required. Ensure that the mold material finishes to the required specifications.

41. Provide shrink or cooling fixtures if required to maintain dimensions and to prevent warping of the part.
42. If an ejector shedder is used, locate ejectors in the line to give maximum strength to the shedder.
43. Ensure that molds for automatic presses have ejector pins in both halves if possible, to obtain proper ejection.
44. Dimension all cavities, punches, and cores to the correcting side of tolerance.
45. Provide channels for water or air cooling of injection punches, cavities, and cores.
46. Maintain uniform wall sections by using material-saving cores where possible.
47. Ensure that the sprue bushing fits properly.

TROUBLESHOOTING

Table 18-8 lists suggested remedies for problems encountered in injection molding operations. As an example of how to use this troubleshooting chart, if the problem is poor surface finish on the molded part, the user would read downward under the "Poor Surface Finish" column to remedy No. 1. This remedy indicates the easiest solution to the problem. If predrying does not correct the situation, remedy No. 2 in the same column would be used. If the problem persists, subsequent remedies are prescribed until the condition is corrected. The same procedure is followed to troubleshoot the various abnormal conditions listed. Any one of the suggested remedies may solve a particular problem; however, some problems may require a combination of suggested remedies.

EXTRUSION FORMING

The extrusion process is a continuous operation in which hot plasticized material is forced through a die opening that produces an extrudate of the desired shape. The most commonly extruded materials are rigid and flexible vinyl, ABS, polystyrene, polypropylene, and polyethylene. Nylon, polycarbonate, polysulfone, acetal, and polyphenylene are included among other plastics that can be extruded.

The extrusion process is used to produce film (thinner than 0.030"; 0.76 mm), sheets (thicker than 0.030", 0.76 mm), filaments, tubes, and a variety of profiles. The process of plastics extrusion also is used to coat cables, wires, and metal strips.

EXTRUSION PROCESS

In the profile extrusion process, the material in pellet, granular, or powder form is placed into a feed hopper which feeds the cylinder of the extruding machine as required (see Fig. 18-17). The cylinder is heated by electricity, oil, or steam, and closely controlled temperature zones are set up along its length. A rotating screw carries the material through the cylinder, mixing and working the material where necessary, and forcing it through a die orifice of the proper shape.

The extruded shape coming from the die is carried through a cooling medium; and when it has been cooled sufficiently to retain shape, it is cut to length or coiled. In some instances the material must be held to shape during cooling. Cooling is done by exposure to air at room temperature, by passing through a liquid bath held at a controlled temperature, or by jets of compressed air. Too-rapid cooling must be prevented because it causes warpage and sets up internal stains in the finished pieces.

The raw material must have a uniform particle size and a controlled moisture content to maintain close dimensional tolerances and a smooth surface on the finished extrusion. The temperature of each heat zone of the cylinder must be held constant to ensure a good extrusion.

The speed of extrusion (pounds or kilograms per hour handled by the machine) varies considerably depending upon the size of the die opening, the delivery of the screw, and the nature of the material being processed. Variable-speed machines are generally considered best for all-round flexibility, particularly in job shops. A wide variation of temperatures, speeds, methods of handling, and design of equipment is necessitated by the wide variation in characteristics of different thermoplastics.

Plastic extrusions are produced as tubes, rods, sheets, flat strips, profiles, filaments, and coatings for wire, cable, pipe, and rope.

EXTRUSION EQUIPMENT

Common extruders consist of three basic units: the drive (power source); the process unit (screw and barrel); the forming unit (head and die).

The screw is the heart of the extruder and consists basically of feed, transition, and metering sections. The feed section is deep flighted and intended to convey solid or sometimes half-molten or molten plastics (for example, the second extruder in a multistage extrusion line) out of the feed throat area to the transition zone—which begins compressing the preheated material. This section forces the plastics against the heated barrel and continues or begins the melting process, which should be completed at the end of the transition or the beginning of the metering zone.

In the transition zone the depth of the flights becomes continuously shallower until the final depth of the transition zone phases into the metering zone. As homogenously as possible, the metering zone conveys the molten plastics to the head and die at uniform rates and high pressure. The compression ratio (c.r.) is dependent on the material, the different melt densities, and the bulk densities.

The extrusion machine has a pilot for the attachment of adapter rings or plates on the outboard end of the cylinder. A die base is placed within the adapter ring to direct the flow of the material toward the die orifice.

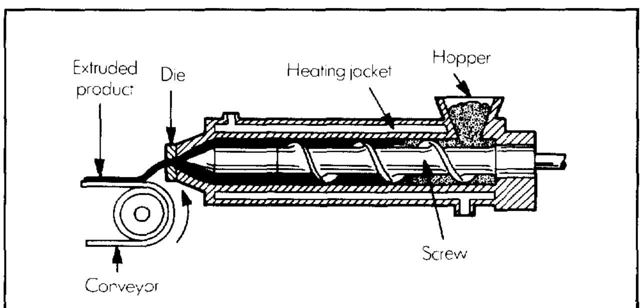

Fig. 18-17 Schematic arrangement of a plastic extrusion machine.

Extrusion Dies

The die is usually made of flat, ground tool steel and is mounted as shown in Fig. 18-18. The design of the extrusion die, unlike that of injection or compression molds, cannot be predetermined precisely. A great deal of secondary work is often required to obtain extruded shapes of the desired dimensions. It is usually necessary to alter an extrusion die by filling or blocking to direct the flow of material to obtain a completely filled shape. Some designers make the orifice 10-30% oversize to allow for shrinkage upon cooling of the finished shape or to allow for controlled tension which pulls the shape to the required size or cross section.

A crosshead is widely used for coating wire with plastics. It is an adapter bolted on the face of the machine which directs the material at right angles to the centerline of the screw. The crosshead is usually T-shaped, having two faces upon which the dies are fastened. The wire emerges from the die and is cooled and carried away. The crosshead can be swung through 360° and thus is adaptable to many coating jobs.

Multiscrew Extruders

Multiscrew extruders have been developed for compounding and pelletizing and (among many applications) for the extrusion of polyvinylchloride (PVC) materials. Advantages of the multiscrew machine are outstanding homogenization and higher output. The four-screw machine is used extensively in the production of PVC pipe. The twin-screw type of machine, illustrated in Fig. 18-19, also is gaining in usage.

Multiscrew extruders differ significantly in both construction and operation from the single-screw extruding machine. A twin-screw extruder with closely intermeshing counterrotating screws can be represented by two series of C-shaped chambers—one series for each screw. These chambers convey the

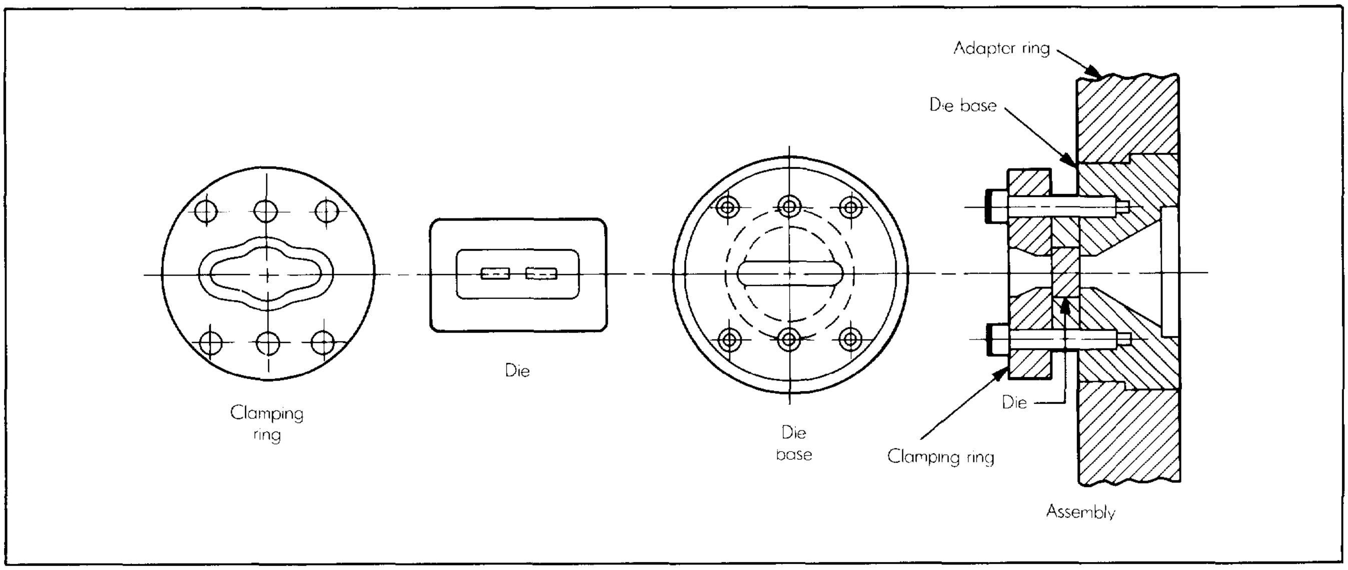

Fig. 18-18 Die assembly for extruding plastics materials.

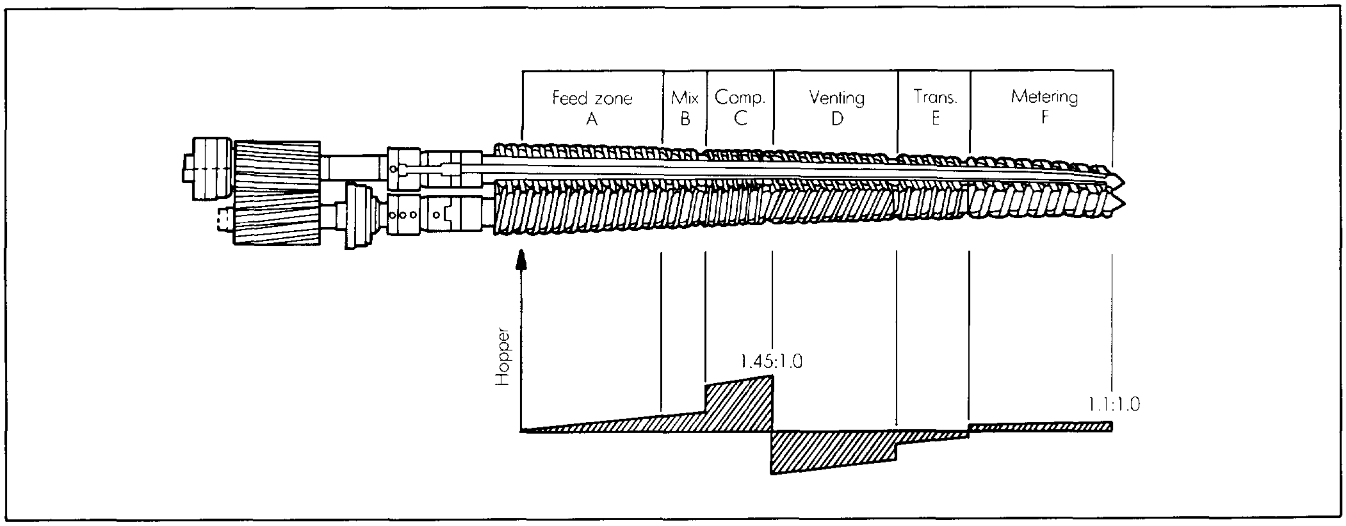

Fig. 18-19 Schematic diagram of conical twin screw layout with compression ratios at each zone. (*Cincinnati Milacron Inc.*)

processing material positively from the hopper to the die by rotation of the screws. In the pump zone, leakage gaps provide an interaction between the chambers. The output can be controlled either by varying the speed of revolution or by controlling the feed. Because of the design of twin-screw machines, a much larger screw and barrel area (surface) is in contact with the material being extruded. Rate of wear is significantly higher than for single-screw and barrel, even though the twin-screw extruders are usually shorter (in the range of L/D = 7 to 17) and the screw speed is lower. The circumference surface speed is also quite different, as indicated in Table 18-9.

TABLE 18-9
Circumference Surface Speed
(Single-Screw vs. Twin-Screw Extruder)

Diameter, in. (mm)	Surface Speed: Single-Screw, ft/min (m/s)	Surface Speed: Twin-Screw, ft/min (m/s)
2.5 (64)	12-118 (0.06-0.6)	6-30 (0.03-0.15)
3.5 (89)	59-256 (0.3-1.3)	2-20 (0.01-0.1)

REACTION INJECTION MOLDING

Reaction injection molding (RIM) is a form of injection molding that brings temperature and ratio-controlled, liquid-reactant streams together under high-pressure impingement mixing to form a polymer directly in the mold. Two liquid reactants (monomers) are mixed together as they enter the mold. A chemical reaction produces the plastics as it forms the part.

When compared to other molding systems, RIM offers more design flexibility, lower energy requirements, lower pressures, lower tooling costs, and lower capital investment. Significant advantages in design and production are gained from the RIM fabricating capability for incorporating a load-bearing, structural skin and a lightweight, rigid, cellular core into a part in one processing operation.

While initial RIM applications were primarily automotive, nonautomotive uses are increasing in industrial, business, and consumer-product applications. Recent production applications include business machine cabinets and vacuum cleaner housings. Thermosetting polyurethanes are the most commonly used RIM materials. Recently, however, the successful completion of development and testing programs on other plastics, such as nylons and epoxies, has led to RIM production usage of these materials. Table 18-10 compares the properties of various RIM materials systems.

RIM ADVANTAGES

Where RIM polymer physical properties are suited for an application, a comparison of RIM to conventional injection molding and sheet molding compound (SMC), discussed later in this chapter, reveals advantages to using RIM.

Design Freedom

With RIM, the designer has exceptional freedom. Parts can be complex and large, and produced without molded-in stresses. Inserts are easily incorporated. Properly designed RIM parts can include ribs, bosses, cutouts, attaching ears, etc., as well as a variety of cross-section thicknesses without sink marks. For flexible RIM with 25-50 ksi (172-345 MPa) flexural modulus, undercuts are attainable on visible surfaces.

Low Pressures

Pressures within the RIM mold are 50-100 psi (345-690 kPa) and require correspondingly low clamp capacities—about 100 lbf (445N) for each square inch of projected part area (0.7N for each square mm) or about 3-5% of the clamp force required for injection molding or SMC.

Low Energy Requirements

For RIM, the connected horsepower is about 25% of the power required for injection molding, and the percentage of time the maximum horsepower is required during an average cycle is about 25% of that for injection molding.

Lower Capital Investment

Reaction injection molding equipment requires lower capital investment for mixers, clamps, presses, molds, etc., compared to other systems. The cost of RIM machinery is about one-third to one-half that of injection molding machinery to mold the same size of part, and considerably lower than that of sheet molding compound (SMC) machinery.

Lower Tooling Costs

Low molding pressures allow the use of less expensive tooling, because lightweight, easily machined materials can be used. However, the mold must be capable of producing the required finish, since the RIM process precisely duplicates the mold surface. Reaction injection molding allows prototyping and low-volume applications with low-cost molds.

RIM LIMITATIONS

Reaction injection molding applications have been limited by the availability of and properties of materials suitable for the process. Originally, RIM materials were primarily polyurethanes. However, recent commercial availability of suitable epoxy and nylon formulations is broadening the potential for RIM applications. Relatively long cycle time, low production rates, and limited applicability have been among the other principal drawbacks of the RIM method. Progress is occurring at a rapid rate, however, and developments in methods, materials, and equipment may eliminate the need for postcuring and mold-spraying in the RIM process—and thereby make it faster and more versatile.

RIM MATERIALS AND APPLICATIONS

Urethanes currently dominate commercial RIM production and can be formulated to produce a wide range of densities, flexible or rigid, from low-density foam to rigid structural foam and from low to high-modulus elastomers.

Reaction injection molding urethane elastomers provide design freedom combining damage resistance, corrosion resistance, and parts consolidation with large and complex shapes. Current automotive applications include front and rear fascia,