SIMONA

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Machining

GLOBAL THERMOPLASTIC SOLUTIONS

Contents

1 Introduction

Thermoplastics can be machined with the help of equipment used in wood and metal processing. High-speed machine tools with strong bearings are preferable; adequate precautions must be taken to vacuum swarf and dust. Machining should always be performed at room temperature.

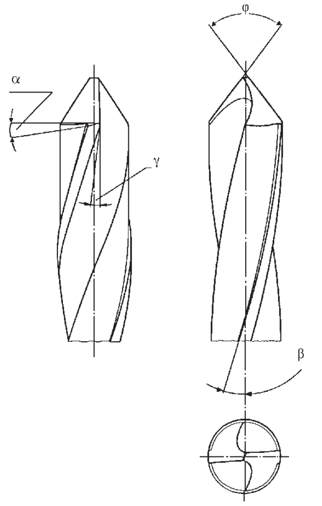
Always bear in mind that plastics are relatively poor heat conductors. Rises in temperature can be reduced by ensuring that cutting edges of tools are sharp and chips are removed efficiently or prevented by cooling with compressed air or water (including cooling lubricants). Standard grades of tool steel are sufficient for machining. Using carbide-tipped cutting tools can prolong tool life and improve the neatness of cutting.

2 Drilling

Holes can be drilled in thermoplastic semi-finished parts using HSS twist drills that are commercially available. Generally speaking, no specific grinding is required, but you should use relief-ground cutting edges and the helix angle should be small. A negative rake angle reduces the risk of jamming and material being torn out of the drill hole. This is recommended up to a drill hole depth of approx. 15 mm.

At large drilling depths it is advisable to withdraw the bit from the hole a number of times in order to extract the shavings efficiently. At relatively large drill hole diameters a rise in material temperature can cause the cutting tool to jam. This effect can be counteracted by making a pilot hole in advance. Drill holes with a diameter above 20 mm should be made using a double-edged bit with a pilot. In the case of drill holes with a diameter above 40 mm it is advisable to use circle cutters.

Cutting speed and forward feed depend on the depth of the drill hole. The thermoplastic material should not smear. As regards thin-walled workpieces, it is advisable to use a high cutting speed.



Drill bit:
α = Clearance angle
β = Helix angle
γ = Rake angle
φ = Point angle

Figure 1: Cutting edge geometry of a drill bit

Reference data for drilling holes in plastics

			PE-HD	PP	PVC	PVDF
Drilling						
α	Clearance angle	°	10 – 15	5 – 15	6 – 10	10 – 16
β	Helix angle	°	12 – 16	12 – 16	12 – 16	12 – 16
γ	Rake angle	°	3 – 10	3 – 10	3 – 6	5 – 10
ϕ	Point angle	°	60 – 90	60 – 90	80 – 120	100 – 130
v	Cutting speed	m/min	50 – 100	50 – 100	30 – 100	50 – 200
f	Forward feed	mm/U	0.2 – 0.5	0.2 – 0.5	0.1 – 0.5	0.1 – 0.5

3 Threading

Screw threads are easy to tap with conventional thread tap sets. A rake angle of 0° should not be exceeded.

For fixings that are taken apart frequently the DIN 405 round thread or threaded bushings are to be recommended on account of the notch effect. Self-tapping screws, which are also referred to as “high-low”, “Spax” or window screws, have also proved suitable for connections that rarely have to be taken apart. Sheet metal screws should not be used.

4 Milling

As regards the milling of SIMONA® plastics, all standard milling machines that are used in metal machining and are designed for high speeds are suitable. It is advantageous to work at a high cutting speed and a small depth of cut.

The milling cutter should have adequate space for swarf to ensure uniform chip removal and efficient dissipation of heat. Good results can usually be achieved if attention is paid to ensure a polished cutting edge and high positive cutting geometry during tool selection. In practice, milling cutters for machining aluminium have proved to be suitable tools. However, there are also product lines that have been specially adapted to the properties of various plastics.

A pointed cutting tool is crucial to the quality of milling. The milling cutter intended for plastics processing should therefore not be used for cutting other materials.

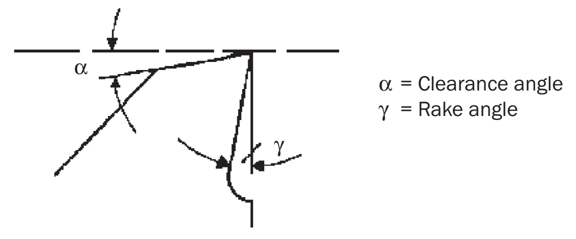


Figure 2: Cutting edge geometry

Reference data for milling plastics

			PE-HD	PP	PVC	PVDF
Milling						
α	Clearance angle	°	5 – 15	5 – 15	5 – 10	5 – 10
γ	Rake angle	°	5 – 15	5 – 15	0 – 15	5 – 15
v	Cutting speed	m/min	up to 1,000	up to 1,000	up to 1,000	up to 1,000
f	Forward feed	mm/tooth	up to 0.5	up to 0.5	up to 0.5	up to 0.5

5 Planing

Planing is performed with the usual tools (short double plane and wood smooth plane) and the conventional surface planing and thicknessing machines. The shaping machine normally used in metal machining can also be used for machining plastics, provided the planing tool is of suitable design.

6 Turning

Thermoplastics can also be machined on lathes. As with all other materials, it is advisable to first rough the finished part with a large depth of cut and high forward feed, and then to obtain the final dimensions with a finishing cut. Forward feed and cutting speed must be matched to one another in such a way that heat is dissipated efficiently via the shavings. If this should prove inadequate, the cutting point can also be cooled with compressed air or cooling lubricant. These measures can also be applied to improve chip removal at the same time.
A small cutting edge radius usually produces a surface that is largely score-free.

Carbide-tipped and HSS indexable inserts for machining aluminium have proved to be suitable cutting tools. The following table includes some reference data relating to the machining of our semi-finished parts.

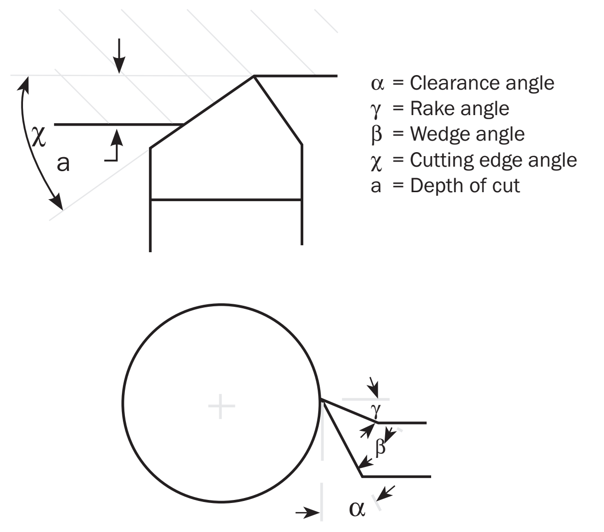


Figure 3: Cutting edge geometry of a lathe chisel

Reference data for turning plastics

			PE-HD	PP	PVC	PVDF
Turning						
α	Clearance angle	°	5 – 15	5 – 15	5 – 10	8 – 15
γ	Rake angle	°	0 – 10	0 – 8	0 – 10	0 – 15
χ	Cutting edge angle	°	45 – 60	45 – 60	45 – 60	45 – 60
v	Cutting speed	m/min	200 – 500	200 – 500	200 – 500	100 – 300
f	Forward feed	mm/U	0.1 – 0.5	0.1 – 0.5	0.1 – 0.5	0.1 – 0.3
a	Depth of cut	mm	up to 10			
r	Tip radius	mm	0.5			

7 Sawing

7.1 Circular Sawing

Neat cut surfaces are made if the saw blade only projects a little beyond the plastic sheet being cut.

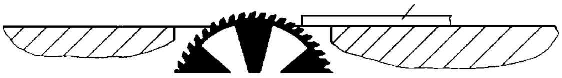
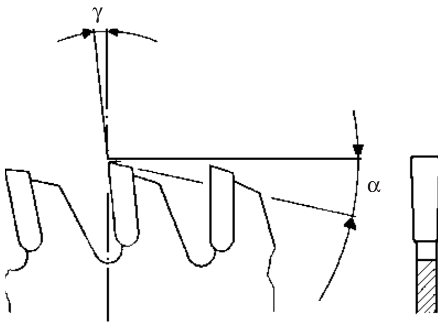


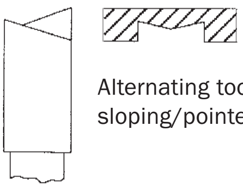
Figure 4: Diagram of circular sawing

Sheets up to a thickness of 5 mm can be cut with unset saw blades. Above that, however, it is advisable to use relief-ground saw blades. The use of carbide-tipped saw blades increases the tool life of the saw blade considerably; this also helps to improve cutting performance and the quality of cut neatness. The latter is also largely dependent on the sharpness of the saw blade. A saw blade intended for sawing plastic should therefore not be used for cutting other materials.



α = Clearance angle
γ = Rake angle

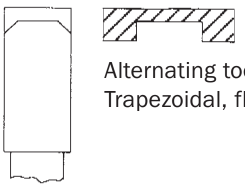
Figure 5: Cutting edge geometry of a saw tooth



Alternating tooth
sloping/pointed

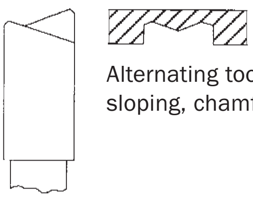
PVC, PE-HD, PP
for PP wide tooth pitch –
Example: Saw blade 220 mm dia., approx. 28 teeth

for PVC narrow tooth pitch –
Example: Saw blade 220 mm dia., approx. 88 teeth



Alternating tooth
Trapezoidal, flat

Co-extruded sandwich sheets
COPLAST-AS



Alternating tooth
sloping, chamfered

Hard, brittle plastics
PVC-GLAS, acrylic glass

Figure 6: Tooth profiles for circular saws (carbide-tipped)

Parameters for circular sawing of plastics

			PE-HD	PP	PVC	PVDF
Circular sawing						
α	Clearance angle	°	10 – 15	5 – 15	5 – 10	5 – 15
γ	Rake angle	°	0 – 10	0 – 10	0 – 5	0 – 8
t	Tooth pitch*	mm	3 – 8	3 – 8	3 – 5	2 – 8
v	Cutting speed	m/min	1,000 – 3,000	600 – 3,000	2,500 – 4,000	up to 2,500

* For brittle materials select a small tooth pitch

7.2 Band sawing

In band sawing, heat dissipation is more efficient owing to the rotating saw band. Band saws are suitable for cutting pipes, blocks, thick sheets and curves. Please note that on account of free-cutting the saw bands have to be set properly (± 2 mm) and they must be sharp.

Parameters for band sawing of plastics

			PE-HD	PP	PVC	PVDF
Band sawing (high-speed steel HSS)						
α	Clearance angle	°	30 – 40	30 – 40	30 – 40	30 – 40
γ	Rake angle	°	0 – 5	0 – 5	0 – 5	2 – 8
t	Tooth pitch*	mm	2 – 6	2 – 6	2 – 5	2 – 8
v	Cutting speed	m/min	500 – 3,000	500 – 3,000	up to 2,000	500 – 3,000

* For brittle materials select a small tooth pitch

8 Die-cutting and cutting with guillotine shears

Die-cutting can be performed effectively on conventional presses, especially if wall thicknesses are thin. The quality of the cut edge is dependent both on the sharpening of the cutter dies and on sheet thickness. In the case of thin sheets, cutting is generally neater than in the case of thick sheets. To avoid stresses and splintering in the sheet to be machined, the cutting angle should be less than 70°.

Depending on the material, SIMONA® plastics can be cut on guillotine shears down to a thickness of approx. 4 mm. Well-sharpened, undamaged blades and a maximum play of ± 0.1 mm between the moving blade and the stationary blade are crucial to the quality of cutting results.

9 Sanding and polishing

In a number of applications it may be necessary to subject the semi-finished part to surface treatment. For example, in swimming pool construction the weld seams are often polished in order to ensure a consistent surface finish and excellent appearance. Another example of an application is the pretreatment of surfaces to be glued. By sanding the surface to be glued, the surface area can be increased for the purpose of improving the adhesion of the bond. As partially crystalline thermoplastics tend to smear during the machining process, this method tends to be more suitable for machining amorphous plastics.

Sanding

The first steps are to roughly flatten the plastic surface. Sanding as preparation for polishing makes a major contribution towards the success of the polishing process. Any weld seams or projecting edges are removed with a chisel, rasp or card scraper. Then sanding is performed, first with coarse emery cloth, then with increasingly fine grain sizes, until the surface is uniform.

Any remaining scratches must also be sanded out carefully. Wet sanding processes have proved successful on account of the favourable heat dissipation. As an alternative to commercial sandpapers, abrasive nylon webs with embedded abrasives are also available. Sanding can be performed by hand or with suitable sanding machines or oscillating sanders; oscillating machines are preferable.

Polishing

Polishing is based on melting the surface and calls for an instinctive touch. Work is performed with rotating polishing rollers. Plastics are relatively poor heat conductors, which has to be borne in mind when polishing. Otherwise the surface may overheat and the outer layer of the semi-finished part may be damaged beyond repair. It is advisable to use two discs one after the other. The first disc is used to flatten out coarse areas of roughness, for which grey cotton cloth mops have proved ideal. A Molton disc is suitable for repolishing with the second disc. In both steps the peripheral speed of 23 m/sec should not be exceeded. At customary rotational speeds of 1,440 rpm this peripheral speed is reached with a disc diameter of 300 mm. By using waxes for prepolishing and repolishing, the appearance of the polished surfaces can be enhanced considerably.

10 Annealing

10.1 Inherent stresses

All semi-finished plastics and all components made from them have a certain amount of potential for inherent stresses. Such inherent stresses are not attributable to any influence exerted by external forces and they develop during the production process. Plastic melt plasticised in the extruder is extruded into the open through a roll gap. The semi-finished part, which is still plasticised and hence readily mouldable, is fed over multiple rolls in succession, during which it cools down. During this process the molecular chains of the polymer are oriented and they freeze in that state.

Additional stresses arise on account of the difference in cooling rates between the interior and exterior of the extruded semi-finished product. Heat is solely dissipated via the outer surface. Cooling from the interior is not possible. Owing to the relatively low thermal conductivity, the core of the semi-finished part cools down much more slowly than the outer surfaces. Therefore, volume contraction occurs inside the semi-finished part. This results in tensile stresses in the interior and a resulting compressive stress on the outer layer. If there is an equilibrium of stresses, they are not immediately detectable in the semi-finished part. They only become visible later when the balance of stresses and strains in the body being considered is disturbed (owing to machining, for example).

10.2 Annealing

The equilibrium of stresses and strains in a semi-finished part may be disturbed considerably, especially if machining is only performed on one side. As a result, deformations can occur such as bending or twisting of the workpiece. One solution is to perform heat treatment beforehand in the form of stress-relieving annealing. The heat treatment temperature depends on the particular material. Amorphous materials are annealed above the glass transition temperature, whilst partially crystalline thermoplastics are annealed at about 10 °C to 20 °C below the crystalline melting point (see figures).

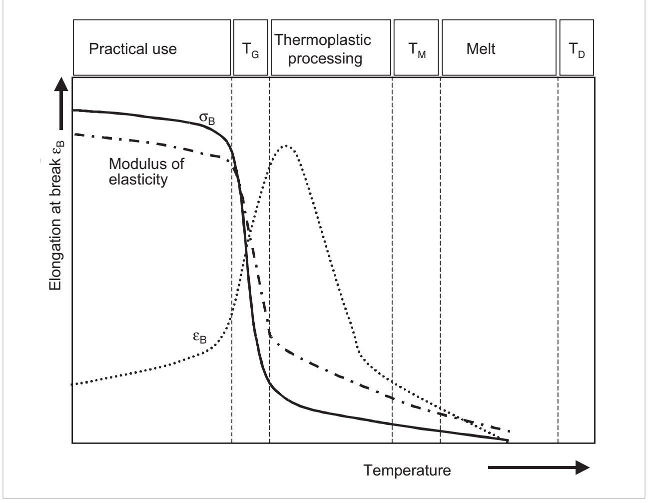


Figure 7: Diagram of the mechanical properties of amorphous thermoplastics as a function of temperature (T_G = glass transition temperature, T_M = melting temperature, T_D = decomposition temperature)

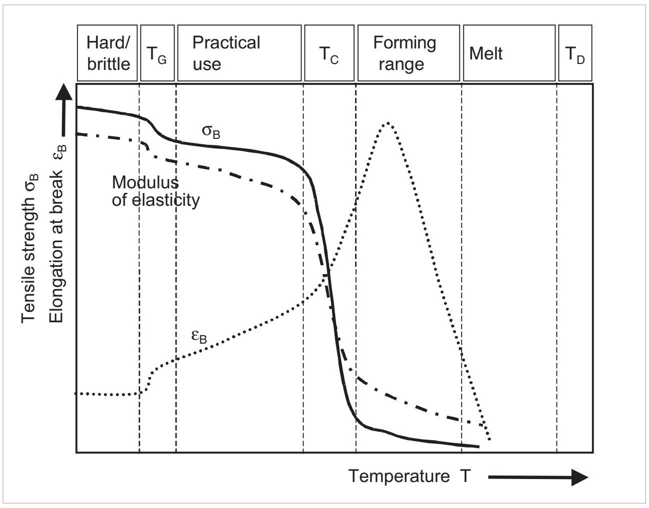


Figure 8: Diagram of the mechanical properties of semi-crystalline thermoplastics as a function of temperature (T_G = glass transition temperature, T_C = crystalline melting temperature, T_D = decomposition temperature)

The duration of annealing, defined as the total of heating time, dwell time and cooling time, is chiefly determined by the thickness of the body being annealed. By selecting the duration of annealing systematically, the aim is to ensure complete internal warming of the workpiece. The parts to be annealed must be positioned in the annealing oven in such a way that the surface areas coming into contact with the temperature required are as large as possible. A forced-air oven with temperature control as uniform as possible is suitable for this purpose.

In the case of solid rods it is advisable to prefabricate blanks first and anneal them at low stress before finishing. After appropriate thermal treatment the blanks can then be finished.

If extruded sheets are to be annealed on pallets, the banding must be removed before that step.

Annealing plastic parts is generally only useful if a change in shape due to thermal expansion can take place without any hindrance. If this is not the case, e.g. plastic sheets firmly clamped in a metal frame, heat stresses are bound to develop. The actual point of annealing should therefore be selected carefully within a production sequence.

10.3 Reference data

Annealing parameters are dependent not only on the characteristics of the component but also on its geometry. For wall thicknesses of < 10 mm heat treatment times of 1 h are generally sufficient at the temperature peak. To prevent any new internal stresses arising, because rates of cooling vary locally and in terms of time, it is important to keep the rate of cooling as low as possible. To be observed in general: the higher the temperature, the lower the rate of cooling should be.

Heating time is usually determined by the oven. If it can be set, it is advisable to use a rate of approx. 20 K per hour.

In the following table you will find some empirical data from our company for guidance purposes.

Assuming a standard reference atmosphere, the annealed component can be removed at a surface temperature of approx. 40 °C. Owing to the small difference between 40 °C and room temperature, the cooling rate of the component is bound to be slow (assuming unhindered convection) on account of the small amount of heat.

Reference data for annealing

	Thickness	Temperature	Holding time	Holding time
	mm	°C	h	h
PE	20	approx. 120	2	takes place in the oven approx. 10 K temperature drop per 1 h
	40		4	
	60		6	
	80		8	
	100		10	
	120		12	
	140		14	
PP	20	approx. 140	2	takes place in the oven approx. 10 K temperature drop per 1 h
	40		4	
	60		6	
	80		8	
	100		10	
	120		12	
	140		14	
PVDF	20	approx. 150	2	takes place in the oven approx. 10 K temperature drop per 1 h
	30		3	
	40		4	
PVC	10	< 70	2	takes place in the oven approx. 10 K temperature drop per 1 h
	20		4	
	30		6	
	40		7	
	50		8	

11 Legal note and advice

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