PRO 204 – Modeling Prototyping

THERMOPLASTIC SHEET AND EXTRUDED SHAPES

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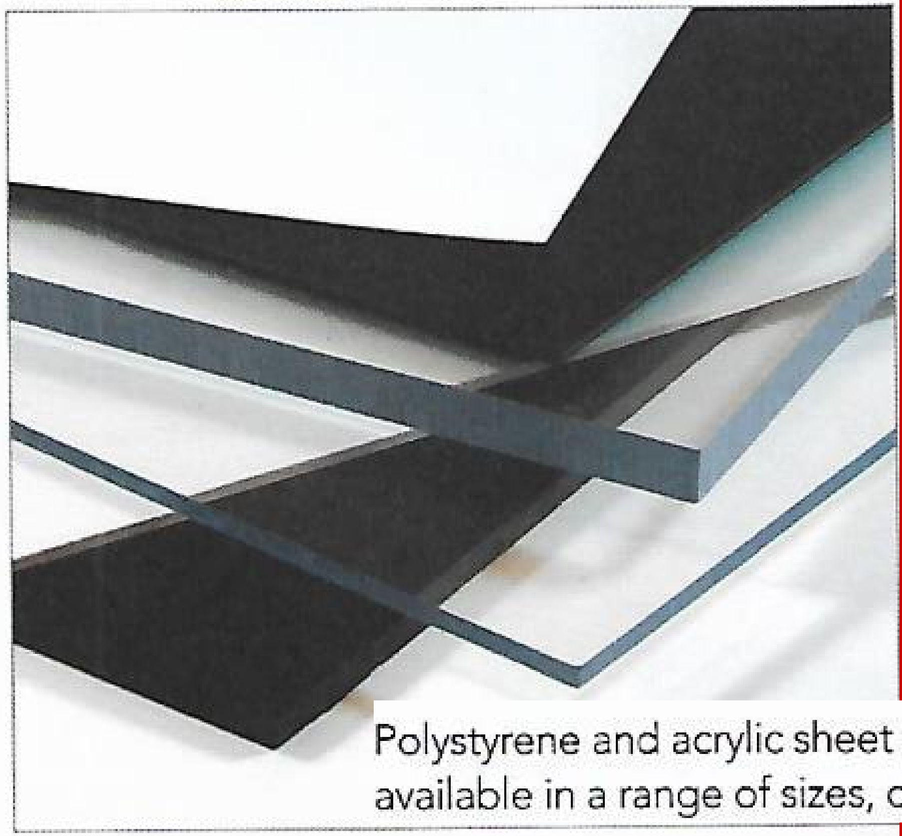
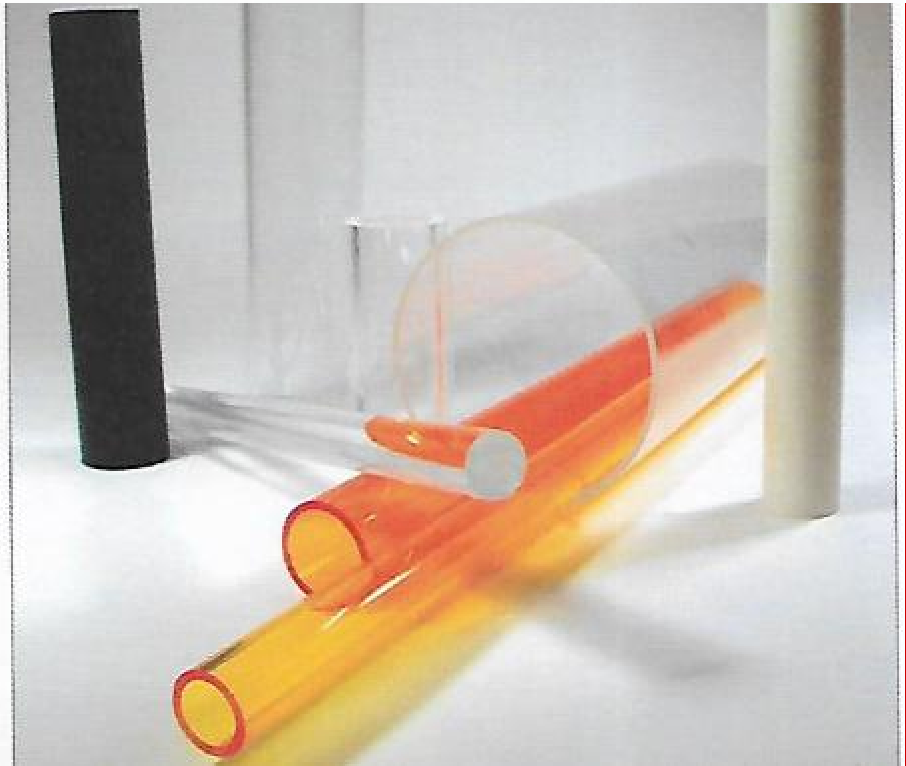
Acrylic (Perspex®) and polystyrene are especially easy to work with and make versatile, general-use modelmaking materials. Other plastics are used mostly for their particular properties: for example, polycarbonate (Lexan™) is tough and impact-resistant, whereas polypropylene is chemically resistant (which also makes it hard to glue or paint).

Plastic is an appropriate material for additive modelling, since pieces of tubing and sheet can be cut and combined with other materials, as well as with custom-printed parts.

Being creative with sourcing materials can save a great deal of time and money on a project. ABS drainpipe, available from building material retailers, is, for example a suitable and inexpensive modelling material. Polystyrene sheet



Polystyrene and acrylic sheet and tubing are available in a range of sizes, colours and finishes.



Thermoplastics include common household materials such as ABS, acrylic, polystyrene, polypropylene and polycarbonate. These plastics become liquid when heated to their viscous melting temperature, allowing for mass-production injection-moulding. Thermoplastics are also extruded or cast into different sizes of tubing and sheet, readily available through commercial retailers for fabrication.

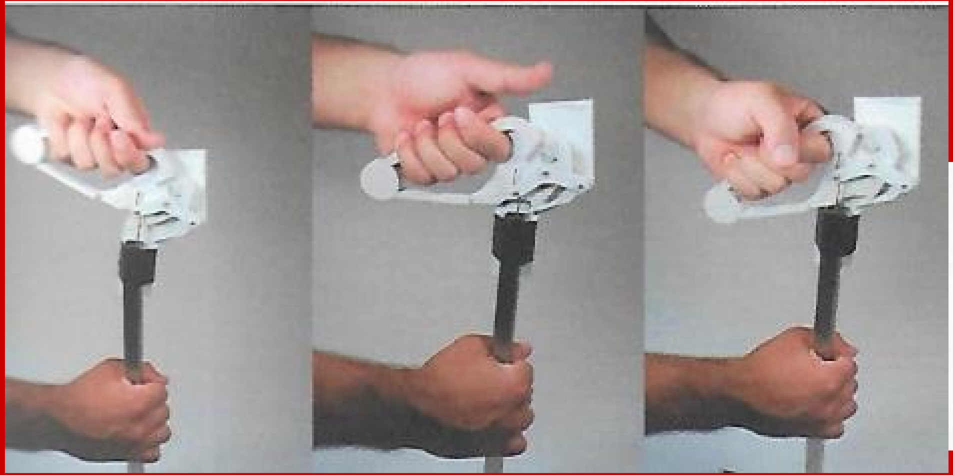
and extrusions made by Evergreen Scale Models are available in hobby shops internationally. These shapes also have the benefit of being designed to telescope.

Plastic is a very versatile material and is therefore used for both low- and high-fidelity models. In my own experience I have often used plastic for proof of works-like prototypes that augment my thinking when sketching and using 3D CAD. Polystyrene (often simply referred to as styrene) is particularly easy to work with and to create working prototypes of mechanisms. It is easy to add and subtract material in an ongoing fashion so as to test the mechanism. Two-dimensional CAD drawings can be transferred to sheets of styrene and cut out with a scroll saw or bandsaw.

This approach is shown in a project for Dana Douglas, a company specializing in products for the home healthcare market, such as mobility aids. The challenge was to rethink the brake mechanisms on rollators (rolling walkers). On previous products, brake handles were connected to brake levers on the rear wheels via bicycle-type cables. *The problem was that the cables could possibly snag on door handles and other obstructions. The objective was therefore to develop an internal rod-activated braking system without cables.*

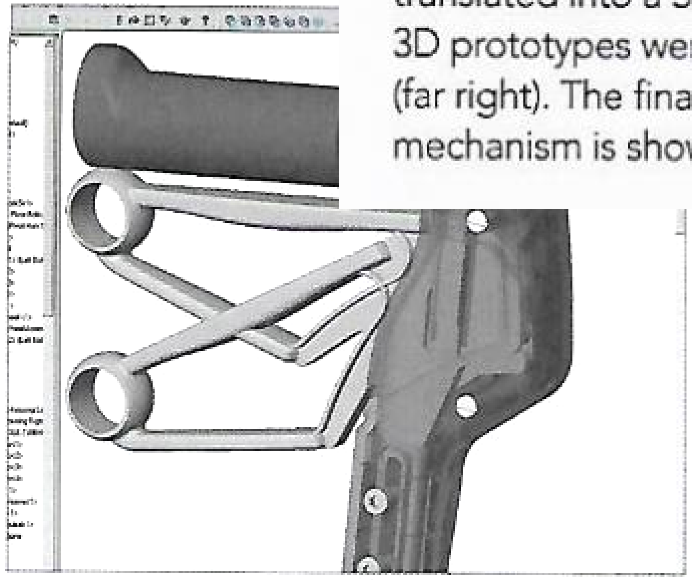
Evergreen Scale Models styrene extrusions and sheets are available in a range of sizes. They also are useful for telescoping structures (above).

These student projects incorporate clear plastic elements as part of their design. These high-fidelity appearance models make use of clear acrylic sheet.



A proof-of-concept model brake mechanism made from styrene sheet. This handmade works-like prototype could be altered quickly to better understand the design parameters for a new internal brake mechanism for a rollator (rolling walker).

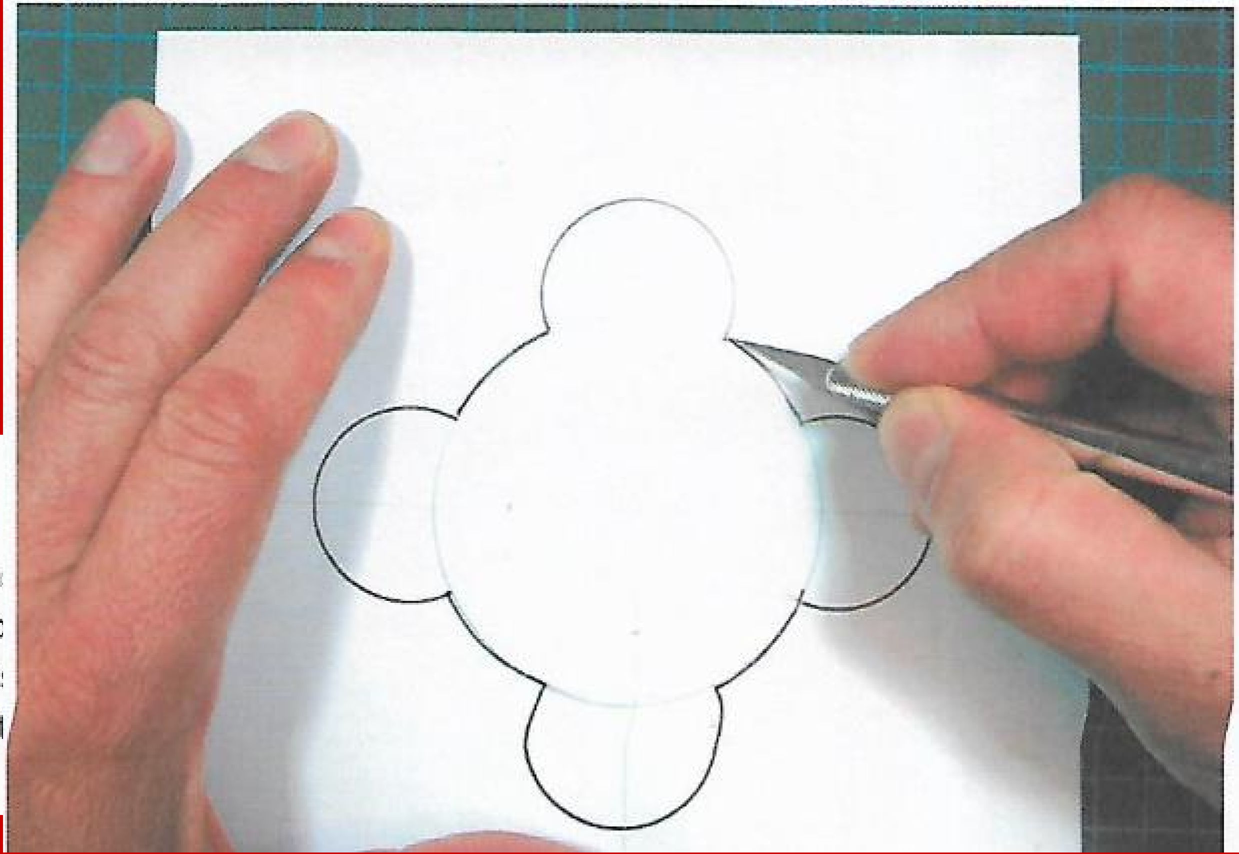
Modelmaking



Explorative work with sketches and simple 2D CAD and paper models progressed toward a simple works-like prototype made out of styrene. This made it much easier to develop an understanding of feasibility. The 3D CAD development was not initiated until the design parameters were better understood, utilizing the simple styrene prototype.

The learning gained from the styrene model was translated into a SolidWorks® 3D CAD model and 3D prototypes were printed for design verification (far right). The final rollator with internal brake mechanism is shown at right.

Thin styrene sheet and extrusions are very easily cut with hand tools. Sheet is usually scored and then broken. Curved outlines in sheet up to 1.5mm ($^1/_{16}$in) can be cut with a scalpel, by tracing an outline in several passes. Thicker materials need to be sawed.



Working with Plastics

Plastic sheet and shapes are worked through both manual and digital mean
Thinner sections of styrene can be worked right on the desktop with a scalp
whereas thicker materials typically require some power tools. Technologies
as laser cutting allow intricate outlines to be realized from simple 2D Illustrat
drawing files.

Acrylic and polycarbonate sheets are usually supplied with a paper or plastic protective cover that can be used to lay out a cutting outline. Intricate outlines can be cut quickly and effectively from a 2D Illustrator® file with laser cutters. Lasers can also deboss patterns and images, allowing for even greater design creativity.

CNC machining is used to machine complex geometry parts in plastic. This is often necessary when creating parts where the exact material qualities are required. Rapid prototyping materials are approximate and may not be applicable in all situations.

Gluing Plastics

Plastics are unique in that they can be solvent-bonded. The solvent melts the plastic, allowing molecules to move from one part to be joined to the other. The limitation is that only similar materials can be joined. However, many of these solvents are toxic and it is critical to read the SDS information for the glue. Cyanoacrylate (super glue) is a popular modelmaking glue and will also allow dissimilar materials to be joined (see Chapter 14, page 125). Polypropylene and polyethylene are virtually impossible to glue and should instead be mechanically joined with screws or rivets.

Filling

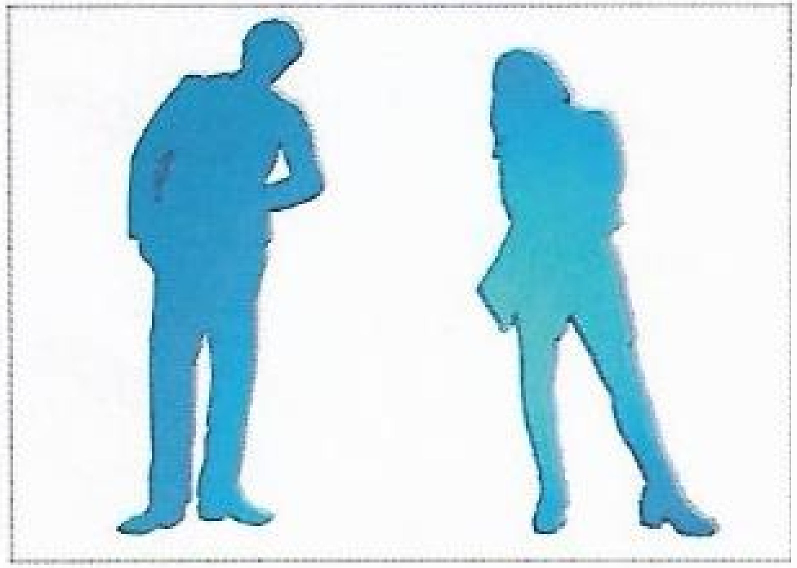
The fillers used with plastics are identical to those suitable for polyurethane modelling boards. Plastic parts can therefore easily be blended with other materials and painted smooth.

Painting and Finishing

Styrene can be painted to simulate many other materials, including metals. It is often easier to make parts in styrene and paint them in a metal finish than to make parts in steel or aluminium. This can be a useful simulation for appearance models, as shown in the tutorial at the end of this chapter.

Thermoforming

Heated thermoplastics reach a soft, formable state at a temperature referred to as the glass transition point. ABS, acrylic and styrene reach this glass transition point at a much lower temperature than their viscous melting temperatures. Heat can therefore be easily used to form thermoplastic amorphous materials such as styrene into various shapes. The simplest form of thermoforming is with a heat gun or heat bender. The material is heated and then set in a form or simply clamped into shape until it cools and sets.



Acrylic can be cut quickly and accurately using a laser cutter.

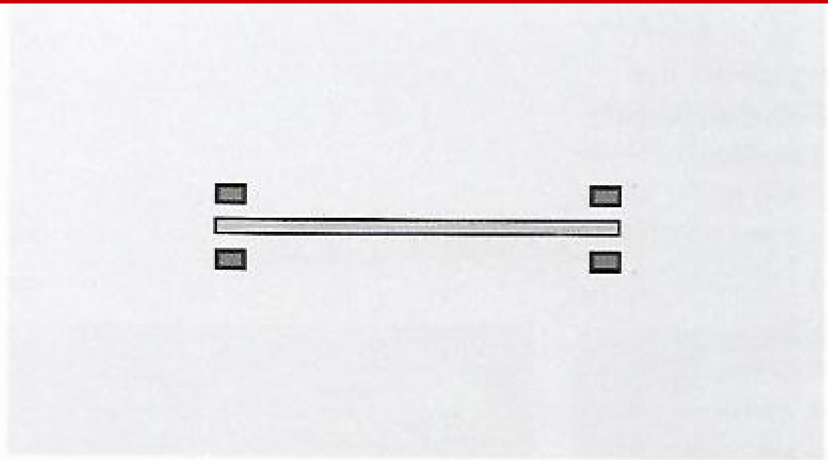
Fine-detail CNC-machined ABS prototype. These parts were machined with a very fine-ball end-mill cutter (1.5mm/0.06in dia.).

A barbecue utensil is heat-formed with a strip heater and hand-held heat gun. Plastic tubes can be thermoformed without collapsing by first filling them with sand and capping the ends (left).

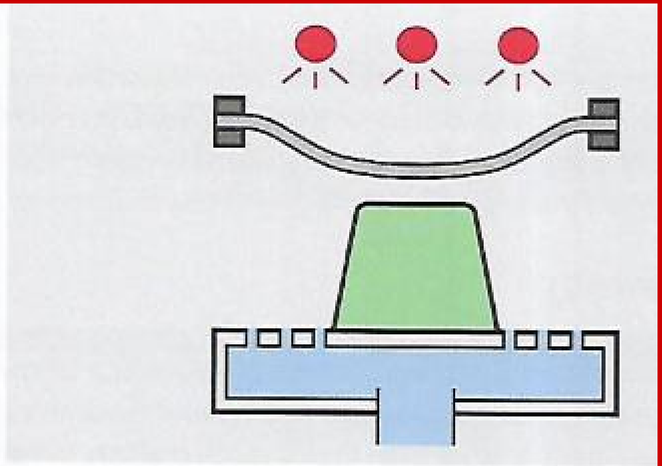
Vacuum forming is a simple and economical approach to making clear plastic parts or multiples using basic tools made from wood or polyurethane board

Vacuum Forming

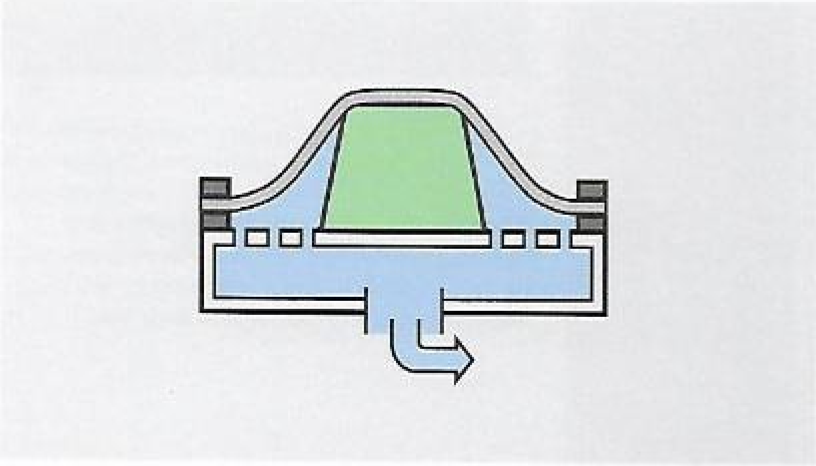
More complex three-dimensional shapes can be created with vacuum forming, using simple handmade or CNC-machined tooling. This is also a good method for creating multiple parts and a more economical way for students to prototype larger parts than is usually feasible through 3D printing. In industry, vacuum forming is used to produce anything from packaging to larger plastic panels such as refrigerator doors. The advantage of this method is that it is a low-pressure process that requires only simple moulds and equipment. The basic ingredients are: a sheet of plastic held in a rigid frame, a mould (to shape the plastic over), an oven and a vacuum source to pull the heated plastic sheet over the mould.



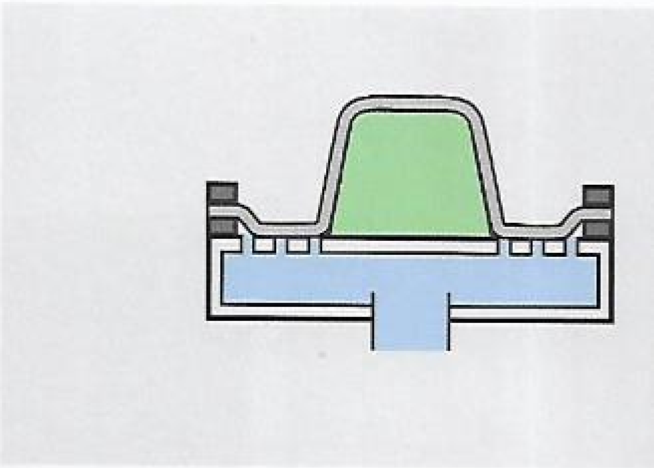
Stage 1: Sheet material is clamped in a metal frame.



Stage 2: The sheet material is heated until it starts to sag and is then brought over the mould (shown in green).



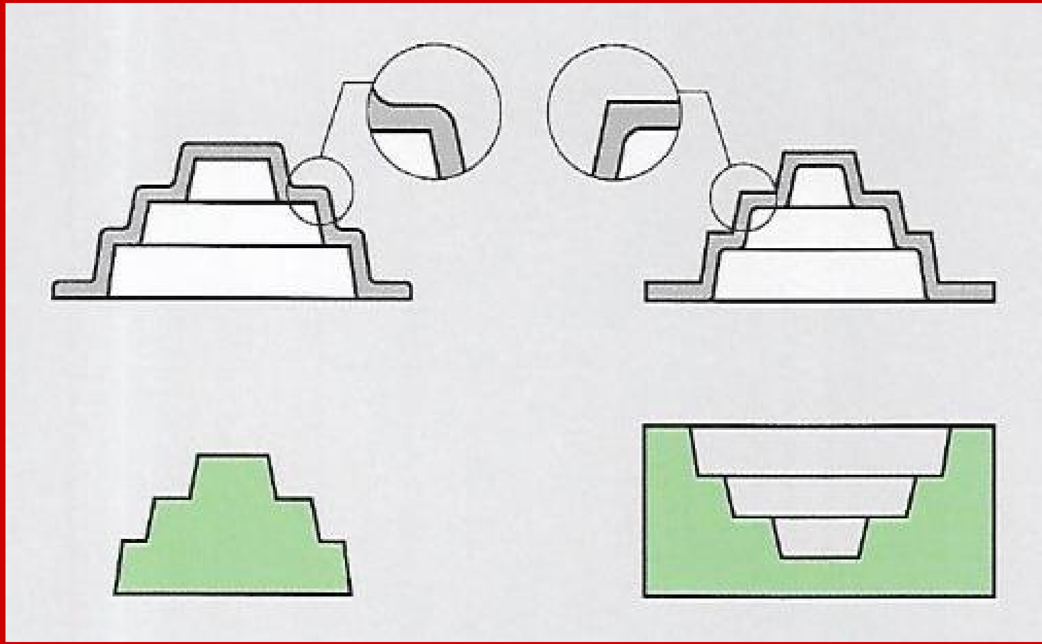
Stage 3: The material is stretched over the mould, making an airtight seal between the mould base and the clamping frame.



Stage 4: Vacuum is applied, sucking the plastic tight against the mould. The part is then removed and trimmed of excess plastic.

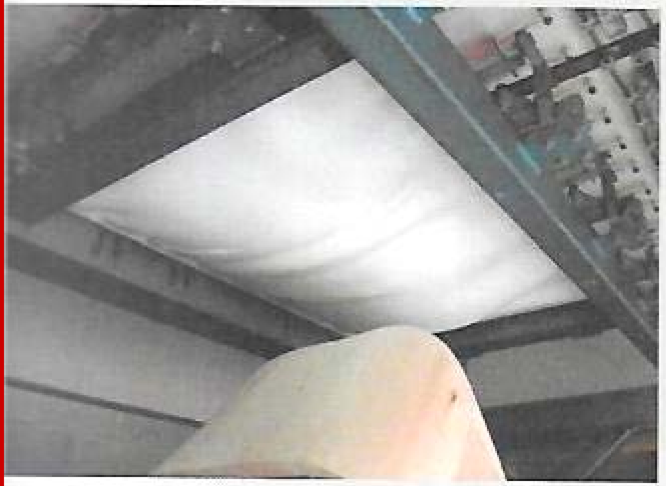
Positive male moulds are more commonly used, but since the material is pulled on top of the mould, the material offset makes all the edges and corners smooth. The thicker the material, the more pronounced the effect. Negative female moulds are created by machining a cavity, into which the heated plastic material is pulled. Negative moulds are usually more complex to manufacture, but offer the benefit of capturing sharp details on the exterior of the vacuum-formed part.

Parts produced on positive moulds have rounded edges (left), whereas negative moulds will allow sharp detail to be transferred to the outside of the part (right).

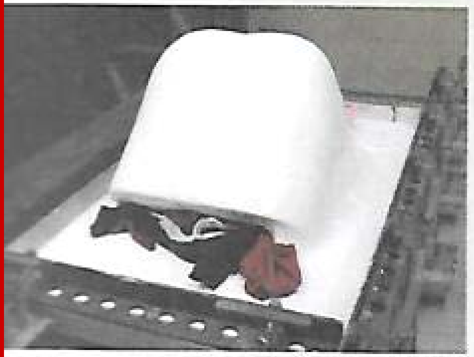


In order to be able to remove the plastic after forming, it is important to follow some specific rules for vacuum forming. Plastic materials will shrink when cooled, so the tools are usually built slightly oversized incorporating the shrinkage rate (this varies from plastic to plastic, but 1 per cent is not unusual). The walls of the tool should have a taper since the plastic shrinks onto the tool as it cools. The taper, also known as a draft angle, enables the part to be removed. Draft angles of 3 to 5 degrees are advisable. The tool must also not have any geometry that has a negative angle or overhang. This situation, also known as an undercut, will permanently lock the part onto the tool. Deeper parts may have problems such as webbing or thinning. Negative moulds require less draft (since material will shrink away from walls) and tend to prevent webbing from occurring. For larger and more extensive projects the references listed at the end of the book may prove useful.

The vacuum-forming mould was made by laminating pieces of wood and shaping with rasps, sanders and templates.



A clamped sheet of styrene plastic is heated under the vacuum-forming oven until it starts sagging and is then pulled down over the positive plug by the vacuum and cooled into shape.

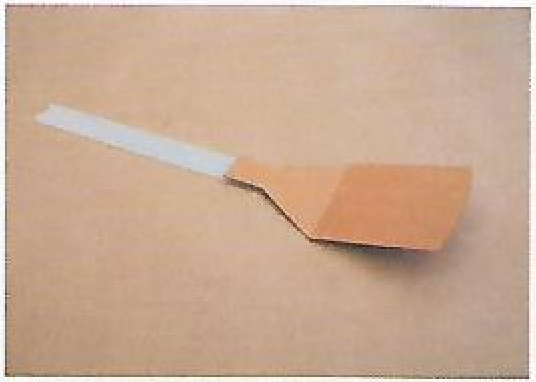


Large vacuum-forming projects require some experimentation in order to achieve proper pulls. With the bugs worked out, the black piece (middle) is ready to be trimmed and painted for the final model (right).

Tutorial Barbecue Utensil

The following tutorial shows how plastic sheet and extrusions can be used to prototype various parts and simulate different materials. An appearance model of a barbecue spatula was made from acrylic sheet and an extruded plastic pipe. Metal was simulated with metallic paint and the rubber handle was simulated with flat paint (rubber appears flat). The focus here was to study and communicate appearance rather than functionality.

Planning: The initial design is planned with sketches and drawings as well as very quick full-scale explorative prototypes in cardboard to establish overall proportions as well as the proper ergonomic angle of the spatula.



Spatula Step 1 The spatula shape is cut out from acrylic sheet on a laser cutter. Two variations of the design are initially cut out to examine visual alternatives. The file for the laser cutter is an Illustrator® drawing.

Spatula Step 2 A chamfer is added with a file and then sanded smooth. This would have been difficult to achieve in metal and would have required machine tools.

Spatula Step 3 The spatula is now bent using heat. First the plastic is heated on the exact line of the bend using a strip heater (far left). When the plastic softens it is carefully bent using a piece of wood as a forming jig (left).

Rubber Handles Step 1 The rubber handle pieces are simulated using a plastic tube. The cross sections of the handle pieces correspond to a section of a cylinder. 3.8cm (1.5in) diameter plastic tubing is trimmed on a bandsaw. It is essential to have adequate training and supervision when using power equipment such as a bandsaw. Note how the lateral push stick has a V-notch taken out of it to hold the circular tube better.

Rubber Handles Step 2 To make the handle pieces appear solid the ends are capped off with a semicircular section of plastic glued on with cyanoacrylate glue. These parts are now ready for primer and paint.

Paint Step 2 The spatula is painted with a metallic water-based paint to simulate metal. The handles are painted in a flat black colour to simulate rubber. Several thin coats are used to ensure good coverage without drips.

Final Assembly The handles could easily be glued to the spatula at this point. By using double-sided tape, however, it is possible to transfer the handles from one spatula to the next, so as to evaluate the two options side by side.

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