Module 4. Thermoforming

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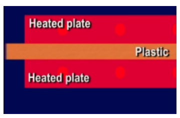
What attributes of the LEGO base plate shown make it not suitable for injection molding?

Thermoforming is usually used to manufacture relatively simple geometries from thin plastic sheets. For example, the lids of disposable coffee cups, pill blister packaging, inexpensive plastic packaging, and large items such as bathtubs and internal door liners for refrigerators. Thermoforming is also used to manufacture large components such as automotive interior panels and small boat hulls. In thermoforming products, dimensional tolerances are typically less critical, and production has lower cost due to lower cost of thermoform tooling compared to injection mold tooling.

What is thermoforming?

(Click for video link)



Thermoforming consists of two main steps: heating and forming. Heating is usually by radiant electric heaters, located on one or both side of the plastic sheet at a distance of normally 10 cm. Duration of the heating cycle needed to soften the sheet depends on the polymer, its thickness and color.

Some Examples (click for video):

- Boats
- Coffee cup lid
- Pharmaceutical Blister Packs

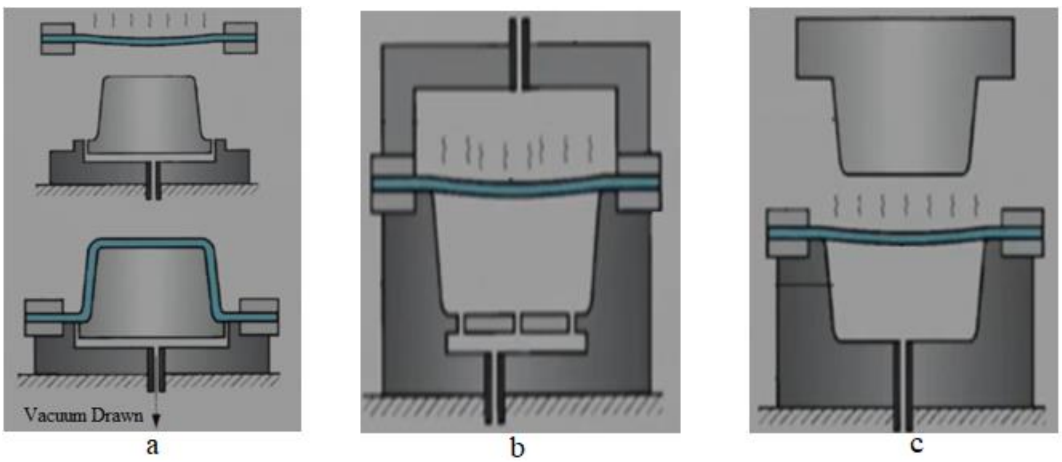
Module Objective:

1. Recognize parts that are thermoformed and identify the machine and tooling configurations for thermoforming.
2. Understand how heated polymer sheets respond to stretch, and the limits imposed by polymer mechanics, along with the required power and time for preheating the sheet.

Thermoforming process:

Definition: Heating a thermoplastic sheet, then shaping it by forcing it against a mold using vacuum or air pressure. The common methods are:

- **Vacuum thermoforming:** Negative pressure is used to draw a preheated sheet into a mold cavity.
- **Pressure thermoforming (blow forming):** A positive pressure is used to force the preheated plastic into the mold cavity.
- **Mechanical thermoforming:** It uses matching positive and negative molds that are brought together against preheated plastic sheet. Compared with the other two methods, this process has a better dimensional control on both side of the part. But, its more expensive to manufacture both side of the mold (positive and negative).



Schematic of a) Vacume forming b)Blow forming c) Mechanical forming

The Four attributes:

Cost: low **Rate:** high **Quality:** low **Flexibility:** low

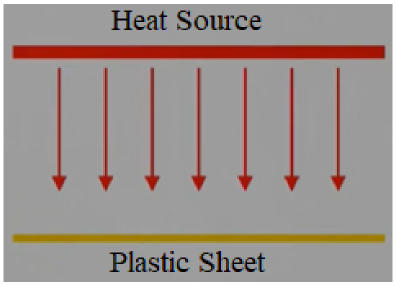
Engineering analysis of thermoforming:

Three factors limit the thermoforming process:

- Heating
- Stretching
- Cooling

Heating is usually a slowest step in thermoforming since it is limited by the rate of convective and radiative heat transfer, as well as heat losses. In a continuous process, the rate of heat transfer also determines the feed rate of the plastic sheet. Usually infrared heating lamp (radiation) is used as source of heating. The temperature range is defined between the material melting point and the point at which Young's Modulus significantly decreases (the glass transition).

Consider heating a sheet using a heating lamp. Since the sheet is thin, the temperature in the sheet is uniform.



Assume the lamp power is P and the absorption coefficient of the sheet is a. The amount of heat delivered to the sheet per unit area q can be calculated as:

$$q = P.a$$

The change in the plastic temperature is related to the amount of heat q, the density, thickness, and specific heat of the plastic sheet by:

$$\frac{dT}{dt} = \frac{q}{\rho h C_p}$$

From these two equations:

$$dt = \frac{\rho h C_p}{aP} dT$$

Integrating for the duration of heating (t_{heat}), assuming the temperature rise in the sheet is from T_0 (initial temperature) to T_f (the final or forming temperature):

$$\int_0^{t_{heat}} dt = \int_{T_0}^{T_f} \frac{\rho h C_p}{aP} dT$$

$$t_{heat} = \frac{\rho h C_p}{aP} (T_f - T_0)$$

Consider a heater with length L_{heater}, then in continuous process the feed rate is:

$$V_{feed} = \frac{L_{heater}}{t_{heat}}$$

Example) Determine the feed rate in a continuous thermoforming machine for a 1.2 mm thick sheet of PMMA(*Poly.methyl.meth.acrylate*) given that it must be heated from room temperature (24 ℃) to the forming temperature of 225℃. A heater with length of 1m and power 200 kW/m^2 is used. The density and specific heat capacity of the sheet are 945 kg/m^3 and 2000 J/kg-∘C. The absorption coefficient a is 0.84?

Areal draw ratio

The ratio between the surface area of the final part and the surface area of the unformed sheet:

$$R_A = \frac{Surface\ area\ of\ formed\ part}{Surface\ area\ of\ sheet\ used\ to\ form\ part}$$

Maximum areal draw ration for some common plastic sheet is summarized below:

Polymer	Suggested Max R_A	Suggested Temperature (℃)
PMMA	3.5	155
ABS	5.5	120
PVC	4.2	120
LDPE	6	140
PP	7.5	175