



TempRite[®]

CPVC Material Solutions

*Industrial
Molding
Processing
Guide*

Introduction

This molding guide is designed to assist the processor of TempRite® Chlorinated Polyvinyl Chloride Industrial Molding Compounds. It is intended to help the molder select equipment and operating conditions which will convert TempRite® CPVC materials into attractive parts with maximum properties while achieving reasonable production economics.

TempRite® industrial molding compounds are commonly used for:

- Pipe fittings for industrial and potable water applications
- Valves and flanges
- Pump housings and impellers
- Filter bodies and parts
- Scrubbing tower packing and parts
- Parts which require fire resistance and low smoke generation
- Parts which require impact and gloss retention after weathering exposure

General Considerations

TempRite® industrial molding compounds are amorphous, and exhibit no sharp melting temperatures. They are relatively high in melt viscosity, and sensitive to excessive shearing and to extended exposure to processing temperatures. Simple plunger/ram machines have proven unsatisfactory, and reciprocating screw equipment is mandatory. **It is extremely important that the molder follow the tooling suggestions** contained in this bulletin to safely and successfully process TempRite® CPVC.

Achieving the right molding conditions for TempRite® compounds requires two distinct operations:

1. Development of a homogeneous melt in the correct melt temperature range through selection of proper barrel capacity, screw and nozzle design and operating parameters.
2. Introduction of this melt into the mold while preserving melt quality and developing good filling and packing of each cavity. Proper design of flow channels and gates, and good flow balancing in multiple cavity molds are critical.

Melt Preparation

Barrel Capacity is usually rated in ounces of polystyrene. If the polystyrene rating is used for TempRite® CPVC compounds, **over-size machinery** will be selected.

To determine barrel capacity for TempRite® CPVC:

$$\text{TempRite® CPVC Capacity} = \text{Rated Capacity} \times \frac{\text{Sp. Gr. TempRite® CPVC}}{\text{Sp. Gr. Polystyrene}}$$

or, typically

$$\text{TempRite® CPVC Capacity} = \text{Rated Capacity} \times \frac{1.5}{1.05}$$

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Note that TempRite® CPVC capacity exceeds rated capacity by 35-50% (43% in the above example) depending on the specific gravity. See the individual product data sheets for specific gravity for each TempRite® industrial molding compound.

The broadest processing latitude consistent with optimum part appearance and physical properties is achieved when utilizing 60-70% of TempRite® CPVC capacity. Good results are achieved with 50-85%. Barrel utilization is calculated by dividing the total shot weight (parts + runners + sprue) by the TempRite® CPVC capacity calculated above.

Many of these compounds have been successfully molded at 30% of TempRite® CPVC capacity, and even less. However, shots this small:

- Increase residence time in the barrel, increasing the probability of burning
- Require reduced melt temperatures which may increase internal stresses and part warpage or cause velocity burning in the gates
- Create a narrow range of processing conditions which often is difficult to maintain in the production environment

Most often, when TempRite® compounds degrade in the barrel, shot sizes under 50% of TempRite® CPVC capacity are involved! **Screw Design** is one of the most critical, yet least understood variables in the injection molding process. Many variations of screw design have been used, and many are proprietary to equipment suppliers. Only the simplest single-stage design will be discussed. *Figure 1* shows such a screw design which is fully capable of processing TempRite® CPVC materials. The most important screw parameters are:

- The rotational speed of the screw (RPM)
- The flight depth in the metering (front) section (h_m)
- The number of metering flights

Of lesser importance is the flight depth of the feed (rear) section (h_f) which determines the **Compression Ratio (CR)** defined as:

$$CR = \frac{\text{Depth of feed section}}{\text{Depth of meter section}} = \frac{h_f}{h_m}$$

Metering Depth (h_m) must vary with barrel diameter (D_B). If h_m is too shallow, the compound will tend to overheat, requiring slower screw speeds (RPM) and return times. TempRite® industrial molding compounds – due to their high viscosity – are very sensitive to screws with too-shallow metering depths. If the screw is too deep (a rare occurrence), the compound will be undermixed, nonhomogeneous, and too high in viscosity to mold properly. This can rarely be corrected with increased barrel temperatures.

Figure 2 shows how metering section depth should vary with barrel diameter, based on screws known to work well with TempRite® industrial molding compounds. Note that h_m represents the distance between the screw root and the barrel (which is normally 0.2% larger than the screw flight diameter).

Feed Depth (h_f) must be sufficient to fill the metering section with compound from which the air space in the cubes has been removed. Experience has shown that a compression ratio (CR) of 2 to 2.5 is sufficient. Feed Depth is calculated from metering depth (h_m) from Figure 2 by

$$h_f = h_m \cdot (CR)$$

If h_f is too shallow, screw return time will be extended; if too deep, overheating of the compound may result.

Screw RPM, given a properly sized barrel and screw, is rarely a problem. Typical starting rpm for various size barrels is shown in Figure 3.

These RPM's are recommended for screws and barrels in like-new condition, utilizing the recommended % of barrel capacity. Lower screw speeds may be required with:

- Excessive clearance between screw flights and barrel(s)
- Small shot sizes
- Shallow screws which generate more shear-heating
- Long barrels and metering sections
- In general, where melt temperature is excessive.

Screw RPM is the single most important determinant of melt temperature. In the injection molding process, the great majority of heat input to the compound is from mechanical energy – not barrel heaters. The shear

Figure 2:
Metering Depth by
Barrel Diameter

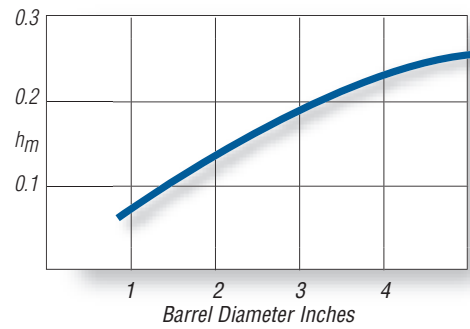
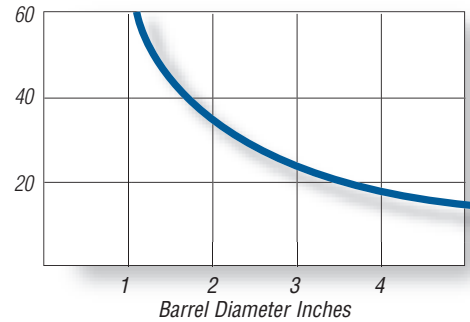


Figure 3:
Screw RPM for
Peripheral
Rate = 200 in/min.



heating developed is proportional to the shear-rate (\bar{r}) imposed. For the screw:

$$\bar{r} = \pi \cdot D_B \cdot n / h_m$$

Where D_B = Barrel Diameter, n = RPM/60 and h_m = meter depth. For a given machine, D_B and h_m are constant, and $\bar{r} = c \cdot n$.

With viscous materials such as TempRite® industrial molding compounds, changing screw RPM is the fastest way to change melt temperature. Indeed, back pressure and barrel temperature settings are merely fine-tuning tools in achieving proper melt temperature!

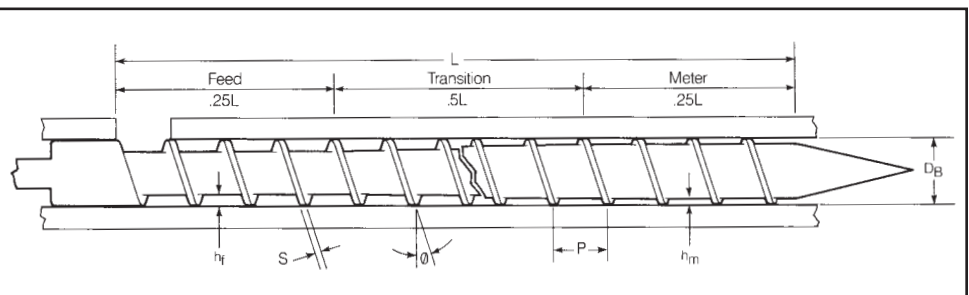
Screw Tip design for TempRite® industrial molding materials must be of **smearhead** design shown in Figure 4. Because of their high viscosity, there is little tendency for back-flow, and check valves are neither required nor recommended. Experience has shown that check-rings perform well for short evaluations, but cause burning due to hold-up of compound during longer runs.

Ball-checks should **never** be used with TempRite® industrial molding compounds.

Nozzles should be as short as possible, and should be provided with a separately controlled heater band. A thermocouple driven solid-state controller (not a Variac) is required. Recommended internal design is shown in Figure 4. Ideally, the taper of the adapter should be extended into

Figure 1: Recommended Screw

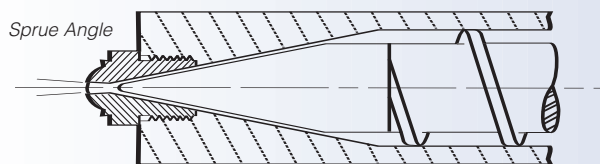
- D_B = Barrel diameter
- θ = Helix angle (usually 17.8° for Pitch (P) = D_B)
- S = Flight land width (usually 0.1 x D_S)
- L = Overall length
- L/ D_S = Length ratio (usually 16:1 to 24:1)
- h_f = Radial clearance between barrel and screw root at feed end
- h_m = Radial clearance between barrel and screw root at metering end
- h_f/h_m = Compression ratio (2-2.5 recommended)



the rear of the nozzle, while the sprue taper is extended back to meet it. This design removes all possible cold material with the sprue, minimizing the size of cold slug wells in the mold.

Nozzle discharge diameter should be at least .3125" (7.9 mm) and never less than .25" (7.112 mm) to minimize shear burning during injection. The entrance and exit ends of the nozzle should closely match the diameters of the adapter and sprue, respectively. If the nozzle is larger than the sprue, it may interfere with sprue removal.

Figure 4: Preferred Screw Tip and Nozzle



Chrome Plating of the nozzle, adapter, screw tip and screw (except for the flight lands) is required to assure that the molten compound does not stick to these surfaces. A hard chrome plate of .0015" (.038 mm) should be applied in three (3) layers of .0005 (.013 mm) with polishing between layers. Chrome applied in this manner will resist flaking, and pitting, and may be repolished several times before resurfacing is required.

Mold Design

The principles of good mold design for other engineering thermoplastics apply to TempRite® industrial molding materials. The high viscosity and shear sensitivity of these compounds indicate that sprues, runners and gates be as large as possible. Corrosion resistant materials should be used extensively for extended production.

Materials – Series 420 stainless steel is the preferred material for mold bodies and cavities. This provides a durable, easily maintained base. If conventional tool steel is used, all surfaces which contact the melt must be plated. Preferred plating is three separate layers of .0005" (.038 mm) of hard chrome, with polishing prior to each. A single .001" (.0254 mm) layer of hard chrome has also been used successfully – especially if a layer of electroless nickel is applied first. The very thin flash chroming is not recommended for long-term service.

Sprue Bushings with a standard $2\frac{1}{2}^\circ$ included angle (0.5" per foot or 42 mm taper per meter) should be used. The entrance diameter to the nozzle should be equal to or very slightly larger than the exit diameter. For shot sizes ranging from 10-24 ounces, the tapered sprue should be at least 5/16" (7.9 mm) diameter at the nozzle and 7/16" (11.1 mm) at the runner. For larger shots, both nozzle and sprue bushing diameters should be increased. A cold slug well 1/2" to 3/4" (13 to 19 mm) deep should be provided as an extension of the sprue whenever possible. Best results have been obtained using the "Z" type sprue puller. The use of heated or insulated sprue bushings is **not** recommended. Excessively recessed sprue bushings should be avoided because they usually require very long nozzles.

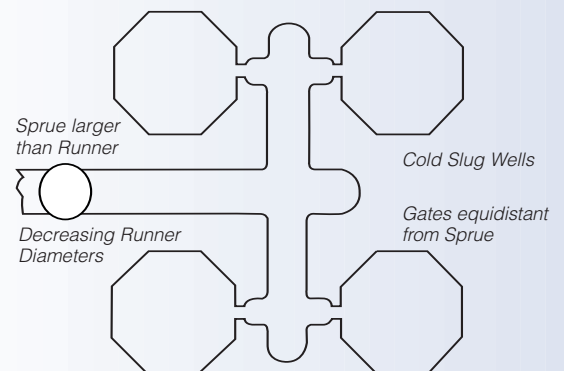
Runner System layout should provide for balanced flow, so that the melt reaches each gate at the same time. To promote this, the primary runner should be smaller than the exit diameter of the sprue bushing, and each subsequent branch should be further reduced. Ideally, each gate will be equidistant from the sprue. Hot runner systems are **not** recommended for these materials.

Full round runners are recommended: a 3/8" (9.5 mm) diameter runner is suitable for 10-24 ounce (280-680 gram) shot. Secondary runners should join the main runner at right angles, with the intersections radiused as shown in Figure 5. Sweeping curved branches are not recommended. Additional cold slug wells near the gates are suggested.

Gates of conventional design may be used for TempRite® industrial molding compounds so long as generous cross sectional areas can be provided. The larger the gate, the faster the shot can be injected. Small gates can cause velocity burning (gray streaks) in the finished parts. Pin gating should be avoided.

Gates should be polished free of rough edges and sharp corners, especially at the runner end. Generally the cavity should be gated in the

Figure 5



thickest portion, with the entering melt impinging on a mold surface. This will avoid "snaking" and promote even filling of each cavity.

Gate land length should be kept to 1/32" (0.8 mm) where possible to promote the best cycle times. Because of TempRite® CPVC materials high viscosity, a gate diameter of 3/32" (2.4 mm) or larger should be used for small cavities. It is often best to start with conservative gate dimensions with the intent to enlarge them as necessary.

Venting of each mold cavity is required to allow complete filling and to prevent gas burning by compressed air and volatiles. Vents should be provided near weld-lines and in the last cavity volume to be filled. Vents can be as deep as .0015" (.0381 mm) x .250" (6.35 mm) wide.

Mold Shrinkage of .004 to .007 inches/inch (cm/cm) may be expected from TempRite® industrial molding compounds, depending on molding and cooling conditions.

Draft Angle of 0.5° is usually sufficient for TempRite® CPVC and other low shrinkage materials. This angle will vary with part size and mold texturing.

Mold Protection – In addition to normal good practices in handling and storing molds, the following steps are recommended at the end of a shift or when storing a mold between runs:

1. Wipe the mold surface clean of any oily or acidic deposits with a clean cloth or tissue.
2. Spray all surfaces with a commercial neutralizer.
3. Wipe again as in 1.
4. Spray all surfaces with a preservative such as Silicone oil.

Processing

Because of the wide variety of machine and part sizes, screw and mold designs, etc., processing conditions must be optimized by the molder for each set-up. The following sections discuss general conditions which will promote the broadest processing latitude for TempRite® industrial molding materials.

Storage – These compounds are supplied as small cubes. Standard packaging is either 50 lb. unlined paper bags or PE lined boxes. These packages should be stored on their pallets in a dry location. When storage conditions involve high humidity, lined boxes are preferred. (These also are convenient for storing regrind.) Opened containers should have the liners reclosed for continued storage.

Drying – Normal predrying is for two hours at an air temperature of 10°F below the heat deflection temperature of the compound. Refer to the individual product data sheet for the heat deflection temperature. Both hopper and tray dryers have been used. Depending on storage time and conditions, longer drying times may be required. Symptoms of inadequate drying include silver- streaking (splay) at the gates, intermittent short shots or part blemishes (due to inadequate venting) or inconsistent molding cycles.

Purging – The press must never be shut down with TempRite® compound in the barrel. Purge with general-purpose ABS or Acrylic resin before shut-down to prevent possible corrosion of barrel parts. **Never use Acetal or Nylon** polymers in conjunction with TempRite® CPVC materials. Be sure that the hopper, barrel, granulator and bins are thoroughly cleaned if these materials must be processed in the same equipment with TempRite® CPVC compounds.

Regrind from sprues, runners and scrapped product can be reprocessed so long as it is kept clean, dry and free of burned material. It should be granulated to a size approximating the original cubes. Parts containing black or severely discolored areas must not be reground. Clean regrind should be stored and predried like virgin compound.

Best results are obtained in continuous or repetitive molding operations by blending regrind with virgin cubes at a consistent ratio which approximates the recycle generation rate. This should be done prior to pre-drying. Levels from 10-30% should be satisfactory.

100% regrind has been processed successfully, although a greater color shift must be expected. A major concern is the great difficulty in keeping count of the number of times material has been recycled.

Adjustments to processing conditions may be necessary for 100% regrind, and processing latitude will be reduced. Shots of less than 50% of TempRite® CPVC capacity should not be run from 100% regrind. Scrap from a 100% regrind run should be junked.

Melt Temperature control is essential to proper molding of these TempRite® CPVC materials. Typical melt temperatures will range from 400-435°F (204-224°C) as measured by needle pyrometer on the first air shot from a machine which has reached a stable cycle. Factors which influence melt temperature include:

1. **Screw design** – especially the flight depth and number of metering flights. For a given press, this is constant.
2. **Screw RPM** In most cases, increasing RPM will increase melt temperature; decreasing RPM will decrease it. These effects are immediately noticeable, and very pronounced. An improper melt temperature can be corrected faster by changing screw speed than by any other means. The effects of improper RPM can rarely be corrected by any other means. See Figure 3 for starting RPM and reasons for possible RPM reduction.
3. **Back Pressure** is typically 50-150 psi (0.3-1 MPa) with larger screws requiring less back pressure. Increasing back pressure will both improve melt uniformity and increase melt temperature – especially in worn equipment.
4. **Injection Speed** affects these viscous compounds profoundly. A slow or moderate injection rate is appropriate. If injected too fast, velocity burning may develop in the nozzle or the gates.
5. **Barrel Temperature Controllers** are capable of fine tuning melt temperature, but mainly serve to stabilize the process. When running small shots, the screw turns a small percentage of the time, and heat conducted from the barrel becomes more important. In this situation, a reverse barrel temperature profile (hotter at the hopper, cooler at the nozzle) has sometimes helped to widen processing latitude. With certain screws, extreme override of the middle zone may occur. Replacing the barrel shroud with an open grid or the use of forced air cooling may be required.

Air Shots offer the best opportunity to observe melt temperature and uniformity in the melt. The first air shot after a machine has been on-cycle offers the best evidence; if more than one air shot is taken, do so at normal cycle frequency and injection rate, reducing injection pressure if necessary.

The rope should emerge smooth and should swell uniformly along its length. Lumpy extrudate indicates poorly mixed or low temperature melt. Discoloration and/or excessive gassing indicates the melt is too hot. Wad the extrudate together as it emerges for needle pyrometer measurements. The melt should be capable of being stretched into a long, thin filament. Caution: Melt is hot. Wear gloves and safety glasses at all times.

Temperature Control of the mold is required to sustain consistent part appearance and performance. Mold surface (inlet water) temperatures of 50-175°F (10-80°C) have been used. Higher temperature molds generally are easier to fill and produce parts with lower internal stresses. In multiple cavity molds, cooling passages must be laid out such that each cavity is cooled as much alike as possible.

Pressures

Injection pressure must be sufficient to sustain the injection rate desired. Means of controlling injection rate vary from machine-to-machine.

Packing pressure is applied after the screw has reached a preset cushion of 1/8"–1/6". A relatively high packing pressure applied for a short time is preferred:

- *The recommended smear tip will move through the cushion. No pressure will be applied once the screw bottoms.*
- *These TempRite® CPVC materials tend to freeze off quickly – especially in multiple cavity molds.*

Holding pressure much lower than packing pressure may be used once the gates have frozen. Slack time is taken here by delaying screw retraction. This minimizes heat history on the compound and increases processing latitude.

Start Up

It is always desirable to start with a clean machine. All traces of Nylon or Acetal materials must be removed from the hopper as well as from granulators and bins. The barrel should be purged with Acrylic or General Purpose ABS before introducing TempRite® compounds.

To establish operating conditions for a first trial, set the barrel at 300°F under the hopper. Increase temperature gradually toward the front, ending with 340°F in the nozzle and front zones. Allow temperatures to stabilize before introducing predried TempRite® compound to the hopper.

Adjust back pressure so that a slight drool occurs during screw retraction. Run air shots at moderate injection speed until all purge material has left the barrel. Provided that no discoloration is observed on or inside the rope, put the press on-cycle. (A minimum number of air shots is desirable – rapid air shots can create overheating.)

Adjust machine variables as usual to achieve a full mold and good part appearance. Refer to the *Problem Solving Guide* as necessary. Watch for signs of overheating and/or burning. Once a number of good parts have been produced, an air shot should be taken.

Generally, one should be slow to increase screw RPM or barrel temperature settings. Melt temperature will increase steadily after start-up as shear-heating takes effect. About 8 minutes per inch of barrel diameter is required for the barrel to come to full equilibrium after a process change.

The stock temperature should be checked with an accurate needle pyrometer for conformance to the temperature range for the material. Both temperature and melt uniformity are indicated by the condition of the air-shot melt. It should be smooth and uniform in size and should swell uniformly along the length.

The melt should be extensible into a thin filament. An excellent indicator of proper melt temperature on-cycle is the tailing of the sprue into a thin filament.

A typical temperature profile to achieve good melt is:

Feed Zone 1.....	280-330°F
Zone 2.....	320-350°F
Zone 3.....	340-370°F
Zone 4.....	350-390°F
Nozzle.....	350-390°F

Air-cooling of the barrel may be required to handle overriding temperatures in the middle zone(s). Adding a fan or replacing the solid hood with a mesh have been effective.

Process Upsets

Cycle interruption – able to purge barrel.

- *Restart press.*
- *Retract injection unit from the mold.*
- *Purge TempRite® compound from barrel with TempRite® compound every ten minutes.*
- *Recheck barrel and nozzle temperatures.*
- *Resume normal operation.*

Cycle interruption – unable to purge barrel.

- *Shut off heaters to barrel and nozzle.*
- *Resolve problem.*
- *Restart injection molding press.*
- *Set barrel and nozzle temperatures 30°F below normal operating temperatures.*
- *Start purging barrel as soon as reduced temperatures have been reached with TempRite® compound.*
- *Reset barrel temperatures to normal operating temperatures.*
- *Resume normal operation.*

Slight¹ degradation of TempRite® compound in the injection molding press.

- *Continue TempRite® molding operation.*
- *Recheck all nozzle and barrel temperature controllers.*
- *Recheck screw RPM and fill rate.*
- *Resolve if barrel temperatures are set too high, or if the controllers are malfunctioning.*
- *Resume normal operation.*

Severe² degradation of TempRite® compound in the injection molding press.

- *Protect eyes, nose, and throat from HCL released from degraded material.*
- *Retract injection unit from the mold.*
- *Dissipate air around injection molding machine.*
- *Remove TempRite® compound from hopper.*
- *Put purge compound such as general purpose styrenics or acrylic in hopper.*
- *Purge barrel as rapidly as possible of degraded material into small portions (less than 1.5 pounds).*
- *Place degraded air shots in a bucket of water if possible, and remove from the building.*
- *Locate errant barrel or nozzle temperature controller and repair.*
- *Purge barrel with small amount of TempRite® compound to make sure controllers are operating properly.*
- *Resume normal operations.*

1 = Color shift and odor change 2 = Charred compound and HCL odor

Trouble Shooting

Introduction: TempRite® CPVC materials run more consistently and produce parts with better properties and appearance when they are processed with melt temperatures toward the upper end of their recommended range. The typical molding problems encountered are too low a melt temperature, and a downward trend of melt temperature with time. If the correct screw design is being used (Page 2) experience has repetitively shown that a few critical process parameters tend to force melt temperature down.

- 1. Condition of the chrome plate:** As chrome wears, contact with the base metal exposes the CPVC melt to the element iron (Fe), which catalyzes the decomposition of the CPVC. The tendency for the machine operator, who may be unaware of the condition, is to reduce melt temperature setting to prevent the burning of the material. This will cause poor fusion at the weld lines and weak, poor appearance parts are the result. Under these conditions, high quality parts cannot be produced.
- 2. Small molds in large presses:** Small molds in large presses cause low utilization of barrel capacity (Page 2). This means the CPVC melt resides in the barrel at processing temperatures long enough to initiate decomposition. Again, the typical response

is to lower melt temperature settings to allow the material to process without burning. The result is again, weak knit lines and flow lines.

Run to run repeatability is often blamed on batch to batch variability of TempRite® CPVC. However, operating procedures should be examined first.

- 3. Melt Temperatures:** Melt temperature in the lower end of the recommended range will cause the entire molding process to be more sensitive to variations of any kind.
- 4. Screw RPM:** Variations in screw RPM will drastically alter melt temperature. Once an RPM has been established that yields the correct melt temperature for a given press/mold combination, it should be standardized. It is not reasonable to expect operators to maintain constant RPM settings **without a working tachometer on the machine.**
- 5. Injection Rate:** Injection speed profoundly affects the temperature of the melt. It should be standardized and optimized for each mold/machine combination. If burning occurs in the sprue, runners or gates, the injection rate must be reduced, or the flow passages enlarged.

Problem Solving Guide

Problem	Possible Causes		
	Barrel/Screw/Nozzle	Sprue/Mold	Feed Stock
Short Shots	Injection Pressure Low Injection Time Short Stroke Short Injection Rate Low Melt Temperature Low	Mold Temperature Low Vents Not Working Gates Too Small Sprue, Runners Small Unbalanced Filling	Hopper Empty Hopper Bridging Compound Undried
Burn Streaks in Parts	Injection Speed Too High Melt Temperature Low	Mold Too Cold Gates Too Small Vents Not Working Unbalanced Filling	Compound Undried
	<i>Check For Burning in Runners & Sprue</i>		
Burn Streaks in Runners	Nozzle Too Hot Nozzle Too Small Chrome Bad	Sprue Too Small Runners Too Small Runners Rough Poor Radii at Branches	
	<i>Check for Burning in Barrel (Air Shots)</i>		
Burning in Barrel	Controller Malfunctioning Screw RPM Too High Screw Too Severe Chrome Plating Bad Back Pressure Too High Shot Size Too Small		Over-Used Regrind Contaminated Regrind
Weak Weld Lines	Melt Temperature Low Injection Pressure Low Packing Pressure Low Cushion Inadequate Injection Speed Low	Vents Not Working Mold Too Cold Mold Release Excessive Gates Too Small Poor Gate Location	Compound Undried
Splay, Silver Streaks, Blisters	Melt Temperature High Injection Speed High Incipient Burning	Mold Too Cold Vents Not Working Gates Too Small	Compound Undried Compound Contaminated Over-Used Regrind
Sink Marks	Packing Pressure Low Packing Time Short Injection Speed Slow Cushion Excessive Cushion Inadequate Nozzle Too Hot Nozzle Too Small	Unbalanced Filling Mold Too Hot Cool Time Inadequate Gates Too Small Sprues, Runners Small Consider Water Quench	
Flow Lines, Delamination	Melt Temperature Low Injection Speed Slow	Mold Too Cold Gates Too Small Gates Rough	Compound Undried
Warping	Packing Pressure Low Melt Temperature Low	Mold Too Hot Cool Time Inadequate Mold Cooling Uneven Consider Cooling Fixture	
Excessive Shrinkage	Melt Temperature Low Packing Pressure Low Injection Speed Low	Mold Too Cold Cooling Time Inadequate Unbalanced Filling	



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