Formech
Perfectly formed

Vacuum Forming Guide



Table of Content

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 ten 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 and a trouble shooting guide 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.

Helmets Polycarbonate body formed on a Formech 1372

Mask DUESITH - Body formed on a Formech 300XQ

Air conditioning units ABS - Body formed on a Formech 686

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 'products' 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 and Porches

Boat Building industry
> Boat Hulls, Covers and Hatches Electrical Enclosures, Dashboards

Chocolate industry
> Manufacture of Chocolate Moulds for Specialised Chocolates
> 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 Concepts for other Plastic Processes

Mask HIPS - Body formed on a Formech 300XQ

Radio Controlled Car - Body formed on a Formech 686

Luggage acrylic - Body formed on a Formech 1372

Applications

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
> Exterior Signs Point of Sale Displays

Souvenir Industry
> Making parts for and moulds to cast craft souvenirs

Theatre
> Manufacture of Props, Sets and Costumes

Golf Car Parts Acrylic Capped ABS - Body formed on a Formech 1500

Props Acrylic Capped ABS - Body formed on a Formech FMDH660

Acrylic capped ABS Kayak seat - Body formed on a Formech HD Series

The Vacuum Forming Process

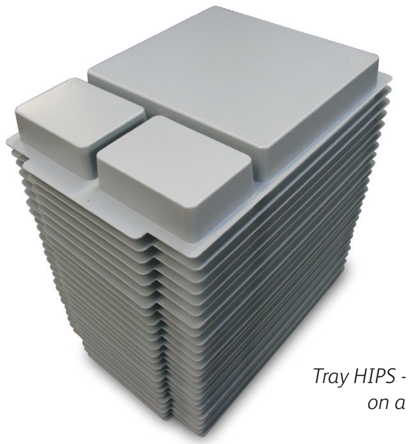
In its simplest form the process consists essentially of inserting a thermoplastic sheet in a cold state into the forming clamp area, heating it to the desired temperature either with just a surface heater or with twin heaters and then raising a mould from below. The trapped air is evacuated with the 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 on page 7. 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 later in this guide - see section Mould and Mould Design.)

The typical process steps can be identified as follows: clamping, heating, pre-stretch, plug assist, cooling with air and spray mist, release and trimming. They are examined more closely under the sub headings on page 8 and 9.

Cup cake POS display - Body formed on a Formech 686

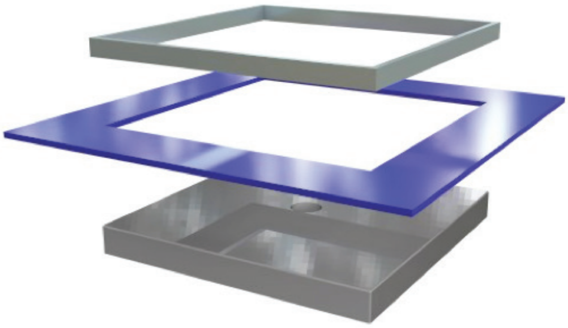


Tray HIPS - body formed on a TF686

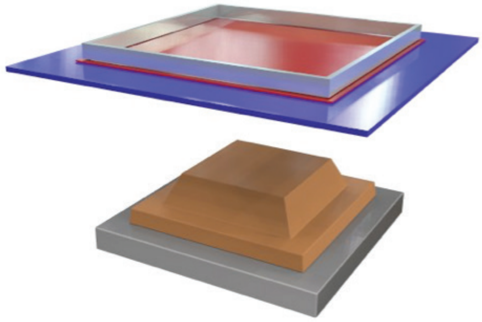
PETG digitally printed on the reverse - Body formed on a Formech xxx

The Vacuum Forming Process

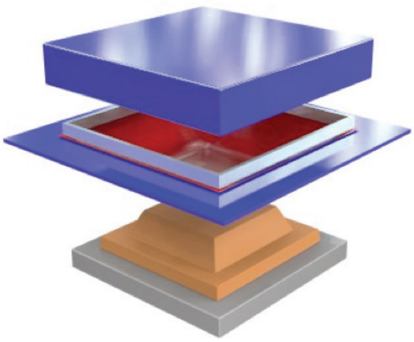
Basic principles of vacuum forming



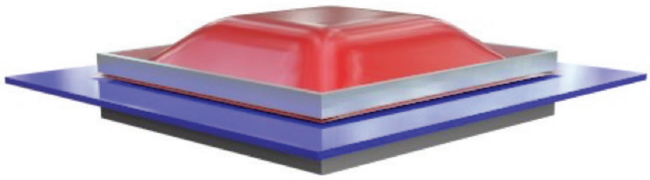
1. Clamping frame, aperture plate & table



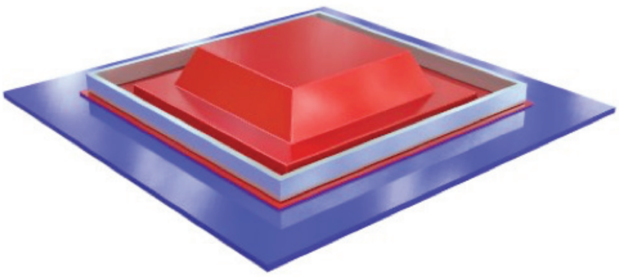
2. Material clamped and tool (mould) mounted on table



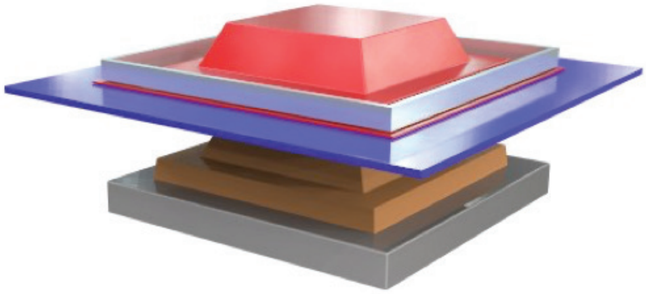
3. Heating the clamped material



4. Material pre-stretched & table up



5. Vacuum applied



6. Cooling, release & table down

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.

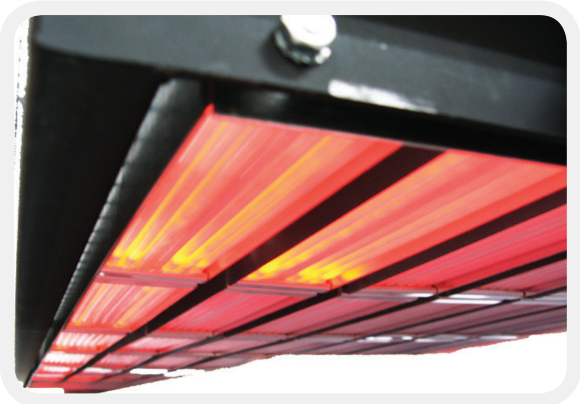
Twin quartz heaters are advisable when forming high temperature materials with critical forming temperatures. By close control of areas of heat intensity, heat losses around the edges caused by convection air currents and absorption from clamp areas can be fully compensated for and consistent results 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 - not available on all the machines

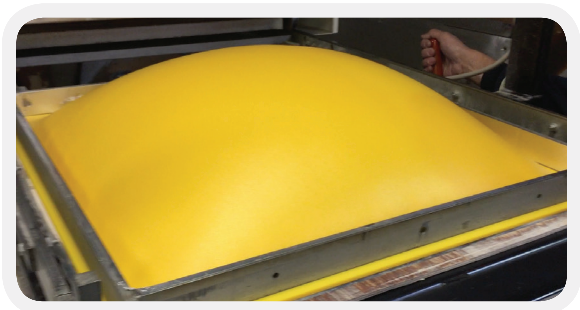
A photo-electric beam is activated under the sheet of plastic during the heating cycle. If the sheet of plastic sags down and breaks the beam, then a small amount of air is injected into the bottom chamber under the sheet, thus lifting the sheet to stop it from sagging until the sheet clears the beam.

Pre-stretch (Bubble) - Not available on all the machines

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 - Only available on HD and TF Series

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 - Not available on all the machines

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 (see page 38 for trimming and finishing methods). Thin gauge parts are normally trimmed on a mechanical trim press – otherwise known as a rollerpress.

Plug assist

Cooling Fan System

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.

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.

Racing car HIPS - Vacuum formed on a Formech 1372

POS PETG - Vacuum formed on a Formech 508FS

Monopoly board game - Vacuum formed on a Formech 686

Overview typical plastics

Material	Glass Transition Temperature	Rec. mould temperature	Rec. forming temperature	Drying temperature	Drying time
ABS	88-120°C / 190.4-248°F	82°C / 179.6°F	150-180°C / 302-356°F	70-80°C / 158-176°F	1 hour per mm
HIPS	100°C / 212°F	82°C / 179.6°F	150-175°C / 302-347°F	n/a	n/a
PC	150°C / 302°F	127°C / 260.6°F	170-205°C / 338-401°F	90°C-110°C / 194-230°F	1mm: 1hr 3mm: 4hrs 4mm: 10hrs
PE	-125°C / -193°F	90°C / 194°F	150-180°C / 302-356°F	n/a	n/a
PETG/PET	70-80°C / 158-176°F	60°C / 140°F	120-160°C / 248-320°F	n/a	n/a
PMMA	100°C / 212°F	82°C / 179.6°F	150-175°C / 302-347°F	70-80°C / 158-176°F	1mm: 1hr 3mm: 4hrs 4mm: 10hrs
PP	5°C / 41°F	90°C / 194°F	150-180°C / 302-356°F	n/a	n/a
PVC	90°C / 194°F	80°C / 176°F	140-190°C / 284-374°F	n/a	n/a

Note: *Values stated are intended as a guide only and for actual values you should refer the material specification from the plastic manufacturer.*

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 our office who will advise exactly what drying temperature and time is required for materials.

E.g.: Polycarbonate with a thickness of 3mm would require 4 hours at a drying temperature of 90-110°.

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 (Typical application examples of thermoformed products are listed on pages 4 & 5).

In table page 12, you will find a selection of more commonly used materials and the approximate heating times required using a single heater Formech machine equipped with Quartz elements (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.

Plastic	Thickness	Approx. heating time (seconds)
ABS	1mm / 0.04“	40
	1.5mm / 0.06“	60
	2mm / 0.08“	80
	3mm / 0.12“	120
	4mm / 0.16“	160
HIPS	1mm / 0.04“	30
	1.5mm / 0.06“	45
	2mm / 0.08“	60
	3mm / 0.12“	90
	4mm / 0.16“	120
PC	1mm / 0.04“	60
	1.5mm / 0.06“	90
	2mm / 0.08“	120
	3mm / 0.12“	180
	4mm / 0.16“	240
PE	1mm / 0.04“	50
	1.5mm / 0.06“	75
	2mm / 0.08“	100
	3mm / 0.12“	150
	4mm / 0.16“	200
PETG	1mm / 0.04“	30
	1.5mm / 0.06“	45
	2mm / 0.08“	60
	3mm / 0.12“	90
	4mm / 0.16“	120
PMMA	1mm / 0.04“	40
	1.5mm / 0.06“	60
	2mm / 0.08“	80
	3mm / 0.12“	120
	4mm / 0.16“	160

Plastic	Thickness	Approx. heating time (seconds)
PP	1mm / 0.04“	50
	1.5mm / 0.06“	75
	2mm / 0.08“	100
	3mm / 0.12“	150
	4mm / 0.16“	200
PS	1mm / 0.04“	30
	1.5mm / 0.06“	45
	2mm / 0.08“	60
	3mm / 0.12“	90
	4mm / 0.16“	120
PVC	1mm / 0.04“	30
	1.5mm / 0.06“	45
	2mm / 0.08“	60
	3mm / 0.12“	90
	4mm / 0.16“	120

Note: This is a selection of more commonly used materials and the approximate heating times required using a single heater Formech machine equipped with quartz elements

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.
Hygrocospic	Yes - pre drying required at approx 80˚C / 176˚F (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	Contact your local Formech office (see end of this guide)

Toy cover

Car parts

Props

Polystyrene – High Impact Polystyrene (HIPS)

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.
Hygrocospic	No.
Strength	Medium to Good impact strength.
Shrinkage Rates	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	Contact your local Formech office (see end of this guide)

Mask

3D cover

POS Display

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.
Hygrocospic	Yes - Drying temperature 90˚ C / 194˚F. 1mm - 1 hr. 3mm - 4hrs. 4mm - 10hrs.
Strength	Very good impact strength.
Shrinkage Rates	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 and digital 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	Contact your local Formech office (see end of this guide)

Mask

3D cover

POS Display

Polyethylene – (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.
Hygrocospic	No.
Strength	Very good impact strength.
Shrinkage Rates	LDPE - 1.6 - 3.0 % HDPE - 3.0 - 3.5 %
Availability	From stock.
Solvent / Filler	No solvent.
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	Contact your local Formech office (see end of this guide)

Bicycle case HDPE

PE Foam

Suitcases HDPE

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 / 176-248˚F.
Hygrocospic	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 / 140˚F.
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	Contact your local Formech office (see end of this guide)

POS Display

Medical mask

POS Display

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.
Hygrocospic	Yes - Consult supplier for drying times.
Strength	Medium to High strength.
Shrinkage Rates	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	Contact your local Formech office (see end of this guide)

Rooflights

POS Display

Bank signage

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 wit-hin temperature band of approx 10°C / 50°F and provides excellent indicator to forming temperature. Good temperature control required in conjunction with a sheet level facility.
Hygrocospic	No.
Strength	Very good impact strength.
Shrinkage Rates	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	Contact your local Formech office (see end of this guide)

Insert tray

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.
Hygrocospic	No.
Strength	Good.
Shrinkage Rates	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 - 750 microns.
Colours	Black / white and colours available.
Applications	Packaging, Machine Guards and Car Trim.
Price	Inexpensive.
Stockist	Contact your local Formech office (see end of this guide)

Blister PVC / APET

Chocolate packaging

Marine Pod

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.

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.

Shaping and smoothing the sculpted clay

Sculpting ready to be vacuum formed

Vacuum formed mould

2- Wood

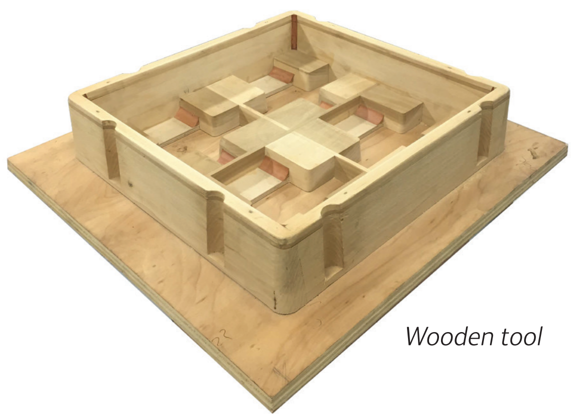
Wooden moulds are cheap and easy to fabricate, and have a longer life than plaster moulds - in many cases being used on a production basis for in excess of 500 formings. Hardwoods are recommended, notably 'jelutong' and 'obeche' which both have a close and even grain which makes them easier to work and 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.

Note: *the majority of vacuum pumps used by Formech are dry vane and are therefore sensitive to release agents and we do not recommend the use of release agents. Please speak to you local Formech office for further details.*



Wooden tool

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 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 up to 15 minutes when using slow acting epoxy resin. Polyurethane resins are usually fast acting (within 5 minutes) and so there is no time to wait for bubbles to rise. 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 an accelerator.

The outer faces of the vacuum forming are strengthened with MDF panels and attached with double sided tape. All the MDF panels are then secured with packaging tape to stop the panels from moving.

Initially stir the resin and hardener by hand with a paddle. Then use a powered stirrer to mix it thoroughly.

3- Cast Epoxy Resins (continuation)

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.

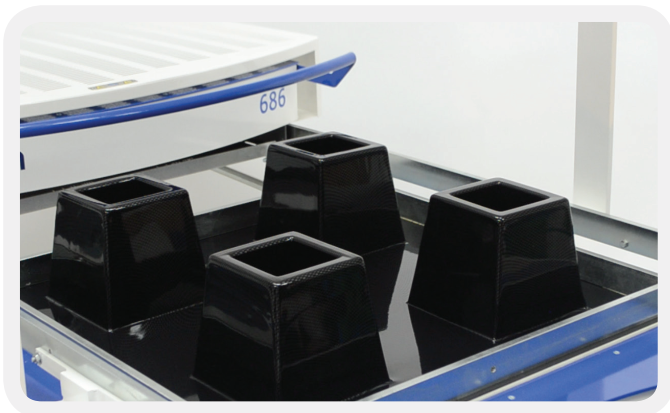
Drilling and Machining

Evacuation holes may be drilled by any one of the engineering techniques available. Alchemie EP426 and SIKA G38 tooling systems are formulated to be easy to mix, pour and finish. They contain no hard fillers and produces swarf rather than dust.

Alchemie EP426 in use on a small scale vacuum former

EP426 + G38 are designed to meet a particular need of the toolmaker for small to medium size cast resin tooling.

These resin ranges also include 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- 3D Printing/Rapid prototyping/Additive manufacturing

Because thermoforming doesn't require extreme heat or pressure, 3D printing is a viable alternative as it can eliminate much of the time and labor associated with machining vacuum-forming tools.

With affordable 3D printed tooling and a wide variety of applications, it could be the perfect fit for prototyping projects. Vacuum forming with 3D printed molds is a great way to quickly create 3D parts from plastic sheet material.

FDM (Fused Deposition Modeling) is the most common technology used for creating 3D printed molds for vacuum forming and offers many unique benfits.

FDM allows you to print in various sparse fill densities, giving the molds an inherent porosity that results in a uniform vacuum to be drawn throughout the tool. This can greatly simplify the fabrication of the tool. In addition, FDM machines are capable of printing molds in a variety of durable, heat resistant plastics that prolong the life of the mold.

PolyJet (UV-Cured Photopolymer Jetting) is another common technology used for 3D printing molds. PolyJet-based machines build parts with fine layer resolution, and as a result, produce parts with very smooth surfaces. PolyJet vacuum form molds require little to no post processing and are great for making molds with organic and curvy surfaces. PolyJet molds don't share the porosity of sparse fill FDM molds, but air vents can easily be designed into critical areas of the mold prior to printing, eliminating the labor and potential inconsistency of manual drilling.

Both technologies simplify the tool fabrication, allowing engineers and designers to test multiple tooling strategies concurrently, and shortening the time to produce the first articles of a design. Other additive manufacturing technologies can be considered.

3D printed mold

Vacuum formed mould

Final part

5- 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.

Wooden pattern

Cast aluminium

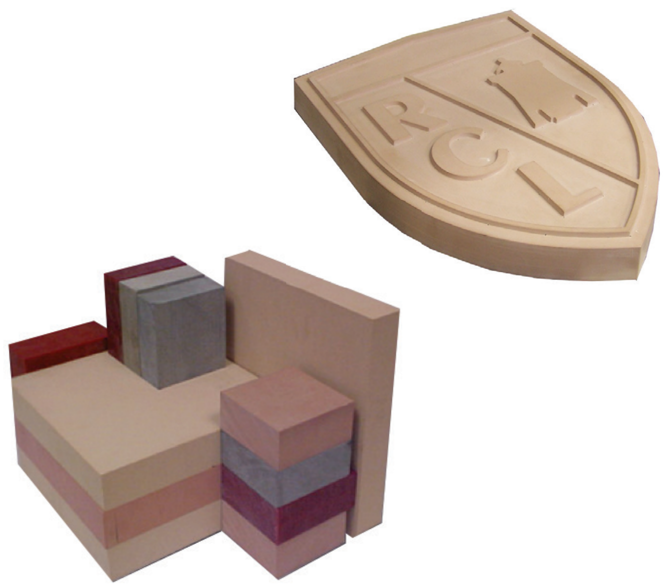
6- CNC machined tooling board or model board

These boards come in a variety of different hardnesses, thicknesses and board sizes. They can also be easily joined together with epoxy adhesive. These materials are also very easy to machine and to sand up.

Metapor is microporous, air-permeable aluminium modelboard that delivers advanced solutions for many thermoforming applications. It eliminates the need to drill vacuum holes, expanding technical capabilities of the thermoforming process, although it is perhaps 10 times the cost of a standard modelboard.

Advantages
> Tooling boards available in variety of sizes and thickness
> Layer up and laminate to achieve depth where required
> Fast, efficient tooling
> Ideal for prototyping and low volume (50-100 cycles)
> Relatively low cost

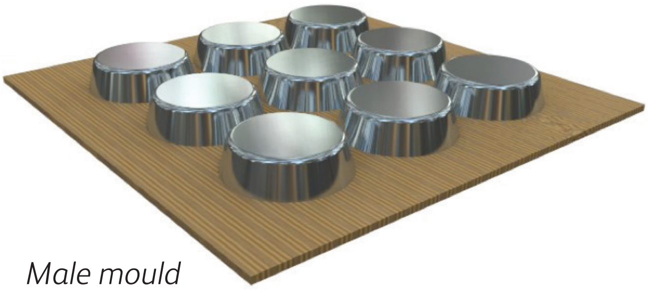
Disadvantages
> Not as robust as aluminium
> Witness lines may be visible on formed part (laminated layers)



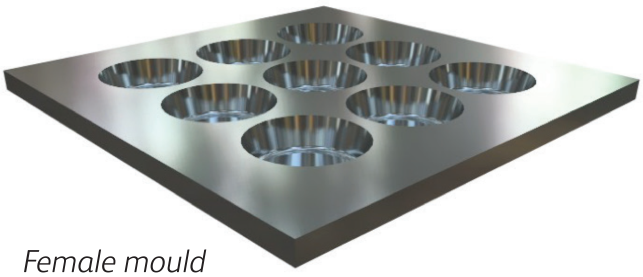
Male and Female Moulds

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

See figures below:



Male mould

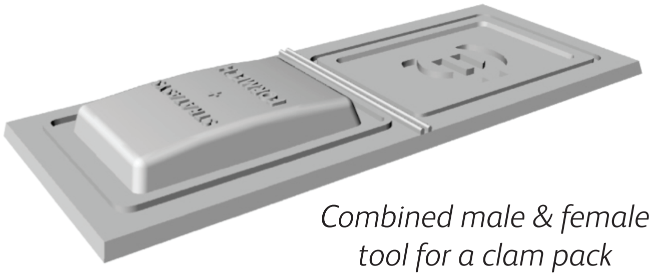


Female mould

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 combined male & female tool for a clam pack:



Combined male & female tool for a clam pack

Formed and die cut clam pack

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.

Basic requirements of vacuum forming

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, direct 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.

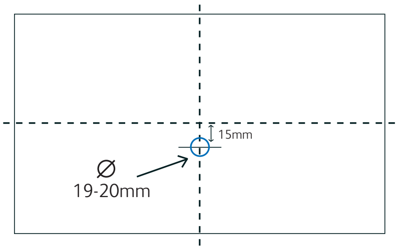
Baseboards and Mounting

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.

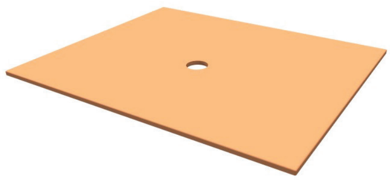
The vacuum hole in the base board can be 19.00 – 20.00mm (3/4’’) and should align with the vacuum hole in the table. Dimensions can be different depends on which machine you’re using.



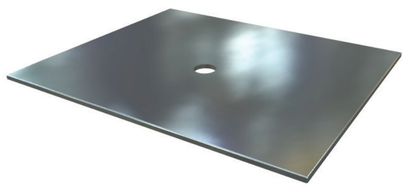
Example of the location of the hole in the base board when used with the Formech Compac Mini.

Depending on which machine you have, you will also have to determine which size the baseboard should be. For a Formech vacuum forming machine, it is recommended that the baseboard is at least 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.

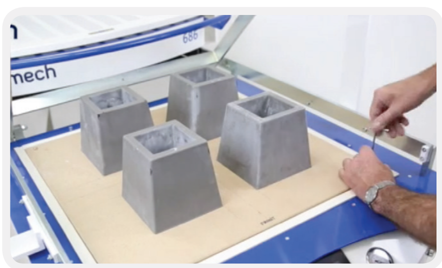
To improve further the release the baseboard can be mounted directly to the table. In order to do this the table needs first to be drilled and tapped in the four corners which act as the location points for the baseboard. When mounting moulds to the baseboard it is necessary to ensure there is some clearance 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



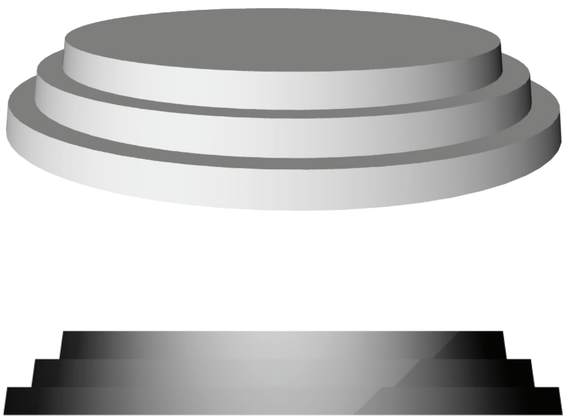
Aluminium Baseboard



MDF baseboard mounted on Formech 686

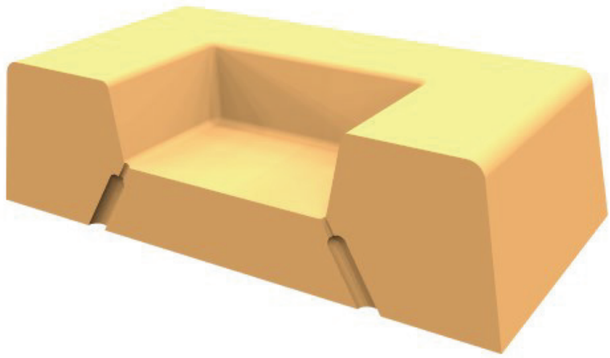
Draft Angles / Tapers

Most moulds are made with a base to sit flat on the forming table and must be provided with a draft 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˚. 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.



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)



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.

Note: *the majority of vacuum pumps used by Formech are dry vane and are therefore sensitive to release agents and we do not recommend the use of release agents. Please speak to you local Formech office for further details.*
It is also possible to use a compressed air line to blow air between the molding and the tool.

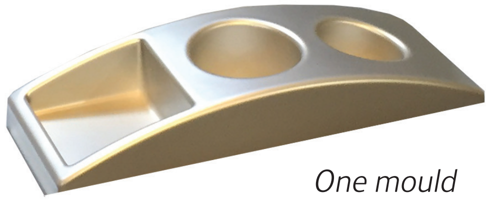
The most effective way to ensure that the moldings are released on a repeated basis is to ensure that the moulds are mounted on baseboards which in turn can be attached to the mould rise and fall table on the machine. This ensures that only the plastic part is ejected when release is activated.

Undercuts, Split and Multi Impression Moulds

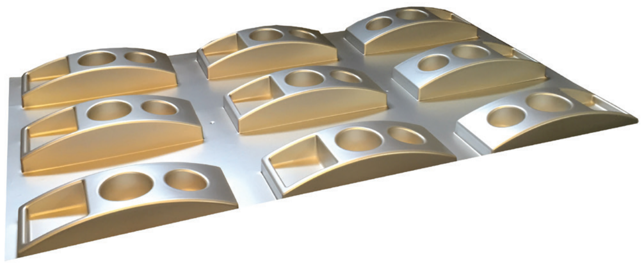
A number of other features can be incorporated into mould design. Although technically not possible as once formed it is impossible to release, undercuts can be incorporated into a mould design with the use of split tooling. With the use of a removable side entrant tool it is possible to achieve undercuts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

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.



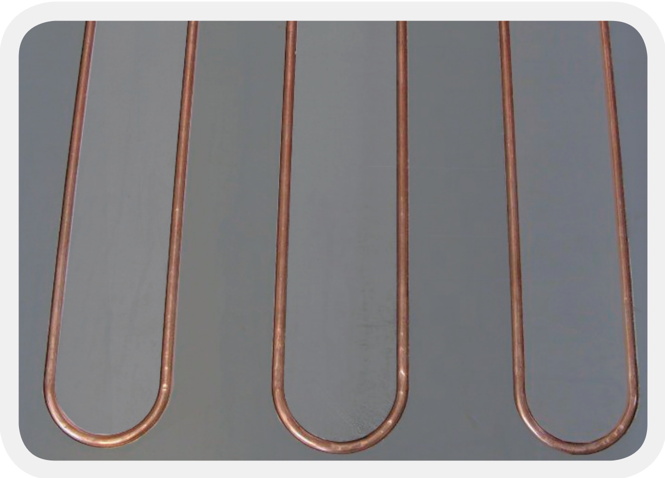
One mould



Multi-impression Mould

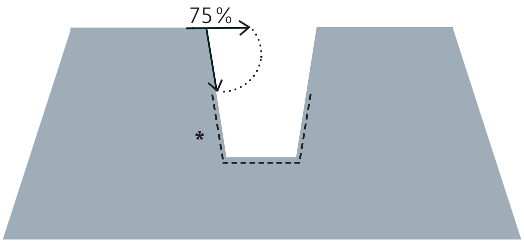
Mould Cooling

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 bolster. 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.

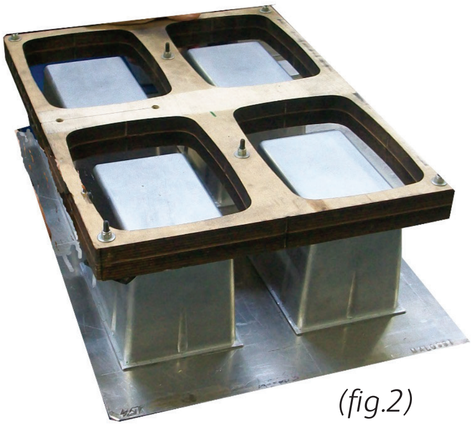


Plug Assist Design

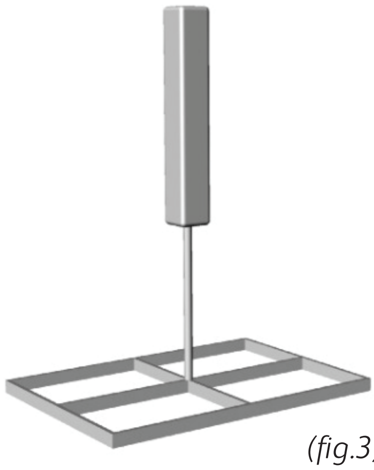
The purpose of a plug feature is three fold. It is used to force material into a cavity before applying the vacuum (fig.1), to restrict the flow of the material to stop webbing when moulds are close together (fig.2) and to act as a restraint when releasing the formed sheet to avoid distortion of the sheet (fig.3). Under normal conditions plastic will start to thin radically once it exceeds in depth more than 75 % of the cross section (fig below).



(fig.1)



(fig.2)



(fig.3)

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.

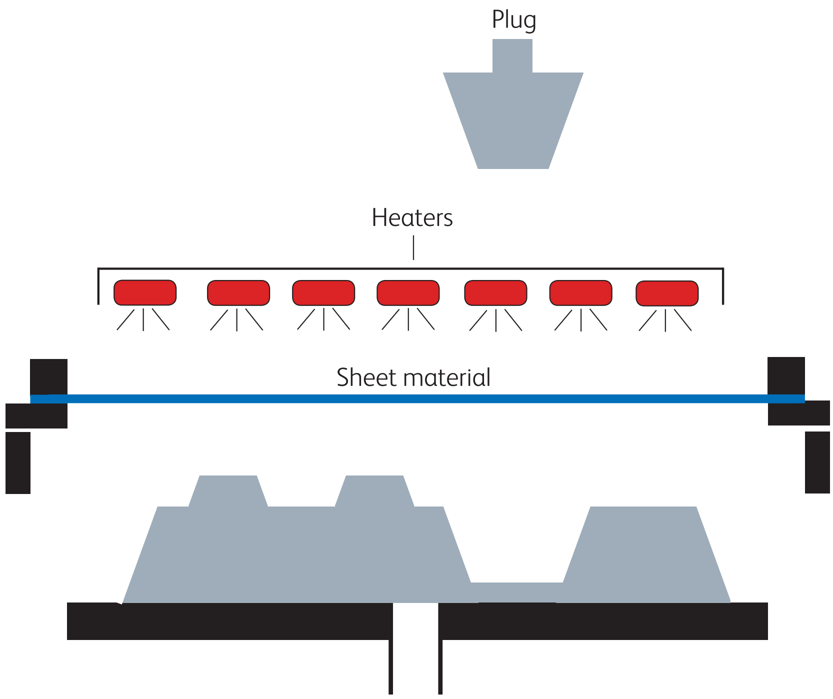
Draw Ratio = depth of the aperture divided by the length of the shortest cross section. For example a refrigerator liner has a large draw ratio in that it is a deep molding with small cross section.

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

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



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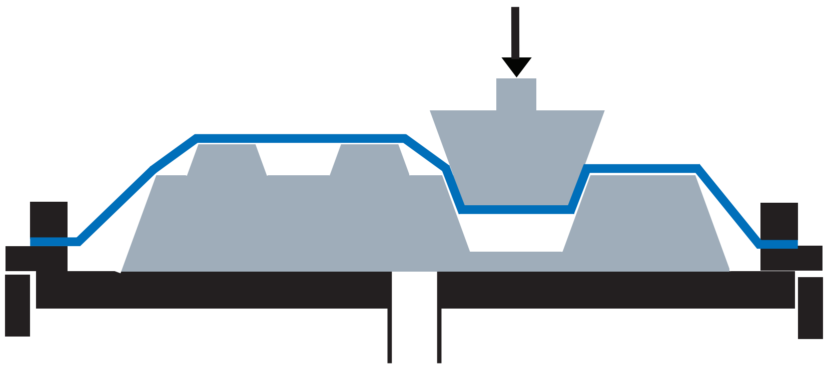

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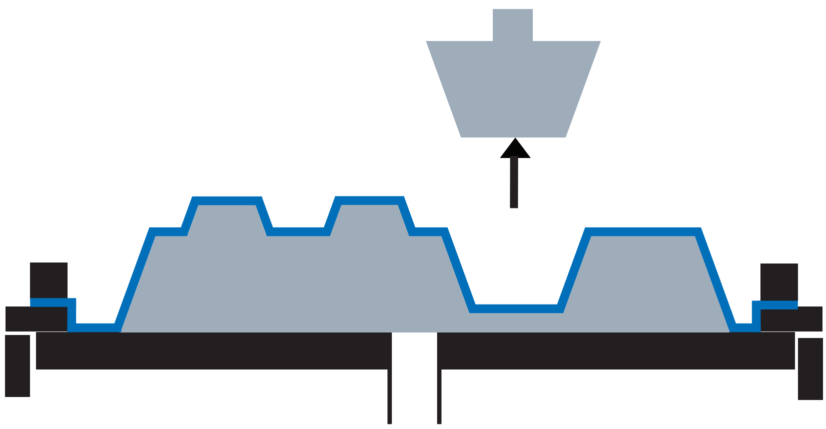


Webbing/ Chill Marks/ Thinning

Webbing

Apart from the tool design, webbing usually occurs when you cannot sufficiently control the flow of the heated sheet as the tool is raised into the sheet. When the vacuum is applied it will always suck down first the part of the sheet that has the least resistance.

If you were to imagine draping a cloth over your tool, rather than a plastic sheet, then the resulting folds and pleats would identify the possible problem areas that your plastic sheet will encounter during the forming process.

The cause of this can be any of the following:

> Mould/Tool too high in relation to its base area (fig.4)

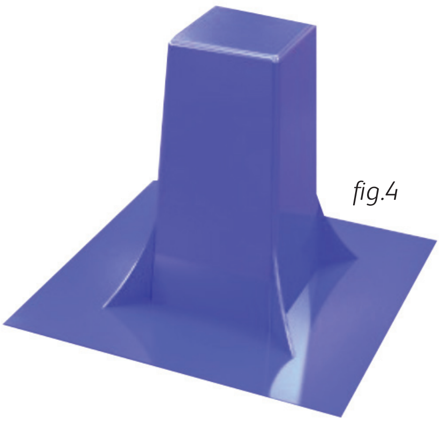


fig.4

> Sharp vertical corners with minimal draught angles (fig.5)

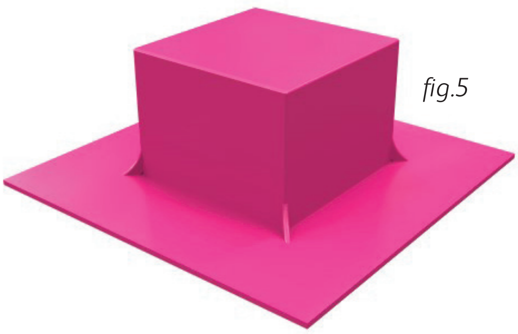


fig.5

> Too much material for the job (fig.6)

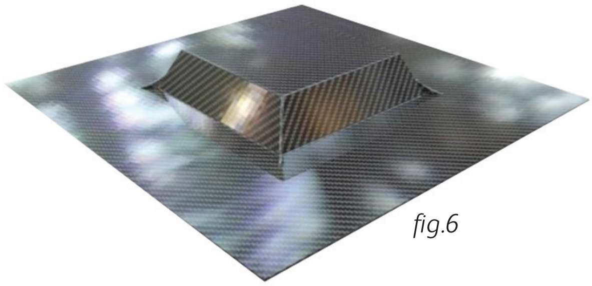
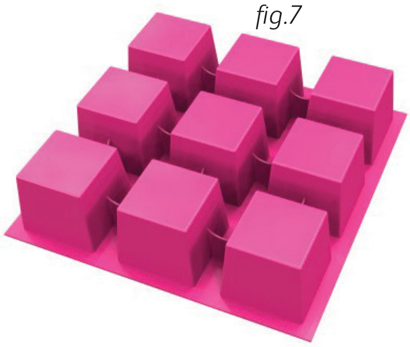


fig.6

> Deep male moulds in close proximity to each other (fig.7)

fig.7



Webbing (continuation)

The following solutions can often overcome the webbing caused by multiple male moulds:

> Slow vacuum down to gently introduce the vacuum to reduce the chance of webbing

> Use a smaller sheet size so that the mould/tool stretches the material more (fig.8)

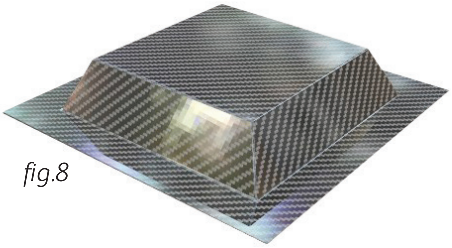


fig.8

> A frame attached to the plug assist that comes down as the table is raised helps to force the material down between the tools and reduce webbing. (fig.12)

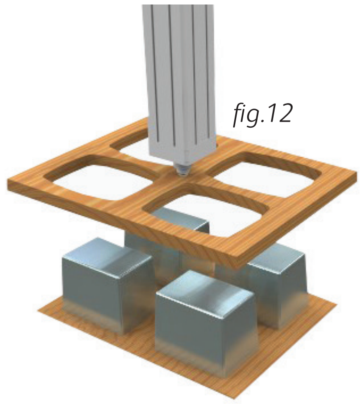


fig.12

> Place angled blocks around the corners to use up the excess material. (fig.9)

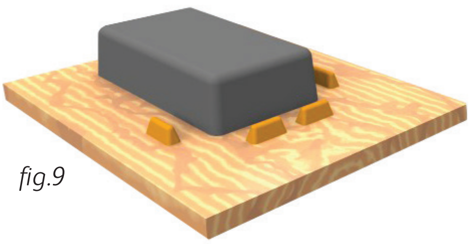
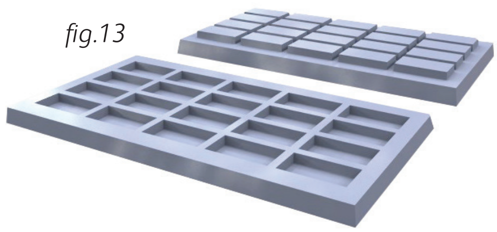


fig.9

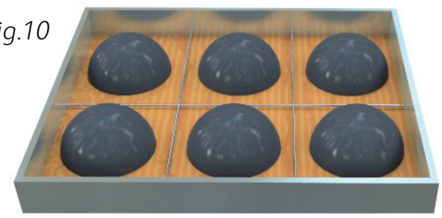
> Try using a female tool instead of a male tool if webbing occurs between parts of the tool. (fig.13)

fig.13



> Fix wires or steel blades to the clamping frame to restrict the sheet movement as the tool/mould is raised into the sheet. (fig.10)

fig.10



> Increase tool height/add 45 degree apron to tool base to use up excess material that cause webs. (fig.14)

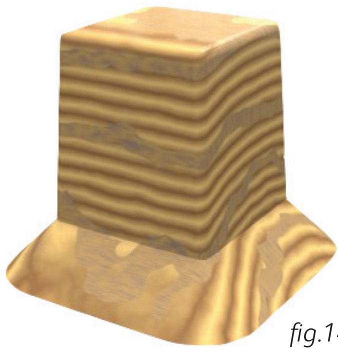


fig.14

> Add draught angle/radius corners to allow the material to flow over the tool/mould/pattern. (fig.11)

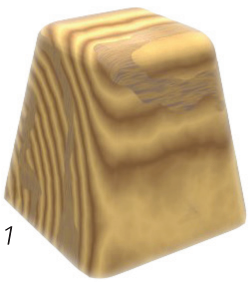
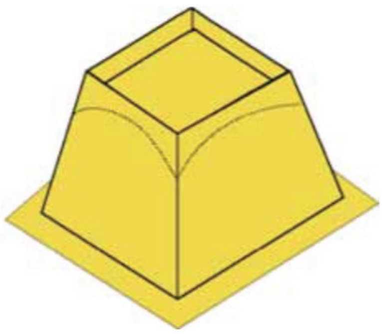


fig.11

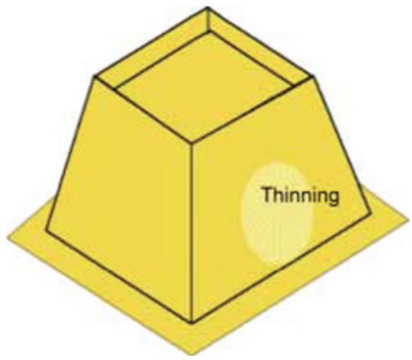
Chill Marks

When raising a deep draw mould into a heated sheet, the point which first makes contact cools, reducing its flow characteristics and producing an uneven flow of material at the top which thins down the sidewalls as the vacuum is applied (figure below). 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

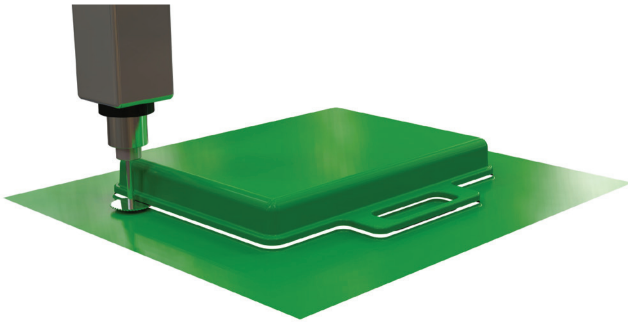
This is one of the most common problems with mould design and is the result of deep draw ratios and minimum draught angles. Figure below shows thinning caused as a result of deep draw male mould with minimum draft angles. There are numerous solutions which include pre-stretch (bubble), plug assist, strengthening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



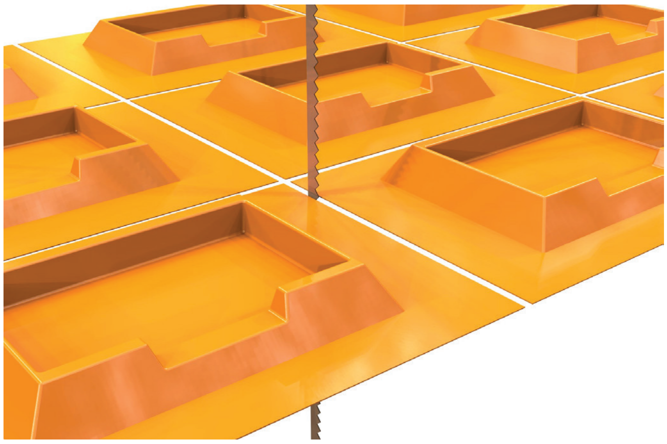
Finishing and Trimming

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.

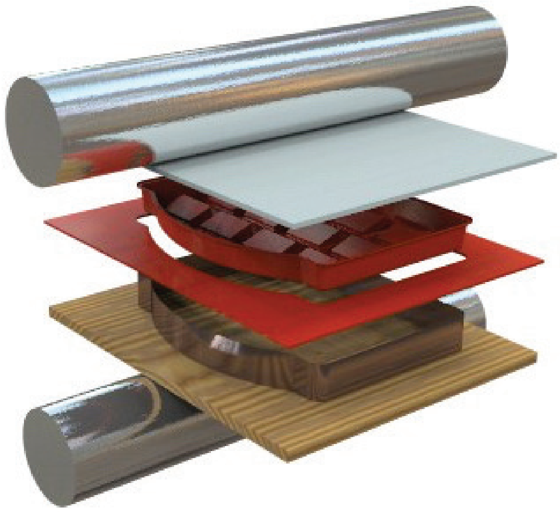
A variety of different trimming methods are used to trim the product from the sheet. The type of equipment best suited depends largely on the type of cut, size of the part, draw ratio, thickness of material and the production quantity required. They are also factors to consider when determining the investment 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 on the following pages.



3 axis router



Vertical bandsaw



Roller press

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.

Trimming by hand

Application: single or small batches

Process: The softer less brittle materials can be scored with a sharp blade (roughly half the thickness of the material) and then snapped away from you for a clean break.
Popular materials cut by hand would be HIPS, ABS, PVC, PP, HDPE & PETG.

Finished edge: Can leave a sharp edge that may need scraping and consistency of cut can be an issue.

Cutting plane: varies

Trimming with a vertical band saw

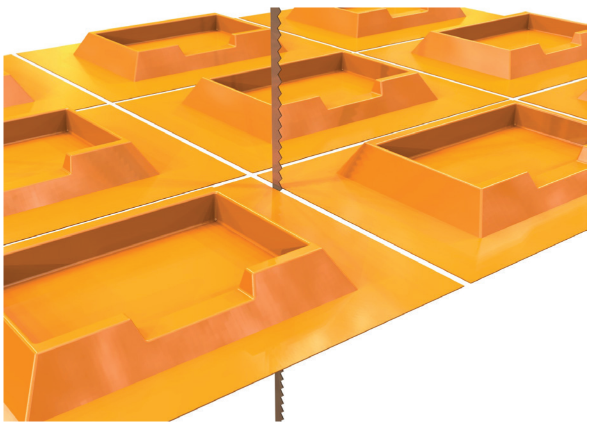
Application: single or small batches where trimmed edge is not critical.

Process: The band saw can be used for rough cutting or more accurately by using a fence or some form jig mounted on the table of the band saw. The band saw will cut all vacuum forming materials.

Finished edge: Leaves a slightly jagged edge that may need scraping and consistency of cut can be an issue.

Cutting plane: usually vertically by cutting into the surrounding waste material.

Stanley knife



Finishing and Trimming

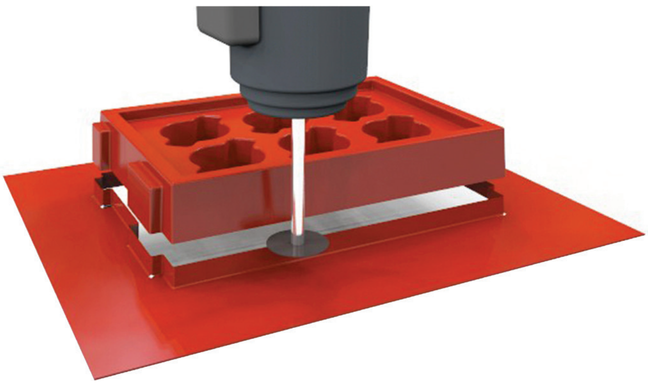
Trimming with a drill press and slitting saw

Application: single or smaller production batches where a decent edge and no flange is required.

Process: The vacuum forming is usually rough cut to remove the excess material and then located over a wooden holding jig for support. The side of the forming is then pushed into the rotating slitting saw and slit all around the circumference to remove the waste from the part you require. This method will cut most materials. The drill press needs to be set at 3000 RPM approximately to obtain the best cut.

Finished edge: Leaves a clean accurate edge that may need slight scraping on the one side only.

Cutting plane: usually horizontally by cutting into the side of the vacuum forming.



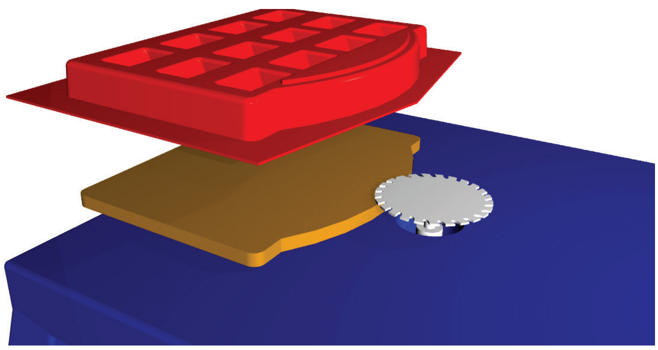
Trimming with an overhead or table mounted router with guide pin/bearing cutter/slitting saw

Application: production batches where a good consistent edge is required with a clean cut.

Process: The vacuum forming is usually rough cut on a band saw and then located over a holding jig. The forming is then pushed into the rotating slitting saw and slit all around the circumference. A guide pin mounted into the table or a bearing cutter will determine the path of the cutter as it travels along the edge of the holding jig. Typical router speed is 20000 RPM approximately which results in a very clean cut

Finished edge: Leaves a very clean accurate edge that often does not require additional cleaning.

Cutting plane: usually horizontally by cutting into the side of the vacuum forming or leaving a slight flange with a bearing cutter.



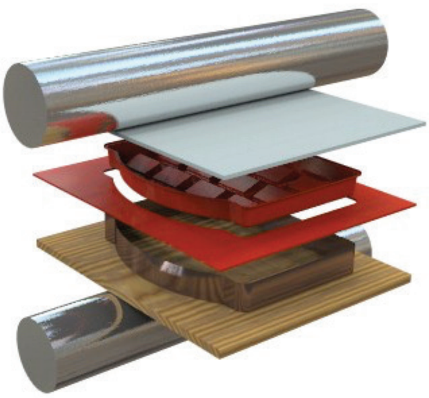
Trimming with a roller press

Application: production quantities for thin packaging trays and inserts (less than 1mm thick). This provides a clean accurate cut but usually a small flange is unavoidable.

Process: The vacuum forming is placed upside down into a custom made steel rule cutting die and a polypropylene cutting board placed on top. This is then fed through the roller press between the top and bottom rollers separating the waste material from the part. This method will cut most thin materials. It is not suitable for PMMA because it will tend to shatter.

Finished edge: Leaves a very clean accurate edge that does not require additional cleaning.

Cutting plane: Always vertically by cutting into the waste material around the base of the vacuum forming.



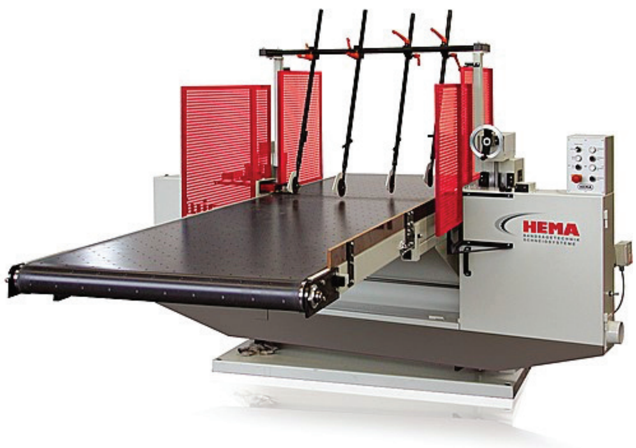
Trimming with a horizontal band saw

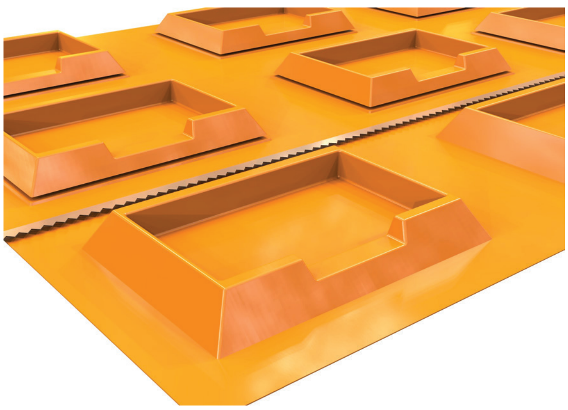
Application: production quantities for materials ranging from 0.5mm – 3.0mm in thickness.

Process: The single or multiple vacuum forming sheet is placed on the conveyor belt of the machine. As the vacuum forming is advanced through the machine the waste material is trimmed from the remaining part by a horizontal band saw blade. This method will cut most materials.

Finished edge: Leaves quite a reasonable edge, but it usually requires additional scraping to remove burrs caused by the sawblade.

Cutting plane: always horizontally by cutting into the side of the vacuum forming.





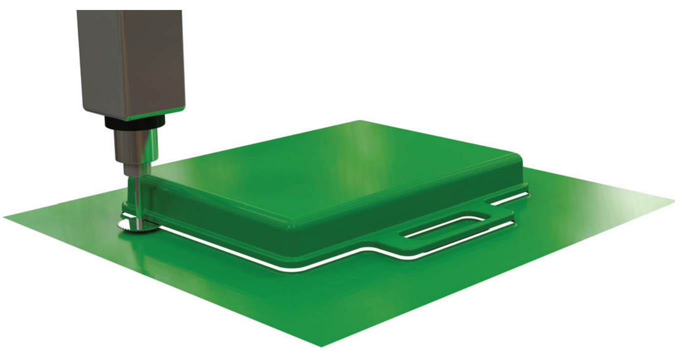
Trimming with a 3 axis router

Application: production quantities for vacuum formings that require a clean consistent accurate cut with apertures in the top face of the forming and trimming of the surrounding waste material.

Process: The rough cut vacuum forming is placed on a vacuum jig on the bed of the machine. The router head will usually rout all the apertures and slots in the top face and then trim with a slitting saw all around the circumference of the vacuum forming to remove the waste material. This method will cut most materials.

Finished edge: Leaves a very clean accurate edge that often does not require additional cleaning.

Cutting plane: X and Y axis for cutting into the side of the vacuum forming and the combined X,Y and Z axis allows for variation in height for top surface routing of the vacuum forming.



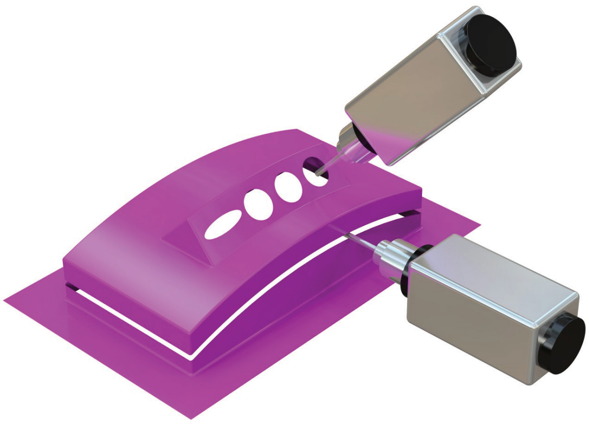
Trimming with a 5 axis router

Application: production quantities for vacuum formings that require a clean consistent accurate cut with apertures on all faces of the vacuum forming and trimming of the surrounding waste material.

Process: The rough cut vacuum forming is placed on a vacuum jig on the bed of the machine. The router head will usually rout all the apertures and slots and then trim all around the circumference of the vacuum forming to remove the waste material. This method will cut most materials.

Finished edge: Leaves a very clean accurate edge that often does not require additional cleaning.

Cutting plane: 3 axis for trimming on the X, Y, Z axis. 5 axis for additional trimming of slots and holes from all directions A + B.



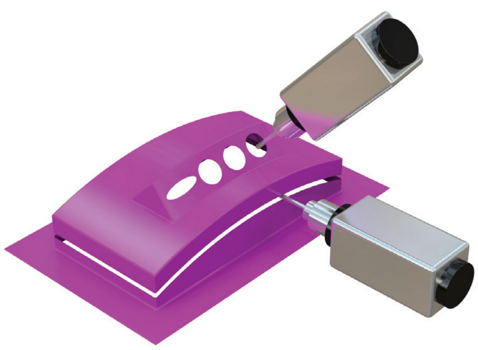
Trimming with a robot

Application: production quantities for vacuum formings that require a clean consistent accurate cut with apertures all faces of the vacuum forming and trimming of the surrounding waste material.

Process: The rough cut vacuum forming is placed on a vacuum jig on the bed of the machine. The robot head will usually rout all the apertures and slots and then trim all around the circumference of the vacuum forming to remove the waste material. This method will cut most materials.

Finished edge: Leaves a very clean accurate edge that often does not require additional cleaning.

Cutting plane: Trimming on the X, Y, Z axis + additional trimming of slots and holes from all directions A + B.



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.

Problem	Cause	Remedy
Blisters or Bubbles	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
Poor Mould Release	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
Sheet Scorching	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
Lack of Definition	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

Problem	Cause	Remedy
	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
		- Check the seal for wear
Webbing	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 radius 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
Whitening	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

Problem	Cause	Remedy
Chill Marks	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
Thinning at corners on deep draw parts	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 distri- bution	- Use plug assist and/or pre-stretch
Tearing of sheet whilst forming	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 radius and draw ratio
	Improper material selection	- Consult supplier
Parts stick in mould	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

Problem	Cause	Remedy
	Poor mould quality	- Polish mould
		- Use release agent
		- Remove rough edges from wooden moulds
Nipples on formed parts	Sheet too hot	- Reduce heating cycle - Reduce heat temp.
	Vacuum holes too large	Plug holes / re-drill
Excessive sag	Sheet too hot	- Decrease heat cycle time. - Decrease heater temp
	Sheet area too large	- Improve zone control
		- Ensure auto level feature activated
Marks on finished moul- ding	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 im- me- diatly prior to forming
Plastic pulls from clamp frame	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

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- Reducing Windows
- Spare Parts and Spare Parts Kit
- Drying Ovens
- Trimming equipment
- Tooling – Prototype and Production

Further Information

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
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Tel: + 44 (0)20 74 57 50 00
Fax: + 44 (0)20 74 57 50 45
www.bpf.co.uk

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