Extrusion Processes

Introduction

Extrusion is the process where a solid plastic (also called a resin), usually in the form of beads or pellets, is continuously fed to a heated chamber and carried along by a feedscrew within. The feedscrew is driven via drive/motor and tight speed and torque control is critical to product quality. As it is conveyed it is compressed, melted, and forced out of the chamber at a steady rate through a die. The immediate cooling of the melt results in re-solidification of that plastic into a continually drawn piece whose cross section matches the die pattern. This die has been engineered and machined to ensure that the melt flows in a precise desired shape.

Examples of extruders products are blown film, pipe, coated paper, plastic filaments for brush bristles, carpet fibers, vinyl siding, just about any lineal shape, plus many, many more. There is almost always downstream processing equipment that is fed by the extruder. Depending on the end product, the extrusion may be blown into film, wound, spun, folded, and rolled, plus a number of other possibilities. This article limits any equipment discussion to the extruder itself.

Plastics are very common substances for extrusion. Rubber and foodstuffs are also quite often processed via extrusion. Occasionally, metals such as aluminum are extruded plus trends and new technologies are allowing an ever-widening variety of materials and composites to be extruded at continually increasing throughput rates. This article will focus only on the extrusion of plastics.

Features and Properties of Plastics

To understand how to optimally process plastics, it is essential to understand some physical and chemical properties.

1. All plastics are composed of long chain molecules (extremely high molecular weights) based on simple “building blocks” called monomers. Each polymer molecule typically contains several thousand monomer blocks and the reaction that creates polymers by monomer linking is called polymerization. Monomer units can either be all the same (vinyl chloride monomer or VCM polymerizes to make PVC) or two or more different monomers can polymerize in a repeating or random pattern (acrylonitrile, butadiene, and styrene polymerize to form ABS copolymer).

2. These long chain molecules vary widely in type as well. Two distinct classifications of plastics, which exhibit highly different physical behavior, are directly related to the degree that the polymer molecules interact or cross-link with each other.

a. Thermoplastics typically have little cross-linking. These materials are easily deformed, flexed, and can be repeatedly melted and re-solidified (barring some off-reactions due to excessive thermal degradation). Examples are polyethylene (plastic milk bottle material) and polypropylene (used as insulation in a spun fiber form, for example.).

b. Thermosets are highly cross-linked polymers. They tend to be hard and brittle, and typically are cured either chemically or by heat. Once formed they are infusible, and will thermally degrade before a melting temperature can be reached. Examples are polyurethane (insulation) and bakelite. Thermosets are typically poor extrusion candidates and will not be discussed any further here.
3. Plastics conduct heat inefficiently. This means that heating (and cooling as well) is a slow process. Extruder designers must take this into account so complete melting of the plastic is considered for the desired production rates. Otherwise the extruded product will be unevenly formed and of inferior quality. However, providing excessive heat to simply assure that melting is complete also has its own set of negatives.

a. Since plastics are inefficient conductors, the excess heating is inefficient and the extra energy involved is costly.

b. Overheated melts require extra time to re-solidify, increasing the likelihood that the extruded product becomes deformed or be misshapen upon hardening.

c. Excessive temperatures can also promote off-reactions of the plastic or between any of the additives. This may result in thermal degradation, off-color/off-spec products, or toxic by-products.

4. Extruded resins are highly likely to contain other compounds and chemicals in varying amounts. These are blended by a process called compounding prior to formation of the pellets or beads. Ranging from trace amounts of property-enhancing additives to bulk filler material, various types and their purposes are mentioned here.

a. Stabilizers are used to block formation of harmful off-products (example: additives in PVC neutralize or absorb hydrochloric acid formed at elevated temperatures.)

b. Lubricants make product more pliable and reduce adherence to the extruder walls. This saves energy and eliminates potential hot spots that could be sites for thermal degradation.

c. Dies and colorants give extruded materials their desired color or tone.

d. Plasticisers reduce brittle behavior, making processing easier and less costly.

e. Fillers are typically inorganic compounds (talc, graphite, chalk, etc.) that are cheap and do not affect the integrity of the resin matrix. This makes the material less expensive on a weight basis than pure plastic. New developments and engineering efforts have utilized fillers to achieve targeted properties as well.

f. Alloying polymers (similar to metal alloys) can take advantage of desirable properties of either polymer.

g. Other additives give plastics their glossy look, feel, flame retarding characteristics, and other specified properties.

5. Shear, on a microscopic level, is defined as layers or planes of molecules sliding across one another. The measurement of force applied to move these planes is the shear stress and the amount of shear over time is the shear rate. Viscosity is an important fluid property and is defined as the shear stress/shear rate. Molten plastic is subject to shearing as it moves in an extruder, and the lower the melt's viscosity, the less applied torque is required to extrude it.

**Extrusion Equipment Overview**

Figure 1 shows a basic extruder machine. Plastic pellets or beads (also referred to as resin) are fed from the hopper along a feed screw through a barrel chamber. As the resin travels along the barrel, it is subject to friction, compression, and heated zones. The result is that the resin melts and further travel at the exit end of the screw serves to mix the melt homogeneously. The melt enters a chamber designed to ensure an evenly distributed flow to the die. In many machines, a melt pump is used to prevent any pressure surges. Also, breaker plates serve to prevent any solid particles or foreign objects from passing through the die.

The die is a precisely machined part with a patterned opening such that the extruded plastic takes that die pattern for its cross sectional area. With products such as extruded sheet, there are adjustments to the die to allow for a variety of sheet thicknesses with one die. Shapes are varied, and typically are holes for filament, annular rings for pipe and tube, or geometric patterned shapes for items such as vinyl siding and window frame stock. All die surfaces must be free from defects otherwise unwanted patterns will appear on the extruded product.

Product from the die solidifies quickly. Depending on the end
product, this may be achieved by immersion in cooling water, air-cooling, or contact with chill rolls. As mentioned above, overheating the melt is to be avoided at all costs, or the product will not form properly on solidification. Once solid, the product material can be wound, spun, or cut in defined lengths depending upon its intended end-use.

**Figure 1**

**Basic Extruder Machine**

The feed screw, barrel, and temperature controller form a section of the extruder called the plastication unit. Plastication is defined as the conversion of a thermoplastic to a melt. As mentioned before, this is critical to successful extrusion processes.

The major components in an extruder are discussed here.

**Feedscrew**

As the only moving part in many extruders, feed screws must do the job of moving the resins through the barrel chamber in a steady and predictable manner. As a result, and the feed screw is critical to the design.

Figure 2 shows examples of feedscrews. There are at least three defined sections in a basic feed screw, and if specifically engineered to accomplish a definite purpose, they can have additional sections.

1. The feed zone takes resin from the hopper and conveys it along. During the journey, resin pellets encounter friction from feed screw surfaces, barrel surfaces, and each other. This mechanical friction is about 85% of the required heat, so it is critical that the drive equipment to turn the screw have the HP capabilities to overcome friction AND turn the screw at a steady and controlled rate. Some extruders can continue to plasticate materials long after their external heat sources are shut down.

2. The compression zone is next. Here, the channel depth between screw flights diminishes and the result is to pressurize the now melting resin. Friction, barrel heating, and compression in this stage should complete the melting process. Two important design parameters are associated with this zone.

   a. The compression ratio is measured as the channel depth at the end of this zone divided by the channel depth in the feed zone. Different compounds or operating pressures require different compression ratios.

   b. The length of the compression zone affects the rate of compression. These two parameters will be different for different compounds.

3. The metering zone has a constant channel depth and primarily exists to further mix molten resin. The end result is a smooth consistent melt with uniform temperature.

4. In some processes, a de-gassing or devolatizing section is required. This is a shorter zone that immediately follows the compression zone (See figure 2). Channel depth is suddenly increased, and the resulting pressure drop causes a release of any gas, which can be vented or drawn off via vacuum pump. The remaining melt is re-compressed and metered.

**Figure 2 Typical Feedscrews**

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Mechanical screw design also requires the selection of high-grade materials and precision machining. The screw must fit tightly in the barrel to prevent excessive back-flow or drag flow of resin due to excessive gaps between the screw flights and the barrel surface. It must not be so tight that it contacts the barrel surface itself, causing grooves and other damaging effects.

As if the tight tolerances were not enough of a challenge, some materials require extra processing and are best handled in a twin-screw extruder. Here, two screws are tightly mounted in a "figure 8" type barrel, and the screw flights are designed such that they avoid grinding each other during rotation. The screws can be designed to operate co- or counter-currently.

Co-current operation adds a degree of mixing to the process and would be advantageous where, for example, green and blue pellets need to be mixed as extrusion occurs to get a melt that has an aqua hue. The resin is carried from the first screw to the second between each flight.

Counter-current operation serves to convey the melt in a smooth predictable manner and helps eliminate pressure pulsing. Due to machining and operation demands, this equipment is more expensive to build and maintain than single screw extruders, so it is reserved for special extruding needs.

**Barrel Chamber**

This thick-walled steel chamber that is expected to withstand high pressures (~20,000 psig), is precisely machined for a tight fit with the feedscrew, and has a hardened steel alloy on its inside wall to prevent wear and corrosion. Some barrels will also have a grooved feed zone to increase the frictional forces on the resin.

The barrel also is heated to facilitate melting of the resin. Although the major contributor to melting is friction, the heat as conducted through the barrel can serve as a "fine adjust" or vernier in temperature control and energy input. Electrical resistance heating is a common method employed. Advantages are that several temperature zones can be set up with multiple elements, and temperature profiles can be created as material requirements vary. When thermal needs are not so complex, steam heating via a jacketed barrel chamber. A jacketed chamber uses cooling water to prevent overheating of the melt in the vicinity of the die as well.

**Dies**

The opening that allows plasticated material to form particular shapes is also a highly engineered part. Dies are designed to compensate for effects of shrinkage when a melt re-solidifies, two dimensioned size adjustments, and varying rates of solidification. Dies must be free from defects and scratches, otherwise the melt could show the defect's pattern. The flow of melt to the die typically follows a tapered path, with the die having a thickness associated with it. (See figure 3) This results in the melt undergoing a pressure drop as it exits the die, and this prevents unwanted build-up at irregular places along the die, which would spoil the product.

Dies can take on a variety of shapes and have adjustable openings. In the case of filament extrusion and others, multiple duplicate die patterns to extrude many strands in parallel can be found on a single die.

**Figure 3**

**Other Equipment**

There are other parts of the extruder that deserve a brief mention.

Different hoppers are used for different purposes. Feed hoppers hold and supply resins to the feedscrews. Motor driven helical screws or vibrators help eliminate any bridging or arching of the resins that prevent the smooth flow from the hopper to the feed zone.

Mixing hoppers upstream of the feed hoppers compound any
needed plasticisers and fillers to the required specifications. Melt pumps can smooth the effects of pressure fluctuations that otherwise would result in uneven extrusions and resulting off-spec products. These help out in cases where multiple dies are on a machine, and can be individually closed off on the fly. The downside of melt pumps is their expense, plus they are extra moving parts that must be maintained in good condition.

As an alternative to a melt pump, there is a feedscrew design variation that adds an additional zone with screw flights with a reverse pitch from the other sections. This serves to act as a surge suppressor and is illustrated in figure 4.

**Figure 4**

**Power Transmission Equipment**

The suppressor minimizes pressure surges by accepting or rejecting excess resin from metering section.

As mentioned before, the feedscrew is the moving part and it must be driven. Operation in a steady and predictable manner is vital to making quality extrusions. As friction represents about 85% of the energy used in heating resins, this also means that the power transmission equipment must be capable of supplying the energy to overcome this friction, particularly if starting from rest or recovery from a maintenance outage.

Good speed control is extremely important to assure that adequate resin is being fed to the process. However the ability to maintain even pressures to get consistent flow is equally important. Good response to torque changes as well as steady speed control of high friction loads is the challenge.

Historically, DC drives and motors have been the ideal drives for extrusion. Their relative advantages are listed here.

- DC drives and motors offer wide constant torque speed ranges (20:1).
- DC has been the simplest choice of design when considering choices between AC, DC or servos.
- They offer smaller sizes at larger horsepower ratings (>60HP).
- DC drives are easily retrofitted to existing DC motors.

On the technology front, AC drives/motors are coming into their own as good extruder candidates. With the continual development of PWM technology and more rugged AC motor designs, more and more extruder manufacturers are looking for AC solutions. AC drives/motors offer the following advantages.

- Dynamic response with vector operation. Recent designs employ sensorless vector operation and give high speed response yet require no feedback.
- AC motors require minimal maintenance (no brushes or commutators) and are suitable to harsh environments. (Elevated temperatures, dust, volatiles, etc.)
- Motor designs for extruder duty units feature high overload capabilities and very wide constant torque speed ranges.

Regardless of the choice between AC or DC for an extruder, Reliance Electric has the right products and technologies to provide good solutions.

- Microprocessor-based regulators;
- Easy-to-configure drives with quick-start capabilities;
- Control from any number of sources: local, remote, network, serially to a PC;
- AC and DC motors that are specifically designed as extruder duty; and
- Easily modified with a wide variety of optional kits available for those extra special applications.

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