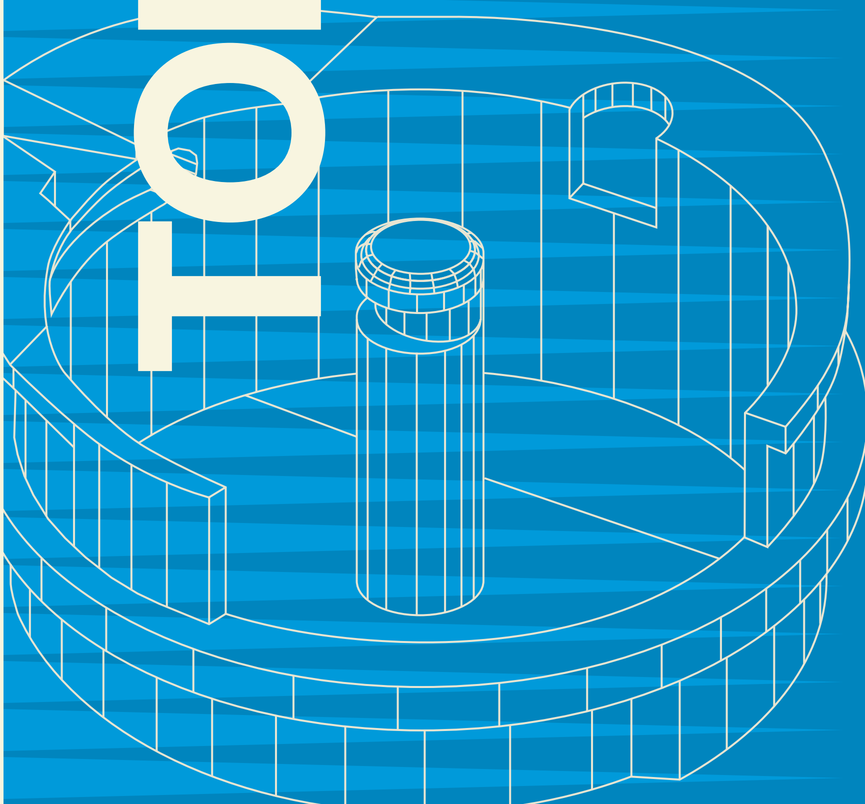
TORLON

molding

TORLON®
Polyamide-imide
Molding Guide



Solvay
Advanced Polymers

Contents

Guide to Injection Molding TORLON® Polyamide-imide (PAI)

About TORLON Polymers

TORLON high-performance molding polymers are being specified for a wide variety of applications requiring strength and durability at extremely high temperatures. Components made of TORLON resin are reliable under conditions too severe for other injection moldable thermoplastics.

Of the many high-performance plastics, TORLON polyamide-imide has a unique combination of properties:

- Injection moldable into complex precision parts
- Useful at temperatures up to 500°F (260°C)
- Exceptionally strong
- Resistant to impact
- Dimensionally stable
- Low thermal expansion coefficients
- Resistant to chemicals and radiation
- A good electrical insulator
- Resistant to flame
- An excellent matrix for low-friction, wear resistant compounds

Introduction to High-Quality Molding of TORLON Resin

This brochure introduces the injection molder to TORLON polymers, offers criteria for selecting injection molding equipment, provides guidance on designing tools, suggests resin drying procedures, furnishes molding parameters, discusses curing, and provides a trouble shooting guide.

Fabricating TORLON resin requires special considerations. The process of injection molding is used for many thermoplastics. This brochure concentrates on the aspects of injection molding that are either unique to or especially important when molding TORLON polymers. You can minimize rejects and optimize the quality of the finished parts by following the recommendations in this brochure. Experience has shown that some machine and mold modifications are often necessary for molding TORLON resin. A trouble shooting guide is included as a handy reference for solving commonly encountered processing problems.

Injection Molding Equipment

In general, modern reciprocating-screw injection molding presses with microprocessor controls capable of closed loop control are recommended for molding TORLON resin. Hydraulic accumulators may be desirable for certain parts.

Injection Molding Press

Shot Capacity

Choose an injection molding press that is properly sized for the part being molded. When molding TORLON resin, the shot size should be between 50% and 80% of the barrel capacity. The ratio of capacity to shot size is important because TORLON polymers are reactive. Excessive residence time will result in a loss of flow due to increasing molecular weight and viscosity.

Clamp

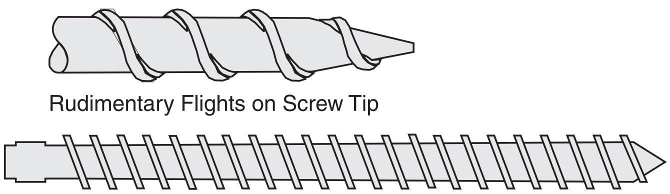
Either hydraulic or toggle clamp machines can be used. Because high injection speed and high injection pressures are used with TORLON resin, the clamp pressure should be at least 6 tons per square inch of projected part area (840 kg/cm^2). Doubling the clamp pressure will help maintain part dimensions at the parting line.

Screw Design

Because of the high viscosity and reactivity of TORLON polymers, a special design is required, as shown in Figure 1.

Figure 1

Screw Design



A low-compression-ratio screw with no check device is required for processing TORLON polymers. A compression ratio between 1:1 and 1.5:1 is recommended. The length-to-diameter (L/D) ratio of the screw should be between 18:1 and 24:1 for uniform heat distribution.

Screw flights must be free from all restrictions such as mixing pins, flutes, and dispersion nozzles. In the feed section, the minimum flight depth recommended is 0.2 inches (5.1 mm). For larger diameter screws, flight depths up to 10% of the screw diameter can be used. The pitch of the screw should be equal to the screw diameter and constant along the full length. The screw should have a smooth, constant taper. A tip and nozzle similar to those used for processing polyvinylchloride (PVC) or thermosets, which have rudimentary flights for self-cleaning, is desirable.

Use of a high-compression screw or one with restrictions to flow can lead to molding problems, such as inconsistent cycling, viscosity changes, and foaming. Under extreme conditions, the screw may seize completely or break.

Controls

Proper processing of TORLON polymers requires rapid mold filling followed by precise timing on the pressure adjustments. To accomplish this, the cycle timers and the hydraulic servo-valves must be capable of controlling the process within 0.01 seconds. Feedback loop controllers that allow programming of the pressure profile have been shown to be effective and beneficial for processing TORLON polymers.

Tool Design

Designing Molds for Processing TORLON PAI

Careful mold design will accommodate TORLON resin's special flow characteristics and ensure successful processing:

- Select the right type of steel
- Consider shrink characteristics
- Design for smooth ejection
- Locate gates and vents strategically
- Vent generously
- Heat the mold

Steel Selection

Select the type of steel according to the length of the run, as shown in Table 1. TORLON polymers are not corrosive, so it is not necessary to plate the mold. In fact, plating is not recommended. Plating increases cost, decreases heat transfer, inhibits mold modification, and can cause ejection problems.

Table 1

Basic Mold Types

Mold type	Number of Shots	Type of Steel	Rockwell Hardness, C scale
Prototype	<100,000	P-20 Pre-hardened or S-7	28-32
Production	>100,000	H-13 Air hardened	50-52

Cavity Design

Shrinkage

Generally cavities should be sized in accordance with the shrinkage rates shown in Table 2. These values were obtained using standard test specimens and are the total of molding and curing shrinkage. Approximately half the shrinkage occurs during molding; the other half during curing.

Table 2

Shrinkage Rates of TORLON Resins

Grade	Shrinkage, %
4203L	0.60 - 0.85
4275	0.25 - 0.45
4301	0.35 - 0.60
4435	0.06 - 0.18
5030	0.10 - 0.25
7130	0.00 - 0.15

Because actual part shrinkage will vary with part configuration, length of flow, and molding conditions, judgment needs to be used in determining final cavity dimensions. Although TORLON polymers are amorphous, and amorphous polymers tend to be isotropic, some variation in shrinkage rate with flow direction has been observed.

Although the variance in shrinkage from shot to shot is low, allowing parts made of TORLON resin to be molded to tolerances of ± 1 part per thousand (even closer in some cases), it may be difficult to predict the precise cavity dimension required to meet a very close tolerance. When extremely tight tolerances are required, it is appropriate to cut a cavity a little smaller (steel safe) than the predicted size, then mold, cure, and measure samples for the critical dimension. And then with that additional information, finish machine the cavity to meet the final part dimensions.

Ejection

As shown in Table 2, TORLON resin has very low shrinkage and only half the shrinkage occurs during molding. Therefore, parts tend to stick in the cavity and positive ejection must be designed into the tool. Because as-molded articles made of TORLON resin are brittle, smooth positive linear ejection is required or sensitive parts may crack upon ejection. Allowing generous draft and careful polishing will facilitate ejection. As a minimum, draft of ½ to 1 degree should be allowed whenever possible. Draw polishing is highly recommended. Design the ejector system to provide a positive smooth action that will not allow the part to tilt or cock. Placing ejector pins on the runners as well as the parts should aid in getting them to move smoothly along the direction of ejection. Use guide bushings and leader pins to ensure the ejector plate moves linearly without tilting.

Undercuts

It is impossible to remove a part made of TORLON from a mold containing undercuts unless side actions are used. TORLON polymers will closely replicate mold surfaces, including machining marks and scratches. In fact, cavities and cores must be draw polished to remove machining marks, which can act as undercuts and prevent smooth ejection.

TORLON resin is unforgiving in the uncured state and undercuts must be avoided. If the part design and tool layout options cannot eliminate undercut areas, they can be accommodated by movable mold features. Internal undercuts require collapsing cores or cores that can be removed manually from the mold.

Multi-Cavity Tools

TORLON resin can be molded in a tradional multi-cavity mold, but success requires that the layout be balanced in flow length and pressure drop. Family mold designs are strongly discouraged.

Typically, multi-cavity molds are designed to increase the number of parts produced per machine hour and thus minimize the molding cost. In many cases, multi-cavity tools will be the most economical solution. However more cavities may not always result in a lower part cost. Four cavities rather than eight or sixteen may result in a lower total cost due to savings in runner material. In some cases, a single cavity mold that can be run on a smaller machine offers the most economical option.

For example, molding a seal ring with a 2-inch outer diameter in a 3-plate, 4-cavity mold requires a runner that weighs 11 grams. The part function requires that the gate be on the inside diameter (the only area where a sub-gate vestige is allowed), thus requiring a 3-plate tool for multiple cavities. The seal rings themselves only weigh about 1 gram each. Each shot produces 4 rings, but consumes 15 grams of resin. Using a hot sprue bushing minimizes the material consumed by the sprue.

The single-cavity mold design has a much shorter runner that only weighs 0.5 grams. Therefore, each shot produces 1 ring, but only consumes 1.5 grams of resin. The same hot sprue bushing is used to minimize the material consumed in the sprue. Molding 4 rings in the single-cavity tool uses 6 grams of resin compared to 15 grams in the 4-cavity mold, and saves 9 grams of resin.

The total cost of molding the rings will be a combination of material cost and machine time. Smaller machines typically have a lower cost per hour and quicker cycle times. In this example, the savings in material more than compensated for the increase in machine hours, making the single-cavity approach more economical.

Flow Path Design

TORLON polymers tend to "jet" very strongly. In other words, in the absence of restrictions, the resin flows in a disorderly fashion and, without proper mold design, will not fill the mold uniformly. Jetting can result in internal voids, which can only be seen by x-ray. Left undetected, these defects can affect the structural integrity of the molded part.

With careful mold design, the flow of the resin can be properly directed to minimize the risk of internal voids. Strategic location of gates and vents is the key.

Sprues and runners

To minimize part cost while maximizing part integrity, keep the distance the resin must flow to a minimum. TORLON resin flows best when runners are large in diameter and short in length. Nozzle extensions are generally successful in minimizing sprue length.

For multi-cavity molds, flow must be balanced. The velocity should be equal in each runner, regardless of length or location. Thus, as runners become branched, the cross-sectional areas should be reduced accordingly. Runners should be laid out in an "X" or "Y" shape, and runner cross sections should be full-round or trapezoidal.

The use of a hot sprue can significantly reduce material cost and should be considered for any high-volume molding. Hot sprues have been successfully used with all TORLON injection molding grades. Hot sprues for TORLON resin should be a straight-through or sprue-gate design, with no restrictions in the flow path. No annular gates, torpedo tips, or other restrictive designs should be used. Parts can be direct-gated or fed by cold runners as dictated by the part design.

Hot runner systems are not recommended for molding TORLON resin. Hot runner tooling utilizes a heated manifold to allow injection of the material directly into the part without a sprue and runner system. Typical hot runner manifolds have right-angle turns, "dead spots", and other areas where flow is impeded, resulting in melt stagnation. The stagnant TORLON resin will continue to react and its viscosity will increase. As processing continues, the stagnant resin will cause additional accumulation and stagnation, resulting in inconsistent flow, tremendous resistance to flow, and even complete blockage of the manifold.

Gates

Standard edge and diaphragm gates can be used. Fan and tab gates minimize loss of strength in the gate area. Submarine gates are permissible for small parts.

For larger parts, spoke gates (multiple gates) will distribute resin quickly and efficiently. Although multiple gates create additional knit lines, the net effect is a stronger part overall. However, each design must be analyzed on an individual basis.

Gate size depends on part size. In general, make the gates as large as possible. To counter the tendency of TORLON polymers to jet, direct the resin to impinge on the mold wall at 90 degrees.

The resin should fill from thick to thin sections. Sprues, runners, and gate lands should be as short as possible. Strategic placement of gates can place knit lines in less critical areas.

Design degating points into the gating system away from the part. TORLON resin tends to break in a laminar manner, thus degating away from the part is very important.

Vents

Adequate venting, accomplished with large vents up to 0.0025 inches (0.064 mm) deep, will prevent burns and increase knit line strength.

Weld or Knit Lines

One way to improve the strength of a weld line is to use an overflow tab. Overflow tabs are essentially large vents which are placed at knit lines in critical areas to improve strength. They are particularly useful in larger parts, especially in conjunction with single gates. The width of the tab should be large enough to encompass the knit line. The depth of the overflow land should be $\geq$ 10% of the part thickness.

Inserts

Because TORLON polymer has a low coefficient of thermal expansion, it is an excellent material for applications requiring the integration of metals. Metal inserts made of brass, steel, stainless steel, and aluminum have been successfully molded into components made of TORLON resin, with stainless steel being the preferred choice. Successful insert molding is a function of good part design. For ease of molding, inserts should be situated perpendicular to the parting line, and should be supported so they are not displaced during injection of the resin. Inserts should be preheated to the temperature of the mold or 300 - 400°F (149 - 204°C). A sufficient radial wall of TORLON resin should be allowed around the insert to prevent cracking during cure, because the insert will expand as the TORLON resin shrinks.

Pre-Drying TORLON Resin

TORLON resin is hygroscopic and will pick up ambient moisture. Before processing TORLON resin, drying is required to avoid brittle parts, foaming, and other molding problems.

The resin must be dried to a moisture content of 200-500 ppm. If the ambient relative humidity is below 30%, drying can usually be accomplished in a heated air circulating oven at 250°F (121°C) for 24 hours. If the relative humidity is often above 30%, the drying oven should be equipped with a desiccant drying system.

Put the resin in layers no more than 2 to 3 inches (5 to 8 cm) deep in drying trays. Figure 2 shows the drying time required at 250°F(121°C), 300°F (149°C), and 350°F (177°C). If drying at 350°F (177°C), limit drying time to 16 hours.

For the injection molding press, a desiccant hopper dryer is recommended. The circulating air suction pipe should be at the base of the hopper, as near the feed throat as possible. During extended runs, keep the resin covered and re-dry if necessary. Purge shots should be examined for surface roughness, excessive foaming, and brittleness. If this occurs, re-dry the material according to the schedule illustrated in Figure 2.

Injection Molding Conditions

Normal conditions for molding TORLON resins are outlined below.

Rheology

When TORLON polyamide-imide is injection molded, its flow behavior plays a critical role. Polyamide-imides, like most thermoplastics, exhibit a viscoelastic behavior in the melt phase. As shown in Figure 3, at high shear rates, TORLON resin's viscosity approaches that of ABS and polycarbonate. At low shear rates, the resin flows only when subjected to high pressure.

Injection Speed

High injection speeds may be necessary to mold high-quality parts, especially parts containing thin wall sections. However, care must be taken when using high injection rates to avoid injecting too quickly. Too high an injection rate can result in blistering at the gate, color change or degradation, splay or surface delamination, and gas burning at the knit lines or

Figure 2

Drying Time of TORLON Resin at Various Temperatures

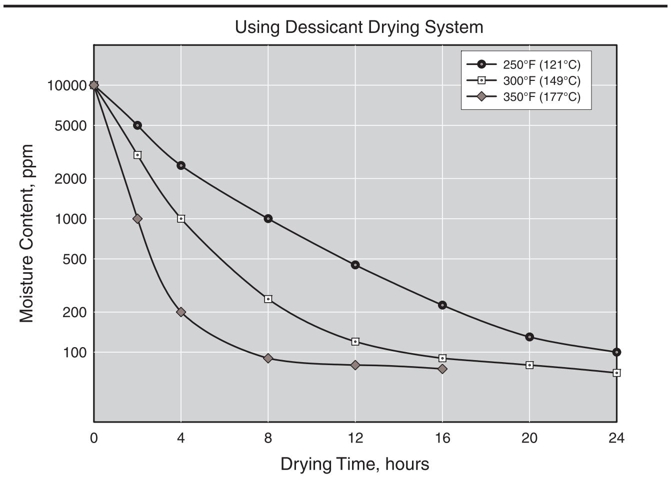
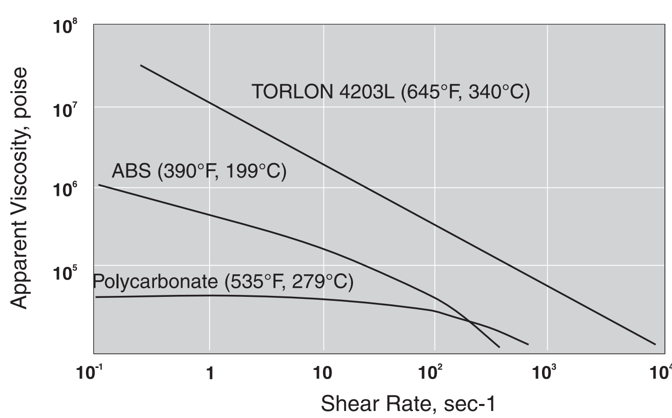


Figure 3

Apparent Viscosity vs. Shear Rate



vents. If these types of flaws are observed, make the necessary adjustments to the injection speed and/or open the gate and the vents.

Injection Pressure

Because of TORLON polymers' rheology and viscosity, high injection speed and pressure are required. Always fill the entire mold with primary injection boost, then drop off to a hold pressure. Newer machines have staged or programmable injection velocity and hold pressure. Begin hold pressure at a high setting 6-8 kpsi (41-55 MPa) for several seconds, then drop off to 3-5 kpsi (21-34 MPa) for the duration of the hold pressure sequence. This will help minimize or eliminate any internal porosity or sink.

Back Pressure/Screw Speed

Because TORLON PAI is shear-sensitive, use moderate back pressure, approximately 1 kpsi (6.9 MPa), and lower screw recovery speeds (50-100 rpm). Avoid intermittent feeding and screw slippage, which can lead to overheating and possible polymer degradation.

Barrel Temperature

Recommended barrel temperatures are shown in Table 3.

Cycle Time

Total cycle time should be as short as possible in order to reduce residence time in the barrel and mold. Excessive residence time will cause TORLON polymer to cure in the barrel, reducing flow. However, if the cycle time is too short, sprue breakage, sticking, warpage of the part, foaming, or blistering in thick sections may occur. Darkening of the material followed by a decrease in shot size indicates excessive residence time and/or barrel temperature. Should this occur, purge the TORLON resin from the barrel immediately. Because cycle time consistency is especially important for successful molding of TORLON resin, automatic operation is highly recommended.

Table 3

Recommended Barrel Temperatures*

	3 Zone Control	
Zone	**°F**	**°C**
Feed	580	304
Middle	620	327
Front	650	343
Nozzle	700	371

*Actual temperature profile may vary depending on grade.

Mold Heating

The recommended range for the surface temperature of the mold is 325°F to 425°F (163°C to 218°C), this can be achieved by either heat transfer fluid or cartridge heaters. Insulate the mold from the platen to minimize heat loss to the molding press. Design moving parts such as slides, to function smoothly at the mold operating temperature. Moisture content, fill speed, and resin grade are all factors that can affect mold temperature.

Molding Problems

A guide to trouble shooting common molding problems is provided in Table 4. Please consult your technical service representative for additional guidance in molding TORLON resins.

Shutdown Procedure

When molding is temporarily interrupted for 15 minutes or longer, TORLON resin must be removed from the machine, or it will set up in the barrel. Resin removal can be accomplished by closing the hopper, withdrawing the injection unit, and emptying the barrel.

For total shutdown, a commercial high-temperature purging compound is recommended. It should be hand-fed directly into the throat of the machine while the screw is turning. Continue until the purge material is clean. Empty the purge and leave the screw forward.

For start-up, reintroduce TORLON resin and purge again until 100% TORLON resin exits the barrel. If the screw cannot be rotated because it is full of cured TORLON resin, set the barrel temperature at 800°F (427°C) for 2-4 hours to break down the resin. Remove the nozzle and proceed with normal purging procedures.

Table 4

Trouble Shooting Guide*

Problem	Probable Causes	Suggested Remedies
Brittle parts	Wet material	Dry the resin
Burn marks	Vents clogged	Clean vents
	Insufficient venting	Deepen vents
	Fill rate too fast	Dry the resin or slow injection speed
Cavity not filling	Injection time too short	Lengthen boost time
	Gate too small	Open gate
	Insufficient venting	Deepen vents
	Shot size too small	Increase shot
	Injection speed too slow	Increase injection speed
Flash	Boost time too long	Shorten boost time
	Clamp pressure too low	Increase clamp pressure
	Mold damaged or misaligned	Resurface or realign mold
	Wet material	Dry the resin
Internal voids	Wet material	Dry the resin
	Gate too small	Open the gate
	Runner too small	Open runner
	Runner too long	Relocate gate
	Injection rate too slow	Increase rate
	Hold time too short	Lengthen hold time
	Hold pressure too low	Increase hold pressure
	Resin melt or mold too cold	Raise temperature
	Insufficient venting	Deepen or add vents
	Jetting	Redesign gate
Post blowing	Wet material	Dry the resin
	Cycle too short	Lengthen mold-closed time
Progressively shorter shots	Residence time too long	Purge and reduce cycle
	Barrel temperature too high	Reduce barrel temperature
	Shot size too small	Use a smaller capacity press or add dummy cavity to increase shot size
Sink marks	Hold time too short	Lengthen hold time
	Hold pressure too low	Raise hold pressure
	Gate too small	Open gate
	Boost time too short	Lengthen boost time

Problem	Probable Causes	Suggested Remedies
Sticking parts	Cycle too short	Lengthen cycle
	Undercuts	Polish mold
	Part overpacked	Shorten boost time
	Wet material	Dry the resin
Sticking sprue	Nozzle-bushing mismatch	Open bushing
	Insufficient sprue puller	Shorten knock-out pin
	Cycle too short	Lengthen cycle
	Undercuts in bushing	Polish bushing
	Nozzle seat damaged	Resurface seat or replace bushing
Surface poor	Resin or mold too cold	Raise temperature
	Injection speed too slow	Increase injection speed
	Injection speed too slow	Raise injection pressure
	Injection speed too slow	Increase boost time
	Poor mold surface	Polish mold
	Excessive mold lubricant	Clean mold, spray less
	Gate too small	Increase gate size
	Poor venting	Open or clean vents
	Wet material	Dry the resin
Surface blisters	Cycle too short	Lengthen cycle
	Contamination	Purge
	Wet material	Dry the resin
	Excessive screw slippage	Lower back pressure
	Excessive screw slippage	Cool rear zone
Warping	Cycle too rapid	Lengthen cycle
	Resin melt or mold too cold	Raise temperature
	Poor gating	Increase or relocate gates
	Excessive packing at gate	Lower hold pressure or shorten hold time
Weld line weak	Resin or mold too cold	Raise temperature
	Insufficient gating	Increase or relocate gates
	Flow too long	Create overflow tab
	Injection speed too slow	Increase injection speed
	Vents clogged or insufficient	Clean or deepen vents
	Wet material	Dry resin

*This quick reference to commonly encountered molding problems should be helpful to the experienced molder. Because no guide can be all-inclusive, our technical service engineers are ready to help you.

Post-Cure

Description of the Post-Curing Process

TORLON polymers are unique in that they are supplied at a relatively low molecular weight to facilitate processing, and the molded articles must be post-cured to achieve maximum properties. The as-molded parts appear finished, but are actually weak, brittle, poor in chemical and wear resistance, and do not have optimum thermal resistance.

The post-curing process involves placing the molded articles in a forced-air oven and thermally treating them to a series of increasing temperatures for various times. The program of times and temperatures is referred to as the cure schedule or cure cycle.

During the post-curing process, the molecular weight of the polymer increases by chain extension. When this chemical reaction occurs, water is generated. The removal of this water of reaction is essential to the progress of the chain extension, and diffusion of the water limits the rate of reaction. As the molecular weight increases; virtually all mechanical, chemical, and thermal properties are affected. Figures 4 through 9 illustrate the changes that occur when test specimens 1/8 inch (3 mm) thick are post cured. Strength and toughness are dramatically increased, while heat distortion temperature increases about 75°F (42°C).

Figure 4 shows that as the molecular weight increases, the tensile strength increases rapidly until it is approximately twice the strength of uncured material.

The as-molded polymer has very low elongation. As shown in Figure 5, during cure the elongation goes from about 5% to about 15%; showing a tremendous increase in toughness.

Figure 6 shows that flexural strength essentially tracks tensile strength.

Figure 5

Cure vs. Elongation

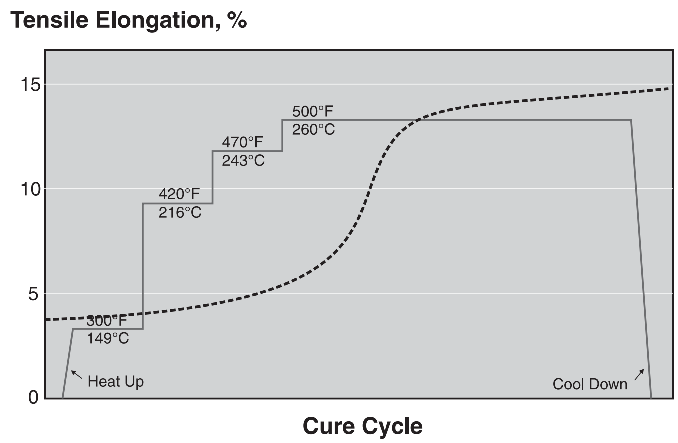


Figure 4

Cure vs. Tensile Strength

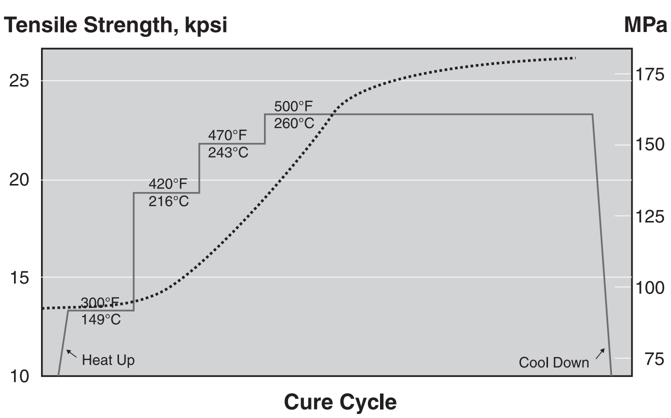


Figure 6

Cure vs. Flexural Strength

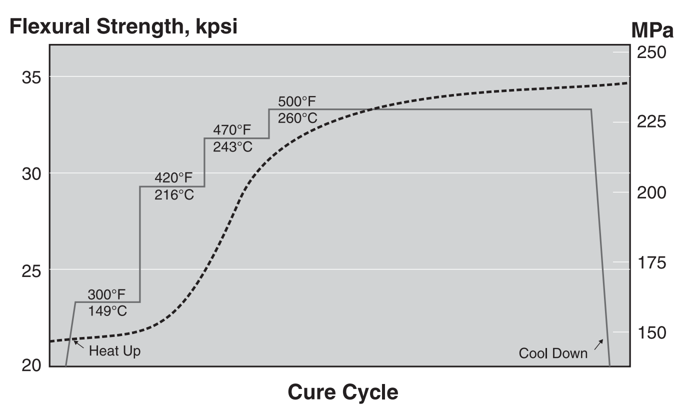


Figure 7

Cure vs. Flexural Modulus

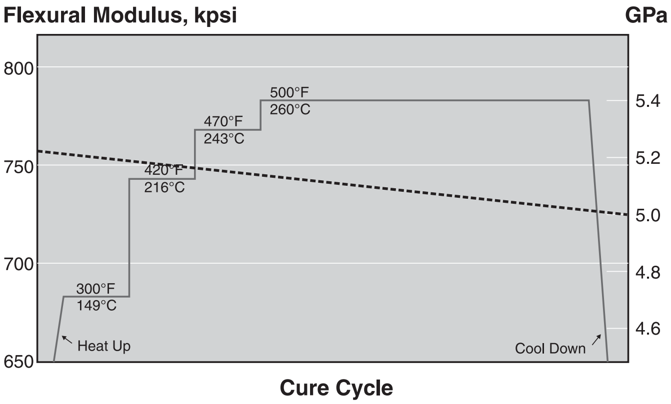
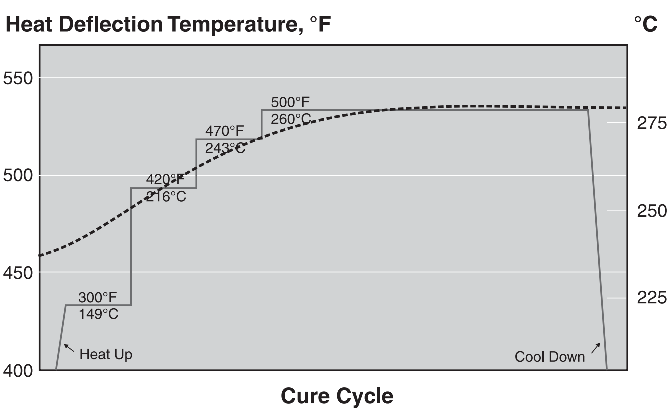


Figure 7 shows that the flexural modulus decreases slightly as cure progresses. As the elongation increases and the resin becomes more ductile, the modulus declines slightly to reflect the increase in toughness.

Figure 8

Cure vs. Deflection Temperature

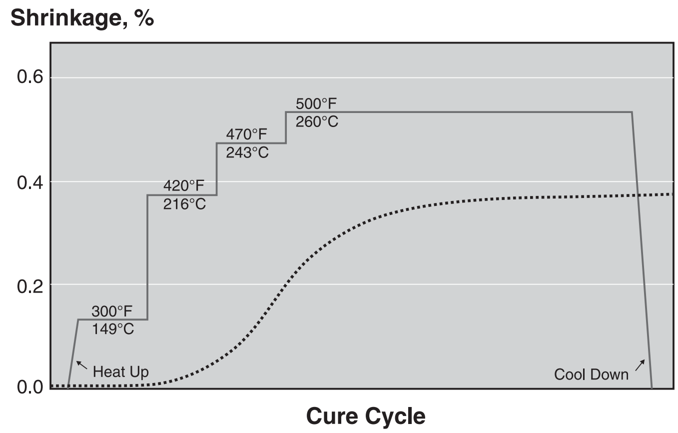


As shown in Figure 8, the heat deflection temperature increases slowly during the curing process. The deflection temperature limits the rate at which the cure temperatures can be raised. It is possible to cause part distortion if the oven temperature exceeds the heat deflection temperature.

Parts molded from TORLON resin continue to shrink during cure. Therefore, the shrinkage rates in Table 2 include both the molding and curing shrinkage. The majority of the shrinkage occurs early in the process, then stabilizes. Generally, cure cannot be used to control dimensional problems.

Figure 9

Cure vs. Shrink



Guidelines for Oven Control

Uniform oven temperatures are essential for the post-curing process. The greatest difference in temperature between the hottest and coldest point of the oven that can be tolerated is 10°F (5.6°C). A hot point commonly occurs near the air intake and a cold point near the exhaust vent.

For best control, place at least four thermocouples in a symmetrical pattern, including one in each of the hot and cold points. Make sure only the thermocouple wires and not the thermocouple leads are in the oven. Thermocouple leads are not designed to withstand oven temperatures and will be ruined if heated along with the thermocouples. The thermocouple leads should be attached to a digital read-out. Large differences in temperature may be controlled by opening or closing the vents. In some cases, it may be necessary to rebaffle the oven or change the blower capacity. Controllers programmed to raise the temperature by 0.5°F (0.3°C) per minute are recommended. Automatic shut-off and manual reset features are desirable. The oven should shut off automatically when the temperature reaches 5°F (2.8°C) above the set point. This is required to avoid distortion of the parts, which can occur if the temperature exceeds the deflection temperature of the part.

Cure Schedules

The manufacturing specifications for TORLON polymers are based upon test specimens that were post-cured using a relatively short cure schedule, about 4.5 days. Translating the cure schedule information generated on thin test specimens to actual molded parts is difficult for the following reasons:

Rate

All properties do not appreciate at the same rate. While mechanical properties, such as strength and elongation, are achieved rapidly, wear resistance and resistance to certain aggressive chemicals take much longer to develop.

Figure 10 shows that wear resistance continues to improve during extended cure.

Thickness

Part thickness limits the rate at which the parts can be cured without distortion. If thick parts are cured too rapidly, the water of reaction can cause blistering or even “ballooning”.

Geometry

Thicker parts take longer to cure because the water of reaction must diffuse from the part for the reaction to proceed, and the reaction rate diminishes as the diffusion path lengthens. Certain parts, such as those with very thin walls and/or delicate features, may require fixturing during post-cure to meet tight dimensional tolerances.

Stresses

Parts may distort due to relaxation of molding stresses. During the post-curing process, the cure temperatures approach the deflection temperature and some highly-stressed parts may tend to distort if the cure schedule is too aggressive. Conversely, extending the post-cure schedule, especially the lower-temperature initial stages may reduce shrinkage variations.

Cure Schedule Determination

Starting Points

The goal of a post-cure schedule is to achieve a sufficient cure to meet the enuse requirements in the minimum amount of time. Like other chemical reactions, the chain extension reaction rate is a function of temperature, and the reaction proceeds more quickly at 500°F (260°C). Generally, it is desirable to bring the temperature of the part to 500°F (260°C) as rapidly as possible consistent with avoiding distortion. The time the part spends at 500°F (260°C) determines the completeness of cure.

No single means for determining the extent of cure in molded articles made of TORLON PAI exists. Minor oxidation during cure causes the surface of the molded articles to become darker, but color is not an indication of adequate cure. Parts heated in a nitrogen atmosphere will cure but will not darken. Various methods for measuring cure have been tried, such as inherent viscosity, glass transition temperature, and dimensional inspection after thermal cycling. While these methods may detect the occurrence of cure, they are inadequate for judging the extent of cure. Destructive testing of sample parts throughout the cure cycle, along with glass transition temperature data, is generally a good measure of the extent of cure.

Optimization of the cure schedule for a particular part molded from TORLON resin requires knowledge of the end use requirements, the dimensional tolerances of the part, and the geometry of the part. It can require considerable testing.

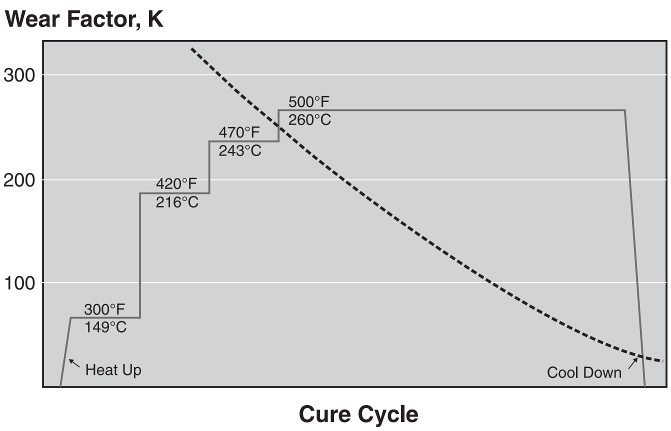
Table 5

Standard Cure Cycles

		Cure Temperature	
Part Type	**Days**	**°F**	**°C**
Parts with a maximum cross-sectional thickness of less than 0.3 inch (7.6 mm)	1	300	149
	1	375	191
	1	400	204
	1	425	218
	1	450	232
	1	470	243
	1	485	252
	10	500	260
Parts with a maximum cross-sectional thickness between 0.3 and 0.5 inch (7.6 and 12.7 mm) or thinner parts requiring high flatness	1	300	149
	1	350	177
	1	375	191
	1	400	204
	1	425	218
	2	450	232
	3	470	243
	2	480	249
	1	490	254
	10	500	260

Figure 10

Wear Factor Decreases with Extended Cure



The standard cure cycles are shown in Table 5. These cycles, while conservative, will assure fully cured parts without distortion.

The outstanding thermal resistance of TORLON polymers makes it impossible to “over cure”. Studies involving aging test specimens at 500° F (260°C) in air have shown mechanical properties continue to increase for more than 60 days. The time at any step may be extended without damaging the parts or degrading properties. In fact, it is often desirable to lengthen the time at 500°F (260°C) to ensure that maximum properties have been achieved.

If the curing process is interrupted, it can be repeated from the beginning without harm. If the interruption is more than 24 hours, the procedure should be started from the beginning. If the interruption is less than 24 hours, revert to the beginning of the step in the process where the interruption occurred. For example, if it is discovered that the oven shut off at 500°F (260°C), do not assume any number of days at this temperature has been completed and start from that point and begin the entire 500°F (260°C), step over again. However, do not exceed 500°F (260°C).

After the post-cure program, no special cool-down procedure is normally required.

Post Cure of Machined Parts

Most parts developed for injection molding are close to near net shape and usually require machining only to control some dimensions to tolerances not achievable by molding or to add features more easily machined than molded in, such as a hole perpendicular to the parting line.

If a part has had more than 0.030 inch (0.76 mm) removed from its surface, it may require recure to achieve the material’s ultimate wear and chemical resistance characteristics.

The procedure for a conservative but safe recure of machined parts would be to dry the parts at 300°F (149°C) for 24 hours for each 1/8 inch (3 mm) of part thickness and then cure the part as follow:

- 1 day at 375°F (191°C)
- 1 day at 425°F (218°C)
- 1 day at 475°F (246°C)
- 5 days at 500°F (260°C)

Experimental Procedure for Establishing a Cure Schedule

Occasionally, it may be desirable to optimize the curing schedule for a particular part. The following procedure may be used to establish a cure schedule experimentally.

Step 1

A drying step is necessary to remove casual water (moisture absorbed from the environment between the time of molding and the beginning of cure). Depending on part thickness, set the oven temperature at 250°F to 350°F (121°C to 177°C) and place the parts in the oven for 24 hours to accomplish drying. In some cases the drying step may be eliminated if the parts are removed from the mold and placed directly into an oven at 400°F to 420°F (204°C to 216°C).

Step 2

After the drying step (temperature below 400°F (204°C), open the oven and inspect parts for blisters or any dimensional change greater than normal shrinkage (40 to 50% of the total shrinkage). If the parts are blistered or distorted, reduce the oven temperature by 10°F (5.5°C), and start step 1 again using fresh parts. If no defects are found, place the parts back in the oven and slowly, over a one-hour period, increase the temperature to the first cure level of 400°F to 420°F (204°C to 216°C).

Step 3

Use the standard cure cycle table (Table 5) to determine the starting cure temperature levels for establishing the proper cycle. The thickest wall section of a part will be the limiting factor. After each 24-hour period at each temperature, check dimensions and surface condition. If no defects are found, proceed to the next higher temperature until the final 500°F

(260°C) level is achieved. If distortion or blistering occurs at any level, the time at the lower level must be extended or an intermediate temperature must be used.

Regrind

Sprues and runners intended for grinding and reprocessing must be removed prior to post-curing. **Post-cured sprues, runners, and/or parts made of TORLON PAI cannot be reprocessed**.

When removing parts from the runner, sever the gate carefully to avoid breaking the part. If side cutters are used, make sure they are sharp and cut the gate at some distance from the part. Remember that prior to post-curing, TORLON resin is quite brittle.

Reground resin should be clean, screened to remove large chunks and very fine dust, and dried. Regrind and virgin resin should be blended prior to feeding it to the injection molding press.

TORLON polymers can tolerate high-regrind levels without significant compromise of properties. Table 6 shows the retention of properties of TORLON 4203L after consecutive regrinds at 30% regrind. A drop in tensile elongation is the most notable effect.

Although the effect of regrinding the fiber-reinforced grades has not been studied extensively, some reduction in flow properties has been seen. Since reprocessing is likely to cause reduction of reinforcing fiber length, some loss of mechanical properties is expected.

Table 6

Property Retention of TORLON 4203L Resin Containing 30% Regrind

	% Retention		
	Regrind Cycle		
Property	**1**	**2**	**3**
Tensile Strength	100	98	96
Tensile Modulus	100	99	98
Tensile Elongation	73	70	68
Flexural Modulus	100	99	98
Izod Impact	100	99	99
Deflection Temperature	101	102	103

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