Plastics Topics – Machining of plastics

TANGRAM TECHNOLOGY Consulting Engineers

Tangram Technology Ltd.
33 Gaping Lane, Hitchin, Herts., SG5 2DF
Phone: 01462 437 686
E-mail: sales@tangram.co.uk
Web Pages: www.tangram.co.uk

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Plastics Topics – Machining of plastics

1. Introduction

Machining plastics often looks deceptively simple. The machines are familiar, the operations are familiar, and anyone from a metalworking background can easily assume the same rules apply. They do not.

Plastics can be turned, milled, drilled, tapped and sawn on equipment that also handles metals, but their behaviour under the tool is very different. They soften at lower temperatures, conduct heat poorly, expand more with temperature, creep under load, and distort more easily under clamping pressure. The real challenge in machining plastics is not removing material accurately. It is removing material without allowing heat, stress, deflection and dimensional movement.

Plastics are not simply ‘metals that cut easily’

Plastic machining is often misunderstood. It is not difficult because the material is weak. It is difficult because the material is sensitive. If the process is right, plastics can be machined to a high standard and can outperform metals in many applications. If the process is wrong, the result is scrap, distortion, poor finish, unstable dimensions and unnecessary cost.

Machining is important even though extrusion and moulding are used to process much larger volumes of material. Machining is often the preferred process where production volumes are low, lead times are short, tooling cost must be low and tolerances or dimensional consistency matter more than individual piece price. It is especially valuable for prototypes, low-volume production, awkward geometries and precision parts.

Some materials are naturally better suited to machining than to conventional extrusion and moulding, e.g., PTFE and PE-UHMW. In most cases, extruded rod, sheet and tube will also contain less moulding stress than standard injection moulded parts, which can improve consistency in certain applications. Machining is not simply a fallback process, in many cases it is the best solution because it offers better control, faster iteration and lower up-front cost.

2. Plastics are not metals!

It may seem obvious to anyone reading this, but plastics are not metals. Plastics have lower softening temperatures, lower thermal conductivity, greater elasticity, greater creep and much higher thermal expansion than metals. These different properties explain most of the machining differences. In practical terms, this means:

- Heat builds up faster in the cutting zone.
- The workpiece can distort under clamp pressure.
- Parts can move after machining due to stress relaxation.
- Slow rubbing cuts are more dangerous than properly loaded cutting cuts.
- Surface finish and dimensional accuracy depend heavily on heat control.

The processing machines may be familiar, but the material response is very different.

3. Control and reduce heat build-up

The most important rule for machining plastics is to control heat. Plastics have poor thermal conductivity and retain heat more readily than metals and soften at lower temperatures. Excess heat causes smearing, poor finish, burrs, colour change, residual stress, dimensional drift and local melting. Whatever the symptoms, many machining failures begin with friction and heat build-up.

The amount of heat input to the material should be controlled by:

- Keeping tools sharp.
- Using tool geometries that cut rather than rub.
- Maintaining adequate clearance.

- Using high chip loads rather than rubbing cuts.
- Evacuating chips aggressively.
- Avoiding recutting of swarf.

In plastic machining, ‘slow and gentle’ is not automatically safer. Excessively light cuts can create rubbing, and rubbing creates heat. Controlled chip formation is usually safer than friction.

Heat exits with the chip

Reducing heat build-up can lead to considering the use of coolants (although this may not be necessary for many simple operations). If a coolant is used then it must be safe to use with the specific plastic. Many plastics can suffer from environmental stress cracking if exposed to unsuitable fluids, e.g., petroleum-based coolants, and choosing a coolant is not simply about cooling but also about chemical compatibility and dimensional behaviour.

4. Machining and materials

Plastics are also not a single material and the machining behaviour varies widely between the various families, between specific grades, whether the material is filled or not and sometimes on the processing history. Poor materials selection can cause projects to succeed or fail before machining even begins.

Thermoplastics soften when heated and machining therefore risks local softening, smearing and re-welding if chips aren’t removed effectively. Inside thermoplastics, amorphous thermoplastics, e.g., PS, ABS, PVC PMMA, PC and some PA types, tend to be more sensitive to stress and cooling fluids whereas semi-crystalline plastics, e.g., polyolefins, PET, POM and fluoropolymers, often generate stringy chips and can burr heavily when soft/tough.

Thermosets (phenolic laminates and many fibre-reinforced laminates) do not melt in the same way, but they are often abrasive and prone to edge breakout and delamination, especially if milled in the wrong direction or with dull tools. [8]

Machinability

The tables below give a broad indication of the machinability of various plastics.

Material	Machinability	Recommendations	Common issues
ABS	Good	Moderate to high cutting speeds with a real chip load; sharp tools.	Smearing/melting, burrs, chatter on thin walls.
PVC (rigid)	Good	Manage heat and fumes; avoid aggressive rubbing.	Melting/smearing; fumes if overheated/burnt; stress risks with some solvents.
PMMA	Fair to good	Light cuts, avoid overheating; coolant/air helpful; good edge preparation for polishing.	Brittle chipping/cracking; stress-cracking/crazing from heat; flame polishing can induce stress.
PC	Good	Keep heat down; evacuate swarf; careful coolant choice.	Heat-generated stress; drilling melt; fluid choices (avoid some oils).

Figure 1: Machinability of amorphous thermoplastics

Material	Machinability	Recommendations	Common issues
Polyolefins (PE/PP)	Fair	Aggressive chip evacuation; larger chip thickness; avoid rubbing.	Heavy burrs/flash; “gumming” and chip welding; work holding marks.
Nylon (PA6/PA66)	Good	High feed/speed to move swarf; good support; manage moisture.	Stringy chips, wrap-around; dimensional change with moisture; burrs.
PE-UHMW	Difficult (very tough/stringy)	Very high attention to swarf removal and wrap-around control.	Severe burrs; chip wrap; part deflection; heat from recutting swarf.
PET (engineering)	Good	Moderate cutting speeds; stable setup.	Chipping on edges if too aggressive; heat in deep drilling.
POM	Excellent	Single/low-flute cutters; sharp edges and chip clearance.	Burrs if dull; heat if rubbing; undersize holes unless adequate cut provided.
PTFE	Difficult (soft, creeps)	Sharp tools, controlled heat; expect burr control work.	Burrs/feathering; deformation/creep in clamping; hazardous fumes if overheated.

Figure 2: Machinability of semi-crystalline thermoplastics

Material	Machinability	Recommendations	Common issues
Phenolic laminates	Fair to difficult	Climb/down milling; carbide/diamond for wear; dust control.	Delamination, abrasive dust, tool wear; breakout on exit.

Figure 3: Machinability of thermosets

5. Work holding and tooling

Plastics need lower cutting forces than metals but also deform far more easily under clamp pressure. Secure work holding is necessary, but excessive clamping can distort the part even before machining starts.

Flat parts and thin sections should be carefully supported and thin-walled tubes should be supported with internal plugs or similar to prevent chatter, deflection and out of round conditions. Good work holding and fixtures in plastics machining is not only about holding the part still, it is about holding it so that machining does not create new stresses or shape errors.

For simple work or short runs HSS may be acceptable for tooling but carbide is generally preferred for better wear resistance and surface finish. For filled or other abrasive plastics, ceramic, diamond-coated or PCD tooling may be better, especially in longer production runs. Glass-filled, carbon-filled and graphite-filled grades are specifically more abrasive and therefore more demanding on tooling.

Tooling should have positive geometry, polished tool surfaces, ground peripheries and generous chip clearance. All of these will reduce friction, reduce material build-up and improve chip flow. The key principle is that the cutter must slice cleanly and the encourage chip removal. Any geometry that encourages rubbing or chip trapping creates heat and instability.

6. Processes

Drilling as the most problematic machining operation for plastics, it combines the two biggest risks in machining plastics, concentrated heat and chip congestion in a confined space. This can lead to smearing, local melting, internal stress, cracking and dimensional error. The best results are achieved by:

- Drills with adequate flute space.
- Relief grinding of the drill to reduce rubbing.
- Peck drilling for chip removal.
- Staged opening of large holes.
- Using extra care at breakthrough to avoid chipping on exit.
- Boring rather than drilling for larger holes or more sensitive material.

In milling, the document often favours climb milling because more heat tends to leave with the chip rather than staying in the workpiece. In milling, lower flute counts are often favoured because they provide more room for chips and reduce the chance of recutting. Low flute counts and good chip clearance are repeatedly recommended. The goal is stable cutting with minimal rubbing.

In turning and boring, long stringy chips can wrap around the tool, chuck or part. Effective chip extraction and good edge condition are therefore important. Stable work holding is especially important for thin or flexible parts.

Sawing requires the right tooth spacing, set and rake angle so chips can clear cleanly and the blade does not bind behind the cut. Plastic-specific saw blades, carbide tooling and enough tooth set to avoid frictional closing are important for good results.

7. Speeds and feeds[1]

The following tables give indicative recommendations for speeds and feeds:

Plastic	Drilling: V_c (m/min)	Drilling feed (mm/rev)	Turning: V_c (m/min)	Turning feed (mm/rev)	Notes
ABS	50-200	0.2-0.3	200-500	0.2-0.5	Avoid chatter on thin walls; keep tool sharp
PVC (rigid)	30-120	0.1-0.5	200-750	0.3-0.5	Control heat; burnt PVC can generate hydrogen chloride
PMMA	20-60	0.1-0.5	90-150 typical; 15-30 for best finish	(often light)	Acrylic softens when heated; brittle-light cuts, control heat

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[1] Conversion formulae:

- Spindle speed from cutting speed:

$$RPM = \frac{1000 \text{ x } V_c}{\pi \text{ x } D}$$

where V_c is cutting speed (m/min) and D is tool diameter (mm).

- Feed rate from feed per tooth (milling/routing)

$$V_f = f_Z \text{ x } z \text{ x } RPM$$

where f_Z is feed per tooth and z is number of cutting edges/flutes.

Plastic	Drilling: V_c (m/min)	Drilling feed (mm/rev)	Turning: V_c (m/min)	Turning feed (mm/rev)	Notes
PC	50-100	0.1-0.3 (lower for sheet)	200-400	0.05-0.4	Avoid oil for drilling PC sheet; evacuate swarf frequently
Polyolefins (PE/PP)	50-150	0.1-0.3	250-500	0.1-0.5	Soft/tough: prioritise swarf evacuation and real chip thickness
Nylon (PA6/PA66)	50-100	0.1-0.3	200-500	0.05-0.5	Manage chip wrap; support parts; moisture affects dimensions
PE-UHMW	50-100	0.1-0.3	200-500	0.05-0.5	“Wrap-around” swarf common; air blast/vacuum helps
PET (engineering	50-80	0.1-0.3	200-400	0.05-0.5	Moderate speeds; watch edge chipping on aggressive entry
POM	50-100	0.1-0.3	200-500	0.05-0.5	Single-flute mills often preferred for chip clearance
PTFE	50-100	0.1-0.3	150-400	0.05-0.4	Burr-prone; creep in clamping; avoid overheating (fume hazard)
Phenolic laminates	RPM set high with light feed	Light and uniform	≈ 180	0.1-0.15	Delamination/dust dominate; climb/down milling recommended

Figure 4: Drilling and turning basic parameters

Plastic	Milling V_c (m/min)	Feed per tooth f_z (mm/tooth)	Routing notes (CNC trimming)
ABS	300-500	≈ 0.05-0.25 (size-dependent)	Often treated as “soft plastic” in routing; O-flute common
PVC (rigid)	300-1000	moderate chip load; avoid rubbing	Treat as soft/hard depending on formulation; prioritise chips not dust
PMMA	(routing can use wide range)	“hard vs soft” acrylic differs	Cast acrylic often treated as “hard plastic”; extruded as softer; affects tooling and chip load
PC	200-400 typical; sheet trimming 100-500	up to ≈0.4 (1-edge)	PC is categorised as “soft plastic” in routing; upcut O-flute for chip removal in sheet work
Polyolefins (PE/PP)	250-500	Often higher chip load than hard plastics	“Soft plastic” chip loads: increase feed if rewelding occurs

Plastic	Milling V_c (m/min)	Feed per tooth f_z (mm/tooth)	Routing notes (CNC trimming)
Nylon (PA6/PA66)	200-500	up to ≈ 0.5	High feed/speed helps avoid wrap-around and heat; evacuate swarf
PE-UHMW	200-500	up to ≈ 0.5 (but control burrs)	Chip evacuation is primary challenge; forced air helps
PET (engineering)	150-300	up to ≈ 0.4	Usually stable; chipping can occur on brittle edges if entry is harsh
POM	200-400	Up to ≈ 0.5	Single-flute mills can reduce frictional heat and improve chip space
PTFE	100-250 (unfilled)	up to ≈ 0.3 (unfilled)	Expect burr control; avoid heat buildup to prevent decomposition fumes
Phenolic laminates	(often moderate)	Set chip load to avoid rubbing and dust	Routing phenolic: published chip load/feed charts exist for coated router bits [73]

Figure 5: Milling and routing basic parameters

8. Summary

Machining plastics is not a simplified version of metalworking. It is a separate discipline with its own process rules. Success depends on respecting the sensitivity of the material and the essential principles are clear:

- Choose the correct polymer and exact grade and buy stable, well-specified stock.
- control heat aggressively.
- Use sharp, appropriate tooling.
- Support the part without distorting it.
- Evacuate chips effectively.
- Select coolant according to polymer compatibility.
- Treat tolerances as a stability problem, not just a cutting problem.
- Use annealing selectively and only when it adds value.
- Match the machining strategy to the material family.

Machining of plastics, when done correctly, can deliver light weight, corrosion resistance, wear performance, chemical resistance, electrical insulation and low noise, often with excellent dimensional control. If done incorrectly, machining of plastics produces warped parts, poor finish, unstable dimensions and needless scrap. The difference lies in restraint, process discipline and material understanding.