Formech International Ltd

A Vacuum Forming Guide

Section 4

Plastic Materials and Their Characteristics

Plastics comprise a of a wide range of materials but fundamentally fall into two groups – thermoset and thermoplastic, the latter being a material which, due to the molecular structure, has the property of softening repeatedly when heated and hardening once cooled. Thermoplastics also have what is known as a ‘memory’ enabling a formed part to revert to its original state when reheated.

It is the thermoplastic type that is used specifically for thermoforming and therefore we will concentrate on this category in this section. Further information on the complete range of polymers can be obtained from the contacts listed at the end of this manual.

Polymers are made up of molecules which in turn are made up of atoms. These atoms have many different combinations which all have different properties and contain a wide range of additives to give each material its own characteristics. There is constant research being carried out to develop new materials suited to an ever increasing range of applications. Later in this section we have provided a breakdown of the more common materials used for thermoforming, their characteristics and the applications to which they are most suited.

Thermoplastics are split into two different groups – amorphous and crystaline. Crystalline thermoplastics contain an ordered manner of molecules and amorphous contain a random arrangement.

Generally speaking amorphous materials, e.g. Polystyrene and ABS are easier to vacuum form as they do not have such a critical forming temperature. When heat is applied amorphous materials becomes soft and pliable – when it reaches this state it is known as its **Glass Transition Temperature (Tg).** If heated to a higher temperature it reaches a **Viscous** state (Tv). The changes occur over a range of temperatures and enable the operator to have a fairly wide forming range.

Semi-crystaline and crystaline materials, e.g. Polyethylene and Polypropylene have a far more critical forming temperature as they go rapidly from the Tg state to Tv a change known as the **Melt Transition Temperature (Tm).** When using crystalline materials is imperative that accurate temperature control is used to monitor the heating process.

In summary, the forming temperature bands for amorphous materials is much wider and as a result are easier to process in comparison to their semi-crystalline counterparts. In other words they have a much better melt strength and will not sag as much as the melt transition temperature is reached.

The accompanying table 4.1 lists some more commonly used amorphous and semi crystalline materials and provides a guideline as to their temperature characteristics.

Table 4.1

Material	*GlassTransition Temperature (tg)*	*Rec.Mould Temperature.*	*Rec.Forming temperature*	*Drying Temp*
PS	94 °C	82 °C	150 -175 °C	70°C
ABS	88-120 °C	82 °C	150 -180 °C	70/80°C
PP	5 °C	90°C	150 - 180 °C	65°C
Acrylic/PVC	105 °C	-	140 - 190 °C	75°C
PC	150 °C	127 °C	170 - 205 °C	90°C

Different thermoplastics have different characteristics and are better suited to specific applications. Ideally the material should be easy to form with a low forming temperature, good flow characteristics and thermal strength, high impact strength and low shrinkage on cooling.

To improve thermal stability in certain materials like, for example, PVC, stabilisers are added to help prevent degradation when heated.

Certain materials are known as ***Hygroscopic*** – namely that they absorb moisture which if not pre-dried prior to forming will result in moisture blisters which will pit the surface of the sheet resulting in a reject part. It is a common misconception that the blisters are as a result of too much heat. This in turn can lead to incorrect heating cycles being entered which in turn cause problems with definition on the finished part. (To avoid the pitting the operator is forced into forming the part before the plastic has reached its forming temperature).

To overcome this problem it is therefore necessary for hygroscopic materials to be pre – dried in an oven before forming. The drying temperature and length of drying time depends on the material and the thickness. It is advisable to contact the suppliers who will advise exactly what drying temperature and time is required for their materials.

E.g.: Polycarbonate with a thickness of 3mm would require 4 hours at a drying temperature of 80-120°.

In the following pages we will look at the more commonly used plastics and list their properties, features and some of the more popular applications for which they are used. (a full schedule of applications for thermoformed products is listed in section 2) For more detailed information and specification we recommend you contact the various suppliers who would be happy to assist with any enquiries.

In table 4.2 you will find a selection of more commonly used materials and the heating times required using a single heater Formech machine equipped with Infra-red ceramics (if twin heaters are used then the heat cycle can be reduced by up to 30%). These are given as a guideline only as many different grades of materials exist and other factors which affect timescales. We would recommend you contact the plastic manufacturer to obtain more accurate figures prior to commencing production.

Table 4.2

Plastic	Thickness	Heat time
		(seconds)
PS	1mm	30
ABS	1mm	40
PP	1mm	50
PE	1mm	50
PETG	1mm	30
PVC	1mm	30
PC	1mm	60

Plastic	Thickness	Heat time
		(seconds)
PS	1.5mm	45
ABS	1.5mm	60
PP	1.5mm	75
PE	1.5mm	75
PETG	1.5mm	45
PVC	1.5mm	45
PC	1.5mm	90

Plastic	Thickness	Heat time
		(seconds)
PS	2mm	60
ABS	2mm	80
PP	2mm	100
PE	2mm	100
PETG	2mm	60
PVC	2mm	60
PC	2mm	120

Plastic	Thickness	Heat time
		(seconds)
PS	3mm	90
ABS	3mm	120
PP	3mm	150
PE	3mm	150
PETG	3mm	90
PVC	3mm	90
PC	3mm	180

Plastic	Thickness	Heat time
		(seconds)
PS	4mm	120
ABS	4mm	160
PP	4mm	200
PE	4mm	200
PETG	4mm	120
PVC	4mm	120
PC	4mm	240

Acrylonitrile Butadiene Styrene– (ABS)

Properties
Hard, rigid amorphous thermoplastic with good impact strength and weather resistance. It contains a rubber content which gives it an improved impact resistance. Available with different textures and finishes in a range of thickness. Needs drying. Available in Fire Retardant and UV stabilised grades.

Formability
Good – forms to a high definition.

Hygroscopic
Yes – pre drying required at approx 80° (1 hour per mm)

Strength
Good – High Impact

Shrinkage Rates
0.3 – 0.8%

Availability
From stock

Solvent/ Filler
Methyl Ethyl Ketene (MEK), Toluene and Dichloromethane Solvent will make filler paste.

Finishing/ Machining
Machines well with Circular Saws, Routers and Band saws– takes all sprays.
Can be Guillotined and Roller cut.

Clear
Not Available

Colours
Black / White / Grey and limited colours.

Applications
Luggage, Caravan Parts, Vehicular Parts, Sanitary Parts, Electrical Enclosures.

Price
Medium

Stockist
Stephen Webster, Amari Plastics, Larger quantities – Doeflex

Acrylic - PMMA – (Perspex, Oroglas, Plexiglas)

Properties
A high quality hard amorphous plastic with good clarity that can be worked after forming. **NOTE:** Only extruded sheet is suitable for vacuum forming effectively. Cast Acrylic will not respond well as it displays a very small usable plastic zone. As a result it will only produce general contours with large drape radii. Needs drying. Often replaced by PETG – see separate heading.

Formability
Tends to be brittle and is temperature sensitive.

Hygroscopic
Yes – Consult supplier for drying times.

Strength
Medium to High strength

Shrinkage Rate
0.3 – 0.8%

Availability
Ex stock – 2 weeks

Solvent/ Filler
Tensol, Solvent and gap filler.

Finishing/ Machining
Prone to Shatter. Takes cellulose and enamel spray. Good for hand working.

Clear
Yes.

Colours
Solid colours

Applications
Signs, Roof Lights and Domes, Baths and Sanitary Ware, Light Diffusers

Price
Expensive

Stockist
Amari, Visijar Tuckers, Multiplastics

Co-Polyester – (PETG / VIVAK)

Properties
An easy forming amorphous thermoplastic. FDA approved for food applications. Optically very good with excellent fabricating performance. Thermoforms with ease utilising low temperatures and fast cycle times. Can be sterilised and is resilient to a wide range of acid oils and alcohols. Not recommended for use with highly alkaline solutions.

Formability
Very Good – forms to a high definition. Forming range 80 - 120°C

Hygroscopic
Not normally required. If sheet is exposed to high humidity conditions for an extended time then pre-drying is required – 8 hours at 60° C.

Strength
Good – High Impact

Availability
From stock

Solvent/ Filler
Cementing can be done using solvents or commercial glues. Can be Ultrasonically Welded.

Finishing/ Machining
Can be Guillotined, Saw Cut or Routered. Die Cutting and Punching also possible up to 3mm. Paints and Inks for Polyester can be used for printing on PETG.

Clear
Yes

Colours
Limited – Contact Supplier

Applications
Point of Sale and Displays, Medical Applications

Price
Expensive – (competitive with other clear materials e.g. PC/ PMMA

Stockist
ABG, Axxis ViVak

Polystyrene– Polyphenylethene (H.I.P.S / BEXTRENE)

Properties
One of the most widely used materials An easy forming amorphous thermoplastic. Thermoforms with ease utilising low temperatures and fast cycle times. Available with different textures and patterns. No pre drying required. Poor UV resistance –not suitable for outdoor applications.

Formability
Very Good – forms to a high definition. Forming range circa 150°C

Hygroscopic
No

Strength
Medium to Good impact strength

Shrinkage Rate
0.3 – 0.5%

Availability
From stock

Solvent/ Filler
Dichoromethane, Toluene. Filler can be made from dissolved plastic in solvent.

Finishing/ Machining
Needs special etch primer before spraying. Good machining with all methods.

Clear
Yes – Styrolux (Clarity not to quality of PETG/ PC/PMMA

Colours
All colours and also available in a **Flocked** finish ideal for presentation trays and inserts.

Applications
Low cost and disposable items, toys and models, packaging and presentation, displays.

Price
Low - Medium

Stockist
Stephen Webster, Larger quantities – Doeflex.

Polycarbonate – (P.C. / LEXAN/ MAKROLON)

Properties
Hard, rigid clear amorphous material with high impact resistance and good fire rating. Self extinguishing. Requires high forming temperatures. Needs drying. Excellent clarity. Similar properties to Acrylic.

Formability
Good

Hygroscopic
Yes – Drying temperature 90° C. 1mm – 1 hr. 3mm – 4hrs. 4mm – 10hrs.

Strength
Very good impact strength

Shrinkage Rate
0.6 – 0.8%

Availability
From stock

Solvent/ Filler
Between PC components Dichloromethane or MEK solvent. Care must be taken with solvents as PC is a stress sensitive material and can be adversely affected by the solvents at its weak points. Most proprietary adhesives can be used to join PC with metal, glass and wood.

Finishing/ Machining
Good for screen printing. Good machine qualities. Can be ultrasonically welded, drilled and tapped. Takes spray.

Clear
Yes

Colours
Translucent and solid colours. Opal and diffuser patterns. Available in a variety of embossed textures.

Applications
Light diffusers, Signs, Machine Guards, Aircraft trim, Skylights, Riot Shields, Guards and Visors

Price
Expensive

Stockist
Amari , Comco

SEE PETG AS AN EXCELLENT ALTERNATIVE TO PC

Polypropylene – (PP)

Properties
PP is a semi-crystalline thermoplastic which has difficult form characteristics with sheet sag inevitable. Chemically inert and very flexible with minimum moisture absorption make it suitable for a wide range of applications. High forming temperature but no drying required. Many grades of PP are available containing fillers and additives. Co polymer as opposed to homo-polymer PP is recommended for vacuum forming, as the copolymerisation process helps reduce stiffness and broaden the melt and glass transition temperatures increasing thermoforming ability.

Formability
Difficult – Translucent material goes clear when in its plastic state – occurs within temperature band of approx 10°C and provides excellent indicator to forming temperature. Good temperature control required in conjunction with a sheet level facility.

Hygroscopic
No

Strength
Very good impact strength

Shrinkage Rate
1.5 – 2.2%

Availability
From stock

Solvent/ Filler
No solvent

Finishing/ Machining
Does not take spray

Clear
Translucent –

Colours
Black / white and colours available

Applications
Luggage, Food Containers, Toys, Enclosures, Medical Applications, Chemical Tanks.

Price
Inexpensive

Stockist
Doeflex

Polyethelene – (PE, HDPE, LDPE, PE FOAM)

Properties
PE is a semi-crystalline thermoplastic with similar forming properties to PP. Good heat control with sheet level required for successful forming. High shrinkage rates but good chemical resistance and strength. Available also as a cross linked closed cell foam (PLASTAZOTE) - ideal for packaging and liners.

Formability
PE – Difficult
PE FOAM – Good but form at lower temperatures to prevent surface scorching.

Hygroscopic
No

Strength
Very good impact strength

Shrinkage Rate
LDPE - 1.6 – 3.0%
HDPE - 3.0 – 3.5%

Availability
From stock

Solvent/ Filler
No solvents

Finishing/ Machining
Does not take spray. Takes some specialist inks.

Clear
Translucent – Goes clear when in its plastic state – occurs within temperature band of approx 10°C and provides excellent indicator to forming temperature.

Colours
Black / white and colours available

Applications
Caravan Parts, Vehicular Parts, Enclosures and Housings.

Price
Inexpensive

Stockist
PE - Amari, Simona
PE FOAM – Polyformes
CONDUCTIVE PE – Dentec

Polyvinylchloride – (PVC)

Properties
Strong, tough thermoplastic with good transparency in thinner gauges. Good chemical and fire retardant properties. Highly resistant to solvents. Thicker materials are rigid with good impact strength ideally suited to outdoor industrial applications.

Formability
Forms well but with a tendency to web.

Hygroscopic
No

Strength
Good

Shrinkage Rate
N / A - Contact Supplier

Availability
From stock – Sheet or Reel

Solvent/ Filler
Toluene may be used – no others solvents suitable. Hot air weld or glue.

Finishing/ Machining
Does not take spray. Takes some specialist inks.

Clear
Yes – Different web widths available with thickness from 150 microns – 750microns.

Colours
Black / white and colours available

Applications
Packaging, Machine Guards and Car Trim.

Price
Inexpensive

Stockist
Smaller quantities – Stephen Webster

Section 5

Mould and Mould Design

The thermoforming mould can be as simple as a wooden block or as sophisticated as an injection mould with all the ancillary elements to enable in mould trimming. They are one of the most important parts of the thermoforming cycle. One of the main advantages of vacuum forming is that the pressures used are significantly less compared to, for example, the injection moulding process. The result is that vacuum formed tools can be produced economically and in a wide range of materials to suit different prototype and production requirements. In this manual we concentrate on moulds ideally suited to the vacuum forming process. The prime function of a mould is to enable the machine operator to produce the necessary quantity of duplicate parts before degradation.

A wide range of materials can be used but it is important to determine the correct mould material and type most suitable for a particular application. In this section we look firstly at the different types of mould material available. We then look more closely at different types of moulds, mould design and techniques and provide some useful tips and hints to assist the ‘in house’ production of moulds.

Mould Materials

Selection of the best suited mould material depends largely on the severity and length of service required. If only a few parts are required using fairly low temperature plastics then wood or plaster could be used. However, if the quantity requirements run into the thousands and material temperatures are higher then ideally an aluminium based resin or aluminium mould would be recommended.

Once a prototype mould has been fabricated then it is a simple process to cast a resin mould into a forming taken from the original tool.

See the heading Resin moulds for further details.

i) Modelling Clay, Plaster

Modelling clay is widely used for educational and model making purposes. It enables the user to quickly shape a low cost prototype which can then be cured in an oven overnight. Suitable only for a few formings as the heat and pressures applied cause it to deteriorate rapidly.

Plaster is a good material for making inexpensive prototype moulds. However it is essential that the plaster is allowed to dry in a warm environment for up to three days. The reasons are twofold;

1) Moisture can be drawn into the vacuum system causing internal damage to the machine and pump.
2) The time is required for the plaster to develop final properties and stabilise the water content.

When using plaster moulds it is also essential to have a filter fitted to ensure no powder or particles are drawn into the vacuum system.

The surface of a plaster mould is sensitive to heat build up and therefore tend to crack and break up after about 50 cycles. It is not normally necessary to vent plaster moulds as the surface is porous.

ii) Wood

Wooden moulds are cheap and easy to fabricate, and have a longer life than plaster moulds – in many cases being used on a production basis for in excess of 500 formings. Hardwoods are recommended, notably ‘jelutong’ and ‘obeche’ which both have a close and even grain which makes them easier to work and less prone to cracking and splitting during the forming process.

Conventional woodworking techniques are used to fabricate the moulds. It is important to ensure the wood is kiln dried before working to ensure there is no warping or cracking during fabrication. As with any wood due to expansion and contraction during the forming process deterioration is inevitable but can be reduced by sealing with an enamel or varnish. This will enable countless mouldings to be produced with minimum refinishing required.

Because of the cost implications there are many cases where for particularly large applications such as signs, displays and whirlpools which require thicker materials wooden moulds are used on a production basis.

Grease, paraffin and vaseline and silicone release sprays can all used as a release agent.

iii) Cast Epoxy Resins

There are numerous resins available which are relatively cheap and easy to work. Moulds made from this material are durable and produce a forming with good surface finish. Some synthetic resins are sensitive to surface heat build up but this can be alleviated by incorporating aluminium powders to increase the heat stability and also the longevity. They are normally supplied as a two part mix; the resin itself and a hardener.

Once an original pattern has been produced either in wood or other material it is possible to use a forming taken off this as a mould in which to cast the resin.
You can see from the accompanying pictures the process in its different stages. The pictures are supplied courtesy of Ciba Geigy who produce a compatible resin XD4500 for vacuum forming applications. Alchemie also supply a range of resin tooling systems suitable for vacuum forming moulds.
(see the suppliers section for company details.)

The plastic moulding should be at least 2mm in thickness, mounted into a wooden frame filled with sand for support to avoid distortion. It is then necessary to mix the resin and hardener according to instructions and then allow time for curing. With larger moulds and to save on resin costs and reduce mould weight it is normally advisable to fill the mould with wooden blocks or foam around which the resin is poured.

1

MODEL

Models may be made from a variety of pattern-making materials, e.g. wood, plastics, and metal etc. Porous materials should be sealed before use, for instance with a polyurethane varnish. Care taken at the model making stage will be reflected in the quality of the finished tool.
The next stage depends on whether a male or female production tool is required.

To produce a female tool, apply a wax release agent or a suitable alternative to the model in preparation for the casting operation.
A male tool can be made by taking a vacuum forming from the model. The forming should be backed with a material such as plaster of paris for rigidity and then be released as above for casting.

2

MIX

Select the pack size which is appropriate to the casting being made. The pack volumes are given below as a guide.

5 kg pack – 3 lt
2 kg pack – 1.2 lt

Pour all of the hardener into the resin container and add accelerator according to the thickness of the cross section to be cast. Mixing instructions are enclosed with each pack and these define accelerator additions. Stir thoroughly taking care to mix in resin from the sides and bottom of the container.
After stirring allow the mix to stand for 3–5 minutes to enable air bubbles to rise and break. Alternatively, if the equipment is available de-aerate in a vacuum chamber.
The mix should be cast well within its pot-life which is 40 min at 21°C. As with all resin systems the mix is exothermic in bulk and this effect is increased by higher temperatures and by the use of XD 4500 accelerator.

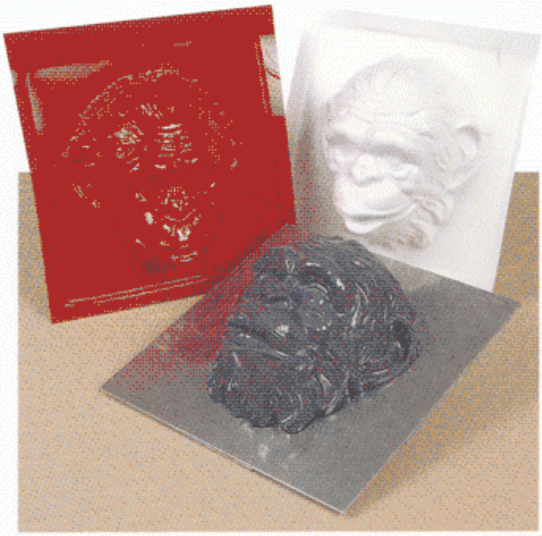
Fig. 5.1

3

CAST

Pour the mixed resin system slowly and in a steady stream into the lowest point of the mould until the required tool thickness is reached.
For mould surfaces with fine detail, first carefully brush a thin coat of mix over the surface and then proceed as above.
Castings of greater thickness than the normal maximum of 3 in (75 mm) can be made by pouring subsequent layers of mix onto the back of the preceding one, once it has gelled but not fully hardened.
Wood or polystyrene blocks can be suspended in the mould cavity to reduce cross sectional thickness. This serves to reduce the risk of excessive exotherm and to economise on resin usage.

4



FINISHING

CURING. Allow the resin casting to harden at room temperature and then post-cure as follows:

16 hours at room temperature – to demould
4 hours at 40°C
3 hours at 60°C
2 hours at 80°C
The above times are minimums.

In the case of tools with a cross section thickness of less than 1 in (25 mm) the room temperature stage must employ a temperature of at least 15°C to provide an adequate initial cure for demoulding and further processing. e.g. machining etc.
When time is at a premium tools may be post-cured by putting them into service. Care is essential to avoid overheating during the early stages of tool life.

DRILLING AND MACHINING. Evacuation holes may be drilled by any one of the engineering techniques available.
Araldite Vacuum Forming Tooling System XD 4500 is formulated to be easy and clean to machine. It contains no hard fillers and produces swarf rather than dust.

Fig. 5.2

XD 4500 in use on a small scale vacuum former.

Araldite Vacuum Forming Tooling System XD 4500 is designed to meet a particular need of the toolmaker for small to medium size cast resin tooling.

The Araldite Tooling resin range also includes resin systems suitable for the production of larger vacuum forming tools. These are produced by employing gel coats, laminating systems in combination with fabrics, and sometimes aluminium pellets, to provide a variety of materials and techniques for many applications.

Fig. 5.3

iv) Aluminium

Aluminium is frequently the material chosen for production tooling due to its good surface hardness, heat conductive properties and low wear. It is lightweight and has an excellent strength to weight ratio. It can be machined from blocks or cast from patterns and due to its thermal properties heat from the formed plastic sheet is quickly and efficiently dissipated.

A wide range of surface finishes are possible but generally speaking a sand blasted surface is ideal in that it prevents air being trapped between the mould and heated sheet.

Aluminium moulds have a virtually unlimited lifespan.

v) Metaphor – Porous Aluminium

Metaphor – F100 Al is a micro porous air permeable aluminium. It is an exciting new breakthrough in material science, where a material has been custom designed specifically to enhance the performance of tools for vacuum forming. Although expensive it has the following advantages over aluminium;

- It permits more accurately finished thermoformings because the micro vents are micro close together, allowing the material to be firmly held in place over the entire tool during tooling.
- It machines faster than aluminium and does not require venting as it is naturally porous.
- More intricate moulds with steeper draughts are possible.

It is available in slab form and can be obtained through the UK supplier, Alchemie. See the suppliers section for company details.

Fig. 5.4 A metaphor mould demonstrated on one of the Formech range of vacuum forming machines

Male and Female Moulds

There are basically two kinds of moulds: male (positive) and female (negative). See fig 5.5 below.

Male Mould

Female Mould

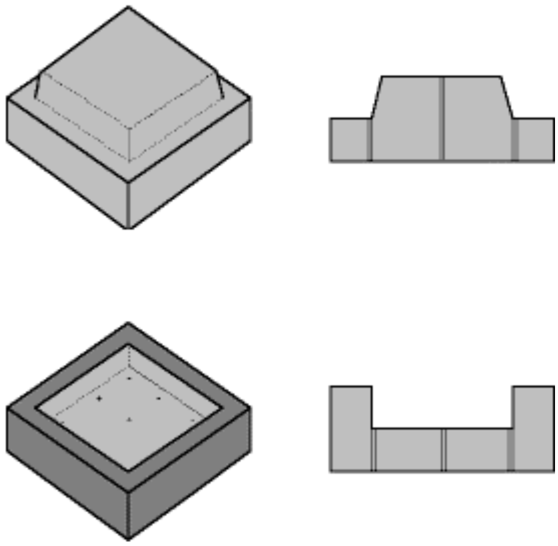


Fig. 5.5

Several factors will affect the decision as to which is more suited and below we provide a few useful pointers.

The top surface of a moulding (the part not in contact with the mould) is invariably the better finished surface, since it cannot pick up any marks such as dust particles from the tool itself. This factor alone may dictate whether a male or female mould is required. Often a male tool is much easier to make and more suitable for a single deep-draw object. On the other hand, a compartment tray with divisions, would typically be of female construction.
Fig 5.6 shows a male and female forming and the effects of thinning to the plastic sheet.

A greater degree of definition is achieved on the side of the plastic in contact with the mould. The choice of a male or female should be considered so that the side requiring the highest definition is the one in contact with the mould especially thicker plastics.

Fig. 5.6

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In general, a mould cavity which is deeper than its diameter will give unacceptable thinning at the bottom corners. Negative moulds will produce a forming progressively thinner towards the bottom, because, directly vacuum is applied, the material will cling to the sides of the mould and will tend to stretch like a piece of elastic. To produce a more uniform thickness a plug should be used to stretch the material mechanically before vacuum is applied. On a positive mould and especially if the Pre-Stretch (bubble) option is used this mechanical stretching is done automatically. It may be worth discussing your mould requirements with the material manufacturer if in any doubt.

Baseboards and Mounting

Generally speaking moulds should be mounted onto baseboards prior to forming to assist release. However, from time to time and often when a quick prototype is required moulds are placed directly onto the mould table and formed over. The main setback with this method is that when it comes to releasing the cooled part from the mould it often, due to shrinkage, sticks to the mould. It is then necessary to remove the part with the mould inside and physically split the two or trim the part whilst attached to the mould.

e.g. In the case of radiotherapy mask moulds which have many undercuts and are placed directly on the table, the part and mould are removed together and trimmed out with an air powered hand operated slitting saw.

In most cases it is recommended to use a baseboard. The baseboard can be made from hardboard or steel plate. It's primary purpose is to locate and hold down the mould when using the reverse blow facility. We recommend that a thickness of between 3 – 5mm is used to ensure it sits flush with the top of the forming area seal on the machine.

Depending on which machine you have will determine which size the baseboard should be. We advise that if, for example, you are utilising the full forming area (620mm x 620mm) with the model 660 machine then the baseboard should be made to fit tightly into this aperture.

To improve further the release the baseboard can be mounted directly to the table. In order to do this the table needs first to be drilled and tapped in the four corners which act as the location points for the baseboard.

When mounting moulds to the baseboard it is necessary to ensure there is some clearance for airflow between the mould base and the board. This can be done by either using a thin gauze or by incorporating channels.

Draught Angles / Tapers

Most moulds are made with a base to sit flat on the forming table and must be provided with a draught or taper to facilitate removal, (fig 5.7.) The degree of taper will depend on various factors, such as the surface quality of the tool, the depth of near vertical faces, type of material used and if the option of pre-stretch is being utilised. In some instances, an internal recess may be made with zero draft angle, since the shrinkage will actually pull the sheet away from the mould. However the minimum typical taper we would recommend to ensure good quality forming and moulding release would be circa 5°. It therefore goes without saying that the greater the taper, the more even the thickness of sheet and the easier it will be to release. In summary, if using female moulds we recommend a minimum taper of 3° and 5° for male moulds.

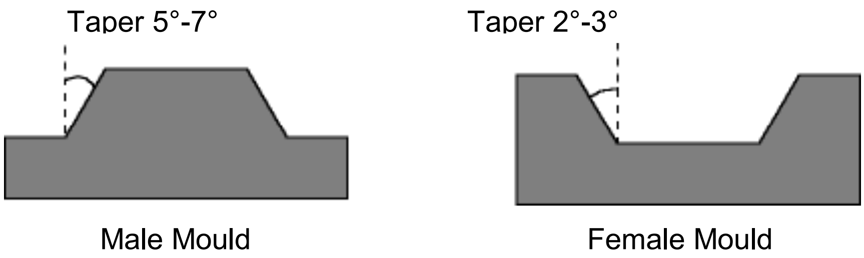


Fig. 5.7

Venting

An important feature of mould design is the requirement for suitably positioned vent holes to facilitate the evacuation of air trapped between the plastic sheet and the mould. Ideally located in parts where the sheet last makes contact - notably edges, cavities and internal corners. All these areas need to be vented to ensure good definition and rapid air evacuation. (fig 5.8 and 5.9)

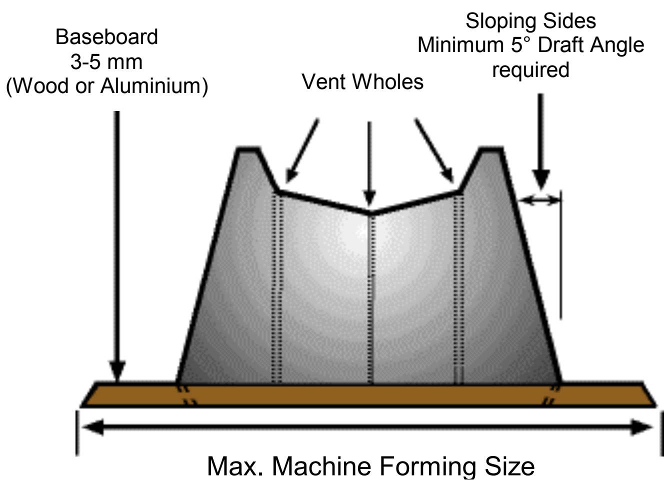


Fig. 5.8

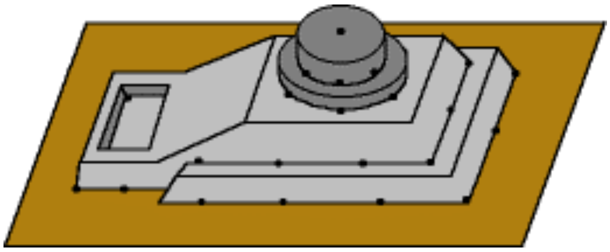


Fig. 5.9 Typical Vent Whole Position

Depending on plastic used and mould design determines the number of vent holes required. Ideally they should be as few as possible and small enough to prevent them witnesses on the finished parts outer surface. However if too few vent holes are provided or if the vent area is too small, the rate of draw-down will be controlled by the rate of air flowing from the bubble. If this is too slow then the plastic may cool before the required definition has been achieved.

The diameter of vents at the surface should be less than half the material thickness at the mould surface or between ½ and 1mm. They can be far larger below the surface and one solution is to drill the smaller hole from the surface using a high speed hand powered drill or pillar drill. The mould can then be inverted and a larger hole drilled from the underneath.

As an alternative to a drill it is possible to use spring steel otherwise known as piano wire. This material when flattened and sharpened is ideal for venting difficult angles and for creating evacuation holes in deeper moulds when drill lengths restrict the venting depth.

Shrinkage and Mould Release

On cooling and hardening, a molding will tend to shrink on to a male mould. Different thermoplastics have differing shrinkage rates depending on the grade and thickness. Crystalline and semi crystalline materials tend to shrink more than amorphous normally due to the higher forming temperatures required. The shrinkage rates of some of the more widely used plastics are listed in the plastics section under the specified materials, however, we do recommend you contact the supplier for more accurate figures as different grades of material may have different shrinkage rates.

The shrinkage rate of the materials will also affect the mould design in that these differences need to be taken into consideration during the design phase especially if tolerances are critical.

Difficulties in stripping the molding from the tool will depend to a large extent on mould design. If generous tapers, no undercuts, good surface finish exist then removal should be fairly straight forward.

In order to assist removal there are a number of oil and silicone based release sprays which when applied to the mould prior to forming facilitate easy release.

It is also possible to use a compressed air line to blow air between the molding and the tool.

The most effective way to ensure that the moldings are released on a repeated basis is to ensure that the moulds are mounted on baseboards which in turn can be attached to the mould rise and fall table on the machine. This ensures that only the plastic part is ejected when release is activated.

(please cross reference with the sub heading ***Baseboards and Mounting***)

Undercuts, Split and Multi Impression Moulds

A number of other features can be incorporated into mould design. Although technically not possible as once formed it is impossible to release, undercuts can be incorporated into a mould design with the use of split tooling. With the use of a removable side entrant tool it is possible to achieve undercuts in forming. Tooling costs are higher in most cases.

If the mould has an undercut at one end but an equal angle at the other end then the finished part can also be released. (fig 5.10)

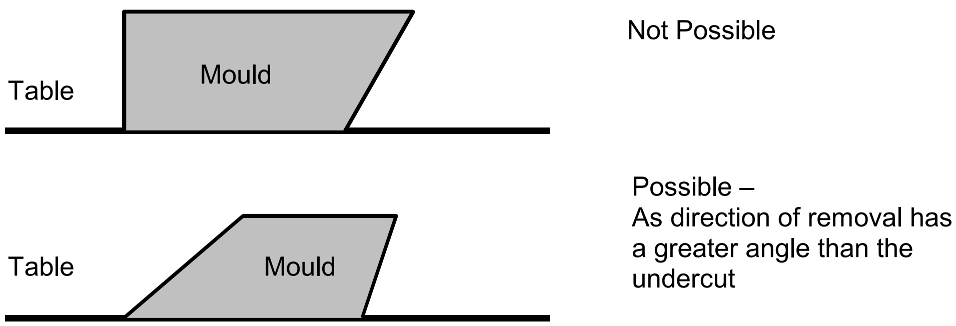


Fig. 5.10

Multi impression moulds are used when production requirements justify the added expense. It is normally the case that with higher levels of production the maximum forming area of the machine is utilized by making multi impression moulds.

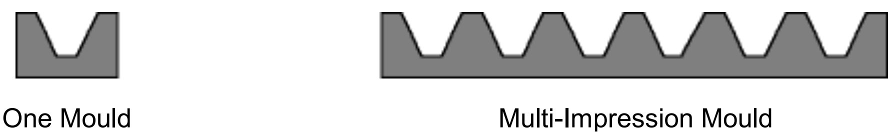


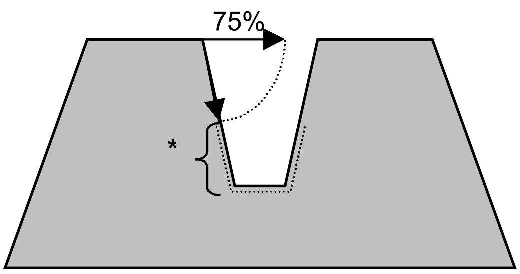
Fig. 5.11

Mould Cooling

For large production runs we recommend a water cooled mould. The temperature can be controlled by a chiller unit which is connected directly to the mould. Channels are incorporated in the moulds during manufacture to accommodate this facility. This helps maintain a constant mould temperature ensure consistent results combined with optimum cycle times. It is also possible to mount the mould onto a cooling bolster which contains channels for circulating cooling fluid. Costs for these moulds are considerably higher than conventional moulds, however it is normally a justifiable expense due to the production levels required.

Plug Assist Design

The purpose of a plug feature is two fold. It is used to prevent webbing in the forming of multiple male moulds which are close together and to help achieve good wall thickness when forming into deep cavities. Under normal conditions plastic will start to thin radically once it exceeds in depth more than 75% of the cross section (fig 5.12).



* Depth of cavity can be 75% of the width of the opening on the surface. Excess thinning will occur beyond this depth.

Fig. 5.12

The plug is used to push the heated material into a female mould prior or in conjunction with the vacuum being applied. It is used whenever large draw ratios are required.

Draw Ratio = depth of the aperture divided by the length of the shortest cross section. For example a refrigerator liner has a large draw ratio in that it is a deep molding with small cross section.

In most cases the plug assist facility is a feature suspended above the forming area and activated by pneumatic or hydraulic systems. (fig 5.13) However on smaller machines with manual operation the plug is often operator handled on a manual basis. The majority of plug moulds are simple in design and made from hardwood. A felt or flocked surface is often added to ensure the plug glides into the aperture without tearing or marking the plastic too much.

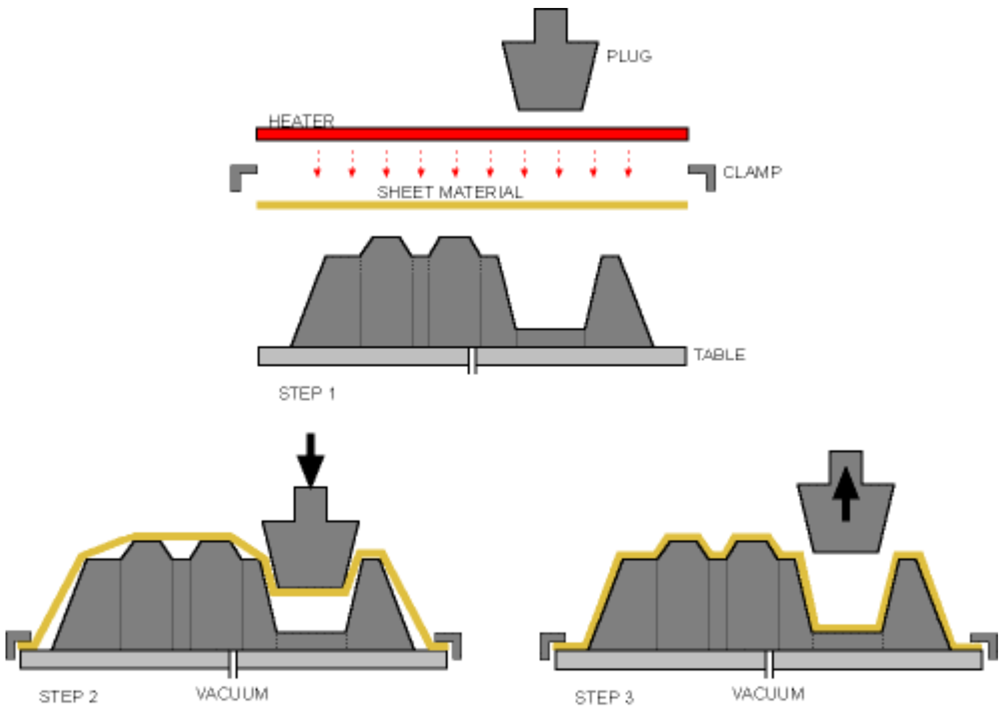

PLUG
HEATER
CLAMP
SHEET MATERIAL
TABLE
STEP 1
STEP 2
VACUUM
STEP 3
VACUUM

Fig. 5.13

Webbing/ Chill Marks/ Thinning

Webbing

Another factor which affects mould design is webbing. This occurs when the material shrinks back on itself. The cause of this can be any of the following;

- When the mould is too high in relation to its base area.
- By sharp vertical corners with minimum draught angles
- By deep multiple male moulds in close proximity to each other.(Fig 5.14)
- Excess of sheet material when using small moulds.

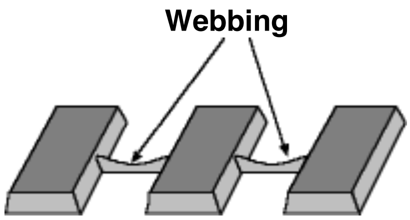


Fig. 5.14 **Male Tool**

A female mould Fig 5.15 can often overcome the webbing caused by multiple male moulds.

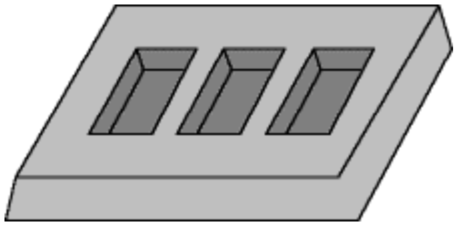


Fig. 5.15 Female Tool

Webbing can be voided by restricting the amount of sheet around the mould. This can be in the form of reducing windows (fig 5.16) or with the use of a plug. It can be minimized by a slower application of vacuum or by using thicker sheet. It may be necessary to modify the mould design if all else fails to solve the problem.

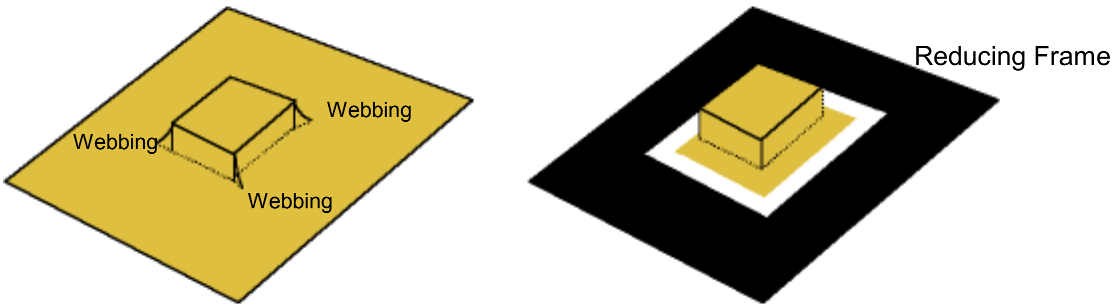


Fig. 5.16

Chill Marks

When raising a deep draw mould into a heated sheet, the point which first makes contact cools, reducing its flow characteristics and producing a uneven flow of material at the top which thins down the sidewalls as the vacuum is applied. (fig 5.17) This can be eliminated by increasing the draught angles and ensuring the mould is not too cool. The pre-stretch facility (bubble) is also a useful feature in overcoming this problem.

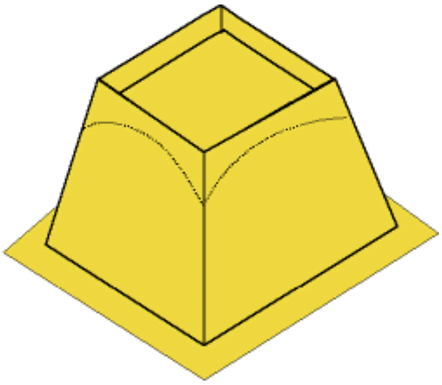


Fig. 5.17

Thinning

This is one of the most common problems with mould design and is the result of deep draw ratios and minimum draught angles. See fig 5.18 shows thinning caused as a result of deep draw male mould with minimum draft angles. There are numerous solutions which include pre-stretch (bubble), plug assist , strengthening ribs incorporated into the mould design and increased internal draught angles.

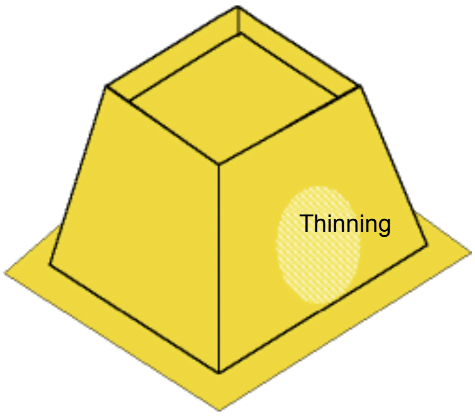


Fig. 5.18

The above three problems are examined further in the trouble shooting section of this manual.

Formech offer a pattern making facility with moulds from wood, resin and aluminium.
For all your mould requirements please contact us at : sales@formech.com

Section 6

Finishing and Trimming

With vacuum forming there are secondary processes and operations required before a finished part will be ready for the customer. Once the formed part has cooled and been removed from the machine the excess material is removed, holes, slots and cut-outs are drilled into the part. Other post forming processes include decoration, printing, strengthening, reinforcing and assembly.

A variety of different trimming methods are used to trim the product from the sheet. The type of equipment best suited depends largely on the type of cut, size of the part, draw ratio, thickness of material and the production quantity required. They are also factors to consider when determining the investment cost of such equipment. Below are listed some of the more popular methods adopted. Thin gauge parts are normally trimmed on a mechanical trim press – otherwise known as a Rollerpress. Heavy gauge parts can be removed, placed into trim “jigs” or fixtures and trimmed with most of the methods listed below.

Heated knife/ Scalpel

Educational user / Model maker/ R & D work – thin plastics only.

Formech Gerbil (Fig 6.1/6.2)

Educational and R & D Depts. Accurate and cost effective method of removing ” Flash” from vacuum formed parts. Suitable for a variety of plastics up to 3mm thick. The cutter is mounted under a table and powered by a motor. Cutter disc is manufactured from Tungsten Carbide to ensure longevity and safety. Multi tool unit suitable for a variety of other purposes including tilting table and drum sander for producing wooden moulds, flange cutter, guide rails for decorative finish on moulds and an adaptor for connection to a simple dust extraction system.

Formech GERBIL

VACUUM FORMING CUTTER

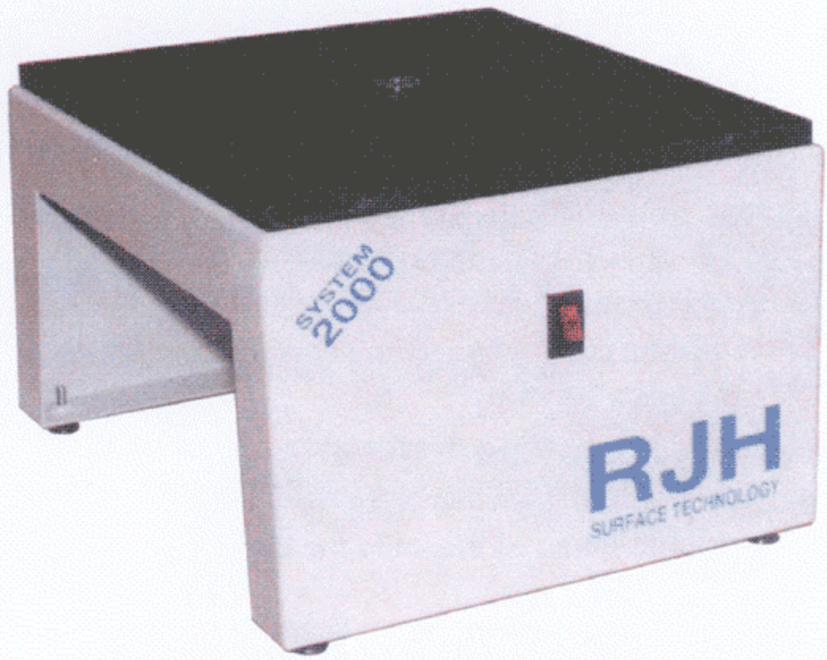
The GERBIL Vacuum Forming Cutter is an accurate and cost effective method of removing "Flash" from vacuum formed moulds.

Suitable for a variety of plastics including Acrylic, PVC and Polystyrene.

Cutter height is easily adjustable for precision cutting, allowing variable material thickness, ranging from 0.5 mm - 3.0 mm.

Intricate and delicate shapes are "cut out" in a fraction of time compared to other methods.

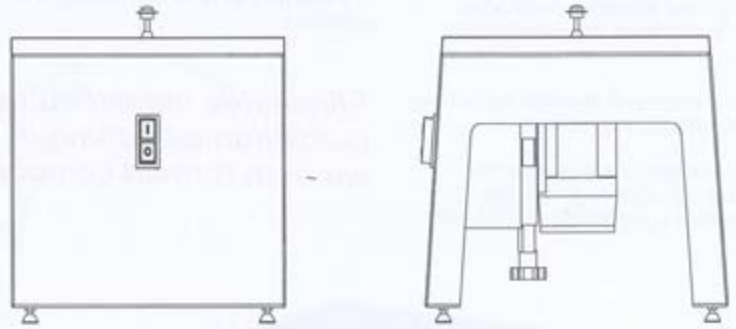
Eliminates the difficulties of conventional cutting in vacuum formed components



16" x 16" (400 mm x 400 mm) Table Size Vacuum Forming Cutter

Fig. 6.1

Formech International Ltd.
Unit 4, Thrales End Lane, Harpenden, Hertfordshire, AL5 3NS, Tel +44 (0)1582 - 469797, Fax +44 (0)1582 469646
Email: sales@formech.com Website: www.formech.com



SPECIFICATION

1 Cutter disc size 32 mm
2 Motor speed 1380 rpm
3 Motor power 0.07kw (single phase)
4 Cutter height adjustment 20 mm
5 Table size 400 mm x 400 mm
6 Bench space 460 mm x 400 mm
7 Overall height 288 mm
8 Overall weight 18 kgs

Fig. 6.2

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Vertical Bandsaw

Fig. 6.3

Horizontal Bandsaw (Fig 6.4)

This method can be used for both thick and thin thermoplastics formings. The technique has a very wide application, the essential features being a sliding table whose height relative to the saw blade can be adjusted (or vice versa).

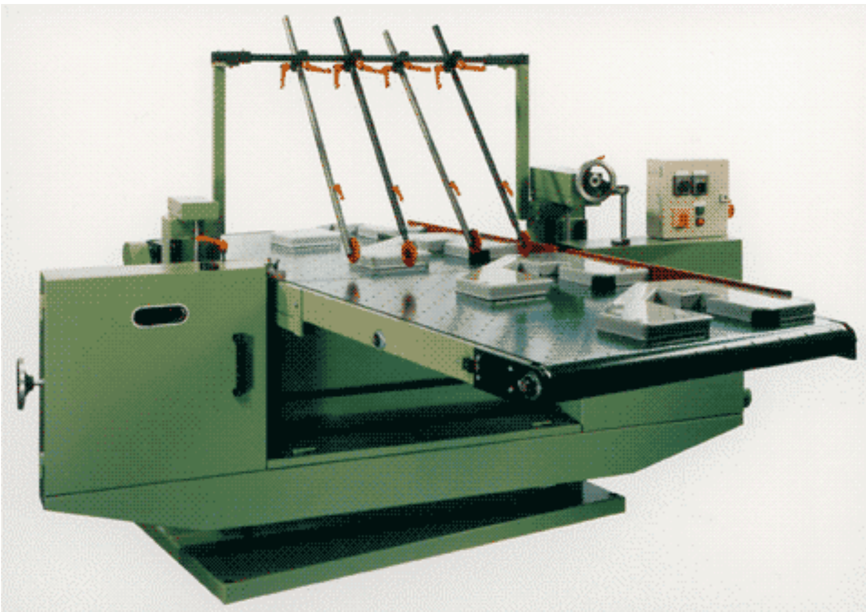


Fig. 6.4

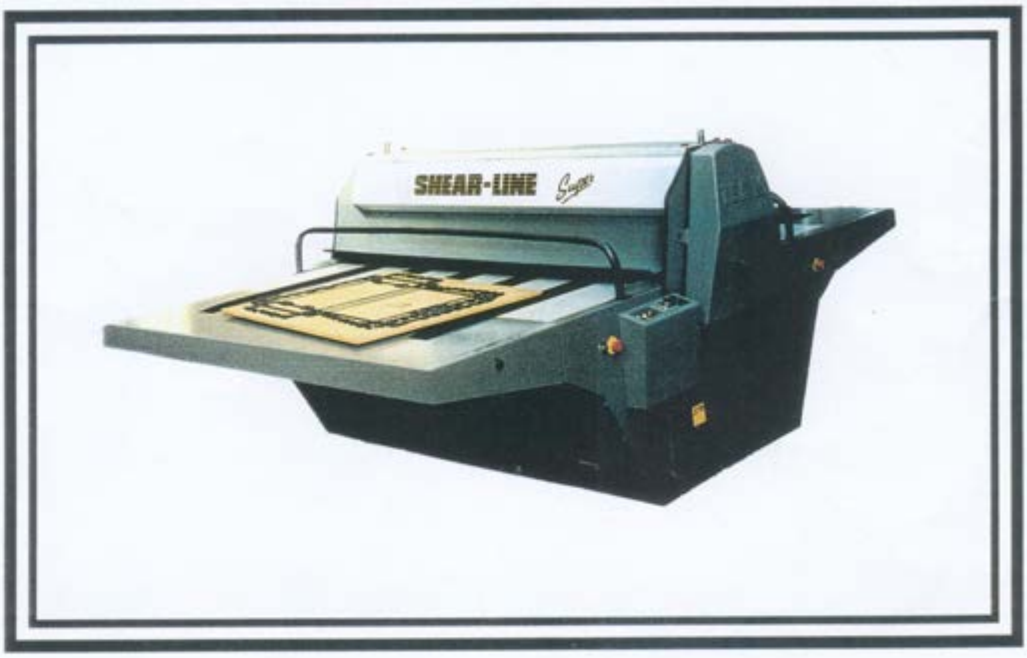
Click here to visit the products section for further information on the horizontal band saws we offer.

Rollerpress/ Steel Rule Dies (fig 6.5)

The machine consists of a pair of adjustable, electrically driven rollers, placed one above the other. The rollers rotate in opposite directions to draw the cutting tool and the material to be cut between them.

High quality shape and hole cutting can be achieved with low cost cutting dies. Simple and easy to operate they will form cut virtually all types of flexible and semi rigid materials up to a thickness of about 4mm. Cutting widths from 700mm upwards can be accommodated.

Please refer to the products section for more information on the range available.



- High quality shape and hole cutting with low cost tooling.
- Easy to use with simple operating controls.
- Cuts virtually any flexible and semi-rigid material quickly and efficiently.
- 50% faster than ordinary Roller Presses -
- Easily replaced polypropylene sleeve eliminates the need for a matrix cutting board
- Cutting form change in minutes ... ideal for both short and long runs
- Conveyor belt tool feed for consistent, accurate quality cutting

Fig. 6.5

Guillotine

The industrial guillotine is similar to those used to cut paper. Used to cut non brittle and thinner materials. Available in manual and powered versions probably the most well known supplier in the U.K is the company Edwards who have a good range of industrial guillotines.

Clicker / Punch Press

A moving head which is moved over the trim jig containing the formed part and then activated to press down and cut the part.

Hand Held Air Powered Router

This is a versatile and accurate manual method of trimming awkward shapes. The moulded part is located in a ‘trim jig’ with guidelines along which the operator can run the router. A bearing is attached to the router cutter to ensure smooth movement when trimming parts. See fig. 6.6-6.9 for examples of products trimmed using this method.

Fig. 6.6

Fig. 6.7

Fig. 6.8

Fig. 6.9

De Soutter provide very reliable air tools and have branches nationwide. Bearings and cutters are added to suit.

CNC Routers - 3, 4 and 5 axis

State of the art CNC routers are used for large parts on a production basis and prices start at around £50,000.00. The machine is computer programmed to select the correct cutting tools and angle to suit each cutting area.

Formech recommend and work closely with the company **Thermwood**. They are firmly established as the market leader in this field and supply a complete line of CNC Machining Centres for plastics. Visit our links section to contact them.

Circular spindle saw

As the name suggests this is a circular cutter mounted on a spindle and fixed in a pillar drill. The cutting disc is reversed to ensure safety when trimming parts. Cuts vertically from above.

Circular Cutter mounted from under table.

Larger industrial version of the Formech Gerbil and powered by a router motor mounted under a table. Ideal for cutting on a vertical edge.
Below we have provided a guideline to the preferred trimming methods for a range of the more commonly used thermoplastics.

Table 6.1

Material	***Thickness***	***Preferred***	***2nd***	***3rd***
P.S	< 3mm	Die	Shear	Band Saw
P.S	**>** 3mm	Circular Saw	Router	Band Saw
ABS	< 3mm	Die	Shear	Band Saw
ABS	**>** 3mm	Circular Saw	Router	Band Saw
HDPE	< 3mm	Shear	Die	Circular Saw
HDPE	**>** 3mm	Shear	Router	Circular Saw
LDPE	< 3mm	Shear	Die	Circular Saw
LDPE	**>** 3mm	Shear	Router	Circular Saw
PP	< 3mm	Shear	Die	Circular Saw
PP	**>** 3mm	Shear	Router	Circular Saw

< = less than
> = more than

Formech are able to assist with any questions you may have and also provide further details of suitable trimming machines and suppliers. Please also refer to the products section of the web page.

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