

# ⋮ Vacuum Forming Guide



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Thermoforming is one of the oldest and most common methods of processing plastic materials. Thermoformed plastic products are all around us and play a major part in our daily lives. It is a very versatile process used to manufacture a wide range of products from simple packaging trays to high impact aircraft cockpit covers. It is also used extensively to make design prototypes of products to be produced by other processes.

The process, however, is basically the same in each case. In its simplest form thermoforming is the heating of a plastic sheet which is then draped over a mould whilst a vacuum is applied. The moulding is then allowed to cool before it is ejected from the mould using a reverse pressure facility.

Thermoforming covers all processes which involve heat to shape polymers. However, in this manual we will concentrate specifically on the 'vacuum forming process' which applies to the range of machines Formech supply. Vacuum forming has generally been promoted as a 'dark art' and best left to companies with sophisticated processing equipment who are able to supply the facility and service. However with their range of compact, easy to use machines Formech have, over the years, endeavoured to introduce vacuum forming to the 'masses' and it is some testament that there are now over six thousand machines worldwide, many supplied to those looking to start vacuum forming for the first time. In this manual we hope to provide an insight into this adaptable process. However, it is only a guide and cannot impart the practical experience and skill that any user will eventually attain. We hope it assists in taking the 'guess work' out of the process and proves useful as a means of technical and engineering support.

In the following sections we have provided a list of the various examples of applications for thermoformed parts along with an insight

into the forming process and techniques. A plastics section follows in which we examine materials and their characteristics. Information on tooling, trimming and finishing, a trouble shooting guide and recommended suppliers list concludes the manual with a glossary of key words to aid navigation through the manual. If you are new to the process and have just purchased a Formech machine we trust you find this manual a beneficial aid in getting started and wish you success in your future business.

Below we have allocated sub-headings to a wide range of industries using vacuum forming for a multitude of applications. The list is fairly comprehensive and although there are many other potential applications we have attempted to highlight the most popular. You can find photographic examples of a selection of vacuum formed products in the galleries contained in the 'support' section of our web page.

## **Aeronautical Manufacturers**

- > Interior Trim Panels, Covers and Cowlings Internal sections for NASA Space Shuttle.

## **Agricultural Suppliers**

- > Seed Trays, Flower Tubs, Animal Containers, Clear Growing Domes;
- > Calf Milking Receptacles, Machines Parts;
- > Lawnmower Enclosures and Covers

## **Architectural Model Makers**

- > Production of Miniature Parts for Architectural Models;
- > Prototypes.

## **Automotive and Vehicular Industry**

- > Wheel Hub Covers, Ski-Boxes and Storage Racks Wind Tunnel Models, Parts for All Terrain Vehicles Truck Cab Door Interiors, Wind and Rain Deflectors
- > Scooter Shrouds, Mudguards, Bumpers and Protective Panels
- > Battery and Electronic Housings, Prototype and Development work
- > Utility Shelves, Liners, Seat Backs, Door Innerliners and Dash Surrounds
- > Windshields, Motorcycle Windshields, Golf Cart Shrouds, Seats and Trays
- > Tractor Shrouds & Door Fascia, Camper Hardtops and Interior Components

## **Building and Construction Industry**

- > Drainpipe Anti Dripfittings
- > Roof Lights, Internal Door Liners, PVC Door Panels Producing Moulds for Concrete Paving Stones and Special Bricks
- > Moulded Features for Ceilings, Fireplaces, Porches and other items.

## **Boat Building industry**

- > Boat Hulls, Covers and Hatches Electrical Enclosures, Dashboards

## **Chocolate industry**

- > Manufacture of Chocolate Moulds for Specialised Chocolates and
- > Easter Eggs etc. and Packaging

## **Computer Industry**

- > Manufacture of Screen Surrounds
- > Soft Transparent Keyboard Covers Enclosures and Ancillary Equipment

## **Design Industry**

- > Production of prototypes and Pre-Production Runs
- > Prototype Cocepts for other Plastic Processes



Formech 300XQ - model making HIPS



Formech 686 - Motorcycle Parts Acrylic Capped ABS



Formech 1372 - Luggage Acrylic

## Education

- > Training Aids for Students Studying Polymers and Plastic Processing.

## Electronics Industry

- > Manufacturing Enclosures for Specialist Electronic Equipment
- > Anti Static Component Trays.

## Film and Media Industry

- > Manufacture of Costumes and Sets
- > Animation Models and Mock Ups for Computer Simulation

## Furniture Manufacturing Industry

- > Chair and Seat Backs
- > Cutlery tray inserts
- > Kitchen Unit Panels and Storage Modules

## Hospitals and Medical Applications

- > Radiotherapy Masks for Treatment of Cancer Patients
- > Pressure Masks for Burn Victims
- > Prosthesis Parts
- > Dental Castings
- > Parts for Wheelchairs and Medical Devices for the Disabled

## Machinery Manufacturers

- > Fabricating machine guards and electrical enclosures.

## Model Car and Aircraft Industry

- > Production of bodies fuselages and other parts for models.

## Museums

- > Variety of applications within Science and Natural History Museums

## Packaging and related Industries

- > Point of Purchase
- > Trays and Plates
- > Cosmetic Cases and Packages
- > Electronics and Cassette Holders
- > Blister Pack Products, Skin Pack Products Food Trays, Cups and Fast Food Containers

## Plastic Sheet Extrusion

- > Testing and Sampling of Extruded Sheet

## Sanitary Industry

- > Bathroom Fittings
- > Bathtubs, Jacuzzis and Whirlpools
- > Shower Surrounds, Shower Trays and Retrofit Shower Components

## Signmaking Industry

- > Vacuum Formed Exterior Signs Point of Sale Displays

## Souvenir Industry

- > Making parts for and moulds to cast craft souvenir's.

## Theatre

- > Manufacture of Props, Sets and Costumes



Formech 1500 - Golf Car Parts Acrylic Capped ABS



Formech FMDH660 - Props Acrylic Capped ABS



Formech HD Series - Acrylic capped ABS

In its simplest form the process consists essentially of inserting a thermoplastic sheet in a cold state into the forming clamp area, heating it to the desired temperature either with just a surface heater or with twin heaters and then raising a mould from below. The trapped air is evacuated with the assistance of a vacuum system and once cooled a reverse air supply is activated to release the plastic part from the mould. The process is shown in diagram form on fig. 3.1 page 13. In its advanced stage pneumatic and hydraulic systems complimented with sophisticated heat and process controllers allow high speed and accurate vacuum forming for those heavy duty and high end volume applications.

The thermoforming industry has developed despite two fundamental shortcomings. Many other thermoforming processes use a resin base in powder or pellet form. Vacuum forming begins further down the line with an extruded plastic sheet which incurs an additional process and therefore an extra cost to reach this stage. In addition, there is generally an area of material which is cut away from the formed part which unless reground and recycled has to be considered as waste and accounted for in any costings made. However these problems have been invariably resolved by strict control of sheet quality and by clever mould design to minimise the amount of waste material. Throughout this manual you will find useful hints and techniques to assist in maximising the potential from this process.

Despite the above disadvantages vacuum forming offers several processing advantages over such others as blow, rotational and injection moulding. Fairly low forming pressures are needed therefore enabling comparatively low cost tooling to be utilised and relatively large size mouldings to be economically fabricated which would be otherwise cost prohibitive with other processes. Since the moulds witness relatively low forces, moulds can be made of relatively inexpensive materials and mould fabrication time reasonably short. This results in comparatively short lead times. It provides the perfect solution for prototype and low quantity requirements of large parts as well as medium size

runs utilising multiple moulds. (Moulds are discussed in greater detail in section dealing with mould).

The typical process steps can be identified as follows: clamping, heating with sheet level activated, pre-stretch, forming with plug assist, cooling with air and spray mist, release and trimming. They are examined more closely under the sub headings on page 7 and 8.

## Clamping

The clamp frame needs to be sufficiently powerful enough to ensure the plastic sheet is firmly held during the forming process. It can handle the thickest material likely to be formed on the machine – up to 6mm with a single heater and up to 10mm with the twin heater machines. If an automated process is used the operation of the moving parts must be guarded and interlocked to avoid accidental damage. In addition, a safety guard must be provided to protect the machine operator at all times.

## Heating

Heaters are generally infra-red elements mounted within an aluminum reflector plate. In order to obtain the best vacuum forming results, using any material, it is essential that the sheet is heated uniformly over its entire surface area and throughout its thickness. In order to achieve this, it is necessary to have a series of zones that are controlled by energy regulators. Ceramics do have some disadvantage in that their high thermal mass makes them slow to warm up (approx 15 minutes) and slow in their response time when adjustments are made.

More sophisticated quartz heaters are available which have less thermal mass enabling more rapid response time. Pyrometers enable accurate heat temperature control by sensing the melting temperature of the sheet and interacting with the operating process control. Precise temperature readout is also available with a computer controlled system working in unison with the pyrometers. Twin heaters are also recommended when forming thicker materials as they assist in providing more uniform heat penetration and faster cycle times.

Twin quartz heaters are advisable when forming high temperature materials with critical forming temperatures. By close control of areas of heat intensity, heat losses around the edges caused by convection air currents and absorption from clamp areas can be fully compensated for and consistent results achieved on a continuous basis. Cost savings

can also be considerable if quartz heaters are specified, as there is an adjustable percentage power drop when the heaters are in the rear position during the forming process.

## Auto-level / Sheet Level

A photo-electric beam is activated under the sheet of plastic during the heating cycle. If the sheet of plastic sags down and breaks the beam, then a small amount of air is injected into the bottom chamber under the sheet, thus lifting the sheet to stop it from sagging until the sheet clears the beam.

## Pre-stretch ( Bubble)

Once the plastic has reached its forming temperature or “plastic” state it can be pre-stretched to ensure even wall thickness when the vacuum is applied. The method of controlling the bubble height should be that consistent results are obtainable. Vacuum, air pressure, and optional aids such as a plug assist are then used to assist in moulding the heated, stretched plastic.



Quartz Heaters



Pre-Stretch

## Vacuum

Once the material is suitably heated a vacuum can be applied to assist in forming the sheet. A vacuum pump is used to draw the air trapped between the sheet and the mould. The vacuum pumps vary from diaphragm pumps to dry and oil filled rotary vane pumps. With larger machines a vacuum reservoir is used in conjunction with a high volume capacity vacuum pump. This enables a two stage instantaneous vacuum to be applied ensuring rapid moulding of the heated sheet (before the sheet temperature drops below its ideal forming temperature).

## Plug Assist

Plug assisted vacuum forming (moulding) is used when straight vacuum forming is unable to distribute the thermoplastic sheet evenly to all areas of the mold. To help spread the sheet out more evenly, a device known as a plug is utilized to push the sheet into the mold before the vacuum is applied. This process enables more of the thermoplastic material to reach the bottom of the mold and thus more material is available to fill the corners of the mould and limit the plastic from thinning out.

## Cooling and Release

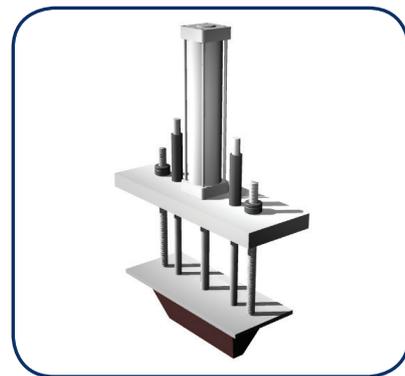
Once formed, the plastic must be allowed to cool before being released. If released too soon then deformation of the moulding will result in a reject part. To speed up the cooling cycle high speed fans are fitted and activated once the part is formed. A spray mist option is also available whereby nozzles are attached to the fans and a fine mist of chilled water is directed onto the sheet. This, in conjunction with the fans can speed up the cooling cycle by up to 30% and is also beneficial in controlling the shrinkage of the moulded parts.

Mould temperature control units are also available which regulate the temperature within the mould ensuring accurate and consistent cooling times when cooling crystalline and crystallizing polymers such as PP, HDPE and PET.

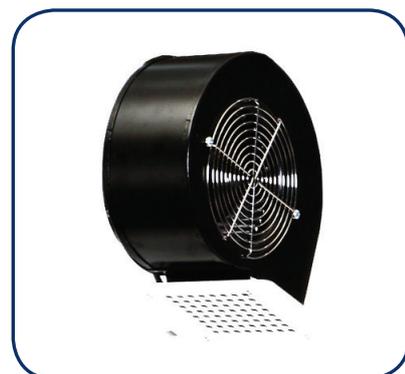
## Trimming and finishing

Once the formed part has cooled and been removed from the machine the excess material is removed. Holes, slots and cut-outs are then 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. Thin gauge parts are normally trimmed on a mechanical trim press – otherwise known as a rollerpress.

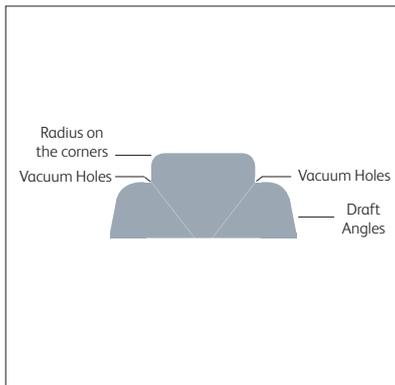


Plug assist

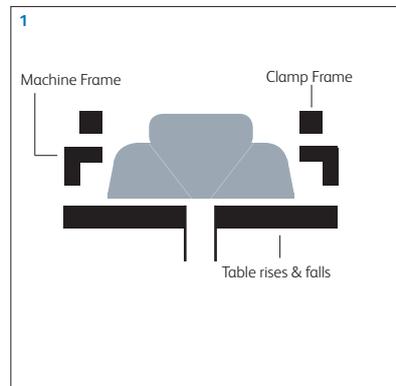


Cooling Fan System

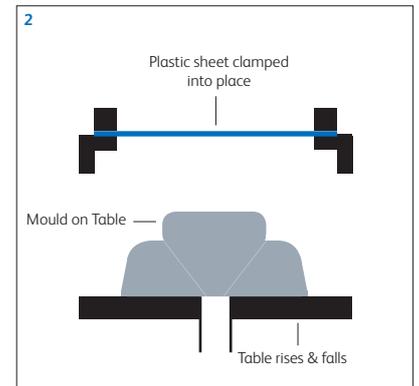
## Basic principles of vacuum forming



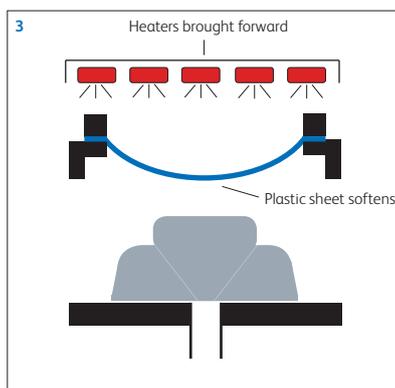
A suitable mould / tool carefully manufactured with draft angles and radiused corners.



Place your mould on the table and lower it down.



Once the table is down, securely clamp your plastic sheet between the clamp and machine frame.



The heaters warm the plastic sheet. Plastic becomes flexible when heated.

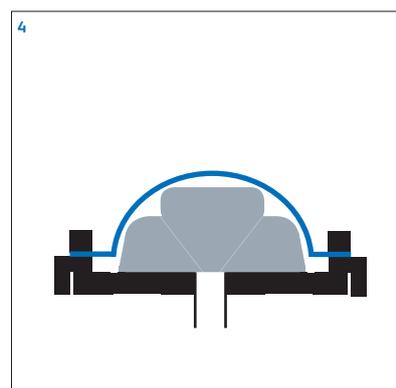
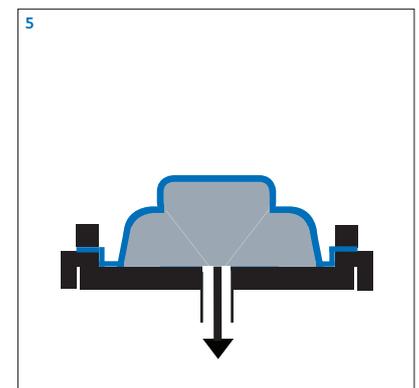
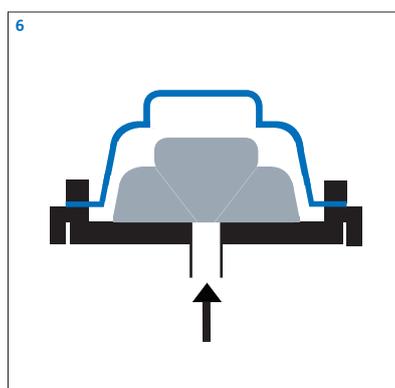


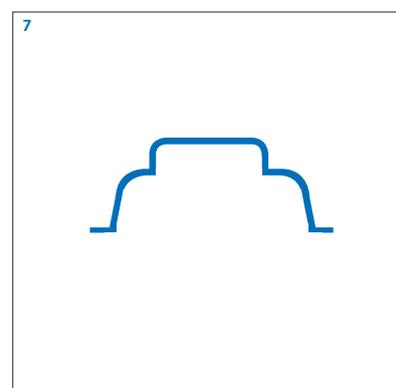
Table raised and locked. The softened plastic is stretched over the mould.



The vacuum pump removes all the air between the sheet and the mould to create the formed shape.



When the plastic has cooled, the air can be blown back to release the forming off the mould.



The formed part is then removed. Some trimming might be necessary to achieve the finished product.

Plastics comprise 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 crystalline. 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 (T<sub>g</sub>). If heated to a higher temperature it reaches a Viscous state (T<sub>v</sub>). The changes occur over a range of temperatures and enable the operator to have a fairly wide forming range.

Semi-crystalline and crystalline materials, e.g. Polyethylene and Polypropylene have a far more critical forming temperature as they go rapidly from the T<sub>g</sub> state to T<sub>v</sub> a change known as the Melt Transition Temperature (T<sub>m</sub>). 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 on page 10 lists some more commonly used amorphous and semi crystalline materials and provides a guideline as to their temperature characteristics.

Material	Glass Transition Temperature	Rec. mould temperature	Rec. forming temperature	Drying temperature
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 predried 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 predried 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 on pages 4 & 5).

For more detailed information and specification we recommend you contact the various suppliers who would be happy to assist with any enquiries.

In table page 12, 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.

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.

<b>Formability</b>	Good - forms to a high definition.
<b>Hygroscopic</b>	Yes - pre drying required at approx 80° (1 hour per mm).
<b>Strength</b>	Good - High Impact.
<b>Shrinkage Rates</b>	0.3 - 0.8 %.
<b>Availability</b>	From stock.
<b>Solvent / Filler</b>	Methyl Ethyl Ketene (MEK), Toluene and Dichloromethane Solvent will make filler paste.
<b>Finishing / Machining</b>	Machines well with Circular Saws, Routers and Band saws - takes all sprays. Can be Guillotined and Roller cut.
<b>Clear</b>	Not Available.
<b>Colours</b>	Black / White / Grey and limited colours.
<b>Applications</b>	Luggage, Caravan Parts, Vehicular Parts, Sanitary Parts, Electrical Enclosures.
<b>Price</b>	Medium.
<b>Stockist</b>	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.

<b>Formability</b>	Tends to be brittle and is temperature sensitive.
<b>Hygroscopic</b>	Yes - Consult supplier for drying times.
<b>Strength</b>	Medium to High strength.
<b>Shrinkage Rates</b>	0.3 - 0.8%.
<b>Availability</b>	Ex stock - 2 weeks.
<b>Solvent / Filler</b>	Tensol, Solvent and gap filler.
<b>Finishing / Machining</b>	Prone to Shatter. Takes cellulose and enamel spray. Good for hand working.
<b>Clear</b>	Yes.
<b>Colours</b>	Solid colours.
<b>Applications</b>	Signs, Roof Lights and Domes, Baths and Sanitary Ware, Light Diffusers.
<b>Price</b>	Expensive.
<b>Stockist</b>	Amari, 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.

<b>Formability</b>	Very Good - forms to a high definition. Forming range 80 -120°C.
<b>Hygroscopic</b>	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.
<b>Strength</b>	Good - High Impact.
<b>Availability</b>	From stock.
<b>Solvent / Filler</b>	Cementing can be done using solvents or commercial glues. Can be Ultrasonically Welded.
<b>Finishing / Machining</b>	Can be Guillotined, Saw Cut or Routed. Die Cutting and Punching also possible up to 3mm. Paints and Inks for Polyester can be used for printing on PETG.
<b>Clear</b>	Yes.
<b>Colours</b>	Limited - Contact Supplier.
<b>Applications</b>	Point of Sale and Displays, Medical Applications.
<b>Price</b>	Expensive (competitive with other clear materials e.g. PC/ PMMA).
<b>Stockist</b>	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.

<b>Formability</b>	Very Good - forms to a high definition. Forming range circa 150°C.
<b>Hygroscopic</b>	No.
<b>Strength</b>	Medium to Good impact strength.
<b>Shrinkage Rates</b>	0.3 - 0.5 %.
<b>Availability</b>	From stock.
<b>Solvent / Filler</b>	Dichloromethane, Toluene. Filler can be made from dissolved plastic in solvent.
<b>Finishing / Machining</b>	Needs special etch primer before spraying. Good machining with all methods.
<b>Clear</b>	Yes - Styrolux (Clarity not to quality of PETG/ PC/ PMMA).
<b>Colours</b>	All colours and also available in a Flocked finish ideal for presentation trays and inserts.
<b>Applications</b>	Low cost and disposable items, toys and models, packaging and presentation, displays.
<b>Price</b>	Low - Medium.
<b>Stockist</b>	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.

<b>Formability</b>	Good.
<b>Hygroscopic</b>	Yes - Drying temperature 90° C. 1mm - 1 hr. 3mm - 4hrs. 4mm - 10hrs.
<b>Strength</b>	Very good impact strength.
<b>Shrinkage Rates</b>	0.6 - 0.8%.
<b>Availability</b>	From stock.
<b>Solvent / Filler</b>	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.
<b>Finishing / Machining</b>	Good for screen printing. Good machine qualities. Can be ultrasonically welded, drilled and tapped. Takes spray.
<b>Clear</b>	Yes.
<b>Colours</b>	Translucent and solid colours. Opal and diffuser patterns. Available in a variety of embossed textures.
<b>Applications</b>	Light diffusers, Signs, Machine Guards, Aircraft trim, Skylights, Riot Shields, Guards and Visors.
<b>Price</b>	Expensive.
<b>Stockist</b>	Amari, Comco.

## 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.

<b>Formability</b>	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.
<b>Hygroscopic</b>	No.
<b>Strength</b>	Very good impact strength.
<b>Shrinkage Rates</b>	1.5 - 2.2%.
<b>Availability</b>	From stock.
<b>Solvent / Filler</b>	No solvent.
<b>Finishing / Machining</b>	Does not take spray.
<b>Clear</b>	Translucent.
<b>Colours</b>	Black / white and colours available.
<b>Applications</b>	Luggage, Food Containers, Toys, Enclosures, Medical Applications, Chemical Tanks.
<b>Price</b>	Inexpensive.
<b>Stockist</b>	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.

<b>Formability</b>	PE - Difficult PE FOAM - Good but form at lower temperatures to prevent surface scorching.
<b>Hygroscopic</b>	No.
<b>Strength</b>	Very good impact strength.
<b>Shrinkage Rates</b>	LDPE - 1.6 - 3.0 % HDPE - 3.0 - 3.5 %
<b>Availability</b>	From stock.
<b>Solvent / Filler</b>	No solvent.
<b>Finishing / Machining</b>	Does not take spray. Takes some specialist inks.
<b>Clear</b>	Translucent - Goes clear when in its plastic state - occurs within temperature band of approx 10°C and provides excellent indicator to forming temperature.
<b>Colours</b>	Black / white and colours available.
<b>Applications</b>	Caravan Parts, Vehicular Parts, Enclosures and Housings.
<b>Price</b>	Inexpensive.
<b>Stockist</b>	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.

<b>Formability</b>	Forms well but with a tendency to web.
<b>Hygroscopic</b>	No.
<b>Strength</b>	Good.
<b>Shrinkage Rates</b>	N / A - Contact Supplier.
<b>Availability</b>	From stock - Sheet or Reel.
<b>Solvent / Filler</b>	Toluene may be used - no others solvents suitable. Hot air weld or glue.
<b>Finishing / Machining</b>	Does not take spray. Takes some specialist inks.
<b>Clear</b>	Yes - Different web widths available with thickness from 150 microns - 750 microns.
<b>Colours</b>	Black / white and colours available.
<b>Applications</b>	Packaging, Machine Guards and Car Trim.
<b>Price</b>	Inexpensive.
<b>Stockist</b>	Small quantities: Stephen Webster.

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.**

## 1- 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.

## 2- 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.

## 3- 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.



## Model

Models may be made from a variety of patternmaking 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.



## Mix

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

- 5kg pack - 3lt
- 2kg pack - 1.2lt

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.



## 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 (75mm) 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.



## 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.

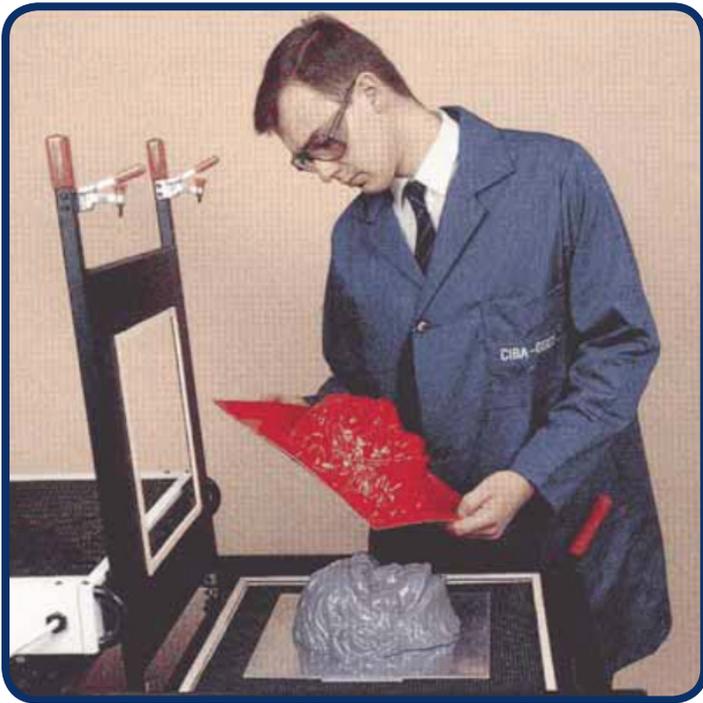
In the case of tools with a cross section thickness of less than 1 in (25mm) the room temperature stage must employ a temperature of at least 15 °C to provide an adequate initial cure for demoulding and further processing, e.g. machining etc.

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.



## **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

## 4- Aluminium - Cast

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.

## 5- AlwaPor – Porous Aluminium

AlwaPor is a micro porous aluminum that is air permeable. It is an interesting development in tooling material science, custom designed specifically to enhance the performance of tools for vacuum forming. 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.

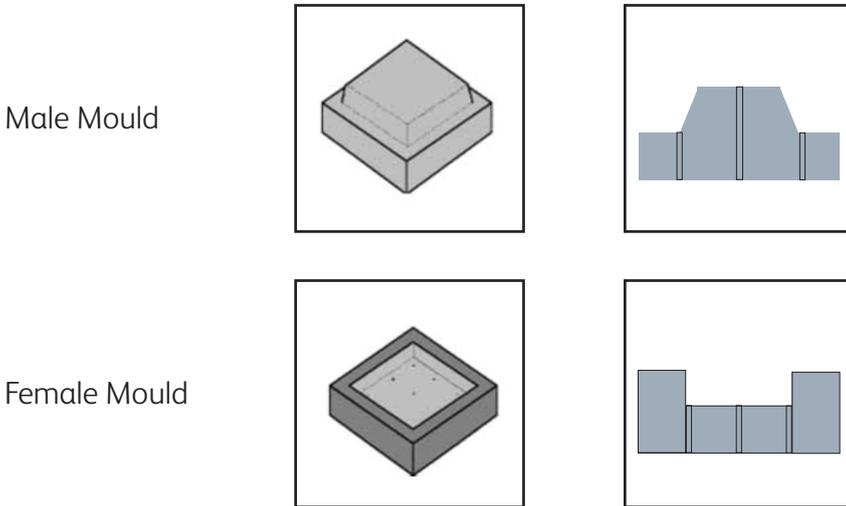
It is available in slab form and can be obtained through Formech at [www.formechdirect.com](http://www.formechdirect.com).



A porous aluminum mould demonstrated on a Formech machine.

## Male and Female Moulds

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



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.

Figure below 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.

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

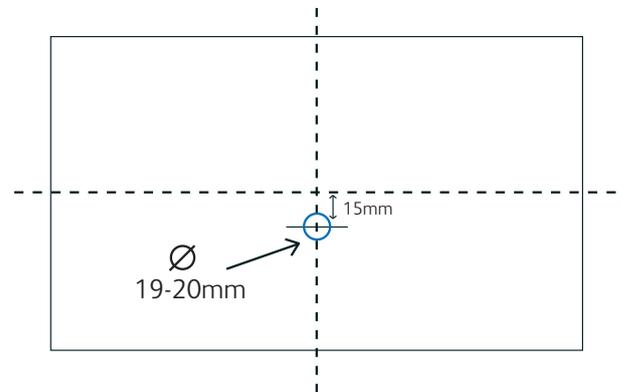
Generally speaking moulds should be mounted onto baseboards prior to forming to assist release. However, from time to time and often when a quick prototype is required moulds are placed directly onto the mould table and formed over. The main setback with this method is that when it comes to releasing 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 either MDF or aluminium. 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 3.00 – 4.00mm (1/8") thick is used to ensure it sits flush with the top of the forming area seal on the machine.

The vacuum hole can be 19.00 – 20.00mm (3/4") diameter and needs to be positioned 15mm forward of the centre of the table. Dimensions can

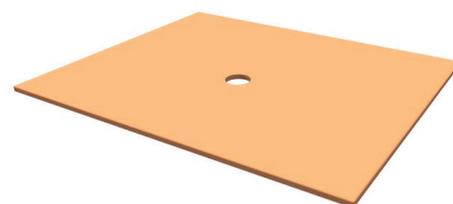
be different depends on which machine you're using.



Depending on which machine you have will also have to determine which size the baseboard should be. The baseboard has to be 4mm shorter in both directions than the forming aperture of the machine e.g. if the forming aperture is 280mm x 430mm, the baseboard size will have to be 276mm x 426mm.

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.



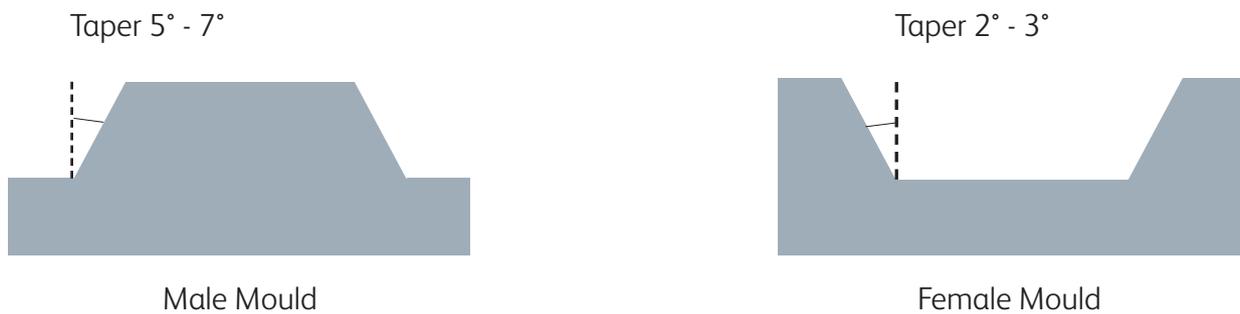
MDF  
Baseboard



Aluminium  
Baseboard

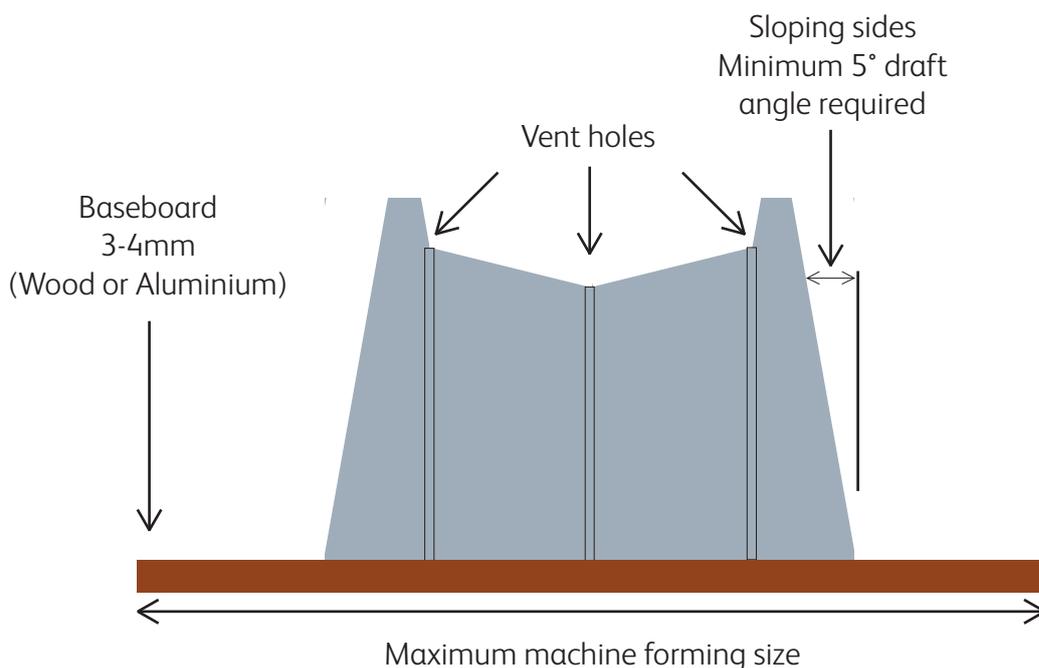
## Draught Angles / Tapers

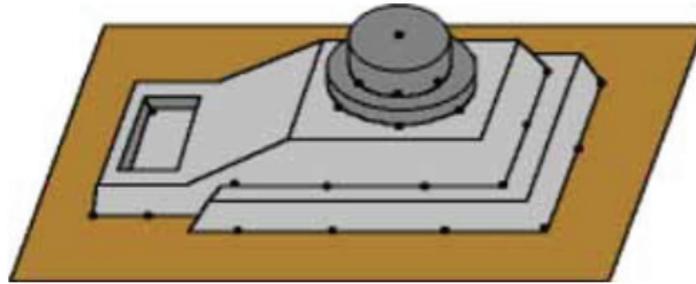
Most moulds are made with a base to sit flat on the forming table and must be provided with a draught or taper to facilitate removal, (figure below). The degree of taper will depend on various factors, such as the surface quality of the tool, the depth of near vertical faces, type of material used and 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  $5^\circ$ . 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  $3^\circ$  and  $5^\circ$  for male moulds.



## 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 below)





Typical vent hole 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 1/2 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 below)

**Not possible**



**Possible - as direction of removal has a greater angle than the undercut**



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.



**One mould**



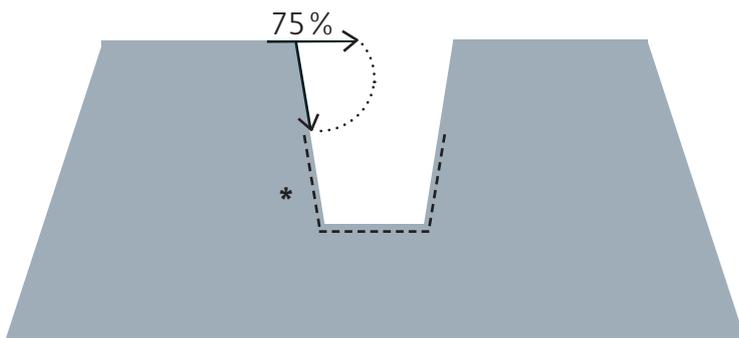
**Multi-impression Mould**

## 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 below).



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

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.

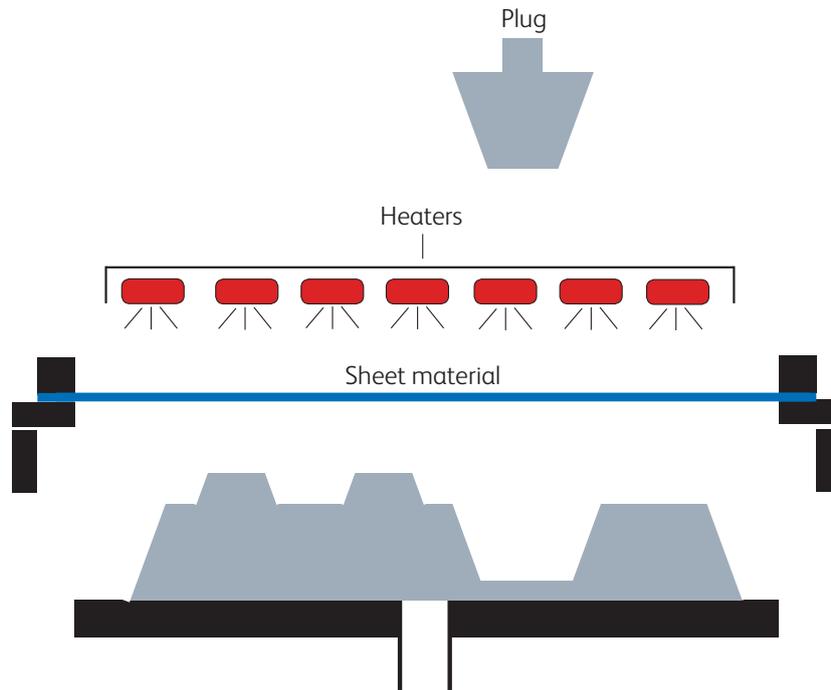
**Draw Ratio** = depth of the aperture divided by the length of the shortest cross section. For example a refrigerator liner has a large draw ratio in that it is a deep molding with small cross section.

In most cases the plug assist facility is a feature suspended above the forming area and activated by pneumatic or hydraulic systems. (fig page 33)

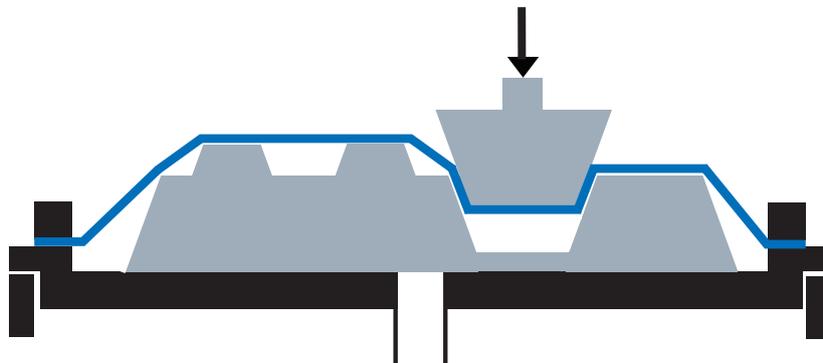
However on smaller machines with manual operation the plug is often operator handled on a manual basis. The majority of plug moulds are simple in design and made from hardwood. A felt or flocked surface is often added to ensure the plug glides into the aperture without tearing or marking the plastic too much.

## Plug assist facility

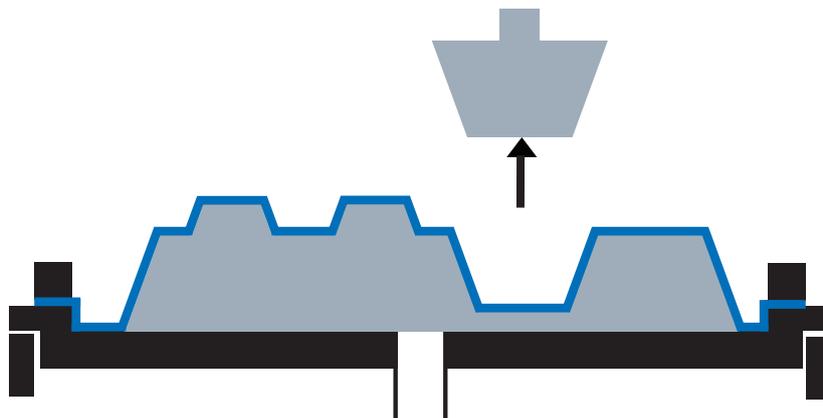
1



2



3



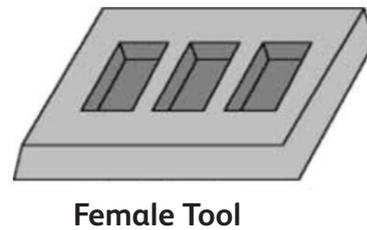
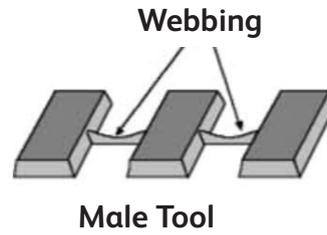
## Webbing/ Chill Marks/ Thinning

### Webbing

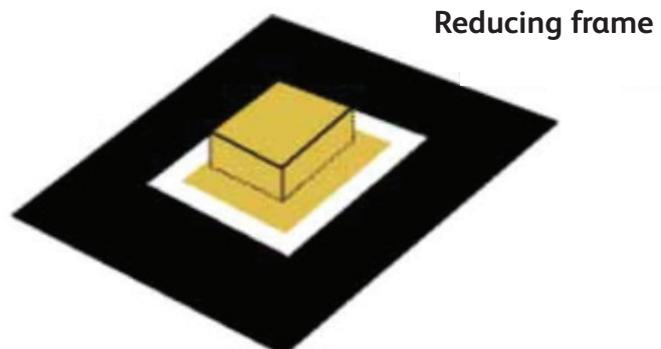
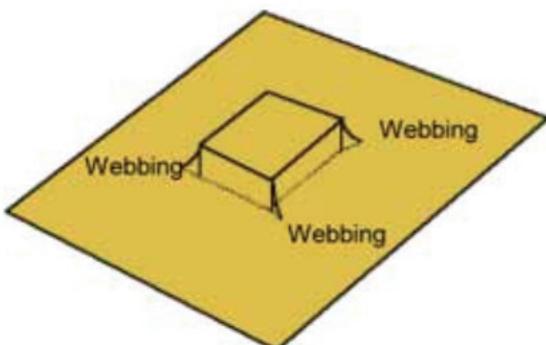
Another factor which affects mould design is webbing. This occurs when the material shrinks back on itself. The cause of this can be any of the following;

- > 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 on the right).
- > Excess of sheet material when using small moulds.

A female mould (fig on the right) can often overcome the webbing caused by multiple male moulds.

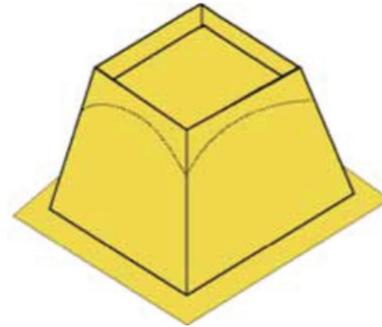


Webbing can be voided by restricting the amount of sheet around the mould. This can be in the form of reducing windows (figure below) or with the use of a plug. It can be minimized by a slower application of vacuum or by using thicker sheet. It may be necessary to modify the mould design if all else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



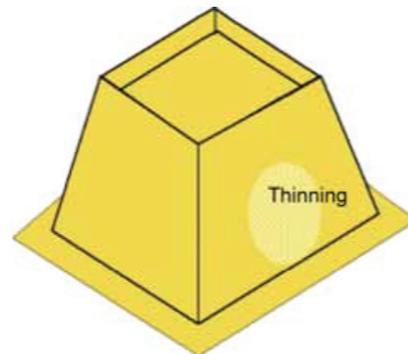
## Chill Marks

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. (figure on the right) 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.



## 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.



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](mailto:sales@formech.com)**

## 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.



## Considerations

Over time you will usually be able to build up a gut feel for which particular plastic processing method is best suited to your particular product. In order to do a comparison to the other processes that are available, you will need to take note of the following factors:

**Quantity:** The amount of parts you wish to produce are critical in determining not only if vacuum forming is the right process for this particular job, but also the number of tools you need to make and the total forming area. If time is limited, then you may decide to invest in a greater numbers of tools in order to complete the job in less time.

**Price:** Very few customers adopt the approach of “money’s no object”. There is always a good reason why a product has been produced in a particular manner and this is usually cost related. As a general rule once the quality and delivery issues have been established then price usually becomes the deciding factor in which process will be used, although occasionally there are exceptions.

**Finish:** What sort of finish do you require? What market is the part going in to? Is the part going to be seen? Is it for indoor or outdoor application? How many post forming operations will be required in order to turn the vacuum forming into the finished part?

**Accuracy:** The more accurate the part the more expensive it becomes to produce. Vacuum forming will not have the consistency of injection moulding, because you are only forming over one face, whereas injection moulding is a totally enclosed die, with toleranced surfaces on all sides.

**Strength:** What’s the application? Will the vacuum forming require additional fabrication in order to give it the rigidity it requires? Will the extra parts be glued , welded or fastened in place?

**Time:** Most processes require CAD these days, either at the design stage or to create the finished tool for production. This all takes time and needs to be added to the total delivery time (including the actual production of the parts) to work out when the parts will be on your doorstep.

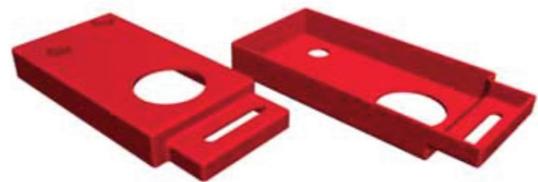
**Example:** Let’s assume that you intend to produce a vacuum formed machine cover based on the following:

### Specification:

Material: 2mm red high impact polystyrene.

Size: 330mm x 180mm x 50mm high.

Quantity: 500 off per annum. To be produced in batches of ten at a time.



Machine cover showing the top side and the underside.

This part would fit comfortably on our 300XQ machine and because of the small quantities and the size of the part we would form the part one up. In this particular case you could only fit one tool on the table of the 300XQ. If you wanted to produce 500 parts in one go then usually this kind of part would be produced two up on one of our larger machines. The benefits of increasing the number of tools used to form the parts is that the job is completed in a shorter time and so you have reduced labour and machine costs and in addition when multiples of tools are used, it usually means that less material is wasted.

## Post forming operations

With most vacuum forming projects using the slightly heavier gauge materials there is always a certain amount of post forming operations to be carried out and in most cases people usually multitask during the machine operation. If you are using an automatic machine you will have all the time between clamping one sheet and the next sheet. A typical automatic cycle will be as follows:

1. Place sheet in machine and clamp the material.
2. Heat the material.
3. Pre-stretch the material.
4. Raise the tool up into the material.
5. Apply the vacuum.
6. Start the cooling cycle.
7. Release the formed part from the tool and lower the tool.
8. Open the clamping frame and remove the formed sheet.

Repeat action 1 to start the next cycle. If you are forming 2mm material with cooling fans, then you will typically have a 3 minute cycle in which to carry out additional tasks. It would be very wasteful just to let the vacuum formings stack up beside the machine and then do all the trimming at a later date. Try if possible to complete or carry out as many other operations relating to the job as possible during the cycle.

The longer parts stand around untrimmed the more dust they collect and the possibility of damage increases. There is another factor that is often overlooked – boredom. Just spending your life waiting for machines to complete their cycles is tedious. When the operator is active and focussed on the job when multitasking there is a tremendous sense of achievement and the time just flies by.

Exactly what is required to complete this machine depends on the equipment you have available. Let's assume that you do not have access to a

five axis CNC router and that you are going to trim the part with more conventional equipment. (Incidentally a five axis CNC router would easily trim the part in under three minutes.



## Heated knife/ Scalpel

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



## Horizontal Bandsaw

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).



## Vertical bandsaw

## Rollerpress / Steel Rule Dies

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.



## 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 figures below for examples of products trimmed using this method.



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

## 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.

Material	Thickness	Preferred	2nd	3rd
PS	<3mm	Die	Shear	Band Saw
PS	>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 is 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.

The purpose of the following section is to help the user in overcoming some problems frequently encountered in thermoforming. Most of the major problems identified in thermoforming can be traced back inadequate process control. Improper sheet temperature at the time of forming is a primary source of problems. Poor vacuum control and insufficient cooling are also typical causes. The table below lists the majority of recurring problems in thermoforming along with the suggested courses of action to correct or eliminate the processing problem.

<b>Problem</b>	<b>Cause</b>	<b>Remedy</b>
<b>Blisters or Bubbles</b>	Overheating/Sheet heated too rapidly	- Lower the heater temperatures or reduce the top heater if using twin heating.
	Excessive moisture	- Pre-dry sheet
		- Pre-heat sheet
		- Heat from both sides
		- Keep material wrapped until ready to use
	Uneven Heating	- Check consumption.
		- Increase zone control.
<b>Poor Mould Release</b>	Mould or part too hot	- Increase cooling cycle.
		- Decrease mould temperature.
	Mould undercuts	- Increase release time and pressure
	Mould undercuts	- Increase release time and pressure
	Insufficient draft angles	- Increase draft.
		- Convert mould to female.
	Poor mould surface	- Use mould release. Improve mould surface.
<b>Sheet Scorching</b>	Top/Bottom surface too hot	- Decrease heating cycle time.
		- Decrease heater temperature.
		- Check for faulty heat zones if problem in isolated area. Pre-heat material.
<b>Lack of Definition</b>	Material too cold	- Increase heating time.
		- Increase heater temperature.
		- Increase heater density and/or wattage.
		- If localized problem check heater zone and elements.
	Mould too cold	- Ensure mould is at optimum temp. for forming

<b>Problem</b>	<b>Cause</b>	<b>Remedy</b>
	Insufficient vacuum	- Adjust vacuum timings.
		- Check vent holes on mould.
		- Increase number and or diameter of vacuum holes.
		- Check mould is not restricting vacuum flow - are vacuum tracks in mould adequate?
		- Check for leakage in vacuum system
		- Increase vacuum capacity
<b>Webbing</b>	Material too hot	- Shorten cycle time.
		- Lower heater temperature.
	Insufficient vacuum	- Check system for leaks
		- Increase size of vacuum holes - Check for blocked holes
	Incorrect Pre-Stretch height	- Adjust pre-stretch flow and time
	Excess material	- Reduce material size and use reducing windows
	Poor mould design	- Increase radii improve draw ratios - Use plug/ring assist.
		- Use assist blocks to pull out webbing.
		- Increase spacing between moulds.
		- Switch to female mould.
	Vacuum speed too fast	- Regulate to suit.
		- Use smaller vacuum holes.
<b>Whitening</b>	Part removed too early	- Part must be below set temp. before removing
		- Increase cooling cycle.
		- Add extra cooling fans
		- Utilise a spray mist facility - Use water cooled moulds.
	Uneven part cooling	- Increase mould temp. and/or temp. uniformity.
	Poor mould design	- Redesign. Incorporate ribs/tapers
	Poor sheet distribution	- Check for uneven heating
		- Use plug assist or pre-stretch for deep draw.
	Excessive mould release pressure or timing	- Adjust to suit.

<b>Problem</b>	<b>Cause</b>	<b>Remedy</b>
<b>Chill Marks</b>	Stretching stops when sheet makes contact with cold mould/ plug	- Increase mould temp. - Increase plug temp.
	Mould design	- Use plug to assist mould flow.
	Insufficient pre-stretch	- Increase pressure, flow or time
	Plug tool too cold	- Wrap tool with felt or similar.
<b>Thinning at corners on deep draw parts</b>	Uncontrolled sheet heat	- Improve zone control.
	Sheet formed too slow	- Use more vacuum
		- Increase number and size of vent holes
	Too much pre-stretch	- Decrease flow or timing.
	Cold spots	- Check elements
		- Check for draughts.
	Too thin gauge	- Increase
	Uncontrolled material distribution	- Use plug assist and/or pre-stretch
<b>Tearing of sheet whilst forming</b>	Sheet too hot	- Decrease heating cycle time. - Decrease temp. settings.
		- Pre-heat sheet.
	Sheet too cold	- Increase heating cycle time - Increase temp. settings.
	Pre-stretch too large	- Reduce time and flow.
	Mould design	- Increase corner radii and draw ratio.
	Improper material selection	- Consult supplier
<b>Parts stick in mould</b>	Part temp. too high	- Increase cooling cycle.
		- Lower mould temp.
		- Reduce heating cycle time.
	Mould not fixed on base-board	- Mount mould to baseboard ensure it is then fixed to table.
	Insufficient draft	- Increase taper.
	Mould undercuts	- Increase air eject.
		- Remove part earlier and use cooling jigs.
		- Use retractable undercut segments in mould.

<b>Problem</b>	<b>Cause</b>	<b>Remedy</b>
	Poor mould quality	- Polish mould.
		- Use release agent.
		- Remove rough edges from wooden moulds.
<b>Nipples on formed parts</b>	Sheet too hot	- Reduce heating cycle - Reduce heat temp.
	Vacuum holes too large	Plug holes/re-drill.
<b>Excessive sag</b>	Sheet too hot	- Decrease heat cycle time. - Decrease heater temp.
	Sheet area too large	- Improve zone control
		- Ensure auto level feature activated.
<b>Marks on finished moulding</b>	Dirty mould	- Clean mould with air gun after each cycle.
	Water droplets	- Decrease spray mist.
		- Check all hoses, gaskets for leaks.
	Poor mould surface	- Smooth/Polish surface.
	Scratched sheet	- Inspect handling procedure
		- Ensure protective film removed immediately prior to forming.
<b>Plastic pulls from clamp frame</b>	Insufficient clamp pressure	- Check clamp pressure.
		- Adjust alignment.
		- Heat frame prior to inserting sheet.
	Material too cold	- Increase heat cycle.
	Wrong material selection	- Consult supplier.

The following list of suppliers has been divided into four sub sections;

1. Formech – Machines & Spares, Ancillary Equipment
2. Plastic Stockists
3. Plastic Extruders (minimum order 500 - 1000 kilos)
4. Resin/ mould material suppliers.

## **Formech International Ltd (Headquarters)**

Unit 4, Thrales End Business Park  
Thrales End Lane  
Harpenden  
Hertfordshire  
AL5 3NS  
England  
Tel: + 44 (0)1582 469 797  
Fax: + 44 (0)1582 469 646  
Email: [info@formech.com](mailto:info@formech.com)  
[www.formech.com](http://www.formech.com)

## **Suppliers of:**

- Vacuum Forming Machines.
- Reducing Windows, Spare Parts and Spare Parts Kit.
- Drying Ovens, Line Bending Equipment, Rollerpresses
- Tooling – Prototype and Production

## **Formech Inc**

2324 Pinehurst Drive  
Middleton  
WI 53562  
USA  
Tel: 312.396.4072  
Email: [info@formechinc.com](mailto:info@formechinc.com)  
[www.formechinc.com](http://www.formechinc.com)

## **Formech Europe**

Am Wolfsberg/An der L553  
76774 Leimersheim  
Deutschland

Tel: +49 (0) 7272 9549868 0  
Fax: +49 (0) 7272 9549868 9  
Email: [info@formech.de](mailto:info@formech.de)  
[www.formech.de](http://www.formech.de)

## 2. Plastic Sheet Stockists

### Amari Plastic Ltd Branches nationwide.

Head Office:  
Holmes House  
24 – 30 Baker Street  
Weybridge  
Surrey  
KT13 8AU  
England  
Tel: + 44 (0)1932 83 50 00  
Fax: + 44 (0)1932 83 50 01 Email: ho@  
amariplastics.com www.amariplastics.com

Suppliers of:  
ABS, PC, PP, PMMA

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### Simona Ltd

Telford Drive  
Brookmead Ind. Park  
Stafford  
ST16 3ST  
England  
Tel: + 44 (0)1785 22 24 44  
Fax: + 44 (0)1785 22 20 80

Suppliers of:  
PE, PP, PETG

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### Stephen Webster Plastics Ltd

Brick Knoll Park  
Ashley Road  
St Albans  
Herts  
AL1 5PL  
England  
Tel: + 44 (0)1727 86 31 38  
Fax: + 44 (0)1727 84 42 91  
Email: sales@stephen-webster.co.uk  
www.stephen-webster.co.uk

Suppliers of:

- Holds in stock a large range of Sheet Polystyrene in black, white, colours and textures.
- Also supplies ABS, PETG, PVC, Acrylic Capped ABS.
- Excellent delivery times and no minimum.
- Discounts for quantity. Free delivery over £ 50.00

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### UKAP

Sterling House 21-25 Station Lane Hornchurch  
Essex  
RM12 6JL  
England  
Tel: + 44 (0)1708 44 77 88 Fax: + 44 (0)1708 44 11  
11 Email: sales@ukap.co.uk www.ukap.co.uk

Suppliers of:  
Flocked P.S and PVC (reel form only)

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### Polyformes Ltd

Cherry court Way  
Stanbridge Road  
Leighton Buzzard  
Beds  
LU7 8HU  
England  
Tel: + 44 (0)1525 85 24 44  
Fax: + 44 (0)1525 85 04 84  
Email: sales@polyformes.co.uk  
www.polyformes.co.uk

Suppliers of:  
Closed cell PE foams.

## 3. Plastic Extruders

### **Athlone Extrusions Ltd**

Grace Road  
Athlone  
Co. Westmeath  
Ireland  
Tel: + 353 (0)902 92 67 9  
Fax: + 353 (0)902 94 08 6  
Email: info@athloneextrusions.ie

Extruders of:  
P.S. ABS (Fire retardant) Acrylic Capped ABS

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### **Doeflex PLC**

Holmethorpe Avenue  
Redhill  
Surrey  
RH1 2NR  
England  
Tel: + 44 (0)1737 77 12 21  
Fax: + 44 (0)1737 77 24 61  
Email: sales.doeflex@dial-pipex.com

Suppliers of:  
Polystyrene / Conductive PE and PP

## 4. Resin Suppliers

### **Alchemie Limited**

Warwick Road  
Kineton  
Warwick  
CV35 0HU  
England  
Tel: + 44 (0)1926 64 16 00  
Fax: + 44 (0)1926 64 16 98  
Email: sales@alchemie.com  
www.alchemie.com

Suppliers of:

- Epoxy Resin Tooling Systems for vacuum forming.
- Metaphor – Porous Aluminium

We hope this manual has provided a useful insight into vacuum forming. Whilst we have tried to cover all aspects of the process the following industry bodies and associations are able to provide further assistance and information on the thermoforming process in general. Please see our contacts section for links to the following companies or you can link directly below.

### **British Plastic Federation (BPF)**

5-6 Bath Place  
Rivington Street  
London  
EC2A 3JE  
England  
Tel: + 44 (0)20 74 57 50 00  
Fax: + 44 (0)20 74 57 50 45  
[www.bpf.co.uk](http://www.bpf.co.uk)

### **British Polymer Training Association (BPTA)**

Halesfield 7  
Telford  
Shropshire  
TF7 4NA  
England  
Tel: + 44 (0)1952 58 70 20  
Fax: + 44 (0)1952 58 20 65  
Email: [samr@bptaserv.co.uk](mailto:samr@bptaserv.co.uk)  
[www.bpta.co.uk](http://www.bpta.co.uk)

### **Institute of Materials**

1 Carlton House Terrace  
London  
SW1Y 5DB  
England  
Tel: + 44 (0)20 74 51 73 00  
Fax: + 44 (0)20 83 91 70 2  
[www.materials.org.uk](http://www.materials.org.uk)

### **Rubber & Plastics Research Association of G.B. (RAPRA)**

Shawbury  
Shrewsbury  
Shropshire  
England  
Tel: + 44 (0)1939 25 03 83  
Fax: + 44 (0)1939 25 11 18  
Email: [info@rapra.net](mailto:info@rapra.net)  
[www.rapra.net](http://www.rapra.net)