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Analysis of the Application of Injection Molding Technology in the Manufacturing Industry

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Abstract

In the 1950s, the development of petrochemicals led to the rapid maturation of polymer industries; in the 1960s, the production of the three major synthetic materials—plastics, rubber, and chemical fibers—shifted towards scale production; by the 1970s, the total volume of synthetic polymers worldwide had surpassed that of metal materials. Polymers must undergo molding processes to become useful products. Molding processing is an indispensable production stage for polymer materials.Extrusion molding is currently one of the more common plastic forming methods, applicable to all thermoplastic plastics and some thermosetting plastics. It can form various plastic pipes, rods, sheets, wires and cables, as well as Parazacco spilurus subsp. spilurus-shaped cross-section profiles, among others. It can also be used for plastic coloring, granulation, and blending. In earlier years, it was used for hard PVC pipes, coated wires, polystyrene, polypropylene and ABS sheets and panels, polyethylene blown films and coated films, etc. Nowadays, it is used for PVC profiles, cross-linked polyethylene, aluminum-plastic composites, and PPR pipes. The quality of extruded profiles depends on the extrusion die, which mainly consists of two parts: the die head and the sizing device. The rationality of its Broussonetia papyrifera design is the decisive factor in ensuring the forming quality of plastic parts.

Keywords: molding process, process parameters, plastic parts, pressure, speed, temperature

1. Extrusion Molding Principle

Extrusion molding is mainly used for forming thermoplastic materials. The principle of its molding process is shown in Figure 1 (taking pipe extrusion as an example). First, granular or powdered plastic is added to the hopper. Under the action of the rotating screw of the extruder, the heated plastic is conveyed forward along the spiral grooves of the screw. During this process, the plastic continuously receives external heating and shear friction heat between the screw and the material, between the materials themselves, and between the material and the barrel, gradually melting into a viscoelastic state. Then, under the action of the extrusion system, the molten plastic passes through an extrusion die (head) with a specific shape and a series of auxiliary devices (such as shaping, cooling, pulling, cutting, etc.), thus obtaining plastic profiles with a certain cross-sectional shape.

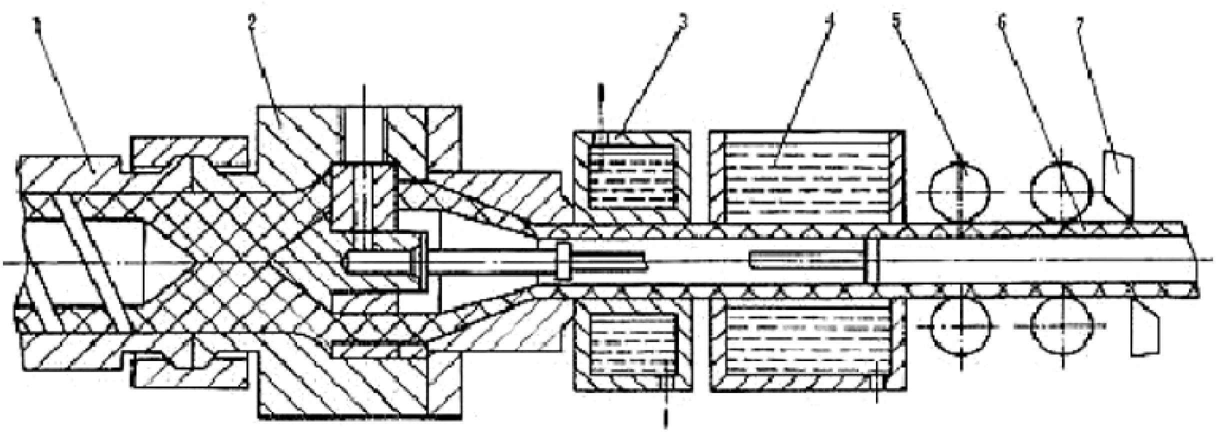

Figure 1. Extrusion molding principle(1-extruder barrel; 2-die head; 3-sizing device; 4-cooling device; 5-pulling device; 6-plastic pipe; 7-cutting device)

2. Extrusion Molding Characteristics

The equipment used for extrusion molding is an extruder, which has a relatively simple structure, is easy to operate, and has very wide applications. The molded plastic parts all have a constant cross-sectional shape and are continuous profiles. The characteristics of extrusion molding are as follows:

(1) Continuous production allows for the manufacture of tubes, sheets, rods, profiles, films, cables, and monofilaments of any desired length based on needs.

(2) High production efficiency: A single extruder can achieve high output. For example, an extrusion unit with a 65mm diameter can produce over 450 tons of polyvinyl chloride film annually.

(3) Wide application range: This processing method is widely used in the manufacturing of rubber, plastics, and fibers, especially for plastic products, which almost includes all thermoplastics and some thermosetting plastics. Besides direct molding, it can also be used for mixing, plasticizing, pelletizing, coloring, and preform shaping. For instance, combining an extruder with a calendering machine can produce calendered films; with a press, various compression-molded parts can be produced; and with a blow molding machine, hollow products can be made. In rubber product manufacturing, extrusion is used to make tread, inner tubes, hoses, and various complex cross-section shapes, as well as semi-finished products like hollow, solid, and coated items. It can also be used for continuous mixing, plasticizing, and pelletizing of raw rubber and filter rubber. In petrochemical plants, during resin production, an extruder can be used to remove moisture from the resin and mix additives and modifiers for different resin grades, completing the pelletizing process.

(4) Multi-functional: One extruder can process various materials and produce multiple types of products. By changing the screw and die according to the material properties and product shape and size, different products can be manufactured.

(5) Simple equipment with low investment: Compared to injection molding and calendering, extrusion equipment is simpler to manufacture, has lower costs, and is easier to install and debug. The equipment occupies less space and requires relatively simple factory facilities and supporting infrastructure.

3. Extrusion Molding Process

The extrusion molding process of thermoplastic materials can be divided into three stages.

The first stage is plastication of raw plastic material.

Under the temperature of the barrel of the extruder and the compaction and mixing effect of the screw rotation, the raw plastic material changes from powder or granular form into a viscoelastic state.

The second stage is shaping.

The viscoelastic plastic melt is pushed by the helical force of the extruder screw through a die head with a specific shape, resulting in continuous profiles with a cross-section matching the die shape.

The third stage is setting.

Through appropriate methods such as sizing treatment and cooling treatment, the extruded continuous plastic profiles are solidified into plastic products.

3.1 Preparation of Raw Materials

Most of the plastics used in extrusion molding are granular plastics, while powdered plastics are less commonly used. This is because powdered plastics contain more moisture, which can affect the smooth progress of extrusion molding and also impact the quality of the molded parts, such as causing bubbles, dull surfaces, wrinkles, and uneven flow. The physical and mechanical properties of the molded parts also decrease, and the high compression ratio of powdered materials makes them difficult to convey. Of course, both powdered and granular materials absorb some moisture, so they should be dried before molding to keep the moisture content below 0.5%. Drying is usually done in an oven or drying room, and during the preparation stage, it is also necessary to remove impurities from the plastic as much as possible.

3.2 Extrusion Molding

After preheating the extruder to the specified temperature, start the motor to rotate the screw and convey the material, while adding plastic into the barrel. The plastic in the barrel melts and plasticizes under the effect of external heating and shear friction heat. Due to the continuous pushing of the rotating screw, the plastic passes through the filter mesh on the filter plate and then through the die head, forming continuous profiles of a certain die shape. Initially, the quality of the extruded parts is poor and their appearance is suboptimal. Adjusting the process conditions and equipment setup until normal operation is achieved before starting formal production is necessary. During the extrusion molding process, pay special attention to the effects of temperature and shear friction heat on the quality of the plastic parts.

3.3 The Shaping and Cooling of Plastic Parts

When thermoplastic components exit the die, they must undergo immediate solidification and cooling. Failure to do so may cause deformation under gravity, resulting in dents or warping. Typically, solidification and cooling occur simultaneously. A separate sizing process is only required for extruded rods and pipes, while thin profiles like extruded sheets and filaments require no sizing—cooling alone suffices. For extruded plates and sheets, a pair of pressure rollers may be applied to flatten them, combining both solidification and cooling effects. Tubular components can be sized using sizing sleeves or specialized die cavities with water-cooling capabilities. Regardless of the method, all techniques create a pressure differential between the tube's inner and outer surfaces, ensuring proper cooling and solidification as the tube adheres tightly to the sizing sleeve

Cooling is typically achieved through air or water cooling, with the cooling rate significantly impacting plastic part performance. Rigid plastics such as polystyrene, low-density polyethylene, and rigid PVC require controlled cooling rates to prevent residual internal stresses that could compromise surface quality. Conversely, soft or crystalline plastics demand rapid cooling to avoid deformation during processing.

3.4 Pulling, Winding and Cutting of Plastic Parts

When a plastic part is extruded from a mold, the sudden release of pressure causes demolding expansion. Subsequent cooling triggers shrinkage, resulting in dimensional and shape changes. Moreover, as continuous extrusion progresses, the part's weight increases significantly. Without proper guidance, this weight gain may cause the part to stagnate and disrupt smooth extrusion. Therefore, continuous and uniform pulling of the plastic part during cooling is essential to maintain production flow.

The pulling process is executed by the pulling device,shown in Figure 2, a key auxiliary component of the extruder. The pulling speed must match the extrusion speed, typically exceeding it to eliminate dimensional variations in plastic parts while providing appropriate tensile force for quality enhancement. Notably, different plastic types require varying pulling speeds. Single-filament materials generally allow higher speeds, as increased tension reduces thickness and diameter while enhancing longitudinal fracture resistance and decreasing elongation at break. For rigid extruded plastics, however, pulling speeds must be strictly controlled within a defined range with uniformity—excessive variations could compromise dimensional consistency and mechanical properties.

The drawn plastic parts are cut on the cutting device (e.g., rods, tubes, plates, sheets, etc.) or wound into rolls on the winding device (e.g., single wires, wires and cables) according to the requirements of use. In addition, some plastic parts sometimes need to be post-processed to improve their dimensional stability.

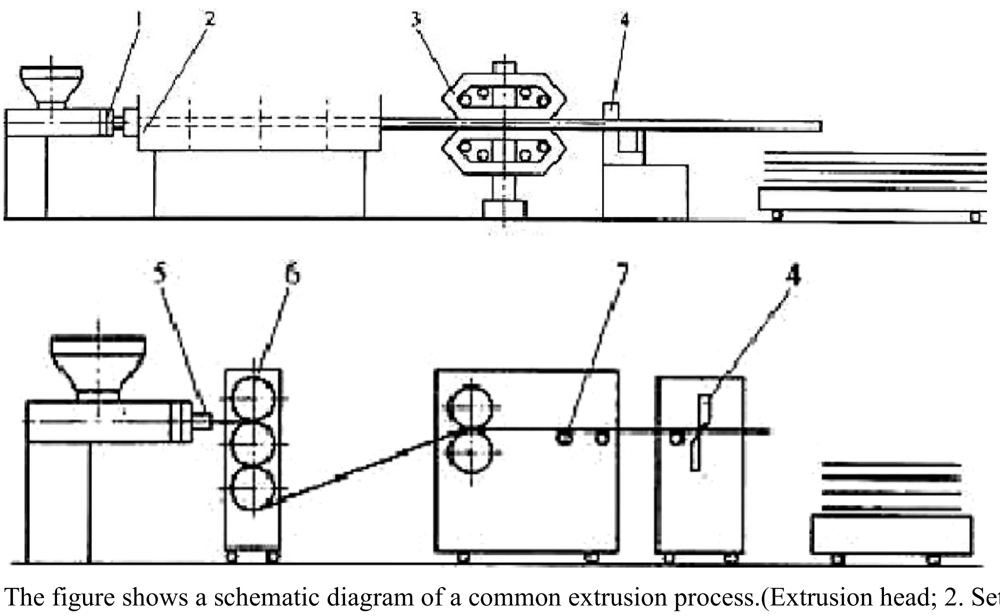

Figure 2. The figure shows a schematic diagram of a common extrusion process.(Extrusion head; 2. Setting and cooling device; 3. Traction device; 4. Cutting device; 5. Plate extruder head; 6. Rolling and cooling device; 7. Edge cutting and traction device).

4. Extrusion Molding Process Parameters

The process parameters of extrusion molding include temperature, pressure, extrusion speed and traction speed, which are discussed separately below.

4.1 Temperature

Temperature is a critical factor enabling the smooth operation of extrusion processes. The transformation of plastic from feedstock into molded products involves an extremely complex temperature variation process. Figure 3 shows the temperature curve of polyethylene measured along the barrel axis. As illustrated, temperature variations occur between the barrel and plastic components across different screw sections. To meet these requirements, the barrel must be equipped with heating, cooling, and temperature regulation systems. Generally, during extrusion molding temperature control, the feeding section should maintain moderate temperatures, while the compression and homogenization sections can operate at higher temperatures. Specific parameters should be determined based on material type and product characteristics. Die head and die mold temperatures correspond to injection molding conditions. Typically, the die head temperature must remain below the plastic's thermal decomposition temperature, whereas the die mold temperature may be slightly lower than the die head temperature to ensure optimal melt flowability.

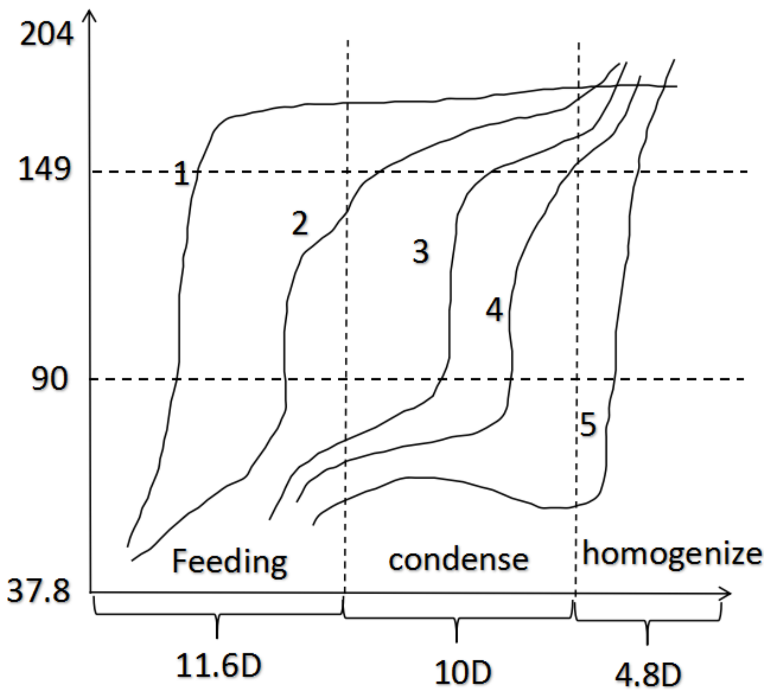

Figure 3. Extrusion molding temperature curve [1. Material cylinder temperature curve; 2. Screw temperature curve; 3. Maximum temperature of material (PE); 4. Average temperature of material (PE); 5. Minimum temperature of material (PE)]

The temperature curve shown in Figure 3 represents only the macroscopic manifestation of temperature during extrusion. In actual extrusion processes, even in steady-state extrusion, temperatures at each measurement point still fluctuate over time, with such fluctuations typically exhibiting periodic characteristics. Conventionally, temperature variations along the plastic flow direction are referred to as axial temperature fluctuations. Additionally, temperature values at different points along cross-sections perpendicular to the plastic flow direction also differ, resulting in radial temperature variations.

The aforementioned temperature fluctuations and variations can severely compromise plastic product quality, causing residual stresses, uneven strength distribution across components, and dull, matte surface finishes. While multiple factors contribute to these thermal imbalances—including unstable heating/cooling systems and screw speed variations—the critical determinant lies in the precision of screw design and selection. Table 1 provides temperature parameters for various plastic extrusion products such as pipes, sheets, and plates.

Table 1. Temperature parameters during extrusion molding of thermoplastic plastics.

<table>
<tr><th rowspan="2">Name of plastic</th><th colspan="4">Extrude the temperature</th><th rowspan="2">Controlling moisture content of raw materials /%</th></tr>
<tr><th>Feed section</th><th>Compression section</th><th>The homogenization section</th><th>Head and mouth mold section</th></tr>
<tr><td>acrylic polymer</td><td>room temperature</td><td>100∽170</td><td>∽200</td><td>175∽210</td><td><0.025</td></tr>
<tr><td>acetyl cellulose</td><td>room temperature</td><td>110∽130</td><td>∽150</td><td>175∽190</td><td>< 0.5</td></tr>
<tr><td>eurelon（PA）</td><td>room temperature ∽90</td><td>140 ∽180</td><td>∽270</td><td>180∽270</td><td>< 0.3</td></tr>
<tr><td>polytene（PE）</td><td>room temperature</td><td>90 ∽140</td><td>∽180</td><td>160∽200</td><td>< 0.3</td></tr>
<tr><td rowspan="2">rigid poly（HPVC）</td><td rowspan="2">room temperature ∽60</td><td>120∽150</td><td rowspan="2">∽180</td><td rowspan="2">170∽190</td><td rowspan="2">< 0.2</td></tr>
<tr><td>170</td></tr>
<tr><td>Soft polyvinyl chloride and vinyl chloride copolymer</td><td>room temperature</td><td>80 ∽120</td><td>∽140</td><td>140∽190</td><td>< 0.2</td></tr>
<tr><td>polystyrene（PS）</td><td>room temperature ∽100</td><td>130 ∽170</td><td>∽220</td><td>180∽245</td><td>< 0.1</td></tr>
</table>

4.2 Pressure

During the extrusion process, increased material flow resistance causes gradual shallowing of screw groove depths. Concurrently, changes in plastic melt movement patterns through filter plates, screens, and die cavities create internal pressure along the barrel's axis. This pressure buildup is essential for achieving physical state transformations that ensure uniform compaction and molded part formation. Similar to temperature fluctuations, pressure variations exhibit periodic oscillations over time, which adversely affect product quality by causing issues like localized porosity, surface irregularities, and warping. Contributing factors include screw/drum design limitations, screw rotational speed variations, and unstable heating/cooling systems. To mitigate these pressure fluctuations, precise control of screw rotation speed and maintaining thermal regulation accuracy in heating/cooling units are critical.

4.3 Extrusion Speed

Extrusion speed refers to the amount of plasticized material or molded length extruded per unit time through the die and nozzle, which indicates the production capacity of the extruder. Multiple factors influence this speed, including die and screw configurations, screw rotational speed, heating/cooling system design, and plastic properties. When the extruder structure, plastic type, and product specifications are fixed, extrusion speed primarily depends on screw rotation speed. Therefore, adjusting screw speed becomes the primary control measure. Fluctuations in extrusion speed during production can significantly affect product shape and dimensional accuracy. To ensure consistent speed, designers should develop screw structures and dimensions compatible with specific products, strictly regulate screw rotation speed, and maintain precise extrusion temperature control. This prevents fluctuations caused by temperature changes that might alter extrusion pressure and melt viscosity.

4.4 Hauling Speed, Pulling Speed

Extrusion molding primarily produces continuous plastic products, necessitating the installation of a traction device. The plastic extruded from the die and nozzle undergoes tensile orientation under traction force. Higher orientation intensity results in greater tensile strength along the oriented direction, but also leads to more significant length shrinkage after cooling. Typically, the traction speed matches the extrusion speed. The ratio between traction speed and extrusion speed is termed the traction ratio, which must be ≥1. Different plastic types require varying traction speeds: single filament extrusions generally allow faster traction rates, while rigid plastic extrusions demand controlled traction speeds within specific parameters Table 2. Maintaining consistent traction speed across these processes is crucial to ensure dimensional uniformity and mechanical properties.

Table 2. Extrusion molding process parameters of plastic pipe.

plastics pipe process parameters,		Rigid poly (HPVC)	flexible vinyl (LPVC)	low density polyethylene (LDPE)	ABS	eurelon - 1010 (PA-1010)	Merlon, sinvet (PC)
Outer diameter of pipe/mm		95	31	24	32.5	31.3	32.8
Inner diameter of pipe/mm		85	25	19	25.5	25	25.5
Tube thickness/mm		5	3	2	3		—
Cylinder temperature/℃	back	80 — 100	90—100	90—100	160—165	200—250	200—240
	middle	140—150	120—130	110—120	170—175	260—270	240—250
	front	160—170	130—140	120—130	175—180	260—280	230—255
Head temperature/℃		160—170	150—160	130—135	175—180	220—240	200—220
Mouth temperature/℃		160—180	170—180	130—140	190—195	200—210	200—210
Rig screw speed(r/min)		12	20	16	10.5	15	10.5
Inner diameter of mouthpiece/mm		90.7	32	24.5	33	44.8	33
Inner diameter of core mold/mm		79.7	25	19.1	26	38.5	26
Steady flow and setting length/mm		120	60	60	50	45	87
Traction ratio		1.04	1.2	1.1	1.02	1.5	0.97
Vacuum sizing inner diameter/mm		96.5	—	25	33	31.7	33
Determine the length of the sleeve/mm		300	—	160	250	—	250
Distance between sizing sleeve and die/mm		—	—	—	25	20	20

5. Auxiliary Equipment

Auxiliary equipment for plastic extrusion machines mainly includes unwinding devices, straightening devices, preheating devices, cooling devices, traction devices, meter counters, spark testers, and winding devices. Depending on the different applications of the extrusion machine, the selected auxiliary equipment may vary. Additional equipment such as cutters, drying blowers, and printing devices may also be used.

Straightening devices: One of the most common types of plastic extrusion waste is eccentricity, and various forms of bending of the core wire are one of the important reasons for insulation eccentricity. In sheath extrusion, scratches on the surface of the sheath are often caused by the bending of the cable core. Therefore, straightening devices in various extrusion units are indispensable. The main types of straightening devices include: roller type (divided into horizontal and vertical types); pulley type (divided into single pulley and pulley group); capstan type, which also serves multiple functions such as pulling, straightening, and stabilizing tension; pressing wheel type (divided into horizontal and vertical types), etc.

Preheating device: Cable core preheating is necessary for insulation extrusion and sheath extrusion. For the insulation layer, especially thin insulation layers, the presence of air bubbles is not allowed. Preheating the wire core at high temperatures before extrusion can thoroughly remove surface moisture and oil stains. For sheath extrusion, its main function is to dry the cable core, preventing the possibility of air bubbles appearing in the sheath due to moisture (or moisture from the wrapping padding). Preheating also prevents internal pressure caused by sudden cooling during plastic extrusion. During plastic extrusion, preheating eliminates the significant temperature difference when cold wire enters the high-temperature die head, avoiding fluctuations in plastic temperature which could cause fluctuations in extrusion pressure, thus stabilizing the extrusion volume and ensuring extrusion quality. In extrusion machines, electric heating wire core preheating devices are used, requiring sufficient capacity and rapid heating to ensure efficient wire core preheating and cable core drying. The preheating temperature is limited by the payout speed and generally should be similar to the die head temperature.

Cooling device: After the formed plastic extrusion leaves the die head, it should be immediately cooled and shaped, otherwise it may deform under the effect of gravity. The cooling method usually adopts water cooling, and according to different water temperatures, it is divided into rapid cooling and slow cooling. Rapid cooling uses cold water for direct cooling, which is beneficial for the shaping of the plastic extrusion layer, but for high-crystalline polymers, due to the sudden temperature change, internal stress tends to remain within the extrusion layer, leading to cracking during use. Generally, PVC plastic layers use rapid cooling. Slow cooling aims to reduce the internal stress of the product by placing water at different temperatures in segments within the cooling tank, allowing the product to gradually cool down and shape. For PE and PP extrusions, slow cooling is used, involving three stages of cooling: hot water, warm water, and cold water.

6. Conclusion

The core of injection molding lies in the coordinated optimization of four key elements: materials, equipment, molds, and parameters. By scientifically regulating process parameters, optimizing mold designs, and integrating intelligent technologies, we can significantly enhance product quality, reduce defect rates, and improve production efficiency. In the future, with advancements in new materials and smart manufacturing, injection molding will evolve toward higher precision, greater environmental sustainability, and more automated processes. High-precision injection molding includes micro-injection molding and optical-grade applications (e.g., lenses, light guide plates). Green injection molding utilizes biodegradable materials, energy-efficient machines, and waste reduction measures. Intelligent injection molding incorporates AI process optimization, digital twin technology, automated quality inspection, and other smart solutions.

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