FABRICATION AND PLASTICS MACHINING

Machining guidelines for high performance materials (HPMs)

by Jeff Warren

Machining of plastic stock shapes provides end users the opportunity to economically produce equipment components and prototype parts in volumes that are significantly lower than what would be cost-effective with injection molding. Acetal and nylon are two of the most widely machined engineering grade stock shape materials. Both of these materials have been in use for over 40 years, and the machining methods for them have been well-documented. What is not nearly as well-known in the fabrication community is the machining methods for newer high performance materials (HPMs) like polyphenylene oxide (PPO), polyetherimide (PEI), polyphenylene sulfide (PPS) and polyetheretherketone (PEEK). This is especially true of the glass fiber reinforced versions of these materials.

Unfilled acetals and nylons are often considered as very forgiving because machinists can utilize a wide range of feeds, speeds, and tool configurations and still produce relatively close toleranced parts with good finishes. Some operators regard HPM stock shapes as challenging to machine because they are usually harder, at times less tough, and are commonly reinforced with glass fibers that can be abrasive to cutting tools. In addition, the substantially higher expense of these materials makes machining mistakes exponentially more costly. While these factors can cause concern to machinists who are new to plastics and especially HPM plastics, there are many techniques that can be used to easily overcome these issues. By learning and adopting these methods, machinists will be able to repeatedly produce high quality fabricated components that possess the truly outstanding performance benefits of HPM plastics.

Before you start

Don't forget the five critical rules for machining any plastic material:

1. Plastics are a lot softer than metals. While this will allow you to remove material much faster than on metal work pieces, it also means that plastic work pieces need to be supported much better than metal pieces.

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2. Plastics are thermal insulators. Any heat created by tool friction or chips binding against the work piece is going to build up in the work piece and degrade the machined surface. To minimize frictional heat, use the sharpest tools available, positive tool geometries, and always make sure that your tools have adequate chip clearance. While coolants are not required for most plastic machining operations, compressed air or water soluble coolants can be helpful in high heat generating operations like drilling, reaming and tapping.

3. The rate of thermal expansion for plastic materials is typically 10 times that of most metals. This increased expansion can cause component features to swell considerably if significant heat is generated during machining. Make sure that this factor is taken into account when removing material on tight toleranced parts.

4. Plastics absorb moisture – some a lot more than others. Moisture that is absorbed from the air or from water sources like wash baths or machining coolants can cause the plastic work piece to swell and soften. On tight toleranced plastic work pieces, this swelling must be taken into account by machining tolerances.

5. The chemical resistance of different types of plastics varies considerably. Common cleaners and coolants can cause some plastics to swell, craze or crack. Check the chemical compatibility of your plastic work piece with any chemicals that may come in contact with it during machining, cleaning or handling.

Machinery

In virtually all cases, plastic materials are fabricated using equipment that was designed for machining soft metals like brass and bronze. The feed, speed and tolerance capabilities of metalworking machinery will be more than adequate for any HPM plastic machining project that you may encounter. In fact, because the tolerances for most plastic parts are often up to 10 times larger than those typically specified for metal parts, equipment that is thought to be "worn out" for machining metals can often be adequately utilized for plastic fabrication.

The only non-metal working equipment that is typically used for machining HPM plastics are cut-off saws and high speed routers. The versions of these machines used for cutting HPM plastics are usually variations of woodworking equipment with blades and cutters optimized for plastics.

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Example of fabricated component machined from a UNITREX™ PEEK engineering stock shape produced by Nytef Plastics, Ltd.

Cutting tools

The standard cutting tools for machining operations on most unfilled acetal and nylon products are high speed steel (HSS). HSS tools are low in cost, can be ground to a sharper cutting edge than carbide or diamond inserts, and will also provide suitable results on many low volume HPM production jobs. Since some HPM plastics can be more abrasive than acetal or nylon, fabrication jobs on these materials that involve multiple pieces or long cutter runs will require carbide cutters.

The most economical way to handle very large HPM jobs, and those involving abrasive glass or carbon fiber reinforced materials, will be by utilizing diamond tipped tools. This significantly higher tool cost will be more than offset by the reduction in downtime due to the increased tool replacement and cutter insert maintenance caused by these fillers.

Always remember: regardless of the tool type that you use – the sharper the tool, the tighter tolerances you will be able to hold and the better surface finish you will be able to achieve. Sharpen your cutting tools often!

Sawing high performance materials (HPM) plastics

The key to success during saw operations on HPM plastics is saw blade selection and saw speed. A saw blade with excessively large teeth will cause HPM plastics to chip and crack. A saw blade with small teeth that is run too slowly will not provide adequate chip removal and will cause excessive heat build-up. While thicker saw blades reduce material yields because they remove more material per cut, they usually improve the cut surface and reduce cracking because they improve heat dissipation. To prevent binding and promote chip removal, saw blades with wide gullets and a slight set of 3° to 10° are recommended.

Machining high performance materials (HPM) plastics

The problem most frequently encountered by machinists working with HPM plastics is cracking. HPM plastics tend to be harder than more commonly used acetal and nylon and their resistance to impact is usually not as high as that of acetals and nylons. If attention is not paid to these factors during machining, this reduced toughness can promote the formation of fractures that once started, can quickly propagate through the work piece.

The first line of defense against cracking during machining is to minimize sharp edges and corners that tend to act as crack initiation points. Where possible, round the corners and fillet the edges of highly stressed areas of machined components and also the areas with thin cross sections. Drilled holes often create high stress areas at the point where they intersect surfaces. Avoid sharp and ragged edges at hole openings by countersinking the hole or breaking the hole edge to at least a 0.030" chamfer. For tapped holes and threaded shafts, thread designs that have square, chamfered or rounded tooth forms will help minimize the micro cracks that can form at the peaks and roots of standard unified coarse (UNC) type threads.

For stress prone HPM plastic component designs where the material cannot be changed, there are several techniques that can be utilized to minimize cracking:

• Lower material removal rates correspond to lower stresses imparted on the HPM work piece. By decreasing the feed rate and slightly increasing the tool surface speed, you can reduce the stresses imparted by the cutting tool and still maintain an excellent surface finish.

SAWING GUIDELINES FOR HIGH PERFORMANCE MATERIALS

Circular Sawing (All Materials)

Material Thickness	Pitch (teeth/in.)	Speed (sfpm)
<1"	6 – 12	9,000
1" – 3"	2 – 4	9,000
3" – 4"	2 – 4	9,000

Band Sawing

Material Thickness	Pitch (teeth/in.)	Amorphous Speed (sfpm)	Crystaline Speed (sfpm)	Fiber Filled Speed (sfpm)
<1"	6 – 14	4,000	4,500	5,000
1" – 3"	4 – 5	3,000	3,500	4,000
3" – 4"	2 – 3	2,000	2,500	3,000

MACHINING GUIDELINES FOR HIGH PERFORMANCE MATERIALS (HPM) PLASTICS

Amorphous HPM Plastics (PC, PEI, PPO, Polysulfone); Crystaline HPM Plastics (PPS, PEEK); Fiber Filled Materials (Glass and Carbon Fibers)

Turning/Threading

Operation	Feed (in./rev.)	Depth of Cut	Amorphous HPM Plastics Tool Material (minimum quality)	Amorphous Speed (sfpm)	Crystaline HPM Plastics Tool Material (minimum quality)	Crystaline Speed (sfpm)	Fiber Filled Materials Tool Material (minimum quality)	Fiber Filled Speed (sfpm)
Rough Cutting	0.005 – 0.015	0.150"	Carbide	800 – 1,000	Carbide	800 – 1,000	Carbide/Diamond	500 – 800
General Turning	0.005	0.025"	Carbide	1,000	Carbide	1,000	Carbide/Diamond	600 – 1,200
Finish Cut	0.002 – 0.005	0.025"	HSS/Carbide	900 – 1,200	HSS/Carbide	900 – 1,200	Carbide/Diamond	600 – 1,200
Cut Off	0.003 – 0.004		HSS/Carbide	1,000	HSS/Carbide	1,000	Carbide/Diamond	1,000
Threading	0.003 – 0.005		Carbide	800	Carbide	800	Carbide/Diamond	800

Milling

Operation	Feed (in./rev.)	Depth of Cut	Amorphous HPM Plastics Tool Material (minimum quality)	Amorphous Speed (sfpm)	Crystaline HPM Plastics Tool Material (minimum quality)	Crystaline Speed (sfpm)	Fiber Filled Materials Tool Material (minimum quality)	Fiber Filled Speed (sfpm)
Face Milling – Rough	0.020	0.150"	HSS/Carbide	900 – 1,300	HSS/Carbide	500 – 800	Carbide/Diamond	500 – 800
Face Milling – Finish	0.005	0.050"	HSS/Carbide	1,200 – 1,600	HSS/Carbide	600 – 800	Carbide/Diamond	600 – 800
End Milling – Rough	0.002 – 0.010	0.250"	HSS/Carbide	250 – 350	HSS/Carbide	300 – 500	Carbide/Diamond	280 – 450
End Milling – Finish	0.001 – 0.005	0.050"	HSS/Carbide	320 – 420	HSS/Carbide	400 – 600	Carbide/Diamond	320 – 520

Drilling/Reaming

Operation	Feed (in./rev.)	Amorphous HPM Plastics Tool Material (minimum quality)	Amorphous Speed (sfpm)	Crystaline HPM Plastics Tool Material (minimum quality)	Crystaline Speed (sfpm)	Fiber Filled Materials Tool Material (minimum quality)	Fiber Filled Speed (sfpm)
Drilling Holes <1" dia.	0.005 – 0.012	HSS/Carbide	150 – 300	HSS/Carbide	200 – 400	Carbide	200 – 400
Drilling Holes >= 1" dia.	0.008 – 0.020	HSS/Carbide	150 – 300	HSS/Carbide	200 – 400	Carbide/Diamond	200 – 400
Reaming	0.005 – 0.015	HSS/Carbide	250 – 450	HSS/Carbide	250 – 450	Carbide	250 – 450

Note regarding tool materials: where two cutting tool types are shown, the first material is for low volume production and the second material is for high volume machining.

• Many cracking problems are the result of vibrations that are created when the work piece is not adequately supported. Always support the material stock as close to the cutter as feasible. Secondary supports like shaft centers and hole pins that are inserted during intermediate machining stages can be very helpful at stabilizing less rigid portions of a work piece. Single- or dual-fluted cutters are usually more desirable than multi-fluted cutters because they cause less vibration in use.

• HPM plastics become softer and gain toughness as temperature increases. By heating HPM plastic work pieces, you make it easier to remove material from surfaces and also improve the material's resistance to cracking. Heating the work piece to 150-175°F is usually adequate to yield a significant improvement. Always avoid rapidly cooling (i.e., quenching) the work piece as this can raise the stress levels in the plastic. Also remember that heating the work piece will cause it to expand. This expansion must be taken into account when material is being removed so that the machined component will be at the desired dimensions after it has cooled.

Minimizing warping problems when machining high performance materials (HPM) plastics

Warping can also be a problem during the machining of HPM plastics. The high strength of these materials alone, or in combination with glass or carbon fiber fillers, tends to make them susceptible to the retention of internal stresses. When HPM plastic stock shapes are machined into components with unsymmetrical features, these stresses can cause the work piece to bend toward the side with the least material. There are several fairly simple fabrication steps that can be taken to minimize or eliminate these effects.

HPM stock shapes are usually annealed by their manufacturer to substantially reduce the level of internal stresses retained in the material. On HPM stock shapes with very thick cross sections (over 2") or for machined components with extremely tight tolerances, a secondary annealing process may be required to adequately reduce residual and machined-in stresses. Re-annealing is most effective when it is done after the work piece has been machined to 80 to 90 percent of its finished dimensions and the work piece is fixtured during the heating and cooling cycles. After re-annealing, the work piece can be finish machined to the final dimensions and tolerances.

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When a component design requires that material be removed from opposite sides of a HPM plastic work piece, always remove the material in small and even steps. Machine one side of the work piece and then flip the material over and remove a similar amount from the other side. Continue machining material from alternating sides of the work piece until the component is complete. Keep the amount of material that is removed in each pass at the smallest amount that is feasible (this amount may often be less than 1/4").

Many HPM plastic materials will "relax" (creep) after machining – especially if a lot of material has been machined away from the work piece. This relaxation will usually take place slowly over 1-3 days and many tight toleranced HPM components will benefit if a 2-3 day "hold" period is built into the machining process. Machine the work piece to 80-90 percent of its finished dimensions, let it sit for 2-3 days, and then finish machine the component to its final dimensions.

The physical and chemical structures of some HPM plastics makes them inherently more dimensionally stable and resistant to warping. For example, amorphous HPM plastics will usually be more dimensionally stable than crystalline materials. HPM plastics reinforced with fillers like glass and carbon fibers tend to retain internal stresses – even after standard annealing processes. When possible, select materials for tight toleranced components that are naturally dimensionally stable. Specify fiber fillers only if they are necessary and utilize the lowest filler level that will meet the needs of the application. ■

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