MACHINING INSTRUCTIONS FOR QUADRANT ENGINEERING PLASTIC PRODUCTS STOCK SHAPES

Quadrant Engineering Plastic Products' stock shapes can be easily machined on ordinary metalworking and in some cases on woodworking machines. However, there are some points, which are worth noting to obtain improved results.

In view of the poor thermal conductivity, relatively low softening and melting temperatures of thermoplastics, generated heat must be kept to a minimum and heat build up in the plastics part avoided. This is in order to prevent deformations, stresses, colour changes or even melting.

Therefore:

- tools must be kept sharp and smooth at all times,
- feed rates should be as high as possible,
- tools must have sufficient clearance so that the cutting edge only comes in contact with the plastics material,
- a good swarf removal from the tool must be assured,
- coolants should be applied for operations where plenty of heat is generated (e.g. drilling).

Machining forces / clamping

Machining forces being lower for engineering plastics than for metals and the former deforming more easily if clamped too tightly, clamping pressures should be reduced. However, avoid any unsafe condition where the plastics part could come out of the clamping tools.

As engineering plastics are not as rigid as metals, it is essential to support the work adequately during machining in order to prevent deflection or deformation, e.g. thin walled tubes often require the use of an internal plug at the chucked end in order to allow accurate machining of bushings with respect to roundness and tolerances.

Tools

High-speed steel (HSS) tools work well with many plastics. However, tungsten carbide (ground cutting edges!), ceramic or polycrystalline diamond (PCD) tooling is preferred for long production runs. This is essential when machining glass and/or carbon fibre reinforced or graphite filled materials (long tool life and good surface finish). When machining Duratron® CU60 PBI, Duratron® PAI or Fluorosint® MT-01, diamond coated or polycrystalline diamond tooling provides optimum results, but carbide tipped tools can be used in case of very short production runs.

Coolants

Apart from drilling and parting, coolants are not typically necessary for thermoplastic machining operations. Keeping the cutting area cool generally improves surface finish and tolerances.

When coolants are required, water-soluble coolants generally do very well. They should, however, not be used when machining amorphous thermoplastics, such as Quadrant® 1000 PC, Quadrant® PPSU, Duratron® U1000 PEI, Quadrant® PSU and Semitron® ESd 410C, because these materials are susceptible to environmental stress-cracking. The most suitable coolants for these materials are pure water or compressed air.

When the use of water-soluble coolants or general purpose petroleum based cutting fluids cannot be avoided during the machining of amorphous thermoplastics (e.g. during drilling of large diameters and/or deep holes or during tapping operations), the parts should immediately after machining be thoroughly cleaned with isopropyl alcohol first and rinsed with pure water afterwards in order to reduce the risk of stress-cracking.

A strong jet of compressed air or coolant also directs or removes chips from the work area, avoiding them to interfere with the cutting tool and the workpiece.

Machining tolerances

The machining tolerances that are required for thermoplastic parts are in general considerably larger than those normally applied to metal parts. This is because of the higher coefficient of thermal expansion, lower stiffness and higher elasticity, eventual swelling due to moisture absorption (mainly with nylons) and possible deformations caused by internal stress-relieving during and after machining. The latter phenomenon mainly occurs on parts where machining causes asymmetric and/or heavy section changes, e.g. when machining a U-shape from a plate or a bush from solid rod. In such cases, a “balanced” machining on both sides of the stock shape’s centreline, reducing warpage, or a thermal treatment (stress-relieving) after pre-machining and prior to final machining of the part may prove advantageous (see “Annealing instructions for Quadrant ‘Engineering Plastic products’ ”).

As a guideline, for turned or milled parts, a machining tolerance of 0.1 to 0.2% of the nominal size can be applied without taking special precautions (min. tolerance for small sizes being 0.05 mm). In this respect, the ISO 2768 can be used as a guide. However, tighter tolerances are possible with very stable ‘Advanced Engineering Plastic Products’ such as Duratron® CU60 PBI, Duratron® PAI, Ketron® PEEK, Techtron® PPS.

Turning

The continuous chip stream produced when turning and boring many thermoplastics can be handled well using a compressed air powered suction system (directly disposing the swarf onto a container), in this way avoiding the chip wrapping around the chuck, the tool or the workpiece.

See table below for tool geometry, cutting speeds and feeds.

Milling

Two flute end mills, face mills and shell mills with inserts as well as fly cutters can be used. Climb milling is normally recommended to help reduce heat by dissipating it into the chip, and melting and poor surface finishes are minimised.

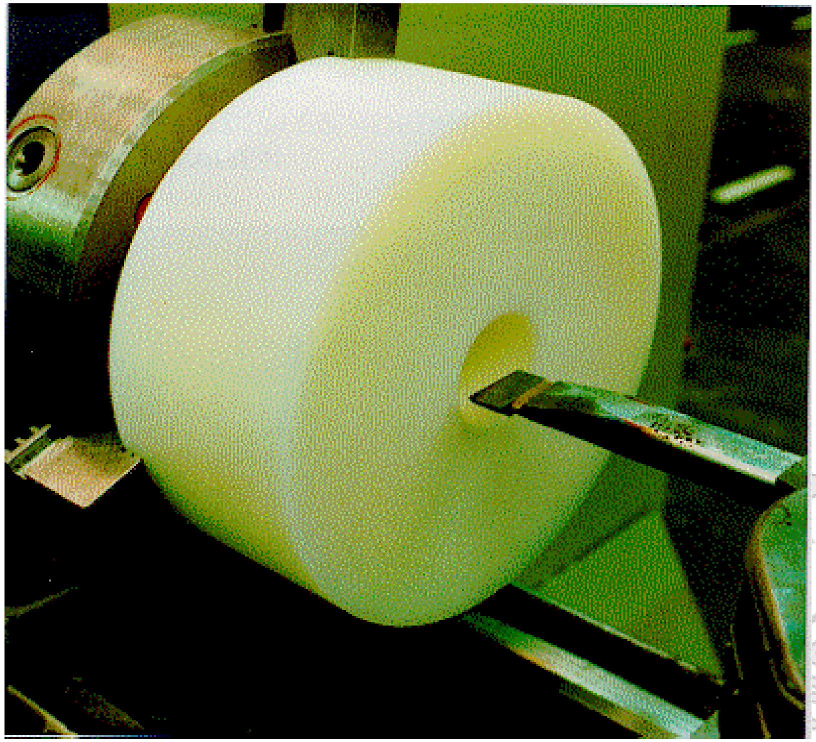
See table below for tool geometry, cutting speeds and feeds.

Drilling

High speed steel twist drills work well, but plenty of heat is generated so that a cooling liquid should be applied, especially when hole depths are more than twice the diameter. In order to improve heat and swarf removal, frequent pull-outs (peck drilling) are necessary, especially for deep holes (pull-out the drill every time a depth ≈ 1.5 x the diameter is attained).

For large diameter holes, it is advisable to use drills with a thinned web (dubbed drill) in order to reduce friction (shorter chisel edge) and consequently heat generation. It is also recommended for large holes to drill stepwise; e.g. a bore diameter of 50 mm should be made by drilling successively with ∅ 12 and ∅ 25 mm, then by expanding the hole further with larger diameter drills or with a single point boring tool.

For Duratron® CU60 PBI, Duratron® PAI, Ketron® HPV PEEK, Ketron® GF30 PEEK, Ketron® CA30 PEEK, Techtron® HPV PPS and Semitron® ESd 410C rods over 50 mm diameter, Ertalon® 66 GF30, Ertalyte®, Ertalyte® TX and Ketron® 1000 PEEK rods over 100 mm diameter, as well as for Ertalon® / Nylatron® rods over 200 mm diameter, it is even recommended not to use high speed twist drills at all in order to avoid cracks, but to "bore" the holes on a lathe using “insert drills” or a rigid, flat boring tool with its cutting edge perfectly set on centre-height (see picture below).
For these materials, some machinists prefer to heat the stock shapes up to about 120 - 150°C prior to drilling. However, care has then to be taken that after drilling and before starting the finishing operations, the plastics piece is completely cooled off to room temperature (uniform temperature all over the section prior to drilling as well as prior to finishing!).



When drilling or boring through-holes, feed should be reduced at the bottom of the cut in order to prevent the drill or flat boring tool from pulling through at the exit-side, causing chipping or breaking out. It is not recommended to hand feed the drill because the drill may "grab" and stress the material ("dubbing" the drill may reduce this effect).

See table below for tool geometry, cutting speeds and feeds.

Sawing

Band saws, circular saws or reciprocating saws that have widely spaced teeth in order to assure good chip removal can be used. They should also have enough set to minimise the friction between the saw and the work and also to avoid close-in behind the cutting edge, causing excessive heat build-up and even blocking of the saw.

Proper clamping of shapes on the worktable is required to avoid vibrations and consequent rough cutting or even rupture.

Important: Reinforced materials such as Ertalon® 66 GF30, Duratron® T4301 PAI, Duratron® T4501 PAI, Duratron® T5530 PAI, Ketron® HPV PEEK, Ketron® GF30 PEEK, Ketron® CA30 PEEK, Techtron® HPV PPS, Semitron® ESd 410C and Semitron® ESd 520HR, are preferably cut with a band saw which has a tooth pitch of 4 to 6 mm (Duratron® CU60 PBI: 2 to 3 mm). Do not use circular saws, as this usually leads to cracks.

Moisture protective packaging

Quite some polymers absorb moisture from the environment. In time, this can cause swelling and affect part dimensions. Therefore it is important that high tolerance components machined from Ertalon® / Nylatron®, Duratron® CU60 PBI, Duratron® PAI and Semitron® ESd 225 stock shapes are kept dry prior to installation. They should be stored in sealed bags with desiccant. An additional "coating" of all surfaces with a film of pure mineral grease or oil also helps to minimise moisture absorption.

Machined parts, which have absorbed moisture and consequently have changed in dimensions, can be dried to regain their original machined size because moisture absorption is a reversible process. This is preferably done in a vacuum oven until constant weight is achieved (60 – 70°C for Ertalon® / Nylatron®, Semitron® ESd 225 and 150°C for Duratron® CU60 PBI and Duratron® PAI). The drying time obviously depends on the moisture content of the parts as well as on their thickness, but a minimum of 24 hours per each 3 mm of part thickness should be considered.

Safety

General industrial safety recommendations as well as eventual specific directions given in the Quadrant Engineering Plastic Products' "Product Handling Information Sheets" should be observed.

Ertalyte® / Ertalyte® TX / Duratron® CU60 PBI / Duratron® PAI / Duratron® PI / Ketron® HPV PEEK / Ketron® GF30 PEEK / Ketron® CA30 PEEK / Techtron® HPV PPS / Fluorosint® MT-01/ Semitron® ESd 410C / Semitron® ESd 520HR

With respect to their hardness and moderate toughness, it is recommended to observe some additional machining and design rules next to what has already been said earlier. This should prevent premature failure of these materials.

Sawing and drilling operations particularly, require a gentle machining approach. In design and assembly, stress concentrations should be avoided.

Especially Duratron® CU60 PBI, Fluorosint® MT-01 and Duratron® PI can be very challenging to machine and requires particular care. We recommend using low cutting speeds and small cutting depths (max. 1 mm).

Some tips:

- Always use light to moderate clamping forces. Never try to force the plastics part.
- Avoid sharp "internal" corners. The radius of curvature should be at least 1 mm. Refer to figure 1.
- To avoid chipping the edges during turning, boring or milling, chamfered edges are advantageous, providing a smoother transition between the cutting tool and the plastics work. Refer to figure 2.

- ♦ Sharp V-threads should be avoided (plenty of notch-sensitive areas) ; threads with a rounded root should be applied whenever possible.
- ♦ The use of thread cutting and thread forming screws is not recommended. Particularly the latter create tremendous stresses around the hole and are most likely to cause cracking at that point.
- ♦ When tapping threads or assembling bolts in blind holes, do not force the bottom of the holes by the tap- or bolt-tip since this is likely to induce cracking.

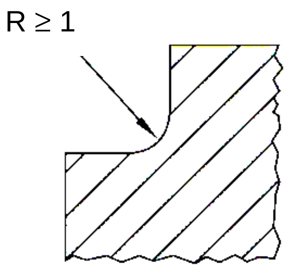


Fig. 1

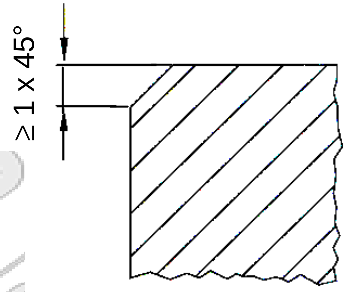
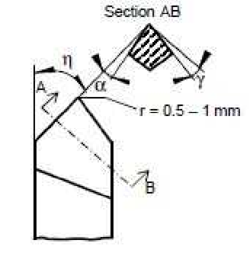


Fig. 2

Table: Tool geometry, cutting speeds and feeds for turning, milling, drilling and sawing.

Recommended tool geometries, cutting speeds and feeds for machining Quadrant Engineering Plastic Products' stock shapes.

TURNING

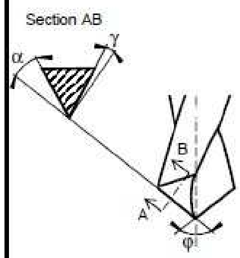


α : side relief angle (°)
γ : rake angle (°)
η : side cutting edge angle (°)
s : feed (mm/rev.)
v : cutting speed (m/min.)

MILLING

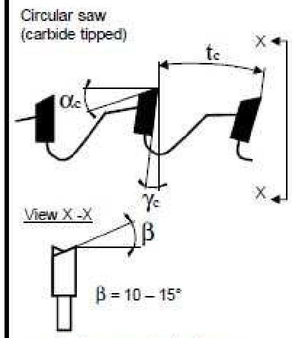
α : relief angle (°)
γ : rake angle (°)
s : feed (mm/tooth)
v : cutting speed (m/min.)

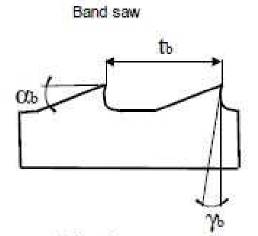
DRILLING



α : relief angle (°)
γ : rake angle (°)
φ : top angle (°)
s : feed (mm/rev.)
v : cutting speed (m/min.)

SAWING





c : circular saw b : bandsaw

α : relief angle (°)
γ : rake angle (°)
t : pitch (mm)
v : cutting speed (m/min.)

	TURNING					MILLING				DRILLING					SAWING							
	α	γ	η	s	v	α	γ	s	v	α	γ	φ	s	v	α_c	γ_c	t_c	v_c	α_b	γ_b	t_b	v_b
Ertalon® / Nylatron® PE 500 TIVAR® Grades Symalit® 1000 PVDF	5 - 15	0 -10	0 - 45	0.05 - 0.5	200 - 500	5 - 15	0 - 15	≤ 0.5	200 - 500	10 - 15	3 - 5	90 - 120	0.1 - 0.3	50 - 100	10 - 15	0 - 15	8 - 45		25 - 40	0 - 8	4 - 10	50 - 500
Ertacetal® Semitron® ESd 225	5 - 15	0 -10	0 - 45	0.05 - 0.5	200 - 500	5 - 15	0 - 15	≤ 0.5	200 - 400	5 - 10	3 - 5	90 - 120	0.1 - 0.3	50 - 100	10 - 15	0 - 15	8 - 45		25 - 40	0 - 8	4 - 10	50 - 500
Ertalyte® / Ertalyte® TX Duratron® T4203 / T4503 PAI Ketron® 1000 PEEK & TX PEEK	5 - 15	0 -10	0 - 45	0.05 - 0.5	200 - 400	5 - 15	0 - 15	≤ 0.4	150 - 300	5 - 10	3 - 5	90 - 120	0.1 - 0.3	50 - 80	10 - 15	0 - 15	8 - 25		25 - 40	0 - 8	4 - 10	50 - 400
Quadrant® 1000 PC Quadrant® PPSU Duratron® U1000 PEI Quadrant® PSU	5 - 15	0 -10	0 - 45	0.05 - 0.4	200 - 400	5 - 15	0 - 15	≤ 0.4	200 - 400	5 - 10	3 - 5	90 - 120	0.1 - 0.3	50 - 100	10 - 15	0 - 15	8 - 25	1000 - 3000	25 - 40	0 - 8	4 - 10	50 - 400
Duratron® PI Duratron® CU60 PBI Fluorosint® MT-01	5 - 10	3 - 5	0 - 45	0.05 - 0.2	25 - 100	5 - 15	0 - 15	≤ 0.15	25 - 100	5 - 10	3 - 5	90 - 120	0.1 - 0.3	25 - 50	10 - 15	0 - 15	8 - 25		25 - 40	0 - 8	2 - 3	25 - 100
Ertalon® 66 GF30 Duratron® T4301 / T4501 / T5530 PAI Ketron® HPV / GF30 / CA30 PEEK Techtron® HPV PPS Semitron® ESd 410C / 520HR	5 - 15	0 -10	0 - 45	0.05 - 0.3	100 - 200	5 - 15	0 - 15	≤ 0.3	75 - 150	5 - 10	3 - 5	90 - 120	0.1 - 0.3	50 - 80	10 - 15	0 - 15	8 - 25		25 - 40	0 - 8	4 - 6	50 - 200
Fluorosint® 135 / 207 / 500 Semitron® ESd 500HR	8 - 12	0 - 5	0 - 45	0.08 - 0.4	150 - 400	5 - 15	0 - 15	≤ 0.3	100 - 250	5 - 10	3 - 5	90 - 120	0.1 - 0.3	50 - 100	10 - 15	0 - 15	8 - 25		25 - 40	0 - 8	4 - 6	50 - 200

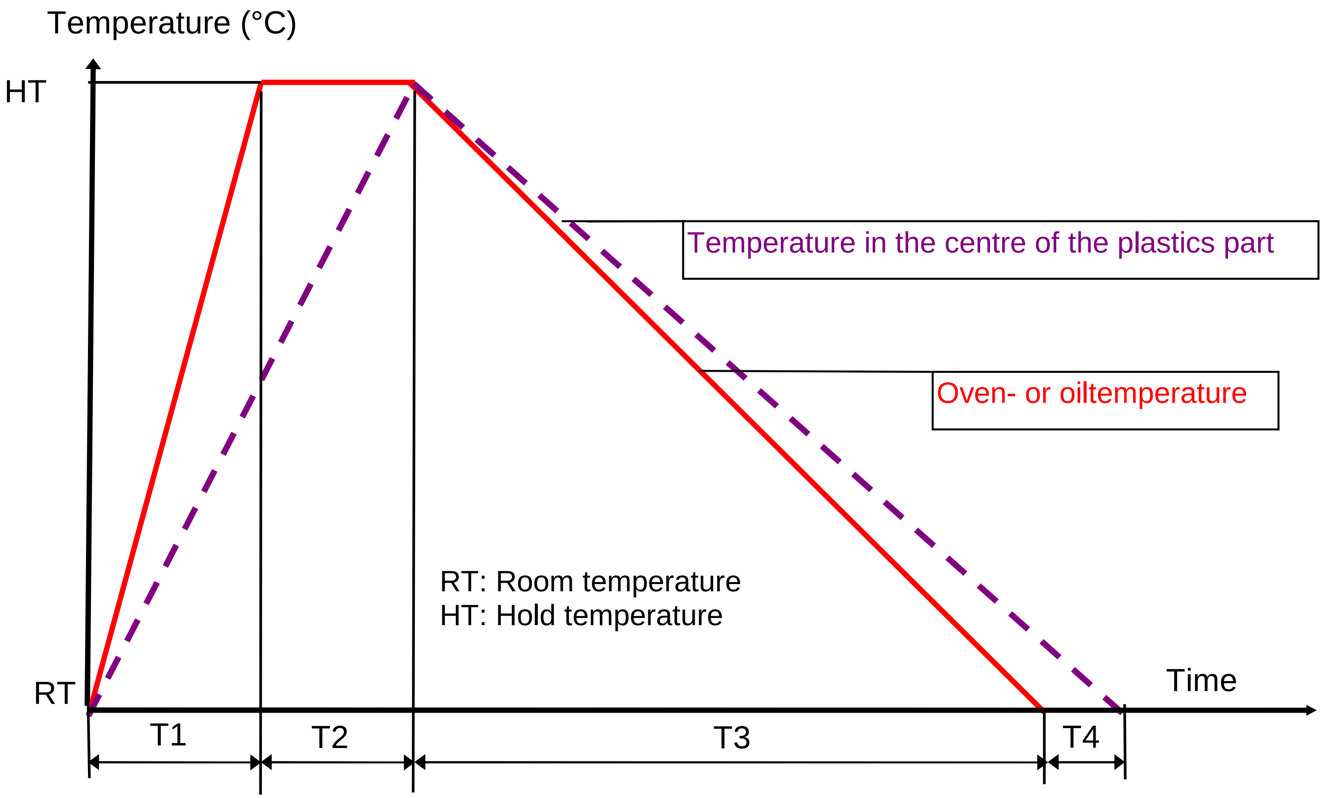
ANNEALING INSTRUCTIONS FOR QUADRANT 'ENGINEERING PLASTIC PRODUCTS'

Quadrant Engineering Plastic Products' stock shapes are annealed using a proprietary stress-relieving cycle to minimise any internal stresses due to the manufacturing process. This generally assures optimum dimensional stability during and after machining. However, as stated earlier, when machining parts which have to meet stringent requirements with respect to dimensional stability (tolerances, distortion, warpage,...) and/or when machining causes asymmetric and/or heavy section changes, it is recommended to apply an intermediate annealing procedure after pre-machining (*) and prior to final machining of the parts, or to let the material at least set in normal ambience for 48 hours to allow some "stabilisation" before finish machining.

Annealing can be done in an air or preferably a nitrogen circulating oven, or in an oil bath (depending on the temperature to be applied, paraffin-oil or the more temperature resistant and more expensive silicone-oil can also be used). When carried out on natural coloured material in an air circulating oven at temperatures over 100°C (particularly with nylon), a more or less pronounced colour change of the outer surface is to be expected (oxidation of a thin surface-layer that, however, most of the time is removed during further machining operations).

(*): this does not apply to turning, milling or drilling pre-machining operations only. Also annealing small rectangular blocks or thin disks immediately after being cut from plate or rod (before any other machining operation starts) can considerably improve dimensional stability during and after machining.

Recommended annealing procedure



General Engineering Plastics *Advanced Engineering Plastics*

Hold temperatures (HT):

Ertalon® / Nylatron®: 150 °C
Ertalon® 66 GF30: 170 °C
Ertacetal® C and H: 150 °C
Ertalyte® and Ertalyte TX: 150 °C
Quadrant® 1000 PC: 130 °C
PE 500 / TIVAR® Grades: 80 °C

Duratron® CU60 PBI: see below
Duratron® PAI / Semitron® ESd 520HR: see below
Ketron® PEEK: 250 °C
Techtron® HPV PPS: 200 °C
Quadrant® PPSU, Duratron® U1000 PEI 1000: 200 °C
Quadrant® PSU: 170 °C
Symalit® 1000 PVDF: 140 °C
Fluorosint® / Semitron® ESd 500HR: 250 °C
Semitron® ESd 225: 150 °C
Semitron® ESd 410C: 200 °C

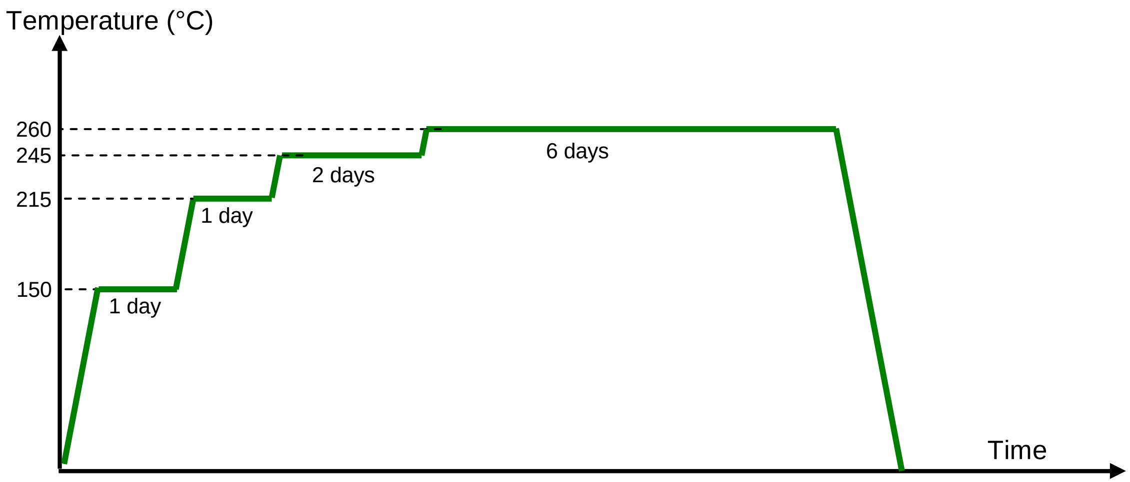
T1 : time required to heat the oven or the oil bath ; heating rate: 10 – 20 °C per hour.
T2 : additional time required to establish the set hold temperature in the centre of the plastics part (function of the wall thickness: 10 minutes / mm part thickness).
T3 : time required to cool the oven or the oil bath down to room temperature ; cooling rate: 5 – 10 °C per hour.
T4 : additional time required to establish normal room temperature also in the centre of the plastics part (function of the wall thickness: 3 minutes / mm part thickness).

Duratron® CU60 PBI

The annealing procedure given above can also be applied on Duratron® CU60 PBI. Heating is to be done in a nitrogen circulating oven at a hold temperature of 20°C above the expected maximum operating temperature, with a minimum of 150°C and a maximum of 350°C. If annealing temperatures over 200°C are used, it is recommended to dry the Duratron® CU60 PBI first at a temperature of 150°C for at least 24 hours.

Duratron® PAI

<u>To achieve maximum chemical and wear resistance</u>, Duratron® PAI parts machined from stock shapes may be post-cured. This can be done after finish machining or, when dimensions are critical, on pre-machined parts. When finish machining the latter, however, one should take care not to remove material to a depth greater than 0.5 mm, in order to preserve the chemical and wear resistance of the "skin" developed during post-curing.
This thermal treatment can be carried out in an air or nitrogen oven. Although the ideal cure cycle is different for every part and although it depends on the part shape and geometry, the cure cycle shown below can be applied for parts with thicknesses up to 12 mm.



Heating and cooling rate: 10 – 20°C per hour

P.S. The surface of Duratron® T4203 PAI turns dark brown when post-cured in air as a result of minor oxidation, but this does not affect the properties. This phenomenon does not occur when post-cured in nitrogen.

This same heat treatment can be used if an intermediate stress-relieving operation after pre-machining and prior to final machining of the parts is estimated necessary.

General remarks:

- When pre-machining, enough oversize should be left to allow the part still to be finish machined (at least 3% on diameters and lengths on circular parts). Always test the annealing procedure on one or a few parts to ensure that adequate material is allowed for dimensional changes due to this heat treatment.
- In order to minimise distortion, it may be necessary to fixture parts during the total annealing cycle (particularly parts machined from plate resulting into asymmetric and/or heavy section changes).
- For uniform heating and cooling, and consequently to avoid stress build up in the plastics material, it is utmost important that annealing temperatures are within +/- 3°C all over the oven or oil bath at all times.
- If the oven or oil bath cannot be heated up or cooled down at the recommended rates, we recommend changing manually the temperature setting every hour.

More information about the machining of Quadrant Engineering Plastic Products' stock shapes can be given on request.