University of Jordan

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Processing of Plastics

3) Thermoforming

When a thermoplastic sheet is heated it becomes soft and pliable and the techniques for shaping this sheet are known as thermoforming. This method of manufacturing plastic articles developed in the 1950s but limitations such as poor wall thickness distribution and large peripheral waste restricted its use to simple packaging applications. In recent years, however, there have been major advances in machine design and material availability with the result that although packaging is still the major market sector for the process, a wide range of other products are made by thermoforming. These include aircraft window reveals, refrigerator liners, baths, switch panels, car bumpers, motorbike fairings etc.

The term thermoforming incorporates a wide range of possibilities for sheet forming but basically there are two subdivisions: vacuum forming and pressure forming.

(a) Vacuum Forming

In this processing method a sheet of thermoplastic material is heated and then shaped by reducing the air pressure between it and a mould. The simplest type of vacuum forming is illustrated in Fig. 1. This is referred to as *Negative Forming* and is capable of providing a depth of draw which is 1/3-1/2 of the maximum width. The principle is very simple: a sheet of plastic, which may range in thickness from 0.025 mm to 6.5 mm, is clamped over the open mould. A heater panel is then placed above the sheet and when sufficient softening has occurred the heater is removed and the vacuum is applied. For the thicker sheets it is essential to have heating from both sides.

In some cases Negative Forming would not be suitable because, for example, the shape formed in Fig. 1 would have a wall thickness in the corners which is considerably less than that close to the clamp. If this was not acceptable then the same basic shape could be produced by *Positive Forming.* In this case a male (positive) mould is pushed into the heated sheet before the vacuum is applied. This gives a better distribution of material and deeper shapes can be formed, depth to width ratios of 1:1 are possible. This thermoforming method is also referred to as *Drape Forming.*

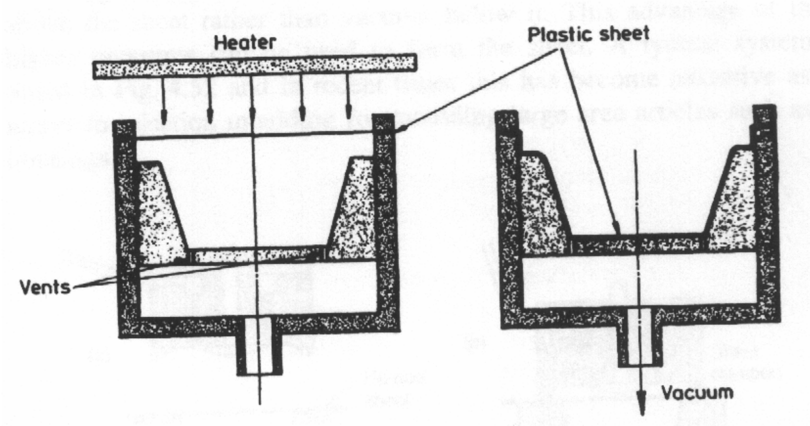


Fig. 1 Vacuum forming process

Another alternative would be to have a female mould as in Fig. 1 but after the heating stage and before the vacuum is applied a plug comes down and guides the sheet into the cavity. When the vacuum is applied the base of the moulding is subjected to less draw and the result is a more uniform wall thickness distribution. This is called *Plug Assisted Forming* and shown in figure 2.

Note that both positive Forming and Plug Assisted Forming effectively apply a pre-stretch to the plastic sheet which improves the performance of the material quite apart from the improved wall thickness distribution.

Plug-assisted vacuum forming

- Better wall thickness uniformity especially for cup or box shapes
- Materials of plug include wood, metal, thermoset polymers.
- Plug is 10% - 20 % smaller than cavity.

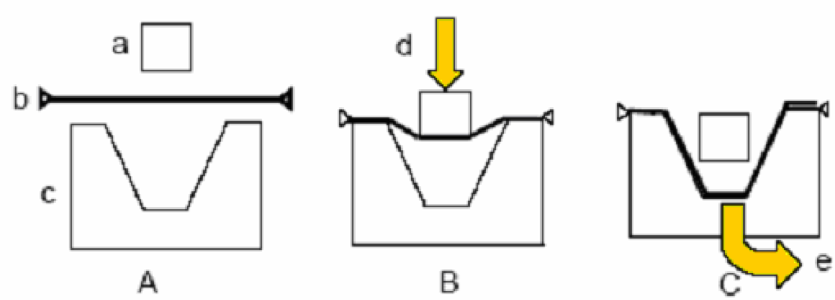


Fig. 2 Plug Assisted Vacuum Thermoforming

In the packaging industry *skin* and *blister* vacuum machines are used. Skin packaging involves the encapsulation of articles between a tight flexible transparent skin and a rigid backing which is usually cardboard. Blister packs are preformed foils which are sealed to a rigid backing card when the goods have been inserted. The heaters used in thermoforming are usually of the infra red type with typical loadings of between 10 and 30 kW/m^2. Normally extra heat is concentrated at the clamped edges of the sheet to compensate for the additional heat losses in this region. The key to successful vacuum forming is achieving uniform heating over the sheet.

One of the major attractions of vacuum forming is that since only atmospheric pressure is used to do the shaping, the moulds do not have to be very strong. Materials such as plaster, wood and thermosetting resins have all been used successfully. However, in long production runs mould cooling becomes essential in which case a metal mould is necessary. Experience has shown that the most satisfactory metal is undoubtedly aluminum. It is easily shaped, has good thermal conductivity, can be highly polished and has an almost unlimited life.

Materials which can be vacuum formed satisfactorily include polystyrene, ABS, PVC, acrylic, polycarbonate, polypropylene and high and low density polyethylene. Co-extruded sheets of different plastics and multi-colour laminates are also widely used nowadays. One of the most recent developments is the thermoforming of crystallizable PET for high temperature applications such as oven trays. The PET sheet is manufactured in the amorphous form and then during thermoforming it is permitted to crystallize. The resulting moulding is thus capable of remaining stiff at elevated temperatures.

(b) Pressure Forming

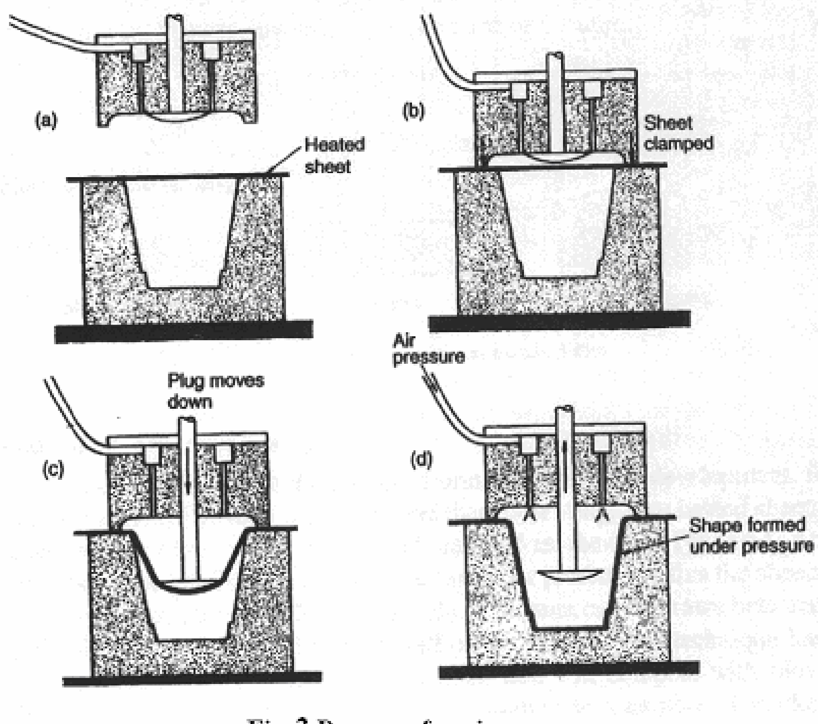


Fig. 3 Pressure forming process

This is generally similar to vacuum forming except that pressure is applied above the sheet rather than vacuum below it. The advantage of this is that higher pressures can be used to form the sheet. A typical system is illustrated in Fig. 3 and in recent times this has become attractive as an alternative to injection moulding for moulding large area articles such as machine housings

(c) Matched Die Forming

A variation of thermoforming which does not involve gas pressure or vacuum is matched die forming. The concept is very simple and is illustrated in Fig. 4. The plastic sheet is heated as described previously and is then sandwiched between two halves of a mould. Very precise detail can be reproduced using this thermoforming method but the moulds need to be more robust than for the more conventional process involving gas pressure or vacuum.

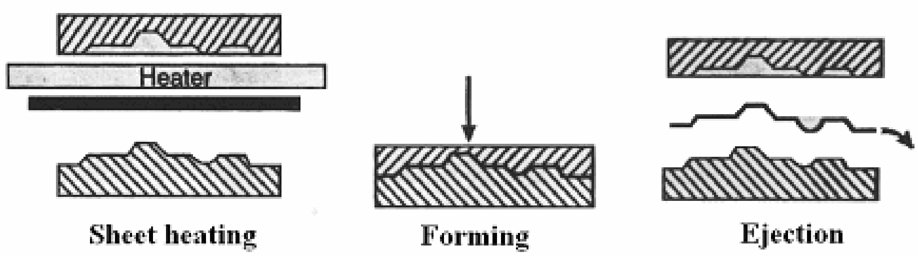


Fig. 4 Thermoforming between matched dies

(d) Dual-Sheet Thermoforming

This technique, also known as Twin-Sheet Forming, is a recent development. It is essentially a hybrid of blow moulding and thermoforming. Two heated sheets are placed between two mould halves and clamped as shown in Fig. 5. An inflation tube at the parting line then injects gas under pressure so that the sheets are forced out against the mould. Alternatively, a vacuum can be drawn between, the plastic sheet and the mould in each half of the system. This technique has interesting possibilities for further development and will compete with blow moulding, injection moulding and rotational moulding in a number of market sectors. It can be noted that the two mould halves can be of different shapes and the two plastic sheets could be of different materials, provided a good weld can be obtained at the parting line.

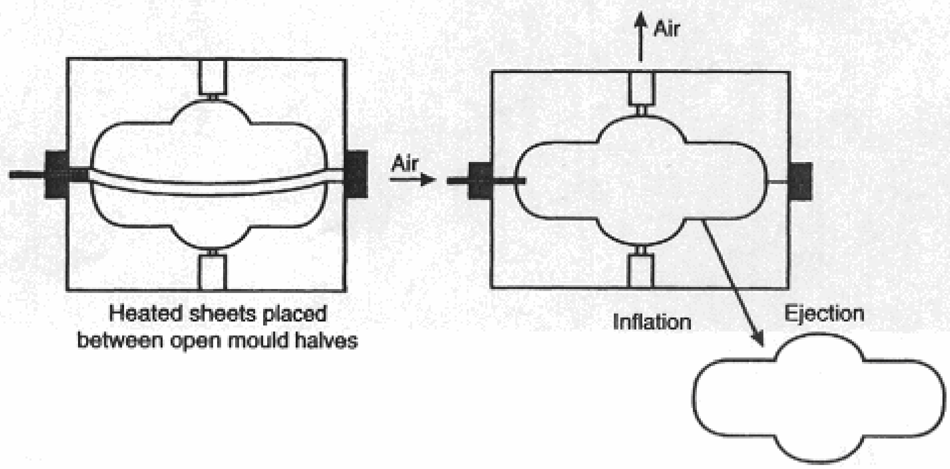


Fig. 5 Dual sheet forming

Advantages of Thermoforming Process

- Low temperature, pressure requirement
- Low mold cost, machine cost
- Large parts
- Fast mold cycles

Disadvantages of Thermoforming Process

- High cost of raw materials (sheets), scraps
- Limited part shapes
- Only one side of part defined by mold
- Inherent wall thickness nonuniformity
- Residual stresses

Analysis of Thermoforming

If a thermoplastic sheet is softened by heat and then pressure is applied to one of the sides so as to generate a freely blown surface, it will be found that the shape so formed has a uniform thickness. If this was the case during thermoforming, then a simple volume balance between the original sheet and the final shape could provide the wall thickness of the end product.

$$A_i h_i = A_f h_f$$

Where A = surface area, and h = wall thickness *('i'* and *'J'* refer to initial and final conditions).

Consider the thermoforming of a plastic sheet of thickness, ho, into a conical mould as shown in figure 6. At this moment in time, t, the plastic is in a contact with the mould for a distance, S, and the remainder of the sheet is in the form of a spherical dome of radius, R, and thickness, h. From the geometry of the mould the radius is given by:

$$R = \frac{H - S\sin(\alpha)}{\sin(\alpha)\tan(\alpha)}$$

Also the surface area, A, of the spherical bubble is given by:

$$A = 2\pi R^2 (1 - \cos(\alpha))$$

It can be shown that the wall thickness distribution is given by:

$$\frac{h}{h_o} = \left(\frac{1+\cos(\alpha)}{2}\right)\left[\frac{H-L}{H}\right]^{\sec(\alpha)-1}$$

The above equation may also be used to calculate the wall thickness distribution in a deep truncated cone shapes but note that the equation is only valid up to the point when the spherical bubble touches the centre of the base.

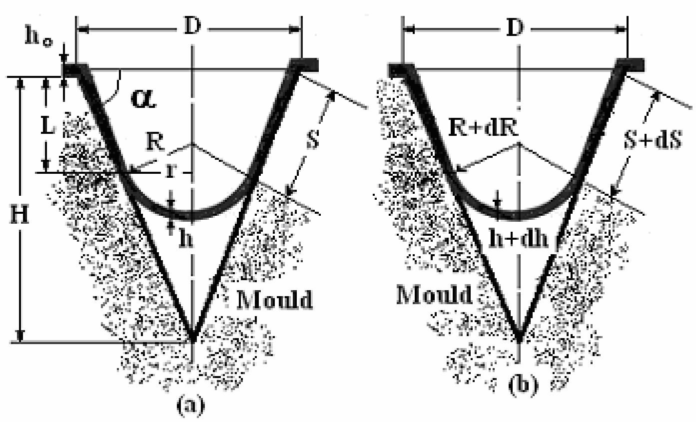


Fig. 6 Analysis of thermoforming

Example 1:

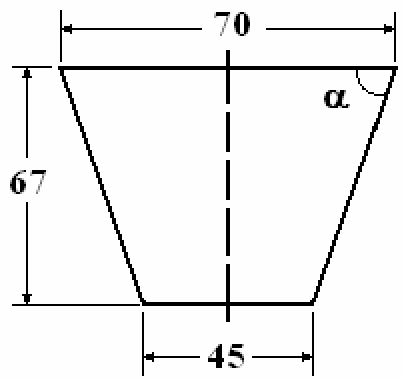
A rectangular box 150 mm long, 100 mm wide and 60 mm deep is to be thermoformed from a flat sheet 150mm x 100 mm x 2 mm. Estimate the average thickness of the walls of the final product if:

a) Conventional vacuum forming is used.

b) Plug assisted moulding is used (the plug being 140 mm x 90 mm).

Example 2

A small flower pot as shown in the following figure is to be thermoformed using negative forming from a flat sheet 2.5 mm thick. If the diameter of the top of the pot is 75 mm, the diameter of the base is 45 mm and the depth is 67 mm estimate the wall thickness of the pot at a point 40 mm from the top



Thermoformed flower pot