft in cavity | Increase draft in cavity. |
| Parts difficult to eject or break on ejection | Insufficient ejector surface or ejector pins in wrong locations | Increase number of ejector pins. |
| | | Increase ejector surface area. |
| | | Add ejector pins. |
| | Part top hot | Increase cooling time. |
| | | Decrease mold temperature to 135–149 °C (275–300° F). |

| | | |
|---|---|---|
| Sprue does not pull | Undercut on sprue bushing | Ream and draw polish sprue bushing. |
| | Flash between nozzle and sprue bushing | Reface sprue bushing and nozzle, check alignment. |
| | Insufficient shrinkage of sprue<br>Insufficient taper of sprue brushing | Decrease packing or hold pressure. |
| | | Decrease hold or cooling time Increase taper on sprue bushing. |
| | No sprue puller | Use “Z” sprue puller. |
| Nozzle drool | Material wet | Dry material for 2 - 4 hrs. at 135–163 °C (275–325 °F). |
| | Nozzle tip too hot | Lower nozzle temperature. |
| | | Increase decompression. |
| | Material too hot | Lower front barrel temperature. |
| | | Decrease back pressure. |
| | | Decrease mold open time. |
| | | Use a smaller orifice nozzle. |
| | | Use a reverse taper nozzle. |
| | | Use a shut off nozzle. |
| Nozzle freeze off | Nozzle temperature too low | Increase nozzle temperature. |
| | | Use a larger orifice nozzle. |
| | | Decrease the cycle time. |
| | Mold temperature too low | Increase mold temperature. |
| | | Insulate the nozzle from the mold. |
| | Material temperature too low | Increase barrel temperatures. |
| | | Increase back pressure. |
| Surface imperfections | Cold slug | Use a cold slug well. |
| | | Decrease nozzle temperature. |
| | Cold mold | Increase mold temperature to 135–149 °C (275–300°F). |
| Flash | Injection pressure too high | Decrease cutoff position. |
| | | Decrease injection time forward. |
| | | Decrease injection pack pressure. |
| | Material temperature too high | Decrease barrel temperature. |
| | | Lower back pressure. |
| | Injection rate too high | Decrease injection rate. |
| | Mold temperature too high | Decrease mold temperature. |
| | Clamp force too low | Increase clamp force or evaluate moving mold to a larger press. |
| | Mold wear or misalignment | Check the mold for cavity edge wear |
| | | Check for proper mold alignment. |
| | | Check for material caught on the parting line surface. |
| Tooling wear | All highly filled compounds are quite abrasive and tend to cause tool wear. This wear is most severe in areas of highest material velocity. | Increase stock temperature. |
| | | Decrease injection speed. |
| | | Use extremely hard inserts such as tungsten carbide in these areas of the mold. |
| | | For tool steel recommendations, refer to Ryton® PPS Design Guide. |
| Excessive Wear of Screws, Barrels and Check Valves | Material not properly and adequately melted | Increase stock temperature. |
| | | Decrease back pressure. |
| | Screw, check valves or barrel Material not hard enough | Use bimetallic barrel along with hardened flights on screw. Refer to Ryton® PPS Design Guide. |

**Specialty Polymers**

Worldwide Headquarters
**SpecialtyPolymers.EMEA@solvay.com**
Viale Lombardia, 20
20021 Bollate (MI), Italy

Americas Headquarters
**SpecialtyPolymers.Americas@solvay.com**
4500 McGinnis Ferry Road
Alpharetta, GA 30005, USA

Asia Headquarters
**SpecialtyPolymers.Asia@solvay.com**
No.3966 Jindu Road
Shanghai, China 201108

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