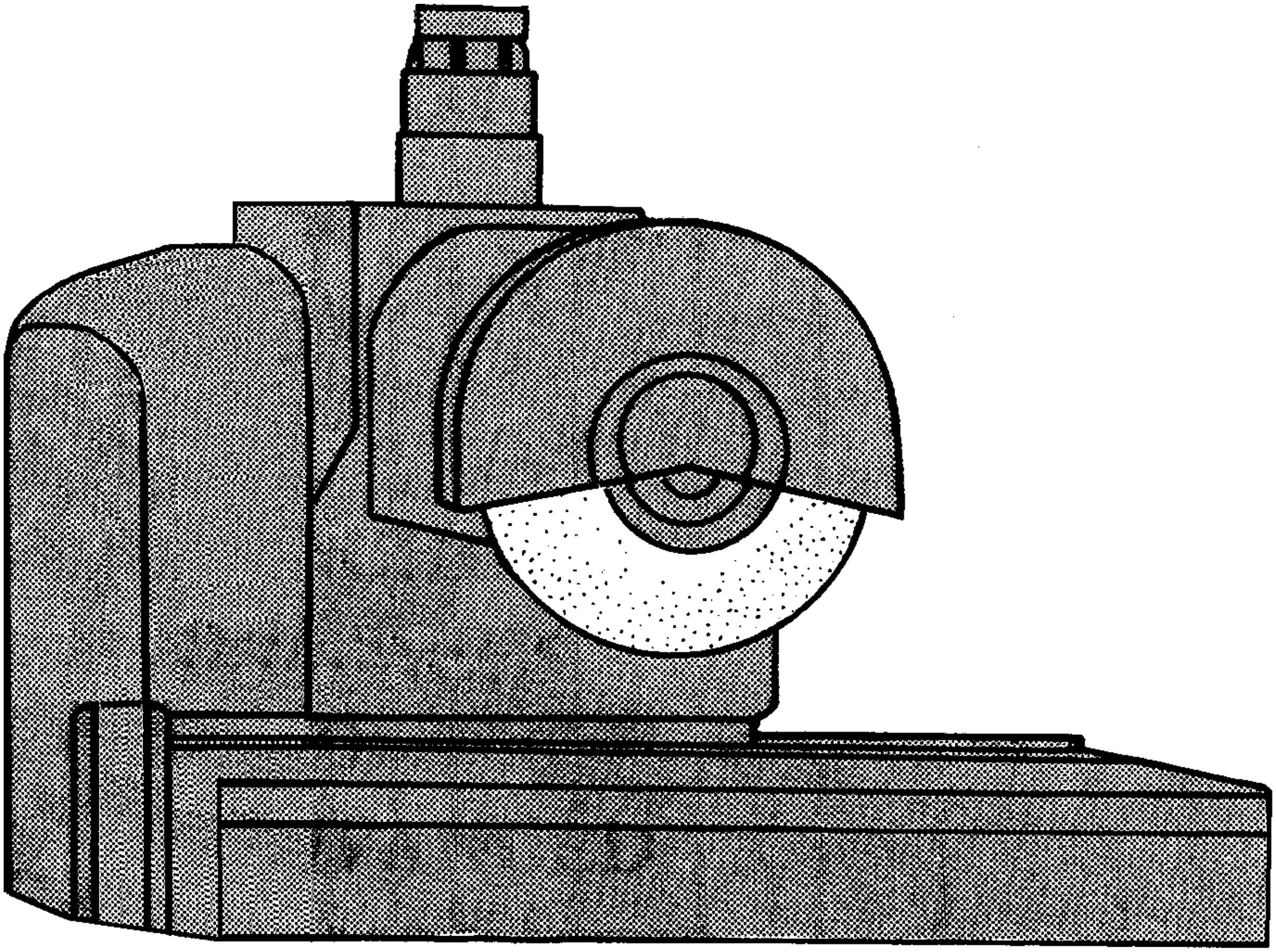
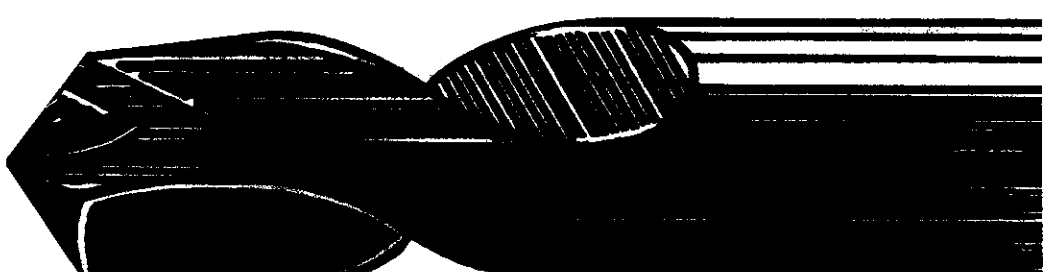


Machining Plastics and Advanced Composites



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MACHINING PLASTICS AND ADVANCED COMPOSITES

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BOEING COMMERCIAL AIRPLANE GROUP

PREFACE

This manual serves as a reference in the machining of plastic and advanced composite materials. Included in the manual are recommended feeds, speeds, depths of cut, coolants, tools, and tool geometry for the machining processes commonly performed on plastics in the Boeing shops.

The technology of machining plastics and advanced composites, however, is still being developed. Processes, methods, and techniques will be improved as new parts are fabricated.

This handbook should be used as a guide only. The information contained herein does not supersede BAC specifications and is not to be used as criteria for inspection. As process technology changes occur, they will be incorporated into the applicable BAC specification.

Reports and information regarding plastics, advanced composites, and machining of these materials should be directed to the appropriate group in Manufacturing Research and Development, Organization A-2020, so that this manual can revised, when necessary.

CONTENTS

Page

LIST OF TABLES

Resin	Any of a class of solid or semisolid organic products of natural or synthetic origin, generally of high molecular weight with no definite melting point. Most resins are polymers.
SFM	Cutting speed in surface feet per minute.
Thermoplastic	A class of plastic materials capable of repeated softening when heated, and rehardening when cooled.
Thermosetting	A class of plastic materials which undergo a chemical reaction during setting (usually in the presence of heat) and are then relatively unfusable.
Kevlar	DuPont registered trademark for a family of high-tensile-strength, aromatic polyimide fibers, which are embedded in any epoxy resin matrix.
Graphite-Epoxy Laminates	High-strength, highly modular carbon fibers embedded in an epoxy resin matrix.

GENERAL MACHINING TIPS

Consideration of the properties of the work material is important in specifying best speeds, feeds, depth of cuts, tool materials, tool geometries, and cutting fluids. Generally, plastics can be machined with feeds, speeds, and tool geometry similar to those used for brass. Plastics are more abrasive than brass and tend to dull tools rapidly, particularly when they are filled or laminated with glass fibers or graphite. These more abrasive plastics are best machined with a climbing cut and finished in the conventional cut mode with one pass of the tool, using a heavy feed. Some plastics (like acid-catalyst cast phenolics) chemically attack cutting tools made of high speed steel; with this type of material, carbide tools are preferred for long production runs.

Each type of plastic has unique properties, and therefore can be assumed to have different machining characteristics. Thermoplastics are relatively resilient when compared to metals; therefore, the material must be properly supported to prevent distortion.

With plastics, clamping pressures should be well distributed to avoid damaging the part. Once a cut is started, it should not be stopped since this may leave tool marks on the surface. With laminated materials, backup strips are helpful in preventing delamination and chipping.

Tools should always be kept as sharp as possible. Dull tools create more heat than sharp ones and, since all plastics are poor conductors of heat, the heat created by cutting friction tends to localize in the tool. This concentration of heat causes tools to break down rapidly and may cause gumming of the chip to the work or even burning of the part. Dull tools also leave poor finishes marked by edge delamination, chipping, crazing, and tearing of fibers.

Another reason for keeping tools sharp is that the higher cutting forces generated by dull tools tend to push the workpiece away and accuracy is lost. This problem of part accuracy is increased because plastics are 10 to 30 times more flexible than steel and require considerably more support during machining.

The following are some general tips for cutting plastics:

Turning

Table 1 gives the recommendations for turning many thermoplastics and thermosetting materials. Coolants as indicated on page 8 should be used to reduce the part temperature.

Milling

Too high a table feed will cause a rough surface; too low a table feed will generate excessive heat that can cause melting, surface cracks, loss of dimensions, and poor surface finish. Use coolants as recommended in tables 2 and 3.

Drilling

Drilling is a very severe operation because of restricted chip flow, inherent poor rake angles, and variable cutting speeds across the cutting edge. Recommended drill speeds and feeds are found in table 11.

Frequent retraction of the drill (peck-drilling) is recommended for cleaning chips to prevent drill binding and tapered holes. In deep holes, coolants are advisable to keep the tool tip from overheating. Feeds should be reduced near the end of the cut to prevent chipping or breakthrough or, in a blind hole, to prevent the formation of burrs or strands. When drilling thin sections, a backup may be required to prevent breakouts.

Tapping

General tapping and threading information is found in table 13. Use of these recommendations will generate the least frictional heat. Oversized taps are recommended because of the elastic recovery of plastic materials.

Oversized taps are designated as:

H1:	Basic -	basic + 0.0005 in.
H2:	Basic + 0.0005	basic + 0.0010 in.
H3:	Basic + 0.0010	basic + 0.0015 in.
H4:	Basic + 0.0015	basic + 0.0020 in.
H5:	Basic + 0.0020	basic + 0.0025 in.
H6:	Basic + 0.0025	basic + 0.0030 in.

The amount of oversize depends on elastic recovery properties of the material and sizes of holes. The number of flutes determines the chip space and the chip lead per tooth; therefore, some compromise must be made. In general, a two-flute tap is preferred for holes up to 1/8 inch in diameter.

Air or lubricant is not essential in tapping, but it permits faster tapping by clearing chips away quickly.

Sawing

Most saws used for cutting metals can be used for cutting plastics. Circular saws are widely used and are ideal for making straight cuts in sheets. Band saws can be used for irregular or curved contours as well as straight cuts. Carbide or diamond abrasive saw blades are recommended for fiberglass or graphite laminates.

Medium to light feed is recommended. Pressure near the end of the cut should be reduced to avoid chipping. Force feeding will result in blade heating, poor cut, and excessive blade wear. Abrasive wheels may be necessary for some thermosetting materials.

Routing

High-speed portable routers or stationary spindle shapers are used to shape curved sections or to cut formed parts to size. Smooth cuts are obtained in most materials by using a straight, two- or three-flute cutter at high speed. When portable routers are used for cutting sheet stock, the material should be firmly clamped to the table. Carbide or diamond-coated cutters are recommended for fiberglass or graphite laminates.

Shearing, Blanking, Piercing

Thin sheet stock of most plastics can be cut to contour by means of a steel rule or punching dies and can be pierced by conventional metalworking techniques.

Because of the tendency of laminates to yield, a pierced hole will always be smaller than the punch which produced it. Similarly, a blanked part may differ somewhat from the dimensions of the die which produced it.

Countersinking

Commonly used materials and the corresponding countersink cutter and pilot geometries are shown in Table 14. Also shown in this table are the recommended cutting speeds for countersinking fiberglass and advanced composite materials.

Grinding and Finishing

With the exception of nylons, fluorocarbons, and polyethylenes, both thermoplastics and thermosetting materials can be readily ground on conventional equipment. Best results with all thermoplastics are achieved by the use of open-coat abrasive or wheels with a water coolant. The water, in addition to cooling, also washes away abraded particles, prolonging abrasive life.

Note

Grinding with abrasive wheels or diamond grit cutters is an excellent way to machine fiberglass or graphite materials.

Polishing

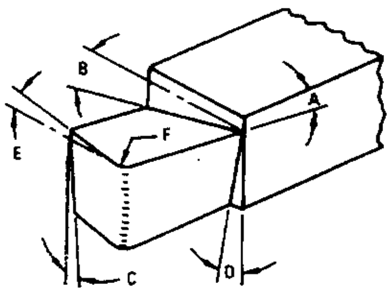
In using abrasives to finish plastic parts, a series of progressively finer grits should be used. After the finest available grit sandpaper is used the material should then be polished.

In polishing, a buffing wheel is charged with a slurry of water and pumice. The part is held lightly against the charged wheel, making sure that excessive heat is not generated. Buffing with suitable compounds follows the polishing operation. Finally, the part is buffed against a clean, flannel wheel.

PLASTICS MACHINING

Because there are so many different plastic materials in use (with more being developed nearly every day), not all of them could be listed in this manual. Instead, the machining tables on the following pages will list the speeds, feeds, and tool geometry, as well as possible coolants and other pertinent machining information, for plastics having similar machining characteristics. The plastic materials are grouped under thermoplastics and thermosetting in each machining table.

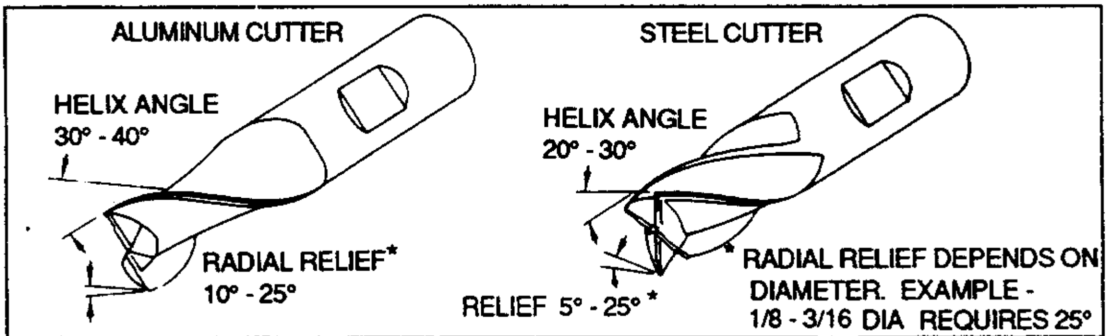
Table 1. Turning



A - BACK RAKE
B - SIDE RAKE
C - END RELIEF
D - SIDE RELIEF
E - END CLEARANCE (8°-15°)
F - NOSE RADIUS

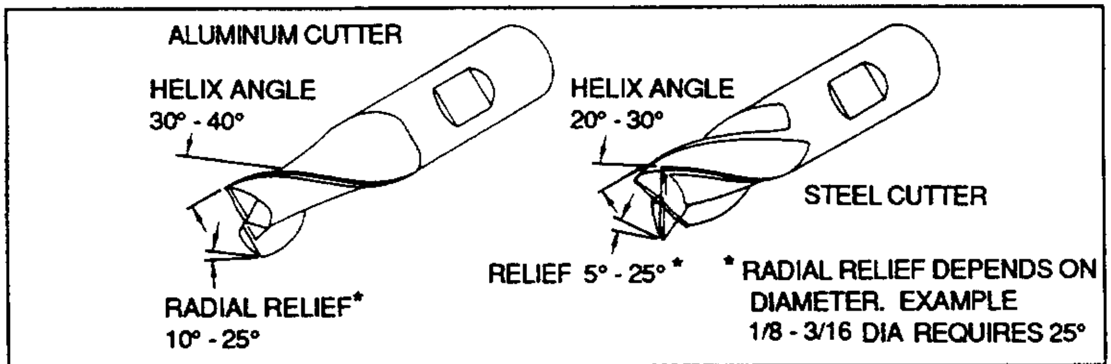
	Plastics material	Tool material	Tool geometry				Speed (SFM)	Feed (IPR)	Coolant	Notes
			A (deg)	B (deg)	C&D (deg)	F				
Thermoplastics	ABS	HSS or carbide	0-10	10-15	10-15	0.03-0.06	400-800	0.004-0.010	Water base	
	Acrylic	HSS or carbide	0-5	5-10	10-15	0.015-0.030	300-500	0.004-0.010	Air	Keep tool very sharp to avoid friction heat.
	Nylon	HSS or carbide	0-5	30-40	10-15	0.015-0.030	800-1200	0.005-0.015	Water base	Keep an extremely sharp edge on tool. Nylon absorbs water.
	Poly-carbonate	HSS or carbide	0-5	10-15	10-15	0.015-0.030	400-800	0.005-0.015	Water base	
	Poly-sulfone	HSS or carbide	0-5	10-15	10-15	0.015-0.030	400-800	0.005-0.015	Water base	
	PVC	HSS or carbide	0-5	10-15	10-15	0.015-0.030	400-800	0.005-0.015	Water base	
	Teflon	HSS or carbide	5-15	30-40	10-15	0.015-0.030	800-1200	0.005-0.015	Water base	Tool should have a very sharp edge.
Thermosetting	Rubber (urethane)	HSS or carbide	10-15	40-50	10-15	0.06-0.12	1500-2500	0.03-0.06	Water base	Cutting edge should be extremely sharp. Deep freeze parts before machining
	Paper/cloth laminates	HSS or carbide	0-5	5-10	8-10	0.015-0.030	300-500	0.004-0.010	Water base	Keep tool edge very sharp and centered to prevent delamination.
	Fiberglass laminates	Diamond carbide (C-2)	0-5	0-5	10-15	0.03-0.06	500-800	0.004-0.010	Air	Use adequate exhaust system. Cutting edge should be on C/L to prevent delamination.
	Graphite laminates	Diamond carbide	0-5	0-5	10-15	0.03-0.06	300-600	0.002-0.006	Air or CO_2	Use adequate exhaust system. Cutting edge should be on C/L to prevent delamination.
	Kevlar	HSS	0	5-7	5-7	0.015-0.025	250-500	0.0015-0.0025	Air or CO_2	Use adequate exhaust system.

Table 2. End Milling - Peripheral



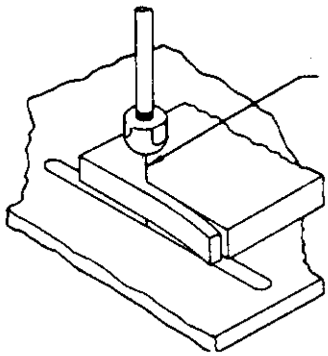
	Plastics material	Tool		Speed (SFM)	Feed per tooth	Depth of cut	Coolant	Notes
		Material	Geometry					
Thermoplastics	ABS	HSS	Aluminum	750-1000	0.004-0.008	0.025-0.100	Water base	
	Acrylic	HSS	Aluminum	750-1000	0.003-0.008	0.015-0.050	Water base	Notch sensitive, should be worked with a back-up material.
	Nylon	HSS	Aluminum	1000-1500	0.003-0.008	0.015-0.050	Air	
	Poly-carbonate	HSS	Aluminum	750-1000	0.004-0.008	0.015-0.050	Water base	
	Poly-sulfone	HSS	Aluminum	750-1000	0.004-0.008	0.015-0.050	Water base	
	PVC	HSS	Aluminum	750-1000	0.004-0.008	0.015-0.050	Water base	
	Teflon	HSS	Aluminum	1000-1500	0.004-0.008	0.015-0.050	Water or air	Emits toxic fumes when heated above 450°F.
Thermosetting	Rubber (urethane)							Does not mill well without freezing.
	Paper/cloth laminates	HSS or carbide	Aluminum	750-1000	0.002-0.005	0.015-0.050	Water base	
	Fiberglass laminates	Diamond abrasive	60-80 grit	600-1000	4-8 (IPM)	0.015-0.050		Climb cut to prevent delamination. Use adequate dust collector.
		Carbide	Aluminum	50-80	0.003-0.005			
	Graphite laminates	Diamond abrasive	60-80 grit	600-1000	4-8 (IPM)	0.060		Use adequate dust collector and respirator.
		Carbide	Aluminum	50-80	0.003-0.005			
	Kevlar	HSS	Aluminum	600-1000	0.003-0.005	0.060		

Table 3. End Milling - Slotting



	Plastics material	Tool		Speed (SFM)	Feed per tooth	Depth of cut	Coolant	Notes
		Material	Geometry					
Thermoplastics	ABS	HSS	Aluminum	300-500	0.001-0.005	0.050-0.100	Water base	
Thermoplastics	Acrylic	HSS	Aluminum	300-500	0.001-0.005	0.050-0.100	Water base	Notch sensitive, should be worked with a back-up material.
Thermoplastics	Nylon	HSS	Aluminum	400-600	0.002-0.005	0.050-0.250	Air	
Thermoplastics	Poly-carbonate	HSS	Aluminum	300-500	0.001-0.005	0.050 0.100	Water base	
Thermoplastics	Poly-sulfone	HSS	Aluminum	300-500	0.001-0.005	0.050-0.100	Water base	
Thermoplastics	PVC	HSS	Aluminum	300-500	0.001-0.005	0.050-0.100	Water base	
Thermoplastics	Teflon	HSS	Aluminum	400-600	0.001-0.005	0.050-0.250	Water base	Emits toxic fumes when heated above 450°F.
Thermosetting	Rubber (urethane)							Does not mill well without freezing.
Thermosetting	Paper/cloth laminates	HSS or carbide	Aluminum	140-600	0.001-0.005	0.050-0.100	Water base	
Thermosetting	Fiberglass laminates	Diamond abrasive	60-80 grit	600-1000	4-8 (IPM)	0.060	Air	Use adequate dust collector and respirator.
Thermosetting	Fiberglass laminates	Carbide	Aluminum	50-80	0.003-0.005	0.050-0.250	Air	Use adequate dust collector and respirator.
Thermosetting	Graphite laminates	Diamond abrasive	60-80 grit	600-1000	3-6 (IPM)	0.060	Air	Use adequate dust collector and respirator.
Thermosetting	Graphite laminates	Carbide	Aluminum	50-80	0.001-0.004	0.060	Air	Use adequate dust collector and respirator.
Thermosetting	Kevlar	HSS	Aluminum	500-1300	0.001-0.003	0.060		

Table 4. Conventional and Abrasive Waterjet Cutting



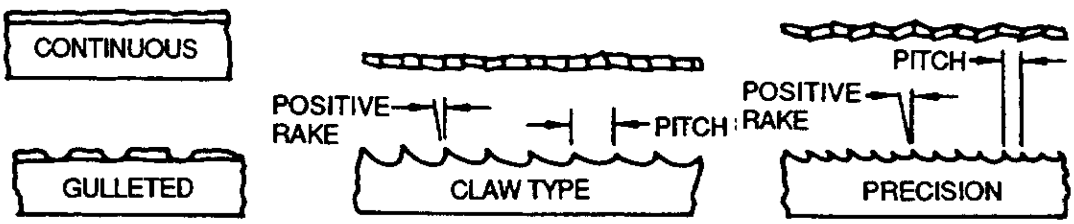
CONVENTIONAL WATERJET

	Material	Thickness	Feed (IPM)	Comments
Thermoplastics	ABS	To .250	3-1000	
Thermoplastics	Acrylic			NOT RECOMMENDED
Thermoplastics	Nylon	To .375	9-305	
Thermoplastics	Polycarbonate	To .100	20-377	
Thermoplastics	Polysulfone	To .100	10-300	
Thermoplastics	PVC	To .125	20-375	
Thermoplastics	Teflon	To .250	20-1000	
Thermosetting	Rubber (urethane)	To .700	3-1000	Foams and Sponges to 3 inches
Thermosetting	Paper/cloth laminates	To .450	3-375	
Thermosetting	Fiberglass laminates	Under .080	20-375	
Thermosetting	Graphite laminates			NOT RECOMMENDED
Thermosetting	Kevlar	Under .080	30-120	

ABRASIVE WATERJET

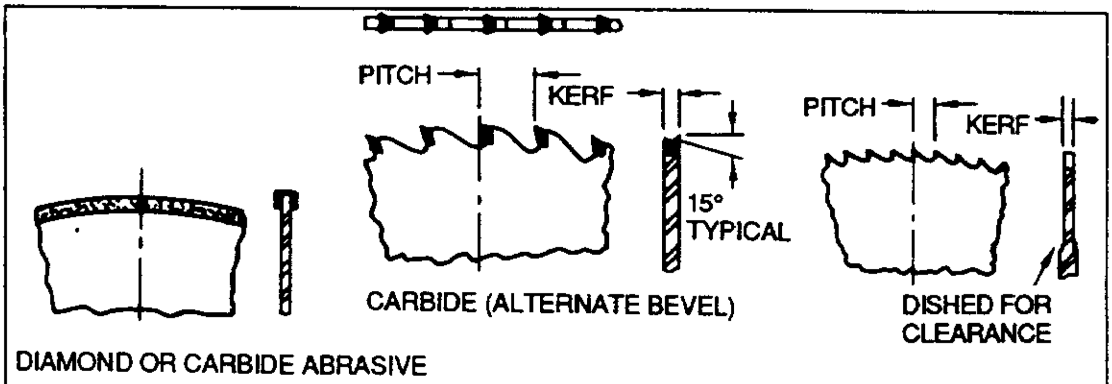
Material	Thickness	Feed (IPM)	Orifice/Nozzle	Comments
Fiberglass	To .125	50	.009"/.031"	Good Cuts in all Cases
	.125 to .250	30		
Graphite	To .125	50		
	.125 to .250	30		
Kevlar	.125	50		

Table 5. Band Sawing



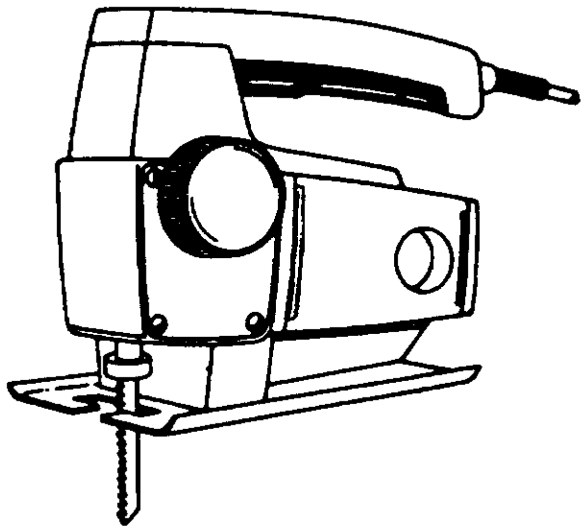
	Plastics material		Saw blade		Speed (SFM)	Feed (FPM)	Notes
	Type	Thickness (in)	Material	Type			
Thermoplastics	ABS	Up to 1/4 1/4 to 1/2 over 1/2	Carbon or HSS	14T precision 6-12T precision 4-6T precision	1500-2000 1200-1500 1200-1500	3-5 2-3 1-2	
Thermoplastics	Acrylic	Up to 1/4 1/4 to 1/2 over 1/2	Carbon or HSS	14T precision 6-12T precision 3-6T claw	3000-4000 3000-4000 3000-4000	3-5 2-3 1-2	Notch sensitive, use finest tooth blade that cuts free.
Thermoplastics	Nylon	Up to 1/4 1/4 to 1/2 over 1/2	Carbon or HSS	14T precision 6-10T precision 3-4T claw	3000-6000 2000-5000 1000-3000	3-6 2-4 1-3	
Thermoplastics	Poly-carbonate	Up to 1/4 1/4 to 1/2 over 1/2	Carbon or HSS	14T precision 6-10T precision 3-4T claw	2000-3000 1500-2000 1000-1500	3-6 2-4 1-3	
Thermoplastics	Poly-sulfone	Up to 1/4 1/4 to 1/2 over 1/2	Carbon or HSS	14T precision 6-10T precision 3-4T claw	2000-3000 1500-2000 1000-1500	3-6 2-4 1-2	
Thermoplastics	PVC	Up to 1/4 1/4 to 1/2 over 1/2	Carbon or HSS	14T precision 6-10T precision 3-4T claw	2000-3000 1500-2000 1000-1500	3-6 2-4 1-2	
Thermoplastics	Teflon	Up to 1/4 1/4 to 1/2 over 1/2	Carbon or HSS	14T precision 6-10T precision 3-4T claw	2000-5000 1500-4000 1000-3000	3-6 2-4 1-2	
Thermosetting	Rubber (urethane)	Up to 1/4 1/4 to 1/2 over 1/2	Carbon or HSS	Knife edge Knife edge Knife edge	2000-5000 2000-5000 2000-5000	2-6 2-6 2-6	
Thermosetting	Paper/cloth laminates	Up to 1/4 1/4 to 1/2 over 1/2	Carbon or HSS	14T precision 6-10T precision 4-6T precision	1000-3000 1000-3000 1000-3000	3-6 2-4 1-2	
Thermosetting	Fiberglass laminates	Up to 1/4 1/4 to 1/2 over 1/2	Carbide abrasive	Medium grit	1000-4000 1000-4000 1000-4000	3-6 2-4 1-2	Use adequate exhaust.
Thermosetting	Graphite laminates	Up to 0.12 0.12 to 0.30 over 0.30	Carbide abrasive	60-80 grit	1000-3000 1000-3000 1000-3000	2-6 2-4 1-2	Use adequate exhaust. Backup on exit side to prevent delamination.
Thermosetting	Kevlar	Up to 0.125 over 0.125	Carbon steel	18-24T precision	1500-5000 1500-5000	4 2	Use adequate exhaust. Run blade in reverse direction.

Table 6. Circular Sawing



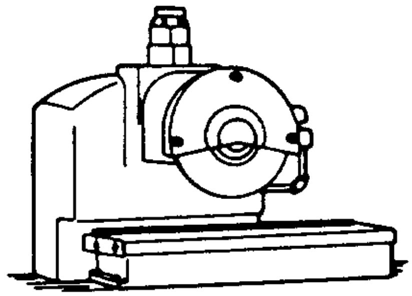
	Plastics material	Saw blade: Material	Saw blade: Type	Speed (SFM)	Feed (IPR)	Notes
Thermoplastics	ABS	Semi-HSS	Fine to medium tooth, metal cutting	7,500 to 12,000	15-25	
Thermoplastics	Acrylic	Semi-HSS	Fine tooth, metal cutting	7,500 to 12,000	10-20	Notch sensitive. Use care in feeding. Watch for overheating
Thermoplastics	Nylon	Semi-HSS	Fine to medium tooth, metal cutting	4,000 to 6,000	15-25	
Thermoplastics	Poly-carbonate	Semi-HSS	Fine to medium tooth, metal cutting	7,500 to 12,000	15-25	
Thermoplastics	Poly-sulfone	Semi-HSS	Fine to medium tooth, metal cutting	7,500 to 12,000	15-25	
Thermoplastics	PVC	Semi-HSS	Fine to medium tooth, metal cutting	7,500 to 12,000	15-25	
Thermoplastics	Teflon	Semi-HSS	Medium tooth, metal cutting	7,500 to 12,000	15-25	Do not overheat. Produces toxic fumes above 450°F.
Thermosetting	Rubber (urethane)					NOT RECOMMENDED
Thermosetting	Paper/cloth laminates	Carbide	Fine tooth, metal cutting	7,500 to 12,000	5-20	
Thermosetting	Fiberglass laminates	Diamond or Carbide abrasive	Continuous or gulleted	7,500 to 12,000	1-20	Use adequate dust collector and respirator.
Thermosetting	Graphite laminates	Diamond abrasive	Continuous or gulleted	7,500 to 12,000	2-6	Use adequate dust collector and respirator.
Thermosetting	Kevlar	Semi-HSS	Medium tooth metal cutting alternate face bevel	7,500 to 12,000	2-5	This process produces excessive burrs.

Table 7. Saber Sawing



	Plastics material	Saw blade		Notes
		Material	Type	
Thermoplastics	ABS	HSS	Fine to medium tooth, metal cutting	
	Acrylic	HSS	Fine tooth, metal cutting	Notch sensitive. Material should have backing while cutting.
	Nylon	HSS	Fine to medium tooth, metal cutting	
	Polycarbonate	HSS	Fine to medium tooth, metal cutting	
	Polysulfone	HSS	Fine to medium tooth, metal cutting	
	PVC	HSS	Fine to medium tooth, metal cutting	
	Teflon	HSS	Medium tooth, metal cutting	
Thermosetting	Rubber (urethane)	HSS	Sharp knife edge	
	Paper/cloth *laminates*	HSS	Fine tooth, metal *cutting*	
	Fiberglass laminates	Diamond abrasive carbide abrasive	60-80 grit medium grit	Use adequate dust collector and respirator
	Graphite laminates	Diamond abrasive	60-80 grit	Use adequate dust collector and respirator
	Kevlar	HSS	Fine tooth, metal cutting	

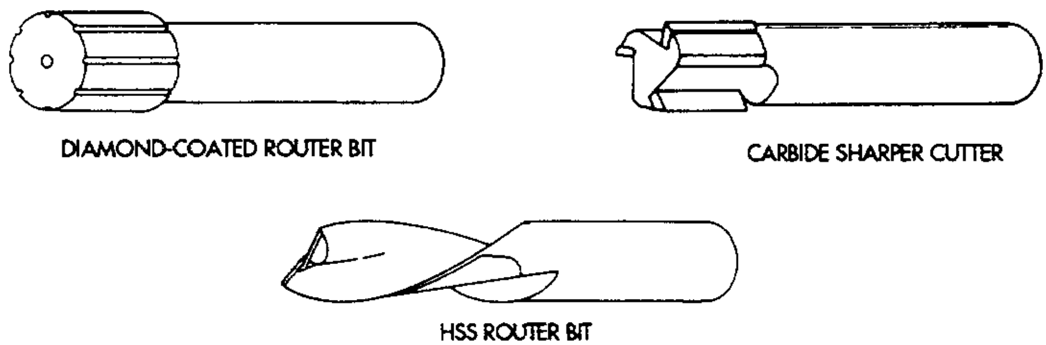
Table 8. Grinding



	Plastics material	Wheel Material	Wheel Grit	Wheel speed (SFM)	Max table speed (FPM)	Depth of cut (MAX)	*Coolant	Notes
Thermoplastics	ABS	Silicone carbide or aluminum oxide	46-80	3000-6000	To 100	1/8 in	Water base, full flood	
	Acrylic	Silicone carbide or aluminum oxide	46-100	3000-6000	To 100	1/8 in	Water base, full flood	
	Nylon	Silicone carbide or aluminum oxide	46-80	3000-6000	To 100	1/8 in	Air	
	Poly-carbonate	Silicone carbide or aluminum oxide	46-80	3000-6000	To 100	1/8 in	Water base, full flood	
	Poly-sulfone	Silicone carbide or aluminum oxide	46-80	3000-6000	To 100	1/8 in	Water base, full flood	
	PVC	Silicone carbide or aluminum oxide	46-80	3000-6000	To 100	1/8 in	Water base, full flood	
	Teflon	Silicone carbide or aluminum oxide	46-80	3000-6000	To 100	1/8 in	Water base, full flood	
Thermosetting	Rubber (urethane)		NOT RECOMMENDED					
	Paper/cloth laminates	Silicone carbide or aluminum oxide	46-180	3000-6000	To 100	1/16 in	Water base, full flood	
	Fiberglass laminates	Silicone carbide or aluminum oxide	46-180	3000-6000	To 100	1/16 in		Use adequate dust collection system and respirator.
	Graphite laminates	Norton 32A46H8VBE or 39C6018VK	46-180	5600-6400	50-70	0.003		Use adequate dust collection system and respirator.
	Kevlar	Alumina	46-180	6000	65	0.003		Use adequate dust collection system.

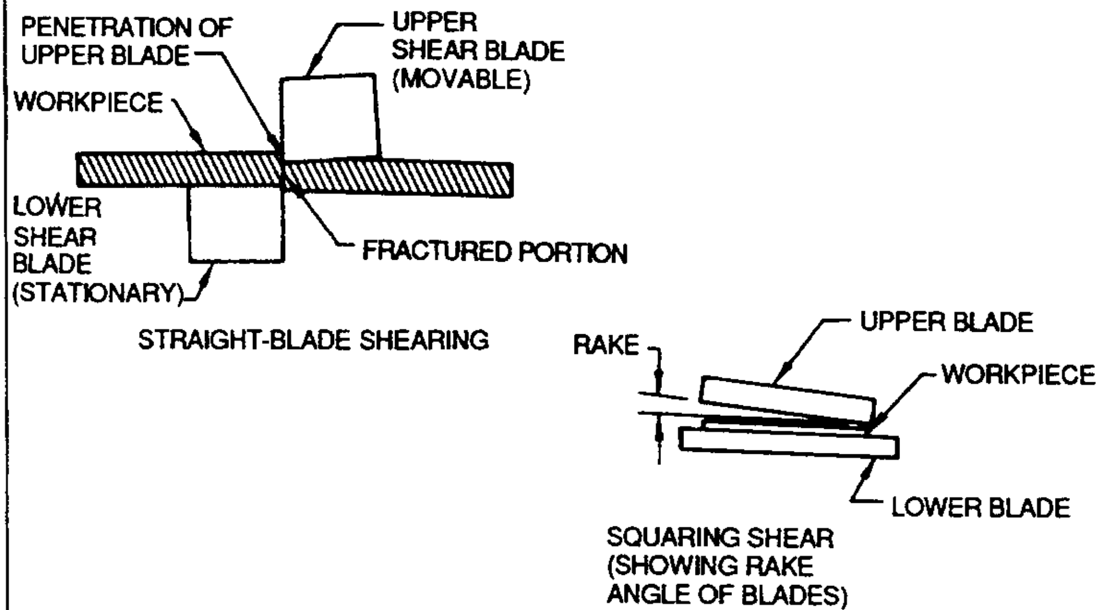
* If thermoplastic material must be dry ground, reduce feed and depth of cut approximately 30%

Table 9. Routing and Spindle Shaping



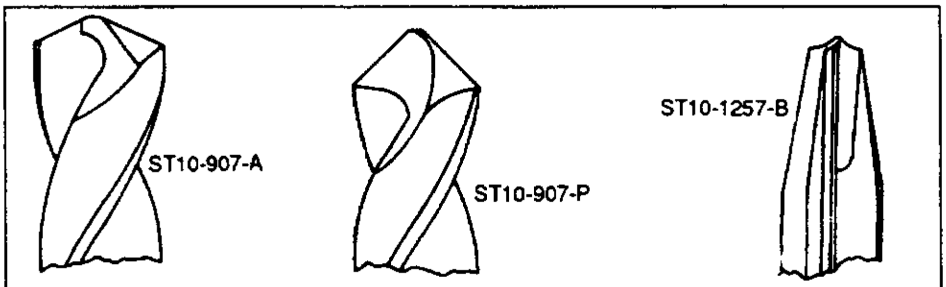
	Plastics material	Cutter		Cutter Speed (SFM)	Feed (FPM)	Notes
		Material	Geometry			
Thermoplastics	ABS	HSS or carbide	Standard (aluminum)	1200-6000	5-15	
Thermoplastics	Acrylic	HSS or carbide	Standard (aluminum)	1200-8000	5-20	Notch sensitive. Start and stop work slowly and carefully.
Thermoplastics	Nylon	HSS or carbide	Standard (aluminum)	1200-6000	15-20	
Thermoplastics	Poly-carbonate	HSS or carbide	Standard (aluminum)	1200-8000	10-20	
Thermoplastics	Poly-sulfone	HSS or carbide	Standard (aluminum)	1200-8000	10-20	
Thermoplastics	PVC	HSS or carbide	Standard (aluminum)	1200-8000	10-20	
Thermoplastics	Teflon	HSS or carbide	Standard (aluminum)	1200-8000	15-25	
Thermosetting	Rubber (urethane)					
Thermosetting	Paper/cloth laminates	HSS or carbide	Standard (aluminum)	1200-6000	5-15	Keep tool sharp to avoid overheating; emits toxic fumes above 450°F.
Thermosetting	Fiberglass laminates	Carbide (C-2)	Standard (aluminum)	500-2000	3-10	Use adequate dust collector and respirator.
Thermosetting		Diamond abrasive	60-80 grit	1200-5000	5-15	
Thermosetting		Carbide abrasive	Medium grit	1200-5000	5-15	
Thermosetting	Graphite laminates	Diamond abrasive	60-80 grit	1200-5000	3-15	Use adequate dust collector and respirator.
Thermosetting	Kevlar	Carbide	Standard (alum.)	1300-2000	5-15	Use exhaust system. Use climb cut.

Table 10. Shearing, Blanking, and Piercing



	Plastics material	Maximum part thickness: Room temperature	Maximum part thickness: Elevated temperature	Die clearance	Notes
Thermoplastics	ABS	3/16		0.002	
Thermoplastics	Acrylic		up to 1/4 (180-200°)	0.002	
Thermoplastics	Nylon	1/8		0.002	
Thermoplastics	Polycarbonate	1/16		0.002	
Thermoplastics	Polysulfone	3/16		0.001	
Thermoplastics	PVC	3/16		0.001	
Thermoplastics	Teflon	1/8		0.002	
Thermosetting	Rubber (urethane)	To 1/2		0.001	
Thermosetting	Paper/cloth laminates	1/16	up to 1/8 (120-250°)	0.002	
Thermosetting	Fiberglass laminates	1/16	up to 1/8 (120-250°)	0.002	
Thermosetting	Graphite laminates	0.05		0.003	Good edge up to 0.015 thick. On thicker materials a 0.020 - wide damaged edge may occur.
Thermosetting	Kevlar	0.062		0.003	

Table 11. Drilling



	Plastics material	Drill: Type	Drill: Geometry	Speed (SFM)	Feed (IPR) ③	Coolant	Notes
Thermoplastics	ABS	HSS twist	ST10-907-P	50-150	0.002-0.008	Water base, air	
	Acrylic	ST10-907K	ST10-907-P	200-400	0.005	Water base, Prestolube	Notch sensitive. Use backup blocks.
	Nylon	ST10-907K	ST10-907-P	180-450	0.003-0.012	Air	Drills cut undersize holes. Avoid over-feeding.
	Poly-carbonate	HSS, carbide twist	ST10-907-A	300-800	0.001-0.0015	Air	
	Poly-sulfone	HSS twist	ST10-907-A	100-150	0.010-0.020	Water base	
	PVC	HSS twist	ST10-907-P	50-150	0.002-0.008	Water base	
	Teflon	ST10-907K	ST10-907-P	200-500	0.002-0.010	Water or air	Drills cut undersize holes; material "grows" when machined.
Thermosetting	Phenolic & phenolic laminates	ST10-907K	ST10-907-A	200	0.005		
	Rubber (urethane)	HSS twist	ST10-907-P	200	0.002-0.008		
	Paper/ cloth laminates	HSS, carbide twist	ST10-907-A	400-500	0.002-0.004	Water base, air	
	Fiberglass laminates	ST10-907H	ST10-907-A	250-350	0.002-0.006		Use Vacuum dust collection
		HSS twist	ST10-907-Q				
		ST1257B	ST10-1257-B	1200			
	Graphite laminates	ST10-907H	ST10-907-A	250-350	0.002		Use vacuum dust collection
		ST1257B	ST10-1257-B	②			
	Kevlar	HSS twist DM step ①	ST10-907-A	250-350	0.002-0.004		Use exhaust system.

Notes:

Thermoplastics - Use drills with slow spirals and polished flutes. Frequent removal of the drill improves chip clearance when drilling deep holes.

Thermosets - powdery chips indicate the feed is too slow. Overly fast speeds result in tearing.

① Klenk drill (BW840) preferred; produces fuzz-free holes

② 6000 rpm maximum

③ Applicable to power-feed equipment only

Table 12. Reaming

COMPOSITES

Material/RPM Values		
Reamer size (inches)	Fiberglass, Graphite-Epoxy or Kevlar-Epoxy	
	Speed RPM [1]	Feed IPR [2]
1/8	2000	0.002
3/16	2000	0.002
1/4	1500	0.002
3/8	1500	0.002
1/2	1000	0.002
5/8	1000	0.002

[1] Use maximum speed of 700 rpm when reaming Kevlar-Epoxy materials. Reaming Kevlar produces holes of marginal quality.

[2] Applicable to power-feed equipment only.

NOTES:

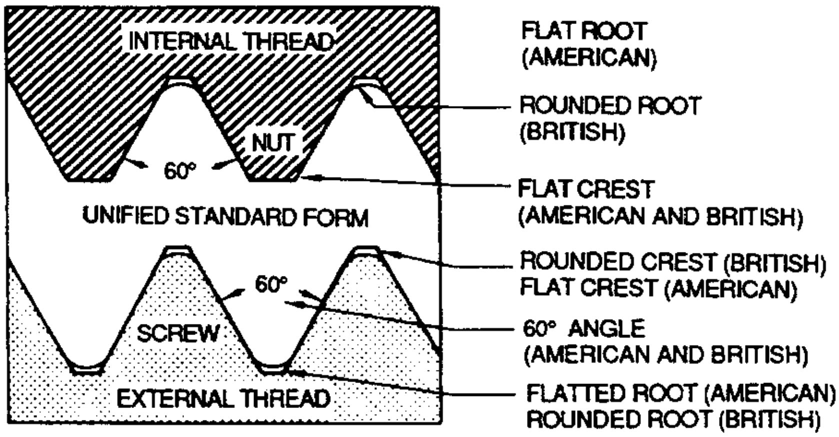
1. Hole size tolerance for reamer diameter up to 1/2 inch is +0.001 inch, -0.000 inch.
2. Hole size tolerance for reamer diameter over 1/2 inch is +0.002 inch, -0.000 inch.
3. A minimum cut of 1/64 inch on the diameter is required when reaming holes up to 5/16 inch diameter.
4. A minimum cut of 1/32 inch on the diameter is required for larger holes.

Recommended Reamer Type	
Material	Reamer Type
Graphite	ST1864P( ) ( ) ( ) (carbide) Single-step or double-step design.
Kevlar	BI-3079-( ) ( ) ( ) (straight, HSS) BI-3085-( ) ( ) ( ) (pilot, HSS) Single-step or double-step design.
Fiberglass	ST1864P ( ) ( ) ( ) (carbide) Single-step or double-step design.

PLASTICS

Decrease drill speed by 1/2-2/3 and increase the feed rate by 2-3 times that which is recommended for drilling. At least 0.005 inch should be removed by the final ream.

Table 13. Tapping and Threading



	Plastic materials	Cutter		Notes
		Material	Speed (SFM)	
Thermoplastics	ABS	HSS	55	
	Acrylic	HSS	25	Notch sensitive, user rounded root.
	Nylon	HSS	50-80	Notch sensitive, user rounded root.
	Polycarbonate	HSS	20-60	Use rounded root.
	Polysulfone	HSS	35-75	
	PVC	HSS	55	
	Teflon	HSS	55	
Thermosetting	Rubber (urethane)	HSS	55	
	Paper/cloth laminates	HSS	25	
	Fiberglass laminates	HSS	25	
	Graphite laminates	HSS	25	
	Kevlar	HSS	25	

Notes:

1. A thread with rounded roots (such as a British Standard series or American Standard Unified Thread form), is recommended since many plastics are notch sensitive.

2. Use taps of H-3 oversize for small diameters, to H-5 oversize for large diameters to allow for elastic recovery.

3. Lathe-cut threads should be made with the tooth ground to cut on one side only and with feed direction parallel to finished thread form. Feed to 0.007-in to 0.010-in per pass.

Table 14. Countersinking Composites

Countersink Cutter Geometry		
Material Usage	Tool Type	Cutter Geometry
All	Countersink Cutter - General Purpose (Carbide Inserts)	ST1221C-C
Fiberglass Graphite-Epoxy	Countersink Cutter Assembly (Polycrystalline Diamond Inserts)	ST1223-C-D
Countersink Cutting Guidelines		
Material	Cutter	Drill Motor Speed (rpm)
Fiberglass	ST1221C-C ST1223-C-D	500 - 1500
Graphite-Epoxy	ST1221C-C ST10-1223C-D	500 - 1500
Kevlar-Epoxy	ST1221C-C ATI AT455SK	500 - 1500

Table 15. Sanding

Plastics material	Sanding grit size (power sanding)	Speed (SFM)	Grit size (hand sanding)	Finish sanding	Notes
All	Silicon carbide or aluminum oxide 50-60 grit	2,000 to 3,000	240 to 600 grit wet or dry paper	600 grit wet or dry with water	Use wet sanding when possible for better finish. Dust removing equipment and respirators are recommended.

Table 16. Polishing

Plastics material	Speed	Finish sanding	Polishing	Buffing	Notes
Acrylics only	Up to 4,000	400 to 600 wet or dry paper	Tripoli and rouge	Clean, soft flannel buff	Work wet when possible.

Table 17. Deburring

Plastics		Deburring method	Notes
Thermoplastics	ABS	Scraper, sandpaper, file, rotary file, or rotoburr	
	Acrylic		
	Nylon		
	Polycarbonate		
	Polysulfone		
	PVC		
	Teflon	Scraper or sandpaper	
Thermosetting	Rubber	Power sanding	
	Paper/cloth laminates	Vibratory, sandpaper, file, rotary file, or rotoburr	Use standard abrasive media and compounds for vibratory deburring. Glassy finish of molded surface will be dulled during deburring. If material will absorb water, it can be vibratory deburred dry and wiped free of loose abrasives.
	Fiberglass laminates		
	Graphite laminates		
	*Kevlar		

* The removal of burrs from Kevlar may be aided by applying a coat of paint or resin compatible with subsequent processing of the part prior to wet sanding of the edge.

CLASSIFICATION OF THERMOPLASTICS BY CHEMICAL FAMILY

ACETALS
- Acetal copolymer
- Acetal homopolymer
- Polyoxymethylene (Delrin)

ACRYLICS
- Polymethyl methacrylate

CELLULOSICS
- Cellophane
- Cellulose acetate
- Cellulose acetate butyrate
- Cellulose nitrate
- Cellulose proprionate
- Ethyl cellulose
- Rayon

FLUOROCARBONS
(or Fluoroplastics)
- Fluorinated ethylene propylene copolymer (FEP)
- Polychlorotrifluoroethylene (CTFE)
- Polytetrafluoroethylene (Teflon)
- Polyvinyl fluoride (PVF)

POLYIMIDES
- Nylon

POLYCARBONATES
- Polycarbonate

POLYOLEFINS
- Crosslinked polyethylene
- Ethylene-ethyl acrylate
- Ethylene-vinyl acetate
- Polyallomers
- Polyethylene
- Polypropylene

POLYPHENYLENE OXIDES

POLYSTYRENE AND ABS
- Acrylonitrile-butadiene-styrene (ABS)
- Polystyrene
- Styrene-acrylonitrile
- Styrene-butadiene

POLYSULFONES
- Polysulfone

THERMOPLASTIC
POLYESTER

VINYLS
- Polyvinyl acetate
- Polyvinyl alcohol
- Polyvinyl butyral
- Polyvinyl chloride
- Polyvinylidene chloride

REFERENCES

BAC 5038	Processing of Acrylic Plastics
BAC 5481	Annealing, Machining, Molding and Preparation for Bonding for Polytetrafluoroethylene (TFE) (Teflon)
BAC 5317/ BAC 5317-1	Fiber Reinforced Composite Parts
D6-22641	Industrial Hygiene and Safety Standards (IHSS)
D6-45055	Fabrication Information Document (FID) for Graphite/ Epoxy Composites
MDR 6-01130	Advanced Composite FID Preparation-Machining
6M59-152	Improved Band Sawing Practices
6M54-253	Geometry and Use of Drills, Reamers and Countersinks