MACHINIST’S TOOLKIT

Guide to machining plastic parts

Specifications to consider when machining high-performing thermoplastic parts

MITSUBISHI CHEMICAL GROUP

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With more than 80 years of experience, 30 branch offices in 20 countries, and a team of technical service experts, engineers, and application development managers, Mitsubishi Chemical Group is the global leader for researching, developing, and manufacturing high-performance engineered polymer materials. Our products make the world a safer place by providing solutions across all industries — Aerospace, Renewable Energy, Chemical / Oil & Gas Processing, Food Processing & Packaging, Construction / Heavy Equipment, Linings, Medical / Life Sciences, Semiconductor, Transportation / rail.

Table of contents

01 Machining plastics vs. metals

Machining plastics vs. metals

For their mechanical, chemical, and lightweight properties, plastics are increasingly replacing metals in a wide range of engineering applications. Many of the same machining methods used to fabricate metal parts are also used for plastics; however, best practices for machining plastics differ considerably.

Plastics exhibit a number of properties that influence machining procedures, including:

- Thermal expansion of plastics is up to 10 times greater than that of metals
- Plastics lose heat more slowly than metals, increasing the risk of localized overheating
- Softening and melting temperatures of plastics are much lower than metals
- Plastics are much more elastic than metals

From material selection to proper tooling, from feed rates to stabilizing methods, part producers must weigh a range of factors in order to achieve good results when machining plastics. The following guidelines cover the most common plastic machining methods and provide useful tips and data for working with engineering polymers from Mitsubishi Chemical Group.

02 Plastic machining processes

Plastic machining processes

This section covers the most common methods of machining plastic engineering components, providing guidelines and tips to achieve the best results with each.

Proper machining is crucial to achieving part dimensions and performance. Improper machining can create stress within the finished part, negatively impacting its mechanical properties and risking premature part failure.

Common causes of machined-in stress include:

- Using dull or improperly designed tooling
- Excessive heat generated from inappropriate speeds and feed rates
- Machining away large volumes of material, usually from one side of the stock shape

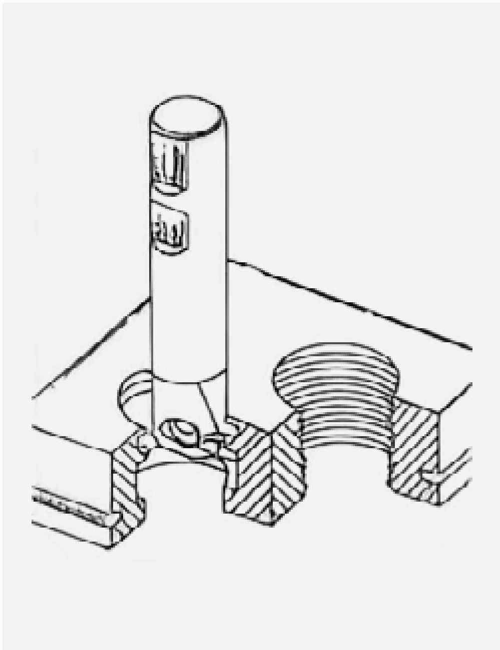
Threading and tapping

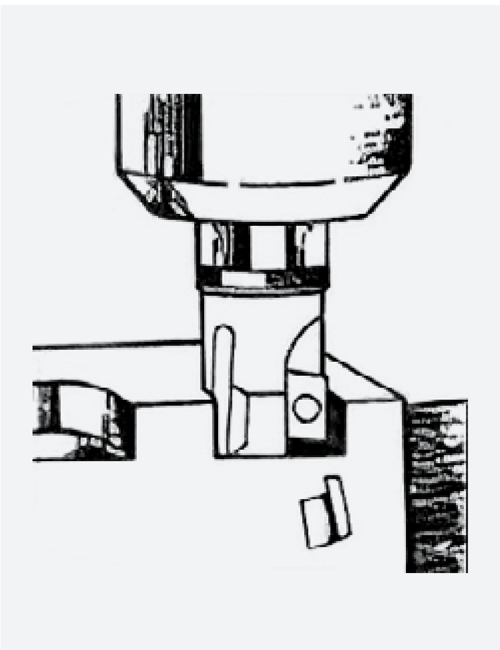
What is threading? What is tapping?
Tapping and threading are two machining methods used to produce screw threads. Threading is the process of using a die tool to carve external threads, where tapping is the process of using a tap tool to create threads on the inside of a drilled hole.

Threading and tapping with plastic vs. metal
A primary consideration when threading and tapping plastic is that plastics are more notch-sensitive than metals. Some polymer materials may tear during threading, especially in fine pitch procedures.

Threading tips for plastic
Threading plastic should be done by single point using a carbide insert, taking four to five 0.001" passes at the end. Coolant usage is suggested.

Tapping tips for plastic
When tapping plastic, use the specified drill with a two-flute tap. Keep the tap clean of chip build-up. Use of a coolant during tapping is also suggested.





Milling

What is milling?
Milling is a machining method that applies a high-speed cylindrical cutting tool to a stationary plastic shape, moving the cutter on an axis to subtract from the shape in different directions. Computerized numerical control (CNC) milling increases the accuracy and efficiency of plastic milling.

Milling plastic vs. metal
When milling plastic, it is crucial to properly stabilize the part on the worktable and minimize vibrations from the high-speed cutting tool – these may result in chatter marks and decreased accuracy due to the shape wandering.

Milling tips for plastic

- Climb milling, also known as down milling, is recommended over conventional milling.
- Sufficient fixturing on the mill bed allows fast table travel and high spindle speeds.
- The shape should not be fixed too tightly, however, as it may deform or spring
- When face milling, use positive geometry cutter bodies.

End milling/slotting guidelines

MATERIAL TYPES	RECOMMENDED CARBIDE	DEPTH OF CUT	SPEED (FT./MIN)	FEED (IN./TOOTH)
TIVAR® UHMW-PE, Nylatron® / Ertalon® PA6, Acetron® / Ertacetal® POM-H, Proteus® PP, Altron™ PC, Sultron® PSU & PPSU, Ertalyte® PET-P, Ketron® PEEK, Techtron® PPS, Fluorosint® PTFE, Duratron® PEI, Duratron® PAI, Duratron® PI	1/4", 1/2", 3/4", 1", 2" 1/4", 1/2", 3/4"	0.250 0.050	270-450 300-500	0.002, 0.003, 0.005 0.008, 0.001, 0.002, 0.004
Duratron® PBI	1/4", 1/2", 3/4", 1", 2" 1/4", 1/2", 3/4"	0.015	250-350	0.002
Fluorosint® MT-01 PTFE	*Contact our Technical Services team for advice			

Face milling guidelines (C-2, carbide tool)

MATERIAL TYPES	RECOMMENDED CARBIDE	DEPTH OF CUT	SPEED (FT./MIN)	FEED (IN./TOOTH)
TIVAR® UHMW-PE, Nylatron® / Ertalon® PA6, Acetron® / Ertacetal® POM-H, Proteus® PP, Altron™ PC, Sultron® PSU & PPSU, Duratron® PEI		0.150 0.060	1300-1500 1500-2000	0.020 0.005
Ertalyte® PET-P	1/4", 1/2", 3/4", 1", 2" 1/4", 1/2", 3/4"	0.250 0.050	270-450 300-500	0.002, 0.003, 0.005 0.008, 0.001, 0.002, 0.004
Ketron® PEEK		0.150 0.060	500-750	0.020 0.005
Fluorosint® PTFE		0.150 0.060	500-700 550-750	0.010 0.005
Techtron® PPS		0.150 0.060	1300-1500 1500-2000	0.020 0.005
Duratron® PAI & PI		0.035	500-800	00.6-0.35
Duratron® PBI	1/4", 1/2", 3/4", 1", 2" 1/4", 1/2", 3/4"	0.015	250-350	0.002
Fluorosint® MT-01 PTFE	*Contact our Technical Services team for advice			

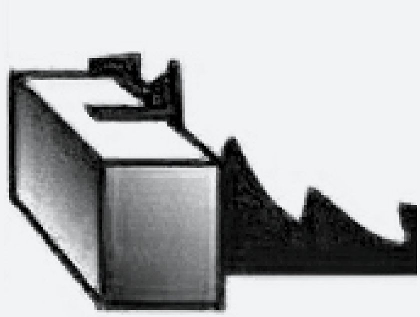
Sawing

What is sawing?
Sawing is a machining method that involves cutting a material into multiple pieces using a bandsaw, table saw, or other specialized equipment.

Sawing plastic vs. metal
The primary difference between sawing plastic vs. metal is that the heat generated by the saw blade can negatively impact the plastic parts due to lower softening and melting temperatures. It is crucial to account for the speed of the blade, the thermal properties of the material, and the thickness of the shape when sawing plastic.

Tips for selecting a saw tool
- Band saws are versatile and perform well for straight, continuous curves, and irregular cuts.
- Table saws are convenient for straight cuts and can be used to cut multiple thicknesses and thicker cross sections – up to 4” with adequate horsepower.

Tips for selecting a saw blade
- Rip and combination blades with a 0° tooth rake and 3° to 10° tooth set are best for general sawing in order to reduce frictional heat.
- Hollow ground circular saw blades without set will yield smooth cuts up to 3/4” thickness.
- Tungsten carbide blades wear well and provide optimum surface finishes.



Sawing guidelines (C-2, carbide tool)

MATERIAL TYPES	MATERIAL THICKNESS	BAND SPEEDS FT./MIN	PITCH TEETH/IN.	TOOTH FORM
TIVAR® UHMW-PE, Ertalon® / Nylatron® PA6, Ertacetal® / Acetron® POM-H, Ertalyte® PET-P	<.5"	3000	10-14	Precision
	.5"-1.0"	2500	6	
	1.0"-3.0"	2000	3	Buttress
	>3.0"	1500	3	
Proteus® PP, Altron™ PC, Sultron® PSU & PPSU, Duratron® PEI	<.5"	4000	10-14	Precision
	.5"-1.0"	3500	6	
	1.0"-3.0"	3000	3	Buttress
	>3.0"	2500	3	
Ketron® PEEK	<.5"	4000	8-14	Precision
	.5"-1.0"	3500	6-8	
	1.0"-3.0"	3000	3	Buttress
	>3.0"	2500	3	
Fluorosint® PTFE, Techtron® PPS	<.5"	3000	8-14	Precision
	.5"-1.0"	2500	6-8	
	1.0"-3.0"	2000	3	Buttress
	>3.0"	1500	3	
Duratron® PAI & PI	<.5"	5000	8-14	Precision
	.5"-1.0"	4300	6-8	
	1.0"-3.0"	3500	3	Buttress
	>3.0"	3000	3	
Duratron® PBI	<.375"-1.0"	3000	10	Precision
	1.0"-2.0"	1500	10	Buttress
Fluorosint® MT-01 PTFE	*Contact our Technical Services team for advice			

Drilling and boring

What is drilling? What is boring?
Drilling is a machining method that creates cylindrical holes and through-holes by means of a pointed helical tool. Boring is a secondary process for enlarging or finishing drilled holes.

Drilling and boring plastic vs. metal
The heat insulating characteristics of plastics require consideration during drilling operations, especially when the depth of the hole is greater than twice its diameter. Excessive heat build-up may result in chipping, rough surfaces, and inadequate tolerances.

Drilling tips for plastic

For small diameter holes (1/32" to 1")

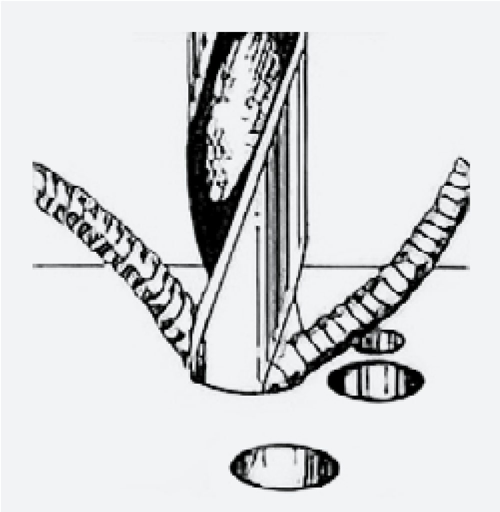
- High-speed steel twist drills are generally sufficient.
- Frequent pullout (peck drilling) is suggested to improve swarf removal.
- A slow spiral (low helix) drill will allow for better swarf removal.

For large diameter holes (1" and greater)

- A slow spiral (low helix) drill or general-purpose drill bit ground to a 118° point angle with 9° to 15° lip clearance is recommended. The lip rake should be ground (dubbed off) and the web thinned.
- Avoid hand feeding – drill grabbing can result in microcracks.
- It is generally best to drill a pilot hole (maximum 1/2" diameter) using 600 to 1,000 rpm and a positive feed of 0.005" to 0.015" per revolution.
- Secondary drilling at 400 to 500 rpm at 0.008" to 0.020" per revolution is required to expand the hole to larger diameters.

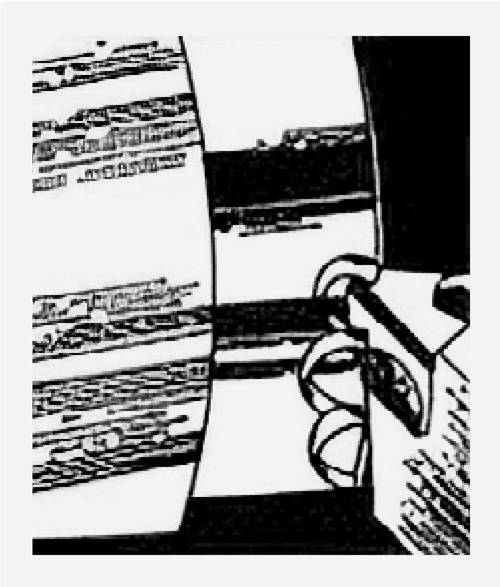
For especially notch-sensitive materials (such as Ertalyte® PET-P and glass reinforced materials)

- A two-step process involving both drilling and boring minimizes heat build-up and reduces the risk of cracking.
- First, drill a 1" diameter hole using an insert drill at 500 to 800 rpm with a feed rate of 0.005" to 0.015" per revolution.
- Next, bore the hole to final dimensions using a boring bar with carbide insert with 0.015" to 0.030" radii at 500 to 1,000 rpm and a feed rate of 0.005" to 0.010" per revolution.



Drilling guidelines (C-2, carbide tool)

MATERIAL TYPES	NOMINAL HOLE DIAMETER	FEED IN./REV.
TIVAR® UHMW-PE, Ertalon® / Nylatron® PA6, Ertacetal® / Acetron® POM-H	1/16" to 1/4" 1/2" to 3/4" 1" to >2"	.007 - .015 .015 - .025 .020 - .050
Proteus® PP, Altron™ PC, Sultron® PSU & PPSU, Duratron® PEI	1/16" to 1/4" 1/2" to 3/4" 1" to >2"	.007 - .015 .015 - .025 .020 - .050
Ertalyte® PET-P	1/16", 1/8", 1/4" 1/2", 3/4" 1", 1-1/2", 2", >2"	.002 - .005 .015 - .025 .020 - .050
Ketron® PEEK, Fluorosint® PTFE, Techtron® PPS, Duratron® PAI & PBI	1/16", 1/8", 1/4" 1/2", 3/4" 1", 1-1/2", 2", >2	.007 - .015 .015 - .025 .020 - .050
Duratron® PBI	1/2" or larger	.015 - .025
Fluorosint® MT-01 PTFE	*Contact our Technical Services team for advice	



Turning

What is turning?

Turning is a machining process in which a plastic shape is rotated around a stationary lathe. Turning is especially useful for machining parts that are symmetrical along a common rotational axis.

Turning plastic vs. metal

As with other plastic machining processes, turning generates heat. In order to prevent damage to a plastic part, rotation speed, tool selection, and coolants should all be considered carefully along with the thermal properties of the material.

Turning tips for plastic

- Turning operations require inserts with positive geometries and ground peripheries.
- Ground peripheries and polished top surfaces generally reduce material build-up on the insert, improving the attainable surface finish.
- A fine-grained C-2 carbide is often recommended for plastic turning operations.

Turning guidelines (C-2, carbide tool)

MATERIAL TYPES	DEPTH OF CUT (IN.)	SPEED (FT./MIN)	FEED (IN./TOOTH)
TIVAR® UHMW-PE, Nylatron® / Ertalon® PA6, Acetron® / Ertacetal® POM-H, Proteus® PP, Altron™ PC, Sultron® PSU & PPSU, Duratron® PEI, Ertalyte® PET-P	0.150 0.025	500-600 600-700	.010-.015 .004-.007
Ketron® PEEK	0.150 0.025	350-500 500-600	.010-.015 .003-.008
Fluorosint® PTFE	0.150 0.025	600-1000 600-700	.010-.016 .004-.007
Techtron® PPS	0.150 0.025	100-300 250-500	.010-.020 .005-.010
Duratron® PAI & PI	0.025	300-800	.004-.025
Duratron® PBI	0.025	150-225	.002-.006

03 Additional treatments

Additional treatments

Depending on the requirements for the part and machining process, coolants and/or annealing may be recommended in order to improve the finished results. This section covers the use of coolants and annealing, as applicable in machining plastic parts.

Coolants

What are coolants?
Coolants reduce the build-up of localized frictional heat, thus improving the machining results and extending the life of the tool. There are several types of coolants commonly used when machining engineering plastics, including pressurized air, dry ice, spray mists, and specially developed cooling agents.

When are cooling agents recommended?

Coolants are not necessary for most machining practices and most engineering plastics.

However, we recommend coolants in the following cases:

- When drilling or parting-off plastics – two processes that generate high frictional heat.
- When machining especially notch-sensitive materials, such as Ertalyte® PET-P, Duratron® PAI, Duratron® PBI, and glass- or carbon-reinforced products.
- When it is necessary to achieve optimum surface finishes and close tolerances.

Tips for selecting a coolant

- Spray mists and pressurized air are very effective means of cooling the cutting interface.
- General purpose petroleum-based cutting fluids, although suitable for many metals and plastics, may contribute to stress cracking of amorphous plastics such as Altron™ PC, Sultron® PSU, Sultron® PPSU, and Duratron® U1000 PEI.
- Two flood coolants suitable for most plastics are Trim E190 and Tim Sol LC SF.

Annealing

What is annealing?
Annealing is a heat treatment process that improves the physical properties of a plastic, increasing its ductility and reducing its hardness to make the shape easier to machine. Annealing helps to relieve internal pressure from within the plastic, giving a machined part higher dimensional stability over time. The annealing process involves heating a plastic shape to half its melt temperature for a determined period and letting it cool at a specific rate.

Annealing pre-machining
All plastic stock shapes from the Advanced Materials division of Mitsubishi Chemical Group are annealed using a proprietary stress relieving cycle that minimizes any internal stresses that may have resulted from the manufacturing process. This ensures that the material will remain dimensionally stable during and after machining.

Annealing post-machining
Few machined plastic parts require annealing after machining to meet dimensional or performance requirements; however, post-machining annealing does have several benefits, including:

- **Improved chemical resistance** – PC, PSU, and PEI materials can benefit from post-machining annealing to reduce stress crazing.
- **Better flatness, tighter tolerances** – Extremely close-tolerance parts requiring precision flatness and non-symmetrical contours sometimes require intermediate annealing between machining operations.
- **High pressure velocity and low wear PAI** – Extruded or injection-molded Duratron® PAI parts requiring high pressure velocities or the lowest possible wear factor benefit from an additional cure after machining. This curing process optimizes the wear properties. Only PAI benefits from such a cycle.

Tips for annealing plastics

- Improved flatness can be attained by rough machining, annealing, and finish machining with a very light cut.
- To reduce the potential for machined-in stress, review the fabrication guidelines for the specific material. Note that guidelines change as the material type changes.
- Ensure parts are fixtured to the necessary shape or flatness to prevent distortion. Do not unfix until the parts have completed the entire cycle and are cool to the touch.
- Finish machining to critical dimensions should be performed after annealing.
- Changes in heat-up and hold time may be possible if cross sections are thin.

Post-machining air annealing guidelines

MATERIAL TYPES	HEAT UP	HOLD	COOL DOWN	ENVIRONMENT
Type 6 Nylons	4 hours to 300° F	30 minutes per 1/4" thickness	50° F per hour	Oil or Nitrogen
Type 6/6 Nylons, Ertalyte® PET-P	4 hours to 350° F			
Ertacetal® C POM-C / Acetron® GP POM-C	4 hours to 310° F			Nitrogen or Air
Ertacetal® / Acetron® POM-H	4 hours to 320° F			
Altron™ PC	4 hours to 275° F			
Sultron® PSU & PPSU	4 hours to 330° F			
Duratron® PEI	4 hours to 390° F			Air
Techtron® PPS	4 hours to 350° F			
Ketron® PEEK	4 hours to 300° F 4 hours to 375° F	60 minutes per 1/4" thickness		
Duratron® PAI	4 hours to 300° F 4 hours to 420° F 4 hours to 470° F	1 day		
	4 hours to 500° F	3 to 10 days		
Duratron® PI	4 hours to 300° F 4 hours to 450° F 4 hours to 600° F	60 minutes per 1/4" thickness		

04

Troubleshooting guidelines

Drilling troubleshooting

DIFFICULTY	COMMON CAUSE
Tapered hole	Incorrectly sharpened drill Insufficient clearance Feed too heavy
Burnt or melted surface	Wrong drill type Incorrectly sharpened drill Feed too light Dull drill Web too thick
Surface chipping	Feed too heavy Clearance too great Too much rake (thin web as described)
Chatter	Clearance too great Feed too light Drill overhang too great Too much rake (thin web as described)
Feed marks or spiral lines on inside diameter	Feed too heavy Drill not centered Drill ground not centered
Oversize holes	Drill ground not centered Web too thick Insufficient clearance Feed rate too heavy Point angle too great
Undersize holes	Dull drill Too much clearance Point angle too small
Holes not concentric	Feed too heavy Spindle speed too slow Drill enters next piece too far Cut-off tool leaves nib, deflecting drill Web too thick Drill speed too heavy at start Drill not mounted at center Drill not sharpened correctly
Burr at cut-off	Dull cut-off tool Drill does not pass completely through piece
Rapid dulling of drill	Feed too light Spindle speed too fast Insufficient lubrication from coolant

Turning and boring troubleshooting

DIFFICULTY	COMMON CAUSE
Melted surface	Too dull or heel rubbing Insufficient side clearance Feed rate too slow Spindle speed too fast
Rough finish	Feed too heavy Incorrect clearance angles Sharp point on tool (slight nose radius required) Tool not mounted at center
Burrs at edge of cut	No chamfer provided at sharp corners Dull tool Insufficient side clearance Lead angle not provided on tool (tool should ease out of cut gradually, not suddenly)
Cracking or chipping of corners	Too much positive rake on tool Tool not eased into cut (suddenly hits work) Dull tool Tool mounted below center Sharp point on tool (slight nose radius required)
Chatter	Too much nose radius on tool Tool not mounted solidly Material not supported properly Width of cut too wide (use two cuts)

Cutting off troubleshooting

DIFFICULTY	COMMON CAUSE
Melted surface	Dull tool Insufficient side clearance Insufficient coolant supply
Rough finish	Feed too heavy Tool improperly sharpened Cutting edge not honed
Spiral marks	Tool rubs during its retreat Burr on point of tool
Concave or convex surfaces	Point angle too great Tool not perpendicular to spindle Tool deflecting Feed too heavy Tool mounted from above or below center
Nibs or burrs at cut-off point	Point angle not great enough Dull tool Feed too heavy
Burrs on outside diameter	No chamber before cut-off diameter Dull tool

05

Appendix

Machinability ratings of advanced materials

Machinability	Rating	Materials
Easy to machine	1	Ertacetal® C POM-C / Acetron® GP POM-C, Ertacetal® / Acetron® POM-H, Ertacetal® H-TF / Acetron® AF POM-H, Fluorosint® 500 PTFE, Fluorosint® 207 PTFE, Fluorosint® HPV PTFE, Nylatron® MC901 PA6 / Ertalon® 6PLA PA6, Nylatron® MC® 907 PA6, Nylatron® GS PA66, Nylatron® GSM PA6, Nylatron® 101 PA66 / Ertalon® 66 SA PA66
	2	Ertalyte® PET-P, Ertalyte® TX PET-P, Nylatron® GSM Blue PA6, Nylatron® NSM PA6, Altron™ PC 1000
	3	Fluorosint® MT-01 PTFE, Sultron® PSU, Sultron® PPSU, Techtron® PPS
	5	Duratron® T4203 PAI, Duratron® T4301 PAI, Ketron® 1000 PEEK, Techtron® PSBG PPS
	6	Duratron® T4501 PAI, Duratron® T4503 PAI, Ketron® HPV PEEK, Techtron® HPV PPS
	7	Duratron® U1000 PEI, Duratron® U2300 PEI, Ketron® GF30 PEEK
	8	Duratron® T5530 PAI
Challenging to machine	10	Duratron® CU60 PBI

Unit conversions

FRACTION (IN.)	DECIMAL (IN.)	MM
1/64	.0156	0.396
1/32	.0312	0.793
3/64	.0468	1.190
1/16	.0625	1.587
5/64	.0781	1.984
3/32	.0937	2.381
7/64	.1093	2.778
1/8	.125	3.175
9/64	.1406	3.571
5/32	.1562	3.968
11/64	.1718	4.365
3/16	.1875	4.762
13/64	.2031	5.159
7/32	.2187	5.556
15/64	.2343	5.953
1/4	.250	6.350
17/64	.2656	6.746
9/32	.2812	7.143
19/64	.2968	7.540
5/16	.3125	7.937
21/64	.3281	8.334
11/32	.3437	8.731
23/64	.3593	9.128
3/8	.375	9.525
25/64	.3906	9.921
13/32	.4062	10.318
27/64	.4218	10.715
7/16	.4375	11.112
29/64	.4531	11.509
15/32	.4687	11.906
31/64	.4843	12.303
1/2	.500	12.700

FRACTION (IN.)	DECIMAL (IN.)	MM
33/64	.5156	13.096
17/32	.5312	13.493
35/64	.5468	13.890
9/16	.5625	14.287
37/64	.5781	14.684
19/32	.5937	15.081
39/64	.6093	15.478
5/8	.625	15.875
41/64	.6406	16.271
21/32	.6562	16.668
43/64	.6781	17.065
11/16	.6875	17.462
45/64	.7031	17.859
23/32	.7187	18.256
47/64	.7343	18.653
3/4	.750	19.050
49/64	.7656	19.446
25/32	.7812	19.843
51/64	.7968	20.240
13/16	.8125	20.637
53/64	.8281	21.034
27/32	.8437	21.431
55/64	.8593	21.828
7/8	.875	22.225
57/64	.8906	22.621
29/32	.9062	23.018
59/64	.9218	23.415
15/16	.9375	23.812
61/64	.9531	24.209
31/32	.9687	24.606
63/64	.9843	25.003
1	1.000	25.400

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