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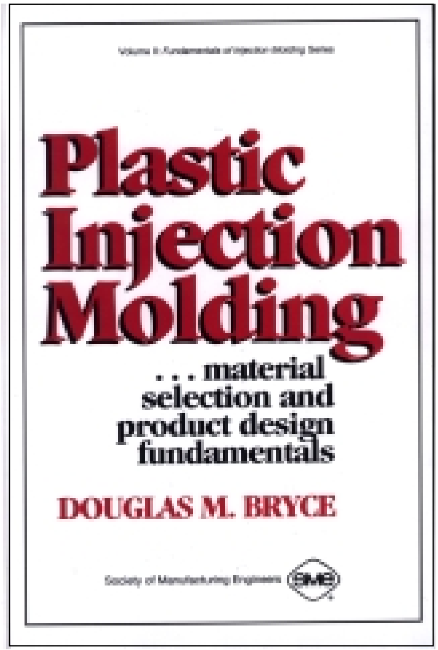

Understanding the Injection Molding Process 1

EVOLUTION OF THE PROCESS

In 1868, a gentleman by the name of John Wesley Hyatt developed a plastic material called *celluloid* and entered it in a contest created by a billiard ball manufacturer. The purpose of the contest was to find a substitute for ivory, which was becoming expensive and difficult to obtain. Celluloid was actually invented in 1851 by Alexander Parkes, but Hyatt perfected it to where it could be processed into a finished form. He used it to replace the billiard ball ivory and won the contest's grand prize of $10,000, a rich sum in those days. Unfortunately, after the prize was won, some of the celluloid billiard balls exploded on impact during a demonstration (due to the instability and high flammability of the material) and further refinement was required to use it in commercial ventures. Nonetheless, the plastics industry was born, and it would begin to flourish when John Wesley Hyatt and his brother Isaiah patented the first injection molding machine in 1872. They used this machine to injection mold celluloid plastic. Over the next 40 to 50 years others began to investigate this new process and expand its application to manufacturing such items as collar stays, buttons, and hair combs. By 1920, the injection molding industry was well entrenched, and it has been booming ever since.

During the 1940s the industry exploded with a bang (*not* because of the instability of celluloid) as World War II created a demand for inexpensive, mass-produced products. New materials were invented for the process on a regular basis, and technical advances resulted in more and more successful applications.

CHARTING INDUSTRY EVOLUTION

From its birth in the late 1800s, to recent developments and applications, the injection molding industry has grown at a fast and steady rate. It has evolved from producing combs and buttons to molding products for all production fields, including automotive, medical, aerospace, and consumer goods, as well as toys, plumbing, packaging and construction. Table I-1 lists some of the important dates in the evolution of the injection molding industry.

Table I-1. Evolution of Injection Molding

1868	John Wesley Hyatt injection-molds celluloid billiard balls.
1872	John and Isaiah Hyatt patent the injection molding machine.
1937	Society of the Plastics Industry founded.
1938	Dow invents polystyrene (still one of the most popular materials).
1940	World War II events create huge demand for plastic products.
1941	Society of Plastics Engineers founded.
1942	Detroit Mold Engineering, Inc. (DME) introduces stock mold base components.
1946	James Hendry builds first screw injection molding machine.
1955	General Electric begins marketing polycarbonate.
1959	DuPont introduces acetal homopolymer.
1969	Plastics land on the moon.
1972	The first parts-removal robot is installed on a molding machine.
1979	Plastic production surpasses steel production.
1980	Apple uses acrylonitrile-butadiene-styrene (ABS) in the Apple IIe computer.
1982	The JARVIK-7 plastic heart keeps Barney Clark alive.
1985	Japanese firm introduces all-electric molding machine.
1988	Recycling of plastic comes to age.
1990	Aluminum molds introduced for production injection molding.
1994	Cincinnati-Milacron sells first all-electric machine in U.S.

EVOLUTION OF SCREW CONCEPT AND EVALUATION OF PLUNGER

The machine the Hyatt brothers invented was primitive but performed well for their needs. It was simple in that it acted like a large hypodermic needle and contained a basic plunger to inject the plastic through a heated cylinder into a mold. In 1946, James Hendry began marketing his recently-patented screw injection machine. This auger design replaced the conventional Hyatt plunger device and revolutionized the processing of plastics. Screw machines now account for approximately 95% of all injection machines.

The auger design of the screw creates a mixing action when new material is being readied for injection. The screw is inside the heating cylinder and, when activated, mixes the plastic well, creating a homogenized blend of material. This is especially useful when colors are being molded or when regrind is being mixed with virgin material. After mixing, the screw stops turning and the entire screw pushes forward, acting like a plunger for injecting material into a mold.

Another advantage of screw technology is a reduction of energy requirements. The injection cylinder that holds the plastic being readied for the next cycle features a series of electrical heater bands around the outside. When energized, these bands heat the cylinder to the point of softening the plastic. In addition, because the screw generates friction when it turns within the cylinder, more heat is produced. Thus the material is also heated from the inside out which results is less heat required from the electrical heater bands to soften the plastic to the correct injection temperature.

Although the screw machine is the most popular, there is still a place for the plunger-type machine. A plunger does not rotate; it simply pushes material ahead, then retracts for the next cycle. It, too, resides within a heated cylinder. Because there is no rotating, there is no shearing or mixing action. So, in a plunger machine the necessary heating action is provided solely by the external heater bands because the plunger produces no friction. Also, if two different colored materials are placed together in the heated cylinder they are not blended together. The plunger simply injects the materials at the same time. If, for instance, the two colors are white and black, the resultant molded part will take on a marbled appearance with definite swirls of black and white throughout the part. This may be a desired finish for particular products, such as lamp bases or furniture, and the use of a plunger machine allows that finish to be molded into the product. Use of a screw machine would result in a single color (gray) product because the two colors would be well mixed prior to injecting.

The injection molding industry has made a huge impact in its short life. Starting in the workshop of the two Hyatt brothers, it has become a major focus for manufacturing of products from toys to medical devices, and most everything in between. The future holds only great promise for more productive, cost-effective methods of producing more products using this technology. Improved methods, materials, processing, and tooling will increase the advantages for product designers and manufacturers who choose plastic injection molding as their primary method of manufacturing.

THE PROCESS

Injection molding is a process in which a plastic material is heated until it becomes soft enough to force into a closed mold, at which point the material cools to solidify and form a specific product. The action that takes place is much like the filling of a jelly donut. A hypodermic-style cylinder and nozzle inject the heated plastic into an opening created in a closed container (mold). The material is allowed to harden again, a finished part is ejected, and the cycle is repeated as often as necessary to produce the total number of pieces required.

Figure 1-1 shows the actual process in simplified form; in actuality, there are more than 100 parameters to be controlled during the process to ensure that a quality part is produced in the most economical way. These parameters are discussed in detail in Volume I of this series, *Plastic Injection Molding...manufacturing process fundamentals*, and should be reviewed by those desiring more information. We highlight some of the parameters in this chapter to better acquaint you with the relationship between the process and the need for proper material selection.

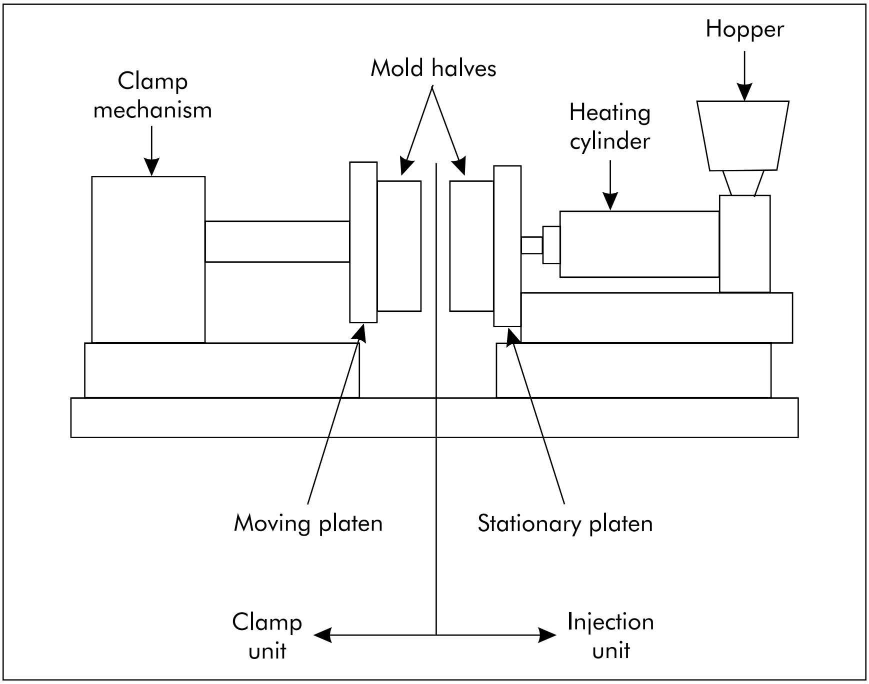

Figure 1-1. The injection molding process.

Categorizing the Parameters

First, we must be aware that, although there are so many parameters to control, they can be detailed within the confines of four major categories. These are *temperature*, *pressure, time*, *and distance* as depicted in Figure 1-2.

Note that the circles in the drawing are interconnected and of different sizes. The interconnections indicate that each parameter is both affected by and affects other parameters. A change in one may have a major effect on another. The different circle sizes represent the order of importance placed on each set of parameters; *temperature* and *pressure*, for instance, normally are more important to the process than *time* and *distance*. We take a look at each of the four categories in terms of what's incorporated within each.

Temperature

Temperature of the material. The primary temperature of concern is the temperature to which the plastic material must be heated before it is injected into a mold. All materials have a range of temperatures within which they are most efficiently injected while still maintaining maximum physical properties. For amorphous materials, (those that soften–not melt–when heat is applied) this range is rather broad; with crystalline materials (those that actually melt when heat is applied) it is fairly narrow. (We discuss the differences between amorphous and crystalline materials in Chapter 2). With both types of materials, however, there is a temperature point at which the plastic flows the easiest and still maintains proper physical properties. This is called the ideal melting point and must be attained through educated guesses and trial-and-error. While this may seem primitive, it is only required as a fine-tuning adjustment once a specific production run is initiated and is finalized as part of establishing particular process specifications for specific products. The guessing process actually begins by setting the temperature of the heating cylinder such that the material being injected is at a temperature recommended for that generic material.

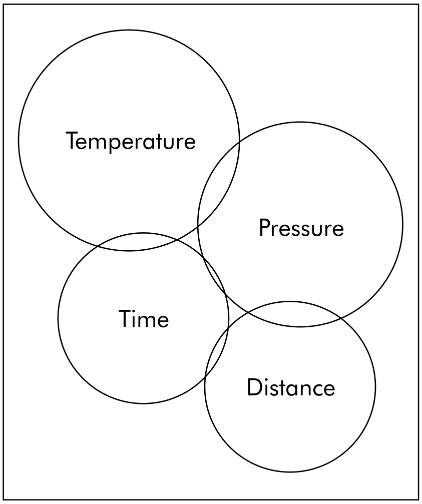

Figure 1-2. Categories of parameters.

The plastic temperature is measured as it leaves the heating cylinder to make sure it is within the proper range, and then adjusted up or down depending on cycle times, required pressures, mold temperature, and a variety of other parameters. These adjustments are made during a pilot run of the process and until acceptable parts are produced. When parts meet specifications, a setup sheet is created listing the values for all parameters of concern. These values are then stored for use when that specific job is to run again. Table I-2 shows the recommended melt temperatures for some common materials. These are the temperatures that should be referred to when measuring the material as shown in Figure 1-3.

The softening (or melting) of the plastic is achieved by applying heat to the plastic material, causing the individual molecules to go into motion. To a point, the more heat that is applied, the faster the molecules move. However, if too much heat is applied, the plastic material begins to degrade and break down into its main constituents, one of which is carbon.

The heat is applied by electrical heater bands wrapped around the outside of the heating cylinder of the injection molding machine as depicted in Figure 1-4a.

The heater bands, which resemble hinged bracelets, are assembled such that individual groups of three or four control the temperature of a single zone. There are three basic temperature zones for the heating cylinder: *rear*, *center*, and *front*. Each zone is monitored by a thermocouple connected to a temperature controller. The thermocouple determines whether or not the zone is at the correct

Table I-2. Suggested Melt Temperatures for Various Plastics

Material	Temperature, °F (°C)
Acetal (copolymer)	400 (204)
Acetal (homopolymer)	425 (218)
Acrylic	425 (218)
Acrylic (modified)	500 (260)
ABS (medium-impact)	400 (204)
ABS (high-impact and/or flame retardant)	420 (216)
Cellulose acetate	385 (196)
Cellulose acetate butyrate	350 (177)
Cellulose acetate propionate	350 (177)
Ethylene vinyl acetate	350 (177)
Liquid crystal polymer	500 (260)
Nylon (Type 6)	500 (260)
Nylon (Type 6/6)	525 (274)
Polyallomer	485 (252)
Polyamide-imide	650 (343)
Polyarylate	700 (371)
Polybutylene	475 (246)
Polycarbonate	550 (288)
Polyetheretherketone (PEEK)	720 (382)
Polyetherimide	700 (371)
Polyethylene (low-density)	325 (163)
Polyethylene (high-density)	400 (204)
Polymethylpentene	275 (135)
Polyphenylene oxide	385 (196)
Polyphenylene sulfide	575 (302)
Polypropylene	350 (177)
Polystyrene (general purpose)	350 (177)
Polystyrene (medium-impact)	380 (193)
Polystyrene (high-impact)	390 (199)
Polysulfone	700 (371)
PVC (rigid)	350 (177)
PVC (flexible)	325 (163)
Styrene acrylonitrile (SAN)	400 (204)
Styrene butadiene	360 (182)
Tetrafluorethylene	600 (316)
Thermoplastic polyester (PBT)	425 (218)
Thermoplastic polyester (PET)	450 (232)
Urethane elastomer	425 (218)

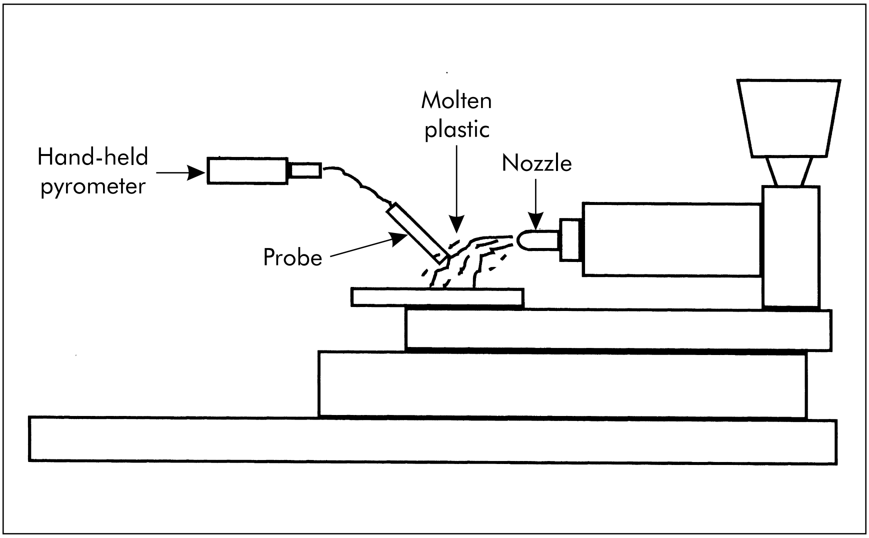

Figure 1-3. Measuring plastic temperature.

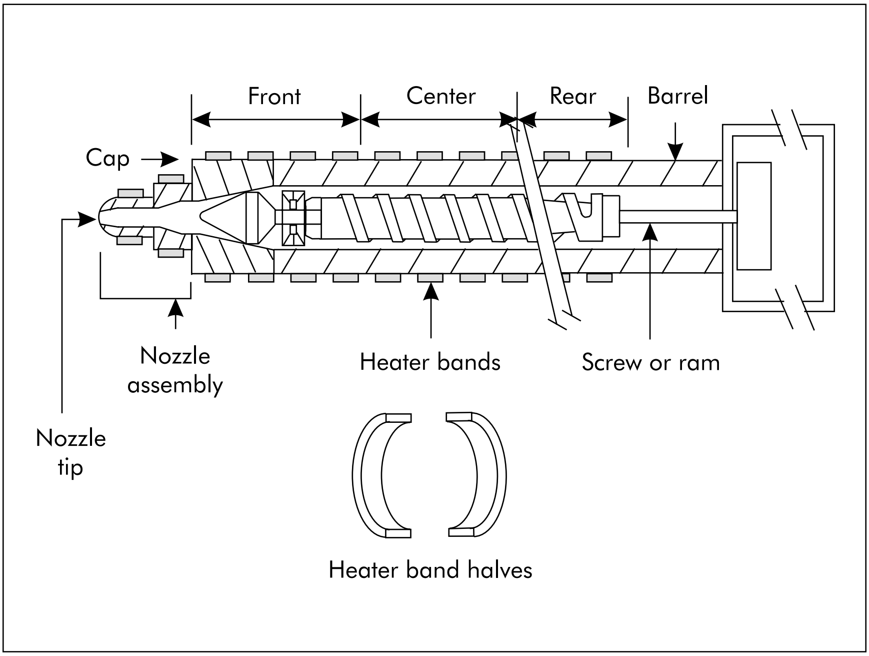

Figure 1-4a. The heating cylinder.

temperature and, if more heat is required, signals the controller to supply more electricity to the heater bands in that temperature zone.

In addition, the machine nozzle (which is mounted at the front of the heating cylinder) incorporates at least one heater and is considered an additional zone called the *nozzle heater zone*. This is depicted in Figure 1-4b.

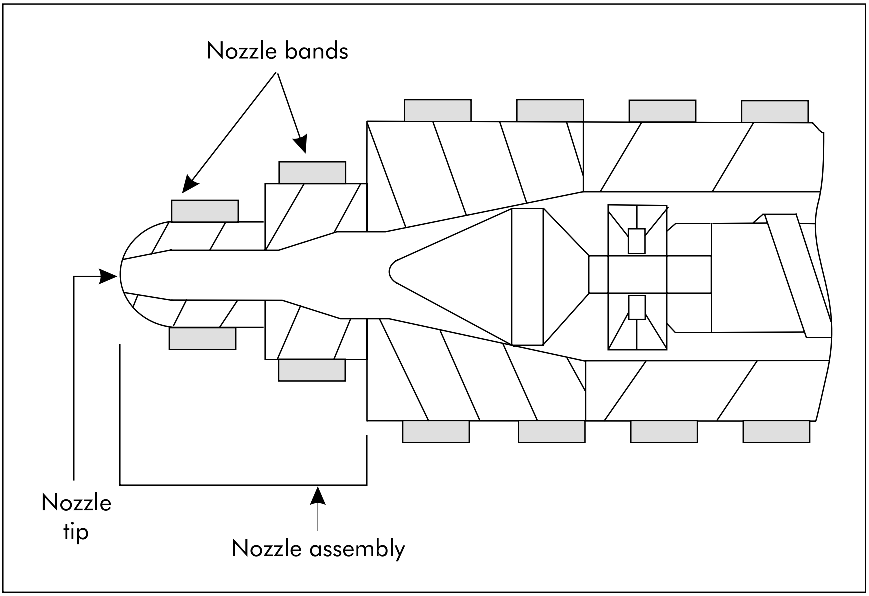

Figure 1-4b. Nozzle heater zone.

Heat is also generated in the heating cylinder by the compressive force of the feed screw turning in the cylinder, Figure 1-5.

This screw augers fresh material into the heating cylinder from the hopper. The turning action squeezes the plastic, thus creating friction, which in turn creates heat. The amount of friction is controlled by a variety of elements such as the rotation speed of the screw, and the distance between the outside diameter of the flights and the body diameter of the screw, which changes along the length of the screw.

Temperature of the mold. Another important temperature is that of the mold. A mold is used for containing the injected plastic in a specific shape while the plastic cools to a solid. After solidifying, the plastic product is ejected from the mold and a new cycle is begun.

The rate at which the plastic cools is an important factor in determining the strength of the plastic material's physical properties, especially with crystalline