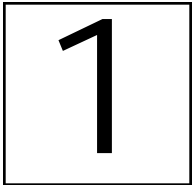


# INTRODUCTION TO THERMOFORMING - Plastic Materials



## INTRODUCTION

Plastics are essential materials of modern day life. Technological advances improving our quality of life through telecommunications, computers, transport, health, sanitation, recreation, education, housing, shopping, banking, clothing, food, water and energy - to name but a few - have been made possible by the unique forming, electrical, thermal, tensile and insulation properties of thermoset and thermoplastic materials.

Life in the home would be very different without *Teflon* or *Fluon* coated cooking utensils, plastic window frames and doors, food containers, fridges, TV's, radios, electrical cables, gas and water pipes....the list is almost endless.

Like more traditional materials such as wood, ceramics and metal, modern engineers, craftsmen and students need to understand the characteristics and potential of the wide variety of plastics that are currently available.

## PLASTICS - POLYMERS

Plastics; synthetic, polymeric products of the petrochemical, coal or gas industry, can be moulded into any shape, are aesthetically pleasing and have low density and friction co-efficients. Some plastics also have excellent corrosion and impact resistance. Materials science is constantly designing and developing new materials for an ever increasing number of applications and plastics are no exception.

Plastics are made from polymers; chemical compounds composed of long molecules made up of chains of small repeat units (monomers). Polymers are rarely used alone, additives are used to enhance the appearance, improve the strength and change the characteristics of different plastics.

Additive types	Effects
Antiblocks	eg. Talc, silica, clay, mica, ceramic spheres - Prevent a film sticking to itself and make separation of film easier
Antifogs	Prevent the formation of fog (water vapour) on the plastic surface
Antioxidants	Prevent oxidization
Antistatic Agents	eg. Carbon, metallized fillers and carbon fibres - Reduce build up of static
Biocides	eg. Preservatives & fungicides
Chemical Blowing Agents	eg. sodium bicarbonate - produce gases on polymerisation to produce foam
Flame Retardants	Halogenated compounds, phosphorus compounds, metallic oxides & inorganic fillers - reduce flammability
Heat Stabilizers	Maintain colour quality at high forming temperatures
Impact Modifiers	Improve ability to absorb and dissipate impact forces
Light Stabilizers	eg. Mica powder - reduce degradation from UV light.
Lubricants	Help the molecules to flow during forming
Mold Release Agents	Prevent material from sticking to moulds
Nucleating Agents	Improve hardness, elasticity, optical properties and transparency
Plasticizers	eg. Epoxidized vegetable oil, butadiene - make material soft & pliable
Processing Aids	Improve the production rates at manufacture by removing the 'sharkskin' or 'orange peel' effect produced by molten polymer sticking to the die
Slip Agents	Amides: Reduce the coefficient of friction, thus helping the molecules to flow
Fillers	eg. talc, chalk, clay - improves stiffness, strength & electrical properties (clay)

Glass, carbon, paper, cotton, zinc, aluminium, magnesium, wood, talc, chalk, calcium, vegetable oil, clay - all sorts of materials are incorporated for a variety of very good reasons (see Table 1).

Plastics can be divided into two main categories; Thermosets & Thermoplastics.

## THERMOSETS

A chemical change occurs in these plastics during the curing process and cross linking of the molecular chains occurs. This irreversible condition is usually induced by mixing a resin with an activator and normally coincides with moulding or forming of the component into its final shape. Thermosets cannot be re-formed after manufacture. Any subsequent shaping is carried out using traditional wood or metalworking type tools.

**PHENOL-FORMALDEHYDE RESINS:** Car distributor heads, electrical plugs, switches and sockets, laminated with fabric for gear wheels or with paper for electrical insulation. Common trade names: *Bakelite* and *Melamine*.

**UREA-FORMALDEHYDE:** Buttons, coloured toilet seats, domestic electrical fittings.

**EPOXIDES:** Encapsulation of electrical components - often glass reinforced, powder coatings, adhesives, marine protection coatings, moulds and dies for thermoplastics.

**POLYESTER:** Glass reinforced for boat hulls, car bodies, vehicle cabs, weather enclosures and many applications where strength and aesthetics are important.

## THERMOPLASTICS

Thermoplastics soften or melt when they are heated, rather like wax, and regain their rigidity when cool. Various 'Thermoforming' processes have been developed for changing the shape of thermoplastic sheets by exploiting this property, including:

Line Bending	Vacuum Forming
Dip Coating	Dome Blowing
Blow Moulding	Rotational Moulding
Injection Moulding	Extrusion

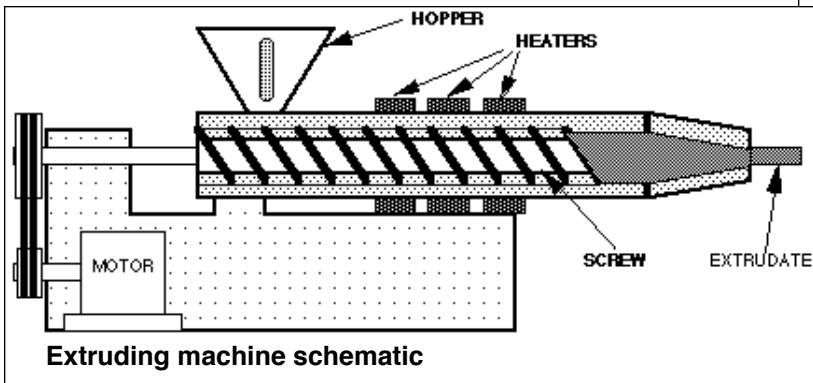
Unlike thermosets, no chemical change, or cross linking of molecules, occurs during heating and cooling so that when a thermoformed object is re-heated, it will soften again and can be re-formed or left to return to its original shape.

**Table 1**

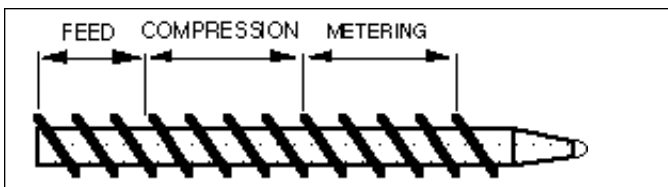
## MANUFACTURING TECHNIQUES EXTRUSION

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:



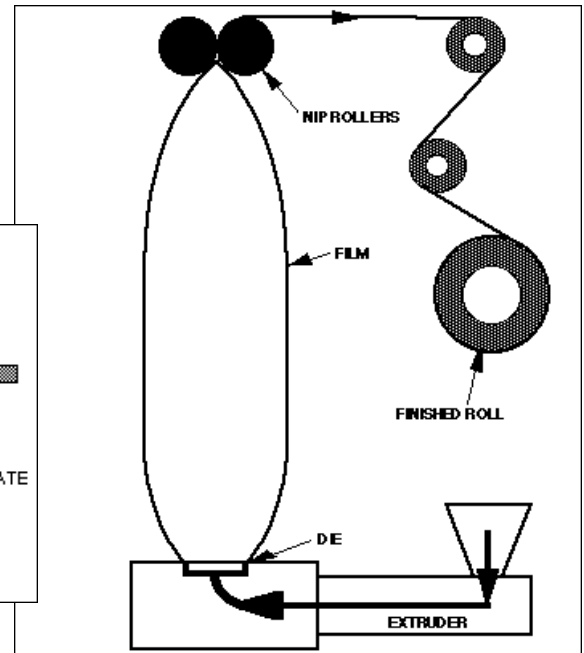
- 1 Collection and feed; forcing the polymer along the barrel towards the extruding die. The screw flights, at this stage, are quite coarse and widely spaced.
- 2 Compression, homogenising, mixing and purging. In the centre section of the screw the flights become shallower and closer together. The polymer 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.

tic 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.

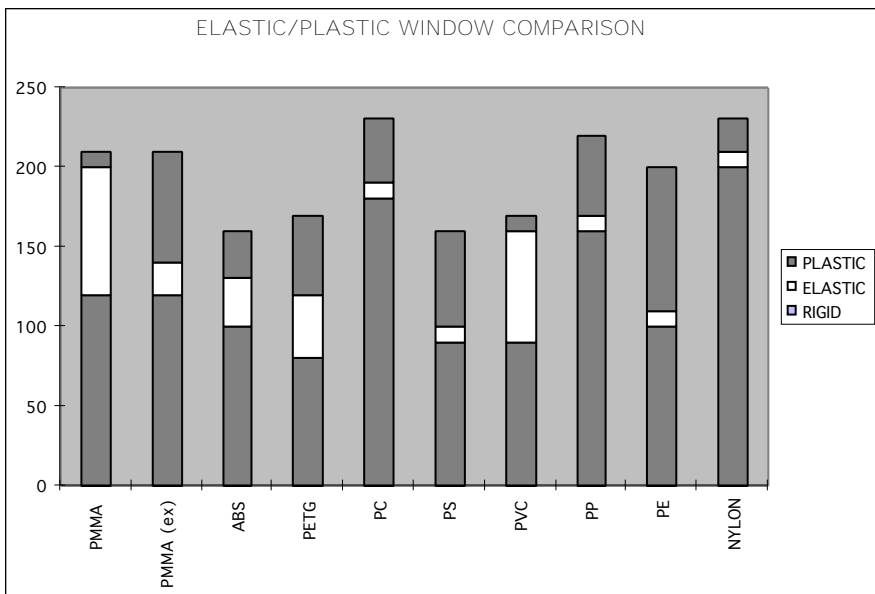
### HYGROSCOPY

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.



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 transferred 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/plas-

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 TP's 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 TP's).*

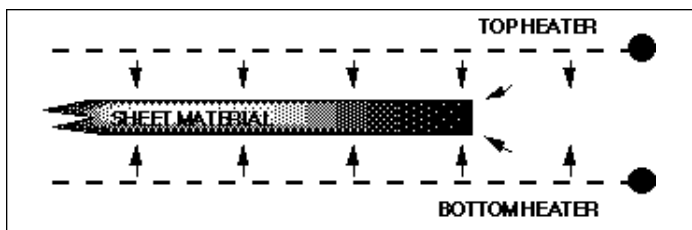
## WORKING WITH TP MATERIALS

### 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 laser 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

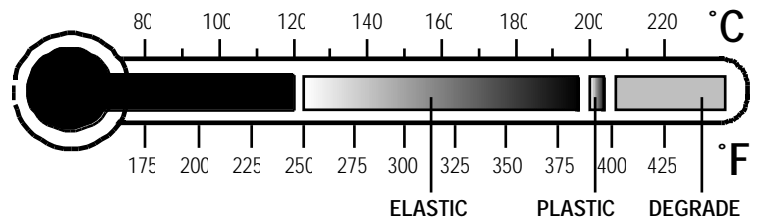
Stress can be created by forming, cementing, welding or flame polishing and manifests itself as crazing and cracks which can appear any time after a stress inducing procedure is carried out - hours, months or even years after. Annealing before cementing, after forming or when a product is finished, reduces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

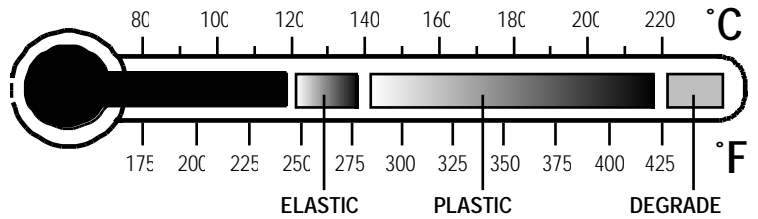
**Welding:** It is not feasible to weld acrylic because the stresses caused ruin the optical quality of the material).

### 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)..

### Joining

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.

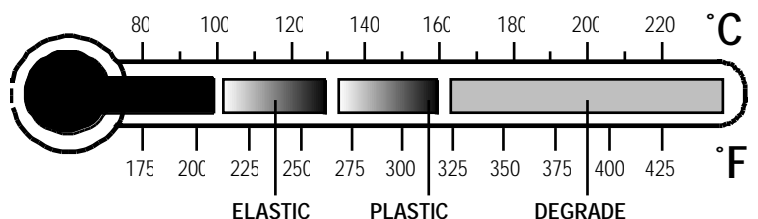
### Identification

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

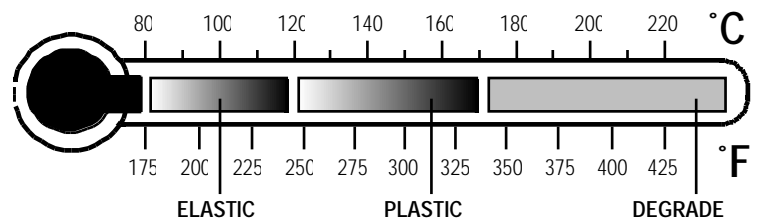
Dinghy hulls, telephone handsets, domestic appliance housings, car dashboards, domestic waste systems and rainwater goods, compressed air lines, smart cards.

<b><u>Line Bending</u></b>	Heaters - all types. Pre-drying - not needed. The thermoforming temperature is quite low (starting at about 100°C) so heating times are relatively quick.		
<b><u>Vacuum Forming</u></b>	Good quality, high definition. Pre-drying is essential. Gives off a hot rubber smell (the butadiene evaporating) during heating.		
<b><u>Other Forming Techniques</u></b>	Free dome blowing, drape and press forming.		
<b><u>Machining Cutting and Finishing</u></b>	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.		
<b><u>Stress Relieving</u></b>	Due to its 'rubber' content, ABS suffers little stress and doesn't need to be stress relieved.		
<b><u>Joining</u></b>	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.
<b><u>Identification</u></b>	Burns, but is self-extinguishing and does not drip. Smells of rubber and produces black smuts.		

# PETG

(PolyethyleneTerephthalateGlycol )

## Heating/Thermoforming Characteristics

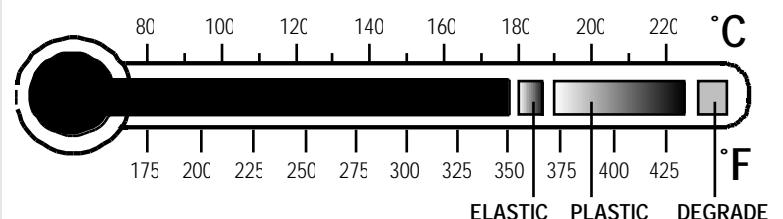


<b><u>General</u></b>	Many of the properties of PMMA, temp. resistance & durability similar to PVC, impact resistance similar to PC.		
<b><u>Applications</u></b>	Point of sale retail displays, signs, vacuum formed products, drinks bottles, smart cards.		
<b><u>Line Bending</u></b>	Heaters - all types. Pre drying - not needed. With a reasonably sized and relatively low elastic window, PETG folds easily and quickly with good aesthetic results.		
<b><u>Vacuum Forming</u></b>	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.		
<b><u>Other Forming Techniques</u></b>	Dome Blowing, Press and Drape Forming.		
<b><u>Machining Cutting and Finishing</u></b>	All techniques - tools should be keen, lubricants or coolants may need to be used.		
<b><u>Stress Relieving</u></b>	Anneal at 60°C.		
<b><u>Joining</u></b>	Proprietary solvent cements are available.	Welding is possible but the stresses caused are usually big enough to cause aesthetic and structural problems.	Mechanical fixing.
<b><u>Identification</u></b>	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

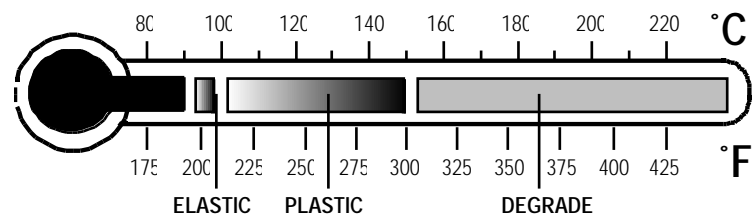


<b><u>General</u></b>	A dense TP with high impact resistance and superior fire rating, available in a number of forms and sections, including sheets. Limited colours, clear, smoke shades plus a variety of embossed textures. Good weather and UV resistance, with transparency levels almost as good as acrylic.		
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<b><u>Applications</u></b>	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.		
<b><u>Line Bending</u></b>	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.		
<b><u>Vacuum Forming</u></b>	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.		
<b><u>Other Forming Techniques</u></b>	Press and drape forming.		
<b><u>Machining Cutting and Finishing</u></b>	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.		
<b><u>Stress Relieving</u></b>	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.		
<b><u>Joining</u></b>	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.
<b><u>Identification</u></b>	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



<b><u>General</u></b>	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.	
<b><u>Applications</u></b>	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.	
<b><u>Line Bending</u></b>	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.	
<b><u>Vacuum Forming</u></b>	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.	
<b><u>Other Forming Techniques</u></b>	Extrusion, injection moulding, press and drape forming.	
<b><u>Machining Cutting and Finishing</u></b>	All techniques are suitable, tools must be keen.	
<b><u>Stress Relieving</u></b>	Very prone to stress (coloured material turns white when it is cold bent). Anneal at 60-80°C (150-175°F).	



### Joining

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.

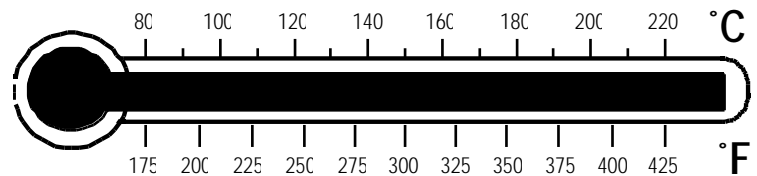
Mechanical fixing is okay.

### 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 shield on Appollo CM.

### Machining Cutting and Finishing

All techniques are suitable.

### Stress Relieving

Not prone to stress.

### Joining

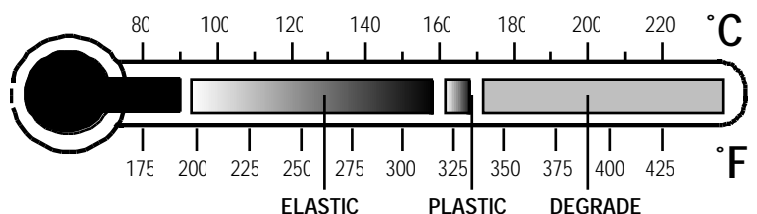
Mechanical fixing

### 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/sewage), pipe fittings, hosepipes, footwear 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.

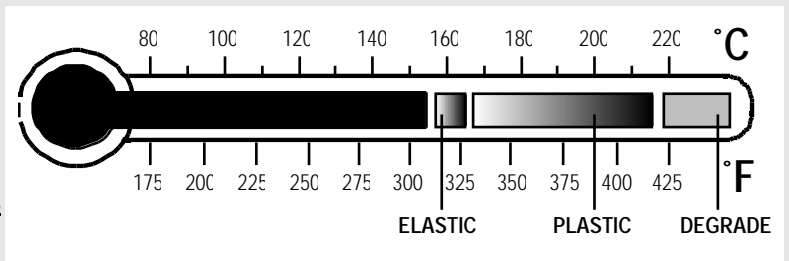
### Line Bending

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

<b><u>Vacuum Forming</u></b>	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.	
<b><u>Other Forming Techniques</u></b>	Free dome blowing, press and drape forming.	
<b><u>Machining Cutting and Finishing</u></b>	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).	
<b><u>Stress Relieving</u></b>	Not particularly prone to stress but, can be annealed at 60-70°C (140-160°F) if it is causing concern.	
<b><u>Joining</u></b>	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
<b><u>Identification</u></b>	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



<b><u>General</u></b>	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.
<b><u>Applications</u></b>	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.
<b><u>Line Bending</u></b>	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.
<b><u>Vacuum Forming</u></b>	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.
<b><u>Other Forming Techniques</u></b>	Injection moulding, rotational moulding.
<b><u>Machining Cutting and Finishing</u></b>	All techniques are suitable. Can be guillotined up to 6mm.

**Stress Relieving**

Not prone to stress.

**Joining**

Because it is solvent resistant, polypropylene cannot be solvent cemented.

Welding is possibly the most common method of joining.

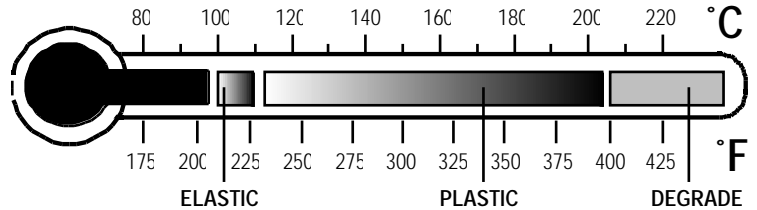
Mechanical fixing.

**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.

**Joining**

Welding.

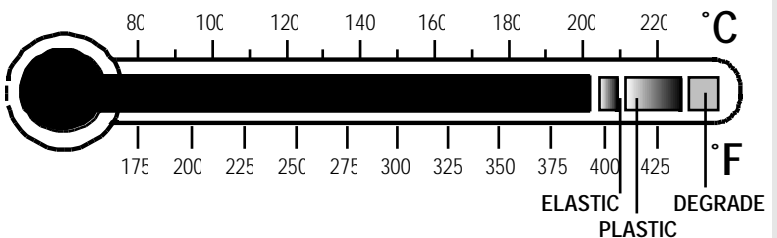
Mechanical fixing.

**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.

**Joining** Mechanical jointing.

**Identification** Doesn't burn easily, when it does it bubbles quietly, drips and self extinguishes.



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