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Torlon® PAI

Processing Guide

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Introduction

Torlon® Polyamide-imide (PAI)

Torlon® PAI polymers are being specified for a wide variety of applications requiring strength and durability at extremely high temperatures. Torlon® PAI parts are reliable under conditions too severe for other injection moldable thermoplastics.

Of the many high-performance plastics, Torlon® PAI has a unique combination of properties:

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

Processing Guide Overview

This brochure introduces the injection molder to Torlon® PAI high-performance polymers, offers criteria for selecting injection molding equipment, provides guidance on designing tools, suggests resin drying procedures, furnishes molding parameters, discusses curing, provides a trouble shooting guide, and finally presents a study of the effects of molding conditions on flow and shrink.

Fabricating Torlon® PAI resin requires special considerations. Although the process of injection molding is used for many thermoplastics, this brochure concentrates on the aspects that are either unique to or especially important for molding Torlon® PAI polymers. You can minimize rejects and optimize the quality of finished parts by following the recommendations in this brochure. Experience has shown that some machine and mold modifications are often necessary for molding Torlon® PAI parts. 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® PAI resin. In some cases, 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® PAI parts, the shot size should be between 50 % and 80 % of the barrel capacity. The ratio of capacity to shot size is important because Torlon® PAI 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® PAI resin, the clamp pressure should be at least 562 kg/cm^2 (4 tons/inch^2) of projected part area. Doubling the clamp pressure will help maintain part dimensions at the parting line.

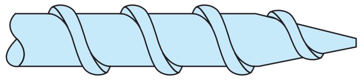
Screw Design

Because of the high viscosity and reactivity of Torlon® PAI polymers, a special design is required, which is shown in Figure 1.

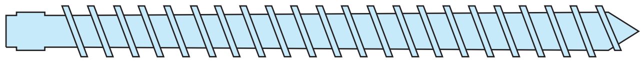
A low-compression-ratio screw with no check device is required for processing Torlon® PAI polymers. A compression ratio between 1:1 and 1.5:1 is recommended. The length-to-diameter (L/D) ratio of the screw should be between 18:1 and 24:1 for uniform heat distribution.

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 5.0 mm (0.20 inches). 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 with rudimentary flights for self-cleaning (similar to those used for processing polyvinylchloride (PVC) or thermosets) is desirable.

Figure 1: Screw design



Rudimentary flights on screw tip



Compression ratio	1:1 to 1.5:1
Length to diameter ratio	18:1 to 24:1
Smooth, constant taper	

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® PAI 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® PAI polymers.

Tool Design

Mold Design

Careful mold design will accommodate Torlon® PAI polymer'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® PAI 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.

Cavity Design

Shrinkage

Cavities should be sized in general accordance with the shrinkage values 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 occurs during curing.

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® PAI polymers are amorphos, and amorphos polymers tend to be isotropic, some variation in shrinkage with flow direction has been observed.

While the variance in shrinkage from shot to shot is low, allowing Torlon® PAI parts to be molded to tolerances of ±1 part per thousand, and even lower in some cases. It may be difficult to predict the precise cavity dimension required to meet a very close tolerance. In those cases, it is appropriate to cut the cavity a little smaller (steel safe) than the predicted size, and then mold, cure, and measure samples for the critical dimension. Using that additional information, finish machining the cavity to meet the final part dimensions.

Table 1: Basic mold types

Mold Type[1]	Number of Shots	Type of Steel	Rockwell "C" Hardness
Prototype	Less than 100,000	P-20 Pre-hardened or S-7	28 – 32
Production	More than 100,000	H-13 Air hardened	50 or higher

[1] *Soft metals, such as aluminum, are not recommended, even for prototype molds.*

Table 2: Shrinkage of Torlon® PAI grades

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

Ejection

Torlon® PAI resin exhibits very low shrinkage. Only half of the shrinkage shown in Table 2 occurs during molding; therefore, parts tend to stick in the cavity and positive ejection must be designed into the tool. Because as molded Torlon® PAI parts are brittle, smooth positive linear ejection is required or sensitive parts may crack on ejection. Allowing generous draft and careful polishing will facilitate ejection. As a minimum, draft of 0.5° to 1° 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 Torlon® PAI part from a mold containing undercuts unless side actions are used. Torlon® PAI 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® PAI 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 which can be removed manually from the mold.

Multi-Cavity Tools

Torlon® PAI resin can be molded in a traditional 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 5.1 cm (2.0 inch) outer diameter in a three-plate, four-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 three-plate tool for multiple cavities. The seal rings themselves only weigh about 1 gram. Each shot produces four 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 significantly reduced runner that only weighs 0.5 grams. Therefore, each shot produces one 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 four rings in the single-cavity tool uses 6 grams of resin as compared to 15 grams in the four-cavity mold, saving 9 grams of material.

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 cavity approach more economical.

Flow Path Design

Torlon® PAI polymers tend to "jet" very strongly. In other words, in the absence of restrictions, the resin flows in a disorderly fashion, and it will not fill the mold uniformly without proper mold design. 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 are the key.

Sprues and Runners

To minimize part cost as well as maximize part integrity, keep the distance the resin must flow to a minimum. There are no hard-and-fast formulas for determining sprue and runner sizes. Torlon® PAI 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.

Hot runners are not recommended for molding Torlon® PAI resins. Hot runner tooling for multi-cavity tools and hot sprue bushings for single-cavity tools utilize heated nozzles to allow injection of material directly into a part without a sprue and runner system. While this is desirable in eliminating waste in the form of sprues and runners, it also adds additional dwell time to the resin in the nozzles or bushings. This additional time under heat will cause Torlon® PAI to react, increasing the melt viscosity and reducing processability. Also, the increased resistance to flow caused by the smaller nozzle size used with "hot drops" is not compatible with the flow characteristics of Torlon® PAI resin.

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® PAI injection molding grades. Hot sprues for Torlon® PAI 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.

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 and at least as large as the part thickness. To counter the tendency of Torlon® PAI polymers to jet, direct the resin to impinge on the mold wall at 90°.

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® PAI 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 0.064 mm (0.0025 inches) deep, will prevent burns and increase knit line strength.

Weld or Knit Lines

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 and 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 ≥10% of the part thickness.

Inserts

Torlon® PAI as a polymer has a low coefficient of thermal expansion, making it an excellent material for applications requiring the integration of metals. Metal inserts including brass, steel, stainless steel and aluminum have been successfully molded into Torlon® PAI parts; stainless steel is 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 supported so they are not displaced during injection of the plastic. Inserts should be preheated to the temperature of the mold or between 149°C to 204°C (300°F to 400°F). A sufficient radial wall of Torlon® PAI resin should be allowed around the insert to prevent cracking during cure, as the insert will expand as the Torlon® PAI resin shrinks.

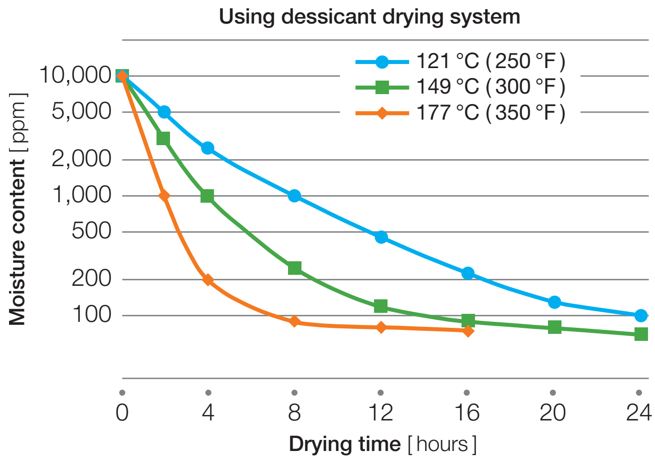
Pre-Drying

Because Torlon® PAI resin is hygroscopic, it will pick up ambient moisture. Before processing Torlon® PAI resin, drying is required to avoid brittle parts, foaming, and other molding problems.

The resin must be dried to a moisture content of 500 ppm or less. A dessicant dryer capable of maintaining a dew point of –40 °C (–40 °F) is recommended. If drying is done in pans or trays, put the resin in layers no more than 5 cm to 8 cm (2 inches to 3 inches) deep in drying trays. Figure 2 shows the drying time required at 121 °C (250° F), 149 °C (300 °F), and 177 °C (350 °F). If drying at 177 °C (350 °F), 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 per the schedule indicated in Figure 2.

Figure 2: Drying time at various temperatures



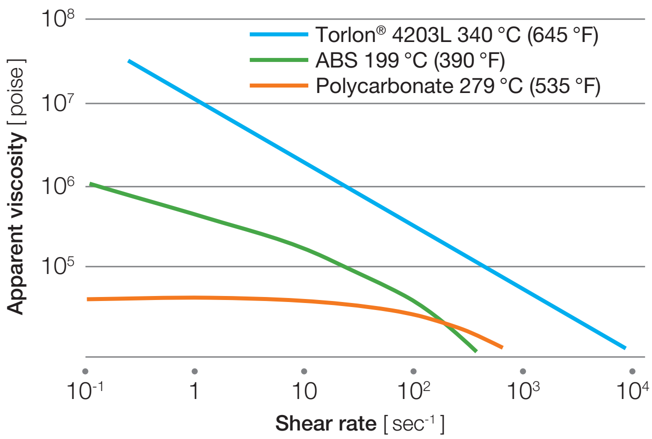
Injection Molding Conditions

Normal conditions for molding Torlon® PAI parts are outlined in this section.

Rheology

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

Figure 3: Apparent viscosity vs. shear rate



Injection Speed

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

Due to the rheology and viscosity of Torlon® PAI polymers, high injection speed and pressure is required. Always fill the entire mold with the primary injection boost, and 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 between 41 MPa to 55 MPa (6 kpsi to 8 kpsi) for several seconds, and then drop off to between 21 MPa to 34 MPa (3 kpsi to 5 kpsi), 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 6.9 MPa (1 kpsi), and lower screw recovery speeds (50 rpm to 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.

Table 3: Recommended barrel temperatures(1)

	Three Zone Control	
Zone	[°C]	[°F]
Feed zone	304	580
Middle zone	327	620
Front zone	343	650
Nozzle	371	700

(1) *Actual temperature profile may vary depending on grade.*

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® PAI polymer to cure in the barrel, thereby reducing flow. However, this must be balanced against a cycle that is too fast, which can lead to sprue breakage, sticking or warpage of the part, and foaming or blistering in thick sections. 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® PAI resin from the barrel immediately. Cycle time consistency is especially important for successful molding of Torlon® PAI parts and an automated operation is highly recommended.

Mold Heating

The recommended range for the surface temperature of the mold is between 163 °C to 218 °C (325 °F to 425 °F); this can be achieved by using either a 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 solving common molding problems is provided in Table 4. Consult your technical service representative for additional guidance in molding Torlon® PAI resins.

Shutdown Procedure

When molding is temporarily interrupted for 15 minutes or longer, Torlon® PAI resin must be removed from the machine, or it will set up in the barrel. This 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. Continue until the purge material is clean, and then empty the purge and leave the screw forward.

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

Table 4: Troubleshooting guide[1]

Problem	Probable Cause	Suggested Remedy
Brittle parts	Wet material	Dry resin
Burn marks	Vents clogged	Clean vents
	Insufficient venting	Deepen vents
	Fill rate too fast	Dry 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 resin
Internal voids	Wet material	Dry resin
	Gate too small	Open 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 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 smaller capacity p... dummy cavity to increa...

...e is a quick reference to commonly encountered molding problems and should be helpful to experienced molder... ...ntact one of our technical service engineers if you require additional information or assistance.

Description of Post-Curing Process

Torlon® PAI 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 they are actually weak, brittle, have poor chemical and wear resistance, and do not have optimal 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 is essential to the progress of the chain extension, and the 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 3-mm (1/8-inch) thick test specimens of Torlon® 4203L are post cured. These figures are included to give a relative indication of the property changes that occur during post-cure. They cannot be used to estimate the anticipated properties of parts cured by shortened or interrupted cycles.

Strength and toughness are dramatically increased, while heat distortion temperature increases about 42 °C (75 °F).

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, the elongation goes from about 5 % to about 15 % during cure, showing the tremendous increase in toughness.

Figure 6 shows that flexural strength essentially tracks tensile strength.

Figure 4: Cure vs. tensile strength

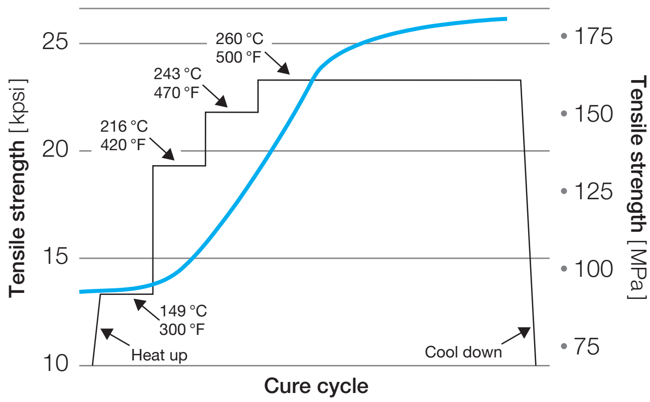


Figure 5: Cure vs. elongation

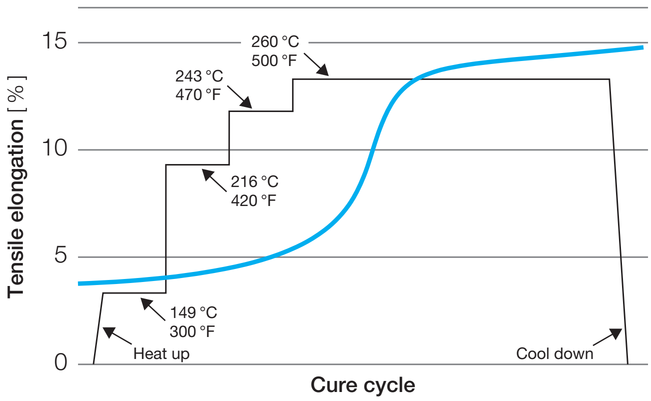
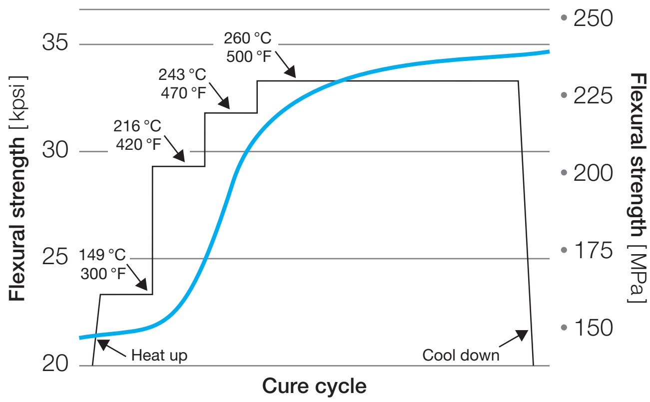


Figure 6: Cure vs. flexural strength



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.

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.

Torlon® PAI parts continue to shrink during cure, therefore, the shrinkage values in Table 2 include both the molding and curing shrinkage. The majority of the shrinkage occurs early in the process, and then stabilizes. Generally, cure cannot be used to control dimensional problems.

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 5.6 °C (10 °F). A hot point commonly occurs near the air intake, and a cold point occurs 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 0.3 °C (0.5 °F) per minute are recommended. Automatic shut-off and manual reset features are desirable. The oven should cut off automatically when the temperature reaches 2.8 °C (5 °F) 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.

Figure 7: Cure vs. flexural modulus

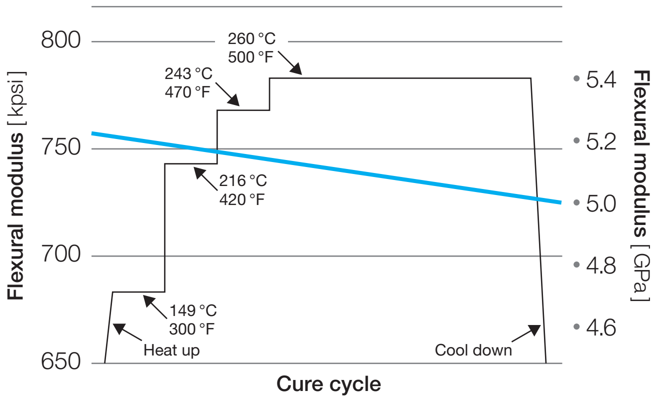


Figure 8: Cure vs. heat deflection temperature

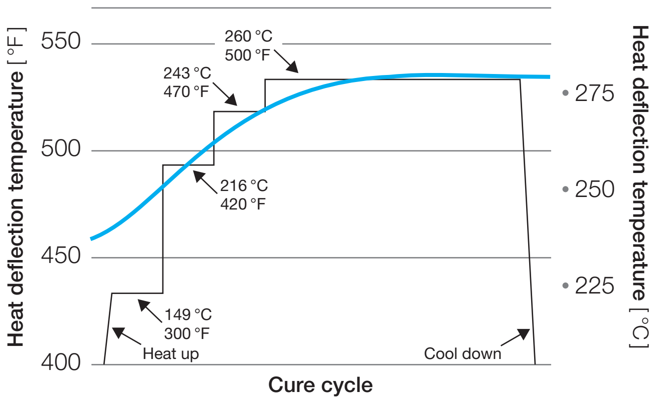
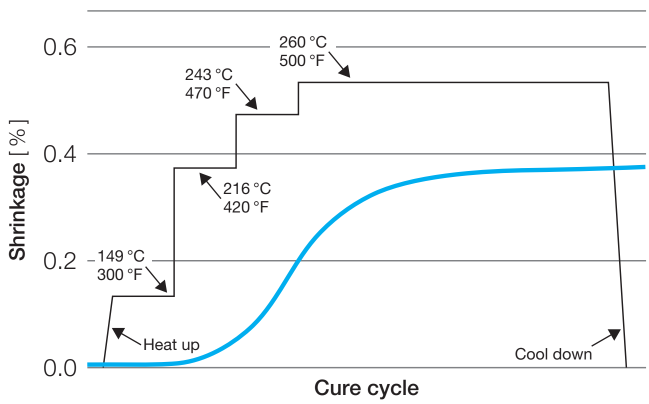


Figure 9: Cure vs. shrinkage



Cure Schedules

The manufacturing specifications for Torlon® PAI 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 reasons discussed below.

Rate

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

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

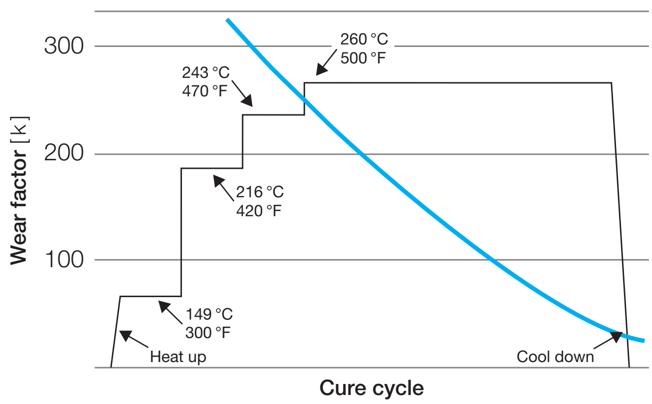
Thicker parts take longer to cure because the water of reaction must diffuse from the part for the reaction to proceed, and the reaction rate diminishes as the diffusion path lengthens. Certain parts, such as those with very thin walls and/or delicate features, may require fixturing during post-cure 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 heat deflection temperature, which may cause highly-stressed parts to distort if the cure schedule is too aggressive. Conversely, extending the time of post-cure, especially in the initial stages, may reduce shrinkage variations.

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

Figure 10: Wear factor decreases with extended cure



Cure Schedule Determination

Starting Points

The goal of a post cure schedule is to achieve a sufficient cure to meet the end use 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 260 °C (500 °F). Generally, it is desirable to bring the temperature of the part to 260 °C (500 °F) as rapidly as possible consistent with avoiding distortion. The time the part spends at 260 °C (500 °F) determines the completeness of cure.

No single means for determining the extent of cure in Torlon® PAI exists. Minor oxidation during cure, causes the surface of Torlon® PAI parts to become darker, but is not an indicator of adequate cure. Parts cured in a nitrogen atmosphere 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 data, is generally a good measure of the extent of cure.

Optimization of a cure schedule for a particular Torlon® PAI part requires knowledge of the end use requirements, the dimensional tolerances, and the part's geometry and can require considerable testing. The standard cure cycles are shown in Table 5. These cycles, while conservative, will assure fully cured parts without distortion.

Table 5: Standard cure cycles

		Cure Temperature	
Part Type	**Days**	**[°C]**	**[°F]**
Parts with a maximum cross-sectional thickness of less than 7.6 mm (0.30 inch)	1	149	300
	1	191	375
	1	204	400
	1	218	425
	1	232	450
	1	243	470
	1	252	485
	10	260	500
Parts with a maximum cross-sectional thickness between 7.6 mm and 15.9 mm (0.30 inch and 0.625 inch) or thinner parts requiring high flatness	1	149	300
	1	177	350
	1	191	375
	1	204	400
	1	218	425
	2	232	450
	3	243	470
	2	249	480
	1	254	[illegible]
	10	260	[illegible]

The outstanding thermal resistance of Torlon® PAI polymers makes it impossible to "over cure". Studies involving aging test specimens at 260 °C (500 °F) 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 260 °C (500 °F) to ensure that maximum properties have been achieved.

Before making any changes to the curing cycles, please consult your Solvay Specialty Polymers technical specialist.

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 260 °C (500 °F), do not assume any days at this temperature have been completed. Instead, begin the entire 260 °C (500 °F) step over again; however, do not exceed 260 °C (500 °F).

After the post-cure program, a special cool-down procedure is not 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 0.76 mm (0.030 inch) 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 149 °C (300 °F) for 24 hours for each 3 mm (1/8 inch) of part thickness, and then cure the part as follows:

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

Sprues and runners used for grinding and reprocessing must be removed prior to post-curing. Post-cured Torlon® PAI sprues, runners, or parts cannot be reprocessed. When removing the parts from either sprue or runner, be careful that you don't break back into the part. Remember that prior to the cure, Torlon® PAI 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® PAI polymers can tolerate high regrind levels without significantly compromising properties. Studies using Torlon® 4203L show that 100 % regrind has values for tensile strength, tensile elongation, flexural modulus, and heat deflection temperature equivalent to those normally obtained for virgin resin. This study was limited to a single regrind cycle. The use of reground resin may cause increased melt viscosity in succesive injection runs. Increased melt viscosity can have a dramatic affect on part fill and density. Reduced fill or density may be linked to dimensional changes, reduced impact strength and/or reduced elongation. The end user should verify that these potential issues are not a limiting factor in the performance of a finished cured part.

Solvay has not extensively studied the effect of regrinding fiber reinforced grades. Some reduction in flow properties has been observed and some reduction of properties due to loss of fiber length is expected.

Table 6 shows the retention of properties of Torlon® 4203L after consecutive regrinds using 30 % regrind. A drop in tensile elongation is the most notable effect.

The use of reground resin can cause increased melt viscosity in successive injection molding runs. Increased melt viscosity can affect part fill and density. The end user should verify that these potential issues are not a limiting factor in the performance of the finished cured part.

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
Heat deflection temperature	101	102	103

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