GCSE – GCE Transition

Product Design

Preparation Work

Read, recap and research

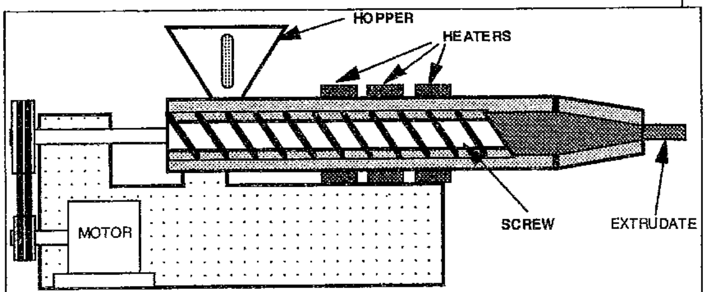
September 2020

MANUFACTURING TECHNIQUES

EXTRUSION

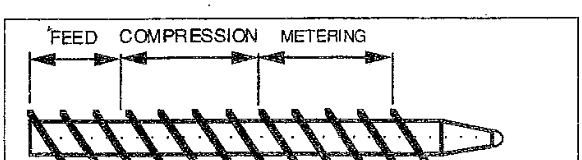
Sheets, films, profiles, rods or tubes are all extruded. Extrusion is a high volume, continuous production technique and uses a relatively unrefined (and inexpensive) raw material; plastic granules.

Granules are fed from a hopper into an archimedean screw rotating inside a heated barrel. The screw is designed to propel and control the polymer through three distinct stages:



Extruding machine schematic

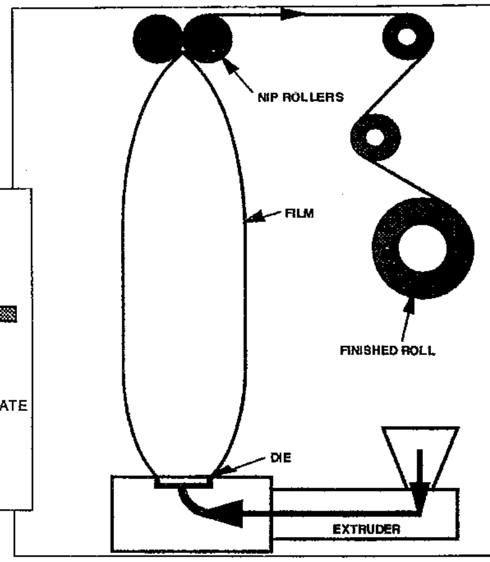
1. Collection and feed; forcing the polymer along the barrel towards the extruding die. The screw flights, at this stage, are quite coarse and widely spaced.
2. Compression, homogenising, mixing and purging. In the centre section of the screw the flights become shallower and closer together. The polymer granules are thoroughly mixed and refined by the shearing action of the flights and heated by both the barrel and the friction created by the screw. Air is purged and escapes through the hopper.
3. Metering. At the third and final section of the screw the flights are at their closest and shallowest, providing a controlled and consistent flow of dense molten material to the die.



The melt is driven through the die, adopts its shape and is quickly cooled by water, air or rollers (which can be used to mould a pattern or texture onto sheets).

To extrude tubes a torpedo shaped mandrel is located concentrically in a circular die. Sheets are extruded using either a wide narrow die or a large tube die with a cutter that slits the extrudate at the top so that it falls flat, eliminating the difficulty of uniformly maintaining the temperature over a wide, narrow die slot.

Tube extrusion techniques produce film for polythene bags and packaging. A small, thin walled tube is extruded vertically from a die and fed through a system of rollers, beginning at a point where it has cooled below forming temperature. Once the flow of



extrudate, through the die and onto the rollers, has been established, air is blown into the tube at the point at which it leaves the die - when it is still pliable - to expand it to the required size. This film tube is flattened, cooled and loaded onto its final reel by the roller system.

CELL CASTING

Cell casting and continuous cell casting (a high volume form of cell casting) is a second production technique available to acrylic. Cell Cast Acrylic does not have the same thermoforming properties as Extruded Acrylic.

A catalyst is mixed with a methylmethacrylate syrup and pumped into a blender where pigments may be added. The mixture is poured into a mould consisting of two vertical sheets of glass separated by a gasket, jointed at the top, whose width determines the thickness of the sheet. When the mould is full the gasket joint is sealed, the mould is laid horizontal and placed in an oven for polymerisation, or 'curing'.

Curing time per mm increases with overall sheet thickness:- a 3mm sheet may take 8 to 16 hours to cure (2.6 - 5.3 hours per mm) a 4 inch sheet will take 4 weeks (6.7 hours per mm).

Consequences of the production technique are:

1. Gravity causes pigmentation to settle nearer the lower face of the mould, increasing concentration of pigment and reducing surface quality. The "good face" is identified by either a clear (polyethylene) or printed (paper) protective layer. This face should always be fabricated as the dominantly visible surface.

2 Production is in relatively small batches of 15 - 19 sheets - making colour changes easy. Up to 3,000 different colours and shades are typically available and a further 2,000 have been produced and discontinued.

3 Cell casting is reasonably labour and time intensive making cast acrylic more expensive than extruded.

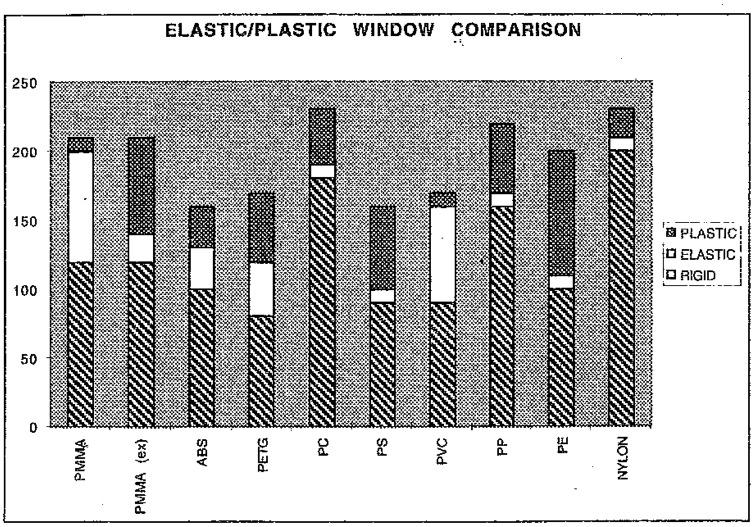
It is relatively easy to identify cast acrylic; any unusually or individually coloured, glossy thermoplastic sheet is probably cell cast acrylic - if it makes a fizzing noise and doesn't drip when on fire, it could well be cast acrylic.

THERMOFORMING PROPERTIES

All thermoplastics go through two distinct phases as they are heated.

At first they become what is known as 'elastic'; the material is springy, like a rubber band, with an element of tensile strength which gives it a reasonable resistance to forming.

As the material is heated further though, it will become what is known as 'plastic'; the material is soft and malleable, like dough, and can easily be formed.



The temperatures at which TP's become elastic or plastic depend on the material type.

As you can see from the above chart, some TP's have a large temperature range during which they are either elastic or plastic. This is useful for thermoforming, either when carrying out a process such as line bending using a radiant element which has hot and cold spots along its length, or dome blowing, where the sheet has to be transfered from an oven onto a dome blowing unit, exposing it to the cooling effects of the air before it is formed; the wider the thermoforming window, the more time you have to do this.

The characteristics of each material's elastic/plastic phase are also unique. Cast Acrylic and PVC both have large elastic windows but behave differently within them. PVC's elastic condition is weak enough for high definition vacuum forming but Cast Acrylic's is not.

PLASTIC MEMORY

TP's ability to regain form is known as 'Plastic Memory' and is another of the material class's properties that has found a number of useful applications. For example:

i Graphics for illuminated, vacuum formed signs like the ones used on shop fronts and garages, can be applied prior to vacuum forming. The design is painted on to a blank vacuum forming which is then heated to recover its original flat shape. The design shrinks along with the material and the new distorted image is printed onto flat sheets which are then vacuum formed, emerging from the process, printed and ready for use.

ii Heat shrink sleeves are extruded as a small tube, heated, expanded and cooled. They shrink back to their original size when re-heated.

HYGROSCOPY

All plastics absorb moisture to varying degrees and this effects the way they behave when heated.

Moisture forms tiny bubbles of water which, when a thermoplastic is heated, turn to steam and expand.

In plastics that have mostly elastic windows, this has no effect, as the tensility of the material resists the pressure of the steam bubbles.

However in plastics that have mostly plastic windows, the steam causes the moisture bubbles to expand and where the bubbles are near the surface they may burst, forming blisters, ruining the surface quality of the sheet.

This characteristic must be understood before heating to avoid confusing hygroscopic blisters with burning. Generally, if a material has blistered but maintains its tensility, then it is hygroscopic blistering and the material will require pre-drying before heating.

Pre-drying hygroscopic TPs with predominantly plastic windows, removes the moisture content relieving the problem of blistering during heating.

Note: PP absorbs so little water that it is effectively, non-hygroscopic. It floats in water and would normally be specified instead of nylon for underwater bearings (whilst nylon is an excellent bearing material it is one of the most hygroscopic TPs).

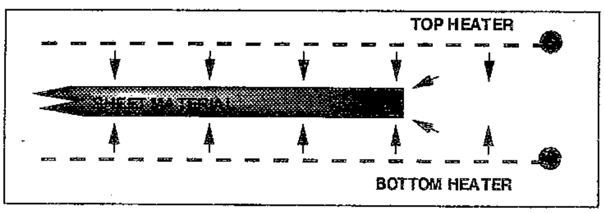
WORKING WITH TP MATERIALS

LINE BENDING

Line bending of TP sheet is normally carried out when the TP is in its elastic state, using a strip heater to heat a line in the sheet, then folding and placing in a jig to cool. There are three types of strip heaters in common use:

1.THE HOT WIRE STRIP HEATER uses tensioned hot resistance wires that are heated by passing an electric current along them. Hot wires emit heat consistently along their length and are straight (providing there is enough tension) so the same amount of heat is delivered to the same point all the way along the bend line - which is important if a TP has a narrow thermoforming window; ie. you want the whole bend line to reach the same thermoforming temperature at the same time. The ends of a bend line can receive more heat because the edge gets heated as well as the surface - some TP's may need 'shielding' with pieces of scrap material at either end of the bend line, to prevent overheating and damage to the ends of the bend.

2. THE CONTACT STRIP HEATER uses heated blades in various sections (pointed, rounded, flat). It is particularly effective on thinner materials but, can be used on thicker materials too. Materials



that thermoform mostly in the plastic window, may experience pressure marks or sticking to the blades. The consistency of heat emission depends on the consistency of the heat source. Contact heater blades tend to be cooler at the ends of the bend line which can cause problems for some TP's as the middle section of a bend may overheat before the ends reach thermoforming temperature.

3. THE RADIANT ELEMENT STRIP HEATER uses a coiled electrical element. Disparities in the heat emitted along the length of these heaters makes them suitable for only a limited number of TP's.

VACUUM FORMING

Vacuum forming is normally carried out when the TP is in its plastic state. The more plastic a TP is when vacuum formed, the better the definition will be. There are many different types and sizes of vacuum forming machine available.

OTHER FORMING TECHNIQUES

FREE DOME BLOWING: Smooth, uniform and virtually hemispherical domes can be blown from sheets, with air pressure of about 0.6bar (10psi) (larger domes or blown shapes need less pressure because the extension per unit of area is less).

DRAPE FORMING: The material's own weight provides the pressure for this type of forming which, as the name implies, involves laying heated sheets onto curved, concave or convex, moulds. The moulds are covered in green baize or mould cloth or greased to minimise marking.

PRESS MOULDING: With a male and female mould and mechanical pressure.

EXTRUSION: Material is driven through a die to produce a section.

INJECTION MOULDING: Material is driven through a nozzle into a mould to produce a product.

DIP COATING: Metal objects are heated and dipped in air-fluidised TP powder which evenly coats the object.

ROTATIONAL MOULDING: Granules are placed in a mould which is then heated whilst being rotated on two perpendicular axis so that the granules evenly coat the inside of the mould. The resulting product will be hollow.

CUTTING

Traditional woodworking tools - circular saws, routers, jig saws and band saws, with fine pitch blades to reduce chipping, are used for cutting out.

Hand saws, fret saws, vibrating saws or hack saws can be used in the school workshop. Score breaking can be done with thinner sheets.

CNC routers and laser cutters are used by commercial fabricators. The router produces an even matt finish to the edge of the material while the laser cutter has a polished finish. However, the lazer cutter puts stress into the material and rounds the corners.

Some of the thinner and less brittle TP's such as ABS or PP can be cut on a guillotine, as long as the edge finish is not important.

EDGE FINISHING

Edge finishing techniques vary from buffing to liquid metal polishing compound, flame and diamond cutter polishing. Every method apart from diamond edge finishing, requires the edge to be prepared with abrasives (such as 'wet and dry') or scraped with a metal edge. Stress can be induced by the heat of flame polishing and post annealing is recommended.

DRILLING

Holes can be drilled using HSS twist drills ground to a 130° point with zero rake, lubricated with water or soluble oil.

Holes can be tapped with standard taps and dies, but, coarse threads and rounded profiles work best and lubricants should be used.

MACHINING

Machine turning, milling and engraving can be done with most TP's.

JOINTING

There are three main ways of jointing TP's:

Cementing using solvent adhesives, such as dichloromethane, chloroform, methyl ethyl ketone (MEK), acetone, or methylene dichloride (in different combinations depending on the material). Different solvents or solvent combinations will be appropriate for different TP's and it is best to consult the technical literature of the material manufacturer before deciding which ones to use. Dissolving chips of the material being bonded in the solvent is sometimes recommended. Care and expertise is necessary to avoid making a mess! Take your time, mask the job properly and get hold of the right solvent applicators (the best ones come with a pipette in the lid of their container).

Welding. Hot air, ultrasonic, vibration, spin and hot plate technologies have all been developed for TP's. If a filler material is being used (like the rod in hot air welding) it must be made of the same material as that being welded (so that it 'melts' at the same temperature).

Mechanical fixing works best with TP's that have high tensile and impact strength so that they can withstand the loads imposed at the bolting, screwing or rivetting points - which should always be minimised by using large washers or countersinking. Stress relief is essential to prevent cracking and crazing at the joints.

STRESS RELIEVING

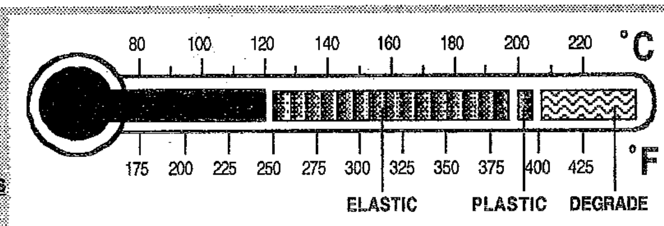
Stress can be created by forming, cementing, welding or flame polishing and manifests itself as crazing and cracks which can appear any time after a stress inducing procedure is carried out - hours, months or even years after. Annealing before cementing, after forming or when a product is finished, reduces the stress imposed on a material and prolongs product life.

SOME COMMON TP'S AND THEIR PROPERTIES

Note: The information contained in the following tables has been accrued through our experience of TP's and thermoforming. It is intended as a rough guide to TP materials and not as a comprehensive listing of TP's on the market (this task is beyond the scope of these data sheets as there are, for example, 138 types or grades of PMMA listed on the Plastics Network at the time of writing, and 839 types or grades of PE! And new materials are being developed all the time).

CAST ACRYLIC (PMMA)

Heating/Thermoforming Characteristics



General More colours are available in this TP than in any other because of its production technique. It has a broad thermoforming heat band that is mostly elastic (see chart), is readily solvent cemented, is more transparent than glass, has reasonable tensile strength (shatter proof grades are available) and good UV and weather resistance. Trade names include Perspex, Plexiglas and Lucite.

Applications baths, signs, aircraft canopies and windows, caravan windows, secondary glazing, display and point of sale, guards, roof lights and domes, pick'n mix bins, aquariums, roadside noise pollution screens.

Line Bending Heaters - all types. Pre-drying - never needed. Because of its large elastic window (70°C) it is easy to heat long sections to the elastic state, making cast acrylic the easiest and most forgiving TP to fold.

Vacuum Forming Only gentle contours with large radii, such as acrylic baths are possible because of it's small plastic window. If small areas of high definition are required, vacuum forming can be used in conjunction with pressure forming (using a highly polished former).

Other Forming Techniques Free dome blowing, drape and press forming.

Machining Cutting and Finishing All techniques work well with cast acrylic.

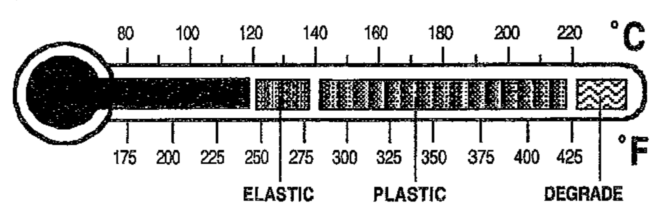
Stress Relieving Anneal at 80°C (176°F).

Jointing

- **Cementing**: A number of solvent adhesives are available, some having an acrylic filler suspended in them. Acrylic can be joined to metals, such as aluminium, with silicone compounds.
- **Mechanical fixing**: Possible with care, although bolted parts can be subject to cracking.
- **Welding:** It is not feasible to weld acrylic because the stresses caused ruin the optical quality of the material).

Identification High optical quality and surface finish with a huge colour range (interesting, unusual or translucent colours). It is springy when heated and if it is burned, it crackles, does not drip and releases a fruity odour.

EXTRUDED ACRYLIC (PMMA)



Heating/Thermoforming Characteristics

General Extruded Acrylic is made from the same monomer as Cast Acrylic, but the different production process gives it some different characteristics. Colours are limited - generally clear, smoked or pastel shades. It has a broad thermoforming heat band that is mostly plastic (see chart), is about 20% cheaper than Cast (because production is less labour intensive) and has slightly inferior impact resistance and optical and surface qualities but, similar UV and weather resistance. Trade names include Perspex TX.

Applications Display and point of sale, headlight lenses, cups and beakers, kitchen products.

Line Bending Heaters - all types. Pre-drying - not needed. The bend ends may stretch and spread, spoiling the aesthetics of the product and contact heater blades may leave pressure marks or stick to the material in places.

Vacuum Forming Good quality, high definition. Pre-drying is essential.

Other Forming Techniques Free dome blowing, drape and press forming are possible but, have to be done in the elastic window which means heating of the sheet has to be accurate and there is less time than with Cast Acrylic for transferring the sheet from the heater to the forming unit, clamping in position and applying pressure. With dome blowing, irregular, asymmetrical shapes will result if forming is attempted in the plastic state.

Machining Cutting and Finishing Machining is more difficult than with Cast Acrylic because cutting tools heat the material to its plastic state, and then get clogged by hot, soft, sticky chips of material.

Prone to shattering if not stress relieved. Flame polishing is difficult because of the narrow elastic range and surface degradation will occur easily.

Stress Relieving Anneal at 80°C (176°F)..

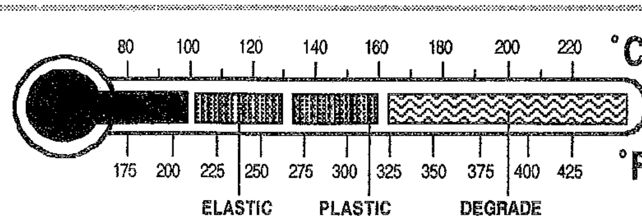
Jointing Cementing; a number of solvent adhesives are available, some having an acrylic filler suspended in them. Acrylic can be joined to metals, such as aluminium, with silicone compounds.

Mechanical fixing; works well.

Although it is technically possible to weld acrylic, it is not practically feasible because the stresses caused will ruin the optical quality of the material.

Identification Not as transparent as Cast Acrylic, so the edge of a clear sheet will have a bluish tint. A limited range of colours (clear, smoked or pastel shades). Bubbles form when it is heated over 140°C (unless it is pre-dried). It burns quietly and drips.

ABS
(AcrylonitrileButadieneStyrene)



Heating/Thermoforming Characteristics

General A durable thermoplastic, resistant to weather and some chemicals. It is used in many applications and is particularly popular for vacuum formed components. A limited colour range of black, grey or white is enhanced by the availability of leather grain textures. It is a rigid plastic with rubber like characteristics (Butadiene (its middle component) is also used in the production of synthetic rubbers) which gives it good impact resistance.

Applications Dinghy hulls, telephone handsets, domestic appliance housings, car dashboards, domestic waste systems and rainwater goods, compressed air lines, smart cards.

Line Bending Heaters - all types. Pre-drying - not needed. The thermoforming temperature is quite low (starting at about 100°C) so heating times are relatively quick.

Vacuum Forming Good quality, high definition. Pre-drying is essential. Gives off a hot rubber smell (the butadiene evaporating) during heating.

Other Forming Techniques Free dome blowing, drape and press forming.

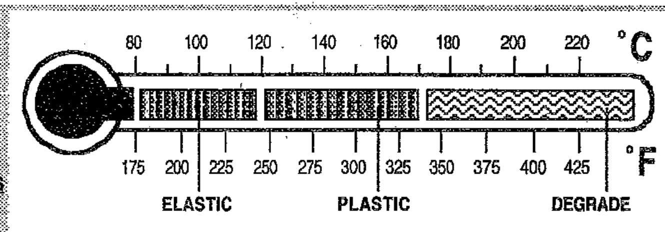
Machining Cutting and Finishing Cutters need to be keen and using a soluble oil coolant or lubricant is essential. Guillotining up to about 3mm is feasible. Edge finishing is not really an option.

Stress Relieving Due to its 'rubber' content, ABS suffers little stress and doesn't need to be stress relieved.

Jointing Cementing; proprietary solvent cements are available, usually based upon ABS particles dissolved in MEK. Welding works well because of ABS's resistance to stress. Mechanical fixing works well because of ABS's tensile strength.

Identification Burns, but is self-extinguishing and does not drip. Smells of rubber and produces black smuts.

PETG
(PolyethyleneTerephthalateGlycol)



Heating/Thermoforming Characteristics

General Many of the properties of PMMA, temp. resistance & durability similar to PVC, impact resistance similar to PC.

Applications Point of sale retail displays, signs, vacuum formed products, drinks bottles, smart cards.

Line Bending Heaters - all types. Pre drying - not needed. With a reasonably sized and relatively low elastic window, PETG folds easily and quickly with good aesthetic results.

Vacuum Forming Good quality, high definition. Pre drying is never needed. The low thermoforming window of 130-140°C (260-280°F) means that it vacuum forms quickly.

Other Forming Techniques Dome Blowing, Press and Drape Forming.

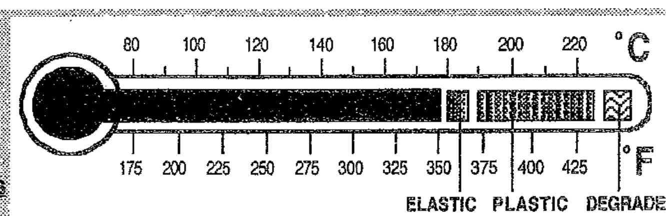
Machining Cutting and Finishing All techniques - tools should be keen, lubricants or coolants may need to be used.

Stress Relieving Anneal at 60°C.

Jointing Proprietary solvent cements are available. Welding is possible but the stresses caused are usually big enough to cause aesthetic and structural problems. Mechanical fixing.

Identification Grey tint to the edge of clear sheets. Burns silently with thick black smoke, drips, self extinguishes leaving a sooty residue.

POLYCARBONATE (PC)



Heating/Thermoforming Characteristics

General A dense TP with high impact resistance and superior fire rating, available in a number of forms and sections, including sheets. Limited colours, clear, smoke shades plus a variety of embossed textures. Good weather and UV resistance, with transparency levels almost as good as acrylic.

Applications Riot shields, security screens, compact discs, helmets, vandal-proof shelters, signs, aircraft panels, bumpers, telephone kiosks, light diffusers, skylights, guards, visors, smart cards, spectacle lenses, computer casings.

Line Bending Heaters - hot wires. Pre-drying is needed if attempting to fold using contact or radiant element heaters. Double sided heating is essential for thicknesses over 3mm. The ends of the heating line will blister unless shielding is used. It is possible to cold bend sheets up to 4mm, using sheet metal folding equipment. Some 'spring back' has to be allowed for though and annealing becomes essential because of the amount of stress inflicted.

Vacuum Forming Good quality, high definition. Pre-drying at 120°C (248°F) is essential. Drying times are long because of the material's density (see table) and material should be used soon after drying as moisture will start to be re-absorbed immediately (in humid conditions, blisters can occur in material that has only been out of the dryer for 4 hours!). High thermoforming temperature means that heating times will be long.

Other Forming Techniques Press and drape forming.

Machining Cutting and Finishing All the techniques can be used but, tools must be keen. Guillotining and punching up to 4mm (0.14"). Diamond edge polishing works but, will blunt the diamonds very quickly. An alternative method of edge finishing is heating Methylene Chloride to around 40°C (104°F) and polishing with the resulting vapour, directed at the edge through a hose.

Stress Relieving Anneal at 80-100°C (175-210°F). If stress is present and the material comes into contact with certain solvents (such as Tipex thinners) it will disintegrate almost immediately.

Jointing Proprietary solvent cements are available, usually based on polycarbonate particles in Methylene Chloride.

Welding is possible but the stresses caused are usually big enough to cause aesthetic and structural problems.

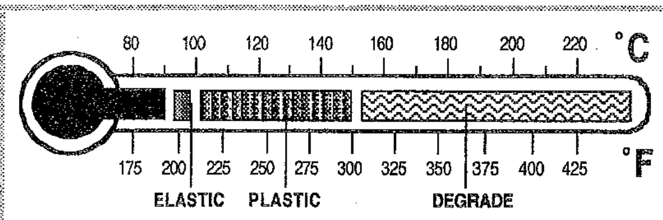
Mechanical fixing works well.

Can be fixed to other materials such as metal, glass, wood and thermosets using adhesives or silicone compounds.

Identification Moisture blisters occur if heated without pre-drying. Burns, but is self-extinguishing and does not drip - gives off a phenol smell. Highly resistant to impact (dents but does not split or shatter). Grey brown tint at the edge of clear sheets.

POLYSTYRENE (PS)

Heating/Thermoforming Characteristics



General Probably the second most common TP in everyday use. High Impact Polystyrene (HIPS) is a polystyrene and polybutadiene mixture that has much better impact resistance than normal polystyrene (and is more expensive). Poor resistance to UV light.

Applications Toys, light fittings, computer and office equipment housings, radio buttons, car fittings, disposable items, vending cups, freezer and refrigerator linings, display bases, packaging trays, low cost injection mouldings, bath panels, domestic appliance housings (hairdryers, blenders, etc), food packaging.

Line Bending Heaters - all types. Pre-drying - never needed. Virtually non existent elastic window means that bending is always carried out in the plastic window, making the bend characteristics difficult to predict but bending itself very easy.

Vacuum Forming Good quality, high definition - one of the easiest, fastest (due to low thermoforming temperature) and most forgiving vacuum forming materials. The protective film can be left on during forming and trimming, protecting the surface quality.

Other Forming Techniques Extrusion, injection moulding, press and drape forming.

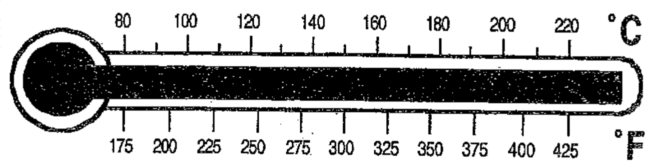
Machining Cutting and Finishing All techniques are suitable, tools must be keen.

Stress Relieving Very prone to stress (coloured material turns white when it is cold bent). Anneal at 60-80°C (150-175°F).

Jointing	Proprietary solvent cements are available. Carbon Tetrachloride and acetone can be used as solvent mediums. Be careful to select the correct adhesive as some of the more volatile compounds will dissolve polystyrene, which has a low resistance to solvent attack.	Welding is possible but the stresses can cause aesthetic and structural problems.	Mechanical fixing is okay.
Identification	Drips as it burns, producing black smuts and a marigold odour.		

PTFE (PolyTetraFluoroEthylene

Heating/Thermoforming Characteristics



General The ultimate material for low coefficient of friction, high temperature performance (softens at over 300°C) - almost completely chemically inert.

Its non-stick properties stem from the fluorine elements repellent tendencies when it is part of a molecule. These tendencies are such that the molecules on the surface of PTFE repel the molecules of almost anything that comes close to it, rather like opposite poles of a magnet.

Available as rod, sheet, tape and tube.

Due to its extremely high melting point, it is not practical to thermoform PTFE

Applications Non-stick pans, low friction coatings, high temperature cable insulation and bearings, artificial body parts, stain-resistant carpets, pipe joint sealant (works as a mechanical aid rather than a sealant, its non-stick properties enabling the joint to be made tighter using the same amount of force). 50mm thick heat sheild on Appolio CM.

Machining Cutting and Finishing All techniques are suitable.

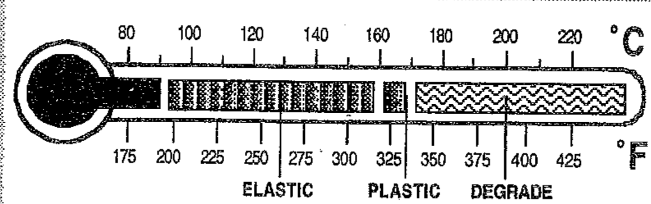
Stress Relieving Not prone to stress.

Jointing Mechanical fixing

Identification Heat it to 290°C and see if its still rigid.

PVC (PolyVinylChloride)

Heating/Thermoforming Characteristics



General Extruded or laminated, PVC has good resistance to chemical and solvent attack, second only to polypropylene. Its vinyl content gives it good tensile strength and some grades are flexible (hence it's suitability for the textile industry). Coloured or clear material is available (the clear material has a blue tint, clearly visible at the edges of sheets). Resistant to water and fire (as it burns it releases chlorine atoms which inhibit combustion) and reasonably impact resistant, it is the leading TP in the construction industry.

Applications Pipes (rain/water/sewerage), pipe fittings, hosepipes, footware components, leathercloth, adhesive tapes, toys, cable insulation, ducting, shower curtains, architectural claddings, floor coverings (linoleum), windows and doors, waterproof clothing, smart cards, food packaging, medical goods and packaging, chemical tanks.

Line Bending Heaters - all types. Pre-drying - never needed. Flexible nature makes it very resistant to thermal stress so stress crazing is never a problem.

Vacuum Forming Reasonable quality, fair definition - the heating properties of PVC are mainly elastic but, the elastic window is weak and more characteristic of the plastic state which makes vacuum forming possible, particularly on thinner sheets. Vacuum forming grades are available which have even weaker elastic windows than standard PVC.

Other Forming Techniques Free dome blowing, press and drape forming.

Machining Cutting and Finishing Tools must be keen, and the use of lubricants, coolants or air is sometimes necessary. Thicknesses up to 4mm can be guillotined (warm the material to 40°C (104°F) if it cracks).

Stress Relieving Not particularly prone to stress but, can be annealed at 60-70°C (140-160°F) if it is causing concern.

Jointing Some proprietary solvent cements are now available (their development has been slowed by PVC's inherent resistance to chemical attack).

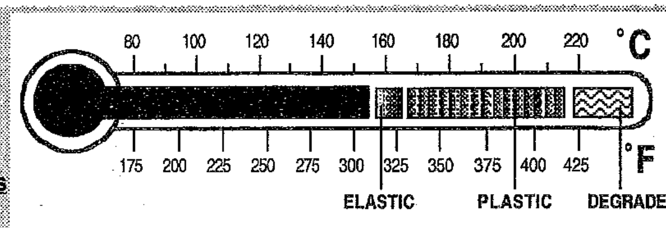
Hot Air welding works well and is largely used in PVC's more utilitarian applications like ducting and chemical tanks. The more sophisticated ultra-sonic welding is used in applications like the manufacture of PVC waterproof and protective clothing.

Mechanical jointing

Identification Blue tint to cut edges. Burns, but is self-extinguishing and has a green element to the flame - gives off an acrid smell (which is the chlorine).

POLYPROPYLENE (PP)

Heating/Thermoforming Characteristics



General Extremely chemically resistant and almost completely impervious to water, it has been extensively used for chemical containers and other tough, industrial applications. More recently it has been finding favour in the home as dishwasher proof utensils, dishes and children's outdoor toys, and the office as brightly coloured and tough stationary. Black has the best UV resistance and is increasingly used in the construction industry.

Thermoforming range is mostly plastic and gets progressively weak with heat. At the top of its range it is almost fluid, like candle wax. White sheets will go clear as soon as they reach the plastic state.

Does not get stressed. Making an impression in a line in a sheet, produces a fold line that will act as a hinge without any material fatigue.

Applications Pipes, pipe fittings, bottle crates, chemical tanks, cable insulation, indoor & outdoor carpets, battery boxes, marine ropes & warps, underwater bearings, storage bins, bottles, dishwasher safe food containers, stationary, petrol cans, toys, lintel covers, disposable cups, patio furniture, household appliances.

Line Bending Heaters - hot wires. Pre-drying is never needed. The predominant and progressively weak plastic state can make line bending tricky. Single sided heating leaving 1mm of material in its rigid state to use as a hinge, works well. Bending the wrong way (ie: with the broader heated face on the inside of the bend) causes a bead of material to form along the inside which acts as a weld, increasing strength. Contact heaters with one 'V' shaped PTFE coated blade for grooving the inside which again, will weld together on folding (uniform heat output is essential) also works well.

Vacuum Forming Very good quality, exceptionally high definition. When using unpigmented, white sheet, vacuum form the sheet as soon as it goes clear. For pigmented sheets, observe the sag of the material as it heats up. Remember that polypropylene's mechanical strength diminishes with heat, so it's important to heat as evenly as possible to avoid excessive sagging which can cause webbing on the final forming.

Commercial vacuum formers have a magic eye that monitors the sagging and injects a slug of compressed air into the chamber underneath the sheet, to support it when the sagging becomes too pronounced.

Other Forming Techniques Injection moulding, rotational moulding.

Machining Cutting and Finishing All techniques are suitable. Can be guillotined up to 6mm.

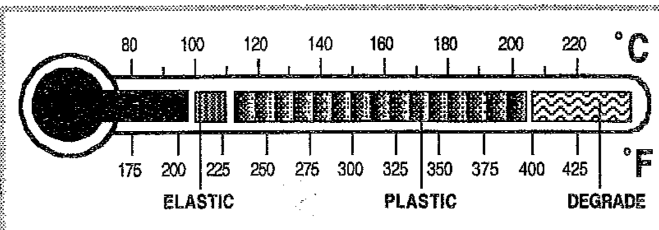
Stress Relieving Not prone to stress.

Jointing Because it is solvent resistant, polypropylene cannot be solvent cemented. Welding is possibly the most common method of jointing. Mechanical fixing.

Identification The only TP that floats! Making identification easy if you have a bucket of water handy. It burns silently with a yellow flame, producing molten, flaming droplets. Leaves a burning candle odour when extinguished.

Withstands repeated bending reversals without fracture.

POLYETHYLENE (PE)



Heating/Thermoforming Characteristics

General Probably the most common thermoplastic in everyday use. Low density polyethylene (LDPE) is the cheapest type, commonly known by its trade name; 'polythene'. It's thermoforming range starts at around 60°C (its most common thermoforming application probably being shrink wrap packaging).

High density polyethylene (HDPE) is more expensive and can be manufactured in a range of densities. The most dense is called Ultra High Molecular Weight Polyethylene (UHMWPE) and has been used, instead of Kevlar, to make bullet proof vests. As the density of PE increases, so does the heat needed to reach thermoforming temperature. Good chemical resistance. Some grades float in water.

PE is the base material for other common TP's such as Polyethylene Terephthalate (PET).

Because of the range of PE's available, it is difficult to say anything specific about its properties but, generally:

Applications Blow or injection moulded containers (household bottles & containers), packaging films, high frequency electrical insulation, dry 'ice' skating rinks, dustbins, milk crates, washing up bowls, pallets, toys, bullet proof vests.

Line Bending Heaters - hot wires. Pre-drying - never needed. Folds very easily but, contact heaters will easily mark the material.

Vacuum Forming Reasonable quality, fair definition.

Other Forming Techniques Dip coating of metal parts, injection moulding, blow & rotational moulding.

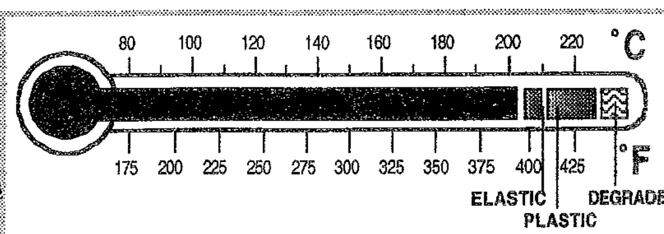
Machining Cutting and Finishing All techniques work well, tools must be keen and sharp.

Stress Relieving Not prone to stress.

Jointing Welding. Mechanical fixing.

Identification Not brittle, available in a variety of non-glossy colours.

NYLON (Polyamides)



Heating/Thermoforming Characteristics

General Most commonly used as a fibre in clothing and textiles, nylon is also a common engineering TP available in rod, tube, sheet and powder. Known as Nylon 6.6 or just Nylon 6. Both these nylons have high resistance to abrasion, low friction characteristics and good chemical resistance. They also absorb water easily and components in wet or humid conditions will expand, precluding their use in applications where dimensional stability is required. Aramids, including materials such as Kevlar (used in bullet-proof vests and sails) and Nomex (used in fire-proof clothing), are also part of the nylon family.

Nylon is found in hybrid forms such as glass reinforced nylon used in electrical components, handles, car parts and similar injection moulded products.

Applications Gears, bushes, cams, bearings, textiles, ropes, toothbrush bristles, bullet proof vests, sails, fire-proof clothing, weather proof coatings.

Other Forming Techniques	Dip coating of metal parts.
Machining Cutting and Finishing	All techniques are suitable.
Stress Relieving	Not prone to stress.
Jointing	Mechanical jointing.
Identification	Doesn't burn easily, when it does it bubbles quietly, drips and self extinguishes.

INTRODUCTION TO THERMOFORMING-
Local Line Bending

2

INTRODUCTION

Local line bending thermoplastic sheets has three stages:

1 Heating the sheet along the bend line to its elastic window using a strip heater.

Note: The best bends are produced when material is in its elastic state; the material retains enough tensile strength to maintain its form, producing uniform, aesthetically pleasing bends.

2 Folding the sheet, normally by hand, taking care to avoid contact with the heated area.

3 Securing the sheet in its folded position to cool, normally using some form of cooling jig.

HEATING A THERMOPLASTIC SHEET FOR LINE BENDING

As already mentioned in part 1, there are 3 types of strip heater commonly used for line bending:

1 Hot wire heaters

2 Radiant element or inconel sheathed element heaters

3 Contact heaters

In this section, we will look at each heater type in greater detail.

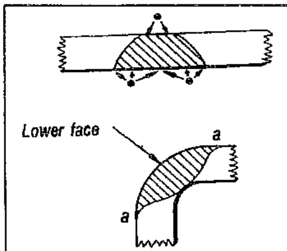
HOT WIRE HEATERS

Suitable for all thermoplastics, including PC, cast and extruded PMMA, PVC, PETG, ABS, PS, HDPE and PP.

When current passes through a resistance wire, every point along the length of the wire emits the same amount of heat.

If the wire is tensioned between two points then it will be straight between those points. The result is an extremely straight and uniform heat source. Add to this the ability to arrange wires alongside each other at distances as close as 1mm and you have the most ideal and versatile heating technique for bending thermoplastic sheets that has been developed to date. Lines as long as 3M can be heated with a negligable temperature differential along their length.

The amount of heat emitted can be controlled (by the voltage) so that material can be placed very close to the wire without burning. This has two benefits.



A typical hot wire heating configuration

Firstly, a very localised heating is achieved - similar to that produced by contact heating but without the contact.

Secondly, because most of the heat being generated is being used to heat the plastic, the rest of the machine remains relatively cool, removing the need for reflectors or water cooling. *(Note: water cooling can be used on a hot wire heater to reduce bowing along the bend line)*

Another advantage for clamping heaters is that the material can be clamped where it is cool, eliminating marks and blemishes.

Heat band widths can easily be controlled by arranging different numbers of wires along a bend line. In material over 3mm for example, bending times can be reduced and aesthetic properties enhanced if a wider heat band is applied to the outside of the bend. This can also help when making two opposing bends simultaneously in the same sheet.

RADIANT ELEMENT OR INCONEL SHEATHED ELEMENT HEATERS

Suitable for thermoplastics with a large elastic window, such as cast PMMA, PVC, PETG or ABS.

The heating element can have hot and cold spots along its length because of the way it is manufactured and the way it is fixed (brackets act as heat sinks).

When a sheet is heated parts of the bend line will be hotter than others. With a large elastic window this doesn't matter because the material will be elastic at say, 120°C as well as 150°C and fold just as well when parts of the bend line are at both temperatures.

If, however, the heating characteristics are mainly plastic, then some areas of the sheet will be ready to fold (ie. elastic) when others are too cool. By the time the cool areas are hot enough to bend, the areas that were previously hot enough, will have become too hot (ie. plastic - or even worse, degraded) and deform when folded, spoiling the look of the bend.

The elements generally consume a lot of power and produce a lot of heat which has to be directed and controlled either by reflectors or water-cooled work supports (or both), to prevent too much of the sheet being heated.

Radiant elements can be fragile and expensive to replace.

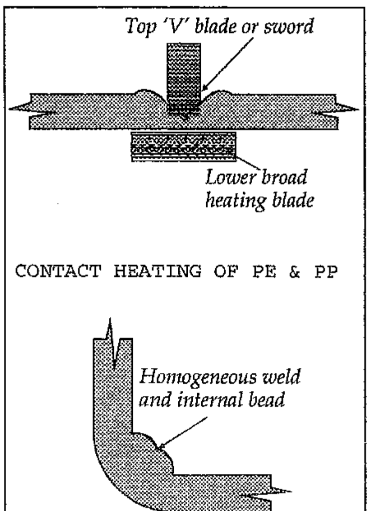
CONTACT HEATERS

Suitable for thermoplastics with a large elastic window, such as cast PMMA, PVC, PETG or ABS.

The material is heated by a blade or blades with integral heating elements, either mounted in groups on a machine or built as an individual and portable 'heating sword'.

Contact heating is particularly useful for very thin material because it is very accurate - the heat goes exactly where you put it. Unlike thicker material, where a wide heat band is required, on thin material you only want to heat an area one or two millimetres wide and this can be governed very accurately by the section of the contact blade.

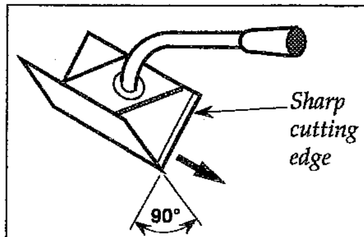
Generally we would say that only elastic materials are suitable because the blades will have a tendency to leave slight grooves in the sheet. Elastic material will recover its original shape using its plastic memory before it cools, whereas material in its plastic state will not recover and will be permanently blemished.



Bend section produced

Sometimes this can be an advantage, as in the case of PP and PE. To improve the speed of bending thick PP and PE sheets, a groove is sometimes routed on the inner face before bending. A 'V' shaped contact blade applied with enough force will form a groove during heating - removing the need for routing and speeding up the process even more.

When the sheet is folded, the material that has been displaced either side of the 'V' shaped contact blade will fuse together, forming what looks like a weld and increasing the strength of the bend (this 'weld' can be trimmed off with a bead trimming knife immediately after forming if it is not wanted).



Bead trimming knife

Note: Some form of PTFE coating is essential when contact heating PP to prevent the material sticking to the blades.

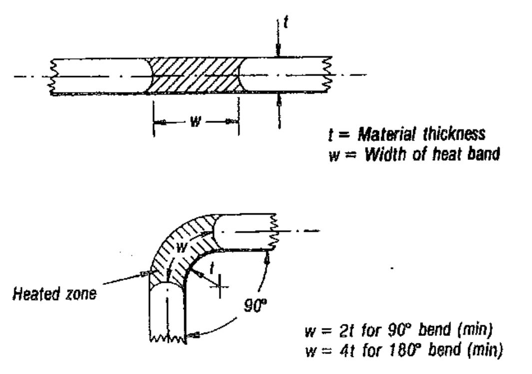
BEND CHARACTERISTICS

The style of a bend, depends mainly on the heat band width, which should be adjustable.

The heat band width determines the radius of the bend, and can be roughly calculated using the formulas below:

90° bend: Heat band = 2 x inner radius [inner radius must be greater than sheet thickness]

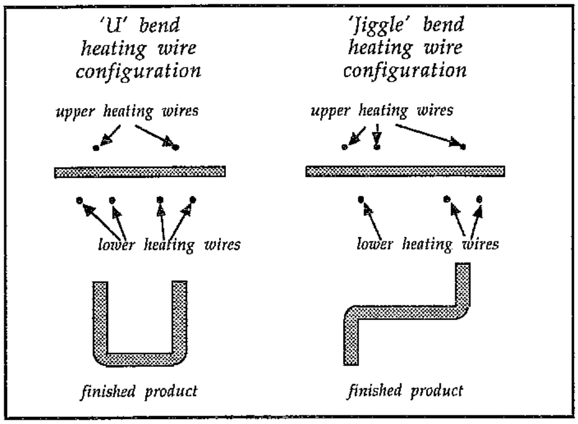
180° bend: Heat band = 4 x inner radius [inner radius must be greater than sheet thickness]



There is no limit to the radius you can give a bend but, large radii only work well with materials that can be folded in their elastic state.

DOUBLE SIDED HEATING

Heating a sheet from both sides can cut the heating time almost in half. Double sided heating with hot wire heaters also enables control of the



bend characteristics and produce opposing bends in single sheets simultaneously.

BENDING THE SHEET

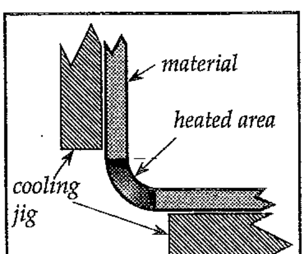
Folding is normally done by hand. There are strip heaters on the market that are equipped with folding apparatus but these are expensive. The folding work of most fabricators involves complex designs and large volumes, so the pieces are folded and loaded onto cooling jigs by hand.

The bend must never be touched when it is hot, even if you are wearing gloves. When it is hot, even if it is only in an elastic state, a sheet is vulnerable to pressure marks from hands and fingers. A hot sheet can be slightly tacky and dirt and fibres can stick to the heated line.

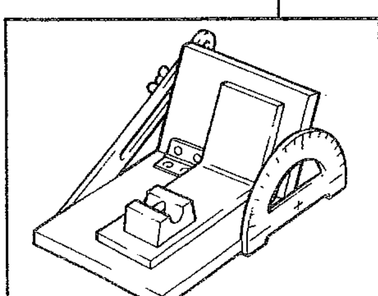
COOLING THE SHEET

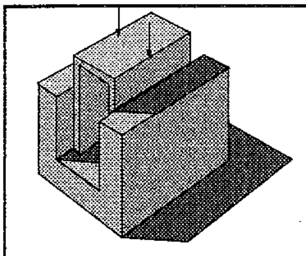
Most fabricators use wooden or composite board cooling jigs, some of them designed to be loaded with 50 pieces or more, held in place with soft jawed clamps if necessary.

When designing a cooling jig, it is important to remember that the heated bend should not come into contact with any other surface to avoid

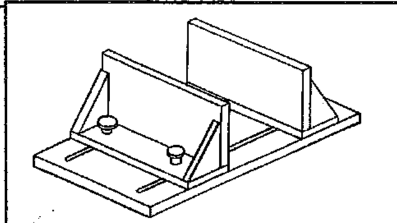


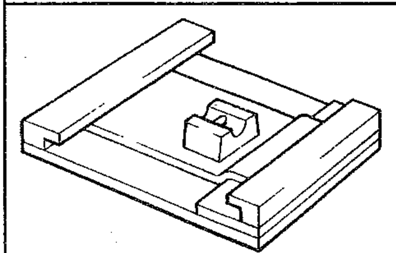
blemishes. The beauty of TP line bending is that only the bending line is flexible so in fact, a jig can be nothing


Adjustable 'protractor' jig to set angles


A dedicated 'U' bend jig accurately controls the outside dimensions

more than four nails in a board that stop the four corners of an angled sheet from splaying apart. But most fabricators have more complex requirements and invest a good deal of time designing jigs that will do the job cleanly and efficiently.


Adjustable right angle jig for 'U' bends, 'L' bends and 'tent' style products


'Jiggle' bend jig used for the manufacture of slat wall display products

Small returns which would be impossible to fabricate by hand can be made by placing the heated edge of the sheet into a slot and then folding the rest of the sheet back against the jig.

DISTORTION

Distortion can be a problem for fabricators. Multiple bends in close proximity, bends in narrow sections or bends near the edges of sheets all suffer from buckling during heating and bowing along the bend line when cool.

The problem arises because the line of heated material expands whilst the cool material either side of it does not.

During heating this can cause distortion which can be restricted by clamping the sheet.

When the sheet is folded, the bend line cools and contracts after it has become rigid again. This produces a bow as the bend line pulls the two ends of the sheet together.

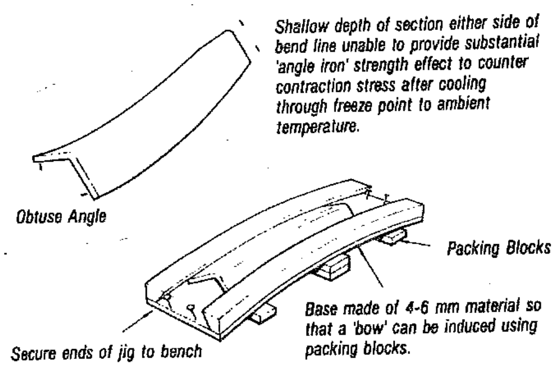
COUNTER BOWING

The effects of bowing can be reduced in a number of ways:

1 Keep bends well spaced and away from edges - if there is plenty of material either side of the bend it helps to restrict its movement.

2 Use minimum width heat lines.
3 Use water cooled heater beams to reduce the heated area.
4 Clamp in a straight cooling jig and anneal.
5 Cool in a counter bowed cooling jig.

A counter bowed cooling jig incorporates a bow in the opposite direction to the one expected in the material, the stresses induced in the bend line due to heating should pull the bend straight when removed from the jig.

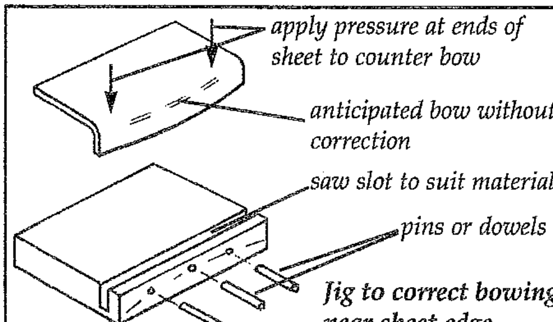


A long shallow item with little depth of section either side of the bend line to oppose stress

It is best to establish counter-stress measurements by experiment - a good place to start might be to measure the bow on a piece of material bent on a normal cooling jig and take if from there.

When producing multiple bends in close proximity there is a tendency for the stress produced by each bend to accumulate and compound the distortion which becomes progressively worse (if the bends are done one at a time).

It is better to use a multiple bending heater to make all the bends simultaneously so that the piece only picks up the distorting stresses from a single heating cycle.



Jig to correct bowing near sheet edge

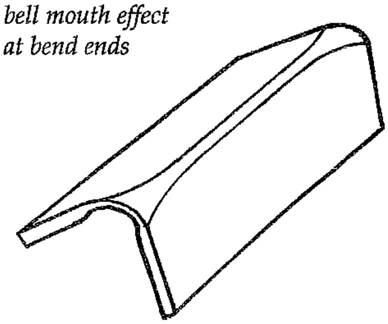
PS & PP

As already mentioned, bending TP's in their plastic state can lead to unsightly bends and 'bell mouth' ends - particular problems for materials like PS and PP - so following are a few things that can help.

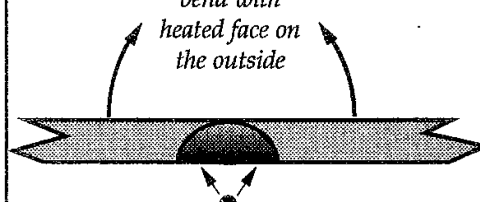
Avoid large radius bends; keep the heat band width to a minimum.

Heat from one side and keep the heating time as short as possible so that a very small area of the top face becomes flexible and hopefully, remains elastic.

Bend with the heated side outwards and a sharp, well defined bend with a minimum radius should be produced. (PP can be bent like this but, bending it the opposite direction works just as well, as a bead of material builds up on the inside of the bend in the same way as if it had been contact heated).



Characteristic spreading of bend ends when bending a material in its plastic state



Heat from one side only for thin polystyrene

INTRODUCTION TO THERMOFORMING- 3
Vacuum Forming

INTRODUCTION

Vacuum forming involves pushing a mould into a heated TP sheet and evacuating the air from between mould and sheet, so that atmospheric pressure pushes the sheet onto the mould, making the forming.

There are many different kinds of vacuum forming machine available from small, manually operated units to fully automatic, in-line production machines, but no matter what the differences between units might be, they are all variations on the same theme, ie:

1 The sheet is clamped in place on a heat proof air-tight seal.

2 The heater system moves under or over the sheet, or vice versa, and begins heating.

3 Once the sheet has reached it's thermoforming temperature the vacuum pump is energised.

4 The heater moves back to it's resting position (or the sheet moves from the heating position to the moulding position).

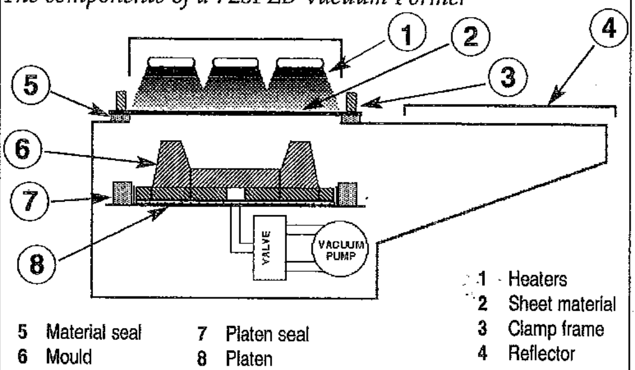
5 The mould, mounted on a moving platen, moves up into the sheet which drapes over it.

6 Once the platen reaches the top of it's stroke, the space between the underside of the sheet and the upper surface of the mould forms an air-tight pocket connected to the vacuum pump, which then pumps air from between the two. This removes air which is preventing atmospheric pressure from pushing the sheet down over the mould.

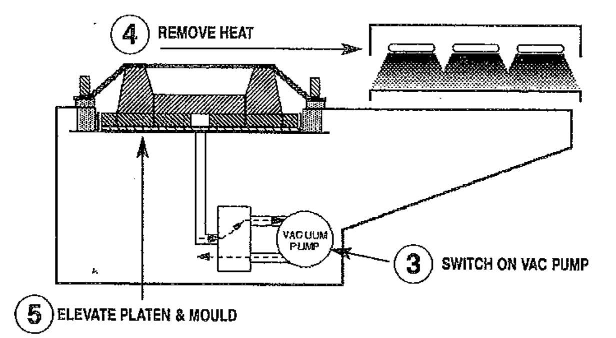
7 As the sheet cools it contracts, gripping the mould. Hence the next step is to reverse the airflow, using air pressure to force the forming off the mould and prevent it sticking, this step has become known as the 'blow cycle'. Blow cycles are short - just long enough for the forming to release from the mould - and immediately followed by another vacuum cycle.

8 Vacuum/blow cycling continues until the sheet is rigid once more. At this time, the vacuum is switched off or the mould lowered and the forming is released from the clamp.

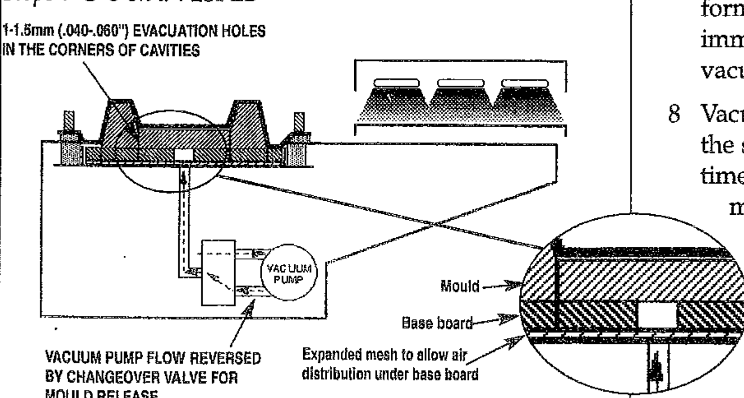
The components of a 725FLB Vacuum Former



Steps 3-5 on a 725FLB



Steps 7 & 8 on a 725FLB

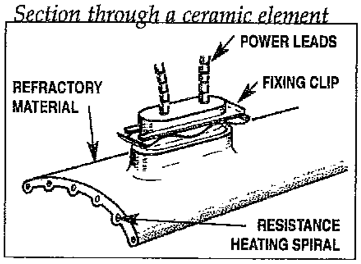


THE HEATER SYSTEM

Ceramic heaters are possibly the most common amongst vacuum forming machines. They consist of coiled resistance wire elements set in moulded china clay. Available in round, square or rectangular shapes, they can be flat (for maximum proximity) or curved (to provide a parabolic reflector which radiates more effectively).

The main advantage of ceramics is that they radiate long wavelength heat which is readily absorbed by TP's.

Section through a ceramic element



They can run at very high power outputs but the normal level for high performance vacuum forming is around 22.25 kw/sqm (2 kw/sqft).

Their only drawback is their high thermal mass, which means they take some time (10 - 15 minutes) to warm up and are slow to respond to energy regulation adjustments.

Quartz emitters are also used in vacuum forming and like ceramics, they have a coiled resistance wire element but housed in a quartz glass tube, rather like a bathroom heater. With much less thermal mass there is hardly any warming up time and the medium wavelength heat is more responsive to reflectors so that a greater percentage of heat can be projected downward.

The drawback of quartz emitters is that medium wavelength heat is not so easily absorbed by TP's as the long wavelength heat of ceramics.

HEAT ZONES

Heaters are arranged in a reflective hood in groups or clusters which can be controlled independently. This allows the operator to control the distribution of heat over the sheet which is useful, particularly for complex moulds (eg. fridge linings).

To determine what each individual heat setting should be, a grid is drawn on a sheet corresponding to the pattern of heat zones. A forming is taken and where there is excess thinning, heat output is reduced. Equally, heat output is increased in zones where definition is poor.

DOUBLE SIDED HEATING

For material thicknesses over 5 or 6 mm, single sided heating is usually too slow, and a double sided system is used. In such a system the sheet will normally move to the heating station, which is pressurised, so that the sheet can be supported by air as it sags to prevent it from sticking to the lower heaters.

THE PLATEN SYSTEM

Lifting the platen is an important part of the process as it needs to be done promptly and as quickly as possible so that forming takes place before the sheet begins to cool and go rigid.

On smaller machines it is done manually with a lever. Bigger machines need pneumatic, hydraulic or other mechanical systems because they have bigger, heavier moulds and bigger, thicker sheets which offer more resistance.

THE VACUUM SYSTEM

Vacuum pumps, appropriate to the size of sheet being formed and the volume of air being evacuated (approximately -0.83 bar [25 inHg]) should be an integral part of the machine.

The type of pump is important because most TP's give off vapours when they are heated which can corrode the delicate components found in some pump units, leading to reduced performance and ultimately failure.

THE BLOW CYCLE

When vacuum forming manually, it is best to make the first blow cycle as soon as the material has been drawn completely over the mould - it will still be soft over much of it's area but, if a short blow cycle, to break the material's grip, is followed by another vacuum cycle, the material will draw back down onto the mould and subsequent blow cycles can be shorter. It's important to keep the blow cycles as short as possible because they will put stress into the corners of a mould if they are done for too long once the material is rigid.

COOLING AND THINNING

As soon as the heated sheet makes contact with the mould, it will start giving up it's heat to the mould and becoming rigid again. This is why it is common to find vacuum formings with deeper material thickness at the top than the base; the material at the top cools first and stops stretching because it makes contact with the mould before any other part of the sheet. The material at the bottom of the mould is the last to cool so it's stretching for longer than other parts (see Heat Zones earlier).

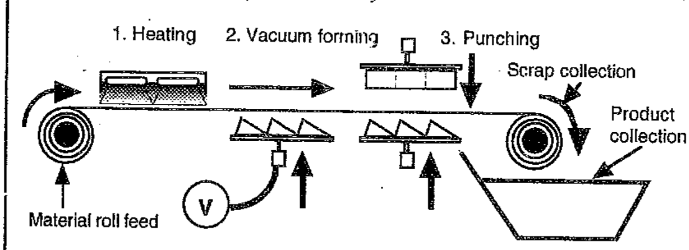
THERMOFORMING MACHINE OPTIONS

AUTOMATION

Any or all of the vacuum forming functions can be automated and indeed they are for most commercial production purposes along with some others, such as automatic cutting, stacking or counting.

For example, vacuum formed pvc sandwich packets are made 24 or so at a time on a large thermoformer. The material is fed from one roller, over the machine and onto a scrap collecting roller. The fixed heater heats an area of sheet at the same time as one batch of packets are being vacuum formed and the previous batch are being punched out ready for stacking and collection. Each cycle takes only seconds to complete and one machine produces thousands of packets each day. The heaters may not be set to work at their full capacity - to allow enough time for the thermoforming to be completed.

Schematic of a sandwich packet thermoformer



VACUUM/PRESSURE FORMING

The pressure exerted by ordinary vacuum forming is limited to atmospheric pressure which, for some applications does not produce enough definition. In such cases vacuum/pressure forming may be used. This technique involves a machine with a sealed pressure chamber over the top of the forming into which compressed air is pumped during forming thus increasing the pressure drawing the material down onto the mould.

PLUG ASSIST VACUUM FORMING

The depth of a forming is limited by the ability of the material to stretch into a long deep shape, such as a cup. Ordinary vacuum formers can only really vacuum form a depth of about half the diameter of a cup - any deeper and the material at the bottom becomes so thin as to be unusable. So cups and yogurt pots are made with machines that have a male mould which pushes the heated material into a female mould before vacuuming commences. This distributes the material more evenly over the mould thus achieving deeper draws.

PRE-DRYING

As we've already mentioned TP's absorb moisture which can lead to problems when vacuum forming -particularly Extruded Acrylic, ABS and Polycarbonate; these materials must be pre-dried before heating.

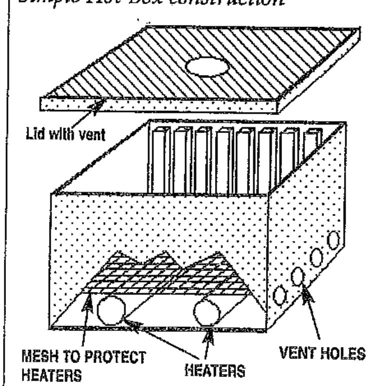
OVEN

Materials can be dried by placing them in a fan assisted oven at 40°C (70°F) below the start of their thermoforming temperature range for about 1-2 hours per mm of thickness. Polycarbonate generally takes longer than ABS or Extruded Acrylic and times will vary from batch to batch - depending on how much moisture has been absorbed due to the conditions that the material has been stored in.

HOT BOX

Alternatively, you can construct a simple hot box using plywood and a low power heater such as a greenhouse heater or even light bulbs. If sheets are stored in the hot box then (as long as they've been in there for more than a day or so) they will always be ready to use.

Simple Hot Box construction



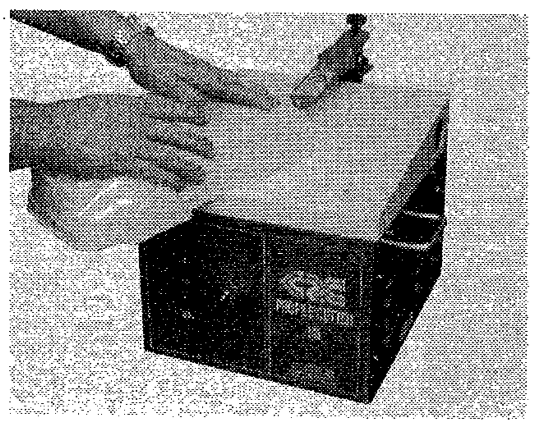
! SAFETY NOTE !
For safe operation ensure that heater power will not exceed 60°C (140°F)

MATERIAL REFERENCE CHART

Material	Pre-drying	Definition	Forming temp. °C(°F)
Polystyrene	NO	Good	120 (250)
Extruded acrylic	YES	Good	160 (329)
PVC	NO	Fair	130 (265)
ABS	YES	Good	159 (300)
Polycarbonate	YES	Good	200 (400)
Polypropylene	NO	Very good	180 (350)
Polyethylene	NO	Fair	120 (250)
PETG	NO	Good	120 (250)

TRIMMING

LOW VOLUMES

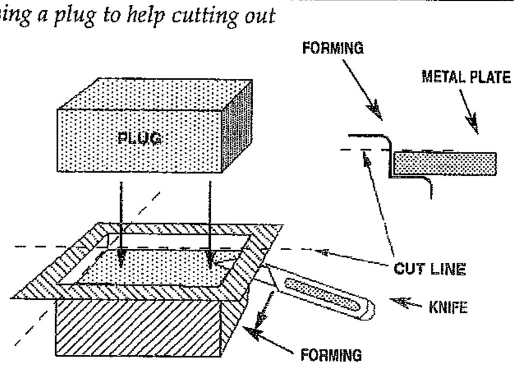


Special machines are available that are designed specifically for cutting out vacuum formings.

Our Profile Router 145, suitable for material up to 3mm thick, comprises a slot drill mounted in a work table with a guard/fence that allows you to follow the profile of a forming accurately whilst protecting against injury from the cutting tool.

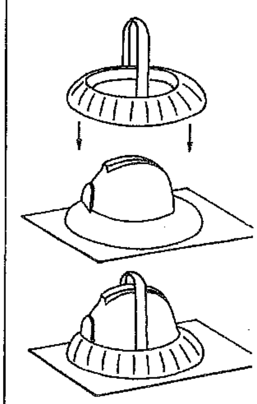
The guard is adjustable so that you can cut into the corners of a forming or leave a flange which is useful for gluing.

Using a plug to help cutting out



Thinner materials, up to 1mm can be cut with an art knife and this process itself can be made somewhat easier if some form of cutting guide or plug is used.

Using a trimming guide



HIGH VOLUMES

Many mass production thermoformers are designed with an integral trimming or cutting device.

Small, lightweight items such as packaging are simply punched out by a die mounted immediately after the vacuum press.

Yogurt cups or tubs designed to take lids are treated specially with a rolling device as they are cut which turns over the top to form the lip.

Heavy gauge products can be cut out using hand held routers, hole saws, band saws or guillotine. A five axis CNC router is probably the fastest and most efficient form of trimming and finishing. These routers not only cut out the basic shape but can also cut out windows from cars or boats and engrave features, lettering or details.

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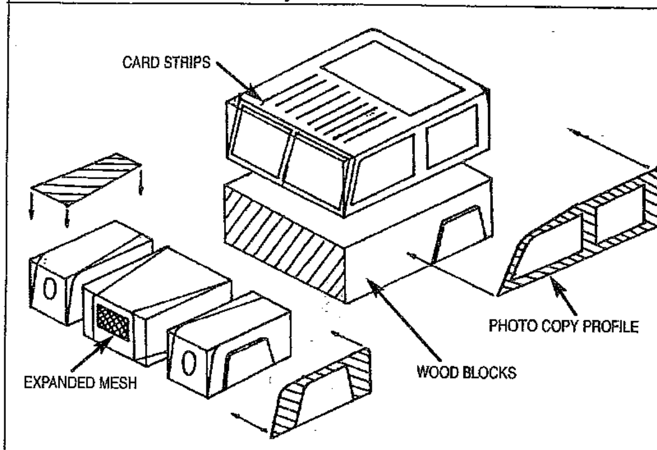
INTRODUCTION TO THERMOFORMING- 4
Mould Making

MATERIALS

Moulds for vacuum forming are most commonly made from a timber product, aluminium or epoxy resin. Other materials such as steel, copper, brass, paper, card, glass, thermosets like 'Bakelite' (Urea formaldehyde), plaster of paris, dental plaster, clay or plasticine can be used on their own or in combination.

Details can be added by mesh, perforated sheet, wire and even sandpaper (which is used for providing surface texture on vacuum formed braille diagrams).

First stages of mould manufacture



TIMBER BASED MOULDS

One of the best materials to work with is Medium Density Fibre Board (MDF) as it has no grain, is easy to shape, and is relatively stable when heated. It is easy to work into reasonably complex shapes using cutting and abrasive tools such as bandsaws or sanders, and other materials such as card or metal can be fixed to its surface using adhesives. Other fibre boards or regular close grained timber can be used.

Tools needed to produce a prototype mould can be found in most carpentry workshops including:

1. Saws
2. Chisels
3. Gauge
4. Drill bits
5. Sanding block
6. Tilt table disc sander
7. Drill press
8. Small high speed PCB drill such as a 'Dremel'
9. Band saw
10. Sash clamps

The tilt table disc sander is particularly useful for quickly developing blocks with draft angles and radii.

1. Prepare the base blocks

If necessary, assemble a composite block or blocks of MDF or some other timber or timber based board. Glue boards together with PVA wood glue, clamp together with sash clamps and cure overnight.

If you have an oven or a hot box (see 4: Vacuum Forming), you can improve the curing time.

2. Marking out

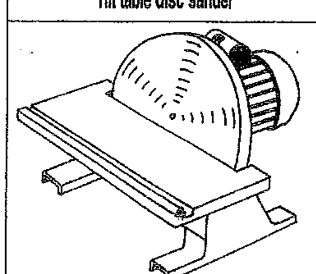
Get an accurate set of scale drawings to work from and if it's a complex shape, break it down into simple components that can be assembled later.

Mark out or paste photocopies of the drawings or drawing sections onto the composite block or blocks (use the same face for each part - usually the base - so that angles are generated from the same datum).

3. Shaping & assembly

Cut roughly to shape using saws and then finish the shapes more accurately with the disk sander. Assemble the mould frequently to check on progress.

Tilt table disc sander



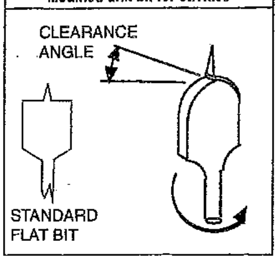
If the mould ends up too long, cut it in half, remove a slice from one of the ends and glue the two halves back together.

If the mould ends up too short, cut it in half, add a section to one of the ends and glue the two halves back together.

4. Adding detail

When you are happy with the mould's basic shape, add detail using wire, mesh, sandpaper or any other heat resistant material that achieves the desired result (metals can be glued to MDF using Locktite 499).

Modified drill bit for cavities



Dimples and hollows can be drilled into the mould using a custom shaped flat drill bit.

Off the shelf mouldings can be used to make decorative bases and surrounds - mitre at the corners and pin in position.

5. Mounting on a baseboard

Once the mould is complete it should be mounted on a baseboard. This is necessary for three reasons:

1. To hold down the mould during the blow cycle.
2. To locate the mould (or moulds) on the platen in the best vacuum forming position.
3. To prevent material stretching all the way down to the platen tray causing unnecessary thinning.

The baseboard can be made from a timber based product or metal and should be cut so that it fits neatly inside the platen tray.

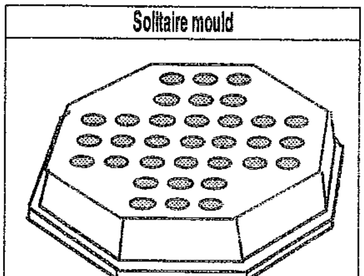
The mould is placed on the baseboard on shimms (double sided sticky pads work well) and screwed into position from underneath. The shimms provide an air track around the bottom edge of the mould.

At least one hole should be drilled in the centre of the base board but, if evacuation is slow, you can drill more.

6. Forming & modifying

Place your mould in a vacuum former and attempt a forming. The first forming will usually show up areas of the mould which need modifying. Keep on modifying the mould and testing it until you are satisfied with the result.

Solitaire mould



RESIN CAST MOULDS

A timber based mould is good for most educational or experimental applications and should last for a hundred formings or so - depending on how well it is made. For a more durable, resin cast mould, first make a timber based mould as described previously, then follow these steps:

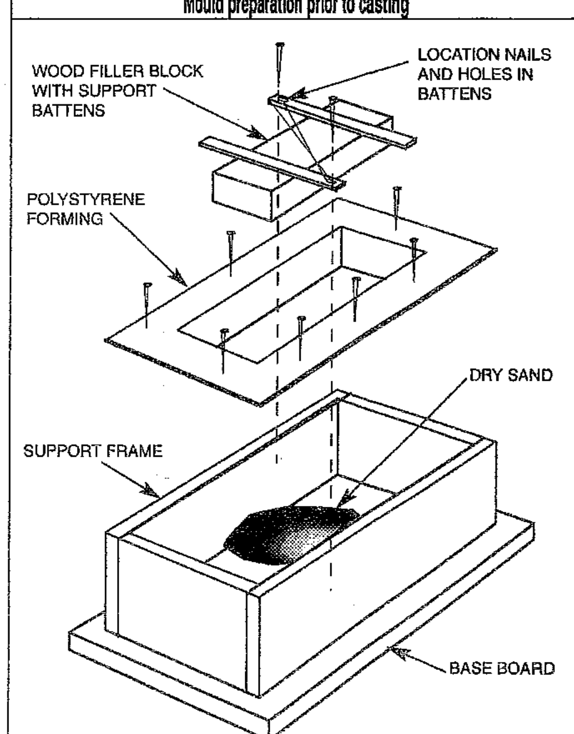
1. Vacuum forming a pattern

Take a forming of the timber based mould in 1.5 - 3.0 mm PS, forming at maximum temperature to attain the best definition. The PS sheet has a gloss side and a matt side - remove the film from the gloss side and form with it on the inside.

2. Making a casting box

Construct a timber frame and fix the forming in it using small, large headed nails or tacks. Turn the assembly upside down and fill with dry sand (moisture may permeate and distort the PS). Strike off the sand level with a straight edge and fix a timber board over the box to prevent the sand tipping out.

Mould preparation prior to casting



Turn the assembly back over, and you will have a sturdy hollow mould, that will not distort even under several kilos of resin or with the heat created by curing.

3. Packing out the cavity

Suspend blocks of expanded PS or timber over the main cavity, making sure that there is always a gap of approximately 20 - 25mm (3/4 - 1") between the forming wall and the packing. This will reduce the amount of resin required to make the mould and make drilling evacuation holes easier (see later).

The blocks can be suspended on wooden battens which will need to be weighted down or fixed to prevent them floating when the resin is poured.

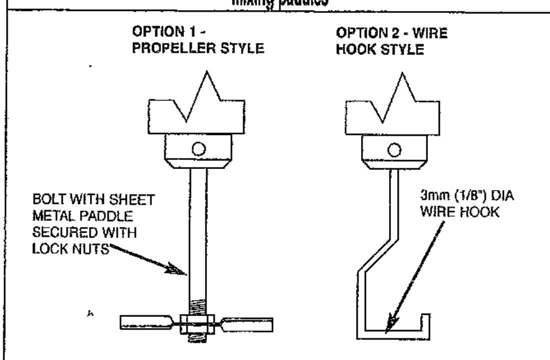
If you are making more than one mould, it might be worth making a vacuum forming of the inner shell which can be suspended over the blocks in the same way.

4. Mixing the resin

Calculate how much resin the mould is likely to need and mix that amount.

The best resin for vacuum forming moulds is aluminium epoxy but, there are others on the market including fast curing types, which can be used. Whichever resin you use it will come as a two part pack and need to be mixed thoroughly before pouring.

Mixing paddles



NB: The twists in the paddle blades will act like a propeller, pushing the drill out of the resin. If they have the opposite effect ie. they suck the resin pot onto the paddle, then you should reverse the direction of the drill or turn the paddles over.

Most resins are too viscous to be mixed by hand so you will need to make some form of paddle mixer, fit it to an electric drill and mix for 3 - 4 minutes, making sure all the resin from the corners of the container is mixed in, to ensure you have a good resin that doesn't have any soft spots when it's cured.

5. Pouring

Brush the forming with resin to prevent any air bubbles spoiling the mould surface (air bubbles will have been formed during mixing and will not be able to escape due to the resin's viscosity - this doesn't cause a problem on the inside).

Once the entire forming surface has been coated, pour resin in until the forming is about half full.

Place the packing blocks in place and pin or weight them down and then pour the rest of the resin. Slight shrinkage may occur during curing so overfill to just above the top of the forming.

6. Curing

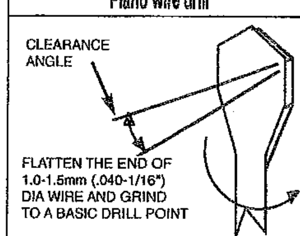
Aluminium epoxy resin needs 24 hours at a minimum 20°C (68°F) to cure after which time it can be taken out of the forming box. The packing blocks will probably remain inside the mould and the original forming may be destroyed in the process of removing it. Once it is out of the box, it should be post cure heated at 80°C (176°F) for about one hour per kg. Other resins will have different curing requirements and you should refer to the manufacturers' recommendations in each case.

7. Drilling evacuation holes

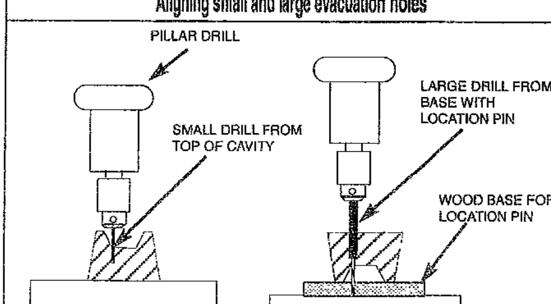
An epoxy mould differs from a wooden mould in that it is not porous and will require evacuation holes for the vacuum to be able to draw material down into all the details.

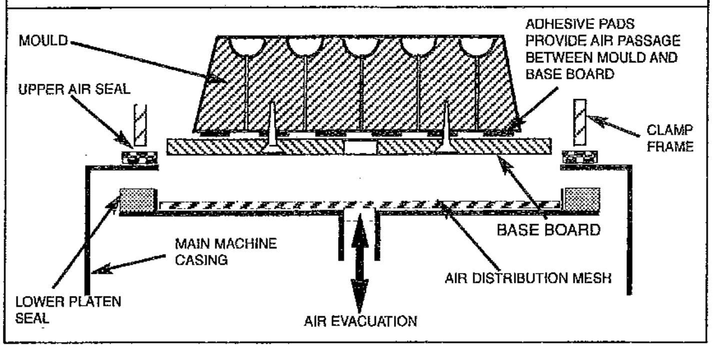
You can easily tell where evacuation holes will be needed initially, by holding the original forming up to the light and seeing where it has thinned the most. These points are exactly the points which need evacuation holes.

Piano wire drill

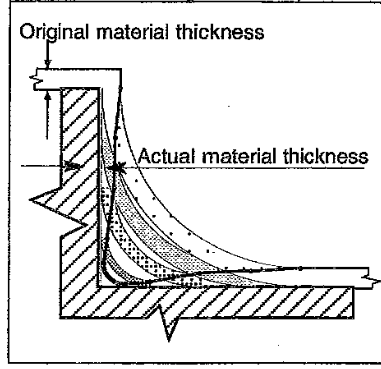


Aligning small and large evacuation holes





Base board details and evacuation considerations



Escalation of thinning effect in a sharp corner

Drill with a 1.0 - 1.5mm (0.04 - 1/16") diameter drill bit, or a section of flattened and sharpened piano wire or similar, in a high speed PCB drill such as a Dremmel.

As well as the thin spots, hemisperical cativities and large flat or gently domed areas such as model car roofs, may need evacuation holes too.

Sand down or grind the bottom of the mould until it is flat and mount onto a baseboard. Try forming it before drilling too many evacuation holes as you may need less than you think.

8. Finishing

Final finishing, patching up with resin or car body filler, sanding with fine grade wet & dry paper and buffing should leave you with a high quality mould that will last for many thousands of formings.

Note: Large aluminium epoxy resin moulds for high volume production may need to be water cooled.

ALUMINIUM MOULDS

Commercial vacuum formers tend to use aluminium moulds which is a technology becoming increasingly prevalent in schools and colleges as CNC milling equipment becomes more widely available.

CNC milling has the potential to make mould production very simple - all you have to do is draw or 3D scan your model into the computer and then wait while the computer and the mill do all the hard work; mount the finished piece on a baseboard, drill the evacuation holes and you are ready to vacuum form.

Aluminium moulds are very stable when heated and the larger ones have such a high thermal mass that they don't need water cooling.

Some complex moulds have moving parts which are easier to engineer in aluminium.

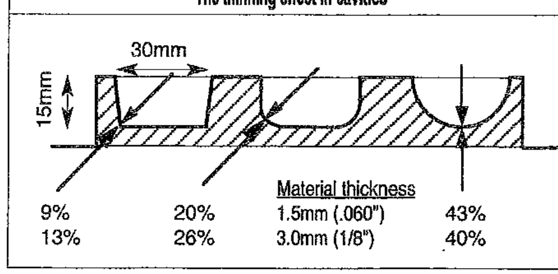
PROBLEMS WITH MOULD DESIGN

THINNING

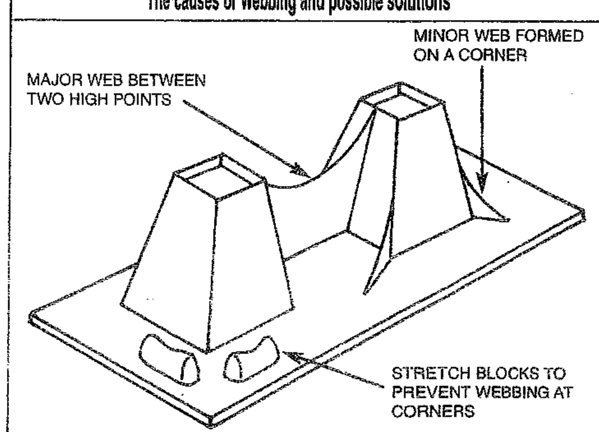
One of the most common problems in the design of vacuum formed products is thinning. Different mould shapes present different thinning problems too numerous and diverse to discuss here.

The circular cup mould though, is helpful to bear in mind. If a cup mould is straight sided with sharp corners, the maximum depth of cavity will be about half the diameter at the top of the cup. Radiusing the corners at the bottom will improve the depth and rounding the bottom completely will treble it.

The thinning effect in cavities



The causes of Webbing and possible solutions



If you go beyond these parameters the material at the bottom of the cup becomes paper thin, like a carrier bag, and the cup won't stand on it's base.

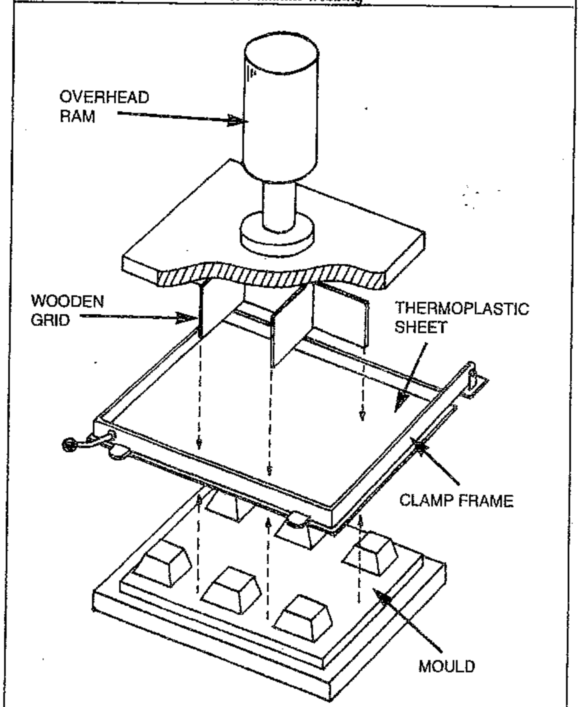
WEBBING

Webs will form between points that are too high and/or too close together. As the material is drawn down it meets itself and forms a fold before it comes into contact with the mould.

Commercial vacuum formers use a plug assist to push the material down before the vacuum takes effect.

This can be done by hand on a manual machine, using a piece of rounded timber, stiff card or TP offcut.

An overhead grid on the plug assist ram as used on a commercial machine to eliminate webbing



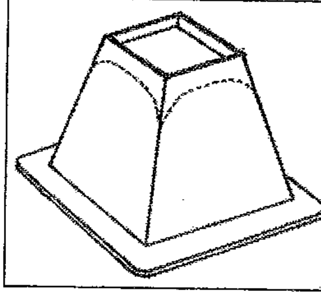
CHILL MARKS

A mark is often left around the top of a forming as a result of the mould cooling or 'chilling' the heated TP sheet as the platen rises (see 3. Vacuum Forming).

These marks are difficult to eliminate completely but there are two things you can try:

1. Increase the heater output over the high spots.
2. Increase the heat of the mould - this reduces the chill effect and helps material to 'flow' over the mould to give a more even forming.

Chill marks on a forming



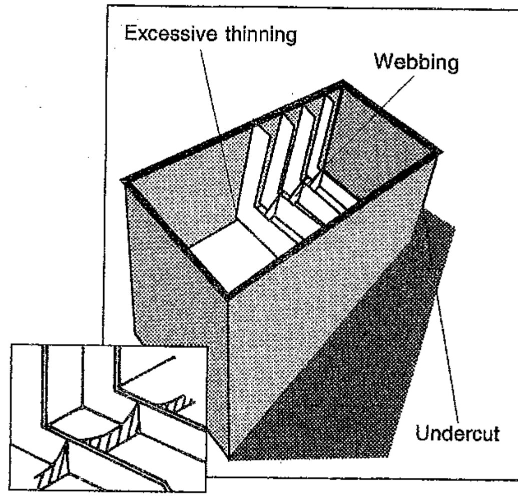
On some machines it is possibleto blow the material before forming, which can help the chill marks but may aggravate webbing.

SOLUTIONS

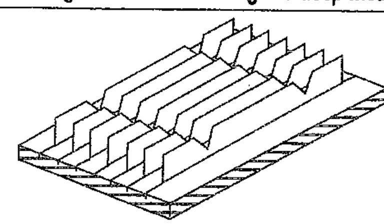
DESIGN

Some products can't be vacuum formed in one piece. But vacuum forming doesn't have to be a one stage solution to any design problem and can produce components for larger products.

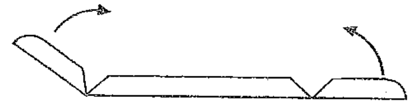
For example, if we tried to vacuum form the CD rack pictured below, we would have problems with thinning, webbing and trapping as illustrated.



Design solution to thinning in a deep mould



FINN'S MADE FROM SHEET METAL USING A STANDARD SHEET METAL CORNER NOTCHING MACHINE AND INSERTED INTO SAW CUTS IN BASEBOARD



FOLD AFTER VACUUM FORMING. 0.5MM (.020") WILL FOLD COLD. FOR THICKER MATERIAL USE A STRIP HEATER.

But if the rack dividers were vacuum formed flat and folded up afterwards, either cold or on a strip heater, they could be an insert in a casing made from another material.

INVESTIGATION

By drawing a grid on a TP sheet before vacuum forming as commercial vacuum formers do when setting up large machines (see 3. Vacuum Forming) you can show where the areas of thinning are originally heated and reduce the heat over those parts.

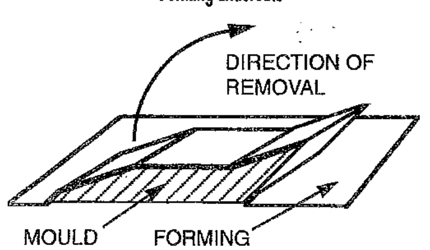
OTHER THINGS TO TRY

NEGATIVE DRAFT ANGLES OR UNDERCUTS

Normally, a negative draft angle will prevent a forming from being released from a mould.

But if a negative draft at one end of a mould, is complemented by a generous positive draft at the other end, it can be possible to get a forming off by releasing the front end first and pulling the forming up and back.

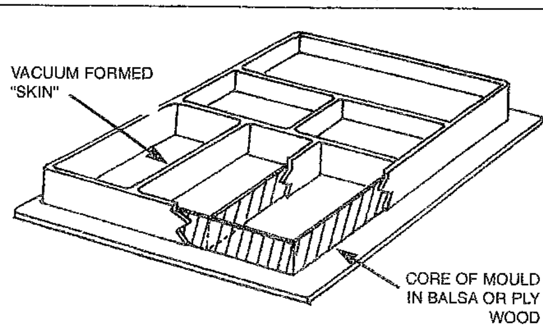
Forming undercuts



ENCAPSULATION

Skin packaging is carried out using very thin PVC film - less than 0.5mm - and vacuum forming it onto a cardboard base, specially prepared with perforations (for the air track) and heat sensitive adhesive. Products are placed on the board and vacuum formed, with the film.

A "one-off" tool tray using encapsulated Balsa or Ply wood as the core



Using thicker material creates a permanent skin for a product that gives it strength, colour and durability.

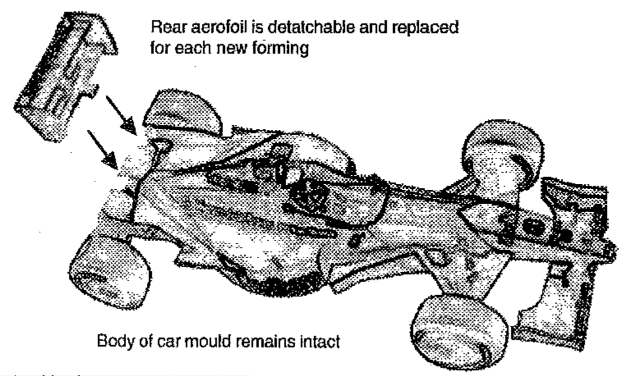
If the mould is going to remain inside the forming, there is no need to worry about draft angles and you can use simple materials, like rectangular sections of balsa wood.

Coins or other artefacts can be simply mounted by encapsulating them in clear PVC, PETG or PS on a decorative base.

PART ENCAPSULATION

You may find yourself faced with the prospect of a complicated mould who's formings are getting stuck on just one part. If you make that part detachable, then you can leave it in the forming and you only have to make another one of those parts and attach it to the main mould with blu-tack or dowel pegs to make another forming.

Formula One car mould concept with encapsulated aerofoil



VACUUM FORMING EXPANDED POLYSTYRENE

Expanded polystyrene, which is easily cut on a Hot Wire Cutter, is an interesting material to use as a mould. The heat of the sheet as it forms over the expanded polystyrene, heats it up to the point of collapse, creating an interesting surface texture. Different density foams collapse to different degrees, creating different surface textures.

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INTRODUCTION TO THERMOFORMING-

Injection Moulding

5

INTRODUCTION

From the moment we get up in the morning until the moment we go to bed at night we are surrounded by products that have been produced, wholly or partially, on Injection Moulding Machines. The alarm clock, shower head, hair brush, coffee machine, toaster, toothbrush – even the buttons on your blouse or shirt, owe their existence in their current form to Injection Moulding. Outside of our homes injection moulded products are still all around us – the car, bus or train you ride to work, school or college is full of injection moulded components and whatever you do, there's a good chance that you will spend a large portion of your day tapping the injection moulded keys of an injection moulded computer or holding the injection moulded hand piece of an injection moulded phone or writing things down with an injection moulded biro. At the end of the day, many of us watch television screens that are encased in injection moulded plastic; often changing the channels with the injection moulded remote control that we hold in our hands. Even when we go to bed at the end of the day, if we look at the switch we use to turn out the light, whether it is on the wall, or in the lamp on the bedside table, or screwed to the head board; it is a piece of injection moulded plastic.

Injection Moulding is an important part of our every day lives, our world would be very different without it and product designers need to know about it; they will use it many times during their careers.

Injection Moulding is the process of heating plastic granules to melting point before injecting them at high pressure through a nozzle into a mould. When the plastic cools the mould is opened and the newly formed plastic part is removed.

The process has been modified and developed in numerous ways and now there are many different types of Injection Moulding, such as:

- Injection Blow Moulding
- Twin/Triple Injection Moulding
- Multi-component injection moulding
- Multi-station injection moulding
- Reaction injection moulding
- Gas injection moulding – and many more.

Both Thermoplastics (including Thermoplastic Elastomers, the Thermoplastic 'rubber') and Thermosetting plastics are injection moulded to produce an enormous and ever increasing range of products and components.

EVOLUTION OF INJECTION MOULDING

One of the earliest forms of plastic moulding was Compression Moulding. Here, a fixed amount of plastic is placed in the lower half of a mould and heated before the upper half of the mould is closed over the top of it. The mould remains closed while the part cools and when it is taken off the 'flash' (excess material that seeps between the two halves of the mould) is removed.

Transfer Moulding introduces a plunger, or ram, that pushes the plastic through a barrel and into the mould cavity, which is already closed. Transfer Moulding reduces the amount of waste and removes the need for de-flashing. Some waste material is still produced though, in the barrel and interconnecting parts of the mould (depending on its shape).

Plunger Moulding has the plunger mounted horizontally and the plastic fed into the barrel from a hopper mounted on top. As the plunger moves along the barrel it automatically cuts off the supply of granules, leaving a fixed amount of material in the barrel for injecting. The barrel has a nozzle at its end that connects to the mould and the mould itself has a 'sprue' or narrow channel through which the plastic moves on its way to the mould cavity.

The last major innovation, which led to the Injection Moulding Machine, was the extruding, Archimedean or plasticising screw. The Screw is a tapered bar with a spiral of flights along its length and was first used, not surprisingly, for extruding. The height and pitch of the flights varies according to which of the three zones of the screw they occupy and hence, which job they are designed to do as the screw turns: Feeding, Compressing or Metering.

1. The Feed zone flights are long and designed to move the material along the barrel as quickly as possible. As they move along, the granules are heated by friction (from the movement of the screw inside the barrel and from the movement of the granules themselves) and by the inside of the barrel against which the granules are forced by movement of the flight.
2. In the Compression zone the flights become shorter and the plastic granules are further heated and compressed, removing any air pockets. The plastic is melted by now and becomes thoroughly mixed or homogenized by the continuing movement of the screw.
3. The Metering zone contains the shortest flights, which are designed to pump the plastic or melt, through the extrusion die.

Various methods of incorporating Archimedean screw extruders into injection moulding machines were developed until the most efficient was found; the Reciprocating Screw. Basically the screw is capable of moving back and fore as well as turning so that it can act as a plunger and an extruder. As melt builds up at the end of the screw, the screw moves backwards. Once there is enough melt to fill the mould (measured by how far back the screw has traveled) the screw is driven forward, pushing the melt through the nozzle, along the sprue and into the mould cavity. A non-return valve is fitted at the end of the screw to prevent the melt from being pushed back along the screw.

The evolution of injection moulding was driven by ever-greater demand for plastic products as their use became more widespread. Reciprocating Screw Injection moulding machines had three important advantages over their predecessors, the plunger moulding machines:

1. Output. The injection moulding machine dramatically increased the amount of melt, and thus the amount of product, that could be produced.
2. Quality. The melt produced by the screw is more homogenized and the heating more thorough (unmelted particles, common in plunger moulding, are never encountered in injection moulding) thus improving the qualit[y] and consistency of products.
3. Energy efficiency. The heat generated by the friction of all the moving components inside the barrel greatly reduces the amount of external heating required. In fact, some thermoset injection moulding machines are fitted with cooling mechanisms because too much friction heat is generated.

The development of Injection Moulding machine[s] at the beginning of the 21st Century sees a move towards all electric machines. Wherever possible expensive, high maintenance hydraulics are replaced by servo-motors which reduce the size and weight of machines and improve accuracy, speed and consistency.

INJECTION MOULDING MACHINE BASICS

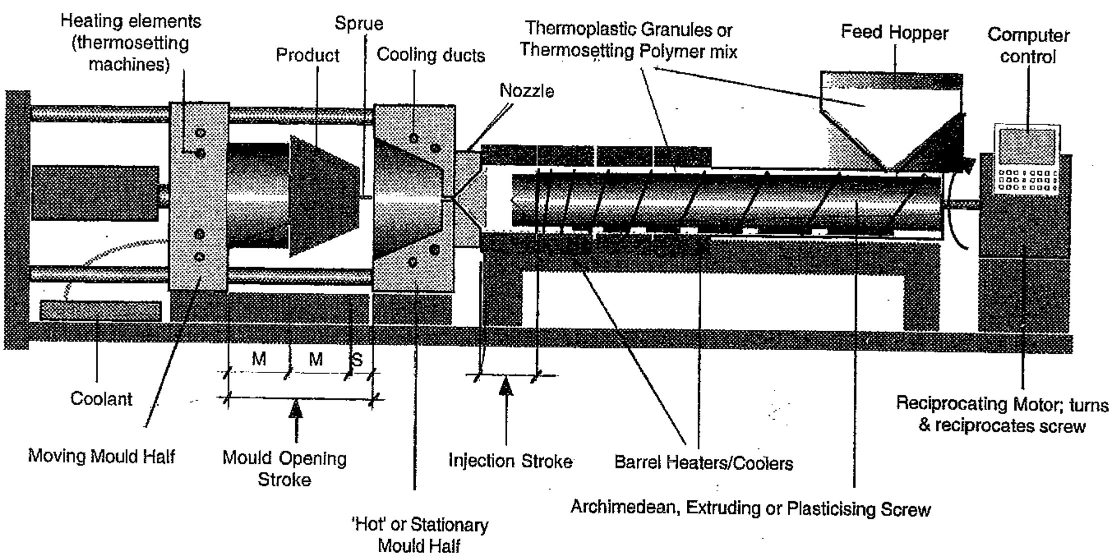
Injection Moulding Machines have become highl[y] sophisticated, complex, computerized machines with many features that need to be considered when deciding which machine will be able to make a particular product. Here, we will talk about some of the main features, how they effect output and, in some cases, the rules that are used to determine these effects.

SCREW

The characteristics of the screw are crucial in determining the type and size of product that ca[n] be produced on an Injection Moulding Machine and many machines are supplied with more than one. One of the most important factors is the rati[o] between the length and the diameter, or the L/D ratio.

22:1 or higher (meaning that the screw is 22 times the length of the diameter) improves the mix of the melt and the quality of the product. Compared to a screw of the same length with a lower L/D ratio of perhaps 20:1, the injection pressure will be higher but the volume lower. Th[e] volume can be increased with a longer injection stroke but this increases the cycle time.

Injection Moulding Machine



Generally speaking for high quality products such as engineering components, a L/D ratio of 22:1 or higher is needed. 20:1 is suitable for medium quality products like garden furniture and 18:1 would typically be used for low quality items such as disposable packaging or cheap children's toys.

SHOT WEIGHT

The Shot Weight of a machine is defined as the weight of plastic produced at the nozzle in a normal cycle (without a mould) in PS (specific gravity 1.05). The shot weight for other materials can be worked out by the following formula:

$$X \times \frac{Y}{1.05} \quad \begin{cases} X = \text{Specific Gravity of material} \\ Y = \text{Shot Weight of machine} \end{cases}$$

The shot weight of a machine does not tell us the maximum volume of part that that machine can produce, because the pressures for moulding are higher than for extruding. Typically, the maximum volume of a low quality part will be 85% of the Shot Weight, or around 75% for a high quality part.

Parts need to weigh between 35% and 85% of the Shot Weight of a machine, any lower and the machine may be damaged during production, any higher and the mould cavity or cavities will not be filled.

INJECTION PRESSURE

This is the pressure in the barrel at the point of injection, expressed in kg/cm2 or kbar. A higher L/D ratio produces greater Injection Pressure. The greater the Injection Pressure the better the quality of product produced.

INJECTION STROKE

The distance that the screw travels during an injection stroke, up to 4 * diameter.

INJECTION VOLUME

Theoretically, the injection volume is the length of the injection stroke multiplied by the cross sectional area of the screw. However, leakage around the screw and movement of the non-return valve mean that in reality, only around 90% of that Injection Volume gets injected. If Injection Volume is used to determine the size of machine needed for a specific part (as opposed to using Shot Weight) then for low quality parts the volume should be within 20 – 80% of the Injection Volume, or within 40 – 60% for high quality parts.

INJECTION SPEED

Two things need to be considered when deciding how fast a product should be injected. Firstly, there needs to be enough speed for the mould to fill before the polymer cures or the melt un-melts. Thin walled parts in particular need fast injection speeds; the narrower a cavity is, the less time is available to fill it.

The other factor is the Constant Melt Front theory, which holds that optimum product quality is attained when the leading edge of the melt (or the Melt Front) travels at a constant speed through the mould cavity. Most parts have varying cross-sections that require different injection speeds in order to move the Melt Front at a constant speed. So whilst a machine will have a maximum injection speed, it will also have a number of other speeds below this, which may be used in any given cycle to try and achieve a constant Melt Front speed.

INJECTION RATE

This is the volume of melt produced by the screw, expressed in cm3 per second.

SCREW ROTARY SPEED

The Screw Rotary Speed (SRS) determines the Screw Surface Speed (SSS), which is another important factor. Polymer manufacturers specify maximum Screw Surface Speeds for each material that they produce and so, using the screw diameter, the maximum Screw Rotary Speed must be determined in order not to exceed this.

For example, imagine we were going to Injection Mould a mobile phone cover from PP. The maximum SSS of PP is 850 – but the optimum is 750. (Because we want the phone cover to be the best quality possible we will use this figure, rather than the maximum).

The screw diameter is 50 mm so the Screw Rotary Speed is:

$$750 = \Pi \times 50 \times \frac{SRS}{60}$$

$$\frac{750 \times 60}{\Pi \times 50} = SRS = 286\ rpm$$

CLAMP FORCE

The melt is injected into the mould under very great pressure, which the mould halves, and any other components or cores, must be able to resist in order to maintain their shape and to avoid any seepage. The larger a component is, the greater the pressure and so, the greater the Clamp Force required. The Clamp Force is often used in the machine name, for example an Injecto 50 would be an Injection Moulding machine with a 50 ton clamp force capability.

The clamp force required for a given part can be calculated once the shape and size of the part is known and some other factors are taken into account.

To calculate the clamp force you can use – the projected area (area of a moulded part projected onto a plane at right angles to the direction of the mould) multiplied by a constant, as denoted (for example) in the following table:

Thermoplastic	Tons/in2	Tons/cm2	MN/m2
HIPS	1.0 – 2.0	0.155 – 0.31	15.4 – 30.9
HIPS (thin walled)	2.5 – 3.5	0.388 – 0.543	38.6 – 54.0
ABS	2.5 – 3.0	0.388 – 0.62	38.6 – 61.8
HDPE	1.5 – 2.5	0.233 – 0.388	23.2 – 38.6
PP	1.5 – 2.5	0.233 – 0.388	23.3 – 38.6
Acrylic	2.0 – 4.0	0.31 – 0.62	30.9 – 61.8
PC	3.0 – 5.0	0.465 – 0.775	46.3 – 77.2

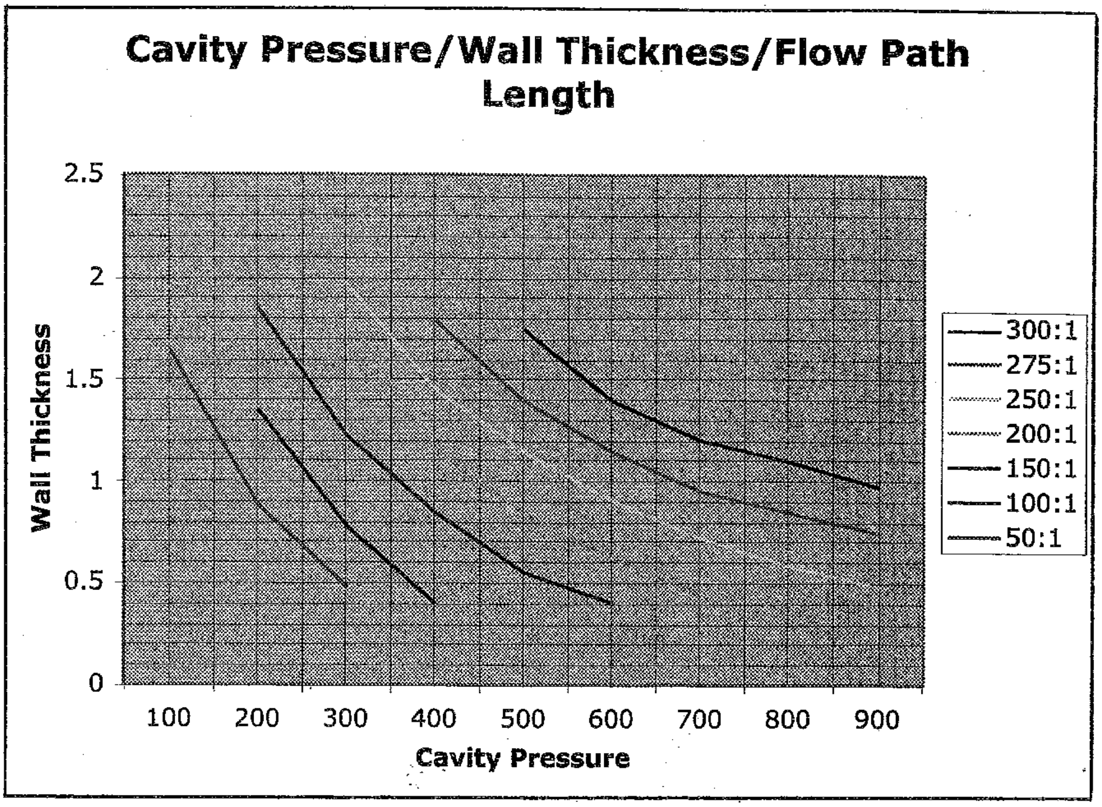
So the clamping force for a thin walled PS product with a Projected Area of 120 cm2 would be:

120 * 0.388 = 46.56 tons minimum or 120 * 0.543 = 65.2 tons maximum.

Perhaps a 50 ton machine will do, or we might need a 60 ton machine.

To help us decide, we can use the Flow Path Length (the distance from the centre of the end of the nozzle to the part of the mould furthest from that point) along with a couple of useful tables.

Unit Conversions		
1 N	1/9.807 kg	0.102 kg
1 kN	1/9.807 ton	0.102 ton
1 Nm	1/9.807 kg-m	0.102 kg-m
1 bar	1.020 kg/cm2	



If our product has a Flow Path Length of 150 mm and a minimum wall thickness of 0.8 mm, then the Flow Path to Wall Thickness ratio is 150/0.8 = 187.5:1. By using the Cavity Pressure/Wall Thickness/Flow Path Length Chart above, we can determine that the Cavity Pressure with a minimum wall thickness of 0.8 mm is around 475 bar. The unit conversions tell us that 1 bar = 1.02 kg/cm2, so:

Clamp Force = 475 x 1.02 x 120 = 58,140 or 58 tons

So that confirms it, we need the 60 ton machine for this particular job.

What happens if we change the material of our product? This brings us to yet another important factor – the viscosity of the polymer being moulded. Luckily for us, the viscosity of PS is 1.0, so all our calculations are right so far. But other materials have different viscosity factors, as can be seen in the table below and these must be taken into account when specifying an Injection Moulding Machine for our product.

Thermoplastic	Viscosity Factor
PS	1.0
PP	1.0 – 1.2
PE	1.0 – 1.3
ABS	1.3 – 1.5
PMMA	1.5 – 1.7
PC	1.7 – 2.0
PVC	2.0

If we decide to make our product out of Polycarbonate instead of Polystyrene, then we will have to multiply our results by the viscosity factor for PC thus:

58,140 x 2.0 = 116,280 = 116 tons

In reality nowadays, the Clamping Force is determined using software, but the programmes use the same principles, constants and conversions as we've used here.

SIZE

The size of an Injection Moulding Machine is described in Europe using the EUROMAP (European Committee of Machinery Manufacturers for Plastics and Rubber Industries) size rating which uses the clamping force in kN, and the product of the injection pressure in kbar and the injection volume in cm3. The EUROMAP size rating for a machine would be worked out as follows:

Injecto 150 Specifications

Clamping Force 150 tons	x	**Conversion** (1 ton = 9.807 kN) 9.807	= 1471 (A)
Injection Pressure 2,000 kg/cm2 = 1.96 kbar	x	**Injection Volume** 300 cm3	= 588 (B)
		EUROMAP size rating (A:B)	**= 1471:588**

Sometimes approximate conversion factors are used, in which case the rating would be 1500:600. In Asia, the number order is reversed and the Clamping Force is described in tons rather than kN, so the same machine would be said to have a rating of 600:150.

MOULD OPENING STROKE

This is the distance that the moving mould half moves from mould closed to mould open. Because the injection moulded part has to clear the mould and have room to be removed from the machine, the Opening Stroke must be greater than:

*(2 * Mould Height) + Length of Sprue.*

MOULD HEIGHT

This should probably be called Mould Thickness, the expression is left over from the days when moulding machines were vertical. Injection Moulding machines are normally adjustable and can accommodate a range of Mould Heights – expressed in the machine specifications as the Minimum and Maximum Mould Height.

MOULDS

GENERAL

Most injection moulds are made in two halves and when you look at most injection moulded products, you can often see a line, which traces the meeting point of the two halves. You can also sometimes see the point at which plastic was injected and the resultant sprue cut off – called a Gate Mark. Products are always designed so that the Gate Mark is concealed on the inside or the underside of a product.

The mould is as important to the process as the injection moulding machine itself and often costs as much. The main factors affecting a mould's price are:

- Choice of material
- Number of cavities
- Size
- Texture of surface finish
- Complexity of part

THE MECHANICS

Normally, one half of the mould – the one next to the nozzle – is stationary while the other half moves for clamping and product release. At the end of a cycle, the Moving Mould Half moves back, pulling the product out of the Stationary (or 'Hot') Mould Half. An ejection system is built in at the end of the platen stroke to push the product off the Moving Mould Half so that it can easily be taken off the machine either manually or by an automatic collection system.

HEATING/COOLING

Because thermoplastic products have to cool before the mould can be opened, water or oil cooling systems are incorporated in the mould design, to reduce the cycle time. Because thermoset products sometimes have to be heated to allow for curing, those moulds may have to incorporate heating and cooling systems.

MATERIALS

Moulds are usually made from stainless steel or hardened tool steel or a combination of both. Occasionally moulds are made from aluminium.

DESIGN

The key to successful Injection Mould design is ensuring there are no undercuts, which can prevent the mould halves from opening without destroying the part. It is also useful if the design is shaped so that when the Moving Mould Half moves back (when the mould opens) the product stays on it – and not the Stationary Mould Half. Then the product will be released by the Ejector System.

VARIATIONS

Having only two halves and one injection point limits the complexity of the shape that can be produced and there are a lot of variations on this basic theme, which produce more complex shapes and indeed, more complicated moulds.

Rotary table injection moulding, for example, has a number of different mould cavities mounted on the stationary half of the machine and a rotating mould with a number of identical cavities mounted on the moving platen. After the first injection the moving platen rotates, taking the part with it, so that on the second injection, a new element is added to the part in a different material.

STUDENT NOTES

<u>Essay Question</u>

Answer below the two questions relating to iconic design, you are to research design eras and pick a product from one of the eras that you find iconic.

0 1 Explain what you understand by the term *iconic design*.
In your answer you should refer to at least **four** criteria that could be used to define a product as being an *iconic design*. *(14 marks)*

0 2 Describe a product that you believe to be an example of *iconic design* and show how the product meets the criteria you have given in part **0 1** .
You **must** use sketches in your answer to identify key features. *(14 marks)*