2 Manufacturing of Polymer Packaging

2.1 Extrusion of Resins

The first step in making polymer packaging is to melt the thermoplastic resins and then form them into films or sheets or into an end product like a cap, bottle, or cup. The machines with which this is done are called extruders. An extruder has two main components, a barrel and a screw. Both are made of alloy steel and are very robustly constructed because a pressure of several hundred bars arises during melting. The resins are furnished sometimes with additives that are abrasive; the extruder must be able to work such a product without getting damaged. Besides hard alloy steel, the inside of a barrel and the screw are treated through a series of physical processes like heating and quenching in water to produce high hardness. Whereas the barrel is a plain pipe, the screw is constructed in a very complicated manner. Around a shaft, helical threads are cut with different channel depths. The barrel has a number of heaters and the same number of fans on the outside. The heaters heat the barrel from the outside, and the fans cool it when necessary. Generally, the extruders for melting resins have one screw, a so-called single screw extruder (SSE). If a resin mixture is to be melted where mixing is very tough, then a twin screw extruder is used. The additive manufacturers have such twin screw extruders. The manufacturers of general packaging materials like film, sheet, and tube use single screw extruders. An extruder has three functions: convey the resin, melt it completely, and homogenize the melt, which is then processed into the target material.

An extruder is described according to "Euromap" with three numbers, for example, 1-25-30. The first number stands for the number of screws, the second one the length of the extruder in terms of its cylinder diameter (D), and the third figure is the diameter in millimeters. It is usual to describe the different lengths of different parts of an extruder in terms of its diameter. So the length of the conveying zone in a 25 D may be 10 D, the compression zone 7 D, and the homogenizing zone 8 D. Generally, the extruders have a length of 20 to 30 D, depending upon what parts are integrated into the screw. For thermally stable polymers like PE or PP, a longer extruder can be used because the resin can be kept hot longer without any material damage. For PVC or PVdC, which are very unstable under heat, the length of an extruder is less.

2.1.1 Technology of Extrusion

As already mentioned, the functions of an extruder are to convey, melt, and homogenize a resin before purging.

The screw has a solid shaft of constant or increasing diameter toward its end. Helical flights divide the screw in pitches. The screw has generally three zones (Fig. 2.1). In the first zone, the channel volume in the pitches is constant, and hence the resin is simply conveyed in this zone. In the second zone, the channel volume is reduced by reducing the channel depth, so the resin is compressed here. At the same time, the barrel is heated from the outside, and the resin melts completely. In the third zone, the metering zone, the channel volume is again constant so the melt can be mixed and homogenized properly to keep a constant temperature and viscosity. High-quality packaging materials can only be manufactured if the melt is free from specks (unmolten resin) or dirt particles and is homogeneous. At the end of most extruders, an adapter is placed to create a certain back pressure, so the melt stays a bit longer in the extruder to get better homogenized in the metering zone. The applied back pressure depends upon the resin type and is generally 50 to 100 bar. A film from an inhomogeneous melt shows streaks, which arise through inhomogeneous refraction of light through the film.

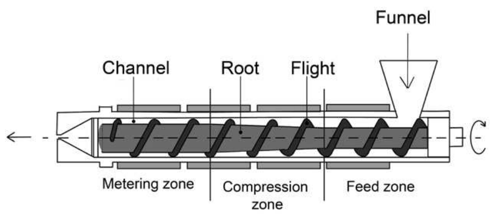

Figure 2.1 Standard three-zone extruder

Standard Three-Zone Extruder

Although only one end of the heavy screw is mounted with the gear system or directly with the motor and the other end is free, it does not rub the barrel during rotating. The melt inside the extruder stabilizes the screw position. Once mounted, the extruder is fed with a resin, and it is always kept full with melt, even if it is turned off. During restarting the barrel is heated until all of the resin melts, and it can then turn. To accelerate the process, the extruder is always fed with a so-called cleaning resin, which is a low-melting resin type, before stopping production. When restarting an extruder, a lot of melt is always lost, until all of the parameters are optimum for the next production. To avoid the loss of material and time, extruders generally run around the clock.

Important facts in producing an ideal melt for a packaging application are an extruder with the proper screw, the choice of the proper resin, the proper additive packet, and finally the proper working parameters. In particular, it is very important to not overheat the extruder. If the extruder is overheated, then resin may burn and produce brown to black particles. Some of them stick to the barrel inner wall. Even if later, good melt quality is produced, the burned particles leave the barrel wall from time to time, which leads to a dirty melt. Spots or even holes in the films or pipes are produced. It may take a whole day to clean the extruder.

The extruder is mounted on a robust base. The screw is turned by a powerful electromotor via a suitable gear system to achieve different RPMs for the screw. The resin is poured into the extruder through a funnel at the beginning of the extruder. To avoid premature melting of the resin, the barrel is cooled at this position. Premature melting of the resin may jam the extruder and then no resin can be fed.

The nozzle of the extruder is connected with subsequent tools to produce the desired material, for example, an annular ring for blown film, a coat hanger die for chill roll films, or injection-molding tools.

Types and Technology of Different Screw Types

A typical screw is shown in Fig. 2.2. The drive shank is mounted on the gear or directly on the motor. It has helical flights and three sections, the feed, compression, and metering sections. The channel depth in the feed section is high and reduces gradually at the compression section as simultaneously the root diameter increases. The resin melts through heat from friction and from external heat supplied outside the barrel. Lastly, the melt is homogenized in the metering section before it is purged out. The pitch is constant throughout the screw. Compression is also possible by reducing the pitch rather than reducing the channel depth. The leading edge of the flight pushes the resin and melt forward. Both pressure and friction are high in this section. The trailing edge has, in contrast, no pressure function. The screw tip can have different forms, depending on use. The screw is the main part of an extruder because through proper construction it is possible to process a particular resin in a particular way. First it must fulfill the proper compression that is necessary to melt the resin. The screw may have a constant shaft diameter and reducing pitch length at the compression zone, or the shaft could have an increasing gradient with the pitch length constant.

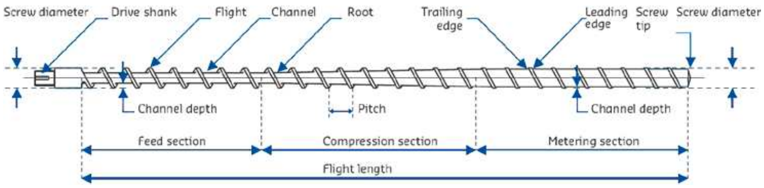

Figure 2.2 Standard three-zone extruder screw, courtesy of William Reay, Kuraray, EVAL Division

It may have two zones, in which compression takes place in the first zone and homogenizing in the second zone. Most often there are three zones: transport, compression, and homogenizing zones. The pitch is constant throughout, but the shaft diameter is low in the first zone and increases gradually to a highest value in the second zone. In the third zone it is once more constant. The compression zone may be short with high gradient, which is suitable for thermally robust resins like PE or PP, or it may be a bit long for thermally sensitive resins. Screws may have a decompression zone with a higher channel depth just after the compression zone. This enables the gas bubbles, which arise particularly when working with recycled resins, to move up and leave the extruder through a valve. In some high-quality screws there is a shearing part, for example, a Maddock element. The diameter of the screw shaft is highest in this part so that the melt has the narrowest possible route through the extruder. This causes the specks to press against the barrel inner wall and ultimately melt.

Finally, there may two different types of barrier screws. The barrier screws have a transition flight after the compression and shearing parts. The objective of the transition flight is to separate the specks from the melt, press them into this part, and ultimately melt them completely. There are two types of barrier screws. One is named after Maillefer, this one having a variable pitch for the transition flight but constant shaft diameter, and the other after Barr, this one with variable channel depth but constant pitch for the transition flight.

Types of Barrels

There are two types of barrels: a barrel with a constant inner diameter and a barrel that has a number of slant grooves in the feed zone. The grooves are placed symmetrically along the perimeter of the barrel with the highest depth at the beginning, which reduces gradually and vanishes after some 3 to 4 D with the inner diameter of the barrel. Through the first type of barrel, a constant amount of resin can always be processed. In a three-zone extruder with such a barrel, the highest melt pressure, around 200 bar, is always at the end of the compression zone.

In a grooved barrel, in contrast, more resin can be transported at the beginning through the grooves than in a normal barrel, and the highest pressure of the melt is just after the position where the grooves end. The highest melt pressure in a grooved barrel is around 1000 bar and is much higher than in a nongrooved one. It is therefore easier to furnish a screw with different parts like shearing or barrier parts, which need more power to drive. Not all types of resin are suitable to be extruded in a grooved cylinder. Resin suppliers advise the manufacturers whether it is suitable for a grooved feed zone or not.

Universal Extruder

A universal extruder is a machine where different resins may be processed. It has no barrier part and only sometimes a shearing part. It is suitable to produce an acceptable quality of melt with different resins. The extruder is optimized for a broad spectrum of applications, such as LDPE, HDPE, LLDPE, EVA, and ionomers with different additives.

High-Performance Extruder

A high-performance extruder is one that has to produce a very high quality melt out of resins to produce a high-quality product. The extruder screw is specially constructed to match a particular polymer like nylon (PA), PET, or PS. Other types of polymers or even resins with some additives cannot be worked with these extruders at sufficiently high quality. The objective of a high-performance extruder is to produce very high quality product, mostly films for a particular application. High-performance extruders always have a shear part, if not barrier parts.

Coextrusion

Packaging performance can, in most cases, not be fulfilled by a single layer of material. Properties of different resins or other packaging materials like paper or aluminum are combined into a multilayer packaging material called a composite. These are the ideal packaging material to fulfill different requirements.

Different layers of composites are written in a line with a slash between the layers, like PET/Al/PE 12/8/60, or the layers can be written one on top of another, like below.

PET	12
Al	8
PE	60

The first version takes less space and is easier to write. The layer thicknesses are written next to the composite in micrometers (µm). In this book the first version will be used. The left side represents the outer layer and the right side the inner layer. The inner layer has most of the sealing function: it is in direct contact with the product, for example, food. This layer must fulfill all of the legislative requirements.

For a pure polymer composite, all of the resins of the different layers are melted in different extruders, and the melts are combined in a suitable series to make the final packaging material (Fig. 2.3).

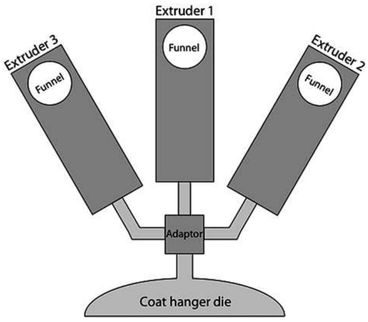

Figure 2.3 Coextrusion line with three extruders

Because the bonding forces between the layers of most resins are not high enough, special bonding resins are necessary, which are called tie resins. For each type of resin, main layer, or tie layer, one extruder is necessary. The suitable layer structure is built in a feed block, where the different melt streams from the extruders are fed. The feed block is the heart of a coextrusion line (Fig. 2.4).

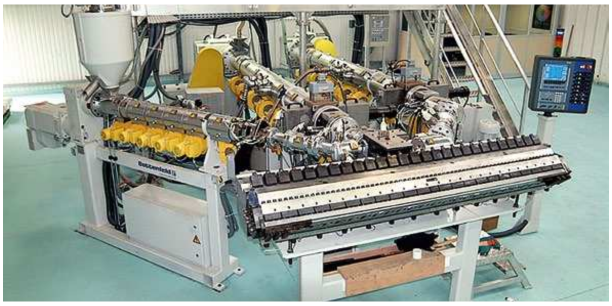

Figure 2.4 Coextrusion with three extruders, feed block, and coat hanger die, courtesy of Battenfeld

Index