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Understanding Thermoforming

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6 Machines for Other Applications

Descriptions of traditional thermoformers are detailed in Chapters 4 and 5. Often, thermoformers are designed for very specific applications. Light-gauge thermoforming, which plays an important role in rigid form, fill, and seal (RFFS) operations, is described in detail in Chapter 5. Other applications are detailed in this chapter.

6.1 Extrusion-Forming Lines

For long-run and specialized applications, the extrusion line is sometimes married to the thermoforming line, for both heavy-gauge and light-gauge production. That is, the sheet from the extrusion line is fed directly to the thermoforming machine. As an example, a typical heavy-gauge extrusion-forming line is shown schematically in Fig. 6.1.

Extrusion line feeding directly to the thermoforming line

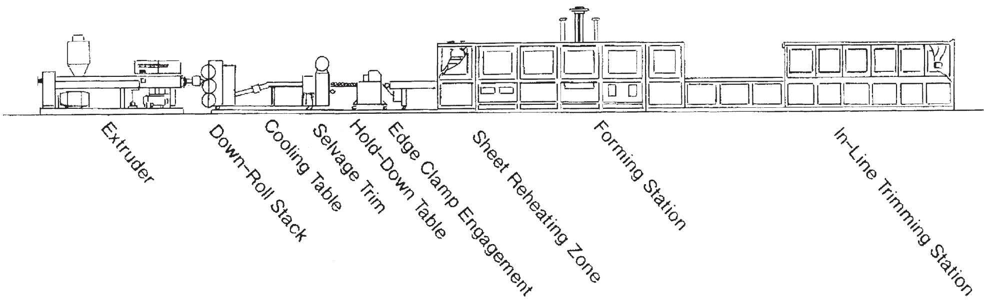

Figure 6.1: Heavy-gauge extrusion-forming line

We will consider the advantages and disadvantages to this concept in the following.

6.1.1 Advantages of Extrusion-Forming Lines for Heavy-Gauge Forming

The sheet is never handled between the extruder and the former. Therefore, there is less opportunity for damage to the sheet. The core of the sheet remains warm as it enters the forming oven. As a result, the temperature throughout the sheet is far more uniform at the time of forming than that for a sheet that is fed cold to the oven. The cost for reheating is minimized.

6.1.2 Advantages of Extrusion-Forming Lines for Light-Gauge Forming

The thermoforming machine is standard, unlike the thermoformer for in-line heavy-gauge operations. The sheet is not handled between the extruder and the former. Roll damage is avoided and the sheet cannot take a curl or set as rolled sheet can. This is particularly important for sheet with a thickness of more than about 0.040 in (1.0 mm) and for certain polymers such as polypropylene (PP) that continue to crystallize for some time after extrusion. The core of thicker sheet remains warm as it enters the pin-chain. This additional heat aids in the heating process, particularly with semicrystalline polymers such as PP that require additional preheating.

6.1.3 Disadvantages of Extrusion-Forming Lines for Heavy-Gauge Forming

Short runs using sheet of specific cut dimensions are used for many heavy-gauge forming operations. The in-line technology is suitable for very limited long-run applications such as refrigerator door liners. As a result, there are few applications for the in-line technology. Whenever the thermoforming line is down, the extrusion line must go down as well, unless, of course, the sheet can be guillotined and palletized while waiting for the thermoforming line to come up again. Standard shuttle and rotary presses are not designed to handle the continuous feed from the extruder. Cabinet presses can be fitted with continuous parallel rails to accept the feed, with the traditional light-gauge pin-chain arrangement replaced with mechanical or pneumatic edge clamps. Special-purpose machines have been designed to accept the continuous feed. These machines often resemble light-gauge press designs. They may also include in-machine trimming and robotic stacking stations, although robustly designed to handle heavy-gauge sheet. These special designs cost considerably more than the traditional heavy-gauge machinery.

6.1.4 Disadvantages of Extrusion-Forming Lines for Light-Gauge Forming

The in-line light-gauge thermoforming technology is ideal for very long runs, more typical of captive operations than custom shops. As with all in-line operations, the extruder output is slaved to the throughput and the cycle time constraints of the thermoformer. Whenever the thermoformer is down even momentarily, the extruder must also go down. For long thermoformer down times, the extrudate is usually fed to the traditional roll stacks. Inspection of sheet quality obviously must be done between the extruder roll stack egress and the thermoforming pin-chain ingress. Visual inspection is not as efficient as computer-aided optical inspection. Because thin sheet, typically less than 0.020 in (0.5 mm) in thickness, loses thermal energy so quickly, there is no energy advantage using the in-line process.

6.1.5 Important Extruder Characteristics in In-Line Forming

The extruder used in nearly every in-line operation should be optimally configured for the polymer being processed. The throughput capacity should be matched to the optimum throughput capacity of the thermoforming machine. Flat sheet dies are used for heavy-gauge sheet extrusion with the sheet width controlled with deckle bars inserted in the die block. Standard roll stacks are used to cool the sheet prior to presenting it to the in-line thermoformer.

Extruder throughput matched to optimum thermoformer capacity

A more serious issue occurs with light-gauge lines. Often the extruded sheet is quite wide but the output in lb/hr (kg/hr) demanded by the thermoforming machine is small. As a result, the optimum screw diameter may be small but the flat die width must be large. Wide dies are often the source of non-uniform sheet caliper. This forces the roll stack nip to redistribute the plastic, an effect that often leads to non-uniform cross-machine orientation in the sheet. An annular die provides a partial solution but care must be taken to minimize wrinkles when splitting and flattening the tubular extrudate prior to the roll stack. Annular die start-up is often difficult, an issue that is particularly vexing for momentary interruptions in the thermoforming cycle.

There is an overarching management concern with in-line extruder-former operations. Extruder management relies on throughput of quality sheet as a measure of efficiency. Thermoforming management depends on quality of discrete products as a measure of efficiency. To achieve a sheet of a given width, the extruder capacity is usually quite large compared to the throughput capacity of the thermoformer. It is imperative that management realizes that thermoforming controls nearly every aspect of the in-line process. Management cannot penalize the extrusion operation because it often operates very inefficiently.

Thermoforming controls every aspect of in-line process

6.2 Matched Mold Forming Machines

Foamed polymers, composites, and composite laminates are quite difficult to form with single-sided tooling. Low-density foams such as polystyrene (PS) and polyolefins (PO) are not easily vacuum-formed and will collapse when pressure formed. Composites, meaning polymers compounded with fibers or fillers, are often too stiff to be formed even with pressures of more than 200 psi (1.4 MPa). If pressures higher than 200 psi are required, pressure boxes usually require special unfired pressure vessel certifications. Composite laminates, meaning polymers that are laminated with non-polymers such as metal foil or cardboard, are also too stiff to be pressure-formed. As a result, two-sided tooling, often called matched tooling or matched molds, is required. The presses for forming these materials must be robust enough to support upper and lower platens.

6.2.1 Foamed Polymer Machines

Special thermoformers are used to heat and form low-density foams. The technology used for these machines is based on light-gauge technology. Typically, the foam thickness ranges from 0.050–0.200 in (1.25–5 mm) and the foam density ranges from 2–10 lb/ft^3 (30–150 kg/m^3). The sheet is typically held at its edges with pin chains. The ovens are relatively long so that the foam is gradually and uniformly heated to its forming temperature range but not to the point where the foam catastrophically collapses. As a result, heater temperatures are often quite low when compared with oven temperatures of traditional unfoamed polymer thermoformers. The oven may contain as many as six sheet indexes. Heater energy efficiency is secondary to sheet temperature uniformity. Although quartz, ceramic, and other advanced heating sources have been used in thermoforming for many years now, foamed polymer machines may still be operating with decades-old metal rod heaters.

Long ovens

Low heater temperature

When the sheet is indexed to the forming press, the lower mold half is raised through the sheet plane. Then mold cavity is evacuated as the upper mold half is lowered into the sheet. In simple presses, the air is simply forced from the mold cavity through sizeable vent holes by the action of the upper mold half. In more complex presses, the air is evacuated pneumatically in a manner similar to that for traditional light-gauge thermoforming.

Low applied forces

Because the applied forces are very low, the platen drivers and the press frame strengths do not need to be high. The press design must include provision for mold coolant lines. Because these machines see relatively low oven temperatures and press forces, their maintenance is low and they have great longevity.

6.2.2 Composite and Composite Laminate Machines

Special machine designs, in particular the forming press

Nearly all the machines built for the composite and composite laminate industry are special purpose, heavy-gauge machines. Many advances in this area are attributable to developments in transportation technology. As examples, an interior truck door panel may be formed from a laminate of polyvinyl chloride (PVC), sound-deadening foam, and cardboard. An automotive bumper may be formed from continuous glass-reinforced thermoplastic polyolefin (TPO). A sanitary tub may be formed from an acrylic (PMMA) sheet that is backed with thermosetting fiberglass-reinforced polyester (FRP), with the FRP cured during the forming step. Machines capable of heating and forming these and other products require special designs. Nevertheless, their components are basically similar to those used in conventional formers. Sandwich ovens using radiant heat are often employed. Sheet handling is similar to that used in traditional heavy-gauge forming. The major design difference occurs in the forming press. These presses are obviously very robust and are more akin to those used in compression molding rather than those used in thermoforming.

6.3 Wheel Machines

Wheel machines, sometimes called *Ferris-wheel* or melt-to-mold machines, are designed for vacuum-formed, light-gauge, shallow draw parts that are needed in extremely high volume. The machine is designed to eliminate the standard extrusion-to-rollstock and reheat-to-form thermoforming sequence. Extrudate from a flat sheet die is laid directly onto the surface of a horizontal wheel that contains a set of molds. The wheel is electrically driven through a gearbox. Usually the output rate of the extruder is slaved to the speed or rotation of the wheel. The rotating wheel includes water, vacuum, and air connections made through sliding or slip collars. These machines are usually dedicated to the production of one product such as carry-away coffee lids and disposable picnic plates. One machine displayed at the National Plastics Exposition (NPE) in Chicago in 1997 was approximately 6 ft (2 m) in diameter and held nearly 400 molds, see Fig. 6.2.

The estimated annual production from this machine was in excess of 250M units. As noted, the advantages of this concept are energy efficiency and production without storage of rolls of extruded sheet. The disadvantages are the high capital and maintenance costs of the machine, the huge number of molds required, the lack of pressure forming and plug assist, the shallow-draw restriction, and the lack of versatility in part production.

No need for storage of extruded sheet

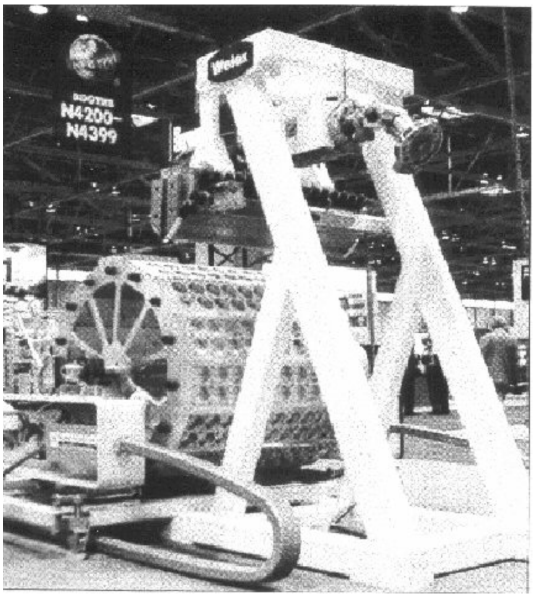

Figure 6.2: High-volume wheel thermoforming machine, showing the sheet extrusion die that feeds the polymer melt vertically onto the surface of the wheel. The product is vacuum formed as the wheel rotates in the clockwise direction. As the sheet containing the formed parts reaches the horizontal plane, it is stripped from the mold and fed to the trim die station.

6.4 Custom Machines

Paint film technology

There are several areas where formers are built for specific applications. In transportation, there is growing interest in paint film technology, meaning that a multilayer appearance film is laminated or applied to a polymer substrate and the heavy-gauge sheet is then formed into a component for an automobile, bus, or truck. The appearance film cannot be substantially stretched. As a result, special folding and bending techniques are designed into the platen action.

Skylights

The production of skylights often does not require a forming press, per se. To produce a *barrel vault* section, the acrylic (PMMA) or polycarbonate (PC) sheet is heated in an oven, then laid over a simple form and clamped until cool. To produce a domed skylight, the transparent sheet is heated in an oven, clamped over a simple box, and air is introduced to inflate the sheet. A photoelectric sensor is used to regulate the air pressure to maintain the correct elevation of the dome until the sheet has cooled.

Microphone diaphragms

Small thermoformers are used in dental laboratories for the manufacture of products such as teeth whitening trays. The presses usually employ matched tooling for precision dimensions. A tabletop contact heat thermoforming press with matched tooling has been developed for the production of microphone diaphragms from sheet thinner than 0.001 in (0.025 mm). Biological cell growth containers are microthermoformed beginning with 25 mm film [12]. As many as 25 × 25 or 625 cell culture chips that are 300 μm in diameter and 350 μm deep are thermoformed on a 400 × 400 μm grid. Although this is currently a manual batch process, it is certain to be automated in the near future.

Despite improved heating technologies and computer-aided design of prestretching plugs, part wall thickness variation is 10% at best. Matched tooling is used when the parts require much tighter wall thickness tolerance. A technique known as coining is used when tight tolerance is needed in local areas. Coining involves local pressing of the heated plastic between the mold and a specially designed piston, as shown schematically in Fig. 2.13. As examples, coining is used in heavy-gauge forming when a fitting of a specific dimension, such as a grommet, must be inserted in a post-drilled hole in the part wall. It is also used to flatten the rim of a light-gauge container that will be filled and sealed against leakage. In this case, the coining piston is part of the cavity isolator or grid.

Blister packs

Blister pack formers are developed for small filling operations. Often, these machines use rotary tables, with the blister vacuum drawn in the first station, manually filled and carded in the second, and sealed in the third, and unloaded in the fourth. The sheet may be manually placed in the fourth station or the sheet may be mechanically drawn across the mold in the first station. If the sheet is handled mechanically, it is trimmed after the blister is formed and before it is indexed to the second station.